Design of Roadway Lighting (TAC Ottawa Spring 2007)

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Today's Presentation Goals

- Provide overview of concepts and principals in new TAC Roadway Lighting Design Guide
- Review new design concepts and principals
- Give opinion of new technologies and products
- Respond to issues and questions

Todays Agenda

8AM to 8:15AM - Introductions

8:15AM to 8:30AM - Value of Lighting

8:30AM to 9:30AM - Vision Fundamentals and Concepts

9:30AM to 9:45AM - Obtrusive Light (discuss issues and IESNA “LCS" system)

9:45AM to 10:00AM - Break

10:00AM to 10:15AM - Design Process Overview

10:15AM to 11:00AM - System Components (types of lighting, luminaires, lamp , ballasts, LED's, high-mast, pole placement (clear zone), etc)

11:00AM to 11:30AM - New concepts (adaptive lighting, LED's, induction lighting, etc)

11:30AM to noon - General discussions and questions

Noon to 1:00PM - Lunch

1:00PM to 1:30PM - Calculation Examples

1:30PM to 2:00PM – Roadways and Vertical Illumination

2:00PM to 2:15PM - Break

2:15PM to 2:30PM - Roadways

2:30PM to 3:30PM - Other Lighting Applications (roundabouts, mid block crosswalks, rail crossings, tunnels, etc)

3:30PM to 4:00PM - General discussion and questions

Reference

- Transportation Association of Canada Roadway Lighting Design Guide
- Illumination Engineering Society of North America (IESNA)
- AASHTO Roadway Lighting Design Guide (new)
- International Dark Sky (IDA)
- Canadian Electrical Code (Part I and Part II)
- International Commission on Illumination (CIE)
- International Municipal Signal Association (IMSA) – Roadway Lighting Level 2 Study Guide

TAC Background

Original Roadway Lighting Design Guide published in 1983. New Guide published in 2006. In preparing the current guide we:

- Undertook a review of standards and research from around the world
- Obtained standards from Canadian governments
- Reviewed practices of the International Commission on Illumination (CIE Europe), Illuminating Engineering Society (IES), AASHTO, FHWA, CSA, Institute of Lighting Engineers (England)
- Consulted members of the IES Roadway Lighting Committee
- Reviewed new technologies and concepts (ie; LED's, adaptive lighting, solar, etc)
- Developed and refined new lighting applications (ie; roundabouts, mid-block crosswalks, etc)

Value of Lighting

Why Light

- Reduces glare effects from oncoming vehicle headlamps
- Improves visibility for drivers
- Improves visibility for pedestrians and cyclists
- Provides a level of comfort and feeling of security

Value and Benefits of Lighting

- 20 year FHWA study showed lighting had the highest $ benefit for each $ spent
- Studies show lighting reduces collisions up to 40%
- Studies show lighting reduces pedestrian fatalities 45% to 80%

Death Statistics in US

People Saving People
http://www.nhtsa.dot.gov

Top 10 Leading Causes of Death in the United States for 2001, by Age Group[1]

NCSA
National Center for Statistics and Analysis

RANK	Cause and Number of Deaths											Years of Life Lost[2]
	Infants Under 1	Toddlers 1-3	Young Children 4-7	Children 8-15	Youth 16-20	Young Adults 21-24	Other Adults 25-34	Other Adults 35-44	Other Adults 45-64	Elderly 65+	All Ages	
1	Perinatal Period 13,734	Congenital Anomalies 496	MV Traffic Crashes 533	MV Traffic Crashes 1,546	MV Traffic Crashes 5,979	MV Traffic Crashes 4,136	MV Traffic Crashes 6,759	Malignant Neoplasms 16,569	Malignant Neoplasms 139,785	Heart Disease 582,730	Heart Disease 700,142	Malignant Neoplasms 23%(8,614,131)
2	Congenital Anomalies 5,513	MV Traffic Crashes 421	Malignant Neoplasms 400	Malignant Neoplasms 829	Homicide 2,414	Homicide 2,738	Homicide 5,204	Heart Disease 13,326	Heart Disease 98,885	Malignant Neoplasms 390,214	Malignant Neoplasms 553,768	Heart Disease 22%(8,110,571)
3	Heart Disease 479	Accidental Drowning 393	Exposure to Smoke/Fire 178	Suicide 447	Suicide 1,879	Suicide 1,924	Suicide 5,070	MV Traffic Crashes 6,891	Stroke 15,518	Stroke 144,486	Stroke 163,538	MV Traffic Crashes 5%(1,700,952)
4	Homicide 332	Homicide 362	Congenital Anomalies 168	Homicide 391	Malignant Neoplasms 814	Accidental Poisoning 771	Malignant Neoplasms 3,994	Suicide 6,635	Diabetes 14,913	Chronic Lwr. Resp. Dis. 106,904	Chronic Lwr. Resp. Dis. 123,013	Stroke 5%(1,687,683)
5	Septicemia 312	Malignant Neoplasms 321	Accidental Drowning 164	Congenital Anomalies 324	Accidental Poisoning 566	Malignant Neoplasms 768	Heart Disease 3,160	HIV 5,867	Chronic Lwr. Resp. Dis. 14,490	Influenza/ Pneumonia 55,518	Diabetes 71,372	Chronic Lwr. Resp. Dis. 4%(1,444,745)
6	Influenza/ Pneumonia 299	Heart Disease 200	Homicide 133	Accidental Drowning 293	Heart Disease 398	Heart Disease 543	Accidental Poisoning 2,507	Accidental Poisoning 5,036	Chronic Liver Disease 13,009	Diabetes 53,707	Influenza/ Pneumonia 62,034	Suicide 3%(1,079,822)
7	MV Traffic Crashes 139	Exposure to Smoke/Fire 170	Heart Disease 82	Heart Disease 273	Accidental Drowning 326	Accidental Drowning 211	HIV 2,101	Homicide 4,268	Suicide 9,259	Alzheimer's 53,245	Alzheimer's 53,852	Perinatal Period 3%(1,070,154)
8	Nephritis/ Nephrosis 133	Septicemia 96	MV NonTraffic Crashes 51	Exposure to Smoke/Fire 140	Congenital Anomalies 244	Congenital Anomalies 206	Stroke 601	Chronic Liver Disease 3,336	MV Traffic Crashes 8,750	Nephritis/ Nephrosis 33,121	MV Traffic Crashes 42,443	Diabetes 3%(1,014,201)
9	Stroke 108	Influenza/ Pneumonia 92	Benign Neoplasms 46	MV NonTraffic Crashes 125	Accidental Falls 114	HIV 167	Diabetes 595	Stroke 2,491	HIV 5,437	Septicemia 25,418	Nephritis/ Nephrosis 39,480	Homicide 3%(924,263)
10	Meningitis 78	Perinatal Period 63	Septicemia 33	Chr. Lwr. Resp. Dis. 102	Acc. Dischg. Of Firearms 114	Accidental Falls 134	Congenital Anomalies 458	Diabetes 1,958	Nephritis/ Nephrosis 5,106	Hypertension Renal Dis. 16,397	Septicemia 32,238	Chronic Liver Disease 2%(623,998)
ALL[3]	27,568	4,288	2,703	6,672	15,851	14,940	41,683	91,674	412,204	1,798,420	2,416,425	All Causes 100%(36,866,317)

[1]When ranked by specific ages, motor vehicle crashes are the leading cause of death for age 2 and every age 4 through 33.
[2]Number of years calculated based on remaining life expectancy at time of death; percents calculated as a proportion of total years of life lost due to all causes of death.
[3]Not a total of top 10 causes of death.

Source: National Center for Health Statistics (NCHS) CDC, Mortality Data 2001

Note: The cause of death classification is based on the National Center for Statistics and Analysis (NCSA) Revised 68 Cause of Death Listing. This listing differs from the one used by the NCHS for its reports on leading causes of death by separating out unintentional injuries into separate causes of death, i.e., motor vehicle traffic crashes, accidental falls, motor vehicle nontraffic crashes, etc. Accordingly, the rank of some causes of death will differ from those reported by the NCHS. This difference will mostly be observed for minor causes of death in smaller age groupings.

Public Expectations for Roadway Lighting

- Aid in police protection & enhanced sense of personal security
- Facilitate traffic flow
- Promote use of business & public facilities during the night hours

Issues

Energy Consumption

- Avoid over-design – Too much light can reduce visibility
- Luminaire efficiency (UPD) – Choose efficient luminaires
- Adaptive controls – Vary lighting levels during off peak periods

Obtrusive Light (Light Trespass)

- Spill light, glare and sky-glow
- Growing concern leading to local ordinances (bylaws)

Local Ordinances (Bylaws)

- Gaining use in US
- Can restrict lighting in specific scenarios
- Some good and some bad

Warrants

"Warrants indicate probable need, but should not be interpreted as an absolute indication of whether lighting should or should not be required. The need for lighting on any transportation facility should be determined under the direction of a qualified professional engineer knowledgeable in roadway lighting."

Warrant system in TAC is dated

Human Factors

- Our vision is reduced in hours of darkness – Daytime vision of 20/20 can be reduced to 20/40 at night.
- As we get older contrast sensitivity is reduced.
- As we age our visibility is reduced – As we get older less light penetrates the eye.
- Older drivers are more susceptible to glare
- Glaucoma can reduce peripheral vision.

Human Factors – We are all getting older

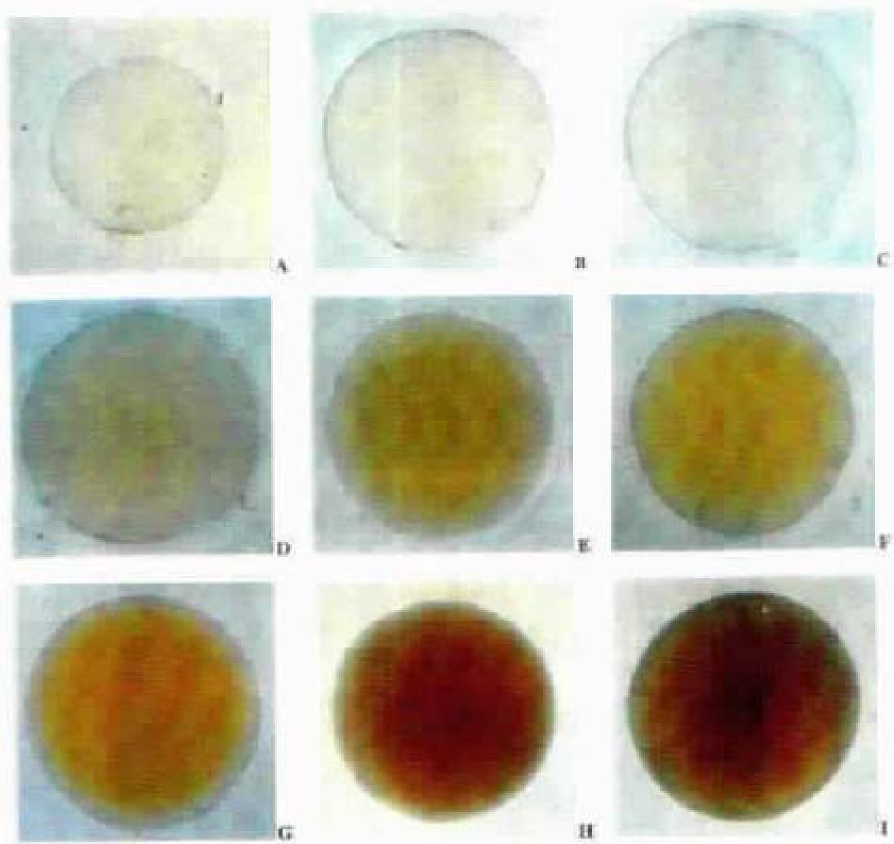


Fig. 3 Yellowing and transparency of the Human Lens from 6 month (A) to 8 years (B), 12 years (C), 25 years (D), 47 years (E), 60 years (F), 70 years (G), 82 years (H) and 91 years (I) of age.

Human Factors

Melatonin Regulation

- Our bodies produce melatonin in darkness
- Research shows spill light can impact our bodies ability to produce melatonin.
- Melatonin suppression has been linked to many diseases including Cancer

Alternatives to lighting

In applications where pedestrians and cyclists are not present:

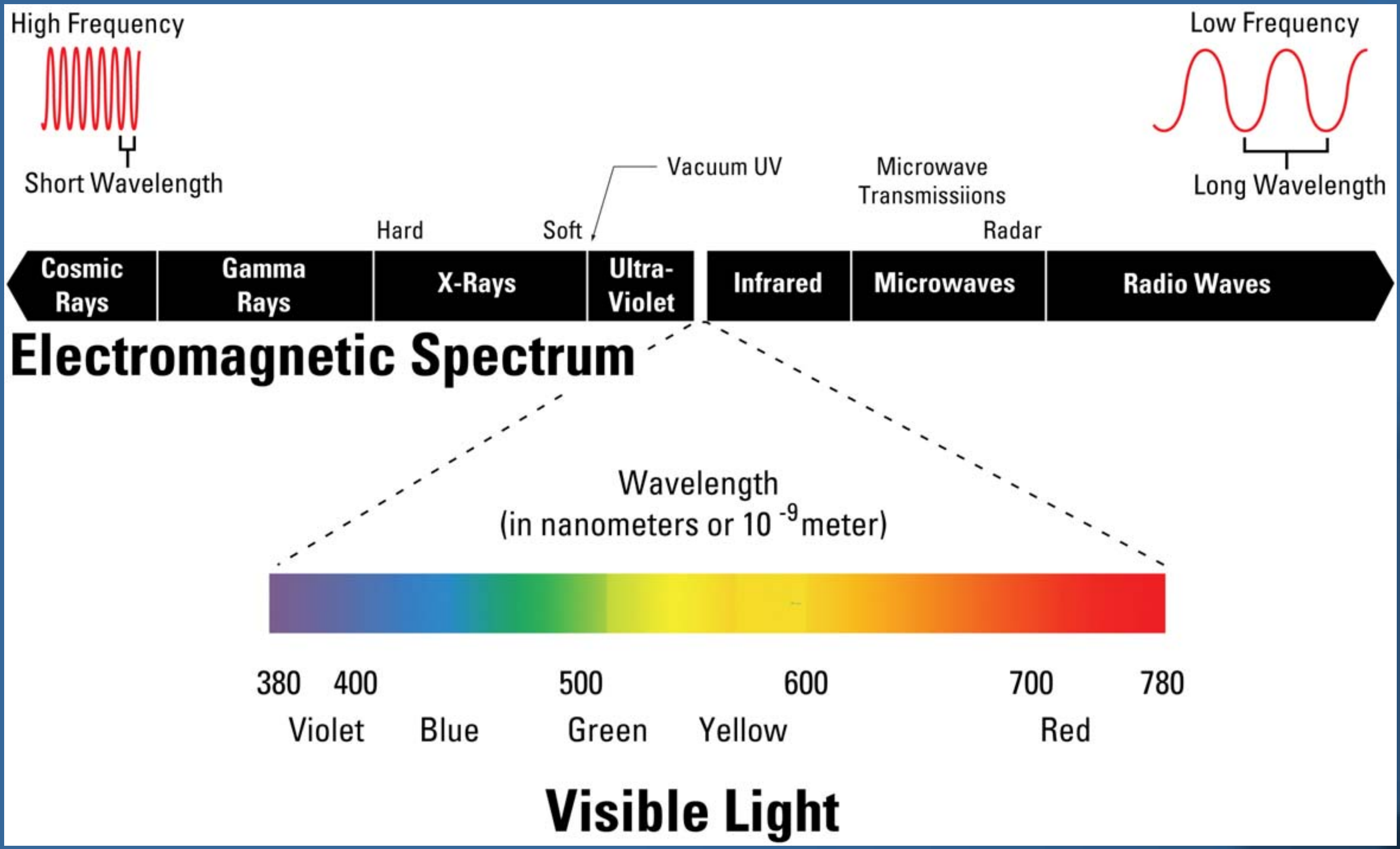
- Retro-reflective markings can improve visibility over traditional paint and glass beads
- Raised pavement markings (RPM's) can improve visibility
- Reflectors can reduce conflicts with wildlife
- Retro-reflective sign sheeting products can mitigate the need for sign lighting

Alternatives to lighting

Vision Fundamentals and Concepts

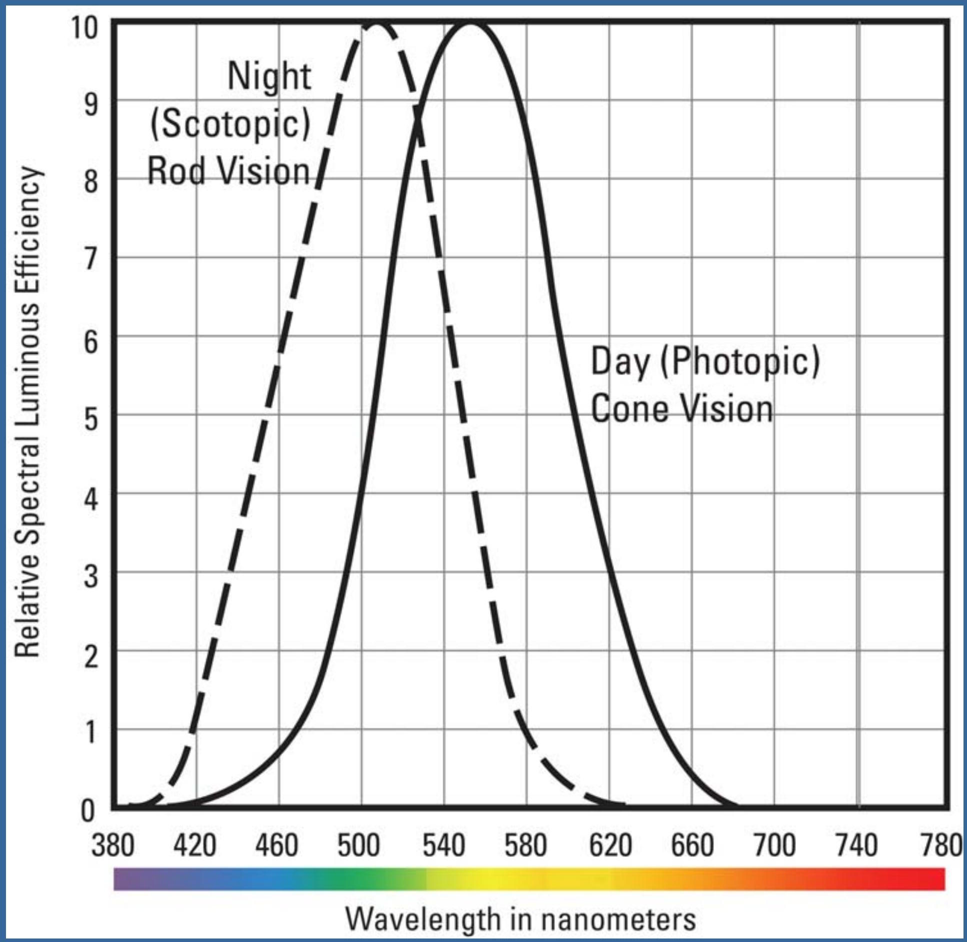
Design Concepts - Light

What is Light? – Light is radiant energy is the visible spectrum between 380-770nm



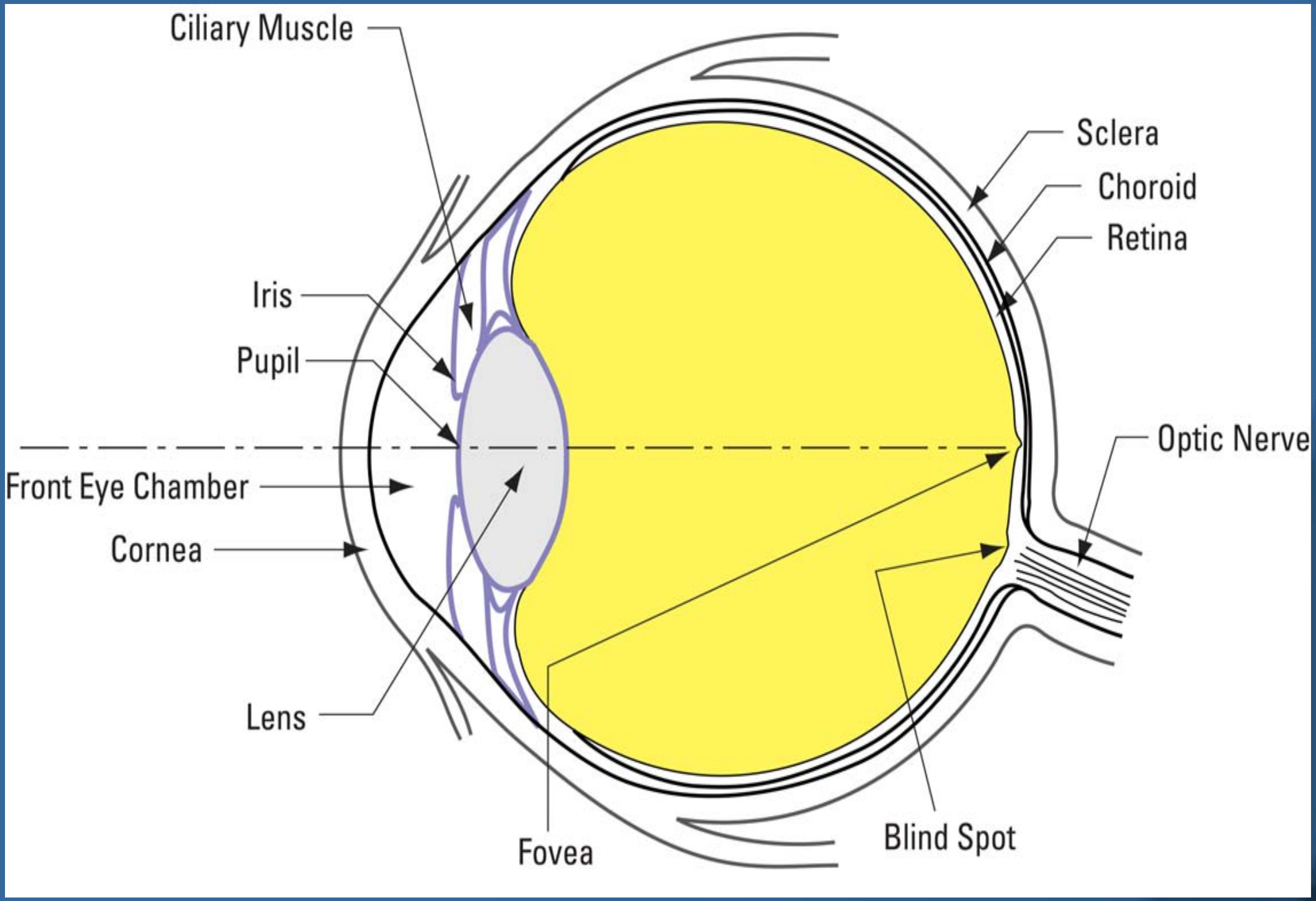
Design Concepts - Light

Visibility Lambda Curve



Basic Principals of Vision – The Eye

Key Elements include the Pupil and Retina



Basic Principals of Vision

Rods and Cones

- Cones - are sensitive to color and operate at high light levels
- Rods – are insensitive to color and operate at low light levels

Adaptation - It is the process in the Retina where the eye adapts to varying brightness

- Photopic Vision - High light levels using cones
- Mesopic Vision - Intermediate level using rods and cones
- Scopotic Vision – Low light levels on using rods

Accommodation – It is the process in the Retina and Lens which allows the eye to focus

Principals of Vision

Cones	Rods	Both Cones and Rods Functioning
"Day" Vision	"Night" Vision	"Dim Light" Vision
Photopic Vision	Scotopic Vision	Mesopic Vision
Operating Range: $\approx 3.4\ cd/m^2$ to $+100{,}000\ cd/m^2$	Operating Range: $\approx 3.4 \times 10^{-6}\ cd/m^2$ to $.034\ cd/m^2$	Operating Range: $\approx .034\ cd/m^2$ to $3.4\ cd/m^2$
Very Good Visual Acuity	Very Poor Visual Acuity	Diminished Visual Acuity
Color Vision	No Color — B & W Only	Driving a Vehicle at Night
Light Adaptation	Dark Adaptation	
Maximum Concentration in the Fovea	Maximum Concentration at the Edge of the Macula	
Number Decreases in Periphery	No Rods in the Fovea	

Table 2.1. Characteristics of Cones and Rods.

There are several terms relating to vision that will now be discussed.

Photometric Measurements

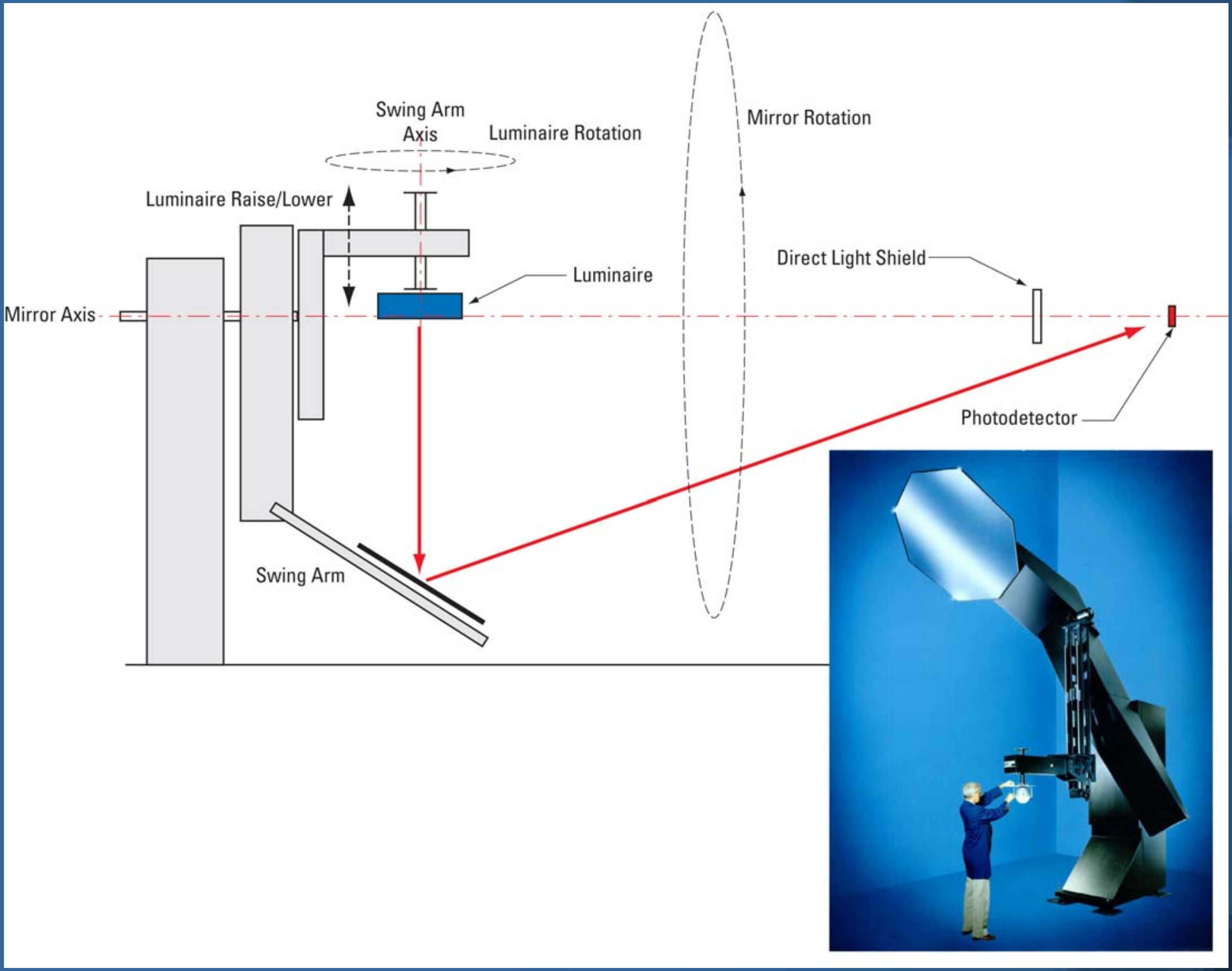
Laboratory Measurements

- Define luminous characteristics and performance of luminaires
- Typically undertaken with goniophotometer
- Undertaken in accordance with IESNA LM-63
- Supplier typically have third party do testing and produce photometric reports

Field Measurements

- Undertaken to verify design and field performance
- Rarely undertaken
- Undertaken in accordance with IESNA LM-50
- Luminance require light meter (typically around $500.00)
- Luminance requires special meter (typically around $4K)

Photometric Measurements



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Key Units and Terms (Round 1)

Lumens – Total amount of luminous flux emitted from the lamp

Intensity (Candlepower) - Concentration of light at given angle measured in candelas (cd).

