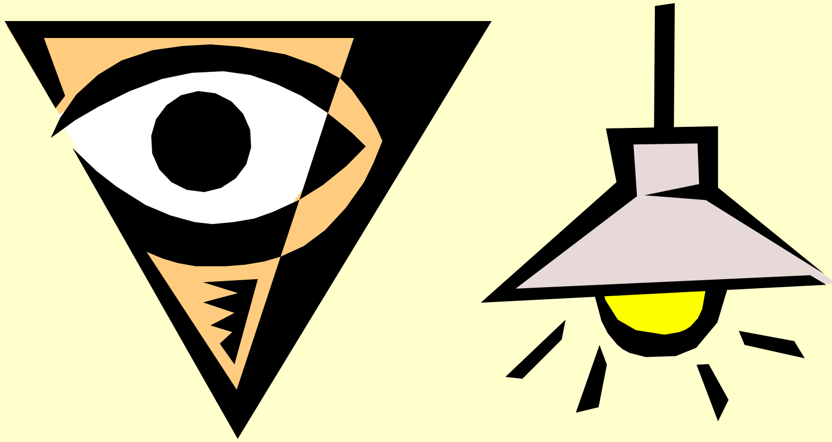


Lighting Calculations

Ir. Dr. Sam C. M. Hui
Faculty of Science and Technology
E-mail: cmhui@vtc.edu.hk

Sep 2017

Contents

- Design Considerations
- Typical Calculations
- Lumen Method
- Point-by-point Method
- Other Calculations
- Outdoor Lighting

Design Considerations

- Video: Lighting Calculations (5:51)

  - http://www.youtube.com/watch?v=sfbXx13JgeU
  - Basic lighting calculations that are required to carry out a lighting design
    - Luminous flux, luminous intensity, illuminance, luminance, colour rendering, colour temperature
    - Glare, working plane, surface reflectances
    - Indoor lighting: calculations are done for both the direct and inter-reflected light; room geometry; maintenance
    - Outdoor lighting: light falls directly on the working plane

Design Considerations

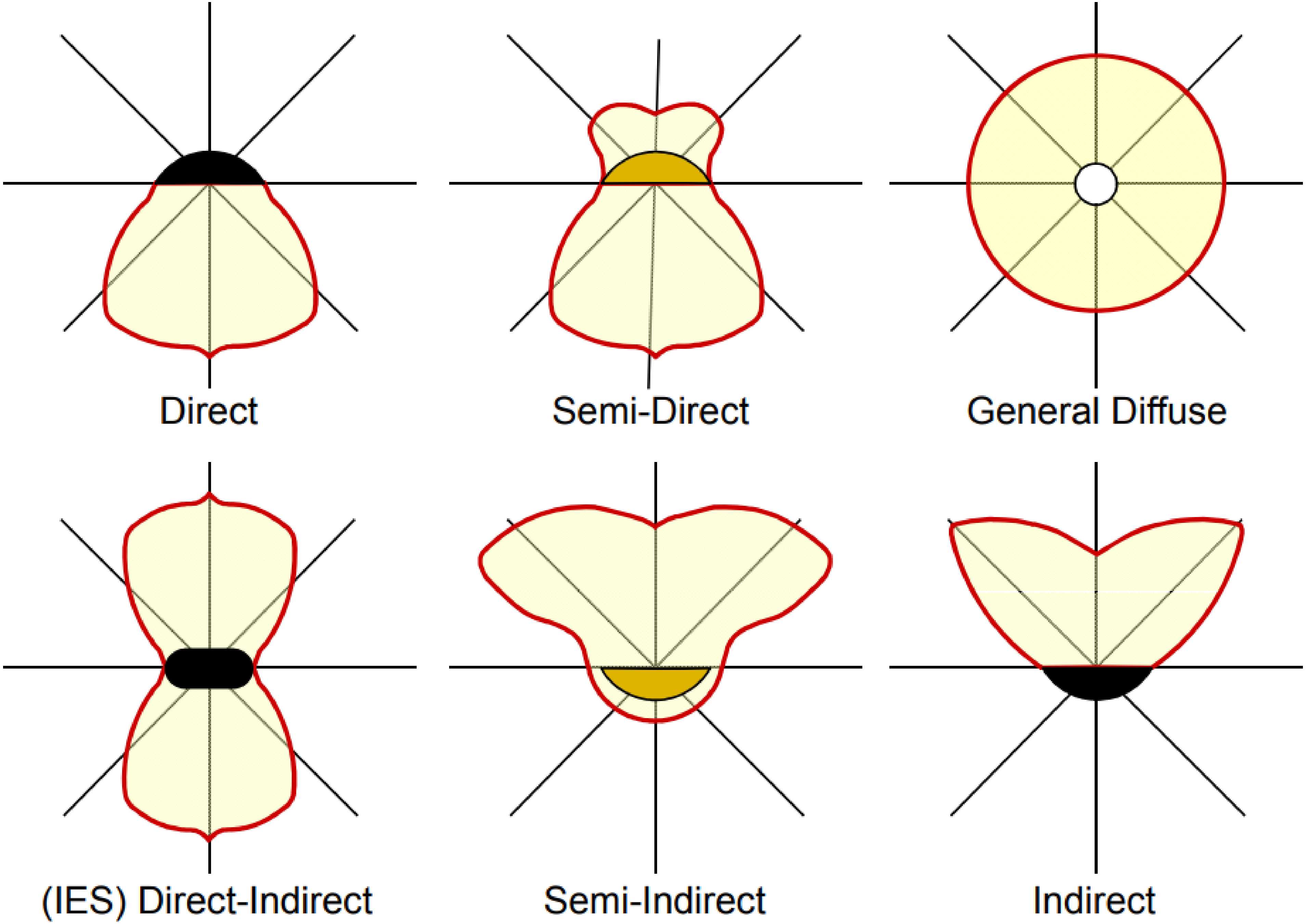
- Lighting design checklist
  - Safety (e.g. emergency escape lighting)
  - Task requirements
    - Lighting scheme to provide suitable quantity and direction for the task; colour rendering; glare problems
  - Lighting appearance
    - Architecture/Interior design
  - Energy efficiency
    - Lighting equipment, controls, daylighting

Design Considerations

- Lighting equipment checklist
  - Lamps
    - Operating characteristics, lamp size/shape, colour
  - Luminaires
    - Size and shape, light distribution, glare control, ballast
    - Operating environment (e.g. corrosive, dusty)
  - Lighting controls
    - Manual switches, time switches, dimming, daylight-linked controls, occupant sensing

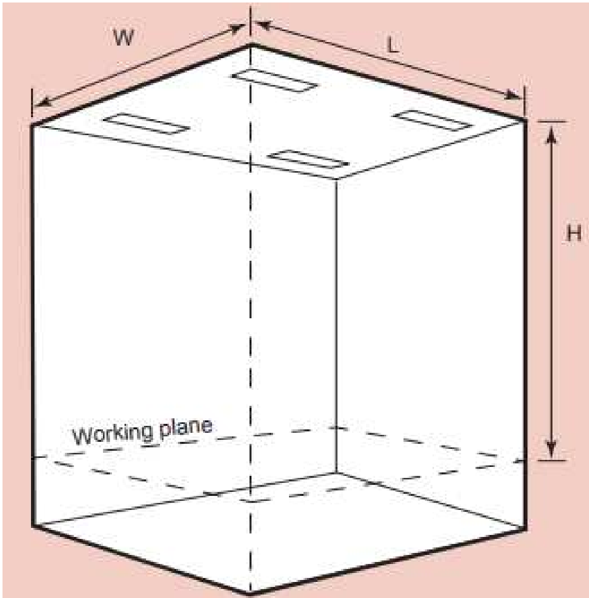
(Examples of the impact on lighting with differing techniques of lighting distribution inside interior spaces: http://iarc.uncg.edu/elight/learn/design/la.html)

