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HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 6: VISION AND LIGHTING

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Revision Note

Since Defence Standard 00-25 (Part 6)/Issue 1 was published in 1986 there has been several recent technical advances in this field. This Defence Standard has been revised to incorporate this new material which reflects these recent technical advances.

Historical Record

This Defence Standard supersedes Defence Standard 00-25 (Part 6)/1 published on 25 August 1986 which had its origins in "Human Factors for Designers of Naval Equipment" (a naval handbook in two volumes) published in 1971.

Arrangement of Defence Standard 00-25

The arrangement of the Parts comprising Def Stan 00-25 is shown below.

PART 1 - Introduction
PART 2 - Body Size
PART 3 - Body Strength and Stamina
PART 4 - Design of Workspace
PART 5 - The Physical Environment: Stresses and Hazards
PART 6 - Vision and Lighting
PART 7 - Visual Displays
PART 8 - Auditory Information
PART 9 - Voice Communication
PART 10 - Controls
PART 11 - Design for Maintainability
PART 12 - Systems
PART 13 - Human Computer Interaction
PART 14 - Training and Instruction (not yet published)

Two or more Parts may apply to any one equipment and it is, therefore, essential that all Parts be read and used where appropritate.

HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 6: VISION AND LIGHTING

PREFACE

> This Part of Def Stan 00-25 supersedes Def Stan 00-25 (Part 6) Issue 1 dated 25 August 1986

i This Part of this Defence Standard presents descriptive detail, technical data, and diagrams relating to vision and lighting. It includes a number of important factors to be considered in the design of lighting systems.

ii This Standard has been agreed by the authorities concerned with its use and is intended to be used whenever relevant in all future designs, contracts, orders etc and whenever practicable by amendment to those already in existence. If any difficulty arises which prevents application of the Defence Standard, the Directorate of Standardization shall be informed so that a remedy may be sought.

iii Any enquiries regarding this Standard in relation to an invitation to tender or a contract in which it is incorporated are to be addressed to the responsible technical or supervising authority named in the invitation to tender or contract.

iv This Standard has been devised for the use of the Crown and its contractors in the execution of contracts for the Crown. The Crown hereby excludes all liability (other than liability for death or personal injury) whatsoever and howsoever arising (including, but without limitation, negligence on the part of the Crown its servants or agents) for any loss or damage however caused where the Standard is used for any other purpose.

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HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT VISION AND LIGHTING

Section One. General

0 Introduction

The aim of this Part of the Defence Standard is to guide and direct designers' attention to the more important factors that contribute to seeing efficiently and to provide a context for a better understanding of user problems related to visual work and comfort. It will be necessary to consult other sources for more detailed information since the fields of vision and lighting are vast and only guidelines can be presented here. Annex A provides a list of references that can be consulted for more in-depth information.

The major emphasis in this Part of this Defence Standard is on the relationship between human vision, visual displays and lighting design. At the present time, there is no analytical model available that will consistently predict the complex interactions between visual displays, lighting design and human vision. This means that the only way to determine the effectiveness of a system is to test it with observers in tasks and conditions equivalent to the operational environment. This document provides guidance to help design usable working environments, but they do not guarantee ease of use.

1 Scope

1.1 This Part of the Defence Standard should be used by designers who wish to develop workstations and working environments that are visually comfortable and reduce visual workload. The majority of recommendations cover conventional visual displays seen with normal vision, but head-up displays and night vision goggles are referred to where necessary.

1.2 This Part of the Defence Standard has been divided into four sections as follows:

(a) Section one is a general introduction, including definitions of technical terms and a glossary used in the remaining sections.

(b) Section two deals with human vision and makes specific design guidelines based on our current knowledge.

(c) Section three describes measurement of light and colour. The information in this section is needed to implement many of the recommendations in sections two and four.

(d) Section four deals with basic features of lighting design practice and applications.

2 Related Documents

2.1 Related documents can be obtained from:

DOCUMENT	SOURCE
British Standards (BS) (BSEN) (IEC) and ISO	BSI Sales Office Linford Wood MILTON KEYNES MK14 6LE
North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) (NATO Publication APP6)	NMST Room 202 Archway Block (South) Old Admiralty Building Spring Gardens LONDON SW1A 2BE
Health and Safety at Work Regulations MOD MANPRINT Handbook PULHHEEM's Administrative Pamphlet	HMSO South Gyle Crescent EDINBURGH EH12 9EB
Defence Standards	Directorate of Standardization (Stan 1) Kentigern House 65 Brown Street GLASGOW G2 8EX

2.2 Reference in this Standard to any related document means in any invitation to tender or contract the edition and all amendments current at the date of such tender or contract unless a specific edition is indicated.

2.3 The documents referred to in this Part of the Standard, together with additional publications providing greater coverage on specific aspects of the subject, are listed at annex A.

3 Definitions and Glossary of Terms

3.1 Adaptation. The process that takes place as the visual system adjusts itself to the luminance or the colour (chromatic adaptation) of the visual field. The term is also used, usually qualified, to denote the final state of this process. For example 'dark adaptation' denotes the state of the visual system when it has become adapted to a very low luminance.

3.2 Brightness. The subjective response to luminance in the field of view dependent upon the adaptation of the eye.

3.3 Candela (cd). The SI unit of luminous intensity, equal to one lumen per steradian.

3.5 Chromaticity diagram. Plane diagram showing the results of mixtures of colour stimuli, each chromaticity being represented unambiguously by a single point on the diagram. Coordinates in this diagram are known as chromaticity coordinates.

3.6 Cockpit lighting conditions. The maximum ambient illumination in a transport aircraft flight deck is at least 86,000 lux while in a bubble-canopy aircraft the value is at least 107,500 lux. These figures are affected by factors such as sun altitude and transmittance of the windshields or canopy.

3.7 Colour coding. Colour coding is a process by which different colours are used to represent different categories of information. For example, a red traffic light means 'Stop' while a green traffic light means 'Go'. If colour provides a completely unique source of information the coding is called non-redundant. Colour can also be combined with other coding dimensions such that two or more codes correlate with one another. This is referred to as redundant coding.

3.8 Contrast. A term that is used subjectively and objectively. Subjectively it describes the difference in appearance of two parts of a visual field seen simultaneously or successively. The difference may be one of brightness or colour or both. Objectively, the term expresses the luminance difference between the two parts of the field. There are four types of contrast used in this standard.

(a) Contrast modulation $= \dfrac{L_{max} - L_{min}}{L_{max} + L_{min}}$

(b) Contrast ratio $= \dfrac{L_{max}}{L_{min}}$

where L_{max} and L_{min} represent the maximum and minimum luminances, respectively.

(c) Effective contrast (C_e):

$$C_e = \frac{(L_t + L_v) - (L_b + L_v)}{(L_b + L_v)}$$

where L_t = luminance of task detail (cd m^{-2})
L_b = luminance of task background (cd m^{-2})
L_v = equivalent veiling luminance (cd m^{-2})

(d) Psychometric contrast $= \dfrac{L_t - L_b}{L_b}$

where L_t = luminance of task detail (cd m^{-2})
L_b = luminance of task background (cd m^{-2})

3.9 Daylight factor, internally reflected component (Di). The illuminance received at a point indoors from a sky of known or assumed luminance distribution after reflection within the interior, expressed as a percentage of the horizontal illuminance outdoors from an unobstructed hemisphere of the same sky. Direct sunlight is excluded from both illuminances.

3.9 (Contd)

distribution after reflection within the interior, expressed as a percentage of the horizontal illuminance outdoors from an unobstructed hemisphere of the same sky. Direct sunlight is excluded from both illuminances.

3.10 Design maintained illuminance. The maintained illuminance used in a lighting specification. Design maintained illuminance is derived from the standard maintained illuminance by taking account of the modifying factors contained in the flow chart.

3.11 Diffuse reflection. Reflection in which the reflected light is diffused and there is no significant specular reflection, as from a matt paint.

3.12 Diffuse lighting. Lighting in which the luminous flux comes from many directions, none of which predominates.

3.13 Direct lighting. Lighting in which the greater part of the luminous flux from the luminaires reaches the surface (usually the working plane) directly, ie without reflection from surrounding surfaces. Luminaires with a flux fraction ratio less than 0.1 are usually regarded as direct.

3.14 Disability glare. Glare produced directly or by reflection that impairs the vision of objects without necessarily causing discomfort.

3.15 Discharge lamp. A lamp in which the light is produced either directly or by the excitation of phosphors by an electric discharge through a gas, a metal vapour or a mixture of several gases and vapours.

3.16 Discomfort glare. Glare which causes visual discomfort.

3.17 Dominant wavelength. Wavelength of the monochromatic light stimulus that, when combined in suitable proportions with the specified achromatic light stimulus, yields a match with the colour stimulus considered.

3.18 Downlighter. Direct lighting luminaire from which light is emitted only within relatively small angles to the downward vertical.

3.19 Effective reflectance. Estimated reflectance of a surface, based on the relative areas and the reflectances of the materials forming the surface. Thus, 'effective wall reflectance' takes account of the reflectances of the wall surface, the windows, the filing cabinets etc, that comprise the sides of the room.

3.20 Emergency lighting. Lighting provided for use when the main lighting installation fails.

3.21 Energy management systems (EMS). Computer base systems for controlling the energy use of the installed load of a complete site, a single building or a section of the building. The signals which initiate the controls may be related to time of year, month, week or day, maximum demand or power factor, daylight availability, occupancy etc. Building energy management systems (BEMS) provide control commands for all equipment on a site, whilst a lighting energy management system (LEMS) will be dedicated to the lighting installation. The LEMs can be independent or

3.21 (Contd)

linked into the BEMS. Such systems can also be linked to security, fire warning and maintenance systems.

3.22 Escape lighting. Emergency lighting provided to ensure that the means of escape can be safely and effectively used at all material times.

3.23 Flicker. Visible modulation of luminous flux.

3.24 Fovea. The fovea is the retinal region that provides a persons best visual acuity. It covers an area of retina of about 5 degrees. A section through the fovea reveals that it is a pit (indeed, fovea is Latin for pit) because the blood vessels and neural machinery that usually lie on top of the photoreceptors are pushed aside helping to improve image quality. At the base of the fovea is a smaller area (the foveola) that contains only cone cells. This covers an area of retina of about 1.5 degrees.

3.25 General lighting. Lighting designed to illuminate the whole of an area without provision for special local requirements.

3.26 Glare. The discomfort or impairment of vision experienced when parts of the visual field are excessively bright in relation to the general surroundings.

3.27 Glare index system. A system which produces a numerical index calculated according to the method described in CIBSE TM10. It enables the discomfort glare from lighting installations to be ranked in order of severity, and the permissible limit of discomfort glare from an installation to be prescribed quantitatively.

3.28 Group lamp replacement. A maintenance procedure where all lamps are replaced at one time. The lumen maintenance characteristics and probability of lamp failure dictate the period after which bulk replacement, usually linked with luminaire cleaning, will take place. This method has visual, electrical and financial advantages over the alternative of 'spot replacement'.

3.29 Hazardous environment. An environment in which there exists risk of fire or explosion.

3.30 Hostile environment. An environment in which the lighting equipment may be subject to chemical, thermal or mechanical attack.

3.31 Hue. The term that most closely resembles our notion of 'colour', for example, red, green and blue. It is that quality of a colour that cannot be accounted for by brightness or saturation differences. An objective measure of hue is provided by the dominant wavelength of that colour's spectral power distribution.

3.32 Illuminance (E, units: 1 m/m^2, lux). The luminous flux density at a surface, ie the luminous flux incident per unit area. This quantity was formerly known as the illumination value or illumination level. There are several illuminance-related terms used in lighting design. The lighting requirements for a specific application are described in terms of 'maintained illuminance'. Maintained illuminance is defined as the average illuminance over the reference surface at the time that maintenance has to

3.32 (Contd)

be carried out by replacing lamps and/or cleaning the lighting equipment and room surfaces.

3.33 Illuminance ratio. The ratio of the levels of illuminance between a work area and adjacent areas.

3.34 Incandescent lamp. A lamp in which light is produced by a filament heated to incandescence by the passage of an electric current.

3.35 Indirect lighting. Lighting in which the greater part of the flux reaches the surface (usually the working plane) only after reflection at other surfaces, usually a roof or ceiling. Luminaires with a flux fraction ration greater than 10 are usually regarded as indirect.

3.36 Installed power density (W/m^2/100 lux). The installed power density per 100 lux is the power needed per square metre of floor area to achieve 100 lux on a horizontal plane with general lighting.

3.37 Lightness. The perceived brightness of the colour. A (very approximate) objective measure of lightness is luminance.

3.38 Load factor. The ratio of the energy actually consumed by a lighting installation with controls over a specified period of time to the energy that would have been consumed had the lighting installation been operated without controls during the same period of time.

3.39 Local lighting. Lighting designed to illuminate a particular small area which usually does not extend far beyond the visual task, eg a desk light.

3.40 Localized lighting. Lighting designed to illuminate an interior and at the same time to provide higher illuminances over a particular part, or parts, of the interior.

3.41 Lumen (lm). The SI unit of luminous flux, used in describing a quantity of light emitted by a source or received by a surface. A small source which has a luminous intensity of one candela emits a total of 4 lumens in all directions and emits one lumen within a unit solid angle, ie 1 steradian.

3.42 Luminaire. An apparatus which controls the distribution of light given by a lamp or lamps and which includes all the components necessary for fixing and protecting the lamps and for connecting them to the supply circuit. Luminaire has officially superseded the term 'Lighting fitting' which is still used colloquially.

3.43 Luminance (l, unit: $cd\ m^{-2}$). The physical measure of the stimulus which produces the sensation of brightness measured by the luminous intensity of the light emitted or reflected in a given direction from a surface element, divided by the projected area of the element in the same direction. The SI unit of luminance is the candela per square metre. The relationship between luminance and illuminance is given by the equation:

3.43 (Contd)

$$\text{Luminance} = \frac{\text{Illuminance x Reflectance factor}}{\pi}$$

This equation applies to a matt surface. For a non-matt surface, the reflectance is replaced by the luminance factor.

The luminance of the sky (and other sources that cannot be visualized surfaces) may be described in terms of the illuminance produced on a surface:

$$\text{Luminance of a small zone of sky} = \frac{\text{Illuminance on a surface directly facing sky zone}}{\pi}$$

3.44 Luminous intensity. Quotient of the luminous flux leaving the source, propagated in an element of solid angle containing the given direction, by the element of solid angle. The standard abbreviation is I and the SI unit is the candela.

3.45 Lux. The SI unit of illuminance, equal to one lumen per square metre (lm/m^2).

3.46 Maintained illuminance (E_m, unit: lux). The average illuminance over the reference surface at the time maintenance has to be carried out by replacing lamps and/or cleaning the equipment and room surfaces.

3.47 Reflectance (factor) (R_r). The ratio of the luminous flux reflected from a surface to the luminous flux incident on it. Except for matt surfaces, reflectance depends on how the surface is illuminated but especially on the direction of the incident light and its spectral distribution. The value is always less than unity and is expressed as either a decimal or as a percentage.

3.48 Saturation. The quality that distinguishes a hue from white. Pastel shades are desaturated, vivid colours are saturated. An objective measure of saturation is purity.

3.49 Spectral power distribution. A function relating the amount of power in a light stimulus with wavelength.

3.50 Specular reflection. Reflection without diffusion in accordance with the laws of optical reflection as in a mirror.

3.51 Spot lamp replacement. A maintenance procedure where individual lamps are replaced only when they fail. Particularly with discharge lamps, this is likely to result in a large proportion of the lamps operating well below their optimum economic efficacy and therefore a greater number of luminaires will need to be installed to achieve the required maintained illuminance during the operational life of the installation. Some spot lamp replacement may be necessary when group lamp replacement is adopted to replace early lamp failure occurring between initial installation and the bulk lamp change.

3.52 Standard maintained illuminance. The maintained illuminance recommended for the assumed standard conditions of the application.

3.53 Standby lighting. Emergency lighting provided to enable normal activities to continue.

3.54 Task area. The area containing those details and objects that must be seen for the performance of a given activity, and includes the immediate background of the details or objects. In the absence of precise dimensions the task area is assumed to be a 0.5 m square, which is placed within a 1 m square surround.

3.55 Transmittance. The light passing through a surface. This is usually expressed as a percentage of the light incident.

3.56 Tristimulus values. In the CIE system, the amounts of the X, Y and Z primaries required to match a colour. The tristimulus values define a set of functions called colour-matching functions.

3.57 Uniformity (illuminance (U_E) luminance (U_L)). The ratio of the minimum illuminance (or luminance) to the average illuminance (or luminance) over a specified surface. The ratio usually applies to values on the task area over the working plane.

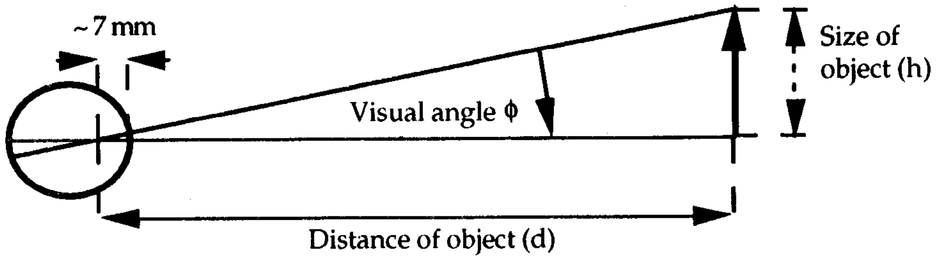
3.58 Uplighter. Luminaires which direct most of the light upwards onto the ceiling or upper walls in order to illuminate the working plane by reflection.

3.59 Visual acuity. The capacity for discriminating between objects which are very close together. Quantitatively, it can be expressed by the reciprocal of the angular separation in minutes of arc between two lines or points which are just separable by the eye. The expression more commonly used for an individual's visual acuity is the ratio of the distance at which the individual can read a line on a standard optician's chart to the standard distance at which a person of normal sight can read that line (eg 6/12 means that the individual can just read at 6 m the line which a normally sighted person can just read at 12 m).

3.60 Visual angle. The angle subtended on the retina by the extremities of an object (see figure 1). For example, if an object of size h is at a distance d from the retina the visual angle subtended, ϕ, is:

$$\phi = \arctan\left(\frac{h}{d}\right)$$

At normal reading distance, a 12-pt letter subtends a visual angle of 13'. The moon subtends a visual angle of 30'.



$$\text{Tan } \phi = \frac{h}{d}$$

Fig 1 Visual Angle

3.61 Visual disability. A disability is any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being.

3.62 Visual environment. The environment either indoors or outdoors as seen by an observer.

3.63 Visual field. The full extent in space of what can be seen when looking in a given direction.

3.64 Visual task. The visual element of the work being done.

3.65 Visual impairment. An impairment is any loss or abnormality of psychological, physiological or anatomical structure or function.

3.66 Working plane. The horizontal, vertical or inclined plane in which the visual task lies. If no information is available, the working plane may be considered to be horizontal and at 0.8 m above the floor.

Section two. Principles of vision

4 Anatomy and Physiology

4.1 Photoreceptors. The initial stage of vision is the incidence of light energy on light sensitive cells called photoreceptors at the back of the retina. Photoreceptors are specialized nerve cells that transduce light energy into electrical energy. The photoreceptor contains a light-sensitive pigment termed a visual pigment, because of its obvious role in vision. There are two classes of photoreceptor, and hence the retina is frequently described as duplex.

4.2 Photoreceptors and vision

4.2.1 The two classes, known as rods and cones because of their structural appearance, perform different visual functions. For example, rods are not used for colour vision. Colour vision is solely the domain of the cone receptors.

