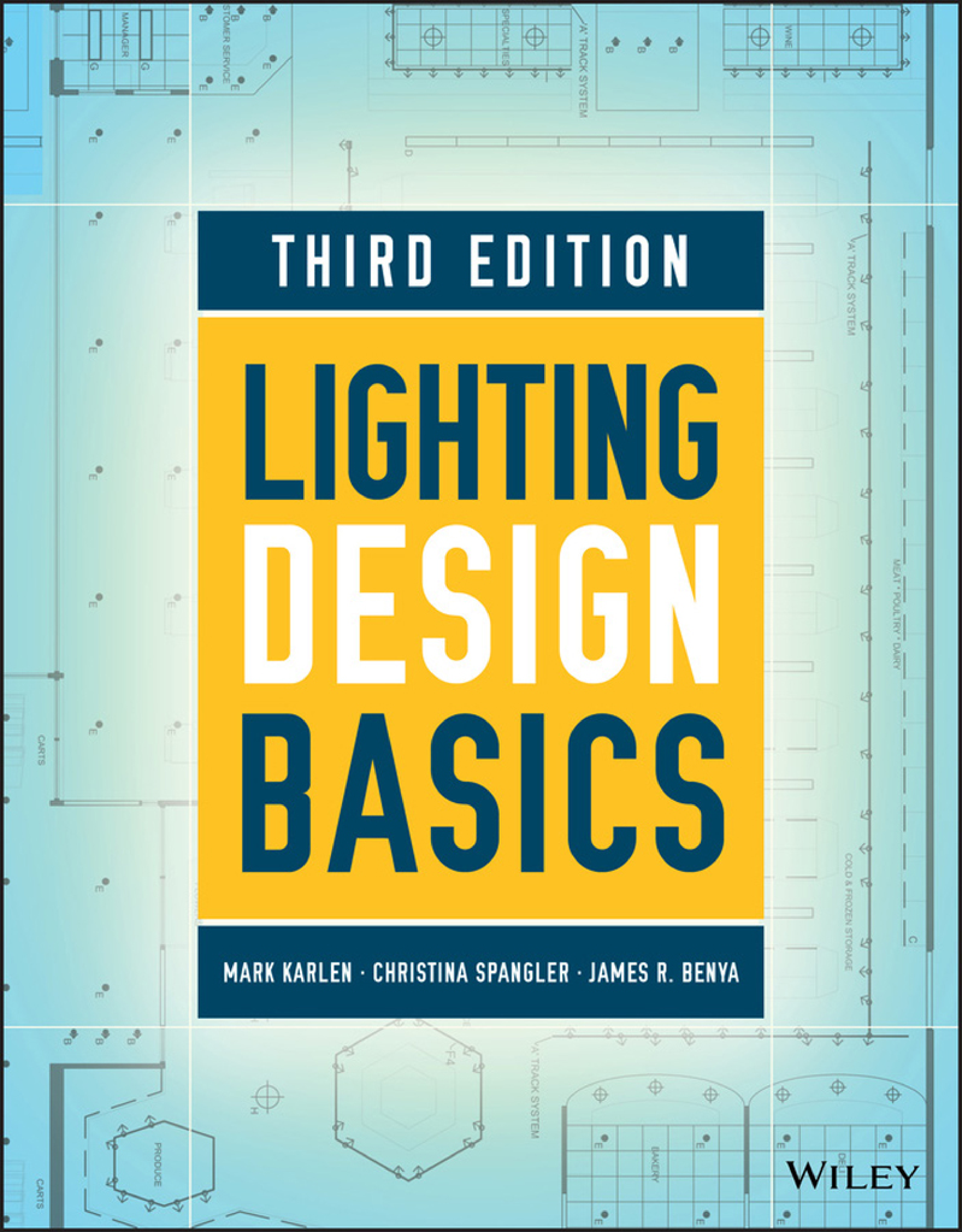

THIRD EDITION

LIGHTING DESIGN BASICS

MARK KARLEN · CHRISTINA SPANGLER · JAMES R. BENYA

WILEY

LIGHTING DESIGN BASICS

Third Edition

MARK KARLEN
CHRISTINA SPANGLER
JAMES R. BENYA

WILEY

This book is printed on acid-free paper. ♾

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

For general information on our other products and services, or technical support, please contact our Customer Care Department within the United States at 800-762-2974, outside the United States at 317-572-3993 or fax 317-572-4002.

Wiley publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at http://booksupport.wiley.com.

For more information about Wiley products, visit our Web site at http://www.wiley.com.

Cover design: Wiley
Cover image: Courtesy of Kathryn Lyons

Library of Congress Cataloging-in-Publication Data:

Names: Karlen, Mark, author. | Spangler, Christina, author. | Benya, James, author.
Title: Lighting design basics / Mark Karlen, Christina Spangler, James R. Benya.
Description: Third edition. | Hoboken, New Jersey : Wiley, 2017. | Includes index.
Identifiers: LCCN 2017013979 | ISBN 9781119312277 (paperback); 9781119394297 (ebk.); 9781119394310 (ebk.)
Subjects: LCSH: Lighting. | Lighting, Architectural and decorative. | BISAC: ARCHITECTURE / Interior Design / General.
Classification: LCC TH7703 .K27 2017 | DDC 621.32—dc23 LC record available at https://lccn.loc.gov/2017013979

978-0-470-47427-3

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

TABLE OF CONTENTS

PREFACE

In the intervening five years since the publication of this book's second edition, the rapidly changing technology in and subsequent practice of lighting design has continued to accelerate. Concurrently, the increasing awareness of and attention to both local and global concerns for a more sustainable environment have touched all who are involved in the decisions we make about the buildings we plan and use. This has affected every building typology, from the homes we live in to the large multiuse buildings we work and play in. This third edition addresses these complex issues by effectively solving the lighting design problems in the interior spaces that we use every day.