CIE luminaire types and their light distributions



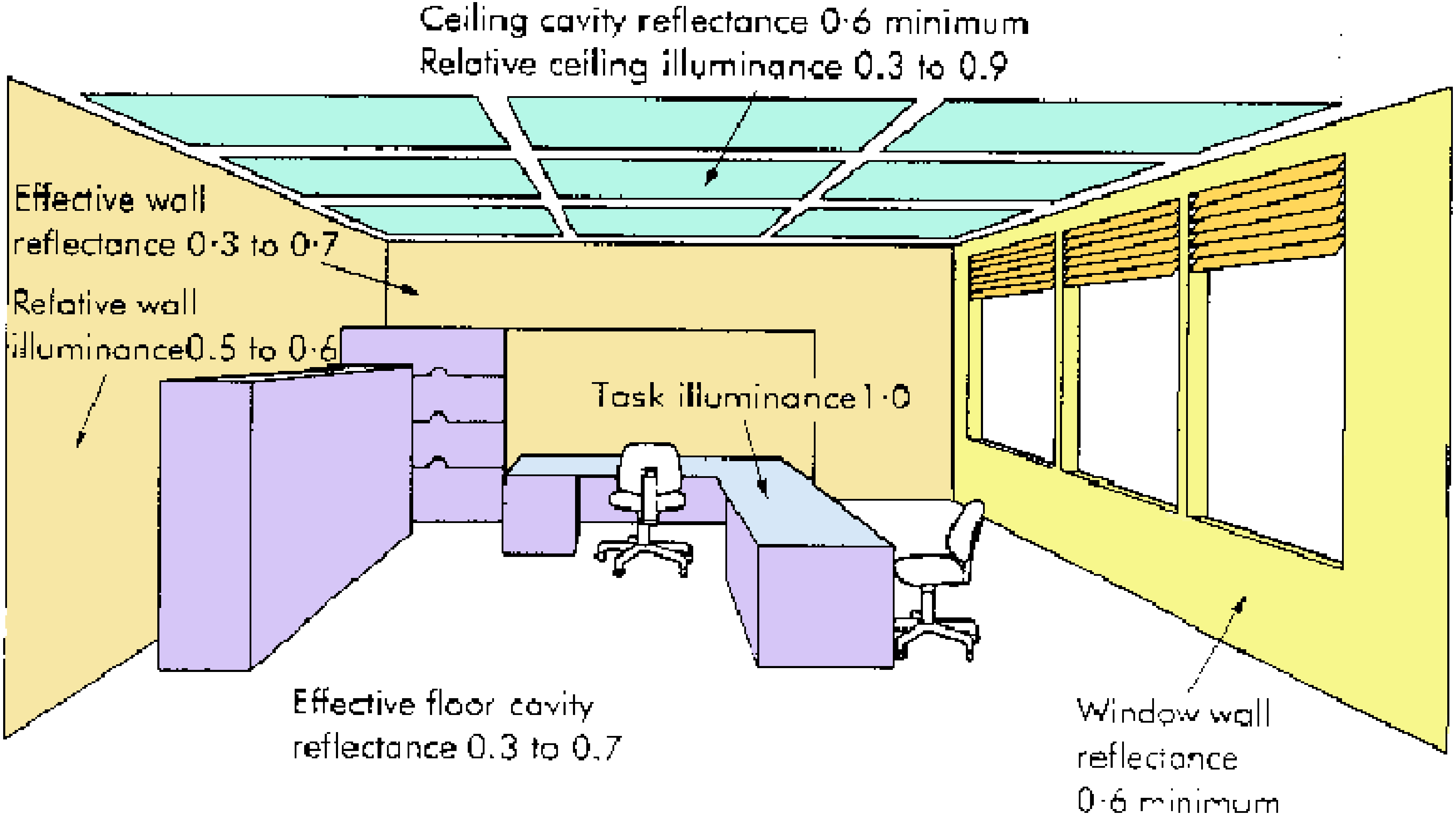
Design Considerations

- Collect information for lighting design
  - Room details:
    - Room size (length, width, height)
    - Horizontal working plane height above floor level
    - Room surface reflectance (ceiling, walls, floor)
    - Window size/s and position
    - Room index
      - $K = (L \times W)/(L + W) H$
    - Cleanliness of the room/environment
    - The regularity of the cleaning



Recommended room reflectances & illuminance ratios

[Source: CIBSE Lighting Code]



Design Considerations

- Collect information for lighting design (cont'd)
  - Task details:
    - Type of task/application (e.g. office, industrial, retail)
    - Task position (e.g. horizontal/vertical, general/local)
    - Special task lighting requirement (e.g. critical inspection, computer use, disabled persons)
    - Special hazards (e.g. wet or dusty environment, rotating machines) --- luminaire thermal and mechanical protection

Design Considerations

- Collect information for lighting design (cont'd)
  - Task lighting requirements:
    - Task illuminance (lux)
    - Task illuminance uniformity (e.g. uniform (0.8), non-uniform (as appropriate))
    - Light colour rendering quality and index (Ra)
    - Average installed power density target (W/m^2), to meet building energy code
    - Light pollution, sustainable lighting design

(Establish design criteria --- lighting concepts: http://iarc.uncg.edu/elight/learn/establish/lc.html)

Design Considerations

- Collect information for lighting design (cont'd)
  - Room lighting requirements:
    - Accent lighting (e.g. display lighting, decorative lighting)
    - Wall lighting (e.g. display lighting, lighting to create room lightness)
    - Ceiling lighting (e.g. lighting to create room lightness)
    - Light colour appearance (e.g. warm, intermediate, cool)
    - Emergency and/or escape lighting requirement

(Examples of the impact on lighting with differing layers of lighting, and material properties of surfaces inside interior spaces: http://iarc.uncg.edu/elight/learn/determine/la.html)

Typical Calculations

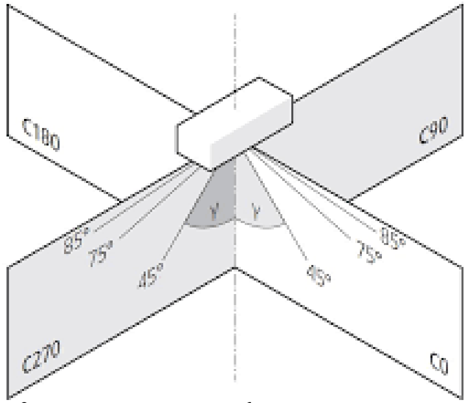
- To calculate the amount of light that will result from a design
  - Critical for commercial & institutional buildings
  - Seldom required for residential design
- Basic considerations
  - Light sources (lamp lumens)
  - Luminaires & light distribution
  - Initial vs. maintained light levels (as lamps age and luminaires get dirty, light level drops)

Typical Calculations

- Design calculations for simple situations
  - The number and layout of luminaires needed for general lighting
  - What additional luminaires are needed to provide local emphasis or accents
  - Energy efficiency of the installation and financial benefits
- Calculation methods:
  - Manual, data sheets/tables, graphical, spreadsheet, computer software

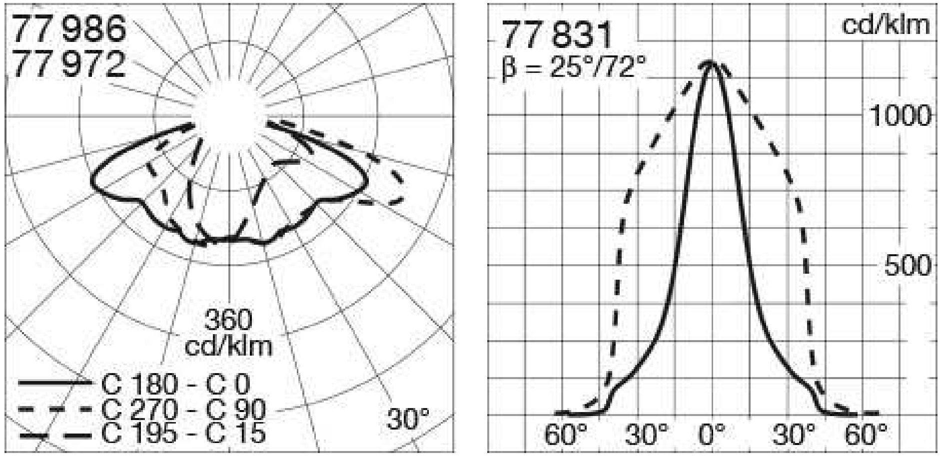
Typical Calculations

- Determine illuminance level
  - Horizontal (most common)
    - Average illumination on the work plane (lux)
      - Sitting 0.75 to 0.9 m; Standing 0.85 to 1.2m
  - Vertical (e.g. on wall surface)
  - Inclined

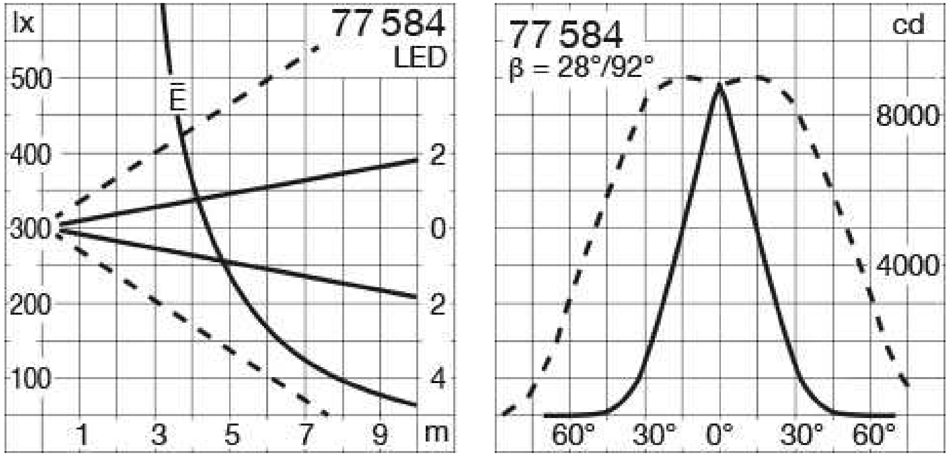


- Analyse light distribution
  - Using light distribution curves, illumination and isolux diagrams
    - Illuminance (lux) or luminance (cd/m^2)

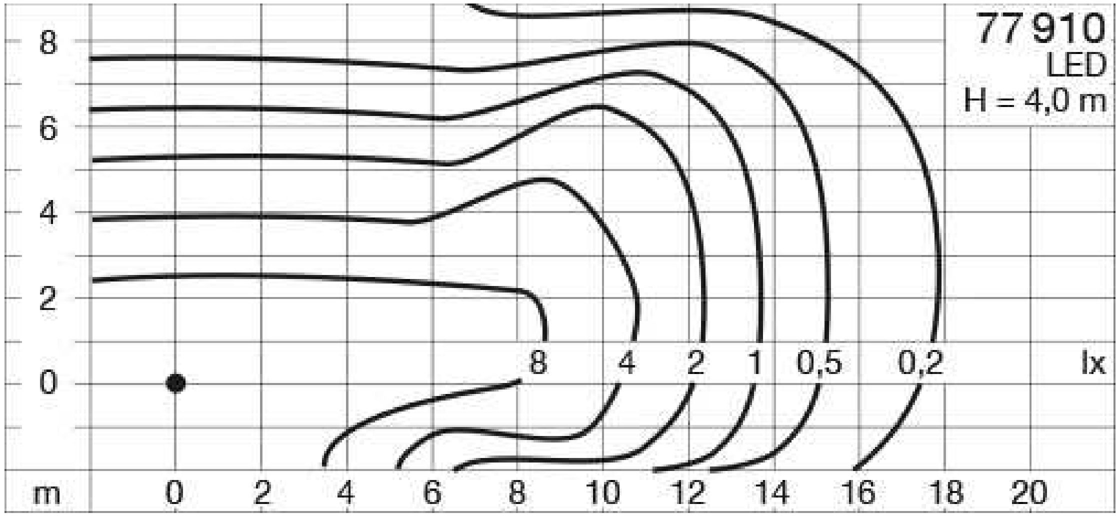
Light distribution curves, illumination and isolux diagrams*