4.2.2 In any one eye there are about 6.8 million cones and about 115 million rods. However, the relative densities of both classes of receptor change quite dramatically as the retina is traversed (see figure 2). Moving out from the foveal region, the density of cone receptors decreases markedly having a density of some 1% of their foveal value just 2 mm from the foveal centre. On the other hand, the density of rod receptors increases to a maximum density some way out from the central foveal region.

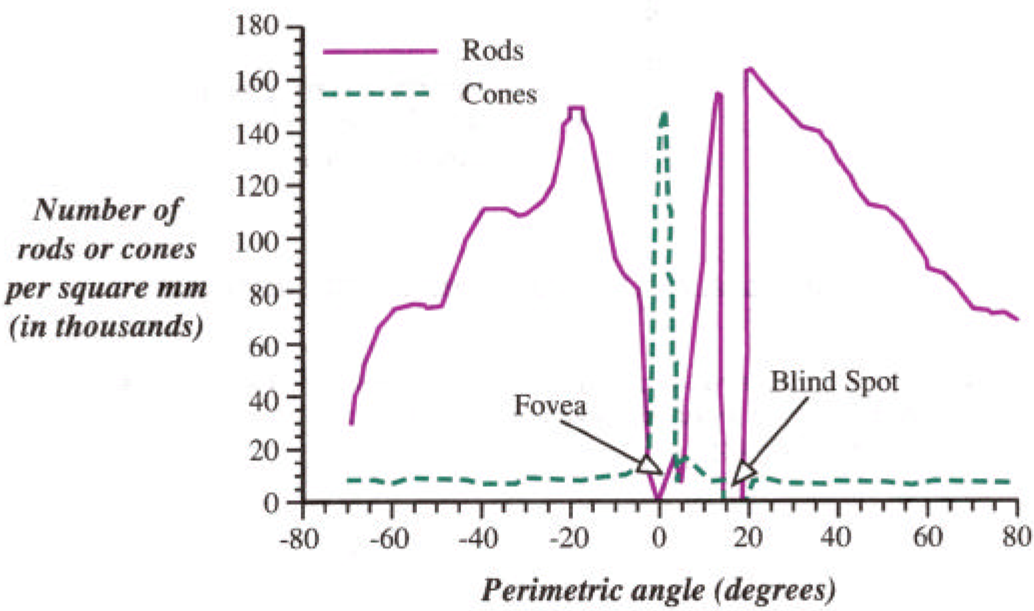


Fig 2 The Relative Densities of Rod and Cone Photoreceptors as a Function of Visual Angle

4.2.2 (Contd)

We use our rods in low light levels. Hence, the duplex anatomical organization of our retina underlies a similar duplicity in the nature of our sensitivity to light. It is as if we have in our retinae two carefully interleaved 'films', one with high sensitivity used in low light levels that yields a black-and-white sensation (the scotopic system); a second with lower sensitivity that operates under brighter light levels and that yields a colour sensation (the photopic system). At intermediate light levels both systems operate: this is known as the mesopic range. Figure 3 shows the relative sensitivity of these two systems. These two functions describe the CIE Standard luminous efficiency functions. Table A shows the visual sensitivity range and some approximate luminances.

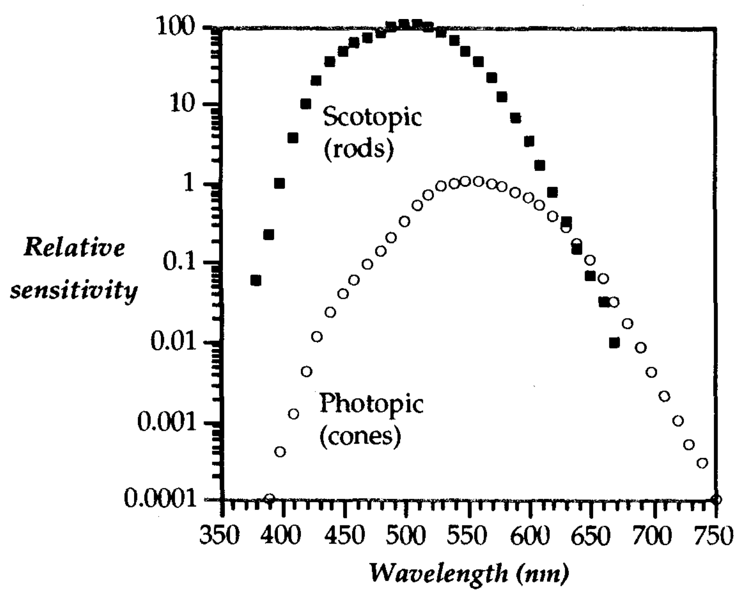


Fig 3 Photopic and Scotopic Sensitivity Functions

4.2.3 The x-axis plots wavelength in nm; the y-axis plots log sensitivity. The scotopic function has been displaced by two log units to reflect its greater absolute sensitivity.

Table A

Visual Sensitivity Range and Approximate Luminances

cd m^{-2}		cd m^{-2}	
1000000	Upper limit of visual tolerance	10^6	
100000		10^5	
10000	Sky - clear day; fluorescent tube	10^4	Photopic
1000	Cloudy day	10^3	range
100	Good reading light on white paper	10^2	
10		10^1	
1		10^0	
0.1	Average luminance of lit roadways at night	10^{-1}	Mesopic
0.01	White surface in full moonlight	10^{-2}	range
0.001		10^{-3}	
0.0001	White surface in starlight	10^{-4}	
0.00001		10^{-5}	Scotopic
0.000001	Lower threshold of vision	10^{-6}	range

4.2.4 Physiological evidence shows that the rods are most sensitive to light radiation around 500 nm (what would be perceived in photopic vision as a bluish-green, see figure 3), whereas the cones fall into three separate classes (see figure 4). The single photopic function shown in figure 3 is actually an amalgam of the three classes of cone. These three classes have maximal sensitivity around 420, 530 and 560 nm. These three classes are known as short- (S), middle- (M) and long- (L) wavelength cones, since these are the regions of the visual spectrum where they are most sensitive.

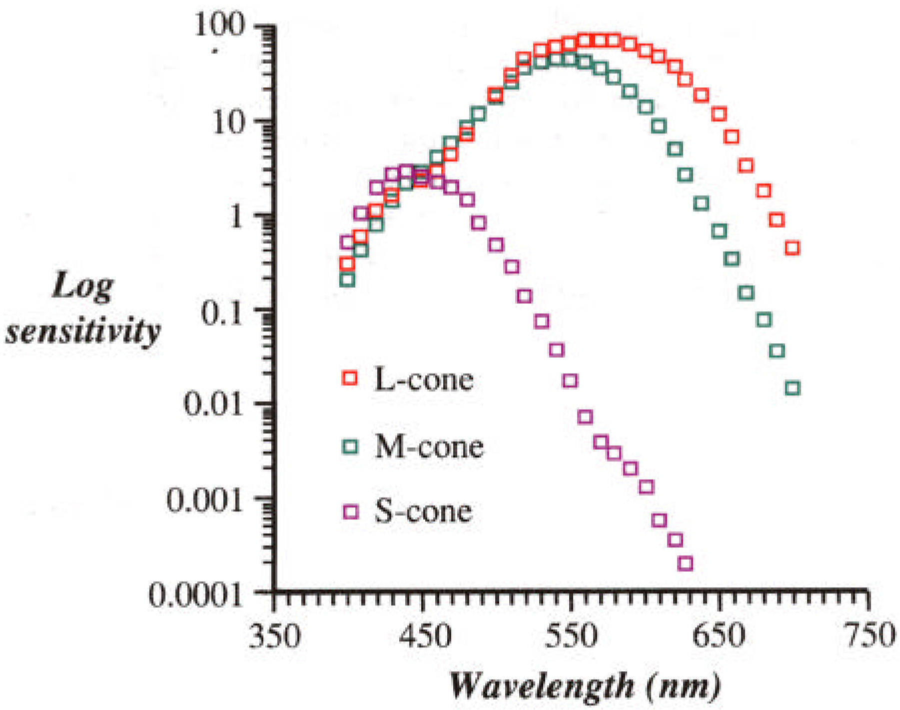


Fig 4 Spectral Sensitivity of the L-, M- and S-Cone Systems

4.3 Dark adaptation

4.3.1 In order to use fully the scotopic system, the eye must be dark adapted. This takes a few minutes after moderate levels of light adaptation, but as long as 30 min if the pre-exposure has been very strong. Light adaptation in the reverse direction (that is, from dark to light) is very rapid, and usually complete in less than a minute.

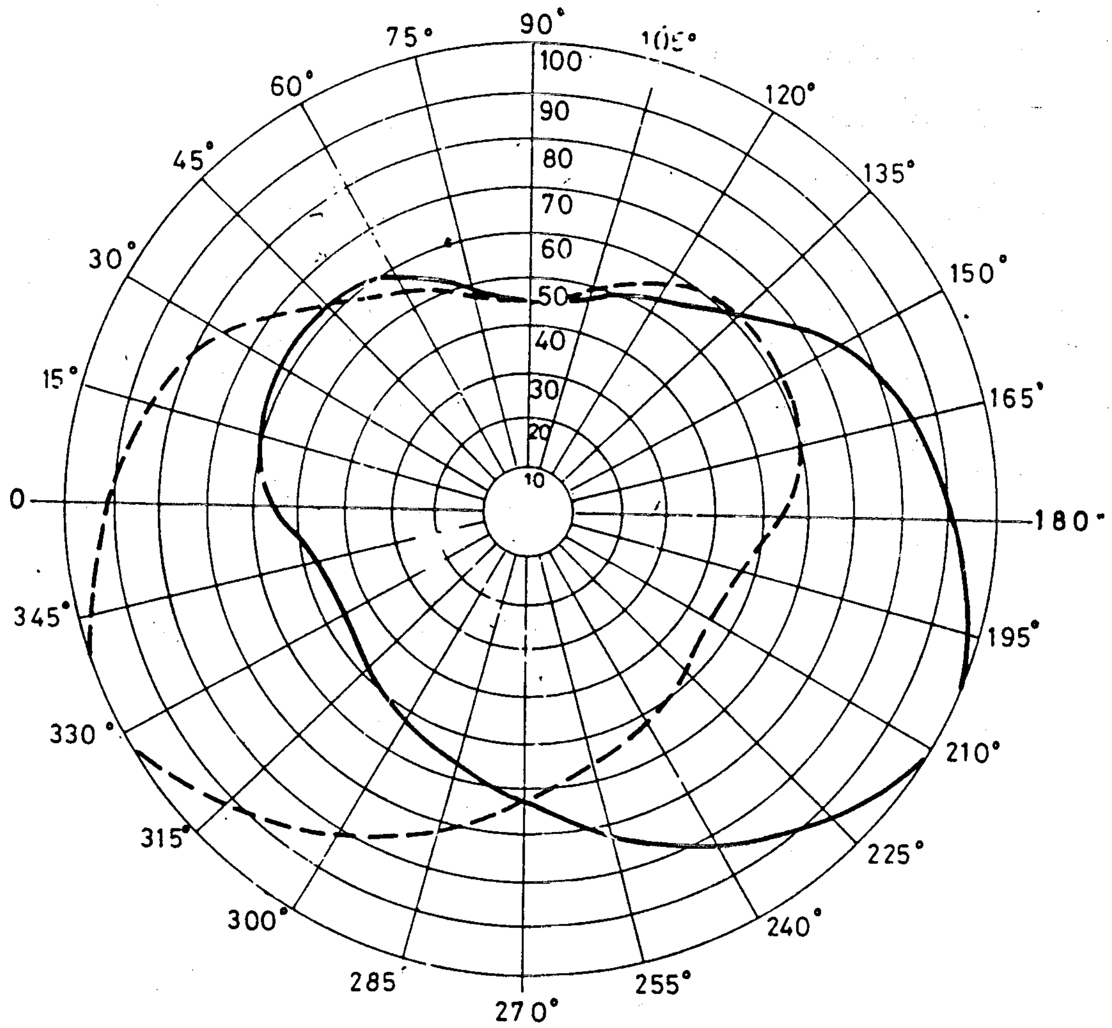
4.3.2 Methods of preserving the sensitivity of the dark-adapted eye have importance for military purposes. If an expected degree of dark adaptation is required, then pre-adapted personnel should wear goggles that pass only long-wavelength (>620 nm) red light. An observer who is in a dark-adapted state is hardly affected by suitable red lighting and is therefore able to receive a sufficient intensity of it in a ready room to read and perform tasks and yet maintain an adapted state. The basis for using red light is that wavelengths beyond about 620 nm have little influence on the scotopic system, yet the photopic system is still active (see figure 3).

4.3.3 A serious restriction on the use of red lighting is that the rendering of colours will be markedly affected and many colour discriminations will not be possible. This restriction is especially applicable to the reading of coloured maps. When it is necessary to read maps at night a special viewing area may be required with a low level of illuminance of white light which is screened from dark-adapted personnel and used by one member of a crew whose dark adaptation does not need to be preserved.

4.3.4 The eye and the nervous system are particularly sensitive to a lack of oxygen and the lowering of the oxygen content of the blood can reduce night vision sensitivity. This may be caused by unusual conditions of ventilation where the air is contaminated by flue gases, especially carbon monoxide, and where there is air-tight ventilation as in submarines. Exposure to reduced oxygen at high altitude causes an increase in the time for dark adaptation, and under conditions equivalent to a height of 1500 to 2000 m the change in visual sensitivity is quite significant.

4.4 Monocular and binocular field of view. Each eye has its own field of view (monocular field) and on a horizontal plane through the line of sight, each field extends from the forward view to approximately 100° outwards, 60° inwards, 65° upwards and 75° downwards. Both monocular fields have an overlap area which form the binocular field of stereoscopic vision. Stereoscopic depth discrimination is very sensitive: under optimal conditions, disparities as small as 2 sec of arc can be detected. This would correspond to a depth difference of less than 0.05 mm at 50 cm, or 4 mm at 5 m.

4.4 (Contd)



- - - - - Left eye ________ Right eye
Monocular fields for left and right eyes.
Binocular field is the overlapping area.

Fig 5 Perimeter Chart and Plot of Visual Fields

4.5 Recommendations

4.5.1 Colour vision is best in the foveal region. If colour is used, ensure that the area can be centrally fixated. For example, do not use colour in the peripheral visual field to gain attention.

4.5.2 Colour judgements require photopic lighting conditions. When making colour judgements from displays the luminance should be at least 35 cd m^{-2}.

4.5.3 Protective goggles or face masks will cause a loss of the field of view and have a marked effect on the detection of movement in the periphery of vision. This needs to be considered if individuals are wearing personal protective equipment for nuclear, biological or chemical protection.

5 Seeing Detail and Movement

5.1 Contrast sensitivity

5.1.1 Visual ability is sometimes defined in terms of the optician's eye-chart. A substantial limitation with this type of acuity measure is that it quantifies vision only for small, high-contrast objects. In the real world, military personnel are often called upon to distinguish large objects of low contrast (such as a tank in a smoke-filled battle zone, or a car in fog). The most complete description of the spatial abilities of the visual system is provided by the contrast sensitivity function (csf). This is a function relating the sensitivity to variations in contrast as a function of the size or spatial frequency of objects. To determine this a subject looks at a spatial sinusoid (a grating) of variable contrast which is adjusted until it is barely distinguishable from a uniform, unmodulated grey. An example of the csf for human vision is shown in figure 6.

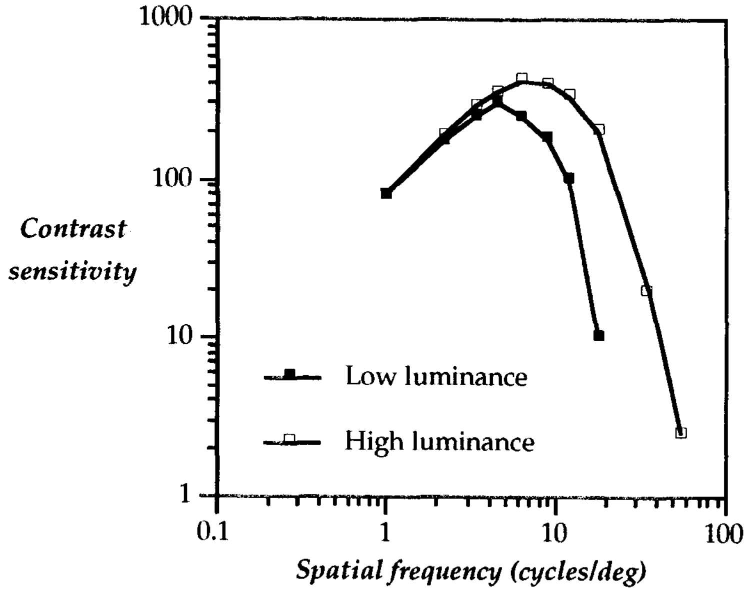


Fig 6 Contrast Sensitivity Functions for Gratings at a High Mean Luminance (about 1000 cd m^{-2}, open symbols) and a Low Mean Luminance (about 10 cd m^{-2}, filled symbols)

5.1.2 The optician's eye chart is just one way of measuring acuity. Our threshold for detailing a letter (about 30s to 1 min of arc) is substantially higher than our threshold for detecting the mere presence of an object (about 0.5s of arc). In terms of the csf, the high frequency cut-off may be extrapolated to a contrast sensitivity of 1, corresponding

5.1.2 (Contd)

to a contrast threshold of 100%. The frequency that can be detected at this contrast represents the observer's acuity, or limit of resolution, for a grating stimulus. In the case of a normal observer the limit lies between 50 and 60 cycles deg^{-1} (equivalent to a bar width between 37 and 30s of arc).

5.2 Practical significance of contrast sensitivity

5.2.1 Measurements of contrast sensitivity are more useful than measures of acuity for predicting visual performance in real-world tasks. Contrast sensitivity differences have been shown to be predictive of the visibility of stationary targets in the detection and identification of letters and aircraft silhouettes, simulated air-to-ground target detection, and in actual ground-to-air target detection. These studies all show that contrast sensitivity predicts these classes of visual performance better than do the results of visual acuity tests. For example (Ginsburg, 1986), two pilots had similar acuity but different contrast sensitivities, and the pilot with the higher contrast sensitivity detected the MiG target at a distance 2.4 times greater than his colleague. This difference translated into detection time differences of 21 seconds for clear and 10 seconds for fog visibility conditions.

5.2.2 Other uses of the csf include evaluating the quality of visual images, including head-up displays, and gauging the disabling effects of glare from various types of lighting sources.

5.3 Factors affecting visual sensitivity

5.3.1 Visual sensitivity is affected by a number of parameters. The csf becomes less peaked and shifts downwards and to the left (see figure 5) if the stimulus moves or if the csf is measured outside the central visual field.

5.3.2 Changes in sensitivity with luminance have direct relevance to the designer of display screens. For example, positive polarity (black text on a white background) screens result in a higher space-averaged luminance than negative polarity (white text on a black background) screens, and have significant advantages. These are:

(a) visual sensitivity increases with luminance;

(b) at high luminance levels the pupil diameter is relatively small, this results in greater depth of field (the operator needs to refocus less often) and fewer optical distortions;

(c) they are less subject to glare;

(d) they cause less contrast adaptation in the user.

The disadvantage with positive polarity screens is that our sensitivity to flicker increases with luminance too.

5.3.3 Other important factors that influence visual performance are:

(a) movement of the task or operator;

5.3.3 (Contd)

(b) vibration;

(c) age of the operator;

(d) visual fatigue;

(e) lack of oxygen to the eye.

