

**SECOND EDITION**

# **THE DESIGN OF LIGHTING**

**PETER TREGENZA AND DAVID LOE**

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Peter Tregenza and David Loe



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# The Design of Lighting

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# Preface

This book is written for those who are new to lighting as a subject and for those who want to bring their knowledge up to a professional level. It is aimed at designers and those who work with designers – in architecture, interior design, environmental engineering, and the many related fields.

The subject is a broad one. The topics that need to be discussed range from visual creativity to applied physics. This implies that whatever your background you are likely to find here familiar concepts and also material that needs to be learnt. That accounts for the structure of the book: the topics are arranged in short chapters which are designed to be used in several different ways – they can be read through as an introduction, skipped by the knowledgeable or used as a source of reference.

As a textbook, the content covers the lighting syllabus of a degree course in architecture and is appropriate as a first text for environmental engineering courses and for specialist master's level courses in lighting. It has three main parts:

*Foundations:* ideas and knowledge that underlie the work of a lighting professional. Eight short chapters explain how light and colour are described and quantified, how the characteristics of human vision determine the requirements of good lighting, how lamps and LEDs work, and how natural light behaves.

*Design:* the approach to a lighting project. Bringing together different strands of knowledge, this part first describes how lighting affects the character and the ambience of a place, then considers the demands of visual tasks and of display, and finally it discusses other criteria of good lighting – in particular costs and maintenance, energy use and an approach to sustainability. It reviews the process of lighting design and how this is related to professional practice.

*Applications:* worked examples and real projects. This part includes discussion on briefing and user needs, examples of calculations and design decisions, and some finished projects by internationally known designers.

We have introduced two new features in this edition. First, the book begins with a chapter we have called *Observing light*. It describes and illustrates the behaviour of light. We argue that just as a composer of music knows the characteristics of instruments and voices, or a painter the colour and nature of pigments, so a lighting designer needs a deep understanding of how light performs. Second, the examples section is enlarged and given a new structure. It reviews some key building types. For each of these there is a discussion about the design brief, worked examples of calculations and finally illustrations and analyses of real buildings.

It is assumed that lighting design software is used by most practitioners but that knowledge of manual calculations is necessary. There is guidance on interpreting computed results and an introduction to lighting theory. Actual calculations are presented in Part Three so their relevance is seen in context.

We hope that the book conveys our enthusiasm for designing with light and colour, and our fascination with a subject which extends into so many different topics.

Peter Tregenza and David Loe

# Acknowledgements

Our thanks are owed to many for help and advice in writing this second edition: to colleagues who have shared their knowledge, to students who gave constructive comments on the first edition; to designers and manufacturers who were generous with the material to include in the book; to our publishers for continuing advice and support. Especially we thank our families who have been so much more tolerant than we deserve about the time we have devoted to the book.

We acknowledge with gratitude the contributions others have made to this book. Much of the information given in the text is based on printed sources. In particular the guideline tables of criteria and design recommendations are largely derived from data in publications from the Commission Internationale de l'Eclairage and the Society of Light and Lighting. Although all diagrams in the book are original, several of them draw heavily on widely reproduced illustrations in standard texts on vision and on lighting technology.

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- Florence Lam of Arup Lighting, London
- Penoyre & Prasad, Architects, London
- dpa Lighting design, London
- Spiers and Major, London.

All illustrations in the book are the authors', with the exception of those listed below.

We are grateful to the following manufacturers, professional practices and individuals for permission to reproduce the following figures/images:

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# Part One

## Foundations

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PART ONE is an outline of the physical ideas underlying lighting design. It begins with a chapter called *Observing light* which gives some examples of the way that light behaves. Its first purpose is to set down systematically facts you need to know about the behaviour of light at the scale of buildings and towns. Its second purpose is to encourage you, wherever you go, to look at the lighting around you – analyse it, identify the primary sources, observe how people react to the place – and to note your own subjective response to the place.

Seven short chapters follow, each introducing an individual topic. They begin with a vocabulary of specialist words and then describe the units in which light and colour can be measured and specified, the human need for light and how the human eye responds, how light is produced electrically and how natural light behaves, and the nature of calculations in lighting and how light is measured.