Light distribution curves



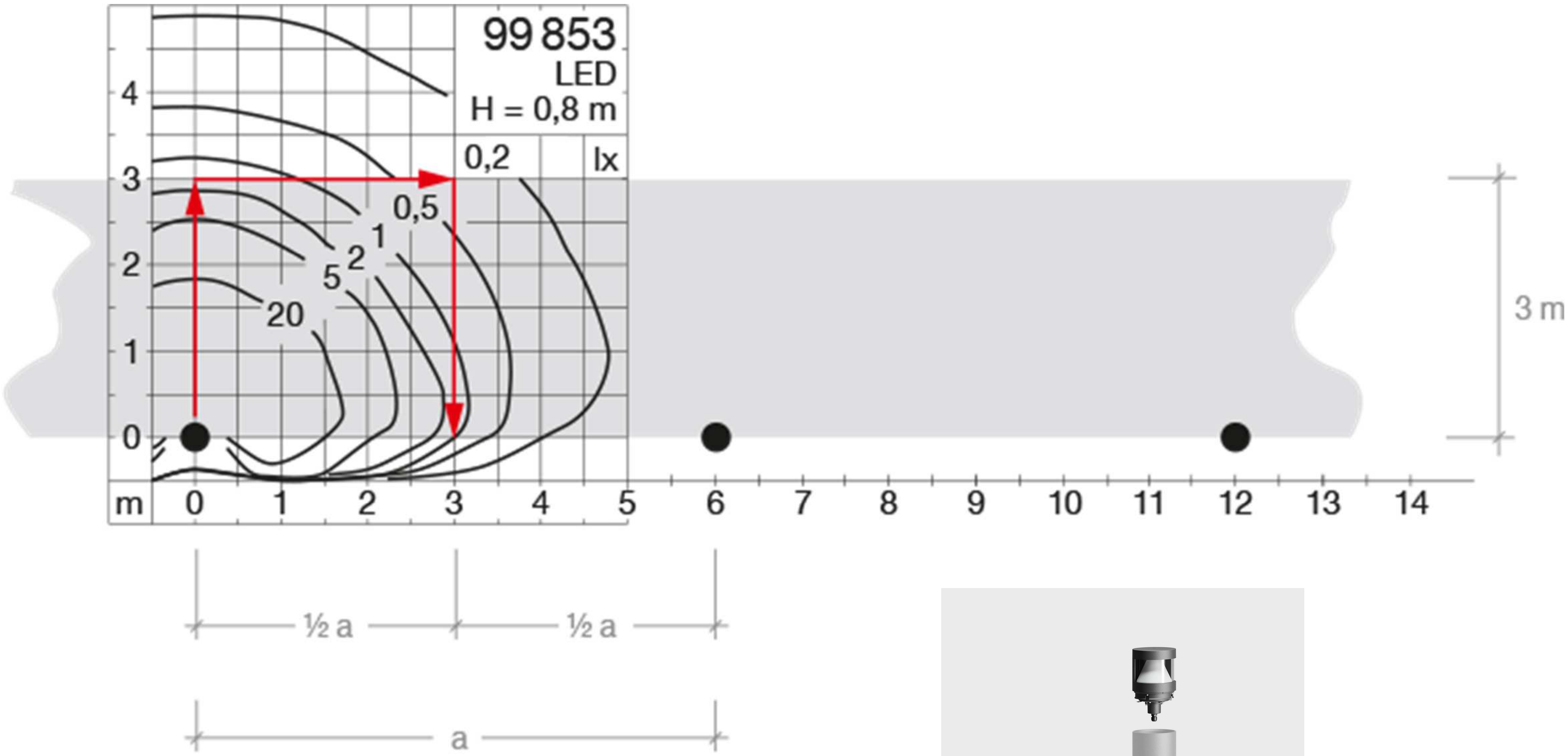
Illumination diagrams



Isolux diagrams

(* See also: http://www.bega.de/en/knowledge/about-light-and-illumination/2-information-about-light-and-illumination/2-06-light-distribution-curves-illumination-and-isolux-diagrams/)

Example: Determination of the luminaire spacing a for pathway illumination of E_{min} = 1 lx on the basis of the isolux diagram



(* See also: http://www.bega.de/en/knowledge/about-light-and-illumination/2-information-about-light-and-illumination/2-06-light-distribution-curves-illumination-and-isolux-diagrams/)

Typical Calculations

- Predict general & ambient light levels
  - Rough estimation based on a Watts/sq.m method
    - Not very accurate, but good for prelim. planning
  - Lumen method calculations (light flux method)
    - Determines average illuminance in large open areas
    - Good for general lighting
  - Point-by-point computer calculations
    - Determines light levels at a specific point on an object or surface; complicated, start from fundamental laws
    - Can be used for outdoor lighting

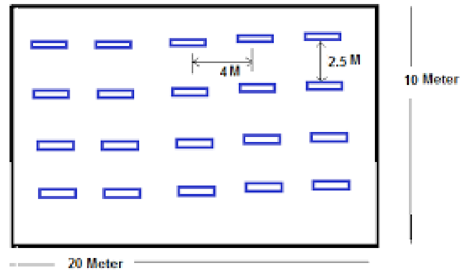
Rough estimation based on a Watts/sq.m method

Average light level desired & typical application	**Watts/sq.m of fluorescent, CFL or HID lights**	**Watts/sq.m of incandescent or halogen lamps**
25-50 lux Hotel corridors, stair towers	1-2	3-7
50-100 lux Office corridors, parking garages, theatres (house lights)	2-4	7-10
100-200 lux Building lobbies, waiting areas, malls, hotel function spaces	4-8	10-20
200-500 lux Office areas, classrooms, lecture halls, conference rooms, ambient retail lighting, workshops	15-25	Not recommended
500-1000 lux Grocery stores, laboratories, work areas, big box retail stores	12-20	Not recommended

[Source: Adapted from Karlen and Benya, 2004. *Lighting Design Basics*]

Typical Calculations

- Predict task lighting & focal lighting levels
  - Difficult to predict accurately
  - Methods commonly used
    - Use data/guide of the luminaire’s manufacturer
    - Use the inverse-square law to estimate
    - Use a display lighting software program

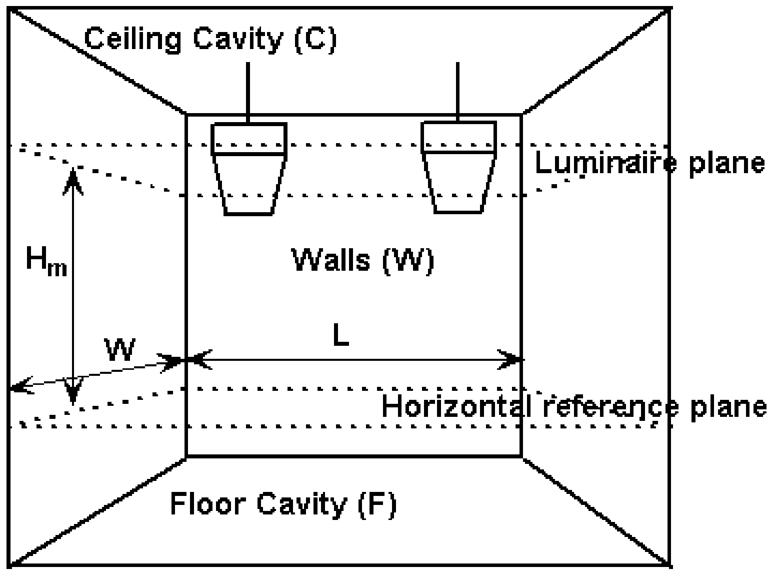


Lumen Method

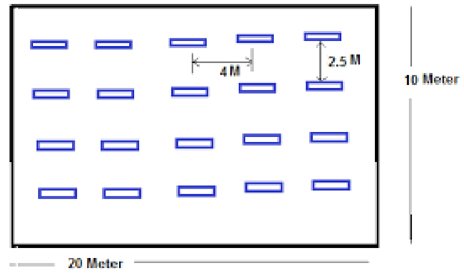
- Lumen Method: average illuminance (E) is

$$E = \frac{F \times n \times N \times UF \times MF}{A}$$

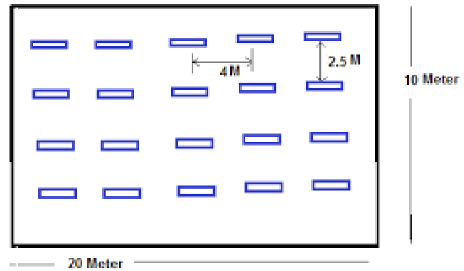
  - F = initial bare lamp luminous flux (lumens)
  - n = number of lamps per luminaire
  - N = number of luminaires
  - UF = utilisation factor
  - MF = maintenance factor
  - A = area of the surface (m^2)



Lumen Method



- Room index (K): a measure of the proportions of the room, for rectangular room
  - $K = (L \times W)/(L + W)\, h_m$
    - L = length of the room
    - W = width of the room
    - h_m = height of luminaire above horiz. reference plane
- Effective reflectances of ceiling, walls & floor
  - Cavity index (CI) = $(L \times W)/(L + W)\, h = K \times h_m/h$
    - h = depth of the cavity (ceiling or floor)
  - Determine effective reflectance from tables or formulae (see examples in *CIBSE or SLL Lighting Code*)



Lumen Method

- Utilisation factor (*UF*)
  - Ratio of total flux received by the surface to the total lamp flux of the installation
    - Indicates the effectiveness of the lighting scheme
  - UF depends upon: the efficiency of luminaire, luminaire distribution, geometry of the space, room reflectance, polar curve
  - Usually, UF tables are prepared for general lighting with regular arrays of luminaires, for 3 main room surfaces: ceiling cavity, walls, and floor cavity or horizontal reference plane

Example of luminaire photometric data and utilisation factor

Luminaire type: single 1.5 m, 58 W fluorescent lamp fitting, incorporating a white louvre attachment.