5.4 Eye movements. Eye movements shift the retinal images over each retina to cause the region of current interest to lie on the two foveae. When this has been achieved, eye movements hold the image steady on the retina by reflex movements compensating for rotations of the head, and also by pursuit movements if these are necessary to track a moving target. Saccadic eye movements are fast but relatively inaccurate movements used to orient towards an object. For practical applications, the most important eye movements are smooth pursuit eye movements. These are the types of eye movement used when tracking objects (for example, a target moving on a display screen). The eyes can track targets comfortably up to about 10°-20° s^{-1}. At higher velocities, eye movements consist mainly of saccadic movements. These attempt to correct errors in eye position every 200 or 250 msec.

5.5 Dwell time. Fixation duration ("dwell time") on an instrument on a control panel is a function of the difficulty of reading the instrument and of interpreting the data from it. Figure 7 shows some typical dwell times for three different tasks. Research shows that pilots spend the majority of their time (95% for some tasks) monitoring instruments, yet changes in design (for example, combining several instruments into single, integrated display) may not reduce the monitoring load as much as would be expected.

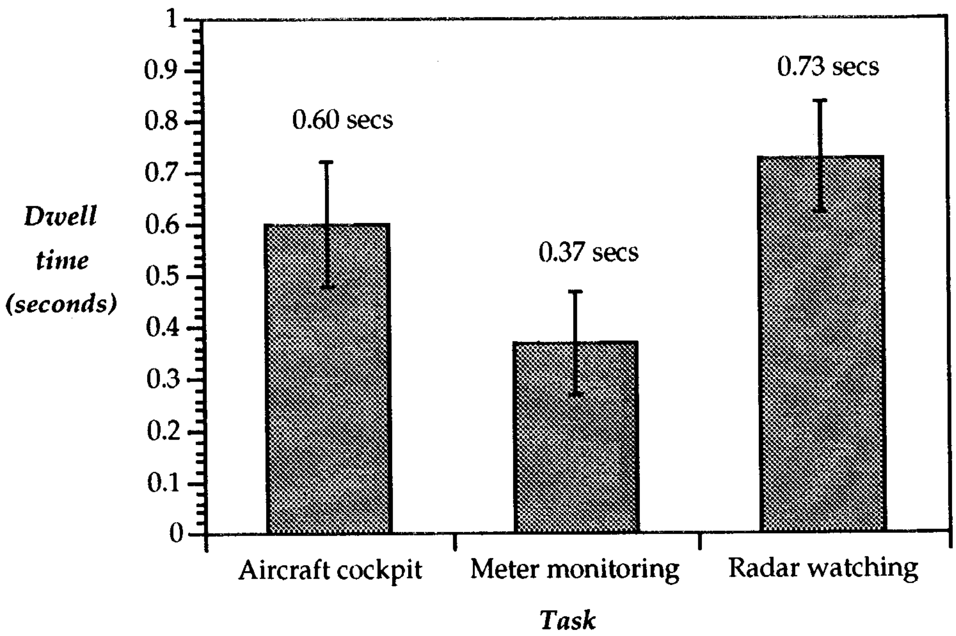


Fig 7 Dwell Times for Pilot Flying a C-45 Twin-Piston-Engined Light Transport Aircraft; a Laboratory Meter-Watching Task; and for Radar Operators (Adapted from Moray (1986))

5.6 Flicker. Display screens that flicker can be extremely annoying to users and they can cause visual fatigue and headaches. Our perception of flicker depends on a number of factors, including the observer, the luminance of the display, position in the field of view, and the area (size) of flicker. So for example, some observers may have lower thresholds for flicker than others, bright screens appear to flicker more than dim screens; perceived flicker is noticed more in the peripheral field of view; and large areas such as drawing boards may reflect light from overhead fluorescent tubes and appear to flicker.

5.7 Speed of response. Reaction time (RT) to symbols or icons increases as the number of alternative responses increase (see figure 8). More formally:

$$RT = a + b \log_2 N$$

where a and b are constants that depend on the task and N is the number of choices. As a rule of thumb, reaction time when only one signal and response is possible is about 180-200 msec. Whenever the number of alternatives is doubled, reaction time increases a roughly constant amount (about 150 msec).

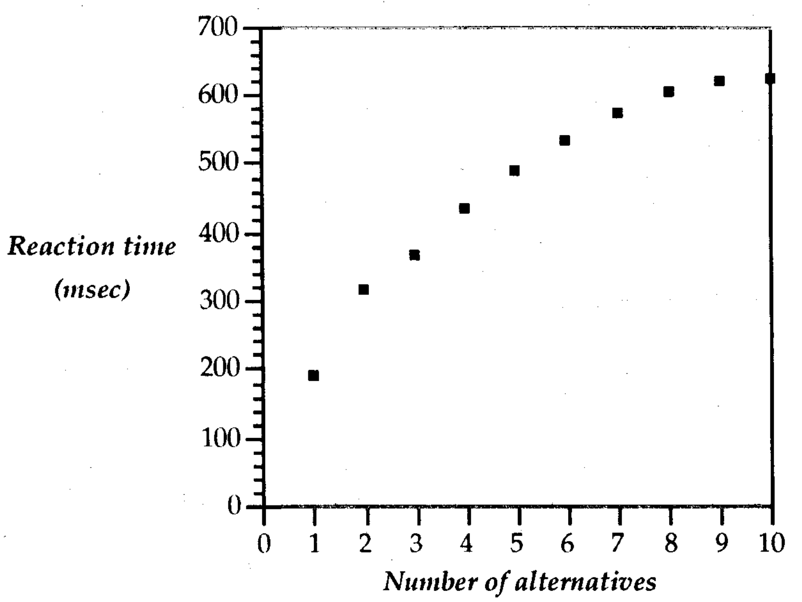


Fig 8 Reaction Time Increases as the Number of Alternatives Increases
(These data are adapted from Keele (1986))

5.8 Recommendations

5.8.1 For visual tasks that require fine discrimination, ensure that the lighting is sufficient (see table B).

5.8.2 Because visual sensitivity depends on a number of variables and varies between individuals, it is advisable to develop mock-ups of critical systems to evaluate the system design.

5.8.3 When prolonged and intensive visual work is likely to be undertaken by personnel, tests of visual acuity and contrast sensitivity should be first carried out by suitably qualified personnel to select appropriate individuals.

5.8.4 Whenever possible, display screens should be flicker-free to the user population. However, because of individual differences in flicker perception, this may not be practicable for all observers under all situations. An algorithm for testing CRT displays for flicker is provided in annex B.

5.8.5 When speed of response is important, reduce the number of choices that the user must make or consider the use of coding (eg shape coding or colour coding).

6 Seeing Colour and Luminance

6.1 Colour coding

6.1.1 The use of colour on visual displays has been shown to be effective in improving performance on search and identify tasks in which the identification or location, or both, of specific quantitative information is important. Colour has been shown to be more effective than shape, size or alphanumerics when certain types of information need to be located quickly within a display.

6.1.2 Colour has been shown to be effective as a coding scheme, particularly for qualitative information. Where more than a small number of coding categories exist, other coding schemes, such as alphanumerics, are more efficient for the transmission of the information. However, the use of colour may still help if the separate categories can be logically divided into several major divisions. Each major division can then be coded using a different colour.

6.1.3 A colour maintains its attention-getting value only if it is used sparingly and consistently.

6.1.4 Colour is useful for grouping or organizing information. This allows information to be transmitted more efficiently as long as the number of colours used for this purpose is limited. A large number of colours may actually be counter-productive to organizing information.

6.2 Redundant coding. Redundancy allows people with colour vision deficiencies to interpret colour coded displays. It may also reduce the impact of individual gun failures in CRTs. In situations such as cockpit lighting conditions, redundancy also helps ensure the accurate transmission of information where colours alone may be difficult to distinguish even for persons with normal colour vision. Figure 9 demonstrates redundant colour coding.

6.2 (Contd)

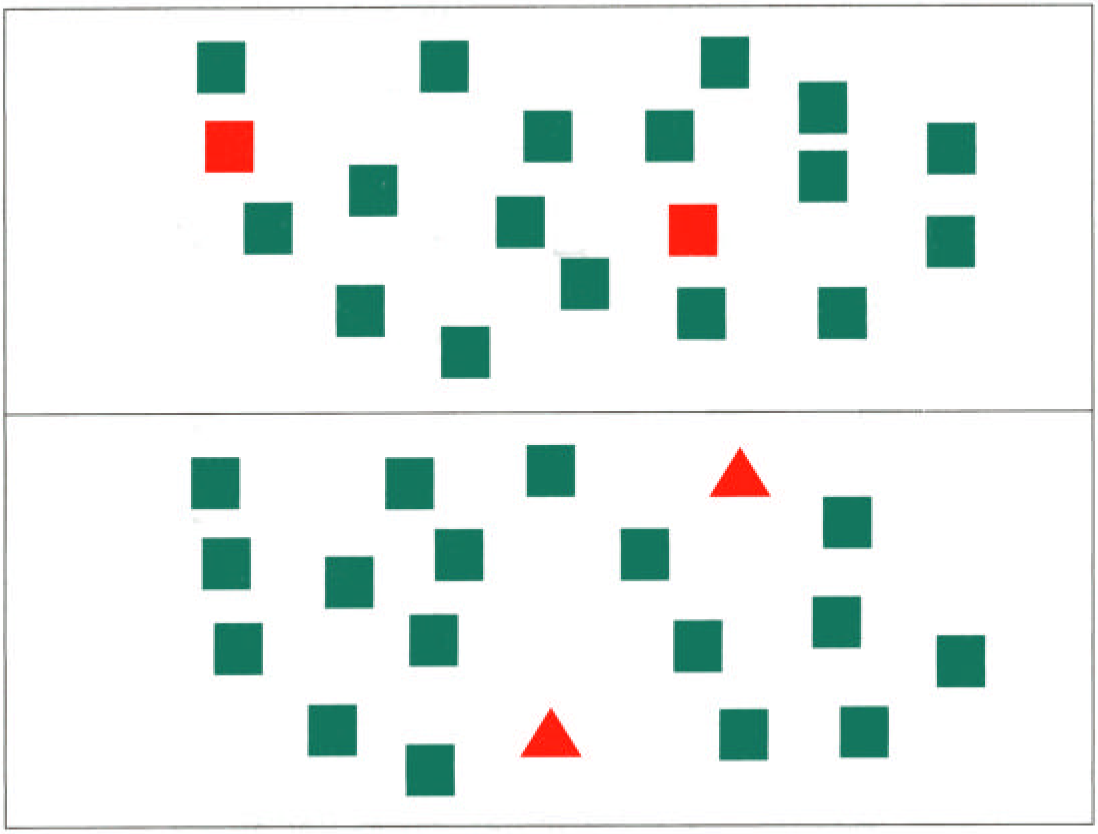


Fig 9 Redundant Colour Coding

In the upper panel, only colour coding (red and green) is used to distinguish between two different sets of data. In the second panel, shape differences are added to the colour coding.

6.3 Contrast and legibility. For contrast and legibility, the important metric is the contrast ratio of the luminances in the image. Colour contrast has a relatively minor effect on legibility, with the exception of saturated blue (for example, the blue phosphor of the CRT by itself). Saturated blue has poor legibility characteristics, partly because of low luminance and partly because the optics of the eye blur short-wavelength light.

6.4 Colour deficiency. Although military personnel are screened for colour deficiency, this should not be interpreted to mean that all have perfect colour vision. Some of the tests used to measure colour vision will pass individuals with mild to moderate colour deficiencies, particularly of the red-green variety. Consequently, there is variability in colour vision among military personnel that have been classified as having normal colour vision. Beyond congenital colour defects, acquired colour defects are also possible. For example, the lens of the eye yellows with age, which makes the eye less sensitive to short-wavelength (blue) light, and exposure to toxic substances may affect colour vision.

6.5 Colour and size. As symbol size is reduced below 30 min of visual angle, blue-greens and yellows become increasingly difficult to distinguish from one another. As symbol size is reduced further (below 15 min of visual angle) reds and greens become increasingly difficult to distinguish from one another (see figure 10).

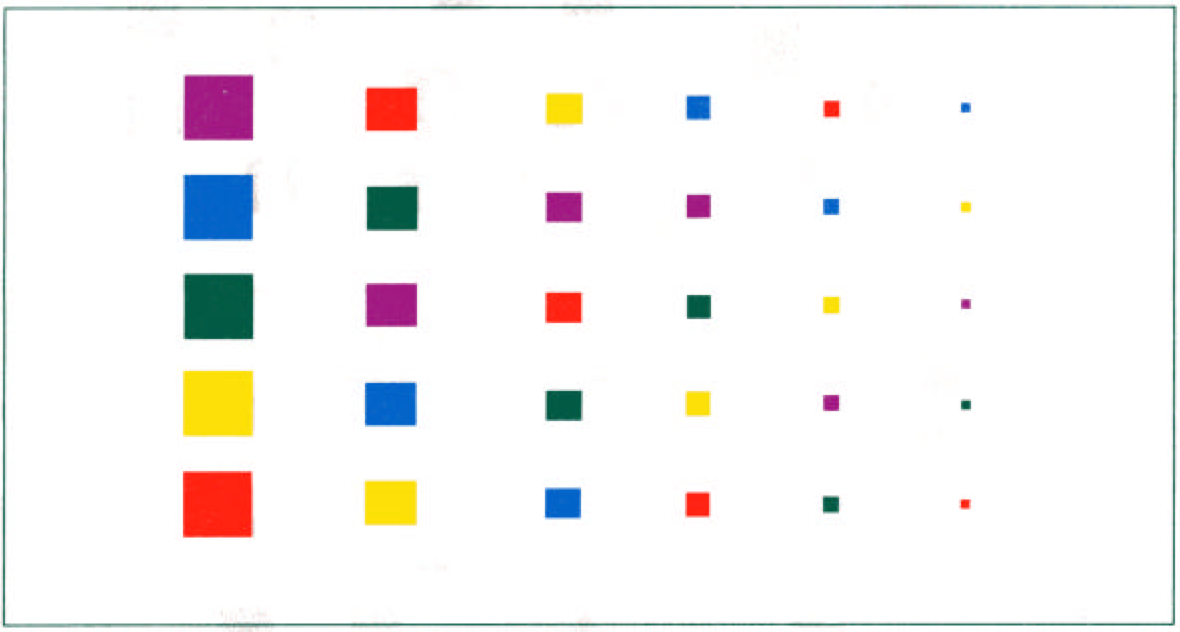


Fig 10 As Symbol Size is Reduced, it Becomes Increasingly Hard to Make Accurate Colour Discriminations

6.6 Recommendations

6.6.1 Colour codes should agree with commonly accepted practices, for example red for warnings, yellow for cautions and green for engaged or OK status. These traditional warning and cautionary colours should be reserved solely for this purpose as the use of these colours for other purposes will degrade their alerting value.

6.6.2 For critical alerting functions, colour should be always redundant with another coding feature, such as shape or an auditory warning signal.

6.6.3 Even for non-critical functions, colour coding should be redundant. This is because redundancy helps operators with colour vision deficiencies.

6.6.4 The number of colours used on a single display should be kept to a minimum. The use of more than six symbol colours may degrade performance on search, identification and coding tasks. The use of more than six colours is not precluded, but careful testing should be undertaken to ensure that the use of a larger number of colours does not degrade task performance. A useful starting palette is: white, red, green, yellow, purple and cyan. These six colours plus black, grey, brown and blue for background shading can be used effectively.

6.6.5 In general, colour should not be used to code quantitative information unless that information can be divided into a smaller number of distinct categories, such as has been done for colour coded weather radar map displays.

6.6.6 Avoid the use of saturated blue (for example, the blue phosphor of the CRT by itself) for fine detail, such as alphanumerics, thin lines, arrows and cursors. Saturated blue should never be used as a text colour. When reading from colour display, it is always preferable to use black or white as the text colour: this has the advantage that most background colours will achieve the required contrast ratio. To compute colour difference and legibility, use the equations in section nine.

6.6.7 If two colours are adjacent (for example, separate windows on a screen) or if one colour is superimposed upon another (for example, text on a coloured background) ensure that the colours maintain a contrast ratio of about 3:1. When a colour-coded target is moving over a coloured background ensure that the colours also maintain a contrast ratio of about 3:1. This can be most easily achieved by drawing a high contrast border around the object.

6.6.8 As symbol size is reduced, care must be taken to ensure that perceived colour differences are maintained.

Section Three. Photometry and Colorimetry

The information in this section provides an overview of the general principles behind photometry and colorimetry. This information is necessary to implement some of the guidance in sections two and four. More complete guidance can be found in Wyszecki & Stiles (1982).

Photometry and colorimetry provide the tools necessary to evaluate workstations and working environments to ensure that they are visually comfortable and reduce visual workload. These tools are indispensable when colour coding information on displays, reproducing colours accurately and evaluating workplace lighting. Photometric and colorimetric principles must be applied to achieve some of the recommendations in sections two and four.

7 Basic Principles of Photometry

Photometry is the process where instruments are used to measure the luminous intensity of a light source or a surface, by comparing it with a standard source. The comparison can be done either with the human eye or with a photoelectric cell.

The basic terms to be understood are shown in figure 11. More formal definitions of these terms are provided in the Definitions section.

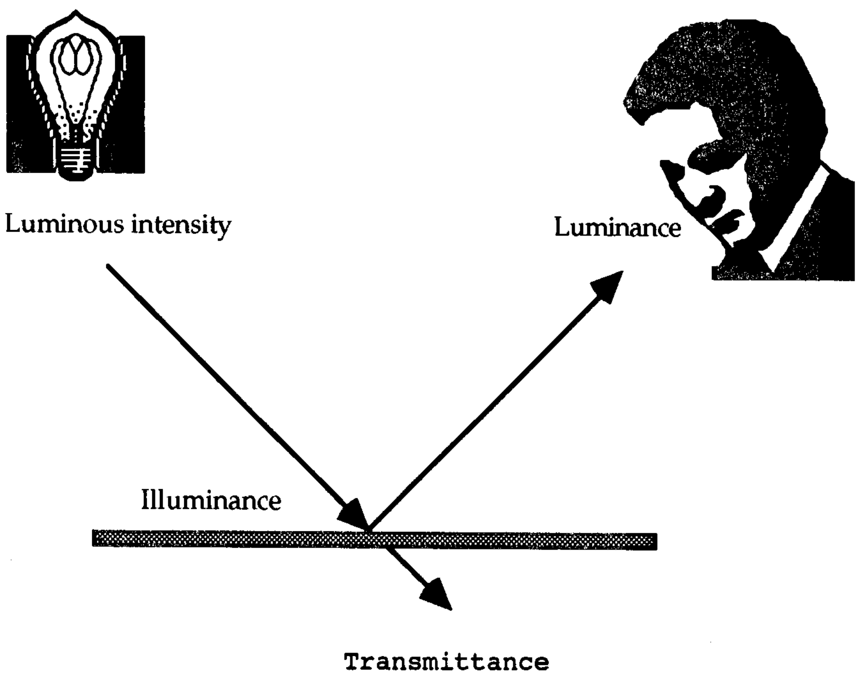


Fig 11 Illustration of Basic Light Concepts

7.1 Photometry: a practical guide. Illuminance levels should be measured in the field, for two reasons. First, to check that an installation has met its design specification. Second, to examine the illuminance levels in an area where complaints about the lighting are occurring. There are several points to note when measuring illuminance levels in a field survey.