Luminance (E) – Density of luminous flux on the surface (lux). If you had a half/white and black surface the luminance would the same even though one half would appear brighter.

Luminance (L) – Is a measure of light reflected from a the road surface (cd/m2). True indicator of visibility.

Key concept: What we see is reflected light

Relationship between Candelas and Lumens

A uniform point source (one candela is shown at the center of a sphere

The illuminance at any point on the sphere is one lux (one lumen per square meter) when the radius is one meter

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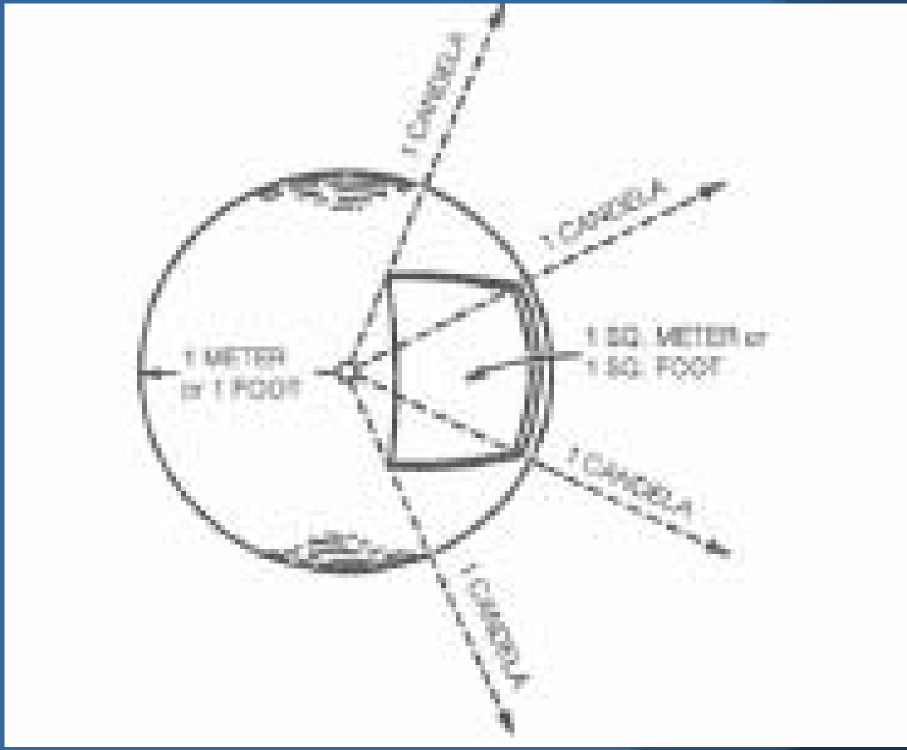


Key Units and Terms

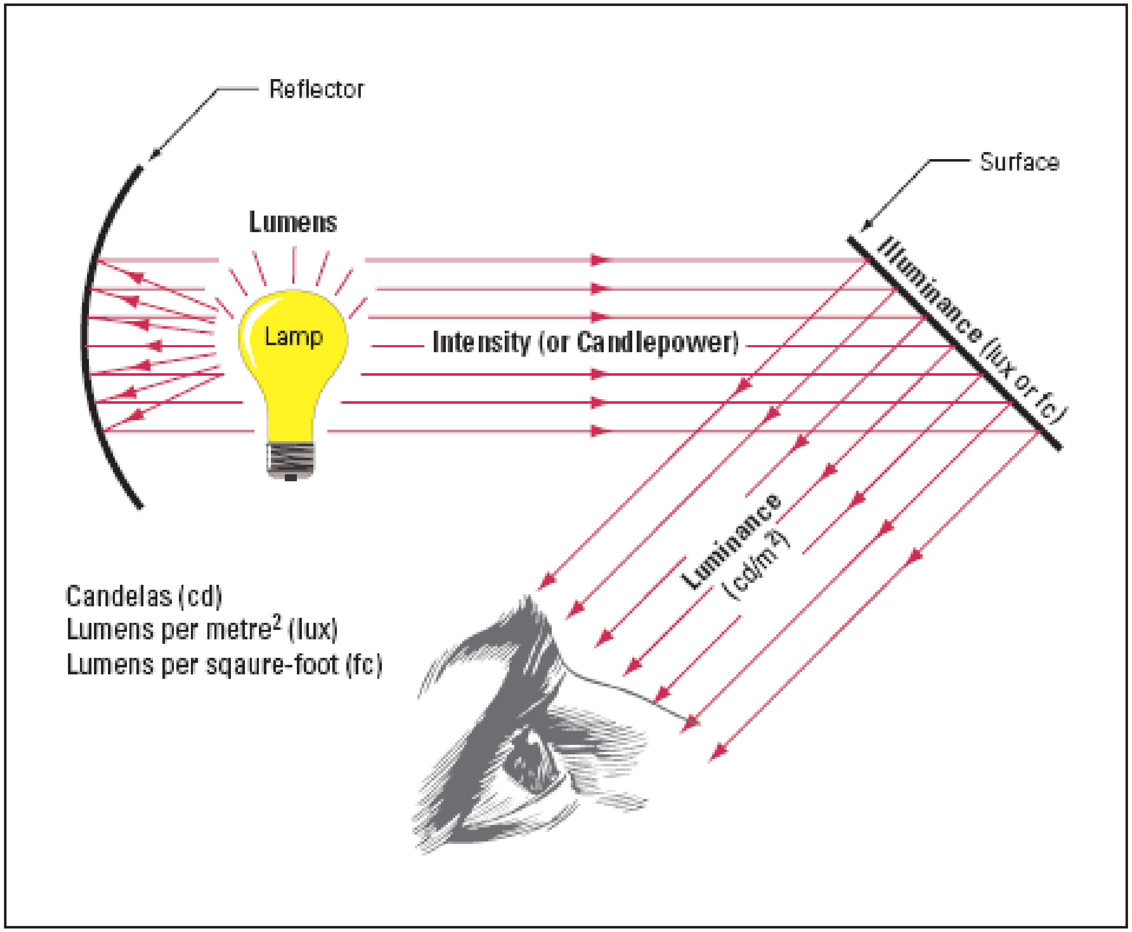


Figure 2-7 – Understanding Lighting Terminology

Luminance Design Method

Direction of View - 1 degree angle (a)

Distance - 83.07m

Height – 1.45m

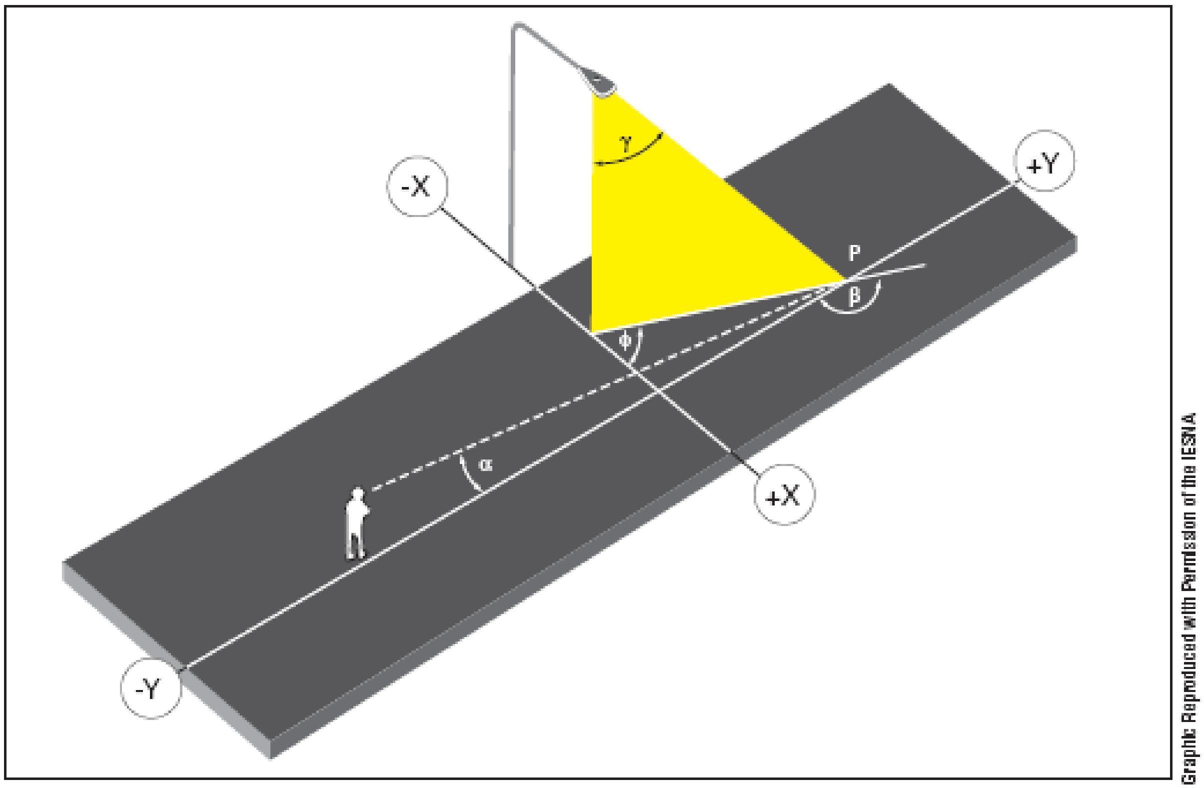
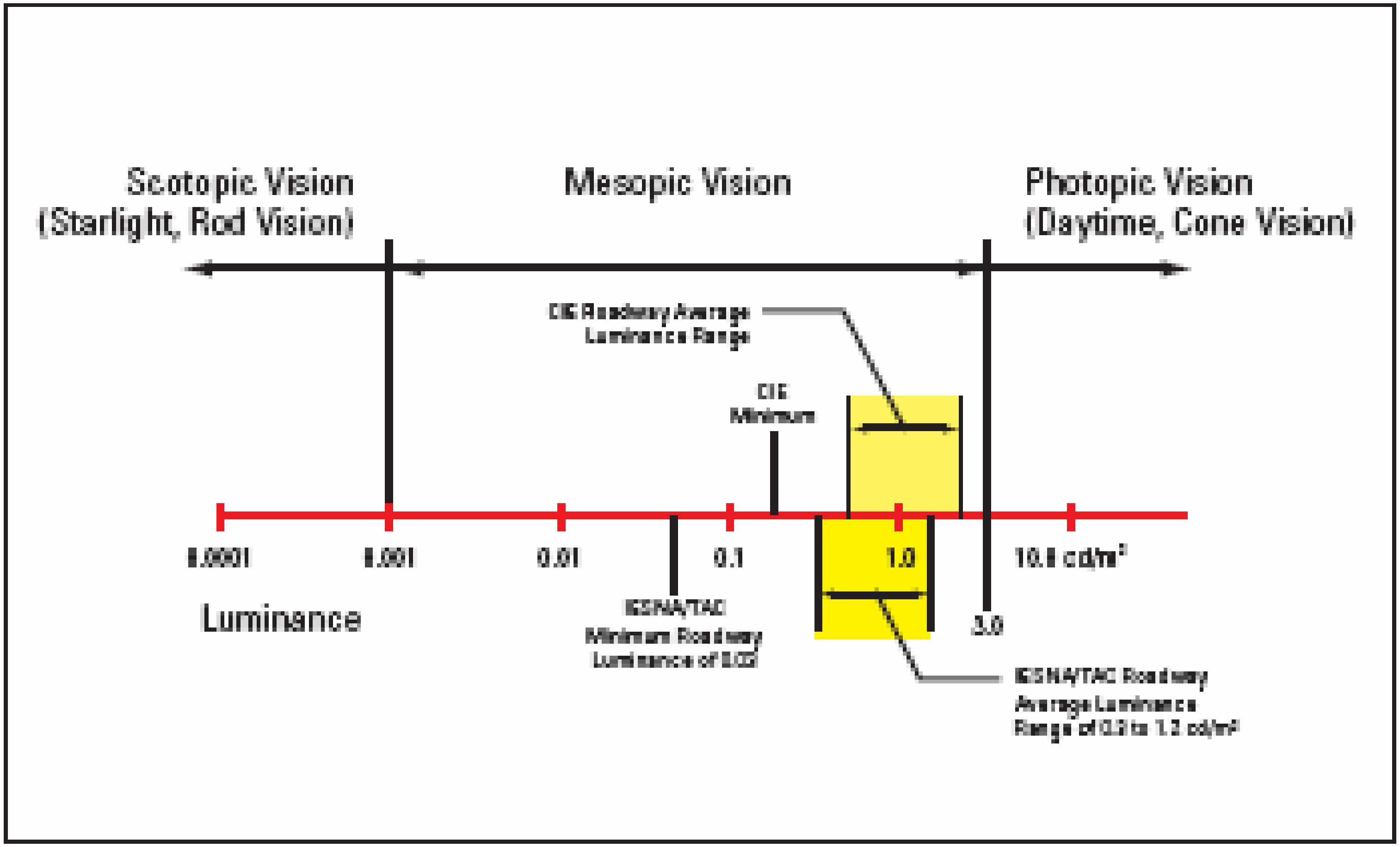


Figure 2-22 – Luminance Calculation Geometry

Spectral Effects



Photometric Test Reports

Typically include:

- Intensity (table and polar plot)
- Cut-off classifications
- Isolux Diagrams
- Utilization Factors

IESNA photometric files contain all of the above information.

Photometric Test Reports

LITHONIA LIGHTING - Lithonia Testing Laboratories

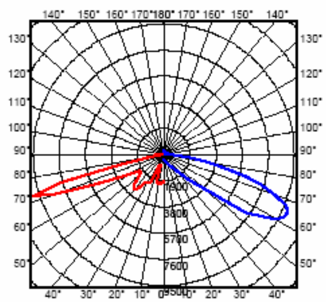
AN Acuity Brands COMPANY
www.lithonia.com

P.O. BOX A, CONYERS, GA 30013-9912
E-mail lithonia@lithonia.com

PRINT DATE: October 7, 2005
MANUFACTURER: AMERICAN ELECTRIC LIGHTING
LUMINAIRE CATALOG NO.: GRS 15S R3 RD PY
LUMINAIRE DESCRIPTION: PREMIUM ROADWAY REFLECTOR SOCKET POSITION N-4
LAMP DESCRIPTION: 70-150 WATT HPS
LUMENS PER LAMP: 16000

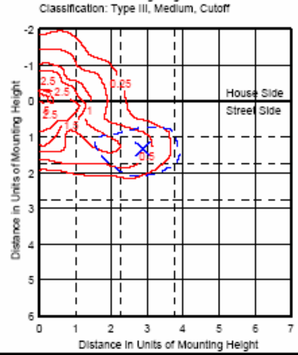
TEST NO: AE3996.IES

MAXIMUM PLANE AND CONE PLOTS
Maximum Candela = 9951



Max - 65° Horiz
Max - 72.5° Vert

ISOILLUMINANCE PLOT (FC)
Mounting Height = 20 ft.
Classification: Type III, Medium, Cutoff

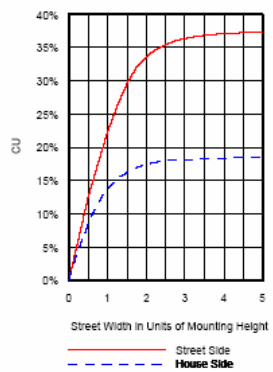


Maximum Intensity
1/2 Maximum Intensity

ZONAL LUMEN SUMMARY

Zone	Lumens	% Lamp
Downward Street Side	6051.6	37.8
Downward House Side	3021.0	18.9
Downward Total	9072.6	56.7
Upward Street Side	128.2	0.8
Upward House Side	82.2	0.5
Upward Total	210.4	1.3
Total	9283.0	58.0

COEFFICIENTS OF UTILIZATION



TESTED BY: ____________

This report is based on IES procedures. Voltage and maintenance, as well as lamp and ballast characteristics, affect field performance. Test distance exceeds five times the maximum dimension of the luminous opening.

LITHONIA LIGHTING - Lithonia Testing Laboratories

AN Acuity Brands COMPANY
www.lithonia.com

P.O. BOX A, CONYERS, GA 30013-9912
E-mail lithonia@lithonia.com

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LAMP DESCRIPTION: 70-150 WATT HPS
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TEST NO: AE3996.IES

CANDELA DISTRIBUTION

	0	5	15	25	35	45	55	60	65	70	75	80	85	90
0	1891	1891	1891	1891	1891	1891	1891	1891	1891	1891	1891	1891	1891	1891
5	2282	2400	2436	2350	2317	2257	2162	2122	2072	2045	2018	1990	1969	1936
15	2538	2582	2671	2674	2621	2465	2250	2134	2013	1707	1125	920	594	389
25	1644	1829	1567	1021	1054	1314	2003	2426	2179	1989	1907	1861	1827	1798
35	2408	2446	2360	2307	1857	2173	3198	3084	2649	2307	2198	2126	2075	2073
45	2211	2496	2060	1949	1643	1347	2346	2701	2987	2920	3273	3421	3213	2713
55	2047	2160	2128	2472	1908	1632	2642	2597	2109	1878	1902	2023	2083	2108
65	768	745	886	1575	2493	3631	6610	6029	4564	3217	2325	2040	2012	2026
72.5	389	370	512	800	1269	2578	7379	9408	9951	8566	6230	3152	1011	479
75	282	271	438	697	972	1497	4390	6083	7805	7649	5968	3790	880	405
85	68	69	87	100	125	308	455	358	256	158	191	174	182	186
90	59	62	72	74	80	268	580	462	274	142	175	139	144	164
95	23	23	23	37	33	100	679	551	422	305	188	177	166	155
105	21	21	5	5	9	4	15	33	51	42	33	27	22	36
115	8	8	2	3	4	1	0	2	5	11	17	24	30	31
125	29	29	30	3	3	0	0	2	4	14	24	26	27	28
135	10	10	5	0	1	0	0	0	0	0	0	2	4	2
145	2	2	1	2	7	11	33	24	15	7	0	0	0	0
155	1	1	5	8	2	0	0	0	0	0	0	0	0	0
165	1	1	0	2	2	0	0	0	0	0	0	0	0	0
175	1	1	3	3	4	1	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0

CANDELA DISTRIBUTION

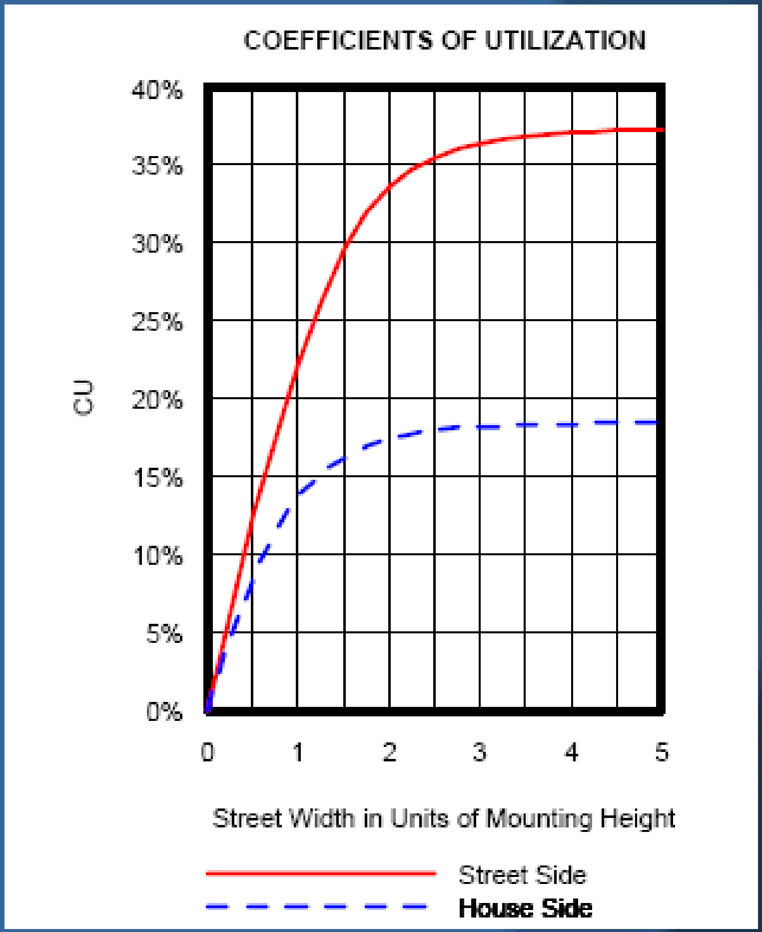
	90	95	105	115	125	135	145	155	165	175	180
0	1891	1891	1891	1891	1891	1891	1891	1891	1891	1891	1891
5	1936	1912	1869	1853	1804	1779	1777	1800	1846	1770	1753
15	389	377	405	1327	1280	797	508	442	571	752	918
25	1798	1802	1879	1946	841	1194	1762	1670	1575	1504	1497
35	2073	1918	1836	1869	1068	1453	1734	1550	1439	1348	1333
45	2713	2060	1785	1734	1079	1102	1501	1372	1288	1231	1198
55	2108	2112	1755	1694	1129	1086	1295	1263	1192	1104	1070
65	2026	1959	1787	1719	1136	805	1067	1191	1121	785	697
72.5	479	370	258	314	150	103	122	244	200	285	244
75	405	301	212	281	123	78	109	223	130	239	232
85	186	189	139	206	160	86	194	244	105	151	132
90	164	156	97	158	207	158	221	163	87	88	80
95	155	144	56	73	81	125	128	109	88	55	55
105	36	51	93	83	51	21	18	32	20	11	11
115	31	32	2	1	0	4	4	1	3	29	29
125	28	29	3	2	0	1	13	7	15	36	36
135	2	0	0	0	0	0	1	0	1	7	7
145	0	0	0	0	0	1	2	1	0	1	1
155	0	0	0	0	0	0	1	0	0	0	0
165	0	0	0	0	0	1	3	1	1	0	0
175	0	0	0	0	0	0	4	2	1	0	0
180	0	0	0	0	0	0	0	0	0	0	0

This report is based on IES procedures. Voltage and maintenance, as well as lamp and ballast characteristics, affect field performance. Test distance exceeds five times the maximum dimension of the luminous opening.

Photometric Test Reports (CU)

CU Chart - % of lamp lumens falling on the Street side or House side of the luminaire

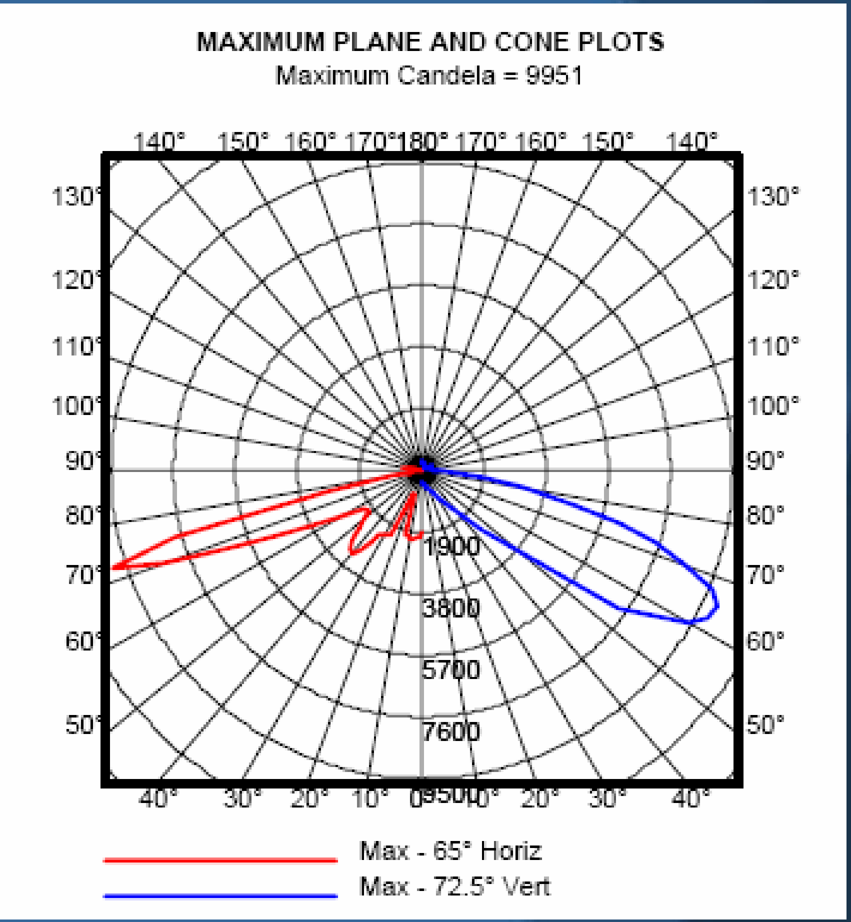
Used to calculate average illuminance



Photometric Test Reports (Plane /Cone)

Plane and Cone Diagram

Vertical and Horizontal cross section through point of maximum intensity



Photometric Test Reports (Iso illuminance)

Mounting Height = 20 Ft

(each square = 1 mounting height)

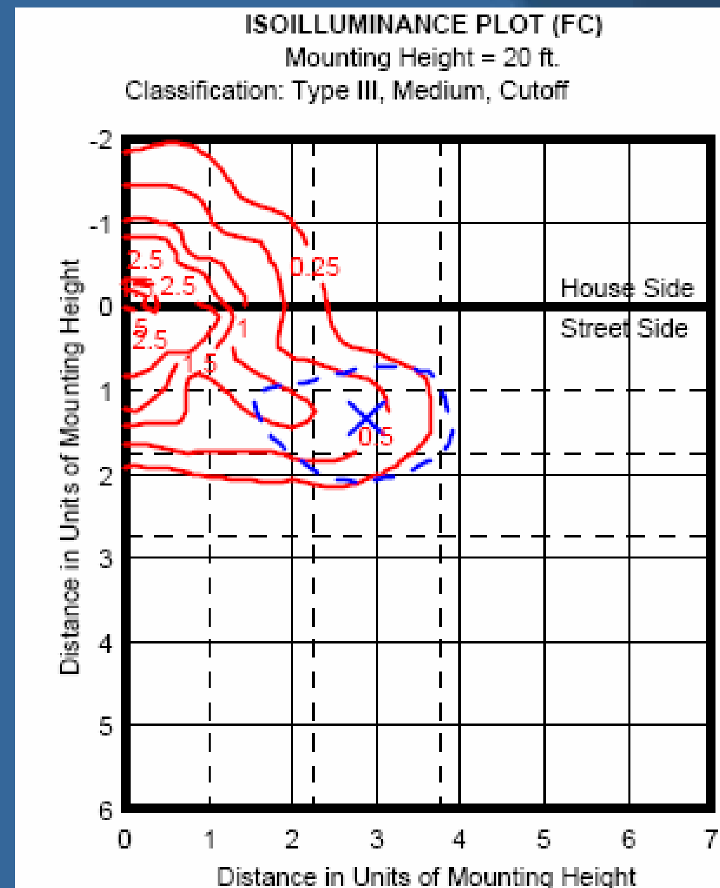
Mounting Height Multipliers

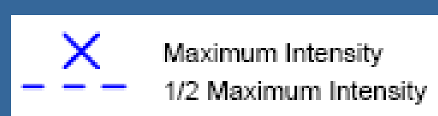
10 ft = 4x

20 ft = 1x

30 ft = 0.44x

40 ft = 0.25x





Visibility - Glare

- Bright sources of light in the visual field are called glare.
- Due to the human physiology glare causes light to be scattered in the eye, resulting in a phenomenon known as "veiling luminance." This results in a visual haze within the eye, reducing vision.
- We have all experienced veiling luminance when bright oncoming headlights significantly reduce one's vision. By blocking the bright source from the visual field with one's hand, the haze associated with veiling luminance is reduced, partially restoring vision.
- Brightly lighted areas or high wattage luminaires may actually reduce vision rather than enhance it by increasing glare.
- Glare can be reduced through the use of proper luminaire mounting heights and luminaire optics.