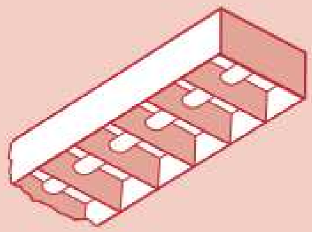
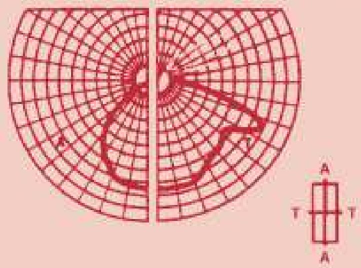


Illustration of luminaire



Luminous Intensity Distributions (polar curves) – axial (A) and transverse (T)

Light output ratio: upward – 0.0; downward – 0.55; total – 0.55.

Spacing/height ratio: nominal – 1.5; maximum (square) – 1.7, maximum (continuous) – 2.0.

Room index	0.75	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
Room reflectances C W F									
70 - 50 - 20	0.36	0.42	0.47	0.51	0.56	0.60	0.63	0.66	0.69
30	0.31	0.36	0.42	0.46	0.52	0.56	0.59	0.63	0.66
10	0.27	0.32	0.37	0.41	0.47	0.52	0.55	0.60	0.63
50 - 50 - 20	0.33	0.38	0.43	0.46	0.51	0.54	0.57	0.60	0.62
30	0.29	0.34	0.38	0.42	0.51	0.51	0.53	0.57	0.59
10	0.25	0.30	0.35	0.38	0.44	0.48	0.50	0.54	0.57
30 - 50 - 20	0.31	0 35	0.39	0.42	0.46	0.49	0.51	0.54	0.55
30	0.27	0.31	0.35	0.38	0.43	0.46	0.48	0.52	0.54
10	0.23	0.28	0.32	0.35	0.40	0.44	0.46	0.50	0.52
0 - 0 - 0	0.20	0.24	0.28	0.30	0.34	0.37	0.39	0.42	0.44

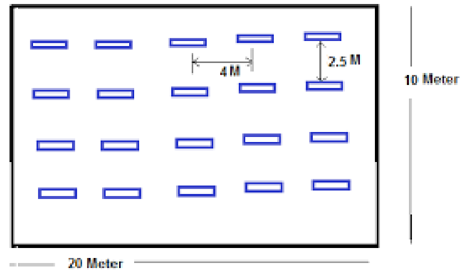
Using the table

Calculate the room index – see section 4, page 15

Decide on the appropriate reflection factors for ceiling (C), walls (W) and floor (F) – see section 4, page 15

Locate utilisation factor at intersection of appropriate column and row

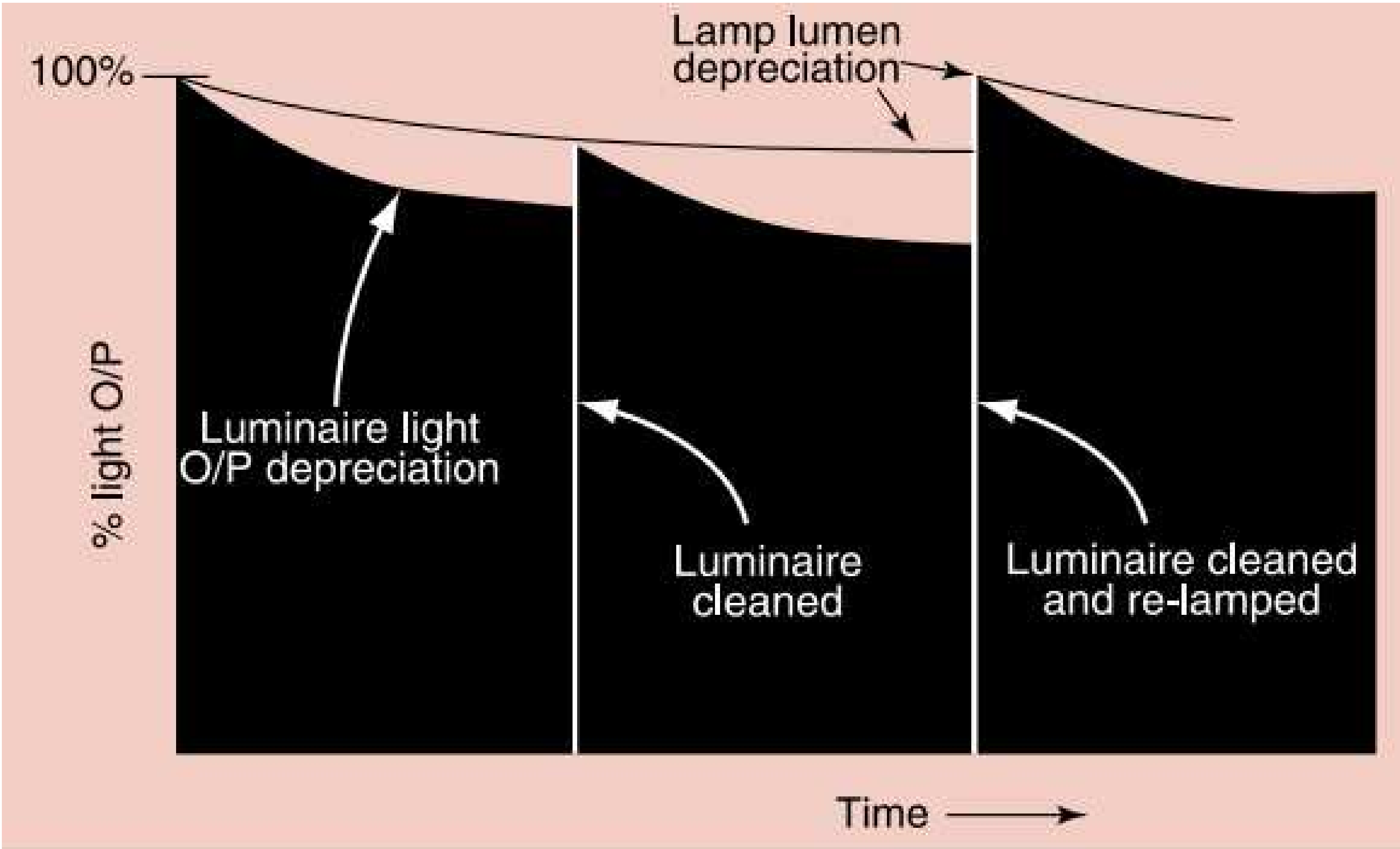
Lumen Method



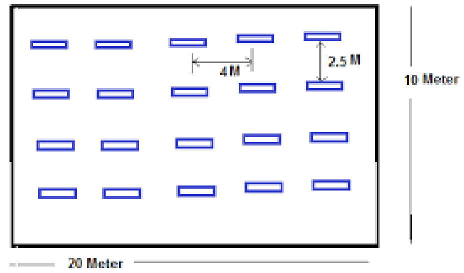
- Maintenance factor (*MF*)
  - Ratio of maintained illuminance to initial illuminance (losses for lamp lumen maintenance)
  - *MF* = LLMF x LSF x LMF x RSMF
    - Lamp lumen maintenance factor (LLMF)
    - Lamp survival factor (LSF)
    - Luminaire maintenance factor (LMF)
    - Room surface maintenance factor (RSMF)
  - See *CIBSE/SLL Code of Lighting* for description

Maintenance factor and light depreciation

Environmental condition	Maintenance factor
Clean	0.9
Average	0.8
Dirty	0.7



Lumen Method

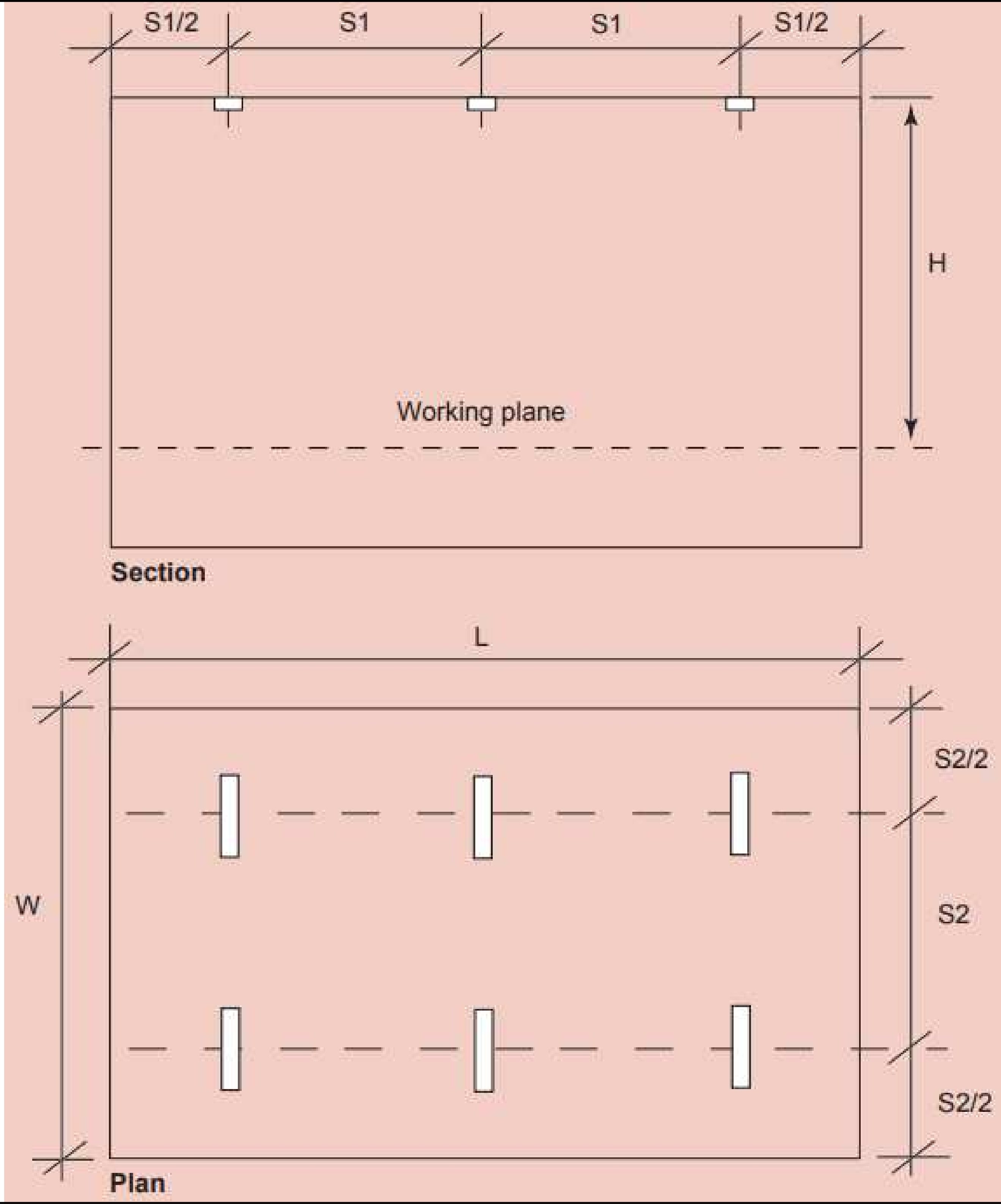


- The number of luminaires required for a required illuminance level *E* (lux) is:

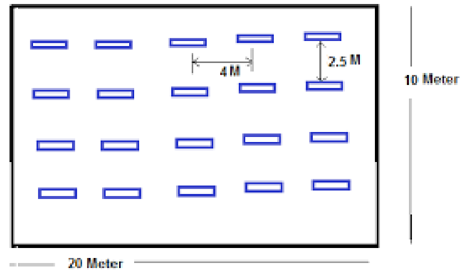
$$N = \frac{E \times A}{F \times n \times UF \times MF}$$

- Planning the luminaire layout
  - Work out a regular layout of luminaires with an acceptable uniformity
  - Rounding the number found to a whole number that will divide into a regular grid
  - Check on the spacing to height ratio

Luminaire layout and spacing



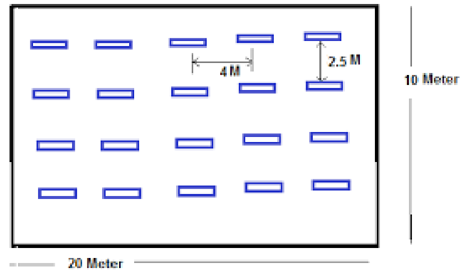
Lumen Method



- Spacing to height ratio (SHR)
  - Ratio of distance between adjacent luminaires (centre to centre) to their height above the working plane

$$SHR = \frac{1}{H_m}\sqrt{\frac{A}{N}}$$

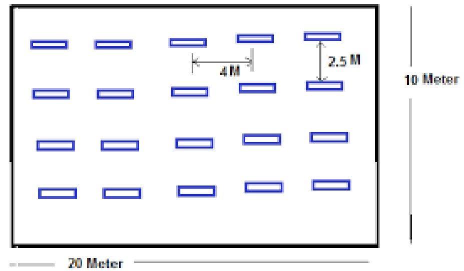
  - where H_m = mounting height; A = total floor area; N = number of luminaires
- Maximum spacing to height ratio (SHR_{max})
  - Luminaire spacing shall not exceed the max. (provided by manufacturer) to ensure uniformity



Lumen Method

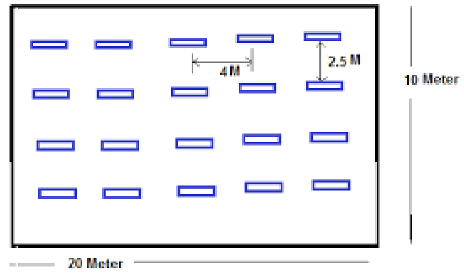
- Lumen method: calculation procedure --- a summary
  - Calculate room index K, floor/ceiling cavity index
  - Calculate effective reflectances of ceiling cavity, walls & floor cavity
  - Determine utilisation factor (*UF*) from manufacturer's data, using the room index and effective reflectances
  - Determine maintenance factor (*MF*)
  - Obtain nos. of luminaires required
  - Determine a suitable layout
  - Check that the geometric mean spacing-to-height ratio
  - Check the layout does not exceed SHR_{max}
  - Calculate illuminance achieved by the final layout

Lumen Method



- Basic assumptions underlying the lumen method
  - Rectangular room
  - Ratio of length to width = 1.6 : 1, with a max. of 4 : 1
  - Completely empty room
  - Uniform reflectance and completely diffuse reflection properties of the perimeter surfaces
  - Uniform distribution of luminous flux over all areas
  - Regular luminaire configuration throughout the room
  - In the case of fluorescent lamps, luminaire axis = room axis

Lumen Method

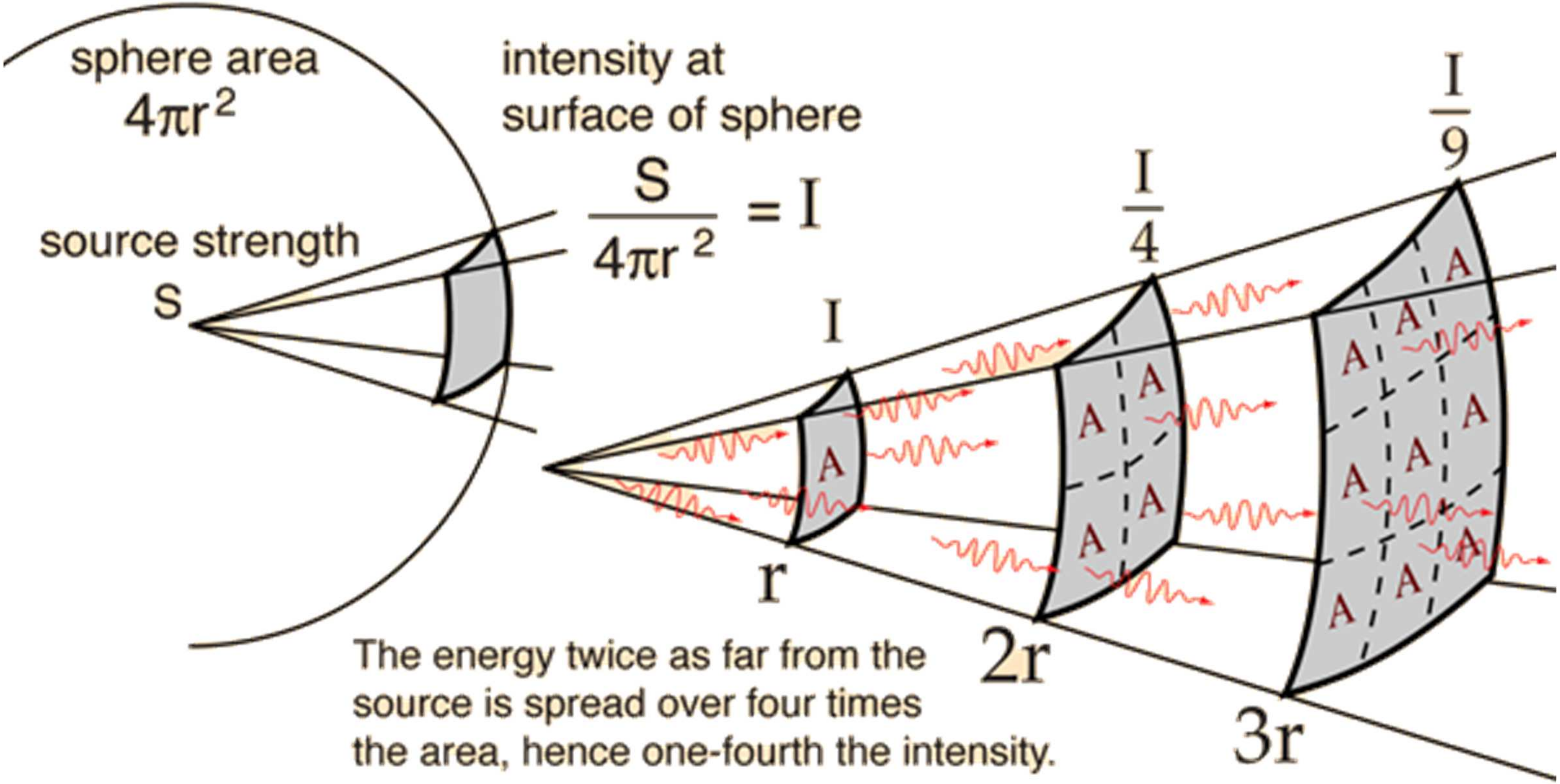


- Examples of lumen method calculations:
  - Lighting Design Calculation in a Building – Step by Step
    - http://www.electricaltechnology.org/2017/03/lighting-design-calculation-in-building.html
  - Lumen method calculations
    - http://www.arca53.dsl.pipex.com/index_files/lummethd.htm
  - The installer's guide to lighting design, Good Practice Guide 300 (page 22-26)
    - http://www.cibse.org/getmedia/0276ac78-dc41-4694-9378-8f984ef924f2/GPG300-The-Installers-Guide-to-Lighting-Design.pdf.aspx