1.1

# Observing light

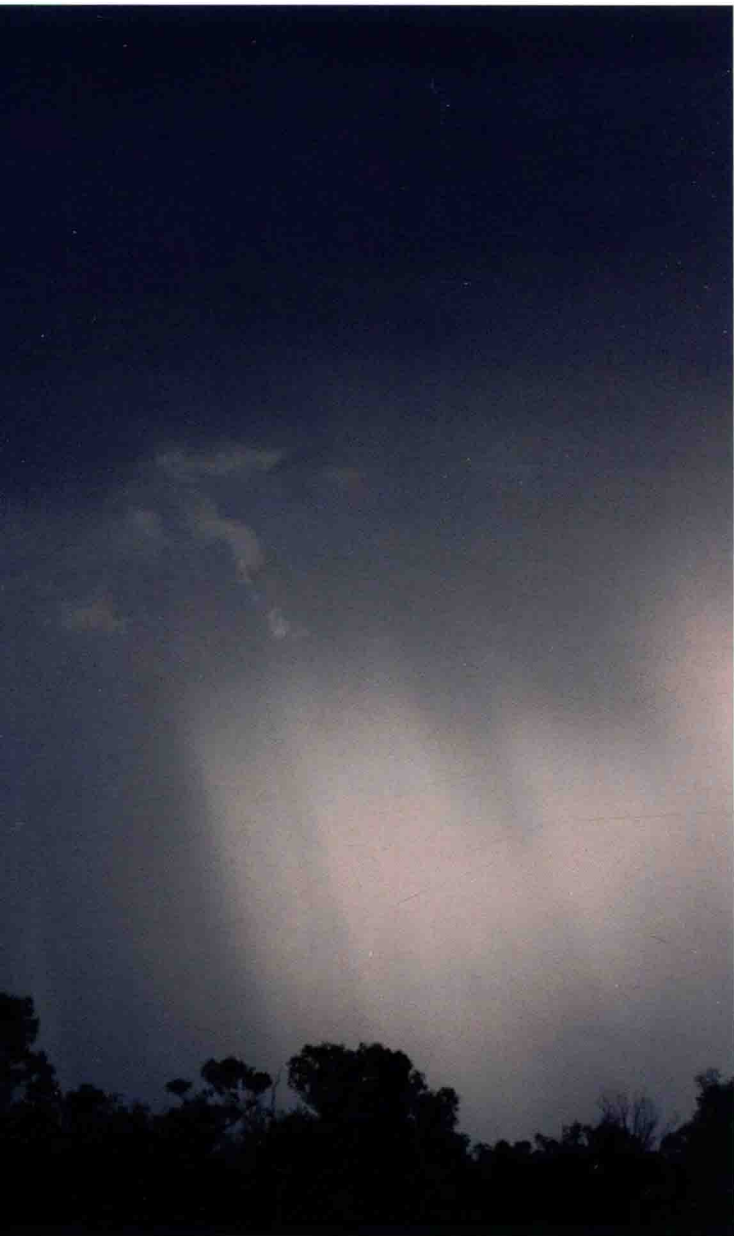
Composers of music know the sounds that voices and instruments make. They know their physical characteristics, their ranges, how easy or difficult it is to sing or play particular notes; and they understand something of the effect that music can have on people. Similar things could be said of those who work in theatre or who paint, or who write poetry, or practice any other art. Part of the process of learning to be creative is to build up vocabularies of sounds or words or images, whatever the medium is. These become the language with which the artist communicates. The lighting designer's language is brightness and colour in three-dimensional space; our medium is the physical building. But to share knowledge, to teach and to learn, we use a second language: the written and spoken word. This is the language we use to build up a theoretical framework that supports our designing. And like other artists we give some words a special meaning: examples are 'brightness', 'lightness', 'colour' and 'space'. They are like 'melody', 'harmony' and 'rhythm' in music.

Such words, though, are meaningless to someone who has not experienced what they describe: the ultimate foundation of creative lighting design is a knowledge of real lamps, real windows and real materials. After that comes the need for words that describe what we observe, then abstract concepts.