7.1.1 Before taking lighting measurements in an area, it is necessary to stabilize the performance of the lamps and luminaires. Depending on the lighting installation, a certain amount of run-up time is required to achieve full light output, for example, discharge lamps take at least 20 minutes to achieve full light output. Ideally, the lights should be on for one hour before measurements are taken.

7.1.2 The photocell of the illuminance meter should be exposed to the levels to be measured for about 5 minutes before taking the first measurements.

7.1.3 The illuminance meter should be calibrated regularly and the zero reading should be checked and adjusted as necessary.

7.1.4 When measurements of the electric lighting installation only are required, daylight must be excluded from the area, or the survey carried out after dark.

7.1.5 Measurement of illuminance should be taken at working positions on the principal horizontal, vertical or inclined planes on which the tasks are performed. If there are no principal planes, a standard horizontal height of 0.7 m for seated tasks and 0.85 m for standing tasks should be used. The floor can be taken as the working plane if movement is the only activity carried out in the area.

7.1.6 The measurer must ensure that their shadow does not fall on the photocell while measurements are being recorded.

7.1.7 Both the average illuminance and the minimum illuminance in the space should be determined.

7.1.8 Two methods of measurement of average illuminance and illuminance variation are recommended: the full grid of measurement points; and the two-line method of average illuminance. details of these techniques are described and illustrated in the CIBSE Code for interior lighting 1994.

8 Basic Principles of Colorimetry

Colorimetry is the science of measuring colour, so that colours can be given numbers or labels and can be communicated and reproduced. This standard briefly reviews two methods: colour order systems and the CIE system. Colour order systems provide a basic overview of colour; the CIE system is needed for more formal specification of colour, especially in the areas of colour coding and colour reproduction.

8.1 Colour order systems. There are a number of colour order systems in general use, including the Munsell Book of Colour, the Optical Society of America Uniform Colour Scales and the Swedish Natural Colour System. A colour order system can be regarded as a subset of the thousands or millions of possible colour perceptions. It samples the world of colour according to three basic perceptual colour attributes that constitute the coordinate axes of the colour system. These three attributes are:

(a) Hue, the term that most closely resembles our notion of 'colour', for example, red, green and blue. It is that quality of a colour that cannot be accounted for by brightness or saturation differences. An objective measure of hue is provided by the dominant wavelength of that colour's spectral power distribution.

8.1 (Contd)

(b) Saturation, the quality that distinguishes a hue from white. Pastel shades are desaturated, vivid colours are saturated. An objective measure of saturation is purity.

(c) Lightness, the perceived brightness of the colour. A (very approximate) objective measure of lightness is luminance.

8.2 The CIE system. The most widespread method of colour specification is the CIE 1931 XYZ system. There are a number of colorimeters that conveniently allow you to measure the CIE coordinates of display phosphors, and most display manufacturers will supply the CIE coordinates of their monitors on request. Calibration of visual displays is usually carried out in the CIE (XYZ) system. For colour modelling purposes (eg colour coding) the CIELUV system should be used. This section describes these two spaces.

8.2.1 The CIE 1931 XYZ system

8.2.1.1 The CIE system is based upon a set of colour matching functions. These colour matching functions can be used to derive tristimulus values for any spectral power distribution, and it is a fact that two colours with the same tristimulus values will match precisely. This is despite the fact that they may have very different spectral power distributions. Colour matching functions provide an objective definition of colour in terms of three standard primary lights, and it is for this reason that the CIE standard of colorimetry is based upon such measurements.

8.2.1.2 Colours in CIE XYZ space are conventionally specified by their projection on a two-dimensional plane. Coordinates in this plane are known as chromaticity coordinates, and the diagram itself is known as a chromaticity diagram. The chromaticity coordinates are denoted by the symbols x, y and z and they are related to the tristimulus values (X, Y, Z) by the following simple algebraic expressions:

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$

8.2.1.3 Essentially, the space is a (slightly distorted) colour triangle, the apices of which represent the colours red, green and blue (see figure 12). All the colours that we are able to see can be plotted in this space, with white close to the centre. Highly saturated colours plot at the sides of the triangle: the locus of these colours is known as the spectral locus since this is where the spectral colours plot. As a colour becomes more desaturated (ie whiter) it is plotted closer to the centre of the triangle.

8.2.1.4 Figure 12 shows the CIE diagram with the location of spectral colours at 5 nm intervals and the coordinates of the UK PAL System 1 television phosphors denoted by R, G and B. All possible mixtures of the three display phosphors fall on or within the lines of the RGB triangle. Hence, there are many colours that cannot be produced with these phosphors (but because most colours in the real world are not highly saturated, this deficiency is rarely noticed). The cross near the centre of the diagram plots the position of an equal energy white. The *y*-axis can be thought of as representing how much green is in a colour and the *x*-axis how much red. Hence blues plot near the origin, since they have little red or green in them.

8.2.1.5 Before specifying display colours in CIE 1931 XYZ space it is necessary to compute the tristimulus matrix of the display. There are two methods of computing the tristimulus matrix. Both methods require the chromaticity coordinates of the three phosphors in cie 1931 XYZ space. In addition, Method 1 requires the chromaticity coordinates of the white that the three phosphors produce when turned on at their maximum. Method 2, which is somewhat simpler, requires measurement of the relative luminances of the three phosphors. Annex C provides step-by-step instructions for computing this matrix.

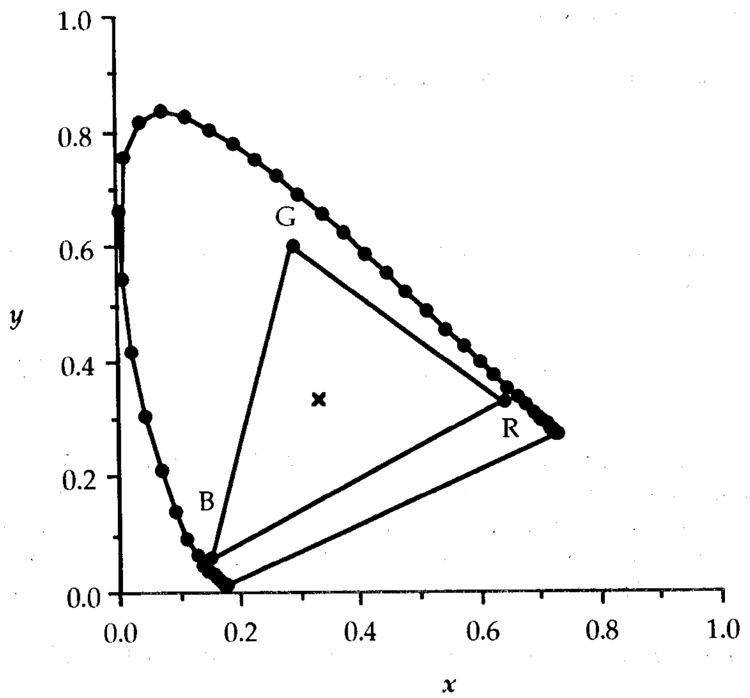


Fig 12 CIE 1931 XYZ Colour Space with the Location of Spectral Colours at 5 nm Intervals and the Positions of the UK PAL System 1 Television Phosphors

8.2.2 The CIE 1976 Uniform Colour Spaces

8.2.2.1 One problem with the CIE 1931 XYZ colour space is that it is not perceptually uniform: equal geometric steps in the space are not perceptually equal. A perceptually uniform colour space provides a useful tool fro the designer who needs to choose a palette of colours that are equally discriminable from each other. In addition, it can be used to

8.2.2.1 (Contd)

provide a quantitative measure of colour difference between different colours. This can be used to maximize the perceptual differences amongst colours in a palette.

8.2.2.2 Two alternative colour spaces have been proposed that are perceptually more nearly uniform. These are the CIE 1976 (L*u*v*) colour space (abbreviated CIELUV) and the CIE 1976 (L*a*b*) colour space (abbreviated CIELAB). The two spaces are very similar and hence only one (CIELUV) is described here.

8.2.2.3 CIELUV transformation is achieved by computing the three quantities L*, u* and v* from the equations:

$$L* = 116\left(\frac{Y}{Y_n}\right)^{1/3} - 16$$

$$u* = 13L*(u'-u_n)$$

$$v* = 13L*(v'-v_n)$$

with the constraint that $\frac{Y}{Y_n} > 0.008856$

if $\frac{Y}{Y_n} \leq 0.008856$, the equation for L* becomes

$$L_m^* = 903.3\left(\frac{Y}{Y_n}\right)$$

8.2.2.4 The chromaticity coordinates u′, v′ are calculated from the XYZ tristimulus values as:

$$u' = \frac{4X}{X + 15Y + 3Z} \qquad v' = \frac{9Y}{X + 15Y + 3Z}$$

8.2.2.5 There is currently no standard definition of Y_n for self-luminous displays. One feasible suggestion is to set Y_n to the maximum luminance within the image under consideration. u'_n and v'_n are the values of the reference white under consideration. Normally, these are coordinates for CIE standard illuminant D_{65} where $u'_n = 0.1978$ and $v'_n = 0.4684$.

8.2.2.6 Within CIELUV, the total colour difference, ΔE^*_{uv}, can be computed from:

$$\Delta E^*_{uv} = \sqrt{[(\Delta L*)^2 + (\Delta u*)^2 + (\Delta v*)^2]}$$

8.2.2.7 For tasks involving symbol legibility, ΔE^*_{uv} is not a good measure and several other methods have been used in an attempt to predict legibility performance. One is the ΔE_{Yuv} legibility measure:

$$\Delta E_{Yuv} = \sqrt{[(\,[155/Y_m]Y)^2 + (367u')^2 + (167v')^2]}$$

where Y_m is the luminance of the brighter of a symbol/background pair. The constants in the equation were derived such that 100 ΔE_{Yuv} units of contrast is predicted to yield asymptotic reading speed performance.

8.3 Colorimetric measurement: a practical guide

8.3.1 In order to perform colour space manipulation of the type described above, the chromaticity coordinates of the visual display need to be specified in CIE 1931 XYZ coordinates. Manufacturers of high quality displays usually include these data with the technical specifications; but chromaticities may change with time and spatial location on the screen so when accurate colour specification is important (for example when colour coding a safety-critical system), it is preferable to measure these coordinates with a colorimeter.

8.3.2 Colorimeters filter light with three filters whose spectral transmittance approximates the CIE 1931 XYZ colour matching functions. There are a number of devices available but they are expensive, and hand-held ones may not be accurate. All devices operate in essentially the same way: the operator simply points the colorimeter at the screen, presses the button or runs a computer program, and reads off the chromaticity coordinates.

8.3.3 However, a warning is necessary. The colorimetry of visual displays poses special problems and suffer from difficulties in measurement. Reference should be made to National Physical Laboratory (1994).

8.4 Recommendations

8.4.1 For critical applications, ensure that displays remain in specification by regular and frequent calibration to the CIE(XYZ) standard.

8.4.2 Use the CIELUV colour space to derive a palette of colours that are perceptually equally spaced.

8.4.3 Use the ΔE^*_{uv} metric to derive a set of colours that are maximally discriminable from each other. For an algorithm see Silverstein et al (1986). For tasks involving colour discrimination, ΔE^*_{uv} has been shown to be an effective predictor of performance and ΔE^*_{uv} can be used to maximize the perceptual differences among colours. However, some problems still exist with this measure and it is impossible to specify a satisfactory minimum acceptable colour difference at this time. No one colour difference measure that is currently available will give an accurate measure for all tasks involving the use of colour.

8.4.4 For symbol legibility use the ΔE_{Yuv} legibility measure.

Section Four. Lighting Design Practice and Application

9 Background

In this section we provide a background to the factors which are important in lighting design practice and application. We also consider lighting design practice for a number of special lighting conditions. We provide guidelines and recommendations for lighting design at the end of each section.

10 British Code of Practice

The main British Code of Practice on lighting is published by the Lighting Division of the Chartered Institution of Building Services Engineers (CIBSE). The CIBSE has recently (at the time of writing) republished their Code for Interior Lighting (1994). The CIBSE code gives more detailed guidance than is covered in this Standard, and should be consulted for further information on:

(a) the effect of lighting conditions on the performance of tasks in a wide range of interiors;

(b) the appearance of an interior;

(c) general and specific lighting design criteria for a range of interior and exterior applications;

(d) the cost-effective use of energy.

11 Main Requirements of Lighting Design

Lighting design in both interior and exterior environments should facilitate three main functions:

(a) Task performance, by providing enough light to make details of the task easy to see and to ensure high levels of speed and accuracy.

(b) Safety, by allowing people enough light to see hazards or potential hazards.

(c) Visual comfort, by making the appearance of the lit space match the requirements of the visual system for comfort and effectiveness.

We consider each of these requirements in the following sections.

11.1 Task performance

11.1.1 When describing task performance in the following paragraphs, we are making the assumption that the major part of the task under consideration is visual, and that the visual part of the task has the greatest effect on performance. For example, map-reading is clearly a predominantly visual task, which will require adequate lighting levels to perform satisfactorily, but telephone or radio communication, equally clearly, is not a predominantly visual task, and performance is unlikely to be affected by increasing illumination levels.

11.1.2 The illuminance needed for a task depends on how much detail needs to be seen. For task performance, planar illuminance is most commonly used metric for design, and relates to the plane in which the task takes place, be it horizontal, vertical or inclined. Many tasks take place in a horizontal plane. The light levels falling on the plane in which the task takes place should be adequate for the type of task, and extreme variation in illuminance across the task should be avoided. In military applications, eg control panels, aircraft cockpits, the working plane is often vertical or inclined. Potential differences in the inclination of the working plane should be taken into account when designing lighting by testing the tasks on mock-ups of the arrangement with different lighting configurations to ensure that the illuminance is appropriate for those tasks.

11.1.3 The ability of the eye to discern detail in a task is determined primarily by the size of the detail, contrast between background and foreground and the state of the viewer's vision. Lighting can make a considerable contribution to improved visual performance, and affects task performance as follows:

(a) Increasing the illuminance on the working plane of the task increases performance, but follows a law of diminishing returns until reaching a 'saturation level' where performance reaches a plateau.

(b) The illuminance level at which performance levels off is inversely related to the size of the detail and the contrast in the task, ie the smaller the size and the lower the contrast, the higher will be the saturation level. It is not possible, however, to make the performance of a difficult visual task match that of an easy visual task merely by increasing the illuminance levels on the task.

11.1.4 A useful lighting design aid is provided in tables B and C. Table B gives examples of tasks/interiors appropriate for each maintained illuminance. It is used in conjunction with modifying factors given in table C (Design Maintained Illuminance Flow Chart) to obtain the design maintained illuminance allowing for departure from typical conditions. The modifying factors are:

(a) the visual demands of the task;

(b) the duration of the work;

(c) the consequences of errors.

11.1.5 We describe an example below of using these tables for lighting design:

11.1.6 You wish to design an interior lighting scheme in an area where the tasks will be the assembly of electronic secure systems for aircraft communication on a day shift of seven hours. The detail on many of the components is small (3-5 min arc). Errors in assembly may have fatal consequences for pilots.

11.1.7 Looking at table B, you would select 750 lux as the standard maintained illuminance for the visual task (1). You would then examine table C in the light of your modifying factors. Starting on the left-hand side with your standard maintained illuminance of 750 lux (2), consider the first two choices, task size and contrast. One or two details of your assembly task are low contrast, so you follow the dashed arrow to 900 lux (3a, if many of the details were low contrast, you would follow the solid line to 1000 lux, 3b). Then consider task duration. The task is not undertaken for unusually long or short times, so follow the 900 lux line through to the third factor, errors (4). You are aware that errors may have fatal consequences for pilots and their aircraft, so you follow the bold arrow, to 1300 lux (5). Your design maintained illuminance is therefore 1300 lux (6).

11.1.8 The CIBSE Code for Interior Lighting 1994 goes further than the general maintained illuminance guidelines described in the previous tables and example. It provides recommendations on the maintained illuminance and limiting glare index for a wide range of interiors and activities. These recommendations are derived from research, workplace legislation, other CIBSE guides for certain industries, and British, European and International standards. For example, they provide specific recommendations for lighting applications which are likely to be represented in MOD installations such as airports, appliance servicing, cold stores, computer workstations, control rooms, garages, gymnasia, hospitals, machine shops, plant rooms, residential buildings and workshops. For detailed information on the specifics of lighting such areas, the CIBSE Code should be consulted.

Table B

Example of Activities/Interiors Appropriate for Each Maintained Illuminance

STANDARD MAINTAINED ILLUMINANCE (LUX)	CHARACTERISTICS OF ACTIVITY/INTERIOR	REPRESENTATIVE ACTIVITIES/INTERIORS
50	Interiors used rarely with visual tasks confined to movement and casual seeing without perception of detail.	Cable tunnels, indoor storage tanks, walkways.
100	Interiors used occasionally with visual tasks confined to movement and casual seeing calling for only limited perception of detail.	Corridors, changing rooms, bulk stores, auditoria.
150	Interiors used occasionally or with visual tasks not requiring perception of detail but involving some risk to people, plant or product.	Loading bays,medical stores, plant rooms.