Point-by-point Method

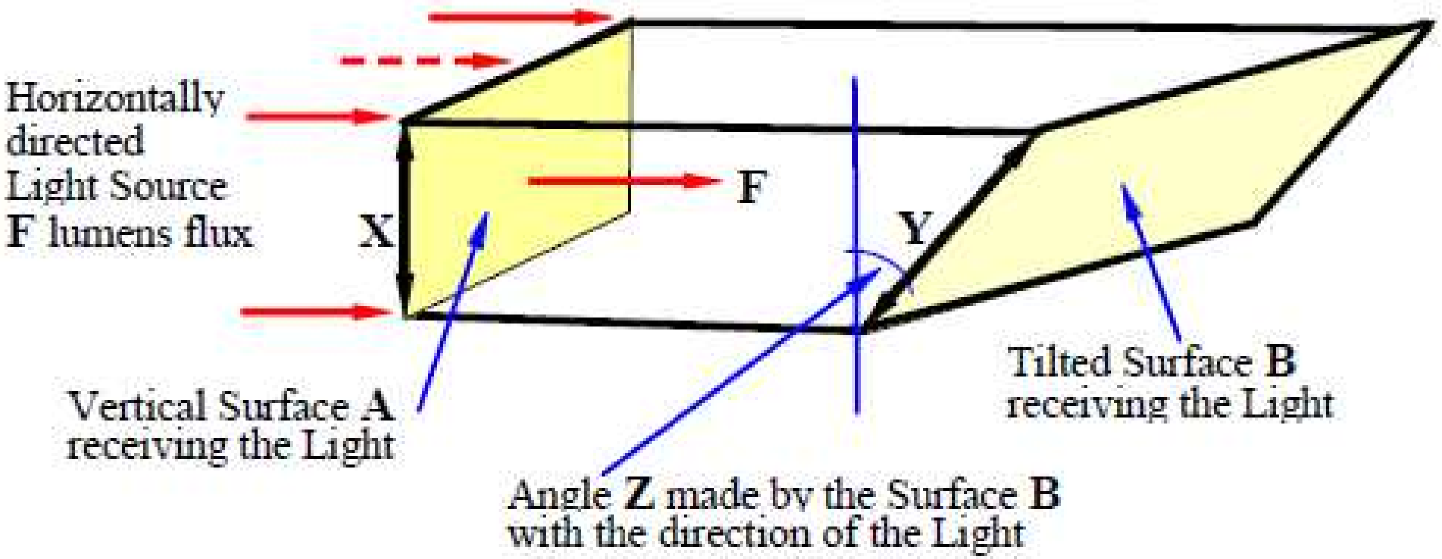
- Predict direct illuminance at each point on a plane, using measured data of luminous intensity distribution of a source or a luminaire
  - Based on the inverse square law and cosine law
- Three factors must be considered:
  - Luminous intensity
  - Distance
  - Orientation of the surface

Inverse Square Law for lighting calculations



Cosine Law for lighting calculations

COSINE LAW (Illuminance on Tilted Surface)



The Areas A and B are proportional to the lengths of their sides X and Y

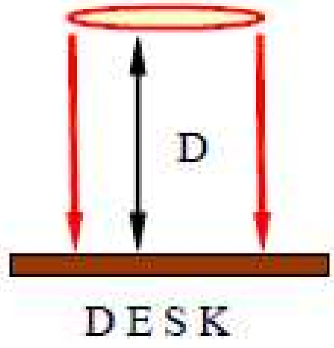
$A / B = \cos(Z)$ $\qquad$ $B = A / \cos(Z)$ $\qquad$ Illuminace $E_A = F / A$

Illuminace $E_B = F / B = F / (A / \cos(Z)) = F / A * \cos(Z) = E_A * \cos(Z)$

$E = I / D^2$ when the incident angle is 0 degrees. The general equation becomes $E = I / D^2 * \cos(Z)$

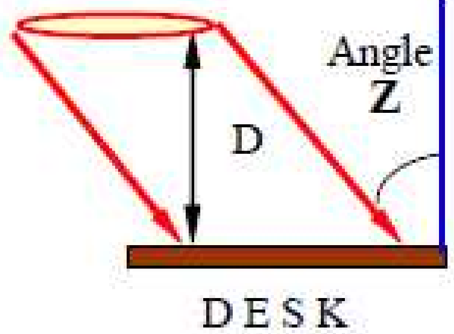
Light Source Intensity = **I** Candelas

$E = I / D^2$



Light Source Intensity = **I** Candelas

$E = I / D^2 * \cos(Z)$



Cosine Values of Angles

0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90
1.000	0.995	0.978	0.951	0.914	0.866	0.809	0.743	0.669	0.588	0.500	0.407	0.309	0.208	0.105	0.000

Point-by-point Method

- Video:
  - Lighting Point by Point (5:08)
    - http://www.youtube.com/watch?v=C8ZKNOvDmCQ
- Limits for using point by point method:
  - Maximum physical dimension of the surface under design is not larger than 1/5th the mounting height above the evaluation point
  - Does not apply to a surface of infinite length

Point-by-point Method

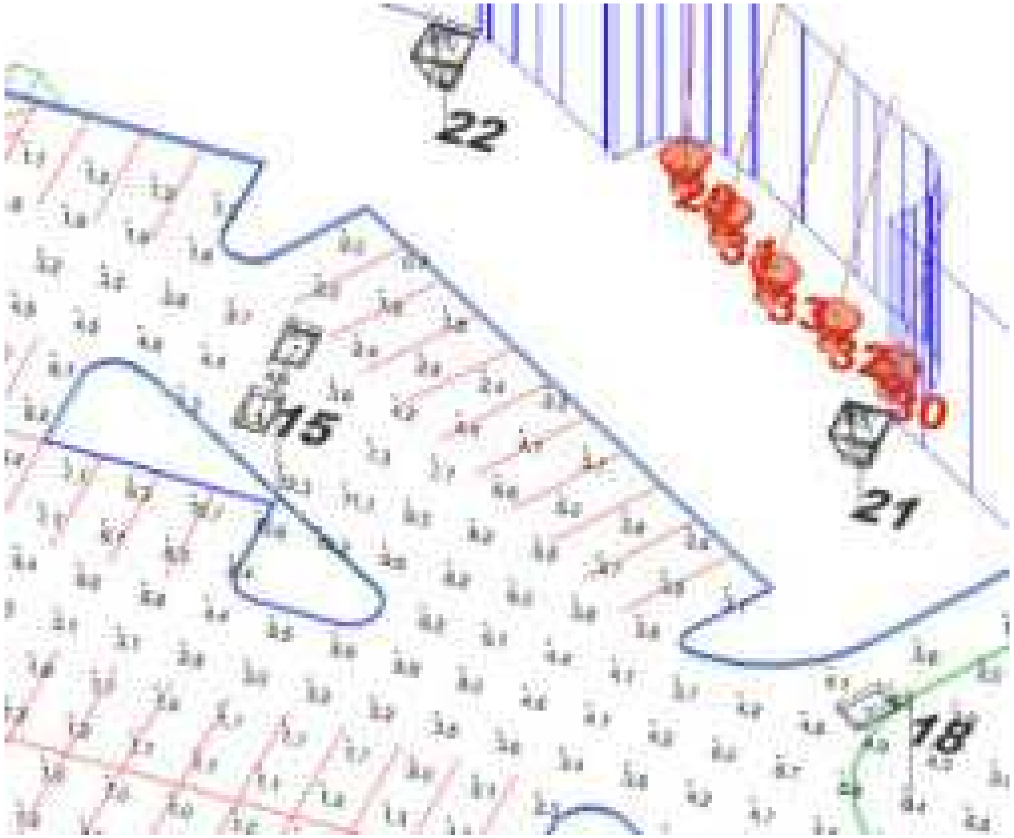
- Computer software can be used to perform numerical point-by-point calculations of direct or reflected light incident on any real surface or imaginary plane
  - The results can be used to predict or quantify the distribution of artificial or natural light in any environment (lighting simulation)
    - Brightness of room surfaces and patterns of light on the ceiling, walls, and floor
    - Also lighting quality & visual performance

Point-by-point Method

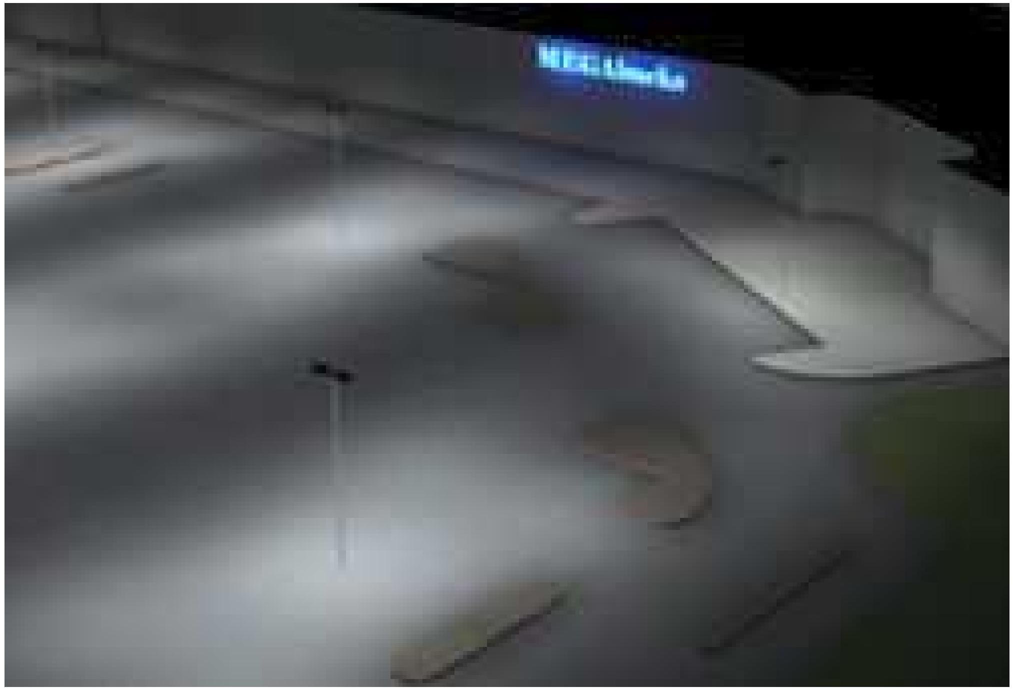
- Two calculation techniques when simulating a lighting application
  - Direct Calculation Method
    - A simplified technique when reflected light need not be considered in the results; often used in exterior lighting applications e.g. road and sports lighting
    - It cannot be rendered
  - Full Radiosity Method
    - Accurate computation of interreflected light; for interior lighting applications or when rendering is desired

