INTERIOR LIGHTING

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Preface

The purpose of this book is to outline the principles of indoor lighting practice and lighting design and to leave the lighting engineer, architect, interior designer, or student of these or related disciplines with a better understanding of both the background to and the application of these principles.

Much of what we practise in lighting today stems from the results of extensive laboratory and field research into the quantity and quality aspects of lighting, from experience continually being gained from the study of existing installations and from information gathered in the allied fields of acoustics and air conditioning.

Lighting engineering is not an exact science. On the contrary, it deals with people as well as things, and the lighting in a given interior is not good unless the occupants like it. An awareness of the fact that lighting is as much an art as a science is, indeed, central to a full appreciation of what interior lighting is all about.

This book is divided into four parts. Part One is devoted to the fundamentals of indoor lighting. Each of the first four chapters makes extensive reference to the relevant research work carried out in this field, both in the lighting laboratories of Philips and elsewhere. The findings most significant to practical lighting design to emerge from this research are analysed and summarised. The section concludes with two chapters in which indoor lighting is seen in the greater context of building design. The first of these chapters considers the interrelation between lighting, ventilating, air conditioning and acoustics and the role played by each of these disciplines in determining the quality of the interior environment, while the second tackles the important question of energy conservation.

Part Two of the book begins by taking a look at the lighting equipment – principally lamps and luminaires – suitable for use in interior lighting. The emphasis here is placed more on the practical features of this equipment than on the technical background to its development, the intention being to help those who select this equipment rather than those who design it. Because new lighting equipment is constantly being introduced, no attempt has been made to furnish technical data; it has been anticipated that those

seeking detailed information will be better served by making recourse to manufacturers' literature. A chapter on the electrical aspects of the lighting installation supplies the reader with a framework of good engineering practice on which to build. Finally in this section, the benefits to be gained from pursuing a well-conceived maintenance programme are outlined.
The three chapters comprising Part Three of the book bridge the gap between theory and practice and supply the reader with the basic 'tools' needed for effective lighting design. A review of the main lighting criteria, which in fact forms a summary of the results arrived at in Part One, is followed by an examination of how these criteria have been incorporated into the various national and international lighting codes. The concluding chapter in this section provides a step-by-step approach to the various calculations employed during the design of a lighting project, as well as an insight into the the techniques currently used to measure the basic lighting quantities.
The final section of the book takes the reader out of the classroom, so to speak, and into each of the main fields of application in turn. Practical advice, based on a consideration of the various lighting criteria discussed earlier in the book, is offered on the best approach to adopt for the solution of a given type of lighting project. In several instances, examples of lighting installations have been chosen from projects completed in the Philips Lighting Design Centres throughout the world.
The emphasis throughout is on artificial lighting and not lighting by natural means. The provision of the latter is rarely, if ever, the concern of the lighting engineer, and his interest in how daylight has been employed for a given interior is limited to the way it will influence his lighting design.

Finally, it should be added that the lighting of domestic interiors has not been dealt with here. This is a sector in which personal taste and preference invariably override many of the established principles of lighting.
We wish to express our warm thanks to G. F. Söllner of the Philips Research Laboratories, Aachen (Germany) for preparing the first drafts of the chapters comprising Part One of this book. Thanks are also due to N. J. Quaedflieg of the Lighting Division of Philips Netherlands for his suggestions regarding the chapter Lighting Maintenance and to A. B. de Graaff of the Philips Lighting Design and Engineering Centre for his help in compiling the chapter Calculations and Measurements. Finally, we wish to record our indebtedness to D. L. Parker, at present attached to the same Lighting Design and Engineering Centre, for his invaluable advice and assistance in preparing the manuscript.

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Contents

Part 1

FUNDAMENTALS

Chapter 1

Lighting Levels

The obvious first question to be asked when planning an interior lighting installation is 'What lighting levels are needed?'. But before this question can be answered it is necessary to clarify exactly what is meant by the term 'lighting level'.

The output of a light source is the so-called luminous flux measured in lumens. The luminous flux incident per unit area of a surface is called the illuminance, which is measured in lumens per square metre, or lux. The brightness of the surface illuminated by the source, or more precisely its luminance measured in candelas per square metre, is directly proportional to the product of the illuminance and the surface reflectance, the latter being the ratio of the reflected luminous flux to the incident luminous flux. These two quantities, illuminance and luminance, are therefore closely interrelated, the connecting link being the reflectance of the surface illuminated. In the case of diffusely reflecting surfaces, for example, the equation connecting these two quantities is

$$L = \frac{E\rho}{\pi}$$

where L is the luminance in cd/m^2, E the illuminance in lx and ρ the reflectance. It is because of this close interrelationship that the two quantities illuminance and luminance are referred to collectively as lighting levels.