Continued on page 35

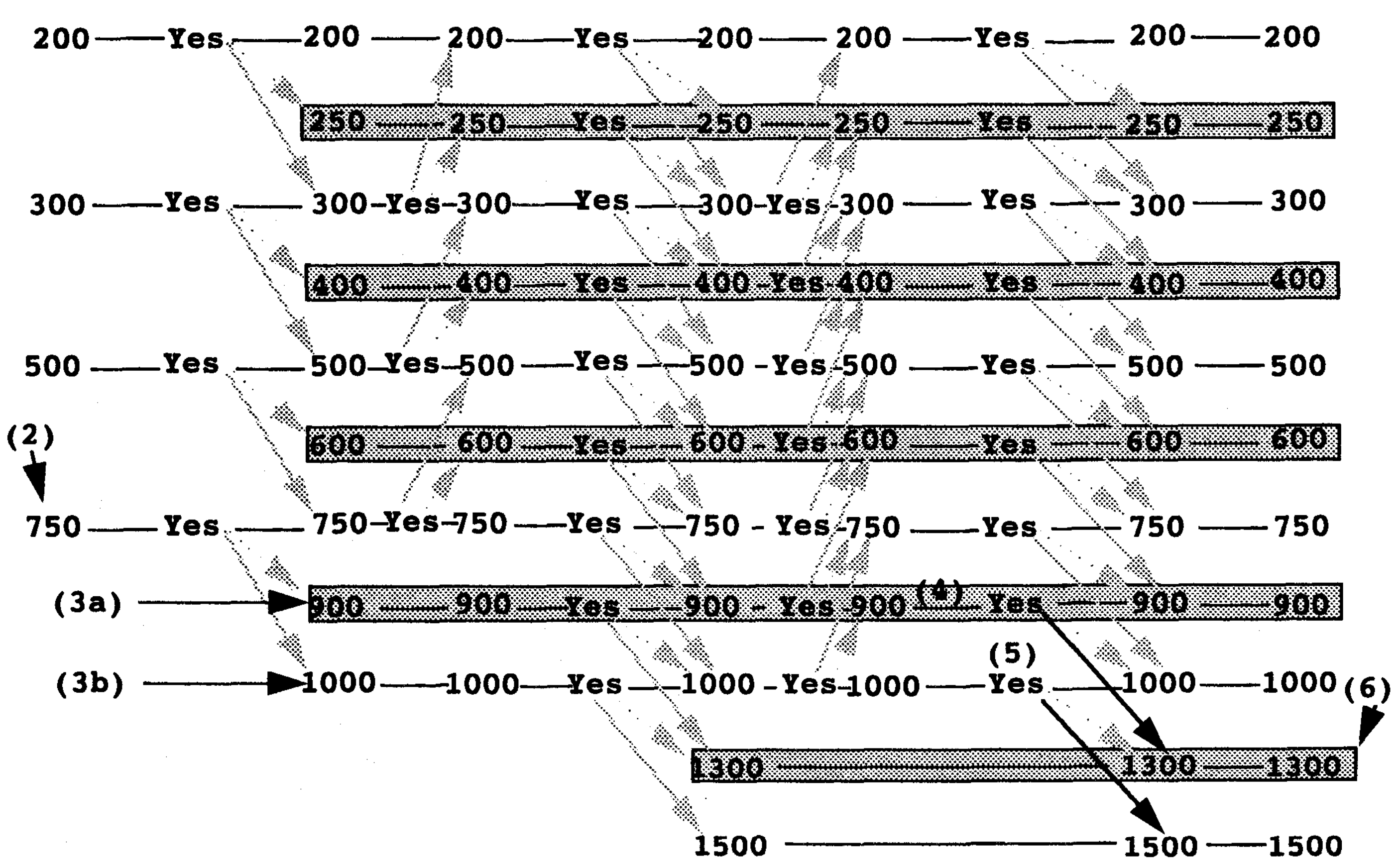
Table B - Concluded

STANDARD MAINTAINED ILLUMINANCE (LUX)	CHARACTERISTICS OF ACTIVITY/INTERIOR	REPRESENTATIVE ACTIVITIES/INTERIORS
200	Interiors occupied for long periods, or for visual tasks requiring some perception of detail.	Foyers and entrances - monitoring automatic processes, casting concrete, turbine halls, dining rooms.
300	Interiors occupied for long periods, or when visual tasks are moderately easy, ie large details (greater than 10 min arc) and/or high contrast.	Libraries, sports and assembly halls, teaching spaces, lecture theatres, packing
500	Visual tasks moderately difficult, ie details to be seen are of moderate size (5-10 min arc) and may be of low contrast; also colour judgements may be required.	General offices, engine assembly, painting and spraying, kitchens, laboratories, retail shops.
(1)750	Visual tasks difficult, ie details to be seen are small (3-5 min arc) and of low contrast; also good colour judgements or the creation of a well lit, inviting interior may be required.	Drawing offices, ceramic decoration, meat inspection, chain stores.
1000	Visual tasks very difficult, ie details to be seen are very small (2-3 min arc) and can be of very low contrast; also accurate colour judgements or the creation of a well lit, inviting interior may be required.	General inspection, electronic assembly, gauge and tool rooms, retouching paint work, cabinet making, supermarkets.
1500	Visual tasks extremely difficult, ie details to be seen extremely small (1-2 min arc) and of low contrast; optical aids and local lighting may be of advantage.	Fine work and inspection, hand tailoring, precision assembly.
2000	Visual tasks exceptionally difficult, ie details to be seen exceptionally small (less than 1 min arc) with very low contrasts, optical aids and local lighting will be of advantage.	Assembly of minute mechanisms, finished fabric inspection.

Table C

Maintained Illuminance Flow Chart

Standard maintained illuminance (lux)	Task Size and Contrast		Task Duration		Error Risk	Design maintained illuminance (lux)
	Are task details unusually difficult to see?	Are task details unusually easy to see?	Is task undertaken for unusually long time?	Is task undertaken for unusually short time?	Do errors have unusually serious consequences for people, plant or product?	



11.2 Safety

11.2.1 Good lighting has an important role to play in promoting health and safety at work. Generally, safety is influenced by lighting in that the more quickly and easily a hazard can be seen and identified, the more easily it can be dealt with or avoided. In working and circulation areas, people must be able to see to move about without tripping, falling or walking into obstacles. The type and levels of lighting needed for safety depend primarily on the type of work being carried out, and the hazards associated with it.

11.2.2 The illuminance produced by lighting installation is usually non-uniform. Using average illuminances can result in the presence of some areas in the environment having much lower illuminance which could lead to health and safety hazards, as well as visual discomfort. Health and safety texts state a 'minimum measured illuminance' for any position within an environment, which is the lowest illuminance permitted in the work area. Visual discomfort can be caused by sharp contrasts between the task and surrounding areas. The difference in illuminance between one area and another is known as an illuminance ratio. We provide recommendations on illuminance ratios at the end of this section.

11.3 Visual discomfort

11.3.1 Appropriate lighting for a task and its environment can reduce the likelihood of various forms of visual fatigue and discomfort.

11.3.2 Common symptoms of visual discomfort include:

(a) soreness, dryness, irritation or inflammation of the eyes and eyelids.

(b) Adverse visual symptoms such as blurred or double vision, and difficulty in focusing on the details of the task.

(c) Indirect symptoms such as headaches, neckaches, fatigue and backache, for example, users of display screen equipment (DSE) may adopt awkward postures to avoid the effects of reflections on their screens, thus causing back or neckache.

11.3.3 Poor lighting is not the only cause of visual discomfort - for example, doing any visual task which causes the visual system to work at the limits of its capabilities for long periods of time is likely to result in visual discomfort. Poorly corrected vision can also be a cause of discomfort in tasks where the primary activity is visual, for example intensive DSE use.

11.3.4 Visual discomfort can also be caused by glare. Glare occurs as a result of bright sources of illumination in a less bright field of view to which the visual system is adapted, for example car headlights on full beam at night. Disability glare occurs when there is a direct effect preventing the visual system from operating; discomfort glare occurs when the effect of the glare is to cause distraction or annoyance.

11.3.5 The psychological effects of lighting have also been linked to reports of what has become known as 'sick building syndrome'. Office workers in certain buildings have complained of general discomfort and symptoms such as lethargy, flu-like symptoms, dry throat/eyes, headaches etc. In general, the best 'healthy' buildings had mechanical or natural ventilation, openable windows, and untinted glazing on the windows. By comparison, the least healthy buildings had air conditioning, no openable windows, and all had tinted windows. Stone (1992) examines the evidence for sick building syndrome in his review paper 'Fluorescent lighting and health'.

11.4 Heath hazards of light

11.4.1 There are also more serious effects of light. Very high lighting levels, and certain wavelengths of light, eg ultraviolet light or high energy laser beams, can also cause tissue damage or specific sight damage. There are two main ways in which light radiation can cause damage:

(a) The radiation causes a chemical reaction in the affected tissue, for example, short wavelength radiation can be absorbed by the eye, causing the cornea and conjunctiva to become inflamed, as in snow-blindness.

(b) The radiation heats or burns exposed tissue, for example, sunburn is caused by prolonged exposure to longer wavelength ultraviolet radiation.

11.4.2 The light sources found in most work situations are unlikely to cause radiation damage. However, there are certain circumstances that may be hazardous, for example:

(a) High pressure mercury discharge lamps. These are used in interior and exterior environments for floodlighting, display lighting and street lighting. If faulty, harmful levels of ultraviolet radiation may be emitted. Fluorescent versions of this type of lamp present the same hazard.

(b) Tungsten halogen lamps. These are used in interior and exterior environments for floodlighting and studio lighting. Under normal operating conditions they are protected by protective filters. However, they can emit significant amounts of ultraviolet radiation when they are being maintained, or if the protective filters are removed or damaged.

11.5 Glare. Glare is the discomfort or impairment of vision experienced when parts of the visual field are excessively bright in relation to the general surroundings. Two aspects of glare are acknowledged and they are referred to as disability glare and discomfort glare.

11.5.1 Disability glare

11.5.1.1 Disability glare (dazzle) is glare which impairs the ability to see detail without necessarily causing visual discomfort. The lights of the headlight of a car on an unlit street at night cause extreme disability glare. Other situations such as strong daylight seen through a window and shining directly into the eyes or specular reflections from glossy surfaces such as dials and metallic surfaces are further examples of disability glare. The effects vary from causing a reduction in the contrast of objects in the field of view to a total inability to see while the glare source is present.

11.5.1.2 Disability glare is measured in terms of its effect on contrast threshold, that is the minimum contrast between the source and the background that can be detected. There are a number of factors that influence disabling effects and they are expressed in terms of the following formula:

$$L_v = 10\sum_{j=1}^{n} \frac{E_j}{\theta_j^2}$$

where L_v = equivalent veiling luminance (cd m^{-2})

E_j = illuminance at the eye on a plane perpendicular to the line of sight, from the j^{th} glare source

θ_j = is the angle between the line of sight and the j^{th} glare source

This formula holds for values of θ_j from 1.5° to 60°. For values of θ_j of less than 1.5° the CIBSE guide should be consulted.

NOTE: It is anticipated that an alternative CIE formula, the unified glare rating, will replace the glare index during the life of this Part of this Standard. The value of the unified glare rating will enable the discomfort glare from lighting installations to be ranked in order of severity and the permissible limit of discomfort glare from an installation to be prescribed quantitatively in the form of a limiting unified glare rating.

11.5.2 Disability glare and contrast sensitivity

11.5.2.1 Disability glare frequently reduces contrast sensitivity and the effect on a static target may be measured in terms of effective contrast (see Definitions).

11.5.2.2 The glare effect is caused by excessive scattering of light over the task and within the eye, the latter creating a light veil over the retina. Increasing sensitivity to disability glare occurs as a person gets older, and the effects are particularly noticeable in people above 40 years. How much a person is affected by disability glare conditions depends on any opacity in the lens as well as scattering of light within the eye.

11.5.3 Discomfort glare

11.5.3.1 Discomfort glare is glare which causes visual discomfort without necessarily impairing the ability to see detail. The effect is assessed subjectively and in the UK the subjective scales used by CIBSE are as follows:

Table D

The Glare Index Rating Scale

GLARE SENSATION	GLARE INDEX
Just intolerable glare	28 25
Just uncomfortable glare	22 19
Just unacceptable glare	16 13
Just perceptible glare	10

The ratings shown in the table are related to certain physical properties of glare situations. The relationship is expressed by the formula:

$$\text{Glare index} = 10\log_{10} \frac{0.45}{L_b} \sum_{j=1}^{n} \frac{L_j^{1.6}\omega_j^{0.8}}{L_b P_j^{1.6}}$$

where L_j = the luminance of the j^{th} glare source (cd m^{-2})
L_b = the average luminance of the field of view, excluding the glare source (cd m^{-2})
ω_j = the subtended area of the j^{th} glare source (steradians)
P_j = the position index of the j^{th} glare source which increases with increasing deviation from the line of sight

NOTE: It is anticipated that an alternative CIE formula, the unified glare rating, will replace the glare index during the life of this Part of this Standard. The value of the unified glare rating will enable the discomfort glare from lighting installations to be ranked in order of severity and the permissable limit of discomfort glare from an installation to be prescribed quantitively in the form of a limiting unified glare rating.

11.6 Flicker

11.6.1 Flicker is a source of both discomfort and distraction and may even cause epileptic seizures in some people. The perceptibility of flicker is influenced by the frequency and amplitude of the modulation and the area of vision over which it occurs. Large amplitude variations over large areas at low frequencies are the most uncomfortable conditions.

11.6.2 The major sources of flicker in fluorescent lamps are as follows:

(a) 100 Hz whole tube flicker (from a 50 Hz electrical supply). This is not usually perceived but some individuals will be sensitive especially in conditions of a large field of view with high surface luminances such as a drawing board.

(b) 50 Hz fluctuation from the end of lamps due to cathode glow which alternates every half cycle.

11.6.2 (Contd)

(c) 50 Hz whole tube flicker, arising due to unequal emissions from electrodes. As a tube ages this fluctuation increases in amplitude.

11.6.3 Flicker from fluorescent lamps can, where necessary, be reduced by one of the following methods:

(a) changing ageing lamps;

(b) using high frequency ballasts;

(c) using lamps fitted with shielded electrodes;

(d) screening the ends of the lamps.

11.7 Recommendations

11.7.1 Carry out user trials on mock-ups of working plane and lighting arrangements. This is particularly important when the tasks are to be carried out at an inclined surface.

11.7.2 Use the standard maintained illuminances in table B in conjunction with the modifying factors in table C to select a design maintained illuminance for the tasks.

11.7.3 Provide appropriate (ie the design maintained illuminance) levels of illuminance for the task. Levels of illuminance on the task which are too low or too high for the size of detail or contrast of the task may cause the operating mechanisms of the eye to operate at their limits, causing visual fatigue.

11.7.4 Prevent glare and reflections wherever possible. Disability glare directly affects the visual system, causing discomfort for the viewer as the bright area falls within their field of view. Reflections can obscure parts of the task which are necessary for effective performance, and often result in referred discomfort such as headaches or postural discomfort. In interior environments, glare is most often caused by sunlight or improperly diffused artificial lighting.

11.7.5 Prevent flicker wherever possible. Flicker (for example, from artificial lighting or reflected movement) may cause discomfort, and usually causes distraction from the task at hand.

11.7.6 Avoid wide variations in illuminance across the working plane. If two or more parts of the task have very different illuminances, the visual system is forced to adapt continually between the different levels, which can lead to visual fatigue and discomfort. Large differences of illumination or contrast in the user's environment have a similar effect, for example, a daylit window directly behind a display screen can cause discomfort as the visual system adapts between the two. For interior environments, illuminance ratios no greater than 5:1 should be used. To illustrate, in an office where the task illuminance is 500 lux, the minimum illuminance in adjacent areas should be no less than 100 lux.

11.7.7 Aim for illuminance ratios for task-to-immediate surround of 3:1, and task to general background 10:1. Task performance is reduced and concentration is more difficult to maintain if the task illuminance is lower than the immediate surround.

12 Interior and Exterior Lighting Design

In the following section we first consider some general factors, namely daylight, reflectances and illumination ratios which affect lighting design for both interior and exterior environments. Secondly, we examine factors specific to interior and exterior environments separately.

12.1 Daylight

12.1.1 Daylight is a major factor in task performance and visual comfort for people in both interior and exterior environments. Unless the function of an interior environment makes it impractical, for example, in some types of control room for security reasons, people will prefer to work in a room which has both daylight and a view to the outside. In terms of energy usage, the integration of daylight with electric lighting and good lighting controls can lead to significant savings in the primary energy used by a building.

12.1.2 A window or roof light can provide three functions which maximize people's visual comfort and promote energy saving, namely a view, illumination for task performance, and an increase in the general brightness of a room. However, care should be taken during the design to ensure that the use of daylight does not cause discomfort through glare or heat gains for other users of an interior space.

12.1.3 Daylight has some important characteristics which are relevant to lighting design in exterior and interior environments.

(a) The illuminance provided by daylight fluctuates with variations in the time of day, time of year, geographical location, and the weather. Therefore a constant task illuminance cannot be maintained, making it necessary to supplement daylighting with electric lighting.

(b) Windows at the sides of a worker performing a task give excellent three-dimensional modelling. Daylight is also useful for tasks where good colour rendering is important.

(c) Daylight can be a cause of both direct and reflected glare, both of which can cause visual discomfort and can affect the performance of a task.

12.1.4 As most people prefer to work in natural daylight it is important to make full use of it wherever possible. The Workplace (Health, Safety and Welfare) Regulations 1992 state that every workplace shall have suitable and sufficient lighting, and, so far as is reasonably practicable, lighting should be by natural light. In most circumstances suitable and sufficient lighting for both interior and exterior environments can be provided by a combination of natural and artificial lighting.

12.1.5 Innovative daylighting systems are designed to even out the effects of uneven daylighting, particularly where the backs of rooms are gloomy, and the perimeter very bright. Innovative daylighting systems may be of particular benefit where there are significant external obstructions. These systems improve the effectiveness of natural light as a source of

12.1.5 (Contd)

illumination for building interiors. This leads to potential energy savings and the quality of lighting is improved by reducing window glare. Littlefair 1990) provides a review of innovative daylighting systems and evaluation methods, and covers light shelves, light pipes, holographic diffracting systems, prismatic glazing, adjustable mirrored louvres and prismatic film.

12.2 Reflectances

12.2.1 For interior environments, the reflectance and finish of the main surfaces - ceiling, walls and floor - play an important part in the use of the light. The reflectance of a room surface is the ratio of the light reflected from a surface to the light falling upon it. Matt finishes on all of these surfaces are recommended so as to prevent reflections and to disguise surface imperfections.

12.2.2 In general, the reflectance of the surface finish of the ceiling should be around 0.8. Wall surfaces surrounding windows should have a reflectance of at least 0.6 in order to minimize the contrast between the bright window and the surrounding surfaces. The ratio between the average illuminance of a wall (or partition surface), to the average illuminance on a horizontal working plane should be within the range 0.5 to 0.8. To achieve this, (non window) wall reflectances should be between 0.32 and 0.7. Floor cavity reflectances should not fall below 0.2, or exceed 0.4, although in practice, in heavily industrial or obstructed areas, a minimum of 0.1 for the former figure is more realistically achievable. For occupied interior spaces, with office equipment or machinery in place, low reflectance worksurfaces should be avoided as they have a major effect on the floor cavity reflectance as well as the possibility of producing visual discomfort caused by sharp contrasts between the task and its immediate surround.

12.3 Illuminance ratios

12.3.1 Safety can be compromised in interior and exterior environments where there are large differences in illuminance between the lighting of the task area, and adjacent areas. Visual discomfort can be caused by sharp contrasts between the task and surrounding areas.

12.3.2 For interior environments, illuminance ratios no greater than 5:1 should be used. To illustrate, in an office where the task illuminance is 500 lux, the minimum illuminance in adjacent areas should be no less than 100 lux. Suggested targets for task-to-immediate surround are 3:1, and task to general background 10:1. Task performance is reduced and concentration is more difficult to maintain if the task illuminance is lower than the immediate surround.

12.3.3 For exterior environments, illuminance ratios of no greater than 10:1 should be used. Where there is movement between interior and exterior working areas, for example a storage area inside and a loading bay outside (exposing the person to a sudden change in illuminance), the maximum ratio should be 10:1. If these ratios between an interior and exterior environment cannot be achieved, a transition zone (lit to a level approximately half-way between the two) should be provided between the two adjacent areas.

12.4 Interior environments

12.4.1 There are three general categories of interior lighting used in workplaces, which should be dependent on the nature of the tasks carried out in the area:

(a) General background lighting, which provides uniform illumination over the whole working and surrounding area.

(b) Localized lighting, which provides levels of illumination appropriate for different types of task in the same area, for example, map/chart reading tasks will require higher localized lighting than display monitoring tasks, but both are often carried out in the same area.

(c) Local, or task lighting, which is required either when a high level of illuminance is needed in a small area, for example, when flexible directional lighting is required during intricate assembly or repair tasks; or where general overhead lighting is impossible or unnecessary to install because of characteristics of the work area.

12.4.2 In many interior working environments where tasks are carried out (as opposed to display or rest areas), a regular array of light fittings is used to provide the general and localized lighting. The spacing between fittings is critical, and manufacturers publish maximum spacing-to-mounting height ratios for each fitting. If these maxima are exceeded, there will be excessive variation in illuminance across the working place, which is likely to lead to visual discomfort, and in extreme cases, risks to health and safety.

12.4.3 In planning the lighting array for an interior environment, it is necessary to consider the eventual use of the space. For example, in an armaments storage warehouse with regularly arranged stacks or shelving, the spacing between the luminaires should match the spacing of the obstruction.

12.4.4 Where linear fittings are to be used for background or localized lighting, the orientation of the fitting is important. Linear fittings cause less glare if they are viewed end on rather than sideways on. Thus a regular array of fittings should be oriented so that they are end on to the viewing direction with the longest dimension.