This edition's primary focus remains on the design issues relating to lighting, while continuing to provide the necessary information for solving technical aspects of the design problems at hand. Human comfort related to visual tasks, as well as the creation of interior spaces that are enhanced by satisfying users' desires for aesthetically pleasing spaces, will always be the objective of lighting design criteria. The "Electrician's Notebooks" introduced in the previous edition are continued and reinforced with additional attention to sustainable design methods and techniques. The expanded inclusion of color theory and technology in the last edition is further developed to enhance learning clarity and aesthetic quality.

We are pleased to have the opportunity to improve upon our earlier efforts in providing a useful tool for learning how to collaboratively create sustainably designed illuminated spaces, with the understanding that the concept of sustainability incorporates the broad concerns for living well in our built environment. Sally Dankner has made excellent contributions to this edition with the creation of several new illustrations, as well as updating many of the earlier works. And special thanks to Amanda Shettleton, Wiley's editor, for helping us through this complex venture.

Mark Karlen and Christina Spangler

Chapter 1

INTRODUCTION: How to Use This Book

This book is an instructional tool designed to develop the necessary knowledge and skills for solving lighting design problems for typical rooms and spaces and for collaborating with lighting design professionals in developing solutions for complex rooms and spaces. The book is directed to students and professionals in architecture and interior design or in related fields, such as facilities management, construction management, store planning, and electrical contracting and engineering.

The primary focus is on design, not technology or terminology. Design is the development of a lighting design concept and the selection and placement of luminaires to provide optimal lighting and aesthetically satisfying spaces for the visual tasks at hand. Lighting technology (and related terminology) is covered in enough depth to serve the design orientation of the book's methodologies. For more information related to these technical factors, the list of recommended readings (p. 251) identifies the best sources.

This is a how-to instructional textbook, the goal of which is to provide its users with the tools required to function effectively in the many design and construction fields of which lighting is an essential part.

ORGANIZATION

Lighting Design Basics is organized into four parts:

Part I: Basics about Lighting. Chapters 2 through 9 provide background for the technical (and related terminology) aspects of lighting design, enough to serve this book's purpose but without unnecessary emphasis on technical issues. More specifically, the technical factors addressed are light sources (and their color implications), luminaires, switching and controls, daylighting, and calculations (including rule-of-thumb techniques).

Part II: Design Process. Chapters 10 and 11 provide a basic approach or methodology for developing successful lighting design concepts and solutions, including the graphic representation tools and techniques used to convey the solutions. In this context, success is defined as meeting functional visual requirements, achieving satisfying aesthetic results, and using lighting design technology (including code compliance) intelligently. To aid in this process, a lighting design criteria matrix has been included as a predesign tool.

Part III: Applications and Case Studies. Chapters 12 through 19 focus on the typical lighting design problems encountered in the major building use types: (1) residential, (2) office/corporate, (3) health care, (4) educational, (5) retail, and (6) hospitality. In addition, Chapter 18 provides case studies for commonly used spaces, such as restrooms, corridors, and airport waiting areas; Chapter 19 addresses the issues of exterior lighting; and Chapter 20 deals with the recurring questions related to retrofitting existing conditions. Case studies are provided for many of the typical rooms and spaces found in conventional buildings. Design problems, their solutions, and the rationales for the solutions are presented in detail.

Part IV: Professional Skills. Chapter 21 provides additional and necessary information about functioning as a designer or design-related professional in matters concerning lighting design. This information is intended to serve as a transition from learning to professional practice.

Several chapters have additional technical and construction-related information in boxed notes called "Electrician's Notebook." These notes will be of specific interest to readers who wish to investigate these areas in more depth.

The volume also includes two appendixes. Appendix A is a discussion of energy codes and how they affect design. Included are the Internet reference for obtaining the most recent energy code information for the United States. Appendix B is a basic summary about how lighting can contribute to achieving LEED certification.

GETTING THE MOST OUT OF THIS BOOK

The information in this book is meant to be applied, not just read. At the heart of the learning process presented here is putting newly acquired knowledge to work shortly after reading and understanding the related case studies.

The examples in the case studies represent typical lighting design applications. Beyond these examples, lighting design becomes increasingly complex and challenging, even for the most knowledgeable and experienced professionals. The purpose here is not to prepare the reader for those complex problems but rather to provide the reader with an understanding of lighting design concepts, techniques, and realistic goals so collaboration with a lighting design professional can achieve the best possible results. The reader must learn to communicate design intentions in a way that a lighting designer can use. Those communication skills require a conceptual understanding of lighting design, the acquisition of which should be one of the major learning goals in working with this book.

Many technical aspects of lighting design go considerably beyond the scope of this book. Issues such as the fine points of color rendition, code compliance, project budget, and lighting live performance spaces can be extremely complex. Working knowledge of these factors is not expected of broad-based design and built environment professionals. However, general familiarity is required to collaborate productively with lighting designers. To acquire deeper knowledge in these more technical matters, consult the bibliography.

In a classroom setting, the value of this book is enhanced by an exchange of ideas among students working on the same lighting design assignments, the instructor's critiques, and open classroom critiques and discussion. Beyond the classroom, the reader should take advantage of every opportunity to discuss lighting design solutions with design professionals, particularly those with extensive practical experience. Such discussion can be invaluable.

Two readily available learning tools should be used concurrently with this book. First is the deliberate observation and critique of existing lighting design applications. The reader should be aware of the lighting in public and semipublic spaces, making note of lamp and luminaire types and, more important, what works well and what does not. A great deal can be learned from the successes and failures of others. Second, many architecture and interior design professional publications present enough programmatic, plan, and spatial information about interesting spaces to use as design exercises for enhancing skills.

It all begins with working on paper or the computer and trying a variety of lighting design solutions to typical design problems.

Although this book prescribes a particular approach to solving lighting design problems, it should be understood that several potentially successful methodologies exist. In the professional community of lighting designers and the other design professionals who work with them, the problem-solving process enjoys many workable variations. It is expected that individual professionals, after repeated experience with actual problems, will develop personalized methodologies.