To return to the question posed above, the answer will depend on the type of interior being considered. In rooms or areas in which visual tasks have to be carried out, the so-called 'working interiors', the required lighting levels will usually depend on the difficulty of the task and the level of performance desired; although a worker's satisfaction with his visual environment must also be considered. In circulation areas and places intended for social contact and relaxation, other than sports areas, the visual performance criterion is not so valid and the emphasis is then placed almost entirely upon the criterion of visual satisfaction.

The way in which these two criteria, visual performance and visual satisfaction, have been used to find lighting levels suitable for recommendation in different types of interior is considered here in some detail. The chapter concludes with a brief outline of the research done to investigate the possible effect that age might have on each of these criteria.

1.1 Lighting for Visual Performance

There are two approaches that can be adopted when seeking to arrive at a lighting level suitable for the performance of a given visual task. One can investigate the effect of lighting level on visibility threshold for artificial tasks under laboratory conditions. Adequate visual performance can then be guaranteed by ensuring that the lighting level is, in practice, well above the threshold value appropriate for the task in question. Alternatively, one can investigate directly the effect on visual performance of lighting levels in the supra-threshold range. The lighting level is then found from the value corresponding to that giving the required visual performance.
The first approach offers the advantage that one obtains an insight into the limitations of the seeing process. The benefit of the second approach is that one is able to draw conclusions concerning the effect that a particular lighting level will have in a practical situation. The CIE has tried to integrate both approaches in one unified framework for evaluating visual performance aspects of lighting (CIE, 1972).

1.1.1 Investigations into Threshold Visibility

The degree of visibility of an object of given size and contrast (as measured relative to a homogeneous background) exposed to view for a given period of time is determined by the visual acuity, contrast sensitivity and speed of vision of the observer.
These terms are defined as follows

Size
For the purposes of visibility investigations the size of an object, or the size of its critical detail, is commonly defined as the angle subtended by the object or detail at the eye of the observer, this angle usually being expressed in minutes of arc.

Contrast
The (luminance) contrast C of a small object of uniform luminance seen against a background of uniform luminance is the difference between object luminance L_o and background luminance L_b, expressed as a proportion of the background luminance. Thus

$$C = \frac{L_o - L_b}{L_b} = \frac{\Delta L}{L}$$

Visual acuity ($1/D$)

1. Qualitatively: Capacity for distinguishing fine detail.
2. Quantitatively: Reciprocal of the angular separation D (generally in minutes of arc) of two neighbouring objects (e.g. points or lines) that the eye can just perceive as being separate.

Contrast sensitivity (symbol S_c)

1. Qualitatively: Capacity for distinguishing luminance difference.
2. Quantitatively: Reciprocal of the minimum perceptible relative luminance difference. Thus

$$S_c = \frac{L}{\Delta L} = \frac{1}{C}$$

Speed of perception (or speed of vision) ($1/t$)

Reciprocal of the time interval, usually in seconds, between the instant at which an object is presented and the perception of its form.

These faculties of visual acuity, contrast sensitivity and speed of perception are closely interrelated, and the luminance of the visual field has a considerable positive influence on all three. An improvement in one's visual faculties is, indeed, immediately apparent when the light is switched on in a poorly-lit room.

Investigations into threshold visibility were undertaken, amongst others, by Fortuin (1951), Balder and Fortuin (1955), Blackwell *et al.* (1959), and later by Blackwell and Blackwell (1971).

In 1951, Fortuin investigated the relation between the size of an object, its contrast, and the field luminance, for threshold visibility of the subject. The viewing time was not limited.

The method of examination adopted by Fortuin was to ask a large number of test subjects, covering all ages, to view a test chart composed of Landolt rings of different sizes and contrasts. A Landolt ring is a two-dimensional ring with a gap, the width of the gap and the thickness of the ring each being equal to one-fifth of the ring's outer diameter (see figure 1.1). Each ring on the chart had one of eight possible orientations viz. gap pointing N, NE, E, SE, etc. Each test subject in turn was asked to view all the rings on the chart, in an order determined by the examiner, indicating for each the direction in which he thought the gap to be pointing. The correctness of the answers received indicated to the examiner which of the gaps had, in fact, been visible.