Visibility – What is it?

It is the quality or the state of just being visible to the eye.

For outdoor applications, visibility is defined as the distance at which something can just be perceived by the eye. *Ref - IESNA Handbook Volume 9, 2000*

Visibility is related to the contrast of the object to its background. There is a threshold contrast at which the eye can just perceive an object. This threshold contrast depends on the size of the object, the viewing time, contrast polarity, and the background luminance.

Visibility – Object Visibility

Visibility Concept - Glare

Three classifications of glare are:

Disability Glare - The presence of an amount of glare so significant as to prevent adequate vision. The presence of disability glare means that other objects in one's field of vision are obscured.

Discomfort Glare - The presence of a sufficient amount of glare to cause discomfort. While the individual may experience a sense of discomfort, this level of glare does not obscure ones vision.

Nuisance Glare - The presence of a sufficient amount of glare as to be bothersome but does not prevent vision or lead to discomfort.

Visibility Concept - Glare

Key Units and Terms (Round 2)

Veiling Luminance (disability glare) – A ratio maximum veiling luminance to the average pavement luminance.

- Typical VL ratios are 0.3:1 or 0.4:1 (Lvmax to Lavg).
- Luminance superimposed on retinal image which reduces its contrast.
- Veiling effect produced by bright sources in the visual field which reduce visibility.

Important Visibility Criteria

Visibility - Contrast

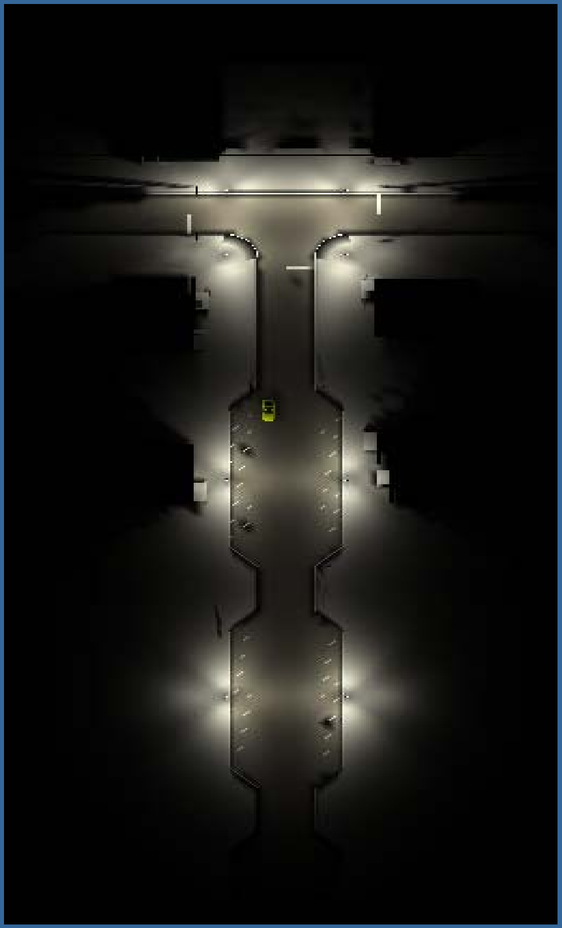
We need contrast to see objects

- Negative / Positive - Prefer positive

Figure 2-14 – Examples of Negative and Postive Contrast.

Visibility - Rendering Examples

Visibility - Rendering Examples



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Key Units and Terms (Round 3)

Uniformity (E) – Evenness of lighting in defined area. Expressed as a ratio of the average or maximum calculated point(s) to lowest calculated point within a defined area. Typical ratios would be:

- 3:1 to 6:1 (Eavg to Emin)
- 6:1 to 10:1 (Emax to Emin)

Uniformity

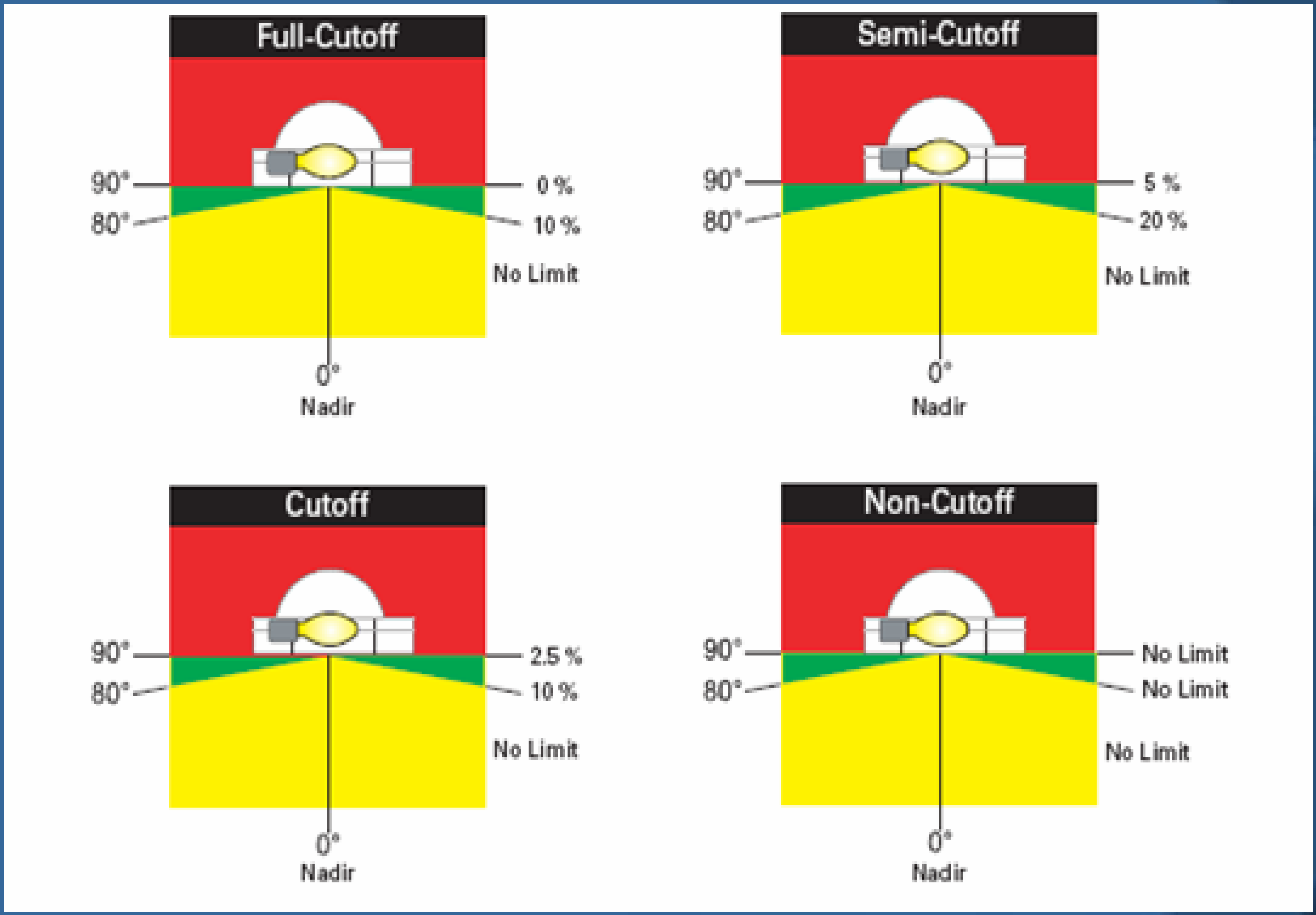
Luminaire Cutoff

The amount of glare is influenced by the intensity (cd) emitted at various angles.

Luminaire cut-off classifications have been developed to aid in luminaire selection.

Classifications based on % of rated lamp lumens at various angles.

Luminaire Cutoff



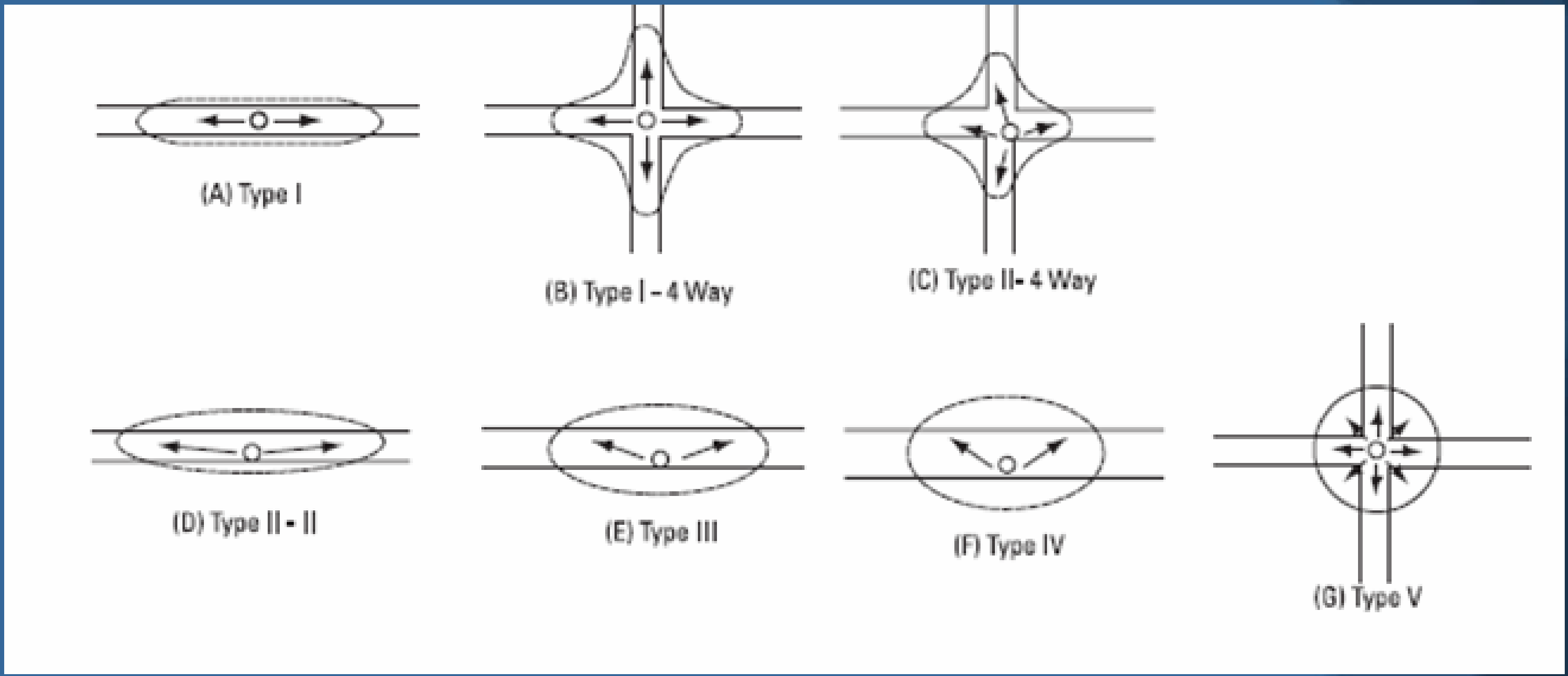
Luminaire Cutoff

The amount of glare is influenced by the intensity (cd) emitted at various angles.

Luminaire cut-off classifications have been developed to aid in luminaire selection.

Classifications based on % of rated lamp lumens at various angles.

Luminaire Distribution



Light Loss Factor (LLF)

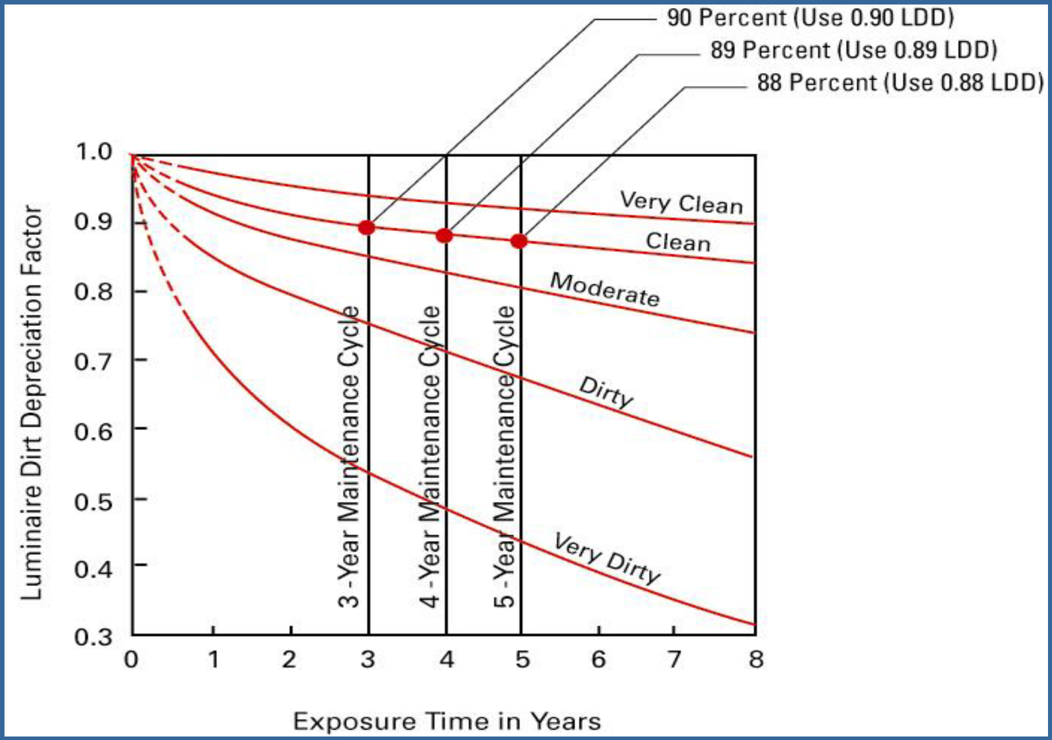
LLF is a factor applied to lighting design to compensate for depreciations over time:

Based on:

- *Lamp Lumen Depreciation (LLD)*
- *Luminaire Dirt Depreciation (LDD)*
- *Equipment Factor (EF) – Fixed number*

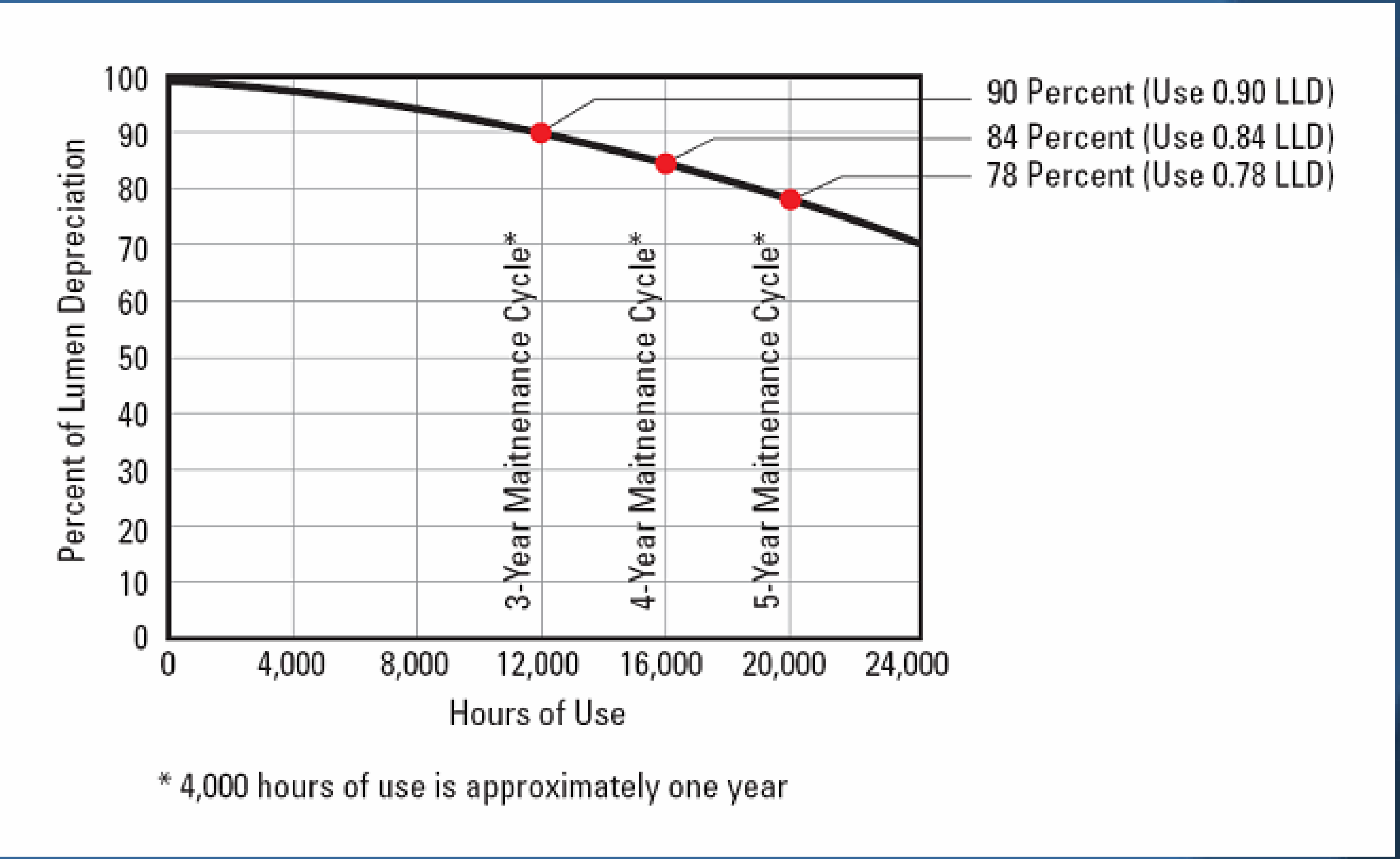
Important Consideration: Light loss factor should be based on end of lamp life at re-lamp ***not mean lumen value.***

Light Loss Factor (LDD)



Very Clean – No nearby smoke or dust generating activities and a low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is no more than 150 micrograms per m3.
Clean – No nearby smoke or dust generating activities and a low ambient contaminant level. Moderate to heavy traffic. The ambient particulate level is no more than 300 micrograms per m3.
Moderate – Moderate smoke or dust generating activities and a low ambient contaminant level. Moderate to heavy traffic. The ambient particulate level is no more than 600 micrograms per m3.
Dirty – Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.
Very Dirty – As above, but the luminaires are commonly enveloped by smoke or dust plumes.

Light Loss Factor (LDD)



Luminaire Cutoff Calculations

Three-Year Maintenance Cycle LLF Calculation:
0.77 (LLF) = 0.9 (LLD) x 0.9 (LDD) x 0.95 (EF)

Four-Year Maintenance Cycle LLF Calculation:
0.71 (LLF) = 0.84 (LLD) x 0.89 (LDD) x 0.95 (EF)

Five-Year Maintenance Cycle Calculation, or Maintenance by Spot Re-lamping LLF Calculation:
0.65 (LLF) = 0.78 (LLD) x 0.88 (LDD) x 0.95 (EF)

Obtrusive Light

Obtrusive Light (Light Trespass)

Obtrusive Light – Lighting outside the area which it was intended which *may* be obtrusive/annoying.

Issues

- Public are less tolerant of over bright lighting
- Lighting can impact humans, plants and animals
- International Dark Sky (IDA) bringing issues to focus
- Lighting bylaws (ordinances) limiting lighting

More lighting is not always better

Spill Light, Skyglow and Glare

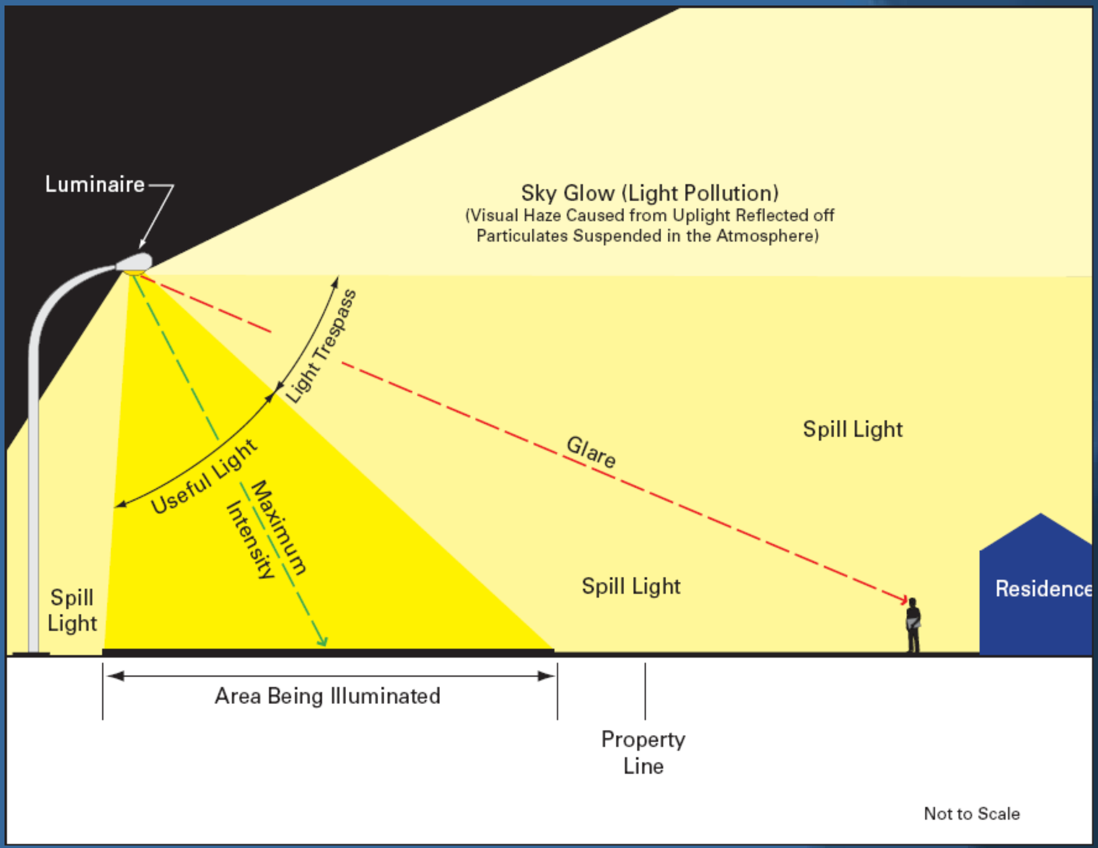
Spill Light

Urban Sky glow

Glare

- Disability
- Discomfort
- Nuisance

For more info
www.darksky.org



Spill Light levels

Designation	Recommended Maximum Illuminance Level (Ee)	
	Pre-Curfew	Post-Curfew (Not Applicable to Roadway Lighting)
LZ 1	1.0 lux	0.0 lux
LZ 2	3.0 lux	1.0 lux
LZ 3	8.0 lux	3.0 lux
LZ 4	15.0 lux	6.0 lux

Spill Light

- Easy to calculate and measure.
- Based on 4 lighting zones with varying ambient levels (LZ-1 Park, LZ-2 Rural, LZ-3 Sub-urban and LZ-4 Commercial).
- Lighting Zones based on CIE (definitions being re-defined by IESNA RP-33).
- Levels based on research project where humans were subjected to varying levels of light with various levels of ambient light. Results defines in IESNA TM-11.

Glare

- Often most major issue as intense sources can cause nuisance glare at distance off site. Their may be no spill light however their may be nuisance glare
- If source intense can be reduce when viewed off site then impacts can be mitigated.
- CIE 150 has developed method to measure sources

Light Technical Parameter	Application Conditions	Environmental Zones			
		E1	E2	E3	E4
Luminous intensity emitted by luminaires (I)	Pre-curfew:	2 500 cd	7 500 cd	10 000 cd	25 000 cd
	Post-curfew hours:	0 cd*	500 cd	1 000 cd	2 500 cd

Light Technical Parameter	Application Conditions	Environmental Zones			
		E1	E2	E3	E4
Illuminance in vertical plane (E_v)	Pre-curfew:	2 lux	5 lux	10 lux	25 lux
	Post-curfew:	0* lux	1 lux	2 lux	5 lux

Glare (Examples)

- Not all luminaire are created equal – This image show how luminaire of the same wattage can have different intensity when viewed off site.

Glare

Until recently no devices were available to field measure candlepower at the luminaire. A device has now been developed to measure illuminance and fixture intensity (candlepower).

The NightMeter™ system is a portable integrated group of meters and accessories to measure outdoor lighting quantities that are related to light trespass. The system is suitable for determining spill light, eye illuminance, horizontal and vertical illuminance, and the intensity of each fixture.

How to Lesson Impacts

- Select luminaires with cut-off or even better full cut-off optics
- Calculate and try to meet required spill light levels at residences
- Assess luminaire source intensity
- Avoid over-lighting
- Consider new concept such as dimming in off peak periods

Caution – Important Considerations

Because roadway lighting is a safety enhancement for the public, designers must always maintain the recommended lighting levels for roadway facilities. The reduction or elimination of obtrusive light must never take precedence over proper illumination for transportation facilities as traffic safety is of paramount importance.

In some cases the control of obtrusive light and the intent of roadway lighting may be in conflict. Illuminating the area adjacent to roadway travel lanes (typically within or adjacent to the road allowance) for instance, can benefit a driver's peripheral vision and improve overall roadway user safety by providing visibility of crossroads, driveways and sidewalks.

Design Process

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Basic Lighting Design Process

Step 1 – Warrant Analysis

Based on a point-score analysis, full intersection lighting will be required.