PART

BASICS ABOUT LIGHTING

Chapter 2 BASIC CONCEPTS IN LIGHTING

Lighting plays an important part in the designer's toolbox because it completely changes how an occupant experiences a space. If the lighting does not adequately and appropriately illuminate the visual tasks and surfaces, the design will not entirely meet its goals. Most environmental experience occurs through vision, and, without light, we literally cannot see. Lighting leads a person instinctively through a space, and it controls what a person sees or does not see. It can quickly and simply change the atmosphere of a space and how a person feels while in it. Additionally, the proper level of illumination allows the user to easily complete the tasks required. Ultimately, the lighting determines how successful a design will be aesthetically and functionally.

As a designer, it is important to study lighting even though a professional lighting designer may be involved with a majority of commercial projects. Designers have the most comprehensive understanding of the space, including the architectural features, programming requirements, furniture and equipment planning, user interaction, and overall design concept. Having a basic knowledge of lighting design, sources, and fixtures gives the designer the opportunity to guide a lighting designer and clearly describe the effects desired. Also, recognizing the importance of lighting allows the designer to make lighting decisions throughout the development of the project instead of at the end.

Developing an approach to a lighting design solution can be highly challenging for a designer because of rapidly changing technology in the field and the countless choices of luminaires. A designer must first determine what objects and surfaces require lighting and develop a visual composition using multiple layers of lighting.

LAYERED DESIGN

The principle of layering provides a framework for understanding and achieving composition and aesthetics in lighting design. Layering permits judicious choices that ensure that design requirements can be established prior to selecting the type or style of fixture. Generally, using layers of lighting gives the space variety and interest while also providing flexibility for the end user. In addition, because more attention is given to lighting specific surfaces, layered lighting is often more efficient than lighting a space uniformly.

LIGHTING LAYERS

The layers of light are identified in the order of their importance and visual impact. Each layer has unique responsibilities to light certain visual tasks; however, the layers often work together to light portions of the space.

Focal Layer

The focal layer is typically used to highlight vertical surfaces and three-dimensional objects, including architectural features and details, artwork, retail displays, and signage. Although this layer often is considered aesthetic in nature, it plays an important role in determining the perceived brightness of the space.

To understand the layer's significance, it is important to recognize how humans interact with light. Humans typically see and respond to bright vertical surfaces. A space where the vertical surfaces (walls, furniture, art, etc.) are well illuminated will feel much brighter than a space where only the horizontal surfaces (desktop, tables, floor, etc.) are lighted. Identifying the key vertical elements, focal points, and visual destinations will lead a person through the space intuitively (see Fig. 2.1).

Most often, the focal layer light source is not seen. The intent is to highlight the object or feature and not see the luminaire.

Task Layer

The task layer is used to illuminate specific tasks that are performed in a space. Many work tasks, such as reading or writing, occur on a table or desk. It is common to provide lights

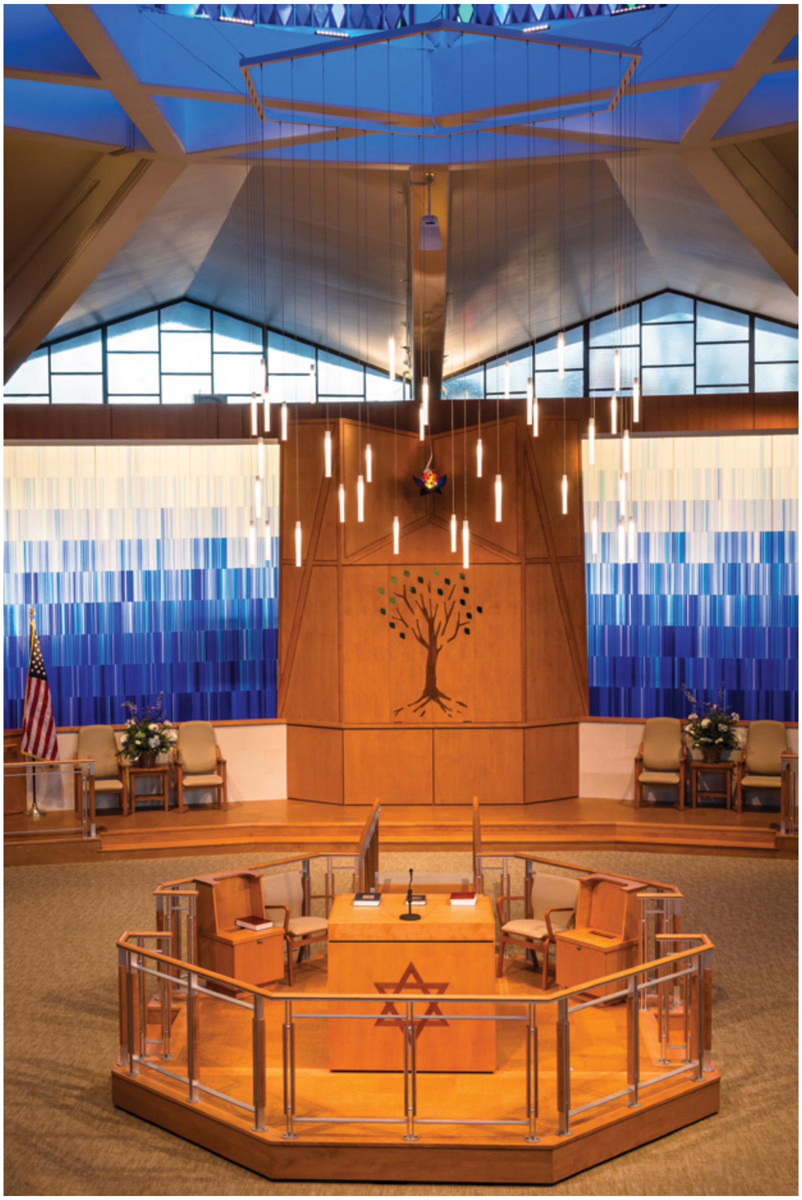

Fig. 2.1 Focal Lighting Example
(Photograph: Stephen Hoppe)

at specific locations where these tasks occur. Using higher levels of illumination at the task location is more energy efficient than providing that level of light throughout the entire space (see Fig. 2.2).