This first chapter is, therefore, a guide to observing the visual world. The aim is not to compile a mental library of images, though that might be useful. It is to answer the question 'What are the rules that govern the behaviour of light?'

Look at the intricate pattern of brightness of the evening sky in the photograph, 1.1, of the Arno in Florence. The patterns of clouds, the range of colours, the continuing change and the sheer scale of the display reveal an amazing complexity. But the distribution of brightness in a room also can be complex. Even a single lamp in a windowless room produces a subtle variation of brightness across the room surfaces – the walls, ceiling and floor. With many lamps the pattern of brightness is elaborate; if there is daylight in the room, the pattern is not only more varied spatially but continually changing.

What happens in the evening sky or in a daylit room is the outcome of a small number of physical principles. For practical purposes these principles can be expressed as simple rules about the interaction of light and materials. Such rules are the foundation of a lighting designer's knowledge. Knowing them makes it possible to predict how a lighting scheme will work, what it will look like, how much energy it will use. The most important of the rules are systematically set out in the following pages. Use them as a structure to your observations.



**1.2**  
Sunbeams made apparent by falling rain. Direct light from the sun passes through gaps between clouds. Some of it is scattered towards the viewer by raindrops, indicating the location and direction of the beams. Kings Canyon, Central Australia.

# 1 THE FLOW OF LIGHT

## 1.1 A beam of light is invisible

Before smoking in cinemas was banned there was a visible beam of light from the projection room window to the screen. But it was not the beam itself that could be seen; it was particles of smoke illuminated by the beam which reflected some of the light towards the viewer. In a modern, air-conditioned cinema the beam cannot be seen. When driving a car at night, the beam from a headlight is only visible if the air is misty. On a clear night all that can be seen are the surfaces on which the light falls.

---

## 1.2 Scattering reduces the intensity of a beam and creates a field of diffuse light

In a large smoky cinema the screen is less bright than it would be in a smoke-free room because some of the beam's energy has been absorbed and scattered by soot particles.

In the earth's atmosphere light is scattered out of the sun's beam. The scattering is not uniform. Gas molecules scatter the blue part of the spectrum much more than the red. Water droplets reflect and refract light at angles that depend on their size. Sometimes we see this as a rainbow. Carbon particles and other pollutants reflect and absorb. The solar beam is less intense at the earth's surface than in space: the light scattered from it creates the diffuse sky.



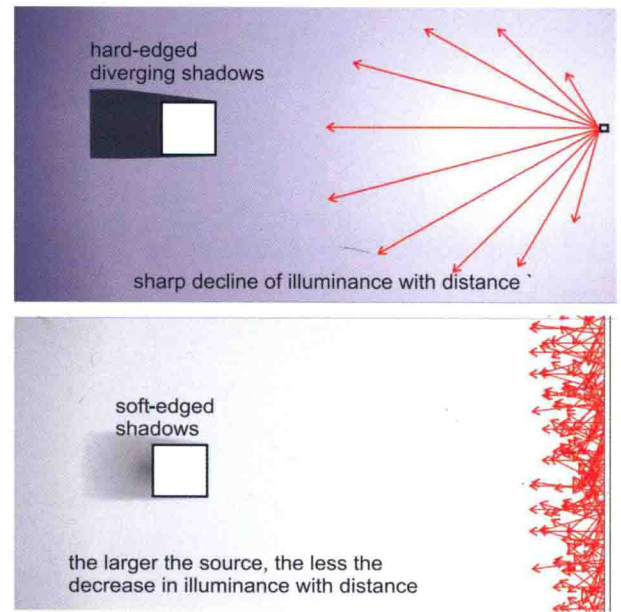
### 1.3 Illuminance depends on distance and the size of the source<sup>1</sup>

If a light source is very small, the illuminance that it gives on a surface facing it decreases greatly with distance. If the source is large, the diminution of illuminance with distance is far less.

Taking this to the limit:

If the source could be a mere point in three-dimensional space, the illuminance from it would be inversely proportional to  $d^2$ , where  $d$  is the distance from source to surface. This is the inverse square law. A clear filament lamp hanging in a room is a good approximation to a point source.

If the source could be infinitely large, the illuminance it would produce would be the same whatever the distance. An overcast sky is a good approximation to an infinite plane of light.