Two calculation techniques for simulating a lighting application

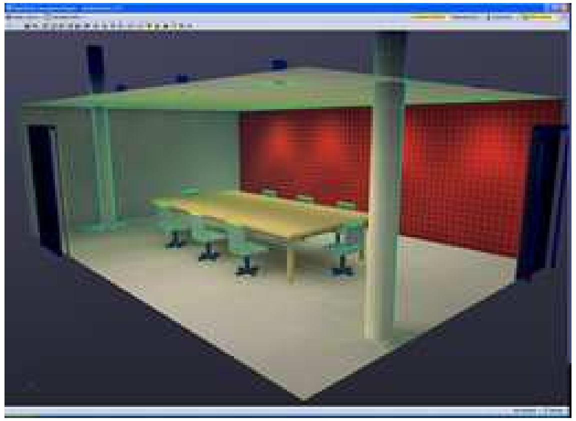
Direct calculation

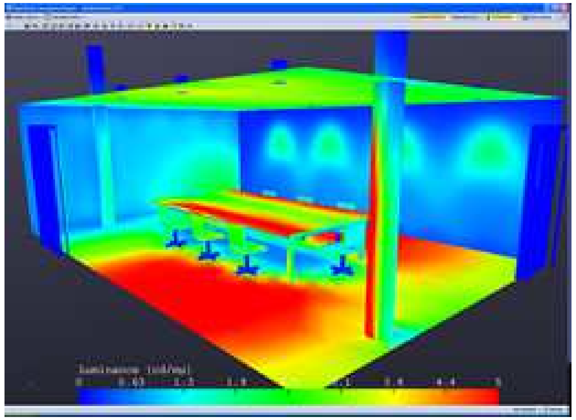


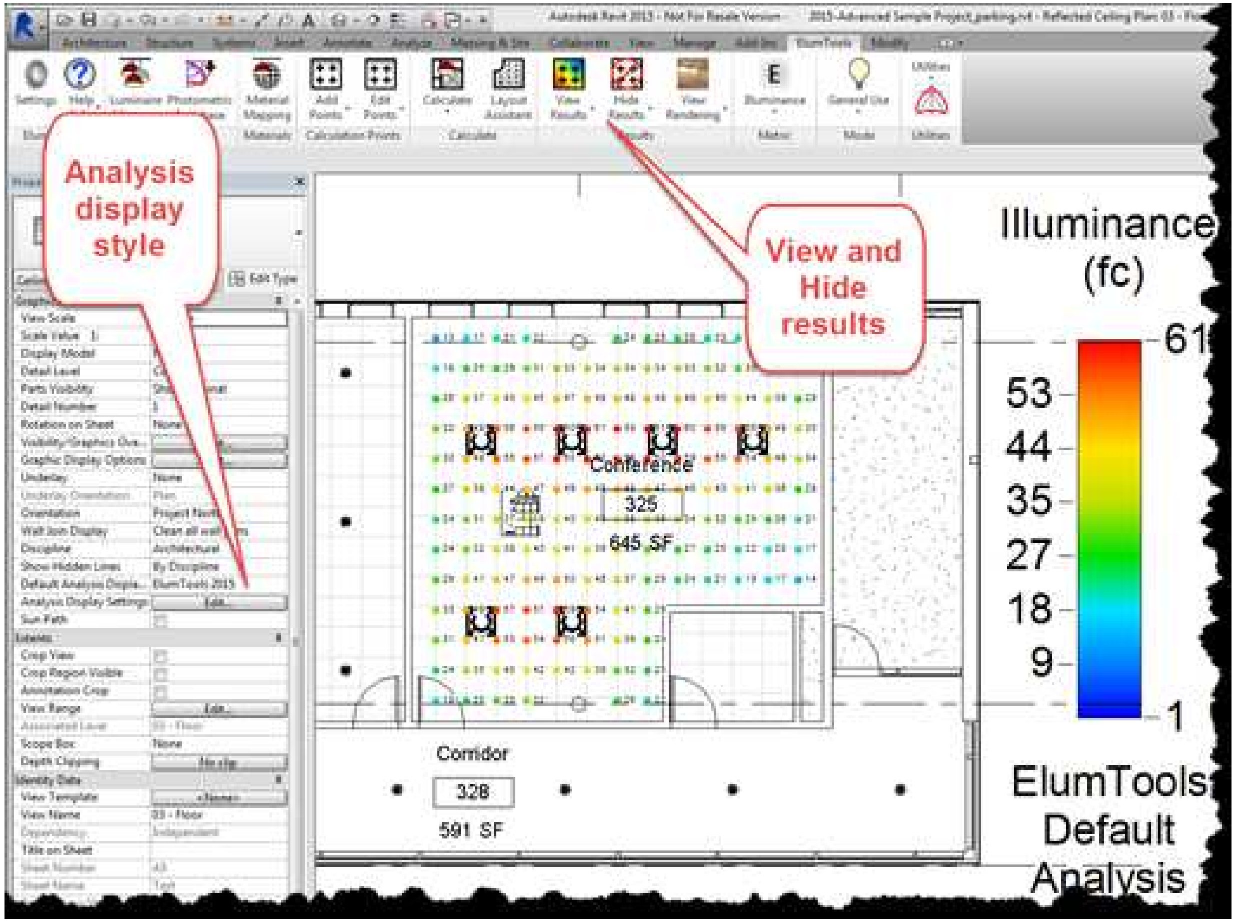
Full Radiosity calculation



Lighting calculations and simulation in Revit BIM using ElumTools

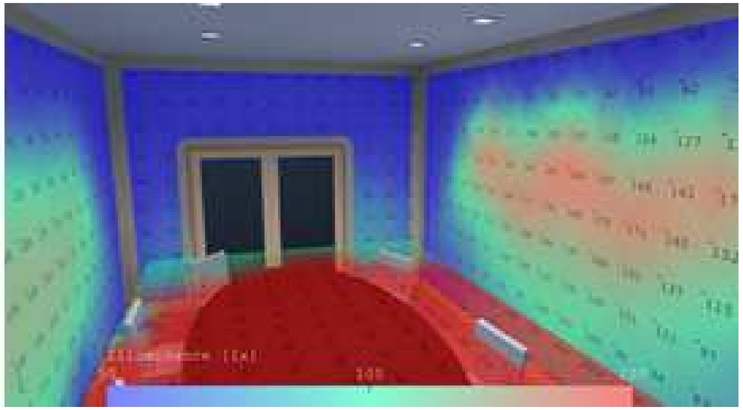


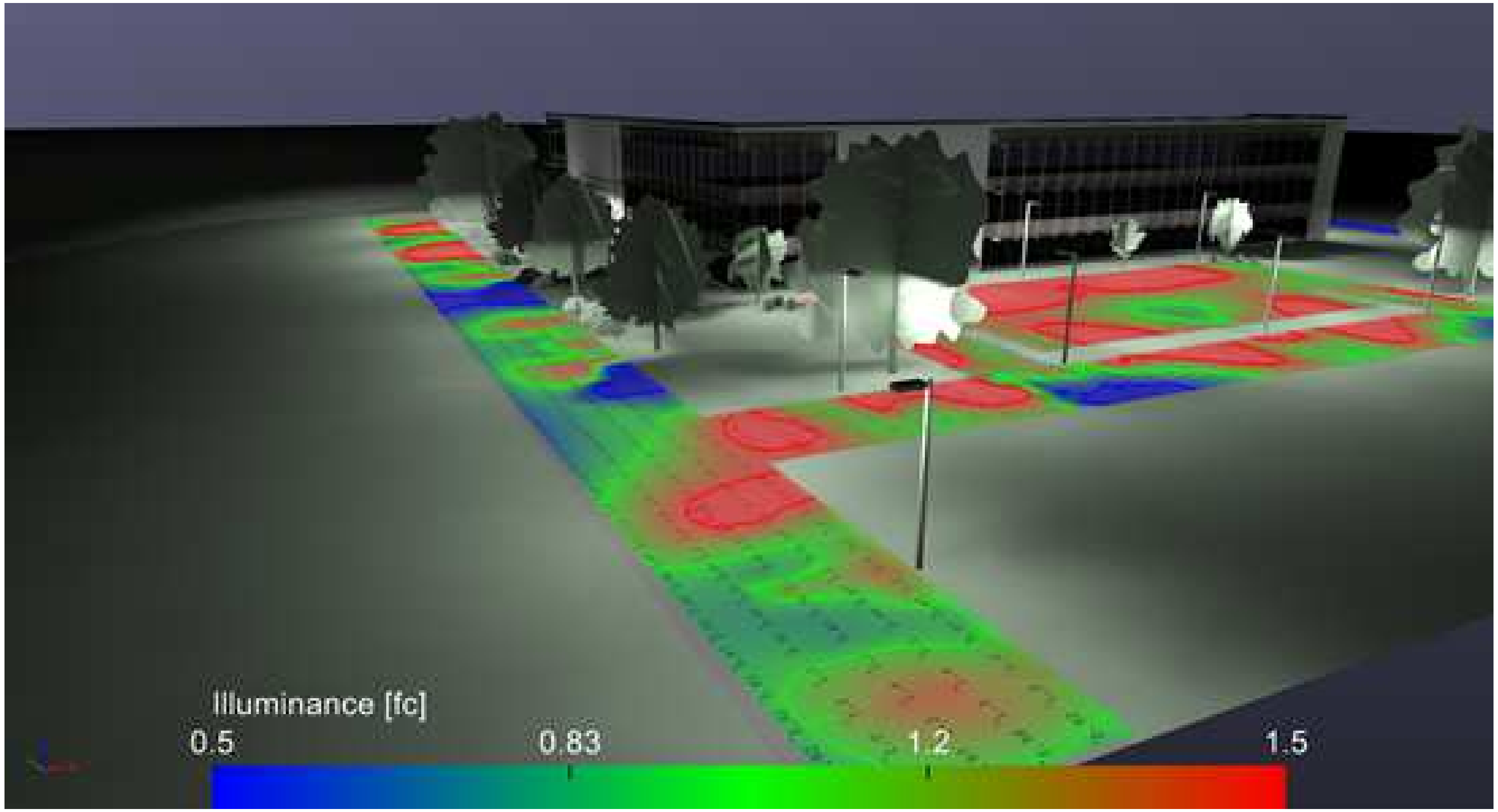




(Source: http://www.elumtools.com/)

Using isolines and spatial maps to evaluate the gradient of light across a workplane or surface





(Source: http://www.elumtools.com/)