Fig. 2.2 Task Lighting Example
(Photograph: © Matt Wargo/Architect of Record: Bradberry & Kheradi)

Electrician's Notebook

Depending on the complexity of the room and its design, it is possible for all layers of light to be represented. Because each of the layers has a different purpose and should be controlled separately, four or more switches or dimmers could be required in a single space. The layers of light can be used intentionally to create a composition in the space, and often users may like to create "scenes" that vary throughout the day or for different uses.

Instead of a row of standard switches or dimmers, the lighting designer can consider using a preset scene controller (see Fig. 2.3). Basic scene controllers fit within four-gang recessed boxes and can control up to six groups or zones of light. This type of system is similar to a car radio since it remembers a preset so that it can be recalled repeatedly without manual adjustments. The individual zones can be set at different levels as required and memorized as a scene. Such a system also allows integration into home theater and commercial audiovisual presentation systems. Refer to Chapter 7 for additional information about lighting control systems.

Fig. 2.3 Wallbox Dimmers versus Preset Dimming System
(© 2012 Lutron Electronics Co., Inc.)

Daylight Layer

The daylight available in a space should be evaluated so that opportunities to reduce artificial lighting can be realized early in the design process.

The advantages of incorporating daylight into the overall lighting design (see Fig. 2.4) are listed next.

- Energy savings can be captured if fixtures are reduced or controlled properly.
- Daylight reveals true colors in a space.
- Building fenestrations provide views and ventilation.
- Daylight creates a positive effect on people by reducing stress and encouraging positive attitudes, as well as increasing productivity.

In addition, the contribution of sun and daylight may require control to reduce glare and unwanted heat gain. Refer to Chapter 4 for a more in-depth understanding of daylighting.

Decorative Layer

One way to think about decorative lighting is as the jewelry of architecture. Like jewelry in fashion, the primary purpose of decorative lighting is as an ornament to the space to catch the eye and make statements about style or wealth (see Fig. 2.5). Decorative lighting plays an extremely important role in interior design and themed environments. Additionally, decorative fixtures can provide a desirable eye-level glow that is missing from spaces lighted only from the ceiling. Generally, because of their decorative nature, such fixtures emit light rather poorly. Although it is increasingly common to avoid counting on the decorative light for the purpose of task lighting, it can contribute to a room's ambient light. It is common to dim decorative fixtures significantly and supplement the room's lighting with separate task, focal, and/or ambient lighting to fulfill the lighting needs.

Fig. 2.4 Daylight Example *(Photograph: Jeffrey Totaro)*

Fig. 2.5 Decorative Lighting Example

Ambient Layer

The ambient layer provides the background lighting that helps create the mood of the space. Typically low in contrast, ambient lighting allows basic visual recognition and movement through a space. It is important to note that often, after all the other layers are considered, lighting specific to the ambient layer may not be required, which is why it should be considered last.

The amount of ambient light is important: If the ambient light level in the space is significantly lower than the focal light level, the contrast between focal and ambient light will be high, and the space will appear more dramatic (see Fig. 2.6). In contrast, if the ambient light levels are nearly as high as the focal and task levels, the room will be brighter and cheerier (see Fig. 2.7). Because of the impact of ambient lighting on the mood or ambience of the room, its choice is surprisingly critical.

Applying Layers to a Design

Once designers have a basic understanding of the five layers of light and their general purpose within spaces, it is important for them to apply this approach early in the design process. As soon as a basic furniture plan and preliminary elevations are developed, the study of layered lighting can begin. At this stage, it is key to think about what surfaces, objects, and tasks require lighting, not what fixtures will be used. Often it is helpful to sketch the layers of light on these early drawings, as shown in Figure 2.8. Graphically showing the layers can help identify lighting opportunities during this early stage of the design. Also, using a different color for each layer quickly shows where the layers may overlap. This simple study of the lighting becomes an invaluable tool to reference as the design develops.

One Light, Two or More Layers

Too many light sources—especially too many types of light fixtures—can be visually busy. It certainly can add cost. A good lighting designer seeks to minimize the lighting design while