1.3

### 1.4 The crispness of shadows depends on the size of the light source

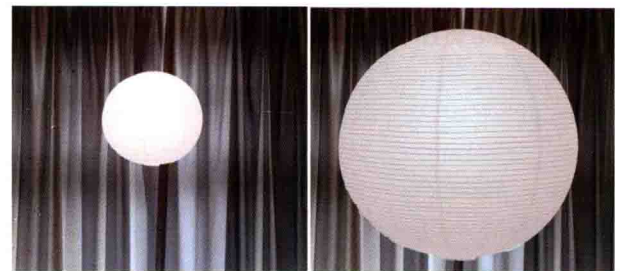
A very small source gives hard-edged shadows that diverge. The divergence decreases with distance from the source. A large source forms soft-edged shadows.



1.4

### 1.5 The luminance<sup>2</sup> of a source depends on its size

A small source is brighter than a large source with the same light output. 1.5 shows a lamp first enclosed in a small paper lantern then in a lantern of twice the diameter. The larger lantern is less bright because the same amount of light is spread over four times the surface area.



1.5

<sup>1</sup> Illuminance is the amount of light falling on unit area of a surface. A source is anything that emits light.

<sup>2</sup> Luminance is the brightness of a source as measured with a light meter. What we actually perceive depends on the state of adaption of the eye and on other factors, and is often called 'apparent brightness'.



1.6

Rows of lights indicating routes. Florence, Italy.

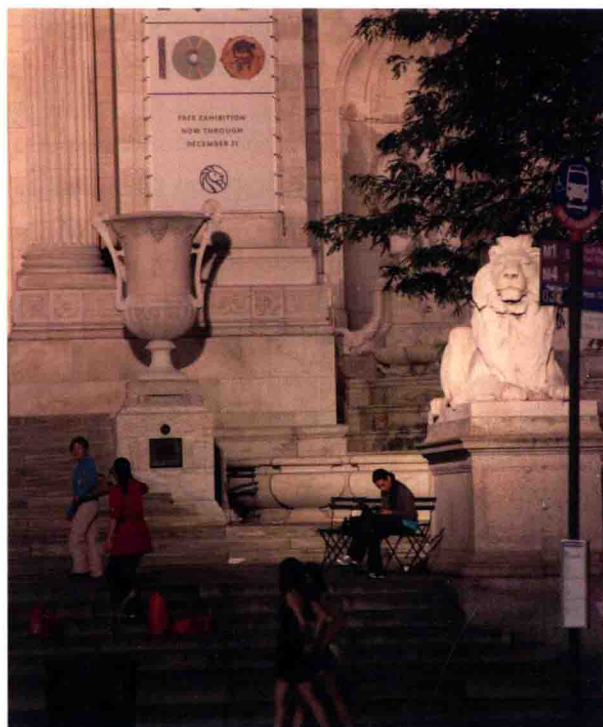
## 1.6 Beacons or projectors?

A source of light may itself be the focus of vision: a stained glass window, a candle on the dining table, a beacon buoy marking hazardous rocks at sea. Or the opposite may be true: the source may be hidden or effectively unnoticeable, entirely secondary to the light that it throws onto the surfaces around it. This is often the case when floodlighting the façade of a building or illuminating a picture on display.

When sources of light are very small in comparison with their distance from the observer, a row of them is perceived as a line rather than a set of independent points. They acquire a meaning: outside they might denote a pathway across a park or the edge of a harbour; in an aircraft they indicate the route to an escape door. The same technique also marks airfield runways. In **1.6** the street lighting marks the routes along the river embankments and over the bridge. The reflections make the impact stronger.

Compare this with **1.7**, the façade of New York Public Library. Here it is the projected light that is important. Although the library façade is flooded with light, it is not a uniform wash: subtle changes in illuminance preserve the three-dimensional moulding of the surfaces. Note, too, that the lion stands out with additional brightness.

Small patches of projected light can also form repeated elements or be used to define an edge. The night-time lighting of the Chrysler building, **1.8**, follows the characteristic motifs of the art deco design but produces an image which is quite different from the daylight appearance.



1.7

New York Public Library.