In his investigations, Fortuin determined for every subject the smallest visible object size at a number of different combinations of contrast and field luminance. It was found, for unlimited time of observation, that the equation

$$\log D + 0.791 = -2.17 \frac{\log C - 1.57}{\log L + 3.96} \qquad (1)$$

described fairly accurately the relation between the field luminance L and the values of object size D (i.e. gap size) and contrast C, for all results taken together.

This relationship corresponds to a surface – the boundary surface between visible and invisible objects – in the three-dimensional D, C, L space, figure 1.1. A point in this figure above this surface represents an object that is visible. It was found that with increasing age of the test subject this surface was displaced in the direction of higher values of D. (Figure 1.2 shows a two-dimensional representation of equation (1) with L as parameter. This figure makes quantitative evaluation easier.)

The greater the values of D and C of an object become, at a given value of the field luminance L, with respect to the values corresponding to a given point on the threshold surface (figure 1.1), the better the visibility of the object. Further, the better the visibility of an object, the shorter becomes the time of observation required. In other words, as the time of observation t becomes shorter, the farther is the D, C, L threshold surface displaced in the direction of increasing values of D, C and L.

This influence of the time of observation on the visibility of stationary objects, i.e. its influence on the position of the D, C, L threshold surface described above, was measured by Balder and Fortuin (1955). Again, a large number of test subjects, covering all ages, were asked to view a series of different-sized Landolt rings. The experimental set-up used is shown in

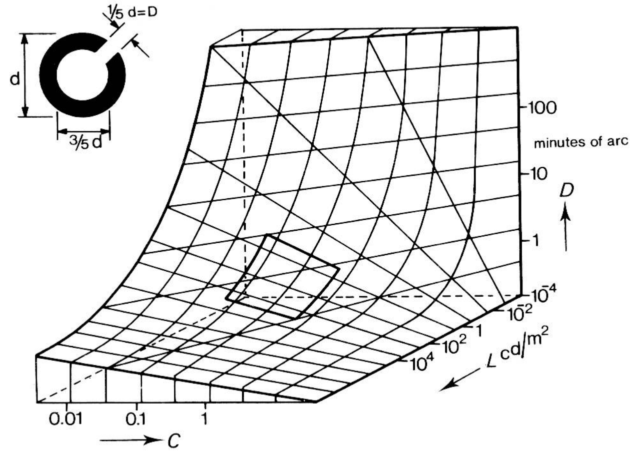

Figure 1.1 Diagram representing an equation of the type $y = x/z$, in this case $\log D + g = p(\log C + m)/(\log L + n)$, giving the threshold size D of the gap in a Landolt ring (top left in figure) as a function of contrast C and field luminance L. The 'square' in the centre of the surface represents the range of the investigation (viz. contrast 0.094–0.94 and luminance 1.2 cd/m² – 1200 cd/m²). Viewing time was not limited (Fortuin).

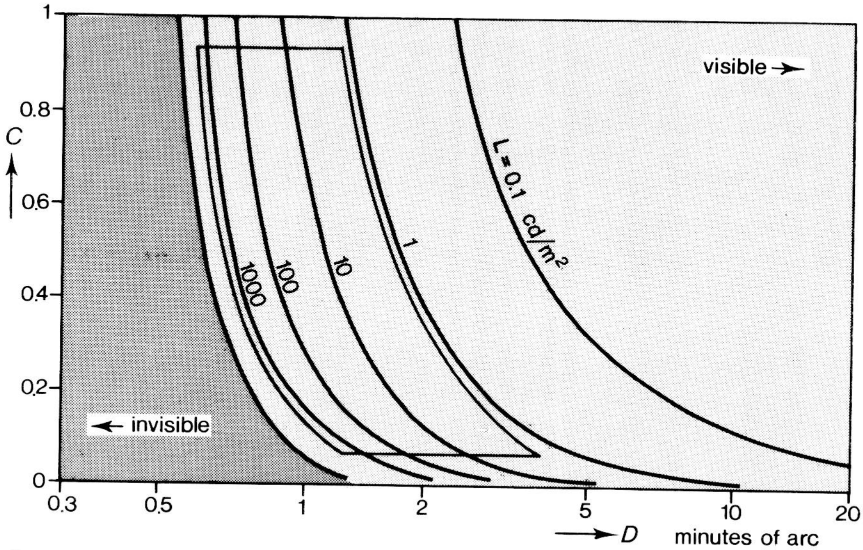

Figure 1.2 Ring contrast C on a linear scale as a function of gap size D on a log scale, with field luminance L as parameter. The 'parallelogram' represents the range of the investigation (viz. contrast 0.09–0.94 and luminance 1.2 cd/m²–1200 cd/m²).