Fig. 2.6 Ambient Lighting with High-Contrast Example

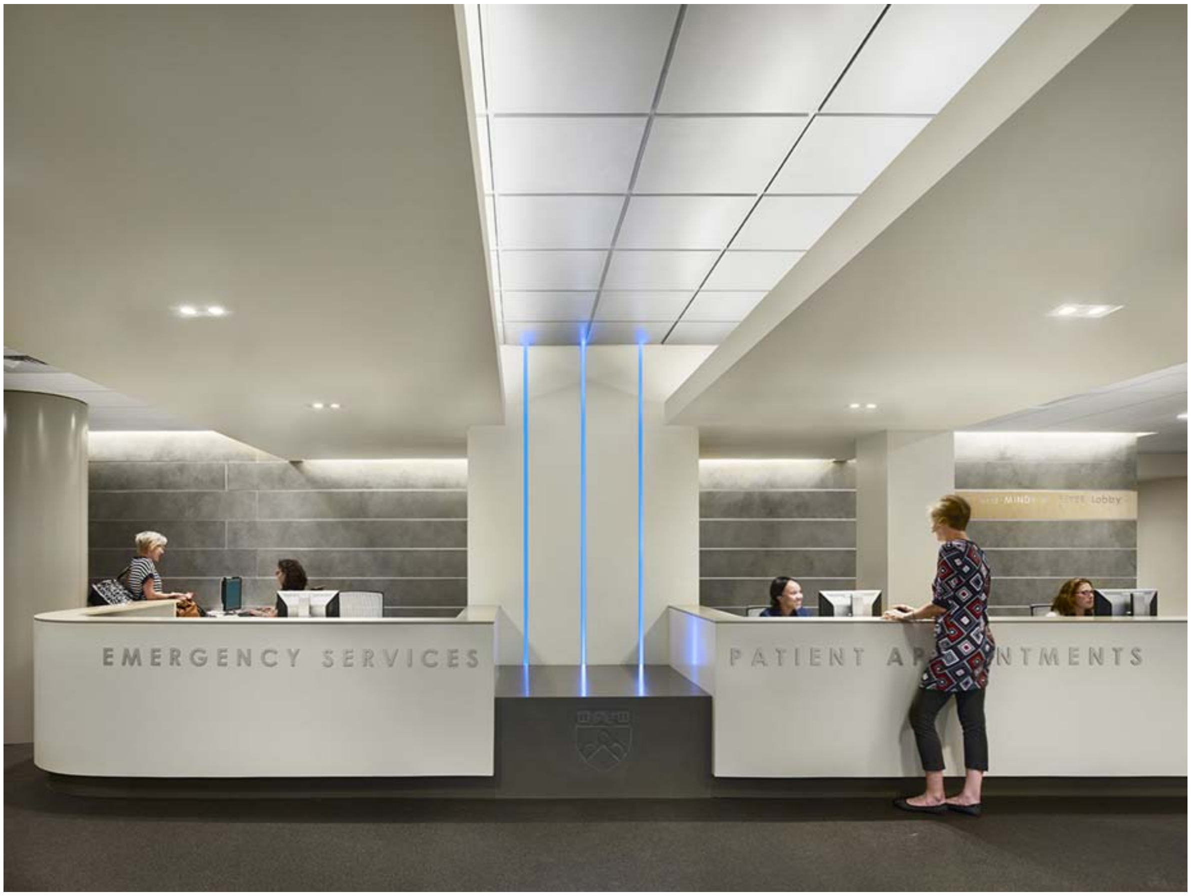

Fig. 2.7 Ambient Lighting with Low-Contrast Example *(Photograph: © Halkin Mason Photography)*

maintaining the desired effects. One common design approach is to have one luminaire or lighting system provide two or more layers. Here are some common examples:

- *Use decorative lighting as ambient lighting*. Careful selection of decorative luminaires is required to prevent glare; luminaires with mostly uplight do an excellent job of providing both decorative and ambient lighting, whereas luminaires with bare lamps and other traditional elements can be poor ambient light sources (see Fig. 2.9).
- *Use the same type of luminaire for focal lighting and task lighting*. Recessed adjustable luminaires and track lighting can be aimed at tasks as well as artwork (see Fig. 2.10).
- *Use decorative lighting as task lighting*. Table lamps, floor lamps, pendants, and other types of decorative lights can make excellent task lights in some applications (see Fig. 2.11).

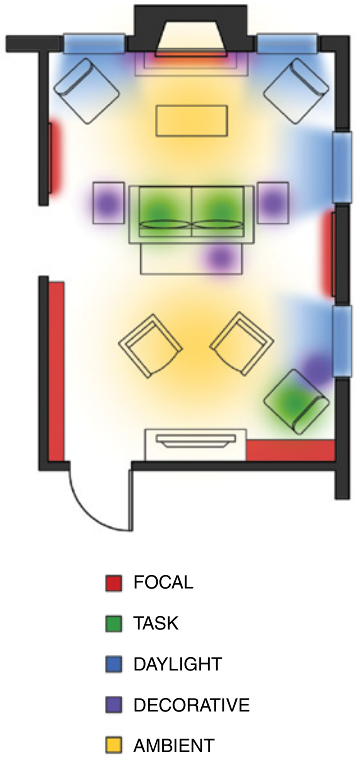

Fig. 2.8 Layers of Light Sketch

General Lighting: Only One Layer

General lighting is an approach whereby only one luminaire or group of similar luminaires is designed to provide all task and ambient lighting (see Fig. 2.12). This single-layer technique is used in many basic lighting designs for offices, classrooms, stores, and many other types of spaces. General lighting tends to be inexpensive and easy to build and use, but it usually lacks the drama and style of designs with more layers.

It is important to note that even very simple general lighting designs can benefit greatly from the addition of focal lighting. For example, focal lighting added at the front of a classroom can help students focus; focal lighting on an office display or bulletin board can inform employees; and focal lighting in a store can lead a person to the sales counter.

Fig. 2.9 Decorative Light as Ambient Light *(Photograph: © Matt Wargo/Architect of Record: Bradberry & Kheradi)*

Fig. 2.10 Combination Focal and Task Light *(Courtesy of Tech Lighting)*

Fig. 2.11 Decorative Lighting as Task Light *(Courtesy of Tech Lighting)*

Fig. 2.12 General Lighting Example *(Photograph: © Joseph M Kitchen)*

A NOTE ABOUT COMPOSITION

Good lighting designs bring together lighting decisions in harmony with the inherent design of the space. As with architecture and interior design, individual skill in lighting design increases with experience, critique, and practice. Simple single-layer designs are generally not as complex as multilayer designs, but achieving a good composition with a limited amount of equipment may be challenging. Energy-efficient lighting designs are especially hard to do because some layers, such as the decorative layer, either will need to do more than one job or will need to be eliminated altogether.

Chapters 3 through 11 provide the designer sufficient technical knowledge to intelligently discuss lighting design with other members of the design team, including the project's lighting designer. This background allows the design team to make deliberate and educated decisions about lighting to ensure the clients' lighting needs are met. The case studies in Chapters 12 through 19 illustrate how that information can be translated into a design solution.

Chapter 3

QUALITIES OF LIGHT SOURCES

The sun, moon, and stars are the most important sources of light for life. But because of the human need for additional light, humankind has learned to create light as well. Understanding light sources begins with the fundamental difference between natural and man-made light.

Natural light sources occur within nature and are beyond the control of people. These natural sources include sunlight, moonlight, starlight, various plant and animal sources, radioluminescence, and, of course, fire.

Man-made light sources occur under the control of people, when deemed necessary and in the amount wanted. These sources include wood flame, oil flame, gas flame, electric lamps, photochemical reactions, and various reactions, such as explosives.

Due to their obvious advantages in terms of availability, safety, cleanliness, and remote energy generation, electric lamps have displaced all other man-made sources for lighting of the built environment. However, because man-made sources consume natural resources, natural light sources should be used to the greatest extent possible, and this remains one of the biggest challenges to architects and designers.

