

Contents

Part I Road Lighting	1
1 Purpose and Benefits of Road Lighting	3
References	5
2 Basic Lighting Quantities	7
2.1 Road-Surface Luminance for Motorized Traffic	7
2.2 Illuminance for Pedestrians, Cyclists and Residents	8
2.2.1 Horizontal and Hemi-spherical Illuminance	9
2.2.2 Vertical and Semi-cylindrical Illuminance	10
Reference	10
3 Visual Performance for Motorists	11
3.1 Object Contrast	11
3.1.1 Contrast and Contrast Threshold	11
3.1.1.1 Field Factor	13
3.1.1.2 Contrast Polarity	13
3.1.1.3 Adaptation Luminance Under Non-uniform Conditions	14
3.1.1.4 Background Luminance Under Non-uniform Conditions	15
3.1.1.5 Object Shape	15
3.1.2 Silhouette Principle of Road Lighting	16
3.1.3 Contrast and Glare	18
3.1.3.1 Disability Glare	18
3.1.3.2 Spectrum and Disability Glare	21
3.1.3.3 LEDs and Disability Glare	21
3.1.4 Contrast and Vertical Illuminance	21
3.1.4.1 Vertical Illuminance and Glare Restriction	21
3.1.4.2 Vertical Illuminance and Reflection from the Road Surface	22

3.2	Threshold Visibility	22
3.2.1	Revealing Power	22
3.2.2	Total Revealing Power	25
3.3	Supra-Threshold Visibility	27
3.3.1	Visibility Level	27
3.3.2	Small-Target Visibility	29
3.3.3	Relative Visual Performance	30
3.4	Visibility on Road Surrounds	33
3.5	Traffic Flow	35
3.6	Adverse Weather Conditions	37
3.6.1	Wet Weather	37
3.6.2	Snow	39
3.6.3	Fog	39
3.7	Fixed Road Lighting and Car Lights	39
3.7.1	Visibility of Objects on the Road	39
3.7.2	Glare from Oncoming Cars	40
3.8	Pedestrian Road Crossings	41
3.9	Optic Flow	43
3.10	Lighting, Brain Activity and Alertness	45
	References	46
4	Visual Comfort for Motorists	49
4.1	Lighting Level	49
4.2	Uniformity	50
4.2.1	Longitudinal Uniformity	50
4.2.2	Luminance Gradient	51
4.3	Glare	52
4.3.1	Discomfort Glare	52
4.3.2	Spectrum and Discomfort Glare	54
4.3.3	Discomfort from Glare Variation	55
4.3.4	LEDs and Discomfort Glare	56
	References	57
5	Visual Performance, Comfort and Pleasantness for Pedestrians, Cyclists and Residents	59
5.1	Visual Performance	59
5.1.1	Safety	59
5.1.2	Security	60
5.1.3	Visual Orientation and Guidance	64
5.2	Visual Comfort and Pleasantness	65
5.2.1	Spatial Brightness	66
5.2.2	Colour Quality of Light	66
5.2.3	Discomfort Glare	67
5.2.4	Impact During Daytime	67

5.3	Lighting Level, Uniformity and Glare Restriction	68
	References	69
6	Mesopic Vision	71
6.1	Spectral Eye Sensitivity	71
6.2	On-Line and Off-Line Vision	73
6.3	S/P Ratio of Light Sources	74
6.4	Adaptation Luminance	76
6.5	Correction Factors for Photometric Quantities	77
6.5.1	Peripheral Task Performance	77
6.5.1.1	CIE Correction Factors	77
6.5.1.2	Consequences for Road Lighting Practice	79
6.5.2	Brightness	80
6.5.2.1	Models for Brightness Prediction	80
6.5.2.2	Consequences for Road Lighting Practice	80
	References	81
7	Age Effects	83
7.1	Age and the Visual Mechanism	83
7.2	Age and Visual Performance	88
	References	88
8	Lighting Quality Parameters	89
8.1	Motorized Traffic	90
8.1.1	Lighting Level	90
8.1.2	Uniformity	91
8.1.3	Lighting of the Surrounds	91
8.1.4	Glare Restriction	92
8.1.5	Summary	92
8.2	Pedestrians, Cyclists and Residents	93
8.2.1	Lighting Level	93
8.2.2	Uniformity	93
8.2.3	Lighting of the Surrounds	94
8.2.4	Glare Restriction	94
8.2.5	Summary	95
8.3	Spectrum of Light	95
	References	96
9	Standards and Recommendations	97
9.1	CIE Recommendation	97
9.1.1	Lighting of Motorized-Traffic Routes	98
9.1.2	Lighting of Conflict Areas	99
9.1.3	Lighting for Pedestrians and Low-Speed Traffic	99
9.1.4	Spectrum of Light	101
9.1.5	Adaptive Lighting	102