Other Calculations

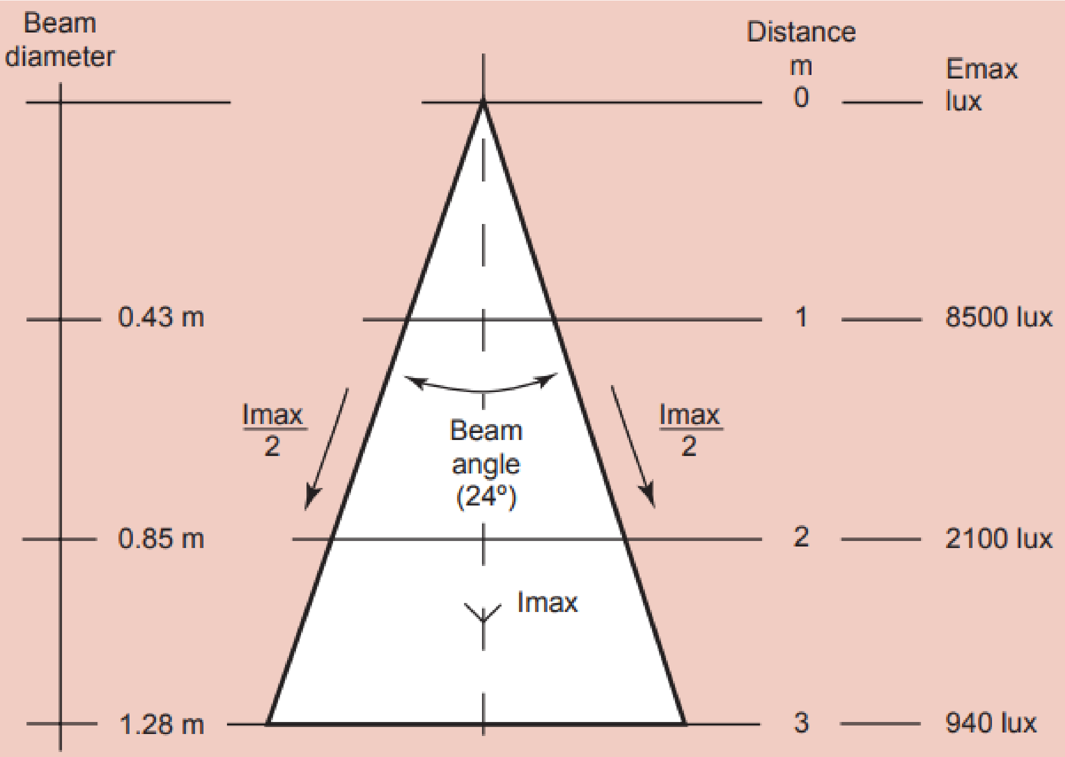
- Lighting to provide local emphasis
  - Emphasis or accent lighting is used to draw attention to an area or an object, e.g. a reception desk in an entrance area or a display in a shop
  - The amount of light needed to emphasise or draw attention to an object depends on the level of general lighting
  - Ratio of display light to general lighting:
    - ‘Subtle’ effect --- 5 : 1
    - ‘Moderate’ emphasis --- 15 : 1
    - ‘Strong’ emphasis --- 30 : 1

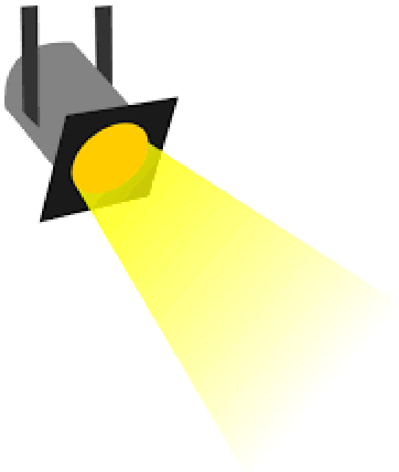
Other Calculations

- <u>Example</u>: Use spotlight for local emphasis
  - Manufacturers usually provide information in a diagrammatic form showing the effect of a particular spotlamp at various distances
    - Width of the beam and either the illuminance at the beam centre or the average illuminance across the beam
    - Calculate the illuminance from a spotlight or any other small source using the 'point source formula'
  - <u>Wall washing</u>: This uses luminaires that usually have an asymmetric beam shape. The manufacturers usually provide details of the luminaire layout and illuminance performance

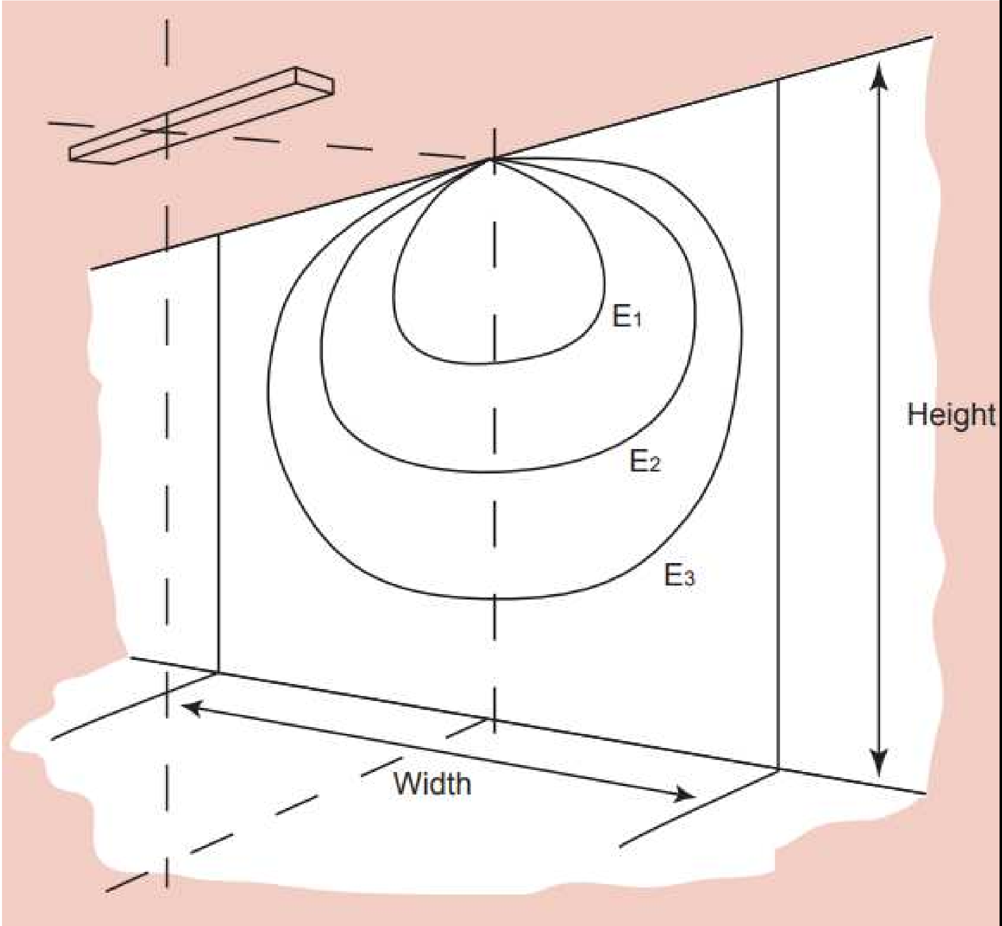
Typical performance data for spotlight and wall-washing luminaire

Spotlight



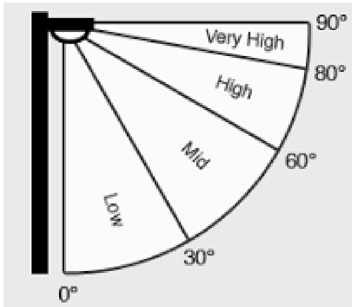


Wall-washing luminaire



Other Calculations

- Outdoor area lighting design, such as floodlighting, sports and road lighting
  - Area lighting Design Calculations - Part One
    - http://www.electrical-knowhow.com/2013/01/area-lighting-design-calculations-part.html



- Daylighting and daylight factor
    - http://personal.cityu.edu.hk/~bsapplec/methods.htm

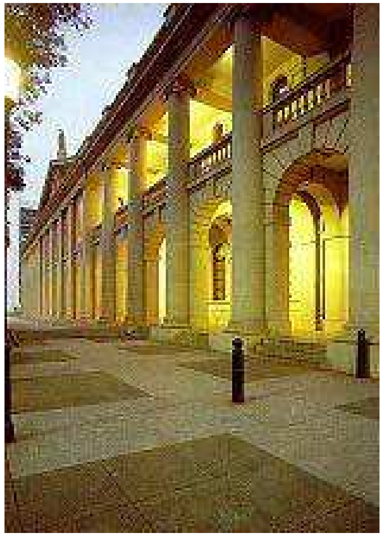
Other Calculations

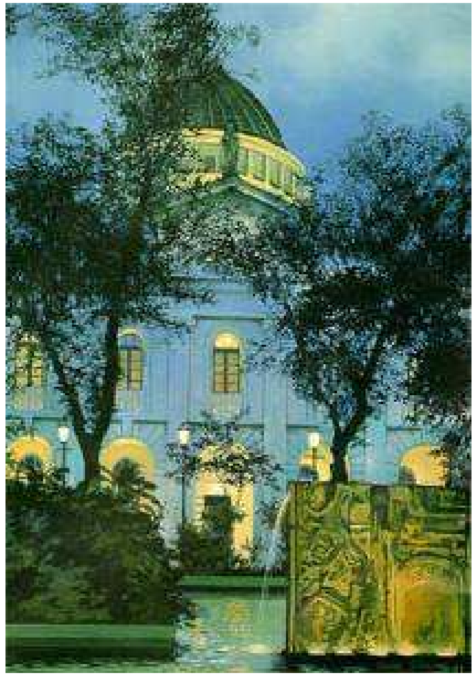
- Other lighting system related calculations:
  - Checking for energy efficiency
    - Local building/lighting energy efficiency code
    - Average installed power density (W/m^2)
  - Energy-saving payback calculations
    - Demonstrate to a client that the additional cost of installing efficient equipment is worthwhile is by calculating payback period – the length of time before the savings match the extra initial cost
      - Payback = (the extra initial cost) / (annual cost savings)
    - After this period, the user has saved more than he has spent and continues to save money

Outdoor Lighting

- Outdoor (or exterior) lighting
  - Floodlighting: flooding a