In practice, light sources can be discussed in terms of the qualities of the light they produce. These qualities are critical to the end result and need to be understood when choosing the source for a lighting design.

HOW LIGHT IS GENERATED

Most natural light, including moonlight, comes from the sun. Its origin makes it completely clean, and it consumes no natural resources while providing light. But man-made sources generally require some consumption of resources, such as burning fossil fuels, to ultimately convert stored energy into light energy. Electric lighting is superior to flame sources because the combustion of wood, gas, or oil produces pollution within the space being illuminated. Moreover, electricity can be generated from natural, renewable sources of energy, including wind, hydro, geothermal, and solar.

How an electric lamp operates determines virtually everything about the light created by it. The incandescent lamp generates light through the principle of incandescence, in which a metal is heated until it glows. Most other lamps, however, generate light by means of a complex chemical system in which electric energy is turned into light energy, where heat is a side effect. These chemical processes are usually a lot more efficient than incandescence is, despite their complexity and other limitations. For instance, a fluorescent lamp generates light by a discharge of energy into a gas, which in turn emits ultraviolet radiation that is finally converted to visible light by minerals that fluoresce, or glow brightly This process generates light about 400 percent more efficiently than incandescence and is the reason that various fluorescent lamps were promoted as environmentally

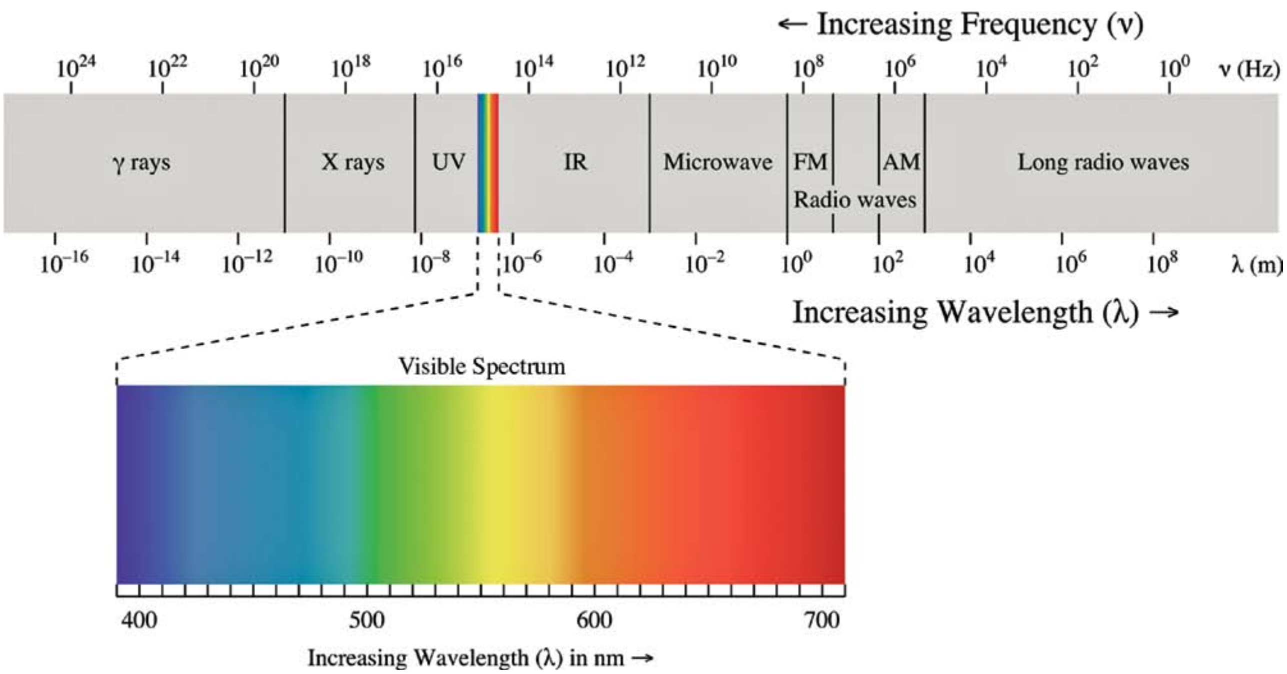

Fig. 3.1 Electromagnetic Radiation Spectrum Diagram with Visible Spectrum Enlarged
(Illustration: Philip Ronan, creativecommons.org/licenses/by-sa/3.0/)

friendly. Light-emitting diode (LED) lamps are unique—they are called "solid state lighting" because light is generated by principles of quantum physics derived from the simple electrical diode. LED offers outstanding efficiency, sustainability, and, best of all, the ability to generate useful light from simple power systems, such as photovoltaic (PV) panels and storage batteries.

HOW THE EYE SEES

To understand the importance of why a quality light source should be selected, it is necessary to be aware of how the human eye works and how it sees color.

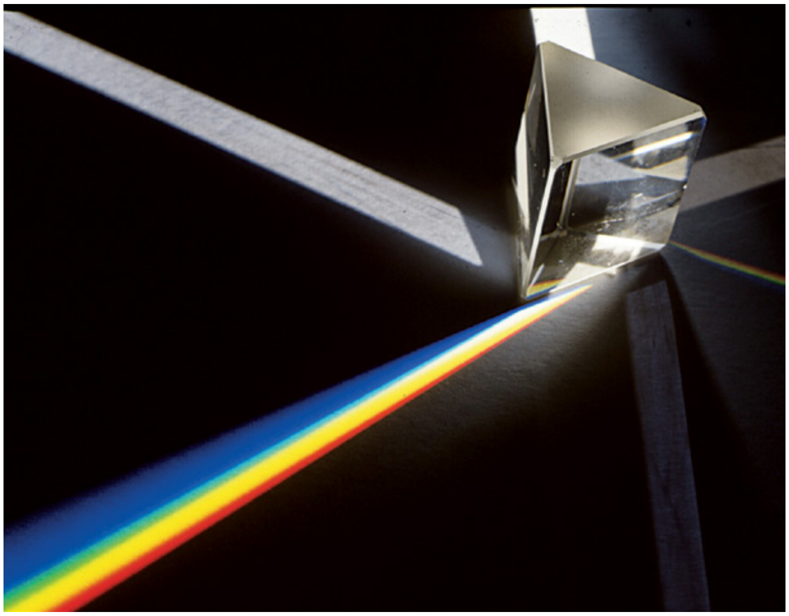

Fig. 3.2 A Prism Refracts White Light into the Full Spectrum of Visible Colors
(Photograph: Adam Hart-Davis)

Spectrum of Light

As shown in Figure 3.1, light is a part of the electromagnetic radiation spectrum. Light encompasses a small portion of that spectrum and has wavelengths in a range from about 380 (violet) to 740 (red) nanometers (nm).