12.4.5 People generally prefer lighting system which possess a degree of uplighting as well as downlighting. For example, Subisak and Bernecker (1993) evaluated four different systems with different degrees of uplighting in industrial premises, and showed a strong preference for the environment with higher average room surface luminances, particularly on the ceilings.

12.5 Exterior environments

12.5.1 The type of lighting installation for an exterior environment depends on the type of activity carried out in the space, and the size of the area to be covered. In general, exterior lighting installations should achieve a reasonably uniform illuminance on all relevant working areas, and avoid glare to the users of those areas, and people working in nearby areas. The lighting should be planned so as to optimize the use of exterior facilities while minimizing energy consumption. Usually, security and safety during the hours of darkness are the primary functional needs associated with most exterior lighting applications.

12.5.2 Exterior lighting can be classified into static or movable systems:

(a) Static - all luminaires are non-adjustable on their support and each is directed towards a single fixed point, for example roadway and pedestrian luminaires.

(b) Movable - luminaires are adjustable on their supports and can be directed at different areas of the exterior environment, either manually or by remote control, eg floodlighting equipment.

12.5.3 Lighting equipment which is used outside should be protected against weather, accidental or deliberate damage and corrosion. Manufacturers of outdoor lighting equipment specify the planes in which they are intended to be mounted. If there is a high risk of deliberate damage or unauthorized access to an area, higher illuminance values should be used.

12.5.4 The next few sections provide lighting design principles for the most commonly encountered types of exterior environment.

12.6 Lighting large areas

12.6.1 The type of lighting used will depend on the likely degree of obstruction in the area, and whether lighting is required primarily on the horizontal or vertical planes. If the horizontal plane is more critical, and if there is likely to be obstruction, the lighting should have a predominantly downward distribution. If vertical illuminance is more important, floodlights can be used, provided glare for the users of the space is avoided.

12.6.2 In large area exterior environments, lights are usually mounted on poles or plinths of varying heights. The spacing between the poles should ensure that excessive variation in illuminances is avoided.

12.7 Entrance areas and building periphery. All fittings for entrance and building periphery areas should be chosen and mounted so as to avoid glare for those entering and leaving the building. Generally, wall, pole or bollard mounted fittings are used for entrance areas and wall-mounted fittings for the periphery of buildings. The spacing of the fittings should prevent excessive illuminance variation which may cause a safety or security risk.

12.8 Perimeter lighting. This is usually for illuminating a fence line, enclosing wall or boundary. Commonly, the luminaires face outwards and are arranged so as to cause glare for any intruders. Typically, the array will be located 3-5 m from the fence. Apart from dazzling intruders, the objective is to ensure that the main flow of light is projected parallel to the ground to obtain the maximum revealing effect.

12.9 Searchlights

12.9.1 There are two main uses for searchlights:

(a) signal lights that are to be seen;

(b) sources of illumination by which distant targets are to be seen.

12.9.2 When considering the design of tasks for which searchlights will be used, several factors need to be taken into account, including the peak intensity of the searchlight, atmospheric transmittance, the size, shape and location of the target, the distance between the target and its background, the reflectance of the background, and the lateral offset distance of the observer from the searchlight.

12.10 Checkpoint Lighting. Checkpoint lighting enables people and vehicles to be checked at a point of entry or egress to an installation. General lighting within the checkpoint accommodation should be sufficient for movement within the accommodation. The lighting objective is to keep the security personnel's dark adaptation level as high as possible. This enables them to keep observation on the lighted area outside and to make minimum adaptation adjustment when stepping outside. Sufficient light may, for example, be provided by spill-light from a desklamp giving a maximum of 300 lux on the desktop. Any illumination in the checkpoint accommodation should be dimmable down to near blackout.

12.11 Roads. Lighting for road surfaces should enable vehicles and objects to appear in silhouette. The current roadway lighting standard uses horizontal luminance and uniformity of illumination as the primary design criteria. BS 5489, Code of Practice for Road Lighting, gives advice on suitable layouts.

12.12 Temporary sites. Many exterior military workplaces have temporary lighting installations. The lighting objectives, ie avoidance of glare and excessive variation in illuminances, are the same.

12.12.1 Further details of lighting design for exterior environments, eg roadways, building and security floodlighting can be found in Helms and Clay Belcher (1991) 'Lighting for Energy-Efficient Luminous Environments'. Further information can be obtained from CIBSE which publishes an applications guide: 'Lighting in Hostile and Hazardous Environments' (1983); and Lyons (1992) 'Lighting for Industry and Security: a Handbook for Providers and Users of Lighting'.

12.13 Recommendations

12.13.1 Determine the illuminance requirements of the tasks carried out in the space.

12.13.2 Determine where the tasks are to be performed in the interior and what planes they will occupy.

12.13.3 Consider what aspects of lighting are important to the performance of these tasks.

12.13.4 Determine if (a) general, (b) localized or (c) local lighting for task or display i the most appropriate for the situation.

12.13.5 Determine what types of equipment are in use.

12.13.6 Ensure that surface reflectances are compatible with a range of proposed lighting solutions.

12.13.7 Ensure that window and naked bulb/tube screening of some form is available.

12.13.8 Ensure that office, desk, equipment and/or machinery layouts re suitable for the range of proposed lighting solutions.

12.13.9 Ensure that the relative reflectance and/or illuminances between the areas that the users are likely to look at in succession are minimized.

12.13.10 Ensure that areas of high or low illuminance are avoided, or provide some way of shielding them, eg blinds on bright windows.

12.13.11 Consider what hazards need to be seen clearly, and determine areas where sudden loss of light might present a serious risk.

12.13.12 Determine whether optical aids are necessary.

12.13.13 Determine what impression the lighting is required to create.

12.13.14 Ensure that the following constraints are considered:

(a) Is a hostile or hazardous environment present?

(b) Are high or low ambient temperatures likely to occur?

(c) Is noise or interference from control gear likely to be a problem?

(d) Are mounting positions restricted and is there a limit on luminaire size?

(e) Is the choice of equipment restricted by the need to make the installation compatible with existing installations?

12.13.15 We recommend that the following detailed design principles are considered when planning the lighting design or refurbishment of an interior or exterior space:

(a) Have all the relevant lighting variables been considered, eg uniformity, illuminance ratios, surface reflectances and colours, light source colour, colour rendering group, limiting glare index, veiling reflections?

(b) Have the designed maintained illuminance and variation been calculated for the appropriate working planes?

(c) Has the glare rating been calculated?

(d) What is the relationship between daylight and electric lighting? Is it possible to provide a control system to match the electric lighting to the daylight available?

(e) Are the windows designed to limit the effects of solar glare and heat gain on the occupants of the building?

(f) Has consideration been given to unshielded bright lights or localized bright areas that may come into the field of view of other users?

(g) Does obstruction make some form of local lighting necessary?

12.13.15 (Contd)

(h) Does any supplementary individual lighting provided to cater for personal needs or a particular task adversely affect visual conditions at nearby workstations?

(i) How will the lighting installation influence other building services?

12.13.16 Ensure that manufacturer's guidance on luminaire spacing for desired illuminance levels is consulted and followed.

12.13.17 Ensure that regular array of luminaires is oriented so that they are end on to the viewing direction with the longest dimension.

12.13.18 Consider providing lighting which includes an element of uplighting as well as downlighting.

12.13.19 Ensure that suitable reflectances (as shown below) are chosen for interior environments, to ensure effective light distribution within the space.

Table E

Reflectances for Interior Environments

SURFACE	REFLECTANCE
Ceiling reflectance	0.8
Walls around windows	0.6
Wall/partition surface to worksurface	0.6 - 0.8
Non-window walls	0.3 - 0.7
Floors	0.2 - 0.4

12.13.20 Ensure that the layout of the installation is consistent with the objectives and the physical constraints.

12.13.21 Allow for the effects of obstruction by building structure, other services, machinery and furniture.

12.13.22 Decide how the luminaires are to be fixed to the building and what system of electricity supply is to be used.

12.13.23 Ensure that the electrical installation complies with the latest edition (with any amendments) of the IEE Regulations for Electrical Installations.

12.13.24 Ensure that stairs are lit in such a way that shadows are not cast over the main part of the treads.

12.13.25 Ensure that places of particular risk (such as pedestrian crossing points on vehicular traffic routes or traffic routes used by pedestrians) are adequately lit after dark.

13 Classification of Lighting Equipment

All lighting installations have three components: lamps, luminaires and some kind of central or local control system. There are many different types of all three components commercially available. Different lamp types produce light in different ways and as a result, the light has different properties. Different luminaire types diffuse or reflect the light produced by lamps in different ways. Finally, the type of control system has implications for safety, security and user satisfaction. Rapid developments in ll three components are common. The general characteristics for tasks are considered below. However, once more for precise technical information it is essential to consult up-to-date technical literature of lamp, luminaire and lighting controls manufacturers.

13.1 Lamps

13.1.1 There are seven principal types of lamp, as shown in table F.

Table F

Principal Types of Lamp

<table>
<tr><th>LAMP TYPE</th><th colspan="2">LAMP GROUP</th></tr>
<tr><td>Filament (tungsten and tungsten halogen)</td><td colspan="2">Incandescent</td></tr>
<tr><td>Tubular and compact fluorescent

Low pressure sodium</td><td>Low pressure

Low pressure</td><td rowspan="2">Discharge lamps</td></tr>
<tr><td>High pressure sodium

High pressure mercury and mercury tungsten blended

High pressure metal halide</td><td>High pressure</td></tr>
</table>

13.1.2 Within each group there is a range of lamps available which differ in shape, colour properties, construction, wattage, luminous efficacy, need for control gear, starting and restarting times, effect of ambient temperature, service period, and relative initial and running costs. Details of the characteristics of different lamp types should be obtained from the manufacturers' technical data publications.

13.1.3 All discharge lamps produce emanations in the range of radio frequencies which can cause interference with communications equipment. Similarly, tubular fluorescent lamps operating on dimmer circuits, dimmers which use wave-chopping, and all lamps operating on high-frequency control gear are prone to producing radio frequency interference. The interference can be radiated, mains-borne, or mains-borne radiated interference and can affect radios, TVs, security monitoring devices, computers etc. Creating radio frequency interference is an offence in law and regulations related

13.1.3 (Contd)

to it have been implemented in the UK. More information can be found in BS 4533, BS 5394 Part 1 and the Electromagnetic Compatibility Regulations 1990.

13.1.4 Table G gives a summary of lamps typically used for particular activities:

Table G

Lamps Typically Used for Particular Activities

TYPE OF LAMP	TYPICAL APPLICATIONS
Filament (tungsten)	domestic, display lighting
Filament (tungsten halogen)	domestic, display lighting, area floodlighting, projectors, vehicle headlamps
Tubular fluorescent	industrial and commercial
Compact fluorescent	replacement for tungsten lamps, with one quarter of the power consumption and 5 to 8 times longer life
Low pressure sodium	exterior applications such as road lighting, security lighting
High pressure sodium	road lighting, floodlighting, industrial interior lighting, sports halls, public concourses
High pressure mercury tungsten blended	as a replacement for tungsten when longer life is essential
High pressure mercury	industrial lighting, road lighting
High pressure metal halide	area floodlighting, industrial and commercial lighting, stadia and studios, display lighting

13.2 Luminaires

13.2.1 'Luminaire' refers to the apparatus that controls the light output from a lamp and includes the electrical components and the equipment for housing and fixing the whole assembly.

13.2.2 There is a wide range of luminaires, but they all have to supply electricity to, provide support for, and protect the lamp. They must be safe during installation and operation. They are classified according to the type of protection from electric shock; the degree of protection against dust or moisture; and according to the surface material to which they can be fixed. They vary in construction, light distribution, maintenance characteristics, glare effects, mounting position, and the efficiency with which they provide light on the working plane.

13.2.3 the standard which covers most luminaires in the UK is BS 4533; at European level, the equivalent standard is EN60 598-1:. Details of different luminaire types should be obtained from the manufacturers' technical data publications.

13.2.4 The manner of light distribution from a luminaire determines both the illuminance on the working plane and the visual appearance of a room. A bare light source is a source of direct and reflected glare, and gives a harsh appearance by producing areas of excessive contrast. It is therefore desirable to use reflectors or louvres to control the light distribution from a luminaire.

13.2.5 Table K in annex D gives a summary of luminaires, their associated lamp types and their typical use for particular activities or environments.

13.3 Control gear

13.3.1 The third component of a lamp is the mechanism by which control over the lamp is effected. The control gear used with lamps has three main functions:

(a) to start up the lamp;

(b) to control the lamp after starting;

(c) to regulate the output of the lamp, for example, during manual or automatically controlled dimming.

13.3.2 Control gear consumes energy. The power consumption of a discharge lamp circuit is the sum of the lamp power and the ballast power loss. Advanced developments in control gear, such as high frequency ballasts, consume only a small proportion of the total power used by the lamp circuit, and also have the advantages that they make little acoustic noise and are lightweight. The current ratings of cables, fuses and switchgear is to be related to the total running current of the circuit. Lamps and their control gear make up an integrated circuit for producing light. Lamps from different manufacturers may not operate with the same control gear even if they are supposed to be of the same type. Care must be taken to ensure that the proposed combination of lamp and control gear is compatible. The life of control gear is dependent on temperature and the control gear used should have a temperature rating appropriate to the situation. For technical information about particular types of control gear and their associated power losses, the manufacturer's information should be consulted.

13.3.3 There is an important trend towards the operation of fluorescent lamps at frequencies of around 30 kHz. High frequency ballasts improve lamp and circuit efficacy, and are also associated with improvements in visual comfort due to the absence of detectable flicker. Light output is approximately the same as an ordinary lamp of the same length, but of a higher wattage. Additional advantages of high frequency ballasts include better control over individual luminaires, daylight linking to reduce energy consumption and dimming.

13.4 Lighting control

13.4.1 Lighting control systems can take several forms, ranging from a simple on/off wall switch, through photoelectrically controlled dimming systems, to a full lighting and energy management system (LEMS) for a whole building. The primary aim of a lighting control system is to ensure that the lighting is only on when it is required, and that when it is operating, that it is doing so in the required state. Lighting control systems can also be a crucial component in reducing energy use.

13.4.2 Essentially, automated lighting controls either combine local switches with some form of central control, or use sensors to detect occupancy and/or daylight in an area and adjust the lighting accordingly. There are five main types of lighting control, which may be used individually or in combination, namely local control, time switch control, occupancy detection, photocell control and lighting energy management systems. Annex D gives details of the most common types of lighting control.

13.5 Recommendations

13.5.1 Use the most up-to-date manufacturers' information on lamps, luminaires, control gear and lighting controls.

13.5.2 Consider all the relevant lighting variables, eg uniformity, illuminance ratios, surface reflectances and colours, light source colour, colour rendering group, limiting glare index, veiling reflections.

13.5.3 Ensure that the light source has the required lumen output, luminous efficacy, colour properties, lumen maintenance, life, run-up and re-strike properties.

13.5.4 Question if noise or interference from control gear is likely to be a problem.

13.5.5 Consider restrictions of mounting positions and limits on luminaire size.

13.5.6 When necessary, ensure that the choice of equipment is compatible with existing installations.

13.5.7 Ensure that the proposed lamp and luminaire package is suitable for the application.

13.5.8 Ensure that the luminaire will be safe and withstand the given environmental conditions.

13.5.9 Ensure that the fixture has suitable maintenance characteristics and mounting facilities.

13.5.10 Ensure that the fixture conforms to BS 4533/EN60 598-1 or other appropriate standards.

13.5.11 Agree an appropriate maintenance schedule.

13.5.12 Where possible, obtain equipment that is resistant to dirt deposition.

13.5.13 Where possible, obtain equipment that can be maintained easily, is easily accessible and for which replacement parts are readily available.

13.5.14 Ensure appropriate control systems for matching the operation of the lighting to the availability of daylight and the pattern of occupancy.

13.5.15 Question if a dimming facility is desirable.

13.5.16 If manual switches or override facilities are provided, ensure they are easily accessible and their relationship to the lighting installation is understandable.

13.5.17 Ensure light switches are carefully positioned so that they may be found and used easily and without risk.

13.5.18 Ensure that lights are not obscured to such an extent that light becomes insufficient.

13.5.19 Ensure that windows, skylights etc are kept clean regularly and kept free from unnecessary obstruction to admit maximum daylight.

13.5.20 Where possible ensure that new and existing workplaces/ workstations take advantage of the available natural light.

14 Energy Considerations

The lighting of an environment or workspace should be appropriate for the tasks carried out, and the occupancy levels in a space. It is important that work quality, productivity and visual comfort are not compromised by poor lighting levels created by too much focus on energy saving. However, in practice, a lot of energy can be wasted by inappropriate use of lighting, for example, lights left on overnight while a building is unoccupied, or artificial lighting used in an area where natural light levels are sufficient. Adequate lighting controls should be installed to ensure that lighting use is appropriate for the types of tasks and occupancy levels of a building at any time.

14.1 Energy efficiency. The energy used by any lighting installation is dependent on two factors, power and time. There are two main ways of maximizing energy efficiency:

(a) By using appropriate lighting controls so that lighting is only used when it is required, ie the time component is minimized.

(b) By using the most energy efficient lighting equipment and control gear for the lighting application required ie the power output for the lighting design and power losses in the circuit are minimized.

14.2 Energy management

14.2.1 A third component is sensitive energy management on the part of the users of a building. High awareness on the part of the occupants of the building space of the ways of reducing energy consumption combined with local control down to the level of the individual user or small group of luminaires has been found to be associated with high energy efficiency and high user satisfaction. The reverse situation, where users have little or

14.2.1 (Contd)

no control over the lighting of their workspace, and low awareness of energy consideration, leads to low user satisfaction and high energy consumption.

14.2.2 The ultimate aim should be to achieve the illuminance level required for the range of tasks and occupancy level of the space, combined with the lowest practical energy use, using a combination of efficient lighting equipment, good lighting control and good lighting management.

14.2.3 There is a popular misconception about fluorescent and discharge lamps that switching them off and back on again when, for example, one leaves a room to go to a meeting etc, uses more energy than leaving them on. However, in reality, the energy taken during starting is a small fraction of the energy used in running the lamp for one minute. Therefore it is almost always more energy efficient to switch lights off when leaving a workspace empty for a short period of time.

14.3 Lamp dimming/regulations. Dimming can reduce the energy consumed by a lamp. It can be controlled manually, or automatically using photocells which respond to daylight availability. Recent developments in control gear technology, namely high frequency electronic ballasts, have made dimming more common in newly designed workplaces. Current lighting design practice favours the use of high frequency ballasts which regulate the lamp output according to task and visual needs. Those systems which are under user local control tend to be those which are most successful in terms of user satisfaction and energy saving.

14.4 Recommendations

14.4.1 Consider appropriate lighting controls for the lighting design.

14.4.2 Consider the use of daylight for illumination wherever possible.

14.4.3 Select the most energy efficient lighting equipment and control gear for the application required.

14.4.4 Match the use of the lighting to the occupancy levels of the interior or exterior environment.

14.4.5 Ensure that the users of the space have high awareness of, and good control over, the lighting.

14.4.6 Provide local dimming control of small numbers of luminaires.

15 Maintenance of Lighting Installations

As a lighting installation ages, the electrical load does not change, but the light output of the installation deteriorates due to the build up of dirt and dust etc. Lighting installations are therefore designed to 'maintained illuminance', which is defined as the average illuminance over the reference surface at the time maintenance has to be carried out by replacing lamps and/or cleaning the equipment and room surfaces. Maintenance of all lighting, including emergency and standby lighting, is essential to ensure that illuminance is kept within the design limits, and to enhance safety and the efficient use of energy.