Step 2 – Define Variables

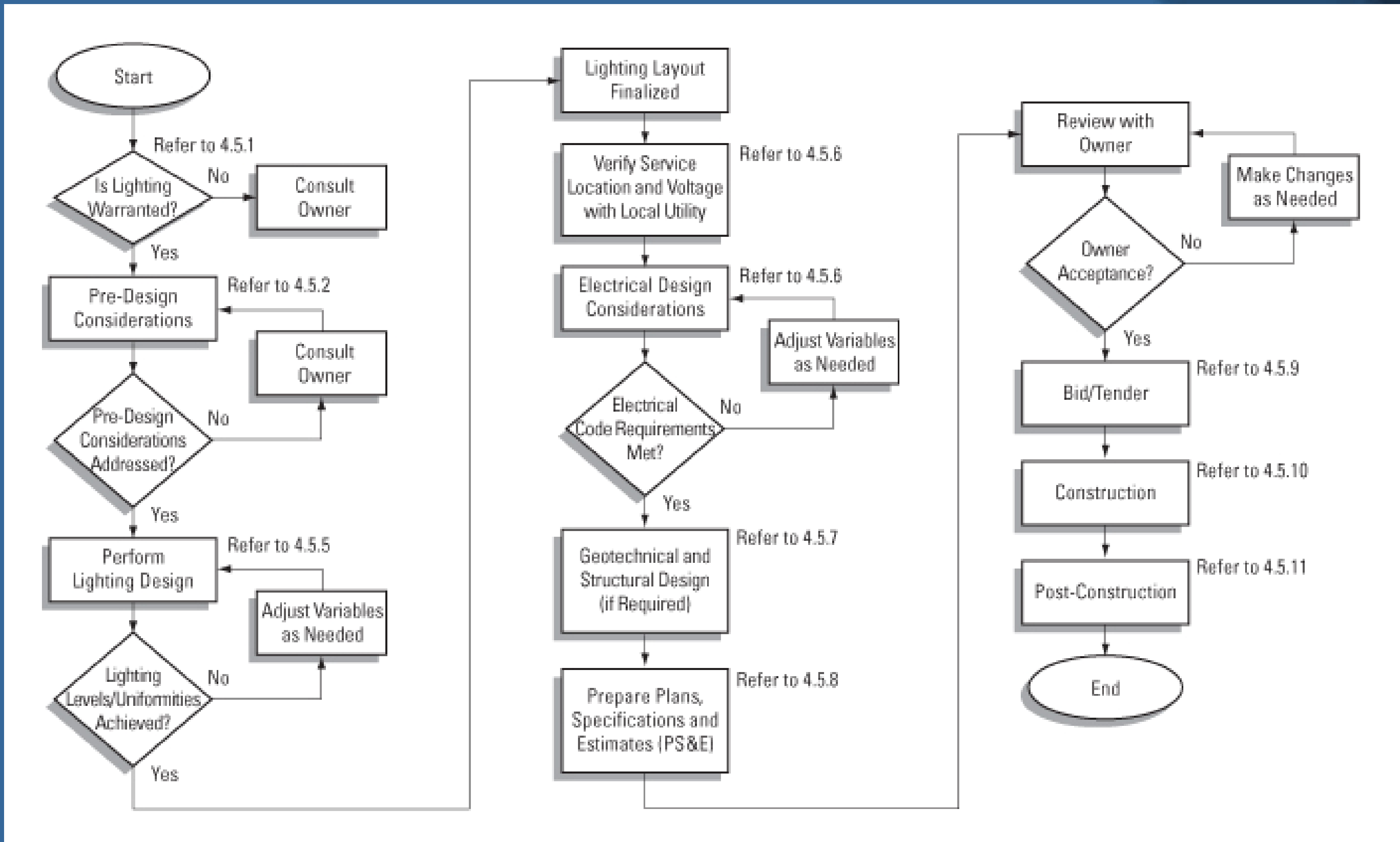
- Luminance of Illuminance
- Road Type
- Pedestrian Activity
- Pavement type
- Crosswalks - Vertical illuminance levels required

Step 3 – Selecting Criteria (from table)

Step 4 – Equipment Selection

Step 5 – Undertake Computer Calculations

Step 6 – Adjust and Recalculate



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Warrant Analysis (Step 1)

Many jurisdictions will have specific requirements as to when lighting is required. Warrants are not required.

Roadways/Intersections

- Based on a number of factors which points are assigned to geometric, operational, environmental and collision factors

Warrant Analysis

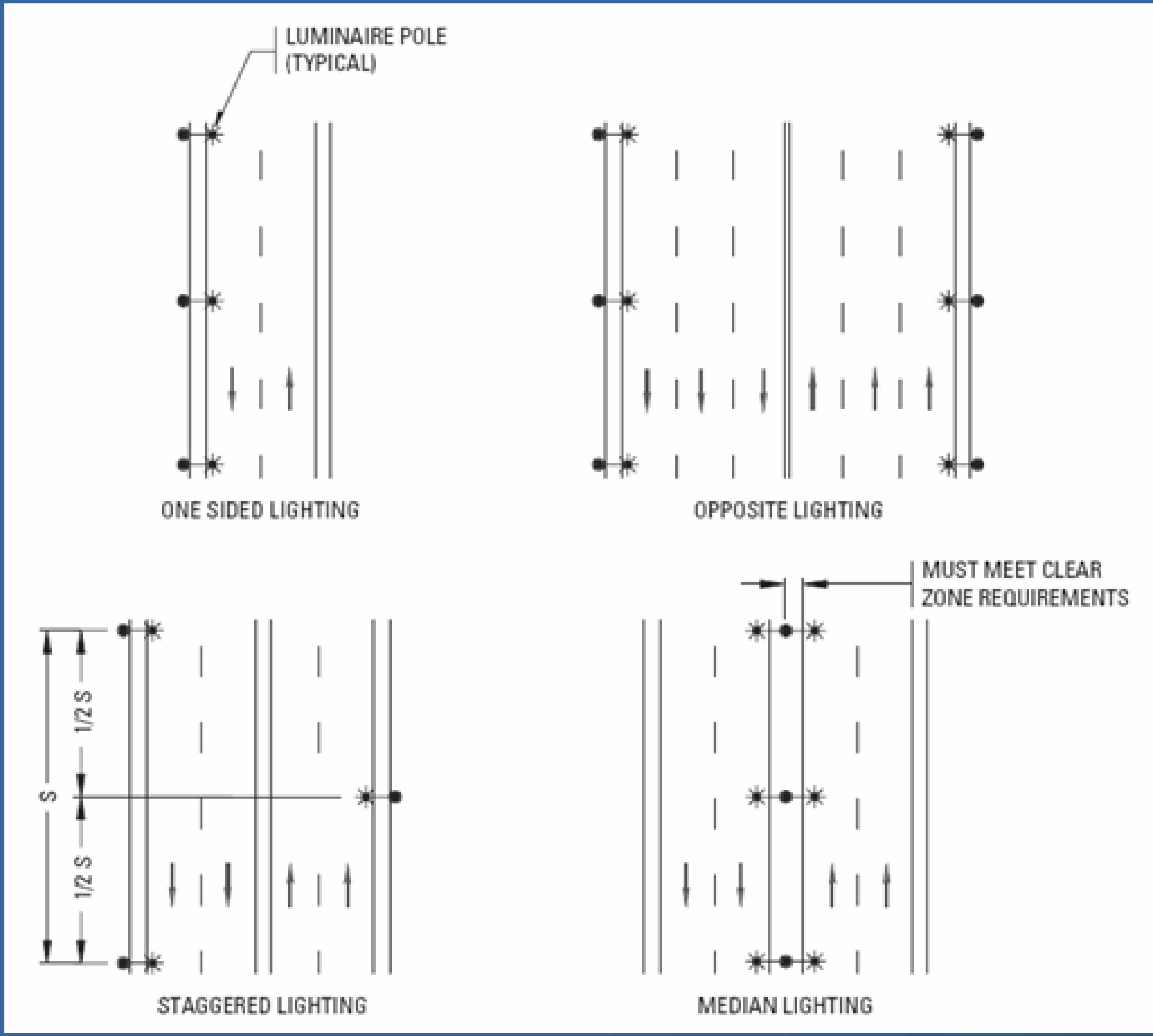
Roundabouts, tunnels, mid block x-walks should always be lighted.

Other applications such as parking lots, weigh scales, walkways, etc have less specific criteria

Define Variables (Step 2)

- Luminance or Illuminance
- Road Type (Local, Collector, Arterial, Expressway, Freeway)
- Pedestrian Activity – High, Med, Low)
- Pavement type (R1, R2, R3 or R4)
- Crosswalks - Vertical illuminance levels required
- Pole offsets (see diagram)

Define Variables (Step 2)



Step 3 – Selecting Criteria (Roadways)

- **High Pedestrian Activity** – Examples are commercial urban areas, downtowns or city centers with high nighttime activity. A high pedestrian activity area will have 100 or more pedestrians over the one–hour period with the highest average annual nighttime pedestrian activity.
- **Medium Pedestrian Activity** –Typically, these are urban commercial or industrial areas, and have some or all of the following types of development: multifamily residential, community buildings, neighborhood shopping and transit lines. A medium pedestrian activity area will have 11 to 99 pedestrians over the one–hour period with the highest average annual nighttime pedestrian activity.
- **Low Pedestrian Activity** –This level of activity can occur in any of the cited roadway classifications. However, it is typical of small urban streets with single-family homes and very low density residential developments (e.g., residential subdivisions). A low pedestrian activity area will have 10 or fewer pedestrians over the one–hour period with the highest average annual nighttime pedestrian activity

Step 3 – Selecting Criteria (Roadways)

Road Area and Pedestrian Activity: Road Type	Road Area and Pedestrian Activity: Pedestrian Activity	Average Luminance cd/m^2	Average-to-Minimum Uniformity Ratio	Maximum-to-Minimum Uniformity Ratio	Maximum-to-Average Veiling Luminance Ratio
Freeway	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Partial Lighting of Interchange On-Ramps/ Off-Ramps	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Expressway-Highway	High	≧ 1.0	≦ 3.0	≦ 5.0	≦ 0.3
	Medium	≧ 0.8	≦ 3.0	≦ 5.0	≦ 0.3
	Low	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Arterial	High	≧ 1.2	≦ 3.0	≦ 5.0	≦ 0.3
	Medium	≧ 0.9	≦ 3.0	≦ 5.0	≦ 0.3
	Low	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Collector	High	≧ 0.8	≦ 3.0	≦ 5.0	≦ 0.4
	Medium	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.4
	Low	≧ 0.4	≦ 4.0	≦ 8.0	≦ 0.4
Local/Alleyway	High	≧ 0.6	≦ 6.0	≦ 10.0	≦ 0.4
	Medium	≧ 0.5	≦ 6.0	≦ 10.0	≦ 0.4
	Low	≧ 0.3	≦ 6.0	≦ 10.0	≦ 0.4

Selecting Criteria (Intersections)

Roadway Classification	Average Maintained Illuminance at Pavement by Pedestrian Conflict (lux)			Average-to-Minimum Uniformity Ratio
	High	Medium	Low	
Arterial/Arterial	34.0	26.0	18.0	≦ 3.0
Arterial/Collector	29.0	22.0	15.0	≦ 3.0
Arterial/Local	26.0	20.0	13.0	≦ 3.0
Expressway-Highway/Arterial	31.0	25.0	18.0	≦ 3.0
Expressway-Highway/ Expressway-Highway/	28.0	24.0	18.0	≦ 3.0
Expressway-Highway/Collector	26.0	21.0	15.0	≦ 3.0
Expressway-Highway/Local	23.0	19.0	13.0	≦ 3.0
Collector/Collector	24.0	18.0	12.0	≦ 4.0
Collector/Local	21.0	16.0	10.0	≦ 4.0
Local/Local	18.0	14.0	8.0	≦ 6.0

Selecting Criteria (Sidewalks)

Pedestrian Activity	Maintained Average Horizontal Illuminance (lux)	Average-to - Minimum Horizontal Uniformity Ratio	Minimum Maintained Vertical Illuminance (lux)
High	≧ 20.0	≦ 4.0	≧ 10.0
Medium	≧ 5.0	≦ 4.0	≧ 2.0
Low	≧ 3.0	≦ 6.0	≧ 0.8

Equipment Selection (Step 4)

Variables

- Luminaire photometrics
- Wattage
- Lamp type and light source
- Pole height and arm length

Equipment Selection

Review

- Architectural requirements – Projects often have specific architectural requirements requiring a specific pole and fixture style
- Local standards – Often jurisdictions will have specific pole and luminaire standards which should be considered for standardization
- Existing equipment – If tying into an existing system then one should confirm what exists

Equipment Selection

Review

Site conditions which can impact equipment:

- Overhead power lines can impact mounting heights
- Proximity to an airport
- Proximity to astronomical facilities
- Clear zone requirements
- Environmental Sensitivity
- Trees and other devices which can block light

Equipment Selection

Hundreds of luminaire types and styles exist. Information available from manufactures.

Poles varying in height and arm length. Consult pole suppliers.

Consider:

- Life cycle cost over capital cost (cheaper is not better)
- Durability
- Aesthetics
- Maintenance
- Obtrusive impacts

Equipment Selection Keys

Avoid sole sourcing. Define multiple products.

If sole sourcing fix pricing (assign in specs).

Avoid custom products

Test new products and technology prior to large deployment

Is product supported by manufacturer? Will they stand behind it?

Undertake Computer Calculations (Steps 5 and 6)

Computer software allows one to input variables and adjust pole height, wattages and photometric files. Obtain photometric from suppliers web sites (must be in IES format)

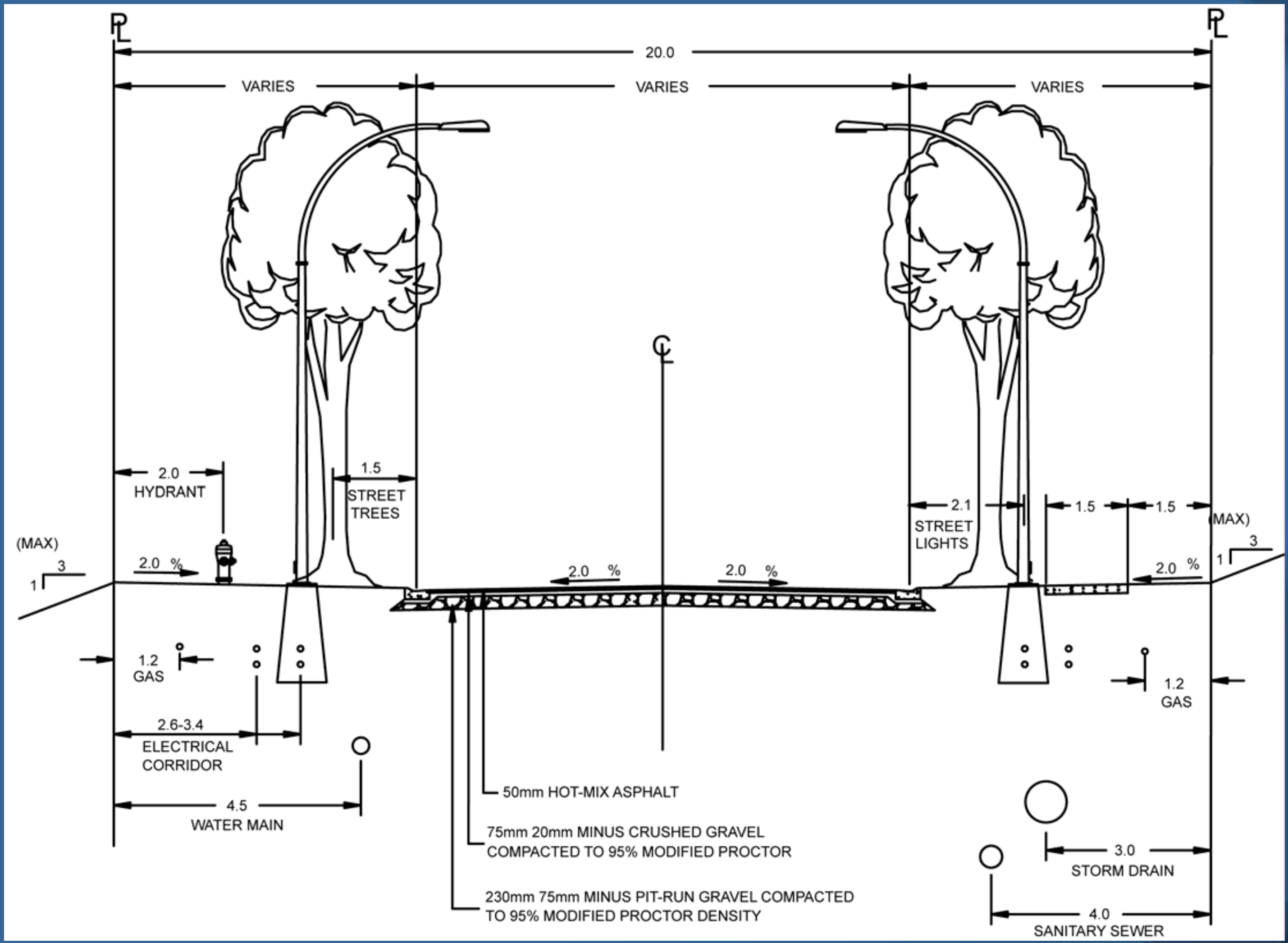
One can optimize via trial and adjust process.

Other Design Considerations

- Availability of power
- Soils conditions
- Underground utility conflicts

Be thorough "don't leave it up to the contractor to figure out"

Typical Urban Cross Section



Clear Zone

The clear zone is defined as the roadside border area adjacent to the roadway to be kept clear of fixed objects, which may be traversed by errant vehicles. Determining the clear zone is a complex task. It is a function of design speed, traffic volumes, the presence of fill and cut slopes, the steepness of the slopes and the horizontal curvature of the road.

Ref TAC Geometric Design Guide

Lighting Components

Overview

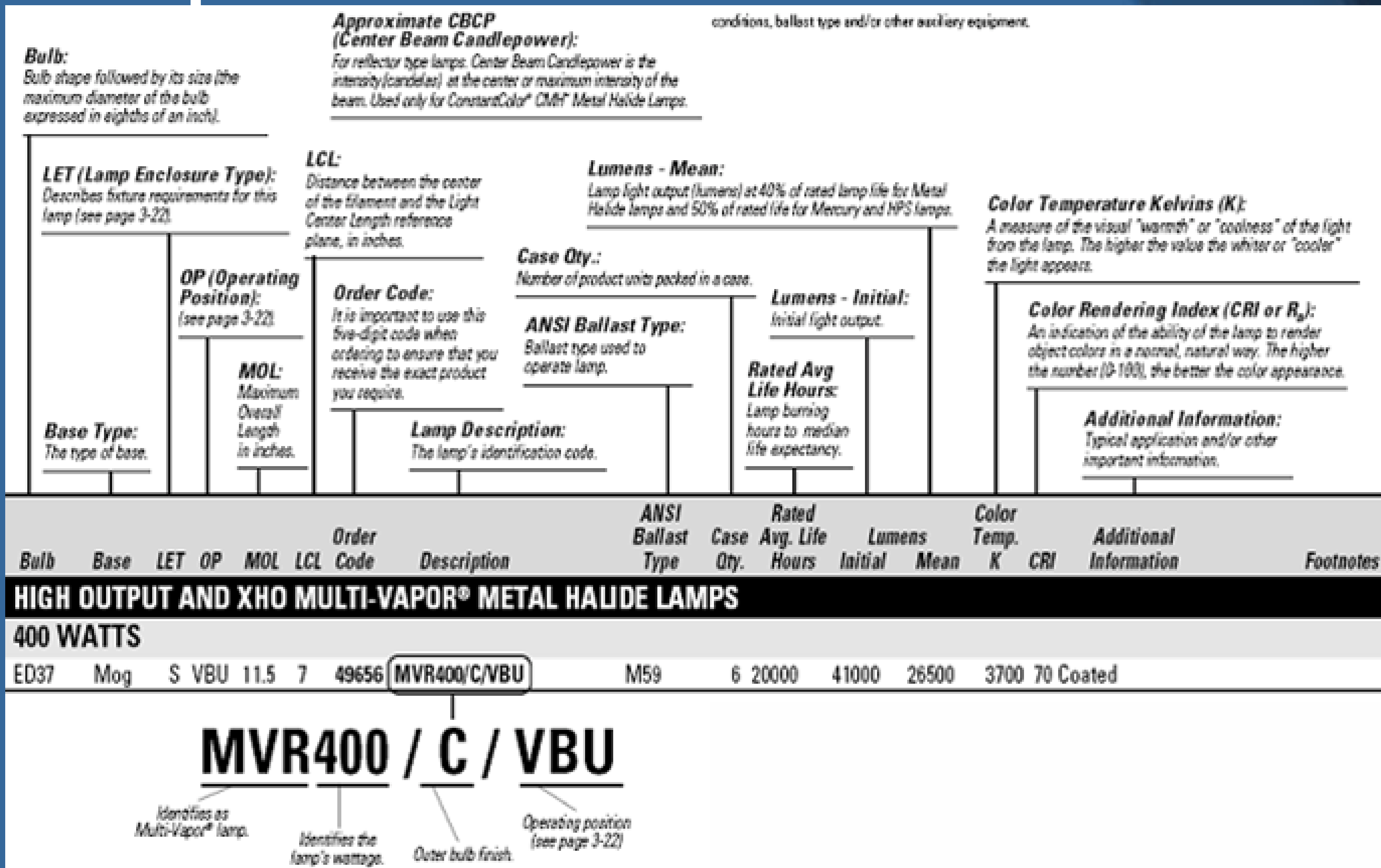
- Light Sources
- Lamps
- Ballasts
- Luminaires
- Poles
- Highmast
- Electrical

Light Source Comparison

Lamp Type	Efficacy (lumens per watt)	% Lamp Lumen Depreciation at End of Life	Average Lamp Life (Hours)	Color Rendering Index
Fluorescent	30 - 70	0.9	7K – 12K	80
Mercury Vapor	30 - 65	0.54	24K +	45 - 50
Metal Halide	75 - 125	0.50	7K to 30K	65 - 80
High Pressure Sodium	45 - 150	0.73	24K +	22
Low Pressure Sodium	145 - 185 (Poor Utilization)	1.0 (Watts Increase)	10K -18K	0
E-Lamps (induction)	75	.70	50K-100K	70

Information on LED's not included

Lamps



Approximate CBCP (Center Beam Candlepower):
For reflector type lamps. Center Beam Candlepower is the intensity (candelas) at the center or maximum intensity of the beam. Used only for ConstantColor® CMH® Metal Halide Lamps.
conditions, ballast type and/or other auxiliary equipment.
Bulb:
Bulb shape followed by its size (the maximum diameter of the bulb expressed in eighths of an inch).
LET (Lamp Enclosure Type):
Describes fixture requirements for this lamp (see page 3-22).
LCL:
Distance between the center of the filament and the Light Center Length reference plane, in inches.
Lumens - Mean:
Lamp light output (lumens) at 40% of rated lamp life for Metal Halide lamps and 50% of rated life for Mercury and HPS lamps.
Color Temperature Kelvins (K):
A measure of the visual "warmth" or "coolness" of the light from the lamp. The higher the value the whiter or "cooler" the light appears.
Case Qty.:
Number of product units packed in a case.
OP (Operating Position):
(see page 3-22)
Order Code:
It is important to use this five-digit code when ordering to ensure that you receive the exact product you require.
ANSI Ballast Type:
Ballast type used to operate lamp.
Lumens - Initial:
Initial light output.
Color Rendering Index (CRI or Ra):
An indication of the ability of the lamp to render object colors in a normal, natural way. The higher the number (0-100), the better the color appearance.
MOL:
Maximum Overall Length in inches.
Rated Avg Life Hours:
Lamp burning hours to median life expectancy.
Base Type:
The type of base.
Lamp Description:
The lamp's identification code.
Additional Information:
Typical application and/or other important information.
Bulb | Base | LET | OP | MOL | LCL | Order Code | Description | ANSI Ballast Type | Case Qty. | Rated Avg. Life Hours | Lumens Initial | Mean | Color Temp. K | CRI | Additional Information | Footnotes
HIGH OUTPUT AND XHO MULTI-VAPOR® METAL HALIDE LAMPS
400 WATTS
ED37 Mog S VBU 11.5 7 49656 MVR400/C/VBU M59 6 20000 41000 26500 3700 70 Coated
MVR400 / C / VBU
Identifies as Multi-Vapor® lamp.
Identifies the lamp's wattage.
Outer bulb finish.
Operating position (see page 3-22)

DMD

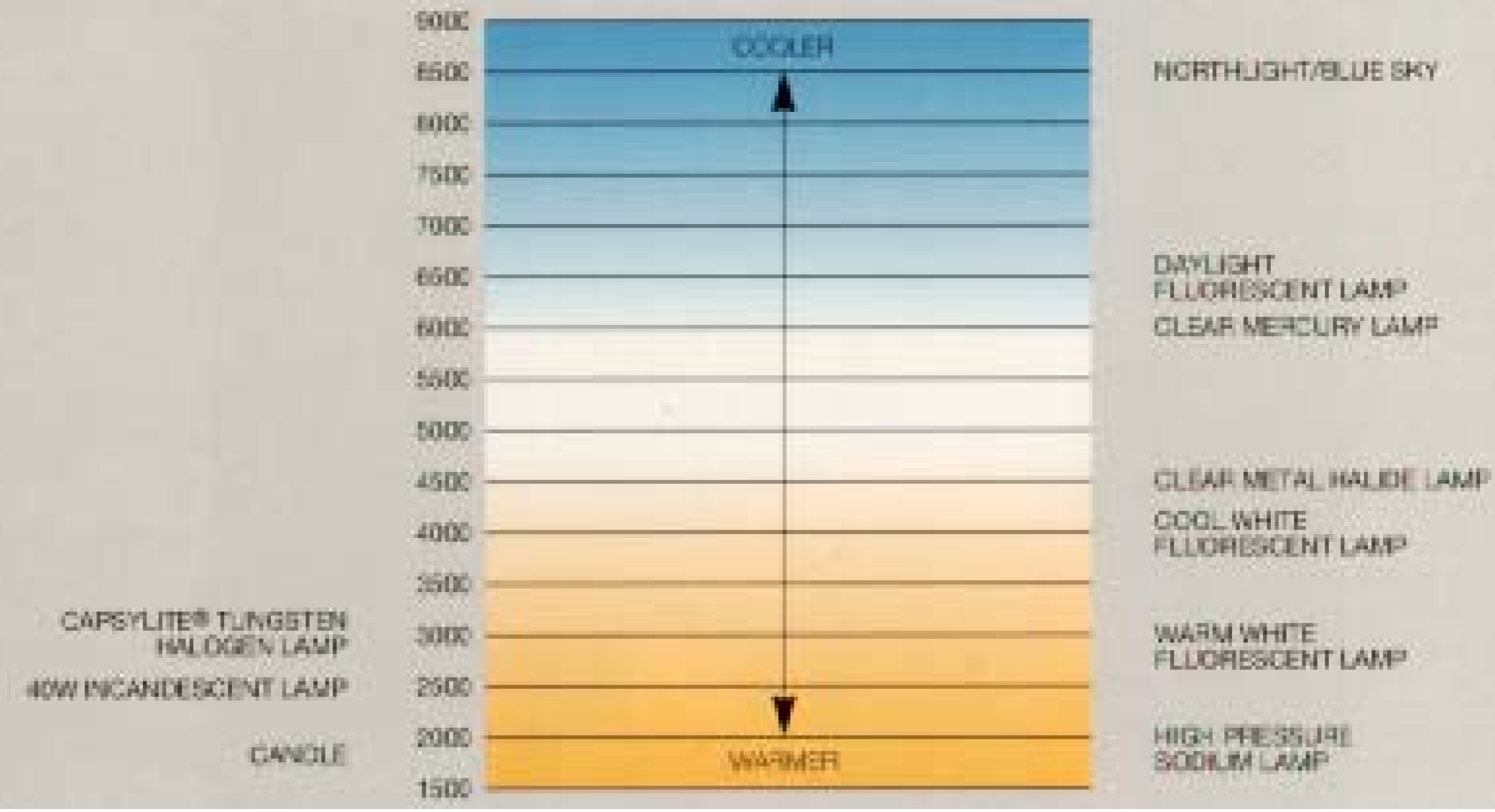
Lamps:

- High Intensity Discharge (HID)- High Pressure Sodium and Metal Halide most common types
- Available in various light sources shapes, sizes, bases and operating positions.
- Luminaire and ballast specific.
- Have different color, lumen output, levels of depreciation and mortality.
- Information available from suppliers.
- In most cases luminaire and lamp suppliers are separate companies. Information is often misleading.