The full spectrum of light can be seen in a rainbow or from a prism (see Fig. 3.2), and it includes all of the visible colors. As Sir Isaac Newton discovered through his experiments with prisms, white light from the sun is made up of all the wavelengths combined.

As we do with pigment color, we tend to organize light color into three primaries (red, green, and blue) and three secondaries (yellow, cyan, and magenta). When the three primaries are overlapped, they create white light, as shown in Figure 3.3.

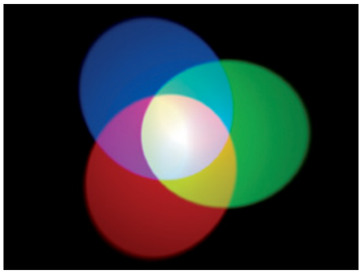

Fig. 3.3 Three Primary Colors of Light—Red, Green, and Blue

When white light hits an object, the object will absorb all of the wavelengths that match its own atomic structure and reflect the rest back to our eyes, as shown in Figure 3.4. The reflected light passes through the cornea into the pupil, which expands and contracts based on how much light is available. The time this adjustment takes varies depending on the age of person and how quickly the light level changes in the surrounding space. It is very important to design transitions between high and low light levels so vision is not impaired. Once the light hits the lens, it is focused back to the retina. The retina contains light receptors called "rods" and "cones," which convert the light into signals the brain can interpret (see Fig. 3.5). The eye sees the wavelength or combination of wavelengths, and the brain translates it into a color.

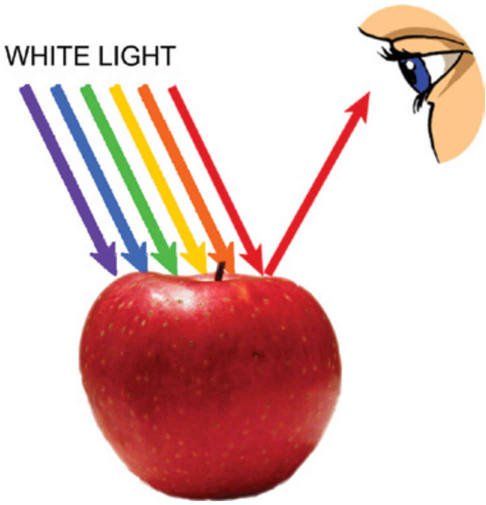

Fig. 3.4 Wavelength Absorption and Reflection

LIGHT SOURCE SELECTION

As can be imagined, the more saturated a white light source is with the full spectrum of wavelengths, the more accurately the eye and brain will be able to interpret the true color of an object. Looking at Figure 3.4, if the artificial light source were weak in red wavelengths, the object would appear muted or less vibrant, because fewer wavelengths are available to reflect back to the eye. Artificial light sources are measured in two very important ways—color rendering index (CRI) and color temperature—to assist designers in making selections.

Color Rendering Index

The CRI describes the quality of a light source on a scale of 0 (horrible) to 100 (perfect). This measurement illustrates the ability of the light source to render the color of objects naturally or realistically, as compared with a reference source with a comparable color temperature (either incandescent light or daylight, both having a CRI of 100). Generally, the more wavelength-saturated the source is, the higher the CRI will be. Figure 3.6 shows the same objects under two different light sources with different CRI values. The higher CRI value renders the colors more accurately, which is important in most interior spaces.

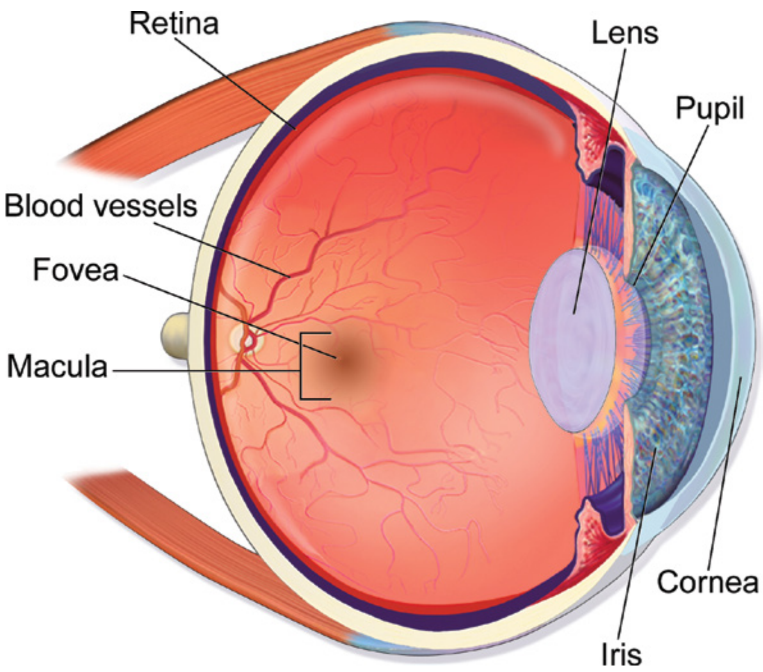

Fig. 3.5 Eye Anatomy

The CRI is calculated by illuminating eight standard colors samples selected by the International Commission on Illumination with the reference and the tested light source. The resulting color differences from the two sources are averaged together. The smaller the average is, the higher the CRI will be. Generally, because the published CRI is an average, the number does not inform the designer about how well a light source will illuminate a specific color. In more critical applications, such as an art museum or high-end retail store, reviewing each color test result is important to ensure the objects are properly illuminated. Also, an expanded set of color samples has been added to address saturated colors, skin tone, and foliage (see Fig. 3.7).