9.2	European Standard	102
9.2.1	Lighting for Motorized Traffic Routes	102
9.2.2	Lighting of Conflict Areas	103
9.2.3	Lighting for Pedestrians and Low-Speed Traffic	104
9.2.4	Spectrum of Light	105
9.2.5	Adaptive Lighting	105
9.3	North American Standard	106
9.3.1	Lighting for Roads with Motorized Traffic	106
9.3.2	Lighting for Intersections	107
9.3.3	Lighting for Pedestrian Areas and Bikeways	107
9.3.4	Pedestrian Crossings	108
9.3.5	Spectrum of Light	108
9.3.6	Adaptive Lighting	108
	References	109
10	Equipment: Lamps and Gear	111
10.1	Performance Characteristics	113
10.1.1	Survey of Lamp Properties	113
10.1.2	System Efficacy	113
10.1.3	Lifetime and Lumen Depreciation	114
10.2	Gas Discharge Lamps	116
10.2.1	Principle	116
10.2.2	Low-Pressure Sodium Lamps	118
	10.2.2.1 Construction	118
	10.2.2.2 Lamp Properties	119
10.2.3	High-Pressure Sodium Lamps	120
	10.2.3.1 Construction	120
	10.2.3.2 Lamp Properties	121
10.2.4	Tubular-Fluorescent Lamps	122
10.2.5	Compact Fluorescent Lamps	122
	10.2.5.1 Construction	122
	10.2.5.2 Lamp Properties	123
10.2.6	Induction Lamps	124
	10.2.6.1 Construction	125
	10.2.6.2 Lamp Properties	125
10.2.7	High-Pressure Mercury Lamps	126
	10.2.7.1 Construction	126
	10.2.7.2 Lamp Properties	127
10.2.8	Metal Halide Lamps	128
	10.2.8.1 Construction	128
	10.2.8.2 Lamp Properties	129
10.3	Solid-State Light Sources	131
10.3.1	Principle	131
	10.3.1.1 Light Emission	131
	10.3.1.2 White Light	132

10.3.2	LEDs	134
10.3.2.1	Construction	134
10.3.2.2	Lamp Properties	137
10.4	Control Gear	139
10.4.1	Igniters for Gas-Discharge Lamps	139
10.4.2	Ballasts for Gas-Discharge Lamps	140
10.4.3	Drivers for LEDs	142
10.4.4	Dimmers	143
10.4.4.1	Gas-Discharge Lamps	143
10.4.4.2	Solid-State Light Sources	144
10.4.5	Power Quality	145
10.4.5.1	Harmonic Distortion	145
10.4.5.2	Power Factor	146
10.4.6	Electromagnetic Interference	147
	References	147
11	Equipment: Luminaires	149
11.1	Photometric Characteristics	150
11.1.1	Light Distribution and Light-Output Ratio	150
11.1.2	Luminaire Classification	154
11.2	Optical Characteristics	156
11.2.1	Reflectors	156
11.2.2	Refractors and Lenses	158
11.2.3	Diffusers	158
11.3	Mechanical Characteristics	159
11.3.1	Material	159
11.3.2	Strength	159
11.3.3	Dirt and Humidity Protection	160
11.3.4	Installation and Maintenance	160
11.4	Electrical Characteristics	161
11.5	Thermal Characteristics	162
11.6	Safety Approval	163
11.7	Aesthetical Characteristics	163
11.8	Smart Luminaires	163
	References	163
12	Equipment: Road Surfaces	165
12.1	Road-Surface Reflection Table	165
12.2	Description System	168
12.3	Classification System	171
12.4	Influence of Spectrum of Light	173
12.5	Wet Road Surfaces	174
12.6	Q_0 and Visual Performance	177
12.7	Acquirement of Reflection Data	178
12.7.1	Laboratory Measurements	178