Lamp Terms (CCT)

The Correlated Color Temperature Scale

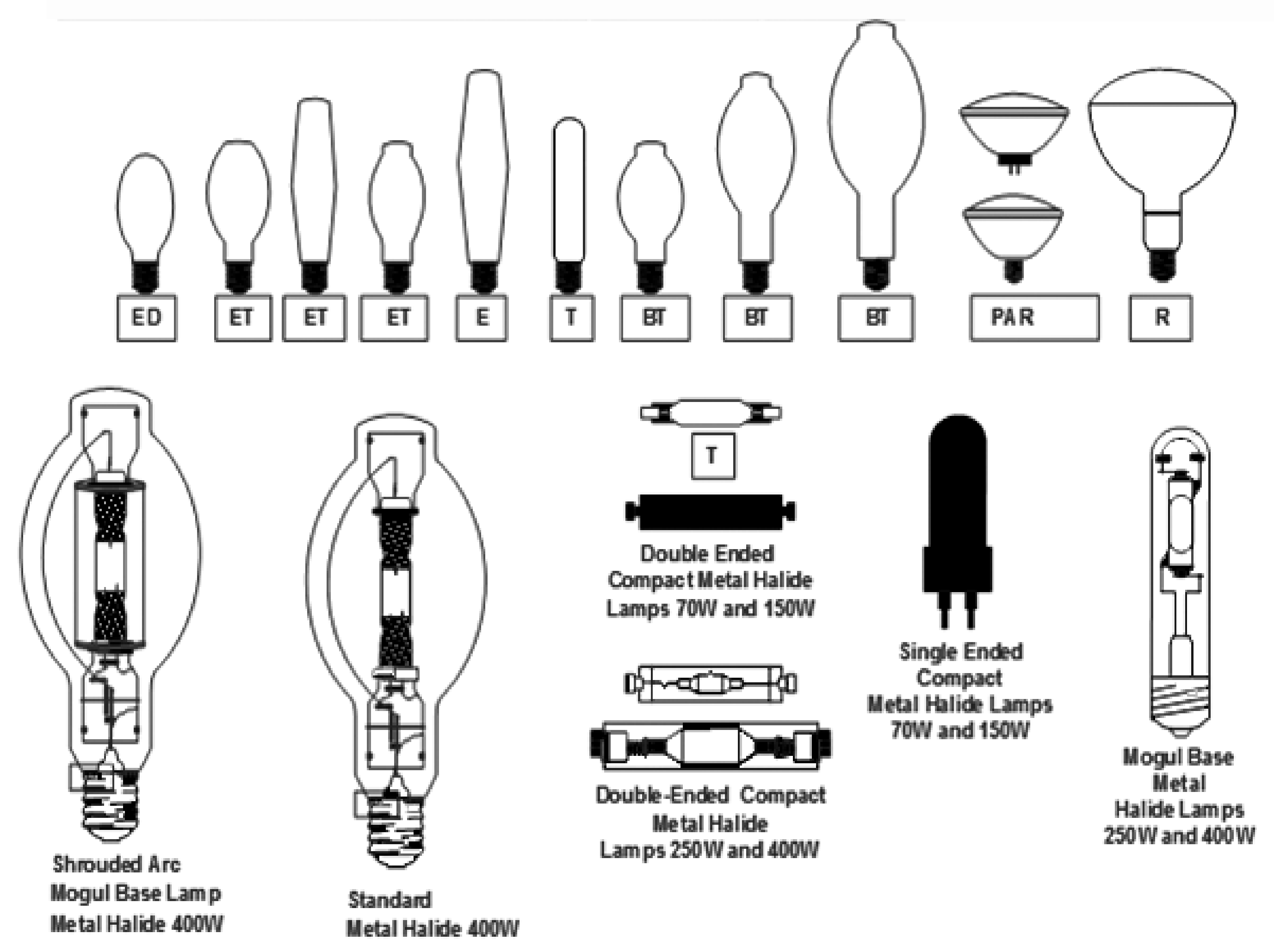
The color appearance of various light sources can be defined in terms of color temperature, measured in "degrees" kelvin (K).



Lamp Terms (CRI)

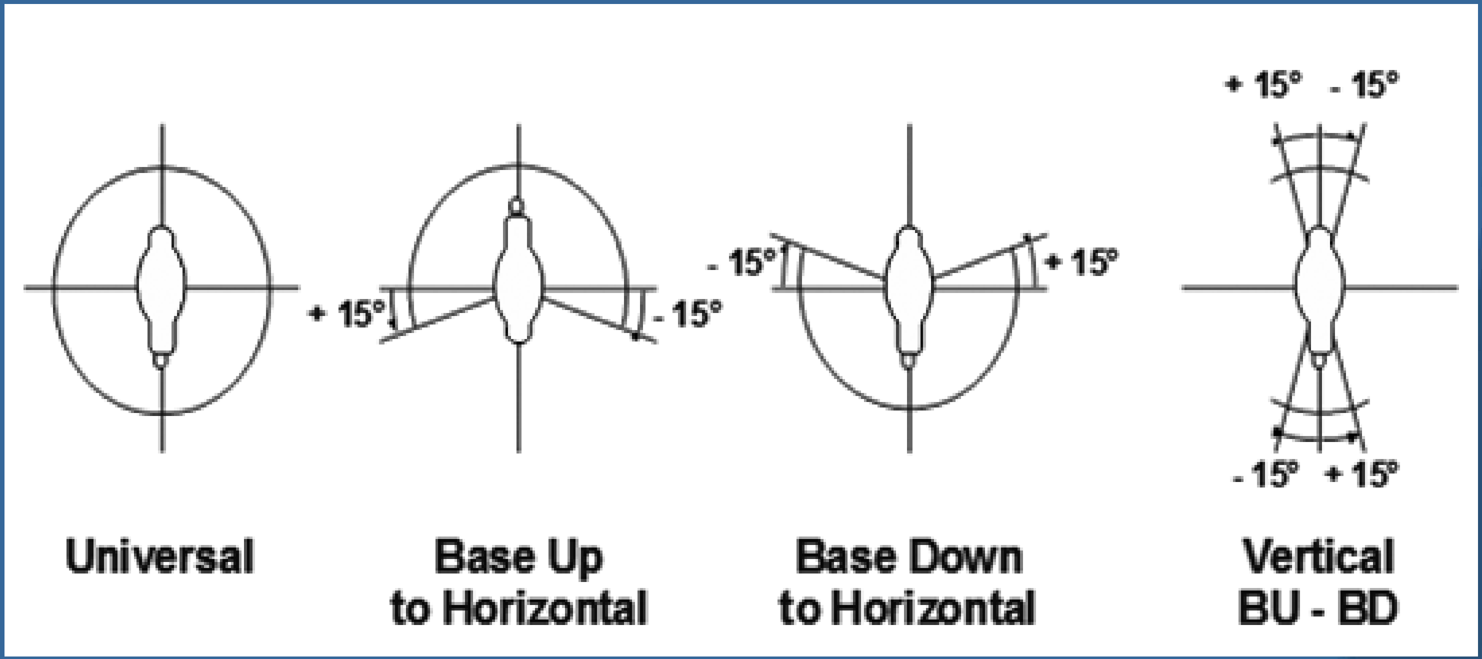
- The CRI describes how well an object's colors are rendered by a source.
- The color chips are examined under daylight and under the source. The less color shift, the higher the CRI (0-100).
- The higher the CRI the better the color rendition

HID Lamp Types (ref IMSA)

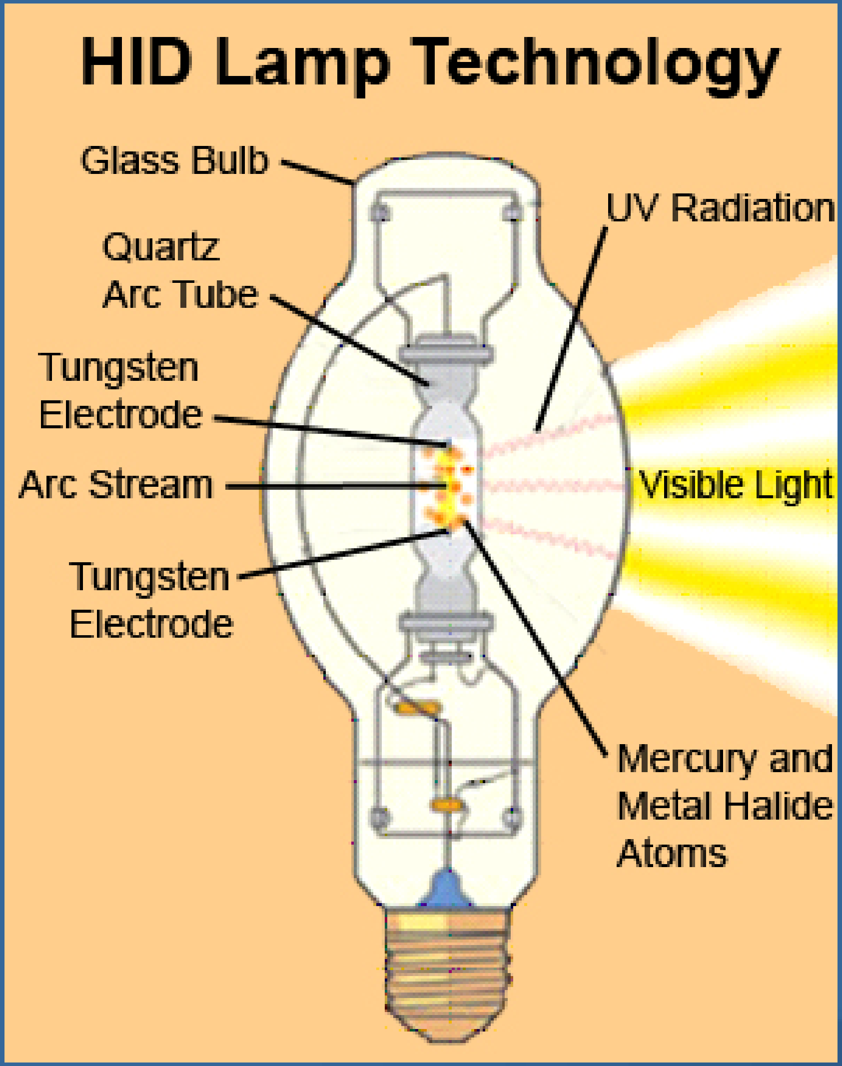


Lamp Operating Positions

Universal is misleading term.
Most lamp testing based on vertical base up. Factors often need to be applied. Read fine print and footnotes on lamp supplier sheets.



Typical HID Lamp



HID Light Sources

A number of light sources and lamp types can be used for roadway lighting. Currently the most common type is high pressure sodium. Growing in popularity it metal halide

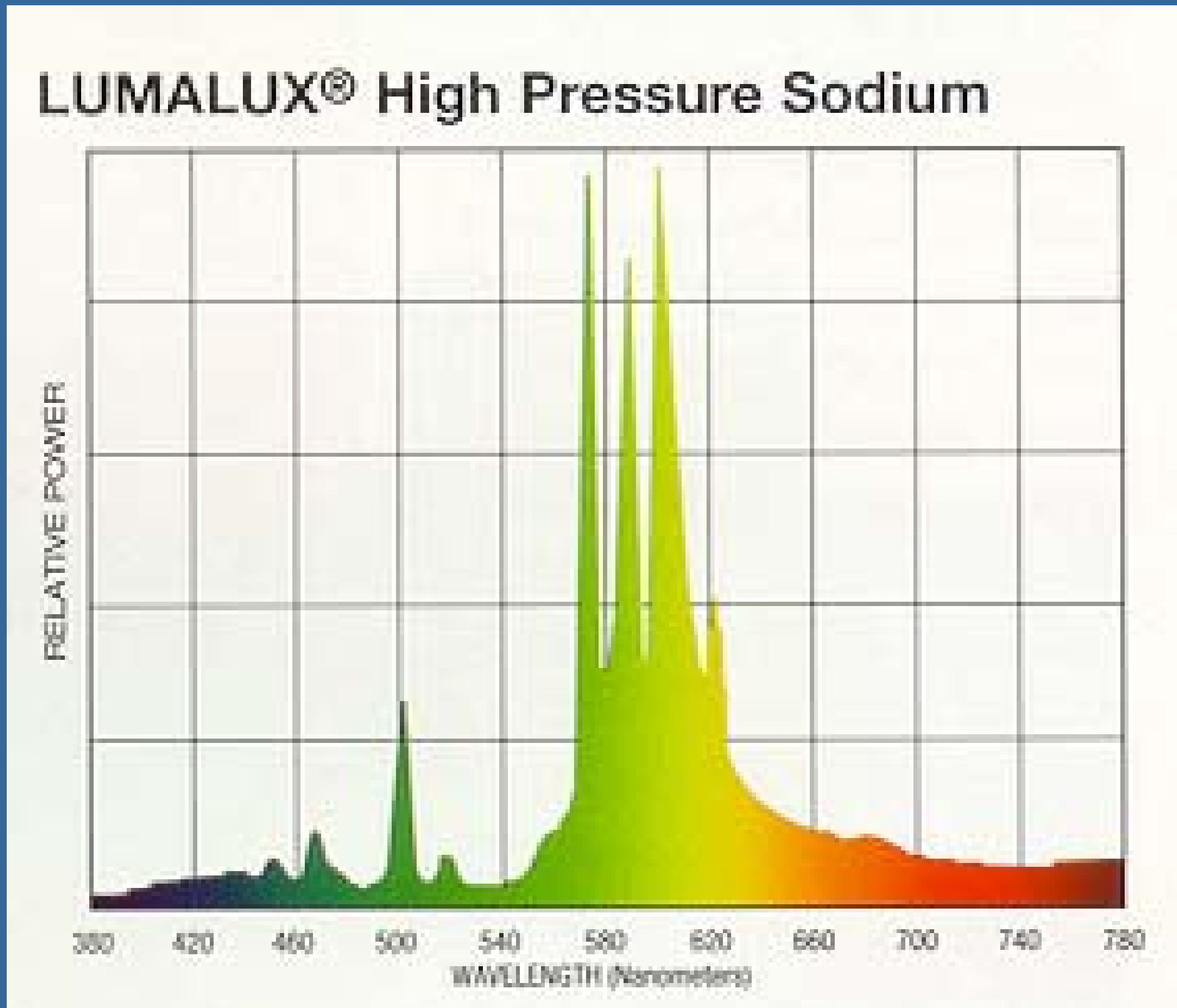
Key Issue:

The American National Standards Institute (ANSI) lists a specific code on the lamp so one can select the correct ballast to operate the lamp. One can't simply use any lamp in any luminaire. The ANSI lamp code must match that of the ballast.

High Pressure Sodium (yellowish glow)

- High Efficacy
- Long life
- Poor color rendering
- Low cost
- Environmentally friendly (low mercury)

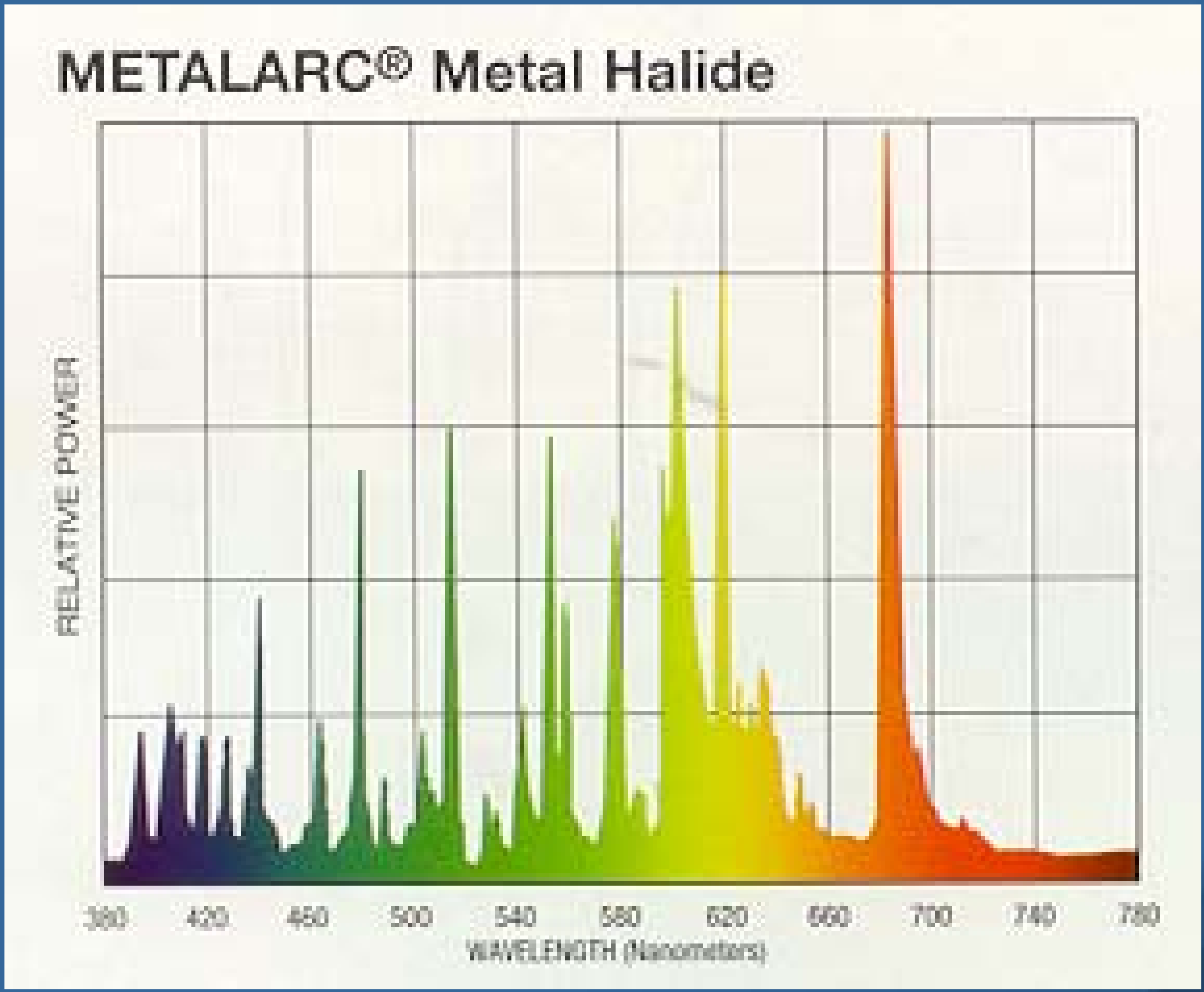
High Pressure Sodium



Metal Halide

- Good color rendition
- Lamp life varies (getting closer to HPS)
- Lumen depreciation can be an issue with probe start
- High cost

Metal Halide



HPS vs Metal Halide

High Pressure Sodium

Metal Halide

Object Detection

Visual Clarity

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Metal Halide vs HPS

- Recent research by Dr. Werner Adrian (University of Waterloo) show that HPS reflects of pavement approx 21% to 25% better than MH
- Other research show MH to more effective with respect to ones peripheral vision. Recent research by Dr Ian Lewin show improvements in reaction time with metal halide

The debate lives on

Additional Consideration - Lumen Depreciation Comparison

Typical High Pressure Sodium:

- 10% at 3 years
- 16% at 4 years
- 22% at 5 years

Typical Pulse Start Metal Halide

- 20% at 1 years
- 30% at 2 years
- 35% at 3 years

Typical Probe Start Metal Halide

- 40% at 1 years
- 53% at 2 years

Ballast Components

The purpose of the ballast is to provide the proper starting and operating voltage and current to initiate and sustain the arc discharge between the electrodes of the lamp.

Common Types are:

- Reactor and High Reactance
- CWA / CWI
- Mag-Reg

Most luminaires require a starter and capacitor

Ballast Terminology

Line Voltage Variation – Line voltage variation is the variance in which the ballast can operate to meet lamp manufacturer's specifications. *Starting problems can occur when the line voltage drops below the defined limits.*

Ballast Losses – Ballast losses represent the power consumed by the ballast to operate the lamp. Line input watts minus lamp watts equal ballast losses. For example a 100W HPS reactor ballast would have an input wattage of 118W minus the lamp wattage would equal a loss of 18W, whereas, a CWI ballast of the same wattage would have an input wattage of 132W; therefore, its losses would be 32W.

Power Factor (PF) – PF is a measure of the relationship between the alternating current source voltage and the actual current. PF determines the amount of current required by the ballast. High PF ballasts require less AC current to provide optimum lighting when compared to the equivalent normal PF ballast. High PF ballasts will operate at 90% or better. Use of ballasts with a power factor below 90% should be avoided as utility companies may apply a premium where the PF is below 90 percent.

Voltage Dip Tolerance – The ability of the ballast to operate the lamp during voltage drops.

Lamp Wattage Regulation – Voltage fluctuations will impact lamp wattage and light output. As lamp voltage is reduced so is the lamp wattage.

Ballast Comparisons

	Reactor/High Reactance Autotransformer	Constant Wattage Autotransformer/ Constant Wattage Isolated	Mag-Reg
Line Voltage Variation	+/- 5%	+/- 10%	+/- 10%
Ballast Losses	20% to 50% less than Meg-Reg	10% to 40% less than Meg-Reg	
Power Factor	55% (Normal) 90% (High)	90% +	90% +
Voltage Dip Tolerance	15% to 7%	50% to 10%	55% to 25%
Lamp Wattage Regulation	2.5% change in wattage for every 1% change in line voltage	1.5% change in wattage for every 1% change in line voltage	0.8% change in wattage for every 1% change in line voltage

Based on GE Catalog

Ballast Components

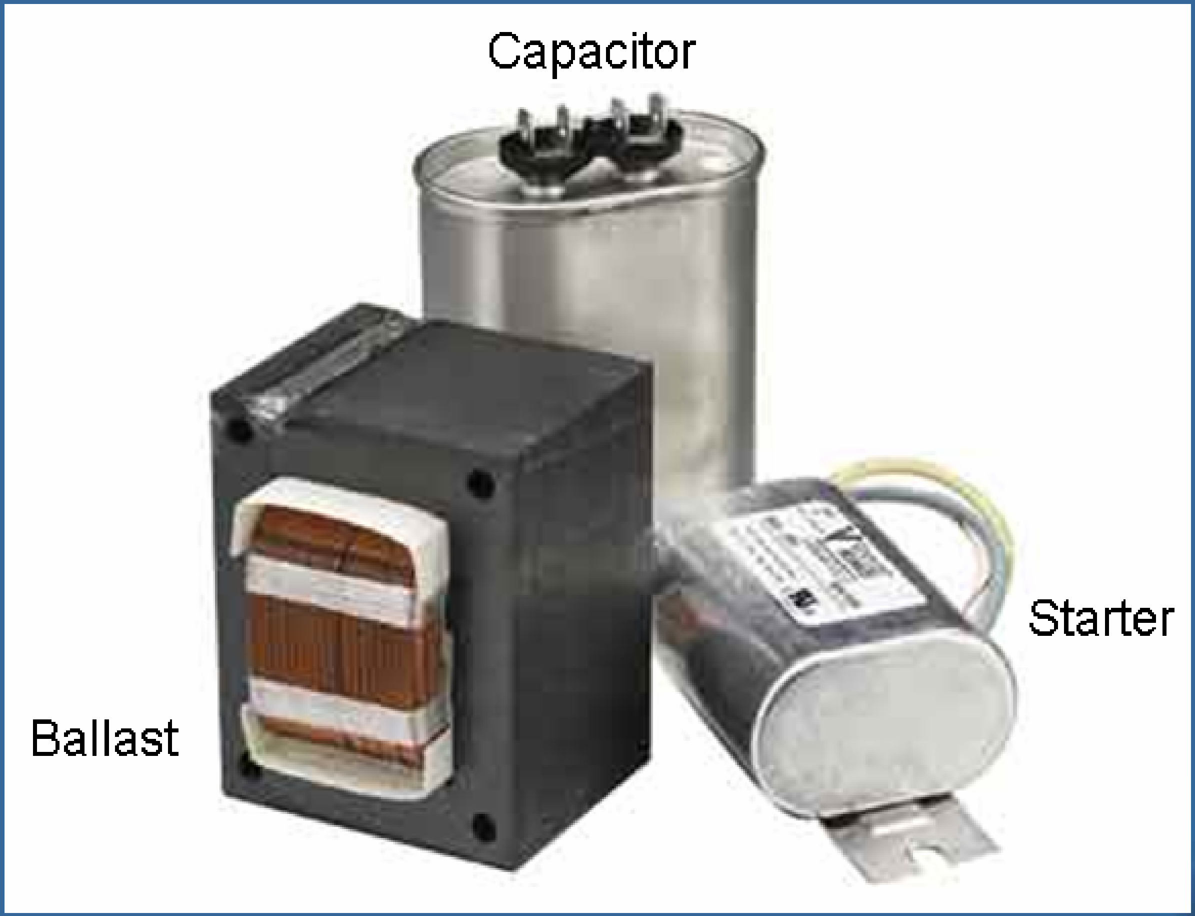
The purpose of the ballast is to provide the proper starting and operating voltage and current to initiate and sustain the arc discharge between the electrodes of the lamp.