Color Temperature

The color temperature of a light source describes whether the light appears warm, neutral, or cool. The higher the temperature, the whiter or cooler the light source appears. The term "temperature" refers to the light emitted from a metal object heated to the point of incandescence. The heated metal begins as a red glow, then yellow, white, and eventually blue. The track of this temperature increase is called the "black-body curve" and characterizes the various light color temperatures in degrees kelvin (K). As an example, the color temperature

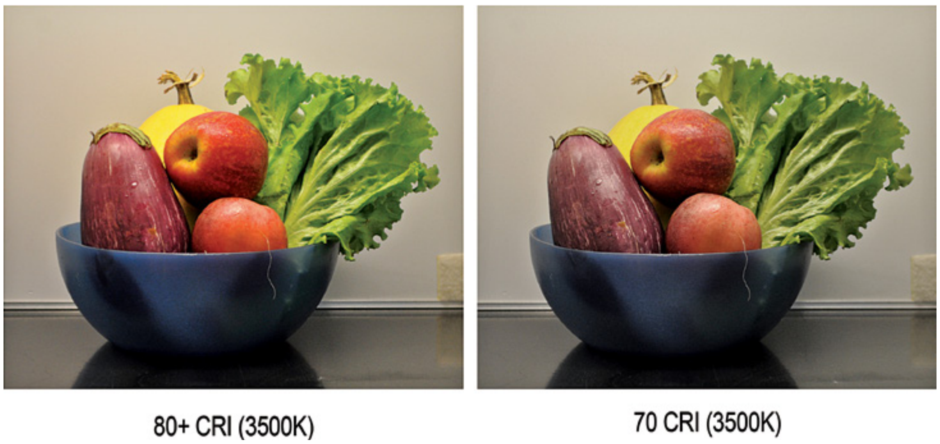

Fig. 3.6 Objects under Two Light Sources with Varying Color Rendering Indexes

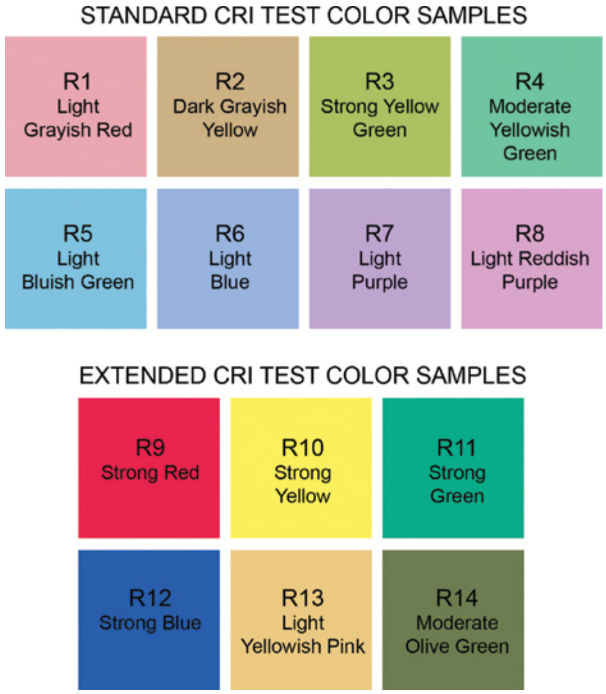

Fig. 3.7 Color Rendering Index Color Chart

Electrician's Notebook

Because use of LEDs is now common, a new system for testing the color rendering was developed in 2015 by the Illuminating Engineering Society of North America (IESNA). The need for this system was driven by the inconsistency between LEDs with similar CRIs and color temperatures. The new testing method, IESNA Testing Method 30 (TM-30), has expanded from testing the original 8 or 14 to test 99 colors. In addition to more colors, the differences in hue and saturation are indicated.

As shown in Figure 3.8, the results are charted on a color space chart, which graphically shows how the tested source compares to the reference source. The graph illustrates how the light source shifts in color or saturation based on the plotted points of the

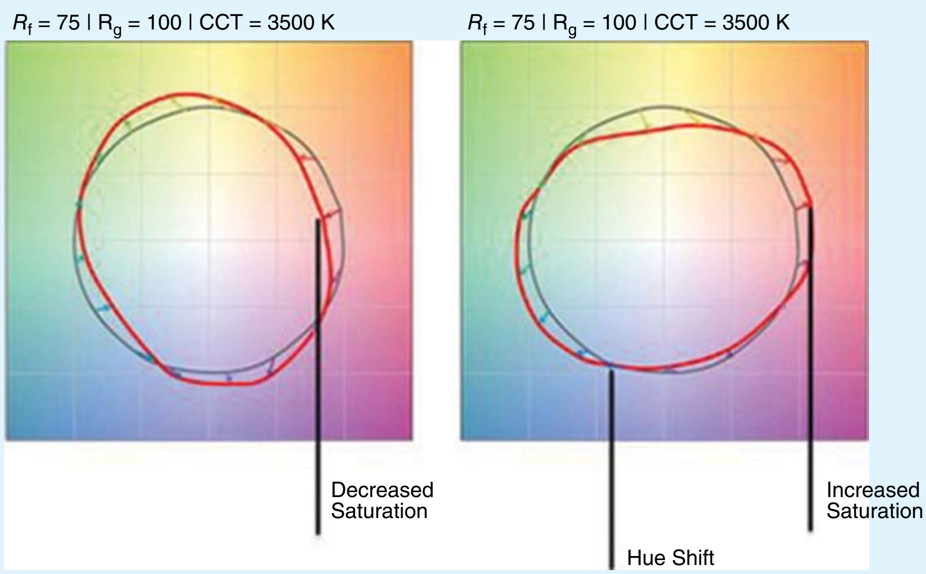

Fig. 3.8 Comparison of Two Sources Using TM-30 Color Space