15.1 Lamp replacement

15.1.1 Lamp replacement is dependent on two potential deteriorations in performance, namely, the reduction in light output and the probability of failure. Tungsten filament and tungsten halogen lamps usually fail before the light output is noticeable, and replacement is therefore dependent on this factor alone. However, all other light sources usually used in interiors show a significant reduction in light output before many of them fail. Frequently, therefore, it is necessary to replace these before they fail, because the light output has fallen to unacceptable levels for the task.

15.1.2 For the majority of installations group replacement is usually the most sensible means of maintenance of the lighting for a number of reasons. This ensures that the appearance and light output of the installation remains uniform; it reduces the time overheads associated with disturbance to task activities in the interior, as it can take place at times when the building is unoccupied, and can be combined with luminaire cleaning. Finally, it ensures that the risk of damage to control gear by faulty operation of lamps near to the end of their life is minimized. Lamps which do fail unexpectedly or start to flicker before the planned maintenance period should be replaced promptly on an individual with lamps of the same type as the rest of the installation. For most installations the general economic time for group replacement is when the lamp light output has depreciated 25% below the initial value. This is also usually the point at which lamp failures are starting to be significant.

15.2 Luminaire cleaning schedule

15.2.1 The frequency of luminaire cleaning depends on the amount and type of dirt in the atmosphere, and on the type of luminaire. Depending on their construction and sealing, luminaires can collect dirt on both the inside and the outside, and need to be cleaned as a result. As a general rule, for most interiors, luminaires should be cleaned once a year. However, for particularly dirty or dusty atmospheres this may not be sufficient. To ensure that illuminance for an environment is maintained, cleaning intervals for a lighting installation should be based on manufacturers' data. Manufacturers also provide information on the most suitable cleaning methods for their equipment. It is usually cost-effective to combine luminaire cleaning with lamp replacement.

15.2.2 If reflected light from room surfaces is an important component of the lighting of the interior, it is also particularly important to keep room surfaces cleaned and redecorated regularly.

15.2.3 Maintenance of lighting installations should only be carried out by experienced and skilled personnel, as they are working with electricity and there are obligations under the Electricity at Work Regulations 1989. There are also often difficulties with access to lighting installations. Maintenance personnel should have received training to satisfy the health and safety legislation associated with this activity.

15.2.4 Certain types of lighting equipment can cause risks to health and safety if damaged. Guidance on the disposal of used or damaged lighting equipment is available from manufacturers' data and the Lighting Industry Federation.

15.3 Recommendations

15.3.1 Ensure that the design maintained illuminance for the installation has been determined.

15.3.2 Agree an appropriate cleaning schedule (yearly intervals are appropriate for most interior installations).

15.3.3 Agree an appropriate replacement schedule.

15.3.4 Ensure that lamp maintenance/replacement is carried out at the agreed time (ie the time that the design maintained illuminance has been calculated upon).

15.3.5 Ensure that workstation and room surfaces are cleaned regularly, especially if reflected light from room surfaces is an important component of the lighting.

15.3.6 Ensure that the equipment can be easily maintained, is easily accessible and that replacement parts will be readily available.

15.3.7 If it cannot be easily maintained, ensure that the equipment is resistant to dirt deposition and has a low failure rate.

16 Special Lighting Conditions

In this section we give guidance on the factors which affect lighting design in particular types of installation.

16.1 Display screen equipment (DSE) installations

16.1.1 The use of display screen equipment is now widespread throughout organizations. The introduction of DSE into traditional office or industrial workplaces has brought with it a host of problems, usually to do with various forms of discomfort experienced by the Display Screen Equipment user. In 1992 the Health and Safety Executive introduced the Health and Safety (Display Screen Equipment) Regulations under which employers are obliged to meet certain minimum standards for workplaces where DSE is used. Guidance on effective lighting for DSE use is described in the 1989 CIBSE Lighting Guide 3, Areas for Visual Display Terminals, and is intended for use by people who wish to introduce DSE into an existing workplace, or to design new buildings where DSE will be used. However, this publication is under revision at the time of writing. A summary of the important points is given below, but for further information, the revised version of this Guide should be consulted.

16.1.2 The main effect of bringing DSE into a traditional workplace is the change from working with paper on a flat horizontal surface, to working with a screen and keyboard. The reading and writing of text is performed on a vertical screen and a horizontal keyboard respectively. The user may also continue to use papers and other equipment on the worksurface as part of their job.

16.1.3 There are four lighting-related problems associated with DSE use.

(a) Firstly is the possibility of high luminance reflections from artificial lighting and daylight on the screen. These reflections may

16.1.3 (Contd)

occlude the screen characters or graphics, making them difficult to see and read, and thus rendering the task more difficult. The presence of reflections may cause the user to adopt awkward postures to 'see round' the reflections, which may lead to postural discomfort and fatigue.

(b) Secondly, there may be an imbalance in the luminance distribution around the main lines of sight, for example, when a display screen is positioned backing into a bright window. This is known as static imbalance. There is evidence that static imbalance causes task performance to be reduced and visual comfort to be decreased.

(c) Thirdly, there may be an imbalance between the luminance of surfaces looked at regularly by the DSE user, for example, white or glossy paper on a dark desktop or positioned in a document holder next to a dark display screen. This causes discomfort as the visual system has to adapt continually as the object viewed changes.

(d) Finally, normal mains frequency pulsations from lighting have been associated with a higher incidence of headaches. For this reason, fluorescent lighting with high frequency ballasts is recommended for new or refurbished lighting installations. New evidence also shows that screen flicker can lead to a high rate of eye movement when reading text on the screen. For this reason, screens with a high refresh rate and non-interlaced display are recommended.

16.2 Illuminance. The illuminance range recommended for areas with DSE use is between 300 and 500 lux. Where source documents are of poor clarity or degraded, levels up to 1000 lux are acceptable.

16.3 Lighting design approaches for DSE. There are three possible approaches to lighting design for DSE, namely downlighting, uplighting or direct/indirect lighting.

16.4 Downlighting

16.4.1 The directions from which high luminance reflections from luminaires can be seen in a vertical or near-vertical screen is geometrically determined. Therefore, if the DSE is on a desk with someone sitting in front of it, limiting the luminance of the luminaire above the angle of view from the screen will also limit the luminance of reflections on the screen. The luminance is limited according to three categories of use: intense DSE use; general DSE use; and minimal/occasional DSE use. Manufacturers' technical data provides the category for DSE use that their luminaires can provide. The luminaires are described as category 1 (for intense use), category 2 (for general use) and category 3 (for occasional use). They have luminance limitation above 55°, 65° and 75° to the downward vertical respectively.

16.4.2 One of the effects of limiting the luminance and directing the light output downwards is that the illuminances on vertical surfaces and the ceiling are very low, creating a 'cave effect' that can appear gloomy and dark.

16.5 Uplighting. Uplighting helps to eliminate reflections by using the ceiling as a large area low luminance luminaire. The luminance of reflections caused by such a luminaire is low, and changes gradually over a

16.5 (Contd)

large area. As long as this luminance is lower than the character luminance, the screen text and graphics remain visible. One of the effects of uplighting is that it gives the impression of a light airy interior, but the lighting is very diffused, causing a lack of visual variety.

16.6 Direct/indirect lighting. This is an approach combining elements of downlighters and uplighters, and is to be recommended wherever possible. Usually the characteristics associated with each approach are softened, ie the cave effect is minimized, and there is more visual variety in the lighting of room surfaces.

16.7 Recommendations

16.7.1 Ensure that operators can take steps themselves to screen or shade local lighting.

16.7.2 To prevent dynamic imbalance, ensure that the relative reflectance and/or illuminances between the areas that the users are likely to look at in succession are minimized.

16.7.3 To prevent static imbalance, ensure that areas of high or low illuminance are avoided, or provide some way of shielding them, eg blinds on bright windows.

16.7.4 Ensure that the keyboard surround and the surround to the display are of medium reflectance in a matt finish.

16.7.5 Ensure that the luminance ratio between the screen and other items in the immediate visual field is not more than 3:1. Aim for a ratio of 5:1 between the screen and background office areas.

16.7.6 Ensure that there are no large areas of unscreened window behind or in front of the operator, and that window blinds or other screening methods are available.

16.7.7 Ensure that flicker from screens and artificial lighting is minimized.

16.7.8 Ensure that screens are positioned, wherever possible, at right angles to the windows. This helps to prevent reflections in the screens from the windows, and areas of high illuminance behind the user's screen.

16.7.9 Ensure that screens are positioned, wherever possible in the spaces between luminaires, in order to minimize reflections of the luminaires in the screen.

16.7.10 Ensure that appropriate (depending on the type of tasks carried out in the space) Category 1, 2 or 3 luminaires are used in the DSE installation.

16.7.11 Consider the use of a combination of direct and indirect lighting to minimize the 'cave effect' and to maximize visual variety.

17 Emergency Lighting

Emergency lighting is intended for use whenever the main lighting is not available or fails to operate. When this occurs, emergency lighting can be used to provide either standby or escape lighting. There are two special requirements for emergency lighting equipment

(a) The need for near-immediate light output in the event of main lighting system failure means that tungsten, tungsten halogen and tubular fluorescent lamps are the only types suitable for emergency lighting (other types take too long to reach full output).

(b) A mechanism for connecting the lamp to the alterative battery or generator electricity supply is needed for when the main lighting system fails.

17.1 Standby lighting. This allows essential work to be continued, whereas escape lighting allows a building to be evacuated. Standby lighting is used under certain conditions where it is not possible, or may not be desirable, to evacuate the building immediately. The illuminance needed for standby lighting depends on what work has to be done under the standby conditions, the expected duration of the tasks and the risk to life, health of safety. Dependent on these factors, the illuminance levels may be between 50 and 100% of the illuminance produced under normal conditions.

17.2 Escape lighting

17.2.1 Escape lighting is covered by BS 5266 Part 1 and is a legal requirement due to its status as part of the Building Regulations, and as part of many local by-laws. European emergency lighting standards are currently being developed by CEN, which may change some of the design values and equipment requirements quoted in BS 5266. A list of the main requirements is given in the recommendations section:

17.2.2 For further information on emergency lighting, CIBSE has produced a Technical Memorandum on Emergency Lighting.

17.3 Recommendations.

17.3.1 General design principles:

(a) Consider what form of emergency lighting is needed.

(b) Ensure that the emergency lighting is powered by a source independent from that of the normal lighting.

(c) Ensure that the emergency lighting will be immediately effective in the event of failure of the normal lighting, without the need of action by anyone.

(d) Will the emergency lighting provide sufficient light to enable persons at work to take any action necessary to ensure their own and others' health and safety?

17.3.2 Detailed design principles:

(a) Define and mark the exits and emergency exits clearly.

17.3.2 (Contd)

(b) Define and mark where changes of direction signs are needed.

(c) Identify and mark the escape routes and areas which will require special provision, eg changes of direction signs, control rooms, plant rooms, fire equipment etc.

(d) Locate light fittings so that recommended illuminances are met, and special provision areas are lit.

(e) Ensure that lighting outside the building is adequate to allow evacuation to a place of safety.

(f) Prevent glare by mounting the emergency fittings at least 2 m above the floor, but not higher, as smoke may then reduce the illuminance on the escape route.

(g) Prepare a maintenance and testing schedule.

17.3.3 Main requirements of BS 5266 Part 1.

(a) All exits and emergency exits must have signs indicating that they are exits or emergency exits. The signs should comply with BS 5499.

(b) Additional signs are required to direct people to these exits if the exits themselves are not visible.

(c) A clearly defined escape route so signed should be lit to a minimum of 0.2 lux along the centre line at floor level.

(d) 50% of the route width of escape routes up to 2 m wide should be lit to a minimum of 0.1 lux.

(e) The emergency lighting must be provided within 5 seconds of the main lighting system failure.

(f) The escape lighting luminaires should not be sources of disability glare.

(g) Escape lighting luminaires should be located near each exit door and emergency exit door and wherever necessary to emphasize hazards, changes of direction etc.

(h) Fire equipment along the escape route must be adequately illuminated at all times.

(i) Lifts and escalators should be adequately illuminated at all reasonable times.

(j) Emergency lighting is required in all control rooms and plant rooms.

(k) Escape lighting should be provided from toilets, lobbies etc.

(l) Regular maintenance and testing of emergency lighting equipment is essential.

18 Illuminance Requirements for Military Circumstances

In the following sections we consider factors affecting lighting design for particular military circumstances.

18.1 Night vision

18.1.1 Some operations, particularly at night, require efficient dark-adapted vision for maximum performance. For example, detection of the enemy; recognition of one's own forces at a distance; vision through a periscope for a submariner; detection of flares and signals etc, all require good night vision. People may also need to move from a lit interior into an unlit environment and maintain good vision. The conditions of these opposite requirements can be partly met by using a red or low intensity white lighting system.

18.1.2 Red illumination suffers from certain disadvantages:

(a) Poor colour rendering, to the extent of making some colours impossible to see.

(b) Visual discomfort and an unpleasant working environment, particularly in those with surfaces of low reflectance.

(c) Focusing problems, particularly for older personnel.

18.2 Night vision and optical instruments. Under low lighting levels the eye changes its focusing power and becomes more near-sighted. In view of this it is advisable for users of binoculars, periscopes and range finders to make a readjustment of the eyepiece under night conditions. Departures of more than 0.5 dioptre in either direction from the optimal focus decrease visual sensitivity and acuity.

18.3 Night vision sensitivity. The eye and nervous system are particularly sensitive to a lack of oxygen, and a lowering of the oxygen content of the blood can reduce night vision sensitivity. This can occur in unusual conditions of ventilation eg carbon monoxide contamination, air-tight submarine ventilation. Exposure to reduced oxygen at high altitudes causes an increase in the time for dark adaptation - under conditions equivalent to a height of 5000-7000 ft the change in visual sensitivity is quite significant. Heavy smoking, a deficiency of glucose, optic neuritis and retinitis pigmentosa are other conditions in which night vision is impaired (see also Def Stan 00-25 (Part 5) Stresses and Hazards: The Physical Environment).

18.3.1 Full dark adaptation

18.3.1.1 Where full-dark adaptation is required for critical detection of objects, eg watch keepers and periscope users, personnel should not be exposed to a red light luminance greater than 0.03 cd m^{-2}. This just permits cone vision to operate and requires a re-adaptation time of 5 minutes in full darkness to achieve complete sensitivity.

18.3.1.2 Where some loss of dark adaptation is permissible and where seeing is essential for charts and instruments, continuously variable illuminances should be provided. Recommended ranges (T.Ivergard 1978) are:

18.3.1.2 (Contd)

(a) White light: 0.5 - 10 lux.

(b) Red light: 1.0 - 20 lux.

18.3.1.3 In general, observers may require a luminance of red light that is 15% higher than white light at these low intensities (Pearce et al 1979) for chart or map reading. For interiors or compartments, stairways, bridge areas and corridors the recommended red lighting illuminance is 20 lux. Repair work with larger size detail can be conducted under 55 lux of red lighting after 30-40 secs of adaptation to that light. A period of 2.5 minutes of adaptation would be required for smaller sized tasks (Kinney et al 1968).

18.3.2 Re-adaptation times following light exposure

18.3.2.1 Dark-adapted personnel seeing a bright light through an open door for 0.3 seconds would require about 6 minutes re-adaptation (Kinney et al 1968). (Waters and Ivergard 1983) showed that exposure of subjects to various intensities of light for about 6.5 minutes after 15 minutes dark adaptation gave the following average times to recover their sensitivity to within 0.5 log units of the threshold to which they had originally adapted.

(a) Exposure to 4.0 cd m^{-2} red lighting - recovery time: 38 secs.

(b) Exposure to 0.5 cd m^{-2} white lighting - recovery time: 57 secs.

(c) Exposure to 2.5 cd m^{-2} white lighting - recovery time 110 secs.

(d) Exposure to 12.5 cd m^{-2} white lighting - recovery time: 200 secs.

18.3.2.2 Hence temporary exposures to higher light intensities for quickly seeing a particular detail may be acceptable for some personnel whose re-adaptation time may not be that critical.

18.3.2.3 Recovery from dark adaptation or a low level adaptation to the fully light adapted state is not an instantaneous process, although it is accomplished in a much faster time than that of dark adaptation.

18.4 Daytime lighting inside compartments and vehicles. Except where security precautions and conditions are required, interior lighting in military transportation should conform with the general requirements of interior lighting design. Guidance on required illuminances should be derived from considerations of task requirements as described in this document and from the CIBSE Code.

18.5 Military fighting vehicles. The table below shows illuminances required for different tasks in military fighting vehicles (adapted from Hedgcock and Chaillet (1964)).

18.5 (Contd)

Table H

Illuminances Required for Different Tasks in Military Fighting Vehicles

TASK	ILLUMINANCE (LUX)	
	NIGHT (RED LIGHT)	DAYLIGHT
Map reading	11	108
Clearing machine gun	4	43
Operation of controls	3	43
Stowage	0.2	1

NOTE: Use of red (or other coloured) lighting for night work and its effect on colour rendering and differentiation is especially relevant in the reading of coloured maps.

18.6 Security lighting and lighting for closed-circuit television (CCTV) surveillance applications

18.6.1 Boyce and Rea (1990) examined the effects of different types of illuminance and light source on the capabilities of guards and intruders. They showed that vertical illumination in the 4-10 lux range usually ensured a high level of detection and recognition. Low pressure sodium lighting was found to be as effective as high pressure sodium for the detection of intruders and the recognition of faces. The guards' and intruders' preferences for the different lighting conditions were found to be consistent with the effect of those conditions on their ability to perform their respective tasks.

18.6.2 The spectral distribution of the light source used in conjunction with CCTV has a significant influence on the quality of monochrome images provided by CCTV. Vermeulen J (1992) discusses this effect and gives guidance on the practical design of lighting systems for CCTV.

18.7 Ships and submarines

18.7.1 Historically, ships used red or blue lighting as the standard ambient illumination for shipboard use, as it provided enough light to perform various watch standing tasks while having the smallest effect on the dark adaptation level of watchstanders on the bridge or in the Combat Information Centre (Luria and Kobus 1985). In more recent times the technology used on board has increased the number and complexity of 'routine' tasks performed. This increase in task requirements led to more complaints from operators about the use of red/blue lighting. The use of red lighting on submarines was also being questioned, and the US Naval Submarine Medical Research Laboratory conducted a series of studies to

18.7.1 (Contd)

evaluate the feasibility of replacing red lighting on board ships and submarines.

18.7.2 Increasingly, red light is no longer used and wherever possible it should be avoided. The best alternative on submarines appears to be the use of an achromatic lighting system at a level of intensity equal to or lower than that of red/blue illumination. This lighting system, Low Level White (LLW) lighting, provides significant improvements in performance without disrupting dark adaptation.

18.7.3 The use of LLW lighting on surface ships was examined by Kobus and Luria (1988), as lighting on surface ships is different in several significant ways from submarine lighting. On surface ships, there is an operational requirement for dark adaptation throughout the twilight hours; and many ships operate continually under night-time illumination conditions in the Combat Information Centre (CIC) while underway. The study evaluated the feasibility of LLW as a replacement for the red illumination used on surface ships. Operational tasks in the combat information centre under low level white lighting were improved, and staff reported fewer headaches and fatigue. However, the use of LLW on the bridges was not recommended as the glare produced on the bridge windows using LLW reduced visibility considerably.

