Interior Lighting

Wout van Bommel

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Fundamentals, Technology and Application

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Dedicated to my former lighting teachers, Prof. Nito de Boer (†), Prof. Jochen Schmidt-Clausen and Prof. Dietert Fischer (†), who gave me lots of trust, motivation and opportunities and to Hari Mamak (†) and Prof. Tai-Ming Zhou who were instrumental in creating challenging teaching opportunities for me in Asia.

Preface

This book outlines the underlying principles on which interior lighting should be based for arriving at good visual performance, comfort, alertness and health for the users of the lit space. It is the first interior lighting book in which the visual and non-visual biological effects of lighting are dealt with on an equal footing. Around the same time that solid-state lighting (LED lighting) was introduced, some 20 years ago, we began to learn that lighting has apart from visual effects also far-reaching non-visual biological effects. These effects influence the way our body "operates" and, therefore, influence our health, well-being and alertness. Interior lighting installations today have to be designed so that they can provide both suitable visual and non-visual biological effects. Lighting that indeed does this is referred to as human-centric lighting. This book gives all the fundamental and practical information needed to design human-centric lighting installations.

The introduction of solid-state light sources has provided the possibility to design innovative, truly sustainable lighting installations which are adaptable to changing circumstances. The design of such solid-state lighting installations is more difficult than it was with gas discharge lamps. To avoid disappointments with LED lighting installations, detailed knowledge of the typical characteristics of the many different solid-state light sources is essential. Already long-available information on vision and colour seeing has to be combined with entirely new fundamental research on the relationship between lighting on the one hand and vision, performance, comfort, health and well-being on the other hand.

LEDs offer the possibility to use them not only for lighting but also for data transmission. LEDs can, therefore, be used as the heart of the Internet of Things (IoT). Here, data communication is combined with microsensor technology to create connected smart environments. The use of LED lighting as a means for data communication is referred to as "light beyond illumination". Visible light communication (VLC), LiFi and light itself used as sensor are part of this subject. The modern lighting professional has to get familiarised with these new technologies and applications.

The book is divided into three parts. Part I discusses the fundamentals of the visual and non-visual mechanisms and the practical consequences for visual performance and comfort, for sleep, for health and for alertness. It includes chapters on shift work, on therapeutic and hazardous effects of lighting and on the effect of the ageing eye. Part II, Technology, deals with the lighting hardware, lamps (with emphasis on LEDs), gear, drivers and luminaires, including chapters about smart connected lighting and light used for data communication (VLC and Li-Fi) and as sensor. It also has a chapter about daylight. Part III, the application part, provides the link between theory and practice and supplies the reader with the knowledge needed for lighting design. It describes the relevant lighting criteria for efficient interior lighting and discusses the international, European and North American standards for interior lighting. This part concludes with a chapter about interior lighting calculations and measurements.

I wish to record my gratitude to Prof. Steve Fotios for reviewing the entire manuscript and to Wang Shen for reviewing Chaps. 14 and 15.

For the lighting professional or student being active in both indoor and outdoor lighting, I refer to my book *Road Lighting: Fundamentals, Technology and Application* that was published in 2015 with Springer.

Nuenen, Noord-Brabant, The Netherlands Wout van Bommel

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About the Author

Wout van Bommel worked for more than 35 years with the head office of Philips Lighting in the Netherlands in different lighting application functions. He became responsible for the company's international lighting application know-how centre. He has carried out research into many different lighting subjects. Some concepts now used in international standards for lighting are based on his research work.

For the period 2003–2007, Wout van Bommel has been president of the International Lighting Commission (CIE). He was president and is now an honorary member of the Dutch "Light and Health Research Foundation" (SOLG).

Wout van Bommel was appointed consulting professor at the Fudan University of Shanghai in 2004 and external examiner of the Master Course "Light and Lighting" for the period 2008–2012 at the University College London (UCL-Bartlett Institute).

He has published many papers in national and international lighting journals in different languages. All over the world, he has presented papers, has taught at universities and schools and has given many invited lectures at conferences.

After his retirement from Philips Lighting, he advises lighting designers, researchers, companies and governmental bodies as an independent lighting consultant, this in addition to his lecturing and writing activities. In 2019, he was the first recipient of an award of the Dutch Lighting Society (NSVV) which got his name: the "Wout van Bommel Award".

Abbreviations

ANSI	American National Standards Institute
CEN	European Normalization Commission
CFL	Compact Fluorescent Lamp
CIE	International Lighting Commission
COB	Chip on Board
COG	Chip on Glass
CRM	Customer Relation Management
CS	Circadian Stimulus
DALI	Digital Addressable Lighting Interface
DLMO	Dim Light Melatonin Onset
DMX	Digital MultipleXed
DOE	Department of Energy (USA)
EC	European Commission
EEG	Electroencephalography (brain wave activity)
EOG	Electrooculogram (eye blinking pattern)
fMRI	Functional Magnetic Resonance Imaging
GLA	Global Lighting Association
GLF	Global Lighting Forum
GLS	General Lighting Service (Lamp)
GPS	Global Positioning System
GSQS	Groningen Sleep Quality Scale
HVAC	Heating, Ventilation and Air Conditioning
IARC	International Agency for Research on Cancer of the WHO
ICNIRP	International Commission on Nonionizing Radiation Protection
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IESNA	Illuminating Engineering Society of North America
IoT	Internet of Things
ipRGC	Intrinsic Photosensitive Retinal Ganglion Cell
IPS	Indoor Positioning System

ISO	International Organization for Standardization
KSS	Karolinska Sleepiness Scale
LED	Light-Emitting Diode
Li-Fi	Light Fidelity
LoS	Length of Stay (in a hospital)
MICI	Mean Indirect Cubic Illuminance
MRSE	Mean Room Surface Exitance
OLED	Organic Light-Emitting Diode
OOK	On-Off Keying (including: none-return-to-zero)
PAI	Perceived Adequacy of Illumination
PCB	Printed Circuit Board
PLC	Powerline Communication
PoE	Power Over Ethernet
PRC	Phase Response Curve
pRGC	Photosensitive Retinal Ganglion Cell
PSE	Power Supply Equipment
PSG	Polysomnography (recording of sleep parameters)
PSQI	Pittsburgh Sleep Quality Index
PVT	Psychomotor Vigilance Test
PWM	Pulse-Width Modulation
RDM	Remote Device Management
RF	Radio Frequency
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks of the European Union
SCN	Suprachiasmatic Nucleus or Nuclei (biological clock)
SMD	Surface-Mounted Device
SSL	Solid-State Lighting
SVS	Subjective Vitality Scale
SWSD	Shift Work Sleep Disorder
TAIR	Target Ambient Illuminance Ratio
TCP/IP	Transmission Control Protocol/Internet Protocol
TIR	Total Internal Reflection
TLA	Temporal Light Artefacts (caused by lamp flicker)
ToF	Time of Flight (of light)
VAS-e	Visual Assessment Scale for Energy (Lee)
VDU	Visual Display Unit
VLC	Visible Light Communication
VLP	Visible Light Positioning
WHO	World Health Organization
Zhaga	International Consortium developing interface specifications that enable interchangeability of LED light sources