Common Types are:

- Reactor
- CWA
- CWI
- Mag-Reg

Most luminaires require a starter and capacitor

Magnetic Ballast Components



Electronic Ballasts

- Emerging technology – Prominent with low wattage MH source used in buildings
- Improve efficiency over traditional magnetic
- Can vary lighting via dimming
- Can improve color and lamp life

Beware of this technology as to date we have found a high failure rate In roadway applications (ref tests By BC Hydro and City of Oakland)

Luminaires

House ballast components (ballast, starter and capacitor), reflector, lens (drop, sag or flat), lamp socket, housing

Optical system have Ingress Protection (IP) rating:

- IP 64 – dust and splash water proof
- IP 65 – Dust and water jet

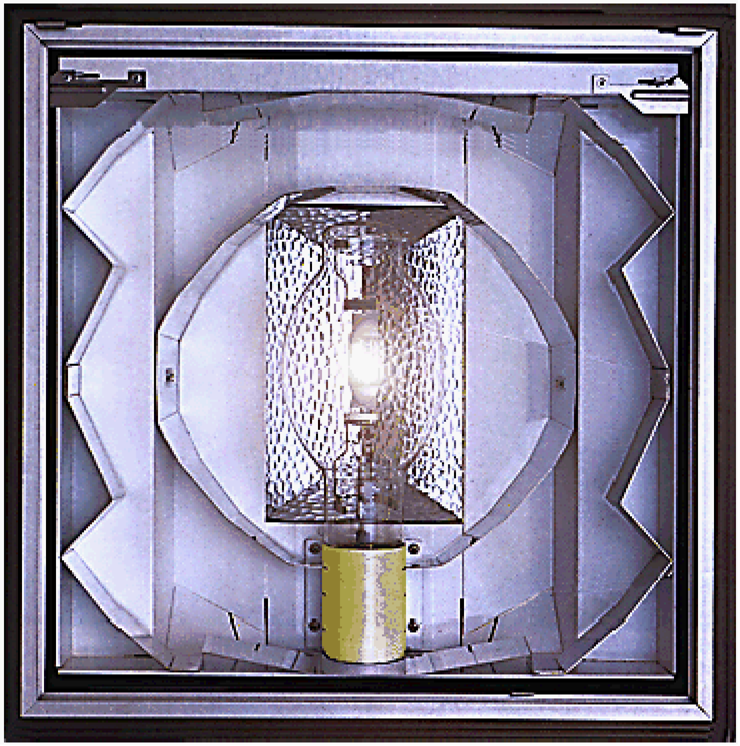
First digit "foreign bodies" second digit "water"

Luminaires - Issues

- Attachment must be reviewed. Needs leveling system.
- Wattage light source label
- Ballast components should have quick disconnect feature
- Where photocell is required it shall be specified. Receptacle for photocell factory mounted

Luminaires

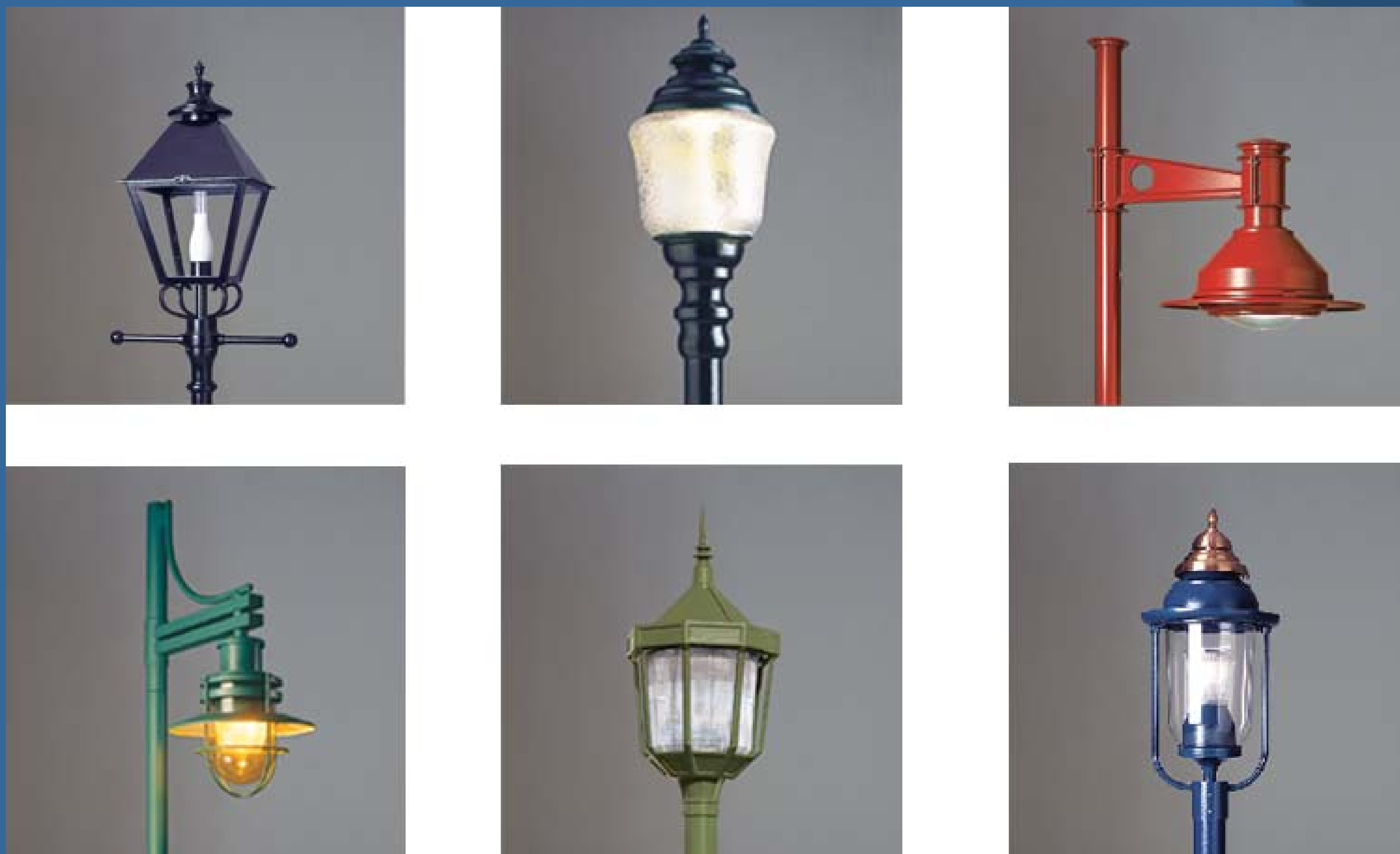
Luminaires



Segmented Reflector

Formed Reflector

Luminaires



Poles

Style

- Davit
- Post top
- Highmast
- Ballard

Material

- Steel (Galvanized, painted, coated)
- Concrete
- Aluminum
- Wood
- Fiberglass

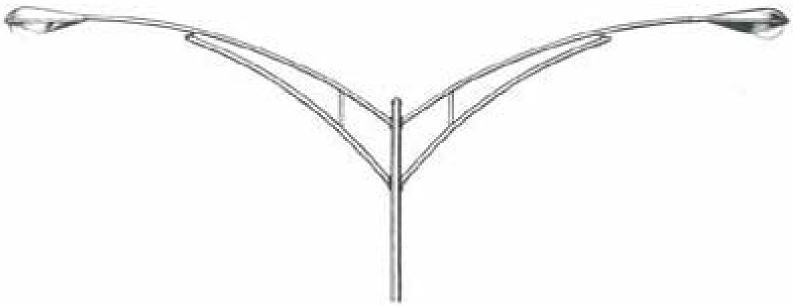
Mounting

- Foundation (concrete, screw in type)
- Direct bury

Poles

Round Tapered Poles with Luminaire Arms | External and Internal Hinged Poles | Round Non-Tapered Poles | Tapered Poles | Fatigue Resistant Square Non-Tapered Poles | Round Tapered Low Level Lighting Poles

Poles



Highmast

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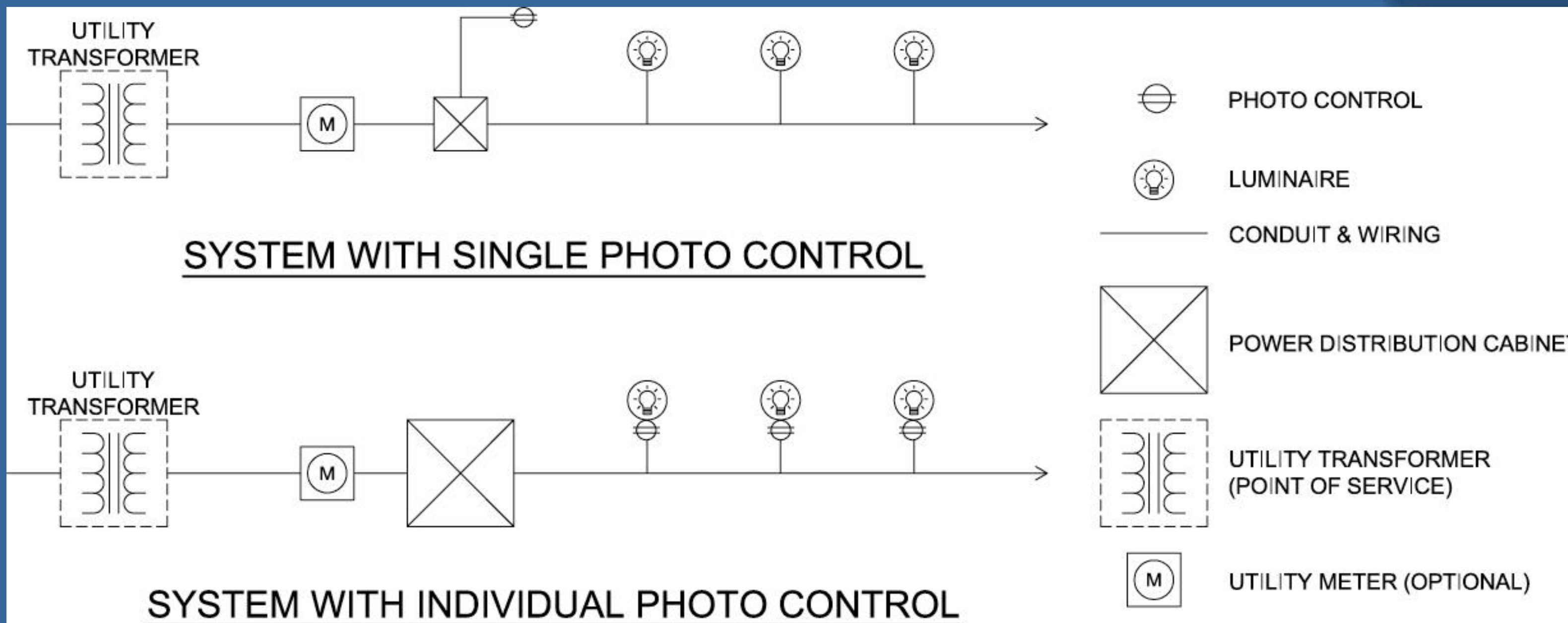
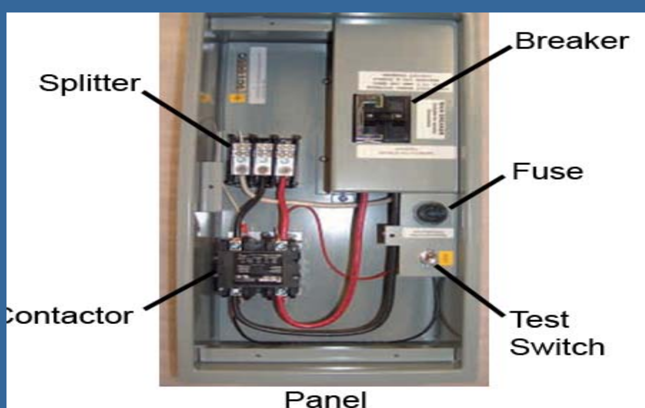
Electrical and Controls





Clear Zone (Breakaway Devices)

Clear Zone (Breakaway Devices)

Coupler

Frangible

Slip base

Ref IMSA 4.4

New Concepts and Technologies

IESNA Luminaire Classification System (LCS)

- New method which will replace traditional cutoff classification system (ie; full, semi, non, etc)
- Define in IESNA TM-15 (new document)
- Will be valuable design tool

Luminaire Classification System

LCS defines the standard solid angles for evaluation and comparison of outdoor luminaires.

It provides a basic model from which limits for lumens within the solid angles by lighting zone and application type will be defined.

LCS utilizes existing photometric test data and can be easily reported by manufacturers or incorporated into software tools.

LCS enables designers to evaluate and compare the distribution of lumens for various types of luminaire optics, thus assisting in the selection of the luminaire most appropriate for the application.

As illustrated, the primary solid angles defined by the LCS are:

- Forward Light
- Back Light
- Uplight

The sum of percentages of lamp lumens within these three primary solid angles is equal to the photometric luminaire efficiency.

Luminaire Classification System

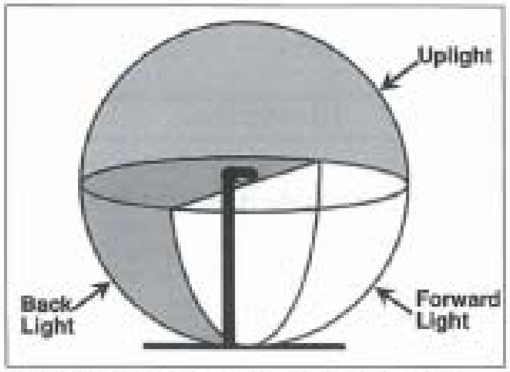


Figure 1. The three primary solid angles of the Luminaire Classification System (LCS).

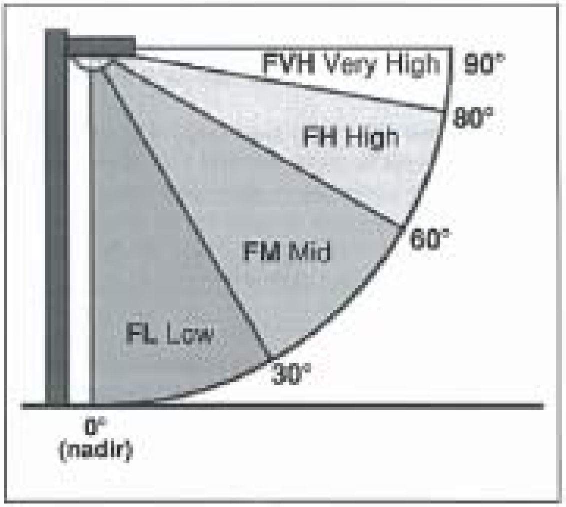


Figure 3. (top) Plan view for forward solid angle, (bottom) Section view for forward solid angle.

Luminaire Classification System

HPS Type II	 100 Watt	 150 Watt	 150 Watt
Forward Light			
Luminaire Lumens	5,365	8,589	9,188
% Lamp Lumens	56.5%	53.7%	57.4%
FL (0°-30°)	6.8%	5.0%	11.5%
FM (30°-60°)	24.5%	27.3%	27.6%
FH (60°-80°)	24.8%	20.6%	17.1%
FVH (80°-90°)	0.4%	0.8%	1.3%
Back Light			
Luminaire Lumens	1,985	3,447	3,832
% Lamp Lumens	20.9%	21.5%	24.0%
BL (0°-30°)	4.2%	4.1%	5.2%
BM (30°-60°)	10.7%	12.3%	11.8%
BH (60°-80°)	5.7%	4.4%	6.0%
BVH (80°-90°)	0.3%	0.8%	0.9%
Uplight			
Luminaire Lumens	42	0	390
% Lamp Lumens	0.4%	0.0%	2.4%
UL (90°-100°)	0.2%	0.0%	1.1%
UH (100°-180°)	0.2%	0.0%	1.3%
Trapped Light			
Luminaire Lumens	2,108	3,964	2,589
% Lamp Lumens	22.2%	24.8%	16.2%

LED's (the facts/fallacies)

- Products are over-hyped with false performance claims
- Recent tests undertaken by the US Department of Energy shows when tested efficacy (lumens/watt) was one third of what was promoted
- In a 2002 report entitled "Light Emitting Diodes for General Illumination OEDA TECHNOLOGY ROADMAP UPDATE" the goal is for LED's to be an HID retrofit by the year 2020.
- Many products don't have photo-metrics available
- Can't retrofit HID system and meet required levels
- See LUKOS Article (link)

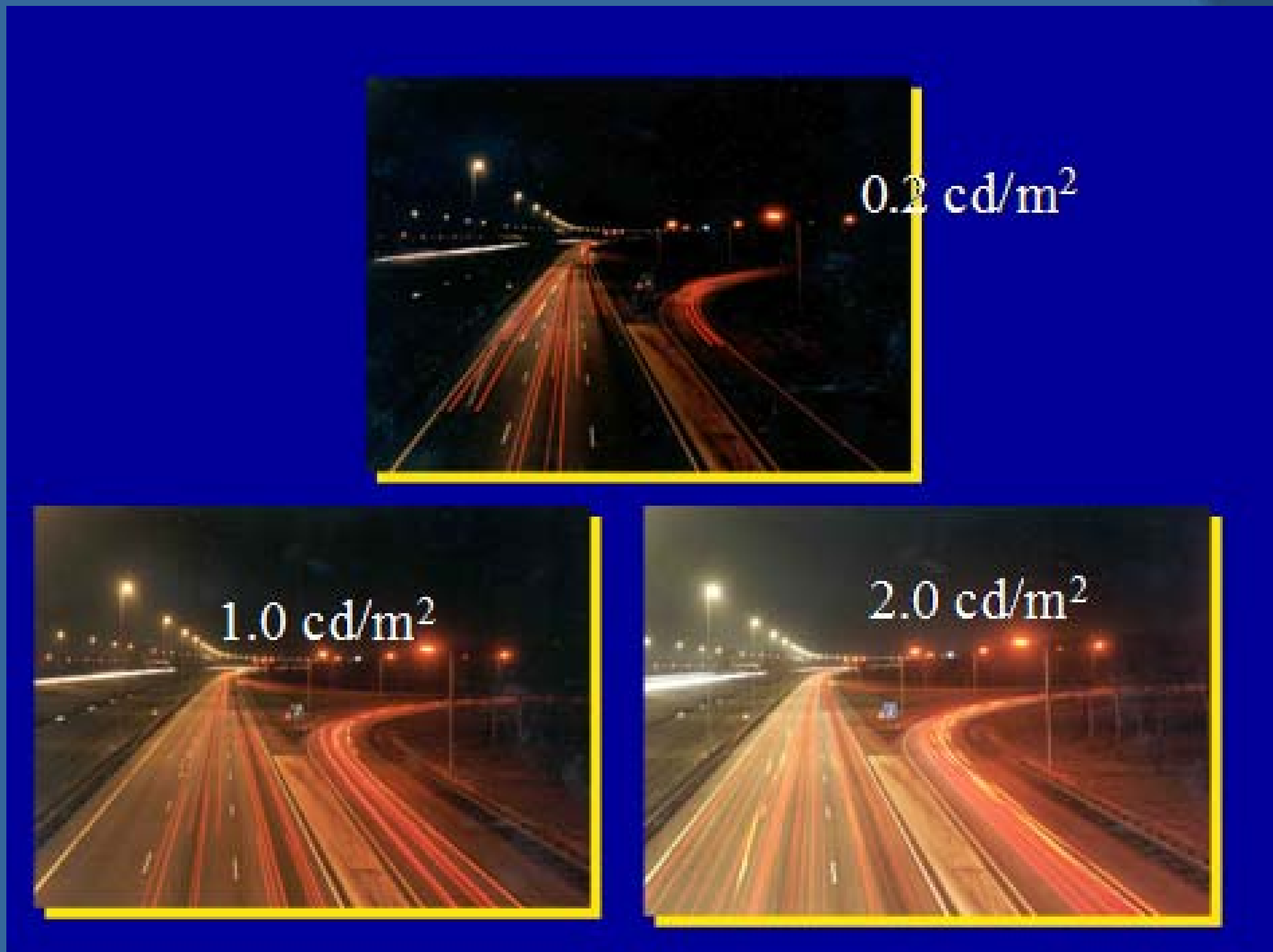
LED's (issues)

- Heat is issues
- Lumen depreciation
- Distribution patterns
- Low efficacy
- High Cost
- At best half efficacy of HPS

Adaptive Lighting (new term):

"The ability to vary lighting levels to suit activity levels."

Adaptive Lighting (new term):



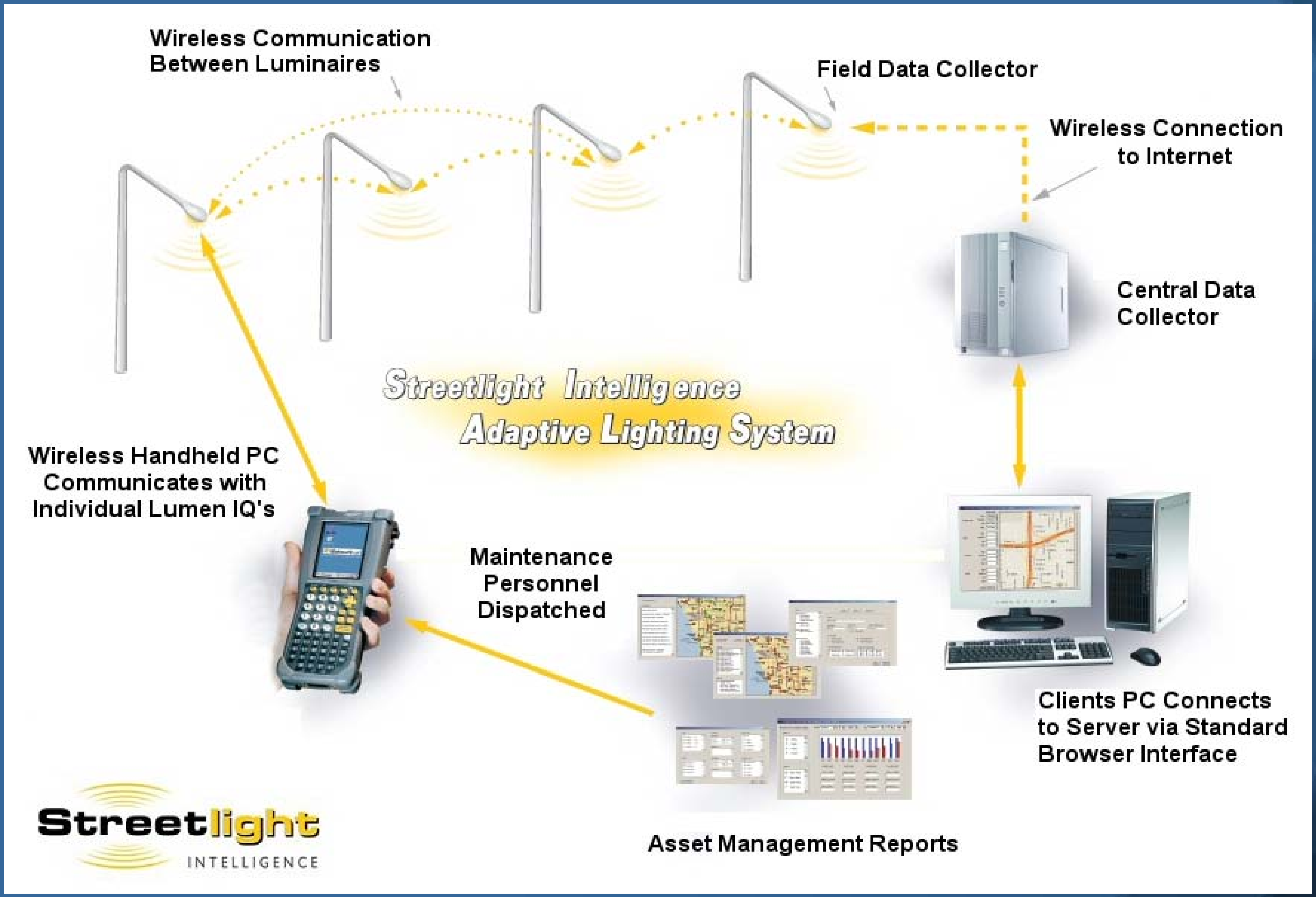
Potential Benefits of an Adaptive Street Lighting System:

- Reduced Energy Consumption
- Obtrusive Light Reduction
- Power Consumption Monitoring
- Streamlined Asset Management
- Alerts of wire theft

Adaptive Street Lighting System – Potential Energy Savings

Application		Advantages
1	Reduce Lumen Output of Lamps to Maintained Levels	• Energy Savings • Obtrusive Light Reduction
2	Reduce levels on over lighted roads to levels required	• Potential Energy Savings • Obtrusive Light Reduction
3	Match Lumen Output to Variable Pedestrian Activity Levels	• Significant Energy Savings • Obtrusive Light Reduction

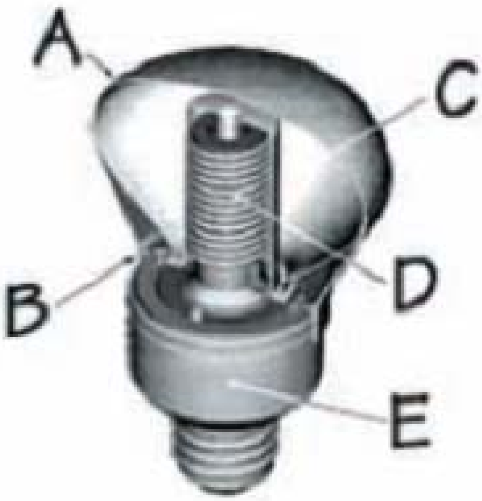
Example Adaptive Lighting System



CSA C653 Luminaire Efficiency:

- CSA C653 establishes a method to assess luminaire efficiency. Current system is not effective.
- New system will be based on luminance and unit power density. Unity power density is "watts per area (m2)"
- It is joint effort between suppliers and designers.
- Will list luminaires which meet requirements.
- C653 will apply to "cobra head" luminaires

E Lamps (Induction):



A. Phosphor Coating
B. Plastic Housing
C. Electron/Ion Plasma
D. Induction Coil
E. Electronics

E Lamps (Induction)

- Light generation by means of induction combined with a gas discharge
- Energy source is lamp's induction coil which is powered by a high frequency generator
- A current is induced in the low pressure gas and metal vapour in the lamp bulb
- Ultra violet radiation is emitted and falls on the fluorescent coating of the lamp envelope causing light to be emitted (Fluorescence)

E Lamps (Induction)

- Advantages include instant start (hot or cold), excellent CRI, minimal color shift over the life of the lamp, long life, not effected by vibration, low electromagnetic interference (EMI), reduced maintenance, and universal lamp burning position.
- Disadvantages include very high cost, large lamp size limiting retrofit options, limited number of wattages and voltages available, low lumen output for many applications, and lamps will require special disposal as they contain mercury vapor. The generator also runs very hot and needs a heat sink.