12.7.2	In-situ Measurements	178
12.7.3	Comparison of Materials and Construction Methods	179
	References	179
13	Design Aspects	181
13.1	Lighting Arrangements	183
13.1.1	Effective Road Width	184
13.1.2	Single-Sided Arrangement	185
13.1.3	Staggered Arrangement	185
13.1.4	Opposite Arrangement	186
13.1.5	Central Arrangement	186
13.1.6	Twin-Central Arrangement	187
13.1.7	Irregular Arrangement	187
13.1.8	Catenary Installation	187
13.1.9	High-Mast Lighting	188
13.2	Mounting Height and Spacing	189
13.3	Visual Guidance	190
13.4	Bad-Weather Lighting	192
13.4.1	Wet Weather	192
13.4.2	Foggy Weather	194
13.4.3	Snowy Weather	195
13.5	Maintenance	195
13.6	Lighting Control	198
13.7	Light Pollution	200
13.8	Sustainability	201
13.9	Master Planning	202
	References	203
14	Calculations and Measurements	205
14.1	Calculation Conventions	205
14.1.1	Calculation Points	206
14.1.2	Observer Position	207
14.1.2.1	Longitudinal Position	207
14.1.2.2	Transversal Position	208
14.2	Measurements	210
14.2.1	Light Detectors	210
14.2.1.1	Types	210
14.2.1.2	$V(\lambda)$ Correction	212
14.2.1.3	Cosine Correction	213
14.2.1.4	Pulsed Light Measurement	213
14.2.1.5	Ambient Influences	213
14.2.1.6	Age Effects	214
14.2.1.7	Accuracy	214
14.2.2	Measuring Lamps	214
14.2.2.1	Luminous Flux	214

14.2.2.2	Spectral Data	216
14.2.3	Measuring Luminaires	217
14.2.3.1	Light Distribution	217
14.2.3.2	Light Output	219
14.2.4	Measuring Road Surfaces	219
14.2.4.1	Laboratory Measurements	220
14.2.4.2	Field Measurements	221
14.2.5	Measuring Installations	224
14.2.5.1	Illuminance and Luminance Measurements ..	224
14.2.5.2	Glare Measurements	227
14.2.5.3	External Influences	228
References	229
Part II	Light Pollution	231
15	Purpose of Light-Pollution Restriction	233
15.1	Balance of Positive and Negative Effects	233
15.2	Disturbing Effects	234
15.2.1	Residents	234
15.2.2	Motorised and Slow-Moving Traffic	234
15.2.3	Astronomers	235
15.2.4	Wildlife	236
15.2.5	Vegetation	238
References	238
16	Light-Pollution Parameters	241
16.1	Parameter Categories	242
16.2	Installation-Bound Parameters	242
16.2.1	Parameters used by CIE	242
16.2.1.1	Upward Light Ratio ULR	242
16.2.1.2	Upper Flux Ratio UFR	243
16.2.1.3	Luminous Intensities Near the Horizontal ...	245
16.2.2	Parameters Used by IDA-IESNA	245
16.2.2.1	Total Initial Luminaire Luminous Flux	245
16.2.2.2	Virtual Flux Ratio	246
16.2.2.3	Virtual Vertical Illuminance	246
16.2.2.4	BUG Luminaire Classification	247
16.3	Disturbed-Area-Bound Parameters	248
16.3.1	Parameters Used by CIE	248
16.3.1.1	Vertical Illuminance on Facades	248
16.3.1.2	Luminous Intensity	249
16.3.1.3	Facade Luminance	249
16.3.1.4	Veiling Luminance	250