18.8 Fixed and rotary wing aircraft

18.8.1 A number of factors affect the viewing conditions in fixed and rotary wing aircraft. Appropriate lighting of aircraft instruments, panels, controls, indicators and displays is essential. The lighting should be usable over a large range of ambient conditions, particularly in twilight and at night. It should be uniform, low glare, and be continuously dimmable to very low luminance levels so that pilots can become partially dark-adapted for good out-of-the-cockpit viewing. A report by Pinkus (1988) provides guidance on various aspects of cockpit lighting. It also examines the use of night vision goggles, and methods of cockpit lighting compatibility with these goggles.

18.8.2 Helicopter operations can pose considerable visual problems for air crew, ranging from factors degrading vision both externally and internally, to the protection of air crew against ocular hazards. Brennan (1984) discusses the importance of ocular physiology, visual standards, transparency optics and cockpit lighting systems in ensuring an adequate level of performance. Hazards from impact, nuclear flash, chemical warfare agents and lasers are discussed and related to the advantages and disadvantages of protective equipment. It also reviews the devices currently available for visual enhancements and the problems associated with their use.

18.8.3 Night imaging systems based on image intensification tubes are important in the night operation capability of helicopters. A major problem with the use of these systems is the interference caused by internal cockpit lighting, which activate the bright source protection control circuits of the intensification tubes and reduce their sensitivity to external natural and artificial illumination. A review paper by Rash and Verona (1989) examines issues surrounding cockpit lighting compatibility with image intensification night imaging systems.

18.8.4 Further information is given in Lloyd (1986), which discusses cockpit lighting standards and techniques for use with night vision goggles and examines image degradation, daylight and unaided eye viewing, complementary filter cockpit lighting, shared aperture systems, window filter systems and illumination, luminance and radiance and low reflection paint.

18.9 Recommendations

18.9.1 Wherever possible for specific military circumstances, mock-ups of the workstation and environment under different lighting conditions, should be tested by users carrying out a set of representative tasks.

18.9.2 Ensure that personnel who require full dark-adaptation to carry out their tasks are not exposed to red lighting levels any greater than 0.03 cd m^2.

18.9.3 Ensure, wherever possible, that complex or safety-critical visual tasks will not be carried out at night under conditions in which night vision is likely to be impaired.

18.9.4 Provide continuously variable illuminances where seeing is essential for charts and instruments, and where some loss of dark adaptation is permissible.

18.9.5 Use white light for design wherever possible, and architecturally separate the areas where red light or darkness need to be used.

18.9.6 Use low level white lighting systems in situations where good dark-adapted vision as well as reading maps, charts or instruments is required. Ensure that personnel whose tasks require higher levels of white illumination are well screened or architecturally separate from those who need to remain dark-adapted.

18.9.7 Use low level white illumination wherever possible for complex visual tasks, in order to minimize visual discomfort.

Table J

Summary of Luminaires, their Associated Lamp Types and their Typical Use for Particular Activities or Environments

LUMINAIRE TYPE	LAMP TYPES	TYPICAL APPLICATION
Globe	tungsten, compact tubular fluorescent, high pressure mercury tungsten blended	offices, domestic, commercial areas
Cone	tungsten, compact tubular fluorescent, high pressure mercury tungsten blended	offices, industrial premises

Continued on page 66

Table J - Continued

LUMINAIRE TYPE	LAMP TYPES	TYPICAL APPLICATION
Bare batten	tubular fluorescent	offices, industrial premises
Batten with visual display screen equipment (DSE) specular reflector	tubular/compact fluorescent	offices with display screen equipment
Industrial batten with trough, or angled reflector	tubular fluorescent	industrial premises
Industrial batten with specular reflector	tubular fluorescent	warehouses, industrial premises with narrow aisles
Batten with opal diffuser	tubular fluorescent	offices, industrial premises where lamps have to be enclosed
Batten with prismatic controllers or opal sides and prismatic base	tubular fluorescent	offices, industrial premises where lamps have to be enclosed
Linear reflector	tubular fluorescent	offices
Linear louvre	tubular fluorescent	offices
Recessed diffuser	tubular fluorescent, high pressure mercury, metal halide, high pressure sodium	offices
Recessed prismatic	tubular fluorescent, high pressure mercury, metal halide, high pressure sodium	offices
Recessed reflector	tubular fluorescent, high pressure mercury, metal halide, high pressure sodium	offices
Recessed louvre	tubular fluorescent, high pressure mercury, metal halide, high pressure sodium	offices

Continued on page 67

Table J - Continued

LUMINAIRE TYPE	LAMP TYPES	TYPICAL APPLICATION
Modular aluminium reflector with transverse blades, DSE category 1	tubular/compact fluorescent	offices with one or more of the following conditions: - high density of DSE, - intensive usage, - where errors are critical, - CAD/graphics screens, - screens with poor contrast/definition, - DSE with highly specular screens
Modular aluminium reflector with transverse blades, DSE category 2	tubular/compact fluorescent	offices with fairly widespread DSE use combined with other office tasks
Modular aluminium reflector with transverse blades, DSE category 3	tubular/compact fluorescent	offices with infrequent DSE use
Bare lamp reflector with or without anti-glare skirt	high pressure mercury with internal reflector, high pressure sodium with internal reflector	high bay industrial premises (5 m or above)
High bay reflector	high pressure mercury, metal halide, high pressure sodium	high bay industrial premises (5 m or above)
Low bay with reflector, louvre, or prismatic base	high pressure mercury, metal halide, high pressure sodium	industrial premises where mounting above 5 m heights is impossible (usually 3 to 5 m)
Coffered ceiling	tubular fluorescent, high pressure mercury, metal halide, high pressure sodium	offices

Continued on page 68

Table J - Continued

LUMINAIRE TYPE	LAMP TYPES	TYPICAL APPLICATION
Luminous ceiling	tubular fluorescent	social/commercial interiors
Uplighters	high pressure mercury, metal halide, high pressure sodium, compact or tubular fluorescent	offices
General diffusing compact luminaires	originally filament lamps, now compact fluorescent	amenity lighting in small areas such as toilets or where compact appearance of the luminaire or a smaller source desirable
Downlighters with reflectors	tungsten, tungsten halogen, compact or tubular fluorescent, high pressure mercury	display areas
Adjustable display lighting luminaires	tungsten, tungsten halogen, high pressure mercury, metal halide, high pressure sodium, compact or tubular fluorescent	narrow to wide spotlights on display areas, accent lighting, asymmetrical floodlighting
Industrial clear patterned proof fluorescent	compact or tubular fluorescent	hostile environments
Bulkheads	tungsten, high pressure sodium, high pressure mercury, low pressure sodium, tubular fluorescent	industrial premises, exterior environments
Floodlighting projector	tungsten halogen, high pressure sodium, high pressure mercury, low pressure sodium, metal halide	industrial area floodlighting, vehicle parks
Street lighting lanterns	high pressure sodium, high pressure mercury, low pressure sodium, metal halide	road lighting

Continued on page 69

Table J - Concluded

LUMINAIRE TYPE	LAMP TYPES	TYPICAL APPLICATION
Hand lamps	tungsten, tubular fluorescent	premises where severe obstruction occurs
Emergency/escape self contained luminaires and signs	compact fluorescent (with rechargeable batteries, and a combined inverter and electronic ballast capable of operating the lamp at reduced output from the batteries	escape route for safe movement to an exit
Emergency/escape slave luminaires	compact fluorescent	alternative to self-contained luminaires (runs off extra low voltage from a battery room or a mains supply from a safety source.
Emergency/escape long lamp inverters with battery packs built into conventional luminaires	compact or tubular fluorescent	alterative to separate self-contained luminaires

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How to Calculate Flicker from a Display

B.1 Write down the luminance from the screen with the display turned on (L_t) and the display turned off (L_r). For example, L_t = 100 cd/m^2 and L_r = 10 cd/m^2. Write down the refresh frequency of the display, f, in Hz, for example, f = 60 Hz. Finally, note the time constant, $TC_{10\%}$, of the phosphor from Table I, and compute $\propto$ from the expression:

$$\propto = TC_{10\%} \times 0.4343$$

For example, for a slow P4 phosphor:

$TC_{10\%}$ = 0.00006, and $\propto$ = 0.0000261 (see ISO 9241/3).

Table K

Time Constants (Spectral Peak Decay Time to 10% Point) of Some Common Phosphors

PHOSPHOR	TIME CONSTANT (SECS)
P1	0.0245
P2	0.000035 - 0.00007
P4	0.000022 - 0.00006
P7	0.4
P11	0.000034
P19	3
P20	0.00006
P22	0.006
P28	0.6
P31	0.000038

B.2 Compute pupil diameter, d, in mm from the formula:

$$d = 5 - \left(3 \times \tanh\ [0.4 \times \log_{10}(L_t \times 3.183)]\right)$$

For example:

$$d = 5 - \left(3 \times \tanh\ [0.4 \times \log_{10}(100 \times 3.183)]\right)$$

$$\therefore d = 2.6421 \text{ mm}$$

Note that tanh is specified in radians and not degrees (to convert degrees to radians multiply the number of degrees by $\pi/180$). Next, computer the pupil area, A, in mm^2 from

B.2 (Contd)

$$A = \pi\left[\frac{d}{2}\right]^2$$

For example, $A = \pi\left[\frac{2.6421}{2}\right]^2 = 5.4826\ mm^2$

B.3 Compute the DC component of the temporally varying screen luminance, DC, from the formula:

$$DC = [L_t - L_r] \times A$$

For example, DC = [100-10] x 5.4826 = 493.434 Trolands.

B.4 Compute the amplitude co-efficient of the fundamental frequency, Amp (f) from the formula:

$$Amp(f) = \frac{2}{\sqrt{1 + [\alpha 2\pi f]^2}}$$

For example, $Amp(f) = \frac{2}{\sqrt{1 + [0.0000261 \times 2\pi \times 60]^2}} = 1.9999$

B.5 Compute the luminance modulation of the fundamental frequency, E_{obs}, from the expression:

$$E_{obs} = DC \times Amp\ (f)$$

For example, E_{obs} = 493.444 x 1.9999 = 986.82 Trolands.

B.6 Compute the visual angle subtended by the display (see Definitions). For example, a 40 cm diagonal display viewed from 69 cm would subtend a visual angle of 30.10 degrees.

B.7 Because of individual differences in flicker perception, it will not be practicable to eliminate flicker for all observers under all situations. Absence of flicker is therefore a statistical decision. For example, to test whether a display will be flicker free to 90% of a young user population, first compute E_{pred} from the expression:

$$E_{pred} = a \times e^{bf}$$

The values of a and b may be read from Table J once you know the visual angle subtended by the display.

B.7 (Contd)

Table L

Values of a and b that correspond to the visual angle subtended by the display

VISUAL ANGLE (DEGREES)	a	b
10	0.1276	0.1424
30	0.1919	0.1201
50	0.5076	0.1004
70	0.53	0.0992

For a display that subtends 30 degrees, a = 0.1919 and b = 0.1201 and hence

E_{pred} = 0.1919 x $e^{(0.1201 \times 60)}$ = 258.58 Trolands.

Now, if $E_{pred} > E_{obs}$ the display will not appear to flicker. Conversely, if $E_{pred} < E_{obs}$, as in our example, then the display will appear to flicker.

Collation Page

How to Apply the CIE System to Displays

Use this method if you do not know the relative luminances of the three phosphors.

C.1 Obtain the CIE (1931) x, y chromaticity co-ordinates of each primary from the manufacturer or if you have your own colorimeter measure them yourself. You can then compute z for each primary from the relationship:

$$x + y + z = 1$$

Write down the matrix:

$$C=\begin{bmatrix} x_r & x_g & x_b \\ y_r & y_g & y_b \\ z_r & z_g & z_b \end{bmatrix}$$

An example of such a matrix for a typical display is:

$$C=\begin{bmatrix} 0.601 & 0.298 & 0.143 \\ 0.363 & 0.598 & 0.070 \\ 0.036 & 0.104 & 0.787 \end{bmatrix}$$

Now compute the inverse of C, C^{-1}. From the example above:

$$C^{-1} = \begin{bmatrix} 2.3591 & -1.1183 & -0.3292 \\ -1.4417 & 2.3820 & 0.0501 \\ 0.0826 & -0.2636 & 1.2791 \end{bmatrix}$$

C.2 Obtain the CIE chromaticity co-ordinates (x_w, y_w, z_w) of the white formed by driving each primary to its maximum. For the monitor above these values were (0.289, 0.321, 0.390).

C.3 Compute the tristimulus values of the white, X_W, Y_W and Z_W, from the following:

$$X_W = \frac{x_w}{y_w}$$

for example , $X_W = 0.9003$

$$Y_W = 1.0$$

$$Z_W = \frac{z_w}{y_w}$$

for example, $Z_W = 1.2150$

C.3 (Contd)

Y_W is set to 1 since all that is generally required is the relative luminances.

Now compute:

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = C^{-1} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix}$$

In our example:

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 0.6056 \\ 1.1449 \\ 1.3648 \end{bmatrix}$$

C.4 Finally, compute the nine-element tristimulus matrix, T, by computing:

$$T = C \begin{bmatrix} V_1 & 0 & 0 \\ 0 & V_2 & 0 \\ 0 & 0 & V_3 \end{bmatrix}$$

In our example:

$$T = \begin{bmatrix} 0.601 & 0.298 & 0.143 \\ 0.363 & 0.598 & 0.070 \\ 0.036 & 0.104 & 0.787 \end{bmatrix} \begin{bmatrix} 0.6056 & 0 & 0 \\ 0 & 1.1449 & 0 \\ 0 & 0 & 1.3648 \end{bmatrix}$$

$$T = \begin{bmatrix} 0.3640 & 0.3412 & 0.1952 \\ 0.2198 & 0.6846 & 0.0955 \\ 0.0218 & 0.1191 & 1.0741 \end{bmatrix}$$

Colour space manipulations are based on either this matrix or on its inverse, T^{-1}. In our example:

$$T^{-1} = \begin{bmatrix} 3.8953 & -1.8466 & -0.5435 \\ -1.2593 & 2.0806 & 0.0438 \\ 0.0605 & -0.1932 & 0.09372 \end{bmatrix}$$

Method 2

Use this method if you know the relative luminances of the three phosphors.

1. Follow Step 1 of Method 1.

2. For each phosphor, write down the relative luminances of the three phosphors. For example, if the luminance of the red phosphor is 21.98 cd m^{-2}, the green phosphor is 68.46 cd m^{-2} and the blue phosphor is 9.56 cd m^{-2}, then:

C.4 (Contd)

$$Y_r = 0.2198$$
$$Y_g = 0.6846$$
$$Y_b = 0.0956$$

Note that these are relative values and add up to one: this normalisation procedure is achieved by dividing each individual luminance by the sum of the three luminances. These are the Y tristimulus values.

3. Compute the X and Z tristimulus values from the Y tristimulus value and the chromaticity co-ordinates for each primary:

$$X_r = Y_r \frac{x_r}{y_r}$$

$$\text{for example, } X_r = 0.2198 \times \frac{0.601}{0.363} = 0.3639$$

$$Z_r = Y_r \frac{z_r}{y_r}$$

$$\text{for example, } Z_r = 0.2198 \times \frac{0.036}{0.363} = 0.0220$$

and similarly for the green and blue primaries. By this method:

$$T = \begin{bmatrix} 0.3639 & 0.3412 & 0.1953 \\ 0.2198 & 0.6846 & 0.0956 \\ 0.0220 & 0.1191 & 1.0748 \end{bmatrix}$$

The small differences between the tristimulus matrix computed here and the one computed in Method 1 are due solely to rounding errors.

In order to convert to and from CIE (x, y) colour space, perform the following steps.

1. To compute the tristimulus values, X, Y and Z, that correspond to a specific RGB vector:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = T \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where T is the tristimulus matrix computed above; then compute the chromaticity co-ordinates:

C.4 (Contd)

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

2. To compute the RGB values given chromaticity co-ordinates x and y and luminance Y^{+}, first calculate the tristimulus values:

$$X = x\left[\frac{Y}{y}\right]$$

$$Y = Y$$

$$Z = (1-x-y)\left[\frac{Y}{y}\right]$$

Then:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = T^{-1} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

where T^{-1} is the inverse of the tristimulus matrix computed above.

† Note that the luminance reading, Y, should be relative to Y_w. Y_w is the maximum possible luminance and is usually set equal to one.

Lighting Control

D.1 Lighting control systems can take several forms, ranging from a simple on/off wall switch, through photoelectrically controlled dimming systems, to a full lighting and energy management system (LEMS) for a whole building. The primary aim of a lighting control system is to ensure that the lighting is only on when it is required, and that when it is operating, that it is doing so in the required state. Lighting control systems can also be a crucial component in reducing energy use.

D.2 Local Control

At its simplest, lighting control consists of a wall switch, or bank of wall switches which the user operates when they enter or leave the workspace. This familiar type of manual control is often combined with automated control as will be described below.

Local controls can take many forms, listed below:

(a) electro-mechanical wall switch;

(b) pull cord;

(c) touch/pressure sensitive switch;

(d) dual press switch;

(e) dimmer switch;

(f) mobile infra red hand-held unit, switching and/or dimming;

(g) wall-mounted infra red (hand-held) unit, switching and/or dimming;

(h) telephone switching.

D.3 Timeswitch Control

Time signals from a central programmed controller switch off lights at certain times of day or night, eg after office hours. Occasionally they also switch the lights on. Time switch control is sometimes combined with internal or external photocell control (see later) to maximise savings where daylight is available.

D.4 Occupancy Detection

Occupancy sensors work in one of three ways; by detecting heat, movement, or sound.

The most commonly used type reacts to both occupancy and lack of occupancy, by switching on when a person enters the space, and off when the space is no longer occupied.

A second type, which is becoming more common, responds solely to the lack of people in a space (often referred to as absence detection), and switches the lights off after a timed interval. 'On' switching, in this scheme, is

D.4 (Contd)

left up to the user of the workspace by means of a local switch. Sometimes the occupant can also switch the light off manually using the local switch when they leave the space.

Occupancy detectors are sometimes combined with photocell linking to prevent lights being switched on when daylight is sufficient. This combination has become widely available only in the last two years.

D.5 Photocell Control

The basic idea of photocell control is to sense either available daylight or internal levels of illumination, and switch or dim lights according to the levels sensed.

With open loop control, an external photocell, mounted on a windowed exterior aspect of a building, is linked to the perimeter row (or two perimeter rows) of lights along that aspect. When the external daylight level exceeds a certain preset level, these rows of internal lights are switched off or dimmed down. When the daylight falls below another preset level the lights are switched back on or brightened back up. Dimming systems are becoming much more common now that high frequency controllable ballasts are used.

With closed loop control, internal photocells control perimeter rows of lighting and switch or dim them to maintain a desired internal illuminance level. With the switching control, a certain amount of hysteresis must be inherent in the way the photocell controls the light, otherwise it would cycle as the off-switching of the lights dropped the illumination. This is normally achieved by having different set points for switch off and for switch on, or sometimes merely by a time delay (which can cause problems). Dimming controls tend to aim for a constant worksurface illuminance.

D.6 Lighting Energy Management Systems (LEMS)

The most recent products to become available are lighting energy management systems. These (usually) run on a standalone personal computer (PC), although this is often linked to the Building Management Systems (BMS), for example to receive time signals. LEMS software usually shows mimic diagrams on the VDU screen of the lighting layouts in the different parts of the building, and fault detection and display, along with time programs and override functions, which can be changed according to the needs of the organisation. These can provide much more flexible and adaptable control than conventional time programmers and hard-wired sensors, but their user interfaces vary from simple hierarchical menu based designs through to Microsoft Windows-based graphical user interfaces. The PC sends signals to local switching outstations or modules, or to addressable luminaires themselves.

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