figure 1.3. With ring size D held constant, the contrast C between the ring and its surroundings, the luminance of these surroundings L, and exposure time t were each varied over a range of four values to give a total of 64 C, L, t combinations. This was repeated for a range of ring sizes.

After each exposure, the test subject was given adequate time to signal to the test leader in which of eight possible directions he observed, or thought he observed, the gap in the ring to be pointing. From the answers received, the threshold value of D was determined for each test subject for a number of C, L, t combinations.

For each of the 64 C, L, t combinations the individual log D values were averaged for all observations carried out by test subjects of all ages represented (approximately 100 observations per C, L, t combination). These average threshold values of log D were plotted, for each of the four observation times employed, as a function of log C and log L. This gave four threshold surfaces in the D, C, L space, with t as the parameter – figure 1.4.

The work carried out by Blackwell has led to the development by the CIE (see ref. CIE, 1977) of a general method, based upon visual performance criteria, by which task performance can be related to lighting variables (see Sec. 1.1.3).

Blackwell conducted basic experiments on the threshold detection of a small luminous disc flashed against the centre of a large luminous screen viewed by observers. The disc appeared briefly during one of four time intervals and the observers had to indicate afterwards during which of the intervals the disc had appeared. Test parameters varied were disc size and luminance, presentation time and task background luminance (i.e. screen luminance). From the results of more than eighty thousand observations one particular contrast/luminance relationship was extracted as a reference – the 99 per cent probability-of-seeing for a disc of 4 minutes of arc exposed for a period of 0.2 seconds, figure 1.5. This and more recent data have been

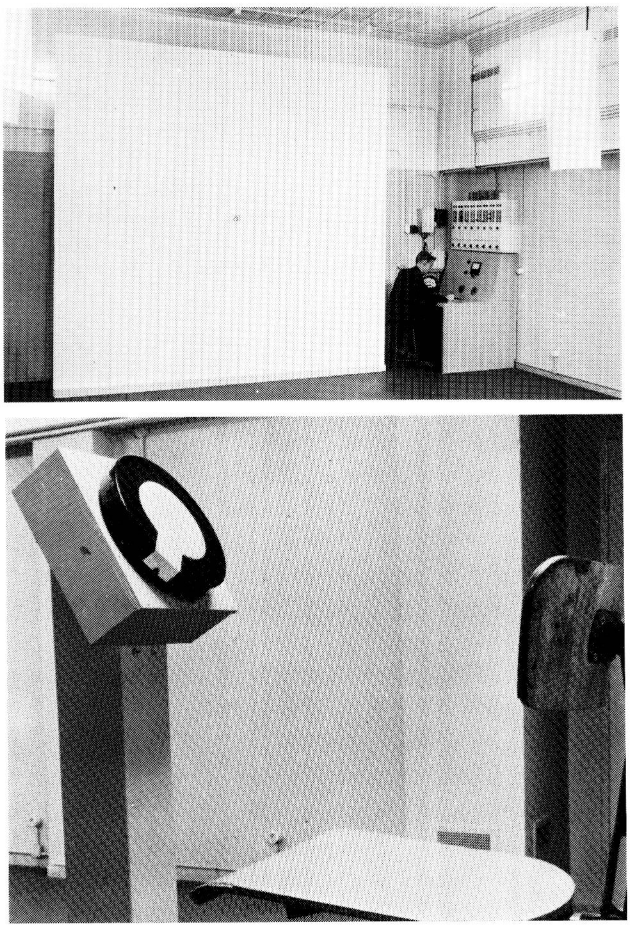

Figure 1.3 Two views of the experimental set-up for measuring threshold visual performance. The photo above shows a uniformly lighted screen in the middle of which Landolt rings of different size and different contrast could appear for an adjustable presentation time. The observer was positioned behind a model Landolt ring at a distance of six metres from the screen (photo below) and had only to turn the ring into the position of the ring being viewed.