1.8

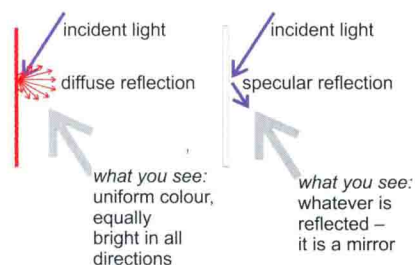
Chrysler building, New York.



## 2 THE NATURE OF SURFACES

### 2.1 Matt or glossy

The luminance of a matt surface depends only on the amount of light falling on the surface and its *diffuse reflectance*. The luminance of a glossy finish depends on the luminance of what it reflects and the *specular reflectance*. The grass in **1.10** is acting largely as a diffusing surface while the water acts as a mirror.



1.9



1.10

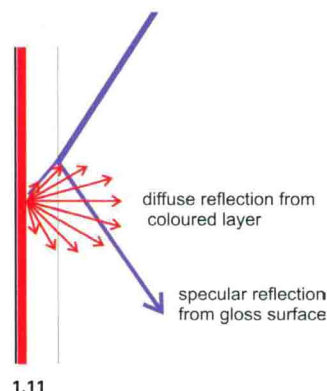
### 2.2 Compound reflection

Many materials have a glossy finish over a patterned or coloured layer. Some of the incident light is reflected at the top surface, the rest passes through the surface layer and is absorbed or diffusely reflected by the lower layer. The proportion of light reflected at the top surface depends on the angle of incidence.

The simplest case is a picture in a glazed frame. In **1.12** the reflection of a window is superimposed on the painting, making it difficult to perceive.

An oil painting itself often has a glossy surface that reflects like the glass in a picture frame. Polished wood, glazed ceramic tiles and gloss paint all behave as complex reflectors.

Colours appear most saturated when none of the surface-reflected light reaches the viewer. This is important for picture lighting. See the section on art gallery displays in Chapter 13.



1.11



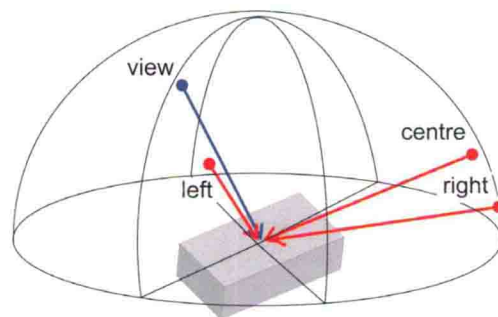
1.12

### 2.3 Surface texture

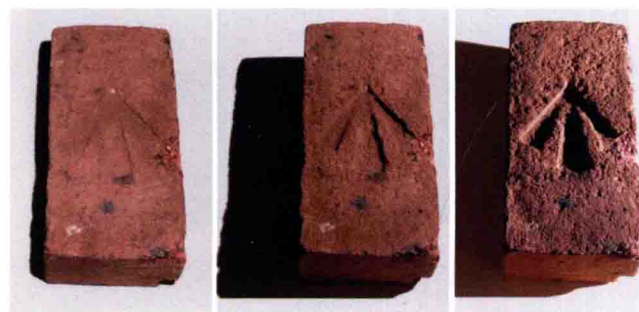
The roughness of a surface can be made either more obvious or visually minimised by choosing the angle at which light falls on a material. An incident beam in the same direction as the line of view minimises the apparent texture of a surface (this is why photographs taken with the built-in flash of a compact camera seem to lack 3D modelling). To reveal or even exaggerate any roughness, two things are necessary: the beam must be about  $90^\circ$  in plan to the direction of view; and it must fall on the surface from a low angle.

The diagram shows the direction of view and the direction of light falling on the brick. In the left-hand case (1.14a) the beam is close to the direction of view; the surface shadows on the brick are masked from sight by the indentations that cast the shadows. In the centre example (1.14b) the beam is perpendicular to the sightline so shadows are visible. On the right (1.14c) the beam falls at a glancing angle onto the brick, a high angle of incidence, and the texture is revealed strongly.

The map illustrates how light at glancing incidence produces shadows and bright reflections which make it difficult to see the printed detail.



1.13



1.14a-c



1.15