16.4	Summary	251
16.4.1	CIE Parameters	251
16.4.2	IDA-IESNA Parameters	251
	References	252
17	Standards and Recommendations	253
17.1	Environmental Zones and Curfew	253
17.2	CIE Guide	254
17.3	European Standards	256
17.4	North-American Recommendations	256
17.4.1	IDA-IESNA Ordinance for Road Lighting	257
17.4.2	IDA-IESNA Ordinance for Sports, Area and Architectural Lighting	257
17.4.2.1	Limit of Luminous Flux	258
17.4.2.2	Limit of BUG Ratings	258
17.4.2.3	Limit of Lighting on Surfaces of Virtual Enclosure	258
17.5	Spectrum of Light	259
	References	260
18	Equipment and Design Aspects	261
18.1	Equipment	261
18.1.1	Lamps	261
18.1.2	Luminaires	262
18.1.3	Road Surfaces	262
18.1.4	Lighting Control Systems	263
18.2	Design aspects	264
18.2.1	Design to Satisfy Functional Requirements	264
18.2.2	Mounting Height and Aiming	264
18.2.3	Embedded Light	265
18.2.4	Spectrum of Light	265
18.2.5	Screening by Structures and Trees	266
	References	266
Part III	Tunnel Lighting	267
19	Purpose and Benefits of Tunnel Lighting	269
	References	271
20	Visual Performance and Sense of Confidence	273
20.1	Tunnel Zones	273
20.2	Threshold Zone	275
20.2.1	Daytime Luminances in the Access Zone	275
20.2.2	Symmetrical, Counter-Beam and Pro-Beam Lighting ...	275
20.2.3	Influence of Traffic Speed	279

20.2.3.1	Adaptation State	279
20.2.3.2	Atmospheric Scattering	280
20.2.3.3	Difficulty of Driving Task	280
20.2.4	Uniform Field-Luminance Concept	280
20.2.5	L_{20} Concept	281
20.2.6	Veiling-Luminance Concept	282
20.2.7	Length of Threshold Zone	286
20.2.8	Sense of Confidence	286
20.3	Transition Zone	288
20.4	Interior Zone	290
20.5	Exit Zone	291
20.6	Uniformity and Glare Restriction	292
20.7	Flicker	292
20.8	Night-Time Lighting	294
20.9	Emergency Lighting	294
20.10	Short Tunnels and Underpasses	295
20.10.1	Short Tunnels for Motorised Traffic	295
20.10.2	Underpasses for Pedestrians and Cyclists Only	298
	References	298
21	Standards and Recommendations	301
21.1	CIE Recommendation	301
21.1.1	Threshold Zone	301
21.1.2	Transition Zone	303
21.1.3	Interior Zone	303
21.1.4	Exit Zone	303
21.1.5	Uniformity and Glare Restriction	303
21.1.6	Restriction of Flicker	304
21.1.7	Switching Steps	304
21.1.8	Night-Time Lighting	304
21.1.9	Short Tunnels	304
21.2	European Report	305
21.3	North American Standard	306
21.3.1	Threshold Zone	306
21.3.2	Transition Zone	307
21.3.3	Interior Zone	307
21.3.4	Exit Zone	307
21.3.5	Uniformity and Glare Restriction	307
21.3.6	Restriction of Flicker	308
21.3.7	Switching Steps	308
21.3.8	Night-Time Lighting	308
21.3.9	Short Tunnels	308
	References	308

22 Equipment and Design Aspects	309
22.1 Lamps and Gear	309
22.2 Luminaires	311
22.3 Daylight Screens	312
22.4 Road and Wall Surface	313
22.5 Design Aspects	313
22.5.1 Tools for the Determination of L_{20} and L_{seq}	314
22.5.1.1 Determination of L_{20}	314
22.5.1.2 Determination of L_{seq}	315
22.5.2 Lighting Arrangement	315
22.5.3 Daylight Variation and Lighting Control	317
22.5.4 Maintenance	318
References	318
Appendix	319
Appendix A Illuminance Formulas	319
Horizontal illuminance, E_{hor}	319
Vertical illuminance, E_{vert}	319
Semi-cylindrical illuminance, $E_{semi-cyl}$	319
Hemispherical illuminance, $E_{hemisphere}$	320
Appendix B Visibility Formulas	320
Contrast Threshold	320
Contrast Threshold, C_{th}	320
Contrast Polarity Factor, F_{cp}	321
Age Factor, AF	321
Observation Time Factor, T_{obs}	321
Visibility Level	322
Visibility Level, VL	322
Small Target Visibility, STV	322
Relative Visual Performance	322
Appendix C Calculation of Q_0 from R-tables	324
Index	327

Road Lighting

Fundamentals, Technology and Application

van Bommel, W.

2015, XXI, 334 p. 193 illus., 59 illus. in color., Hardcover

ISBN: 978-3-319-11465-1