Solar Lighting

Questions and Discussions

Break for Lunch

Calculation Examples

Lighting Software Comparison

Roadway Calculation Types and Complex Layouts	Visual Professional Edition v 2.03	Visual Roadway Tool	GenesysII v 2000.1.7	AutoLUX v 7.69	AGI32 v 1.66	LumenMicro 2000 v 2000.2	Simply Roadway Lighting v 2002.1.8
Illuminating Engineering Society of North America (IESNA)**	Y	Y	Y	Y	Y	Y	Y
Commission Internationale de l'Eclairage (CIE)	Y	Y	N	Y	Y	N	Y
Commission Internationale de l'Eclairage (CIE)-Australian	N	N	N	N	Y	N	N
Complex Layouts (Curves)*	2	1	3	4*	4*	3	1

(Column group heading: Software Package)

Key

Y = Yes
N = No
1 = Straight Section Only
2 = Illuminance only for Complex Layouts
3 = Illuminance, Pavement luminance, Lv Ratio for Complex Layouts
4* = Illuminance, Pavement Luminance, Veiling Luminance for Complex Layouts (Curves)

*Feature Required for Luminance Calculations on Curves
**Feature Required to do a Roadway Lighting Calculation

Lighting Calculation Examples

[Click here]

Computer Software

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Roadways

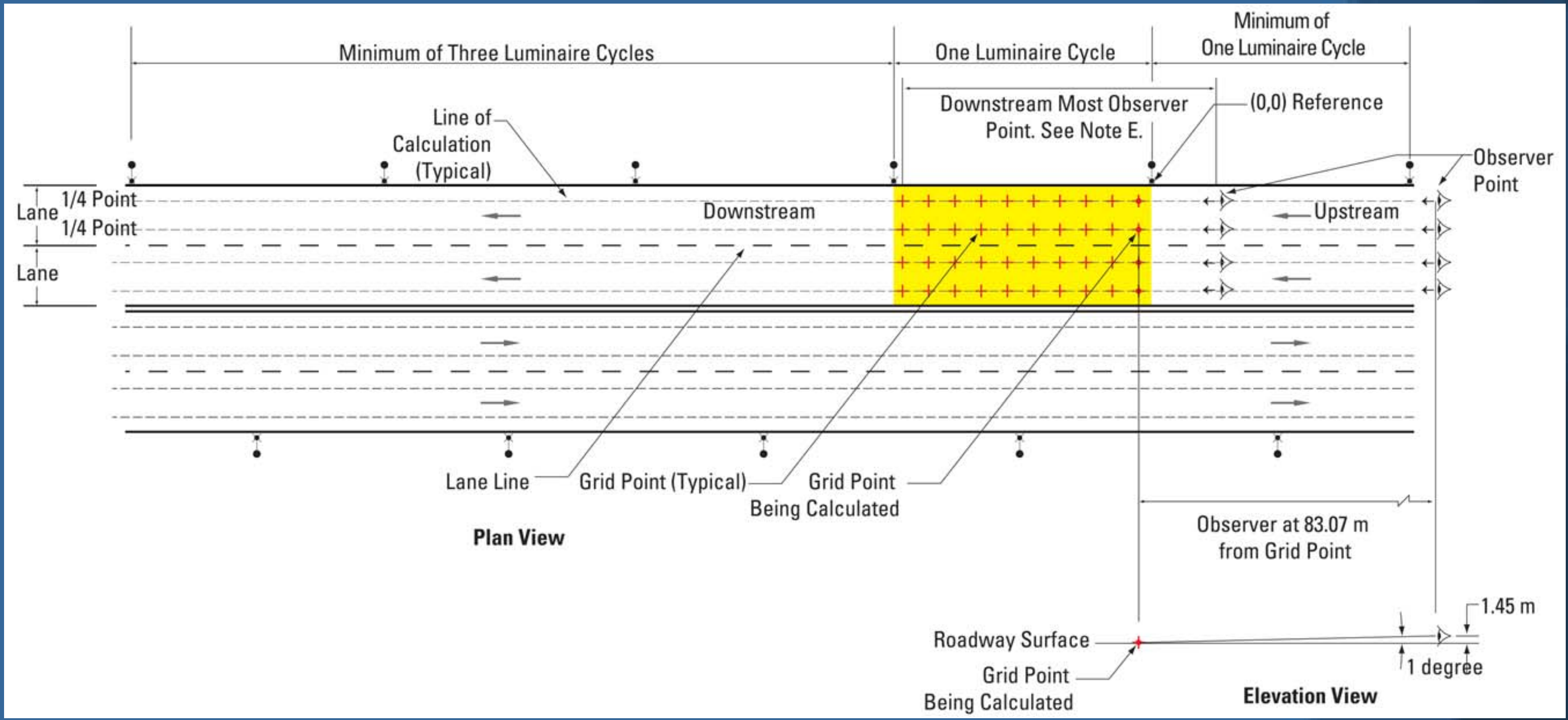
Roadway Luminance Levels

Road Area and Pedestrian Activity: Road Type	Road Area and Pedestrian Activity: Pedestrian Activity	Average Luminance cd/m^2	Average-to-Minimum Uniformity Ratio	Maximum-to-Minimum Uniformity Ratio	Maximum-to-Average Veiling Luminance Ratio
Freeway	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Partial Lighting of Interchange On-Ramps/ Off-Ramps	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Expressway-Highway	High	≧ 1.0	≦ 3.0	≦ 5.0	≦ 0.3
	Medium	≧ 0.8	≦ 3.0	≦ 5.0	≦ 0.3
	Low	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Arterial	High	≧ 1.2	≦ 3.0	≦ 5.0	≦ 0.3
	Medium	≧ 0.9	≦ 3.0	≦ 5.0	≦ 0.3
	Low	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Collector	High	≧ 0.8	≦ 3.0	≦ 5.0	≦ 0.4
	Medium	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.4
	Low	≧ 0.4	≦ 4.0	≦ 8.0	≦ 0.4
Local/Alleyway	High	≧ 0.6	≦ 6.0	≦ 10.0	≦ 0.4
	Medium	≧ 0.5	≦ 6.0	≦ 10.0	≦ 0.4
	Low	≧ 0.3	≦ 6.0	≦ 10.0	≦ 0.4

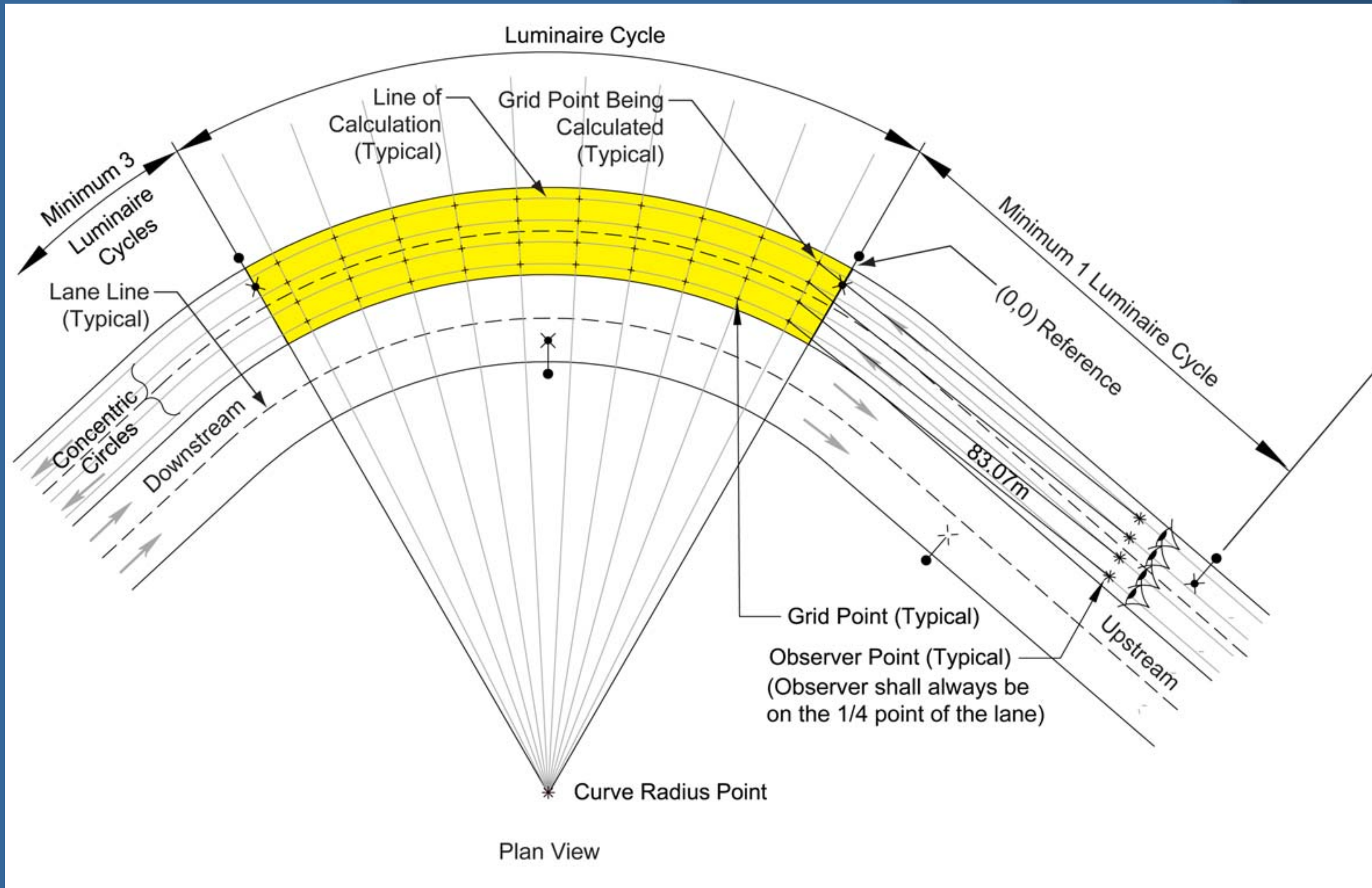
Roadway Pedestrian Illuminance Levels (Sidewalks)

Pedestrian Activity	Maintained Average Horizontal Illuminance (lux)	Average-to - Minimum Horizontal Uniformity Ratio	Minimum Maintained Vertical Illuminance (lux)
High	≧ 20.0	≦ 4.0	≧ 10.0
Medium	≧ 5.0	≦ 4.0	≧ 2.0
Low	≧ 3.0	≦ 6.0	≧ 0.8

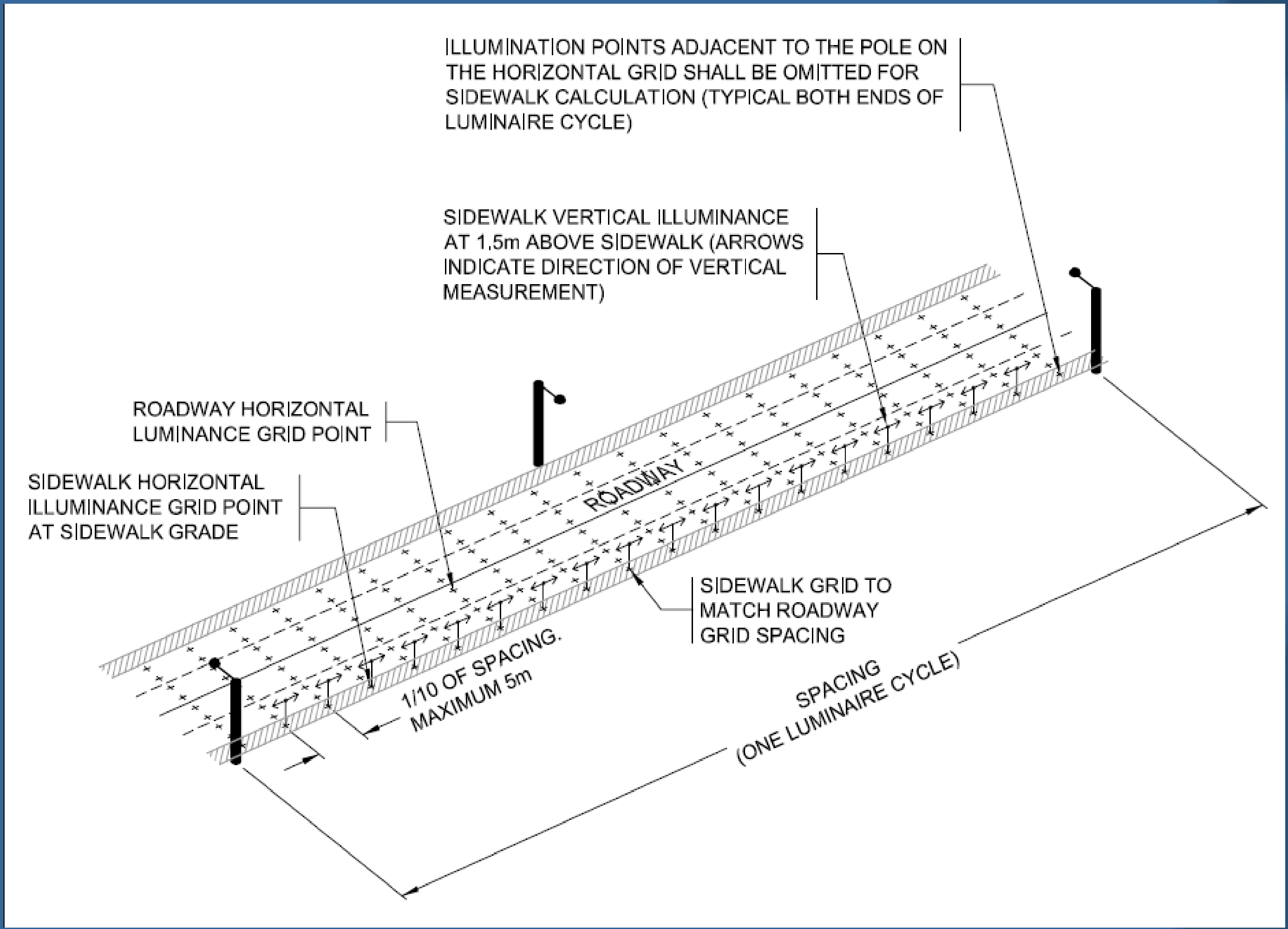
Roadway Calculation Grids



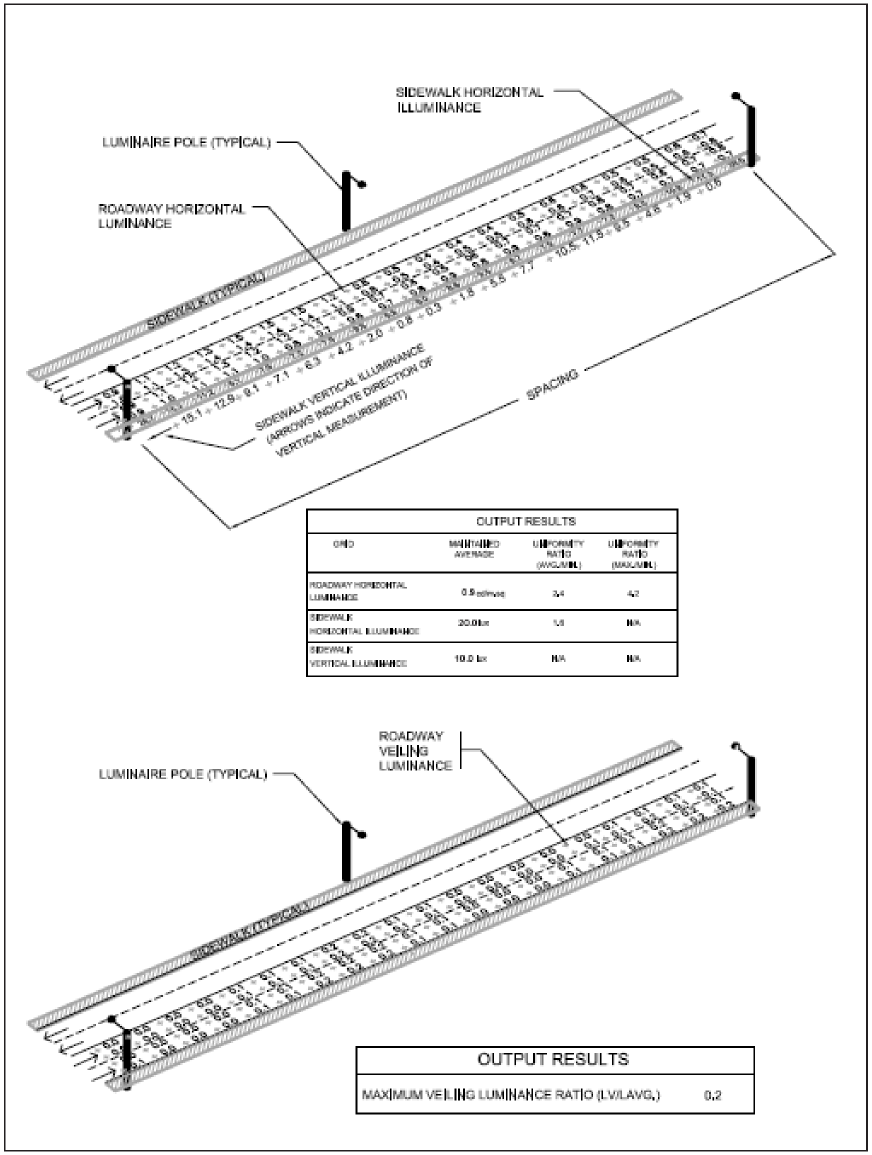
Roadway Calculation Grids



Roadway Calculation Grids



Roadway Calculation Example



OUTPUT RESULTS			
GRID	MAINTAINED AVERAGE	UNIFORMITY RATIO (AVG./MIN.)	UNIFORMITY RATIO (MAX./MIN.)
ROADWAY HORIZONTAL LUMINANCE	0.9 cd/m sq	2.4	4.2
SIDEWALK HORIZONTAL ILLUMINANCE	20.0 lux	1.5	N/A
SIDEWALK VERTICAL ILLUMINANCE	10.0 lux	N/A	N/A

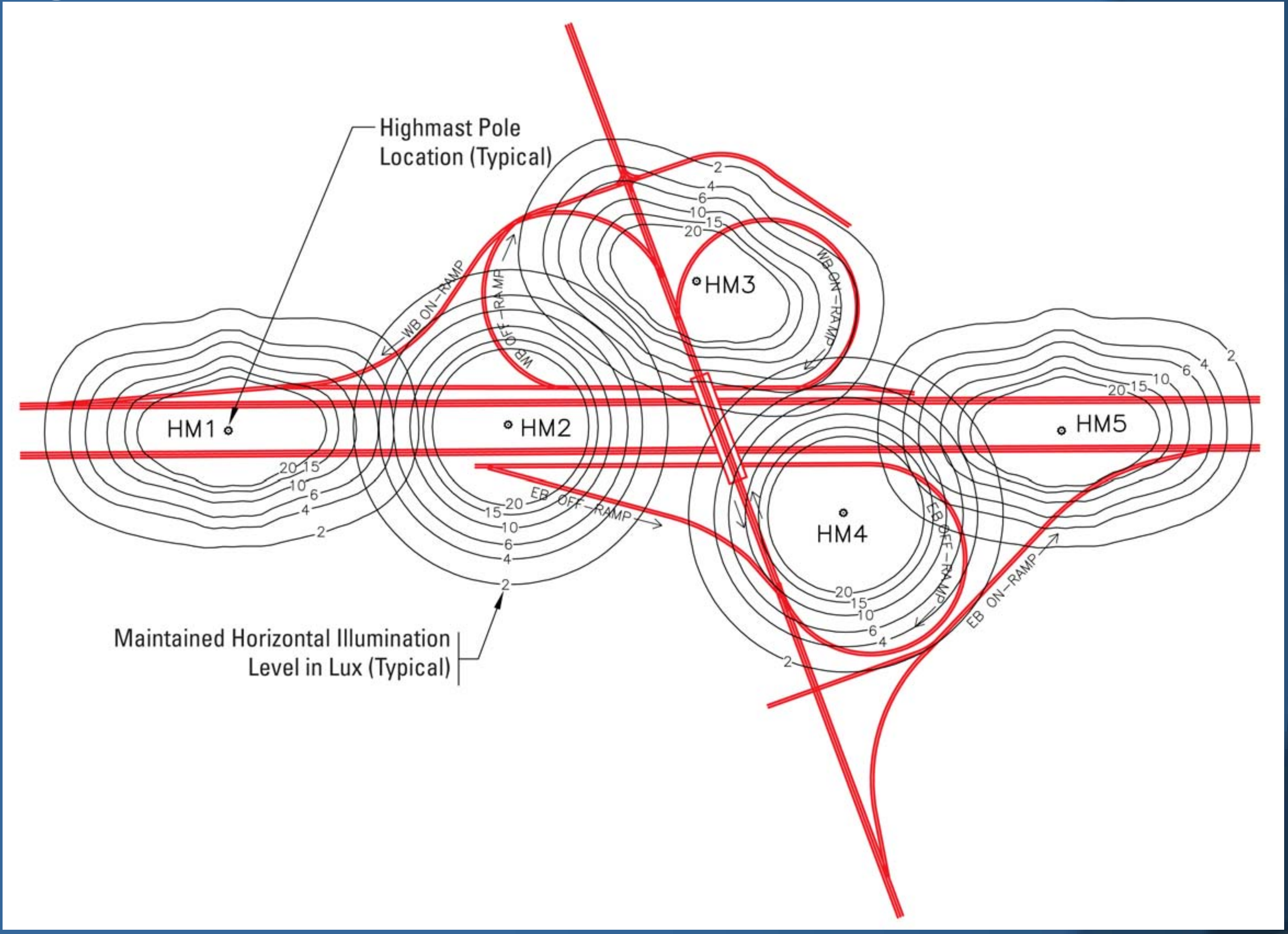
OUTPUT RESULTS	
MAXIMUM VEILING LUMINANCE RATIO (LV/LAVG.)	0.2

Figure 9-21 – Sample Roadway Calculation, Example No. 2, Arterial Roadway

Lighting calc based on one cycle only

Avoid calculating the entire roadway length

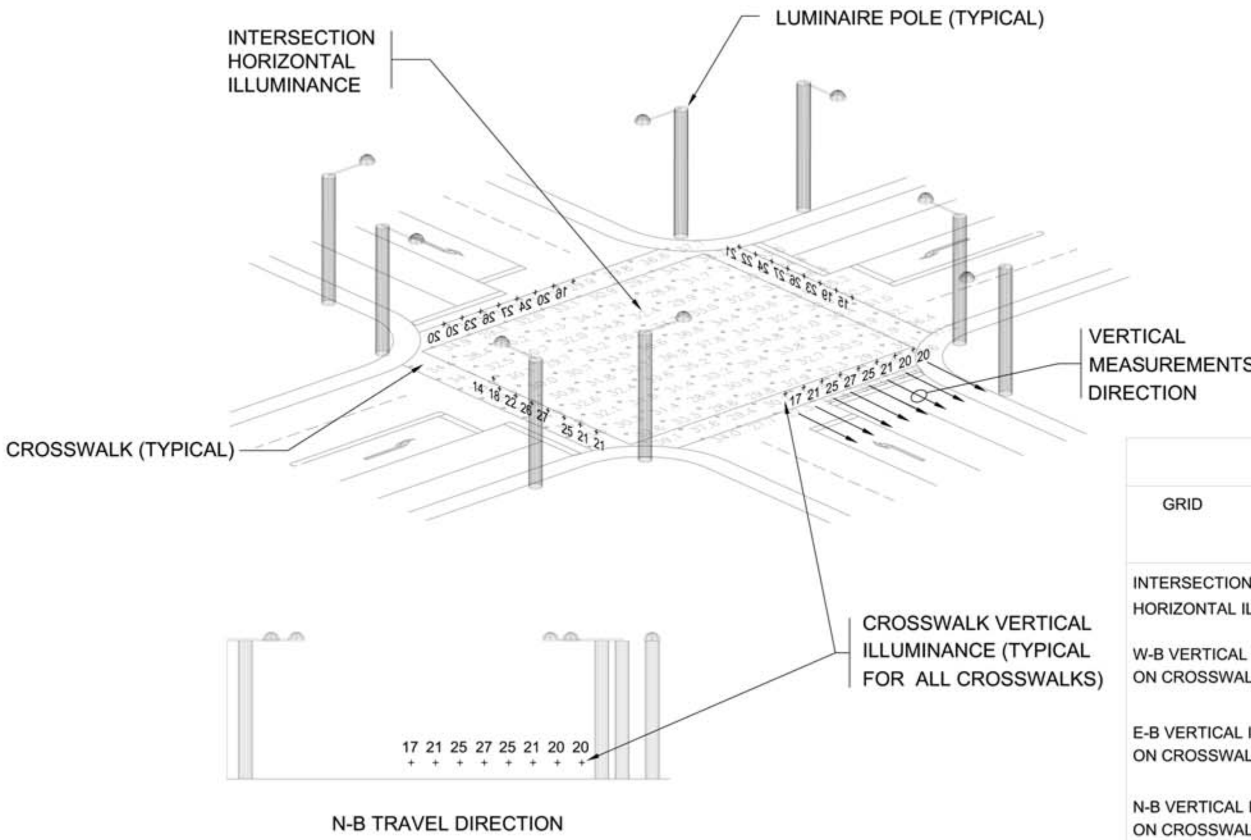
Highmast Calculations



Intersection Lighting

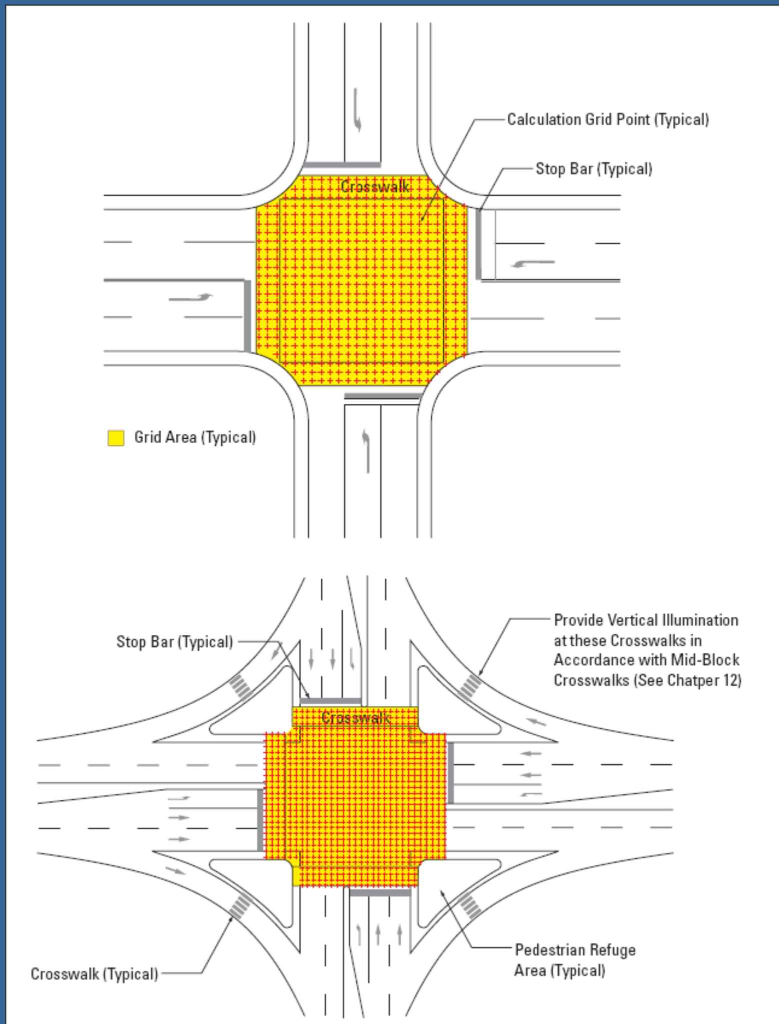
Roadway Classification	Average Maintained Illuminance at Pavement by Pedestrian Conflict (lux)			Average-to-Minimum Uniformity Ratio
	High	Medium	Low	
Arterial/Arterial	34.0	26.0	18.0	≦ 3.0
Arterial/Collector	29.0	22.0	15.0	≦ 3.0
Arterial/Local	26.0	20.0	13.0	≦ 3.0
Expressway-Highway/Arterial	31.0	25.0	18.0	≦ 3.0
Expressway-Highway/ Expressway-Highway/	28.0	24.0	18.0	≦ 3.0
Expressway-Highway/Collector	26.0	21.0	15.0	≦ 3.0
Expressway-Highway/Local	23.0	19.0	13.0	≦ 3.0
Collector/Collector	24.0	18.0	12.0	≦ 4.0
Collector/Local	21.0	16.0	10.0	≦ 4.0
Local/Local	18.0	14.0	8.0	≦ 6.0

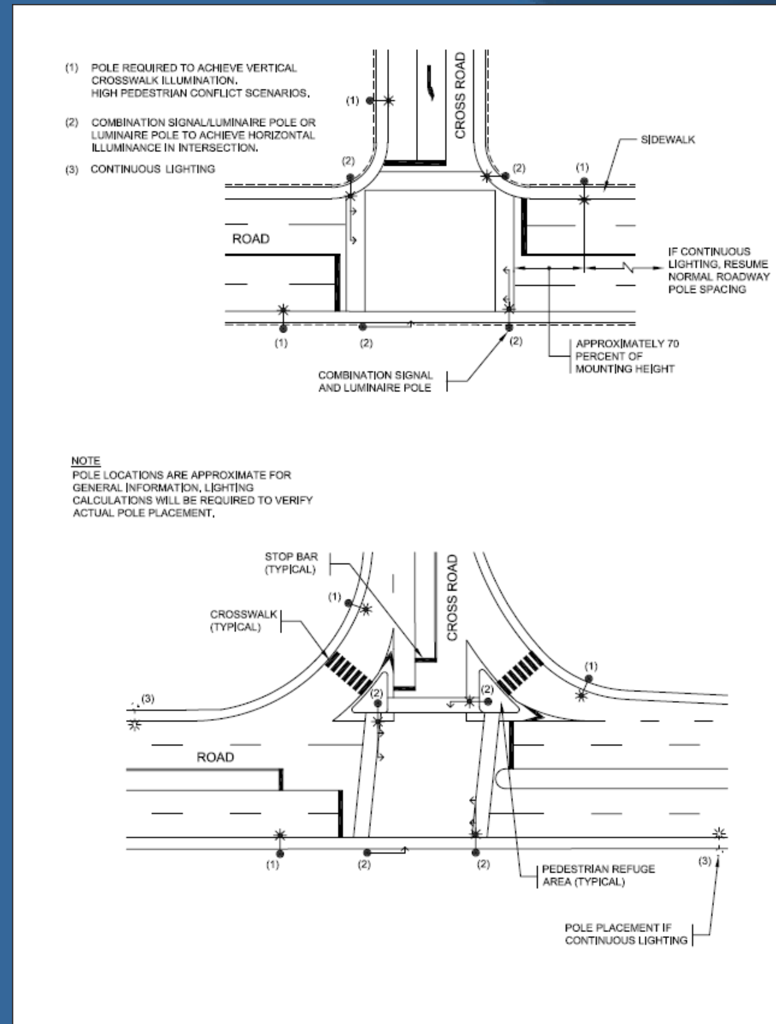
Intersection Calculation Example



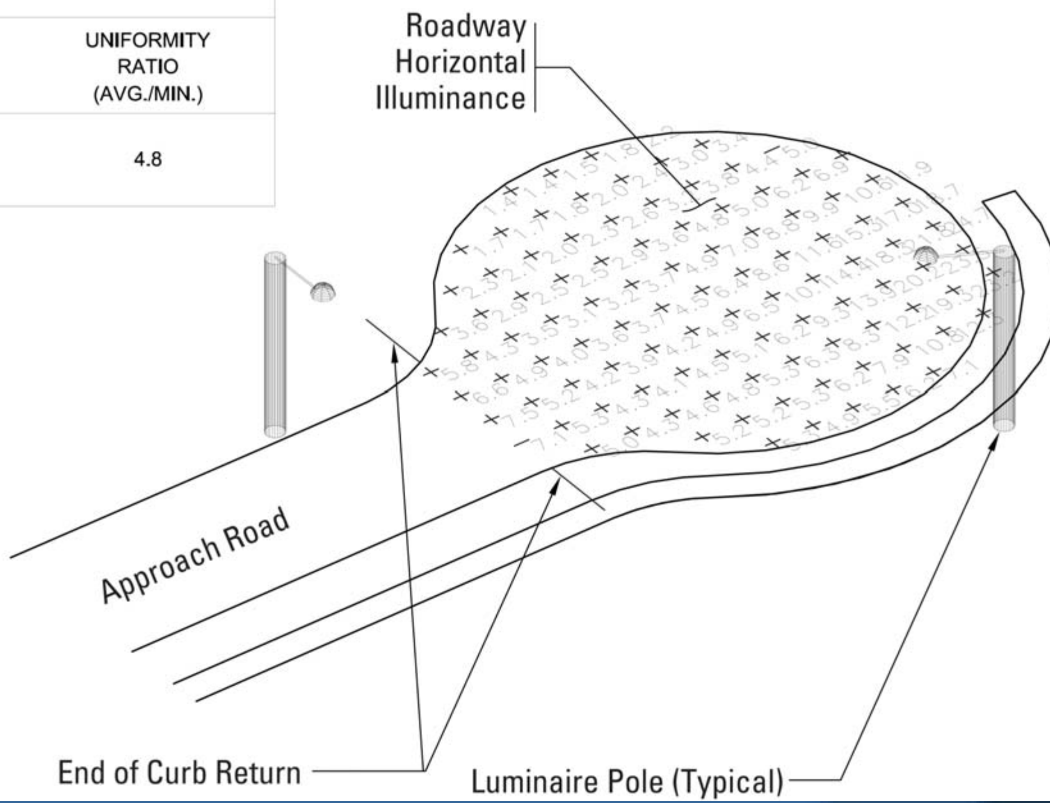
OUTPUT RESULTS		
GRID	MAINTAINED AVERAGE	UNIFORMITY RATIO (AVG./MIN.)
INTERSECTION HORIZONTAL ILLUMINANCE	32.7 lux	1.2:1
W-B VERTICAL ILLUMINANCE ON CROSSWALK	22.0 lux	N/A
E-B VERTICAL ILLUMINANCE ON CROSSWALK	22.0 lux	N/A
N-B VERTICAL ILLUMINANCE ON CROSSWALK	22.2 lux	N/A
S-B VERTICAL ILLUMINANCE ON CROSSWALK	22.3 lux	N/A

Intersection Lighting





OUTPUT RESULTS		
GRID	MAINTAINED AVERAGE	UNIFORMITY RATIO (AVG./MIN.)
C-D-S HORIZONTAL ILLUMINANCE	6.8 LUX	4.8



Lighting Design Tips

Table B1: Common Lighting Systems Changes and The Effects Produced

System Change	Effect on Pavement Luminance	Effect on Small Target Visibility
Increase lamp output *	• Proportional increase • No change in uniformity	Small increase in average
Reduce spacing **	• Increase average • Improve Uniformity	Decrease average
Increase mounting height **	• Decrease average • Improve Uniformity	Decrease average
Increase overhang **	• Increase average • Uniformity change unpredictable	Slight decrease
Change from Staggered to Opposite ***	• No change in average • Improve Uniformity	Large increase
Change from Staggered to Center Mounting ***	• Small change in average • Degrade Uniformity	Large increase

* Assumes no change in luminaire distribution.
** Assumes no change in lamp output or distribution.
*** Assumes spacing is doubled with no change in lamp or luminaire.

Other Applications

Vertical Illumination

- It was found that in Switzerland, a level of 40 vertical lx was used in all crosswalks.
- This level reduced nighttime vehicle to pedestrian crashes by 66%.

Vertical Illumination – Smart Road

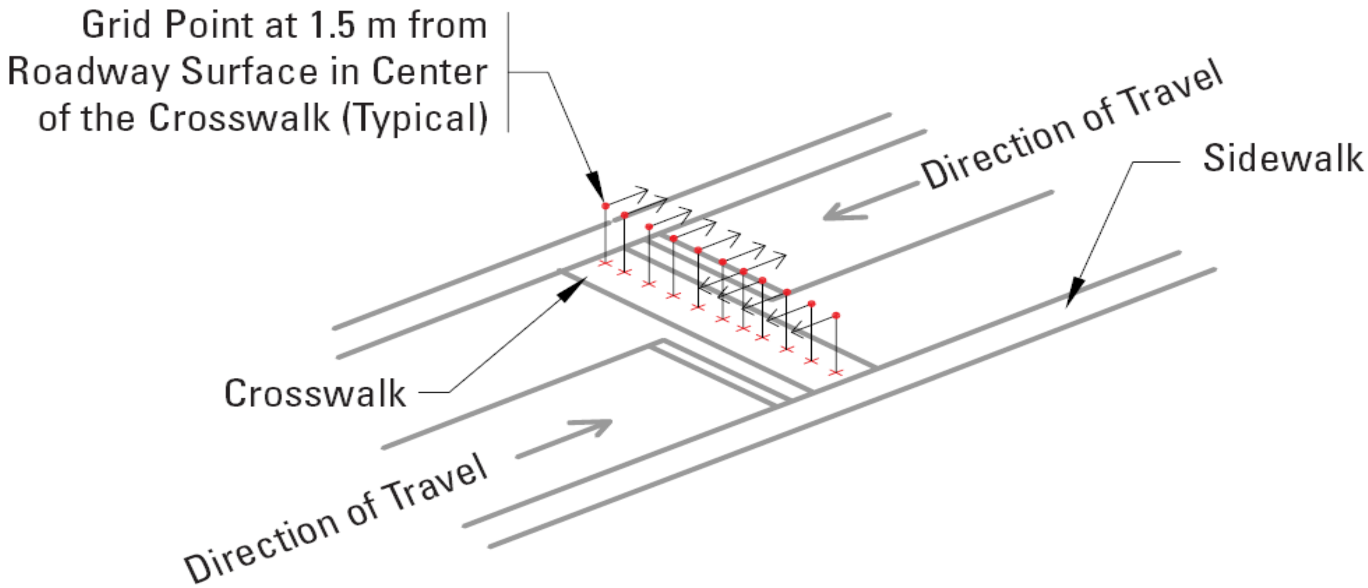
A lighting level of 20 vertical lux seems sufficient for crosswalks with the following limitations:

This is a static test, but dynamic testing may prove that this level needs to be higher.

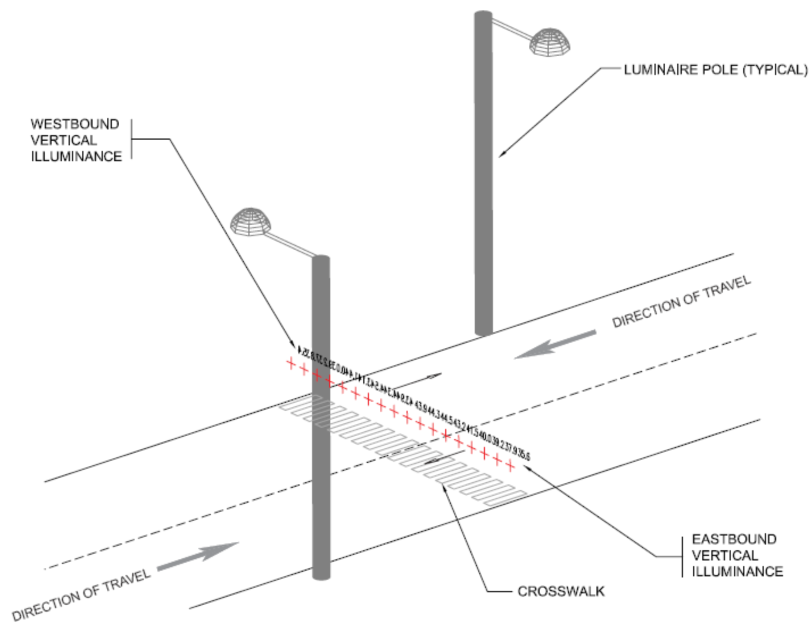
This was a rural road, but an urban area with a complex background may require a higher lighting level.

The addition of overhead lighting does not seem to mitigate the impact of glare.

Mid Block Crosswalk Lighting



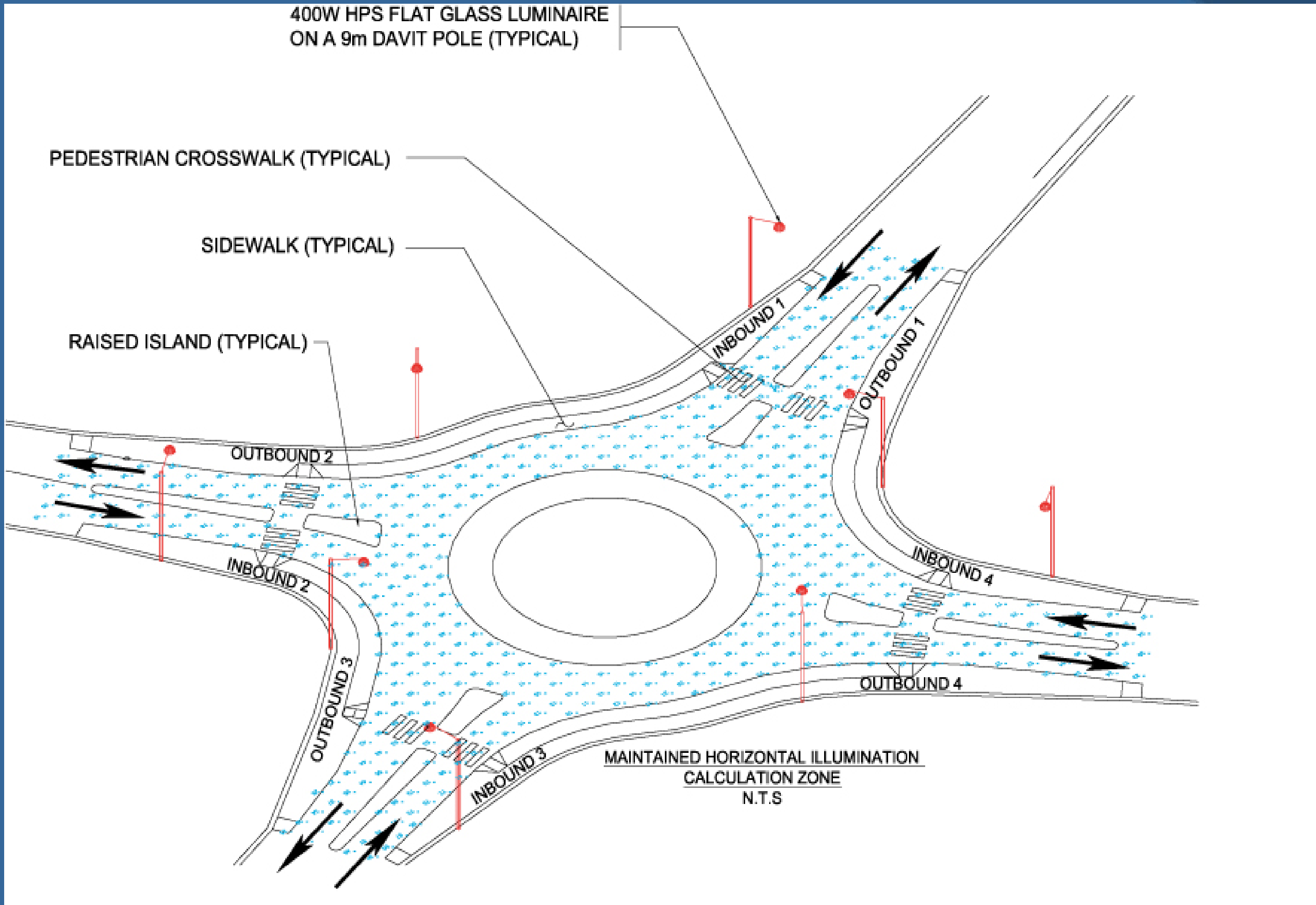
Mid Block Crosswalk Lighting



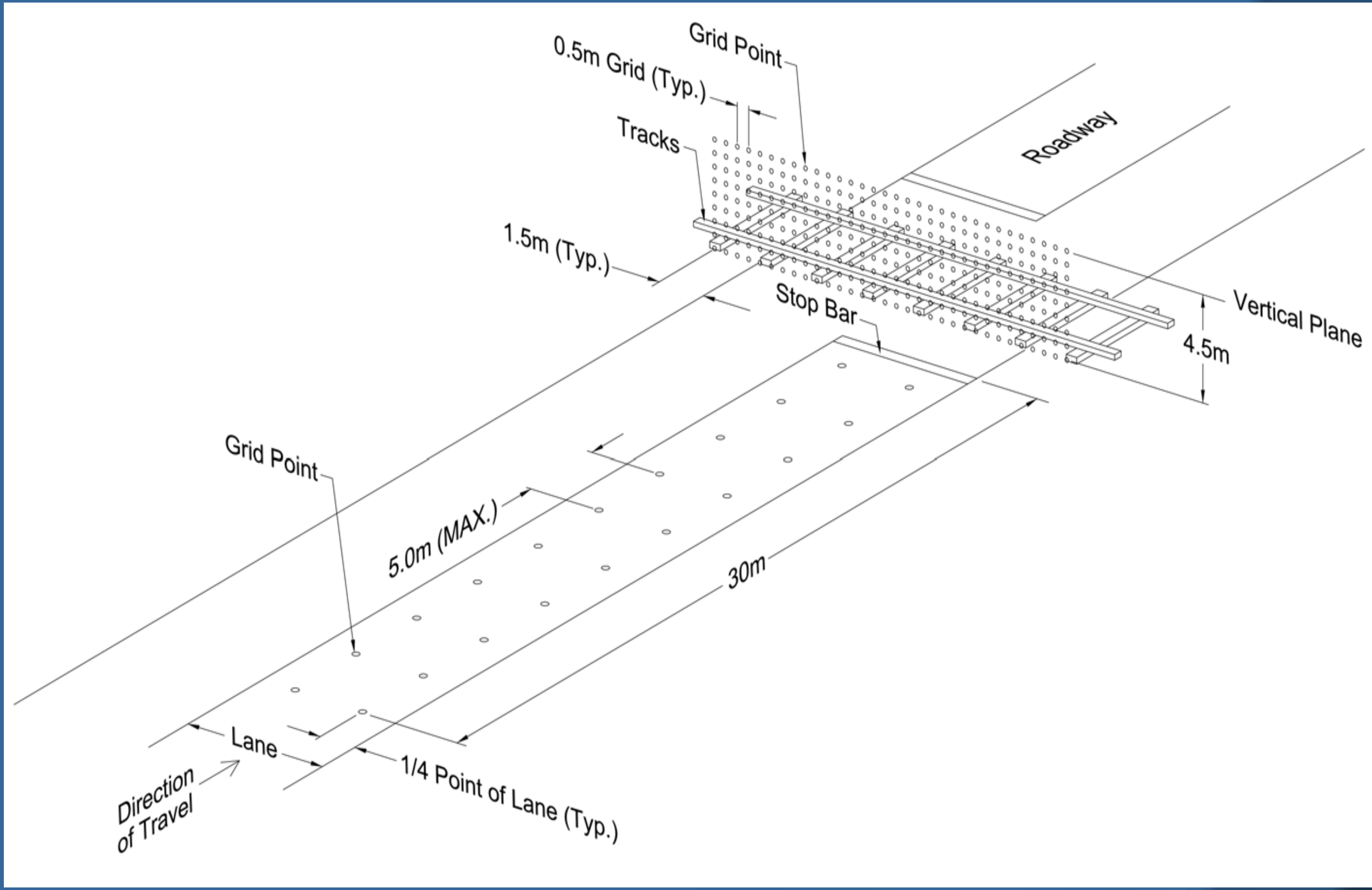
OUTPUT RESULTS	
GRID	MAINTAINED AVERAGE
W-B VERTICAL ILLUMINANCE	41.1 lux
E-B VERTICAL ILLUMINANCE	41.1 lux

Roundabout Lighting

Roundabout Lighting



Railway Crossing Lighting



Railway Crossing Lighting

Based Transport Canada RTD-10

Warrants

- Railway Crossing is unrestricted
- No signals
- Posted Speed on Roadway 50 km/h or greater
- Trains running at speeds less than 24 km/h (spur type line)

Walkways and Bikeways

Description	Maintained Average Horizontal Illuminance	Maintained Average Vertical Illuminance
Walkways and Bikeways for Security	NA	≧ 5.0 lux
Walkways and Bikeways for Guidance	≧ 5.0 lux	NA
Pedestrian Stairways for Security	NA	≧ 5.0 lux
Pedestrian Stairways for Guidance	≧ 5.0 lux	NA
Pedestrian and Cyclist Tunnels for Security	NA	≧ 54.0
Pedestrian and Cyclist Tunnels for Guidance	≧ 43 lux	NA

Parking Lot Lighting

Description	Maintained Average Horizontal Illuminance	Average to Minimum Uniformity Ratio
Basic Parking Lot Illumination Level	10.0 lux	5.0:1
Enhanced Parking Lot Illumination	25.0 lux	5.0:1

Streetscape Lighting

Streetscape/Decorative Lighting

- Obtrusive Lighting
- Surrounds – Other lighting
- Color (example store fronts)
- Vertical Surface Illumination – Define appropriate levels
- Grazing Light - Effect on surface
- Accent Lighting – Enhances features

Streetscape/Decorative Lighting

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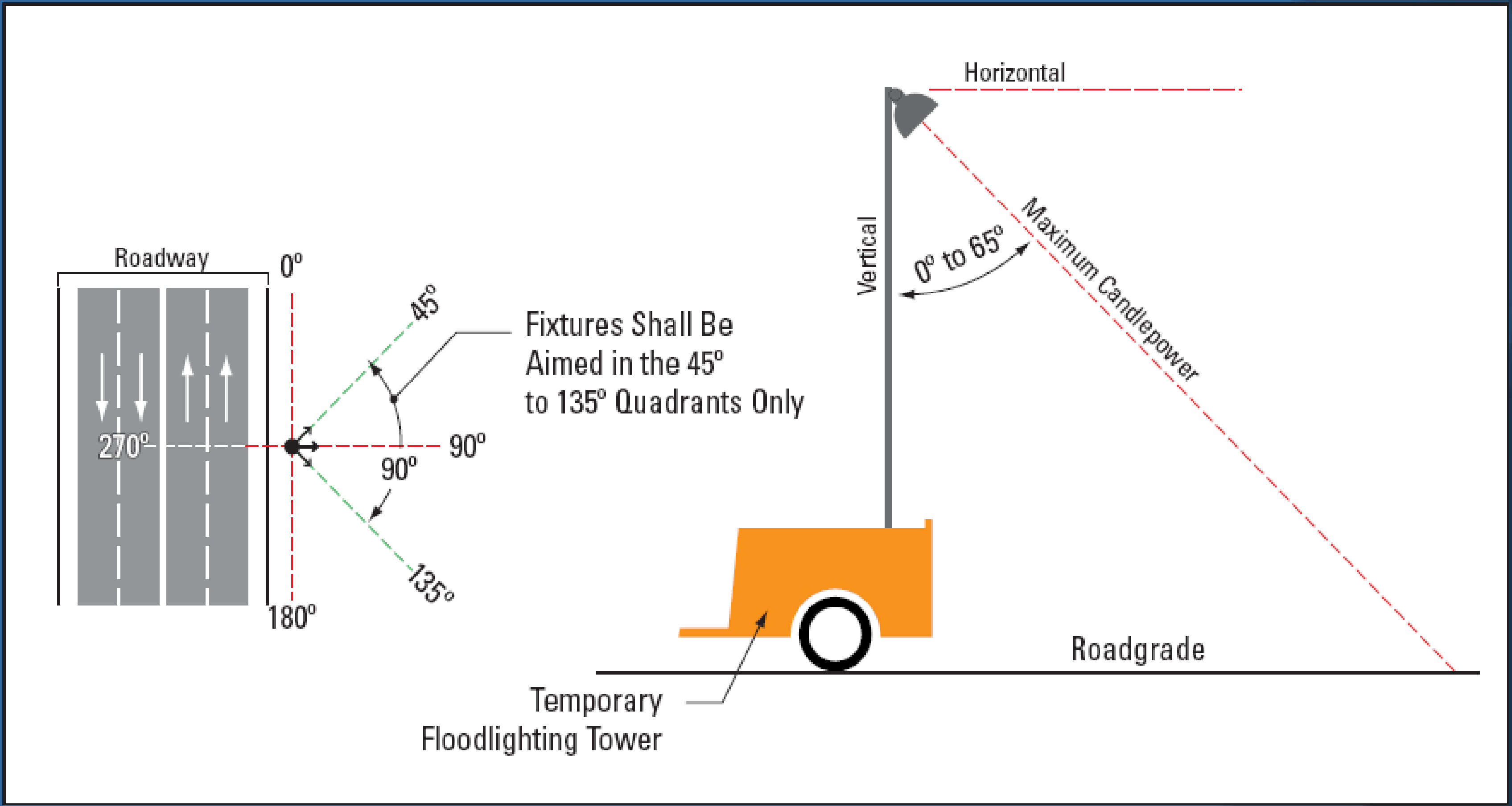
Work Zone Lighting

Category	Minimum Illuminance Level	Area of Illumination	Application	Example Areas and Activities for Illumination
1	54 lux	General illumination through spaces	Large size visual task; low accuracy; general safety requirements	Excavation; sweeping and cleaning; movement areas in work zones; movement between tasks
2	108 lux	General illumination of tasks around equipment	Medium size visual task; low to medium contrast; medium accuracy; safety on around equipment	Paving; milling; concrete work around paver, miller and other construction equipment
3	216 lux	Illumination on task	High size visual task; low contrast; high accuracy and fine finish	Crack filling; pot filling; signalization or similar work requiring extreme caution and attention

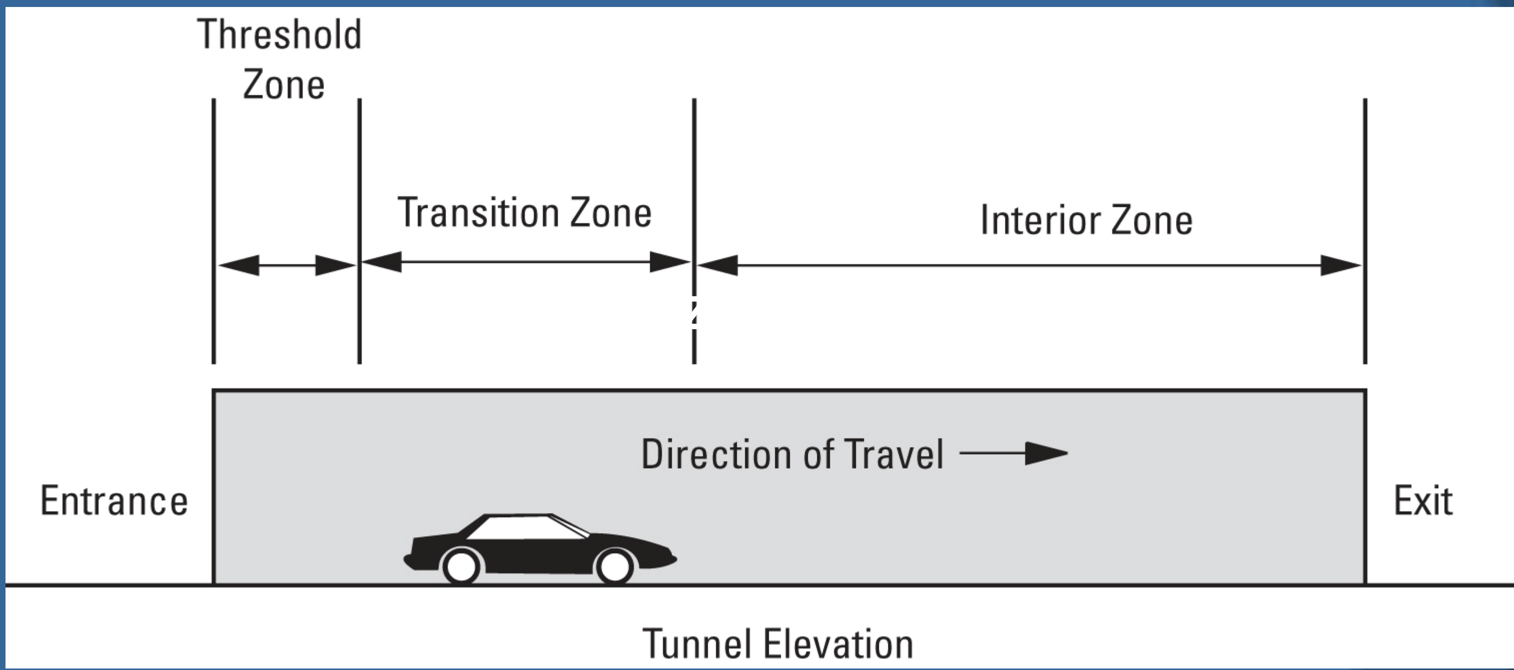
Work Zone Lighting



Tunnel Lighting

Tunnel Lighting

Very technical
Lighting should meet IESNA RP-22 or CIE



Underpass Lighting

Consider lighting if over 30m long or if closed in with vertical walls

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Questions and Answers

Please complete TAC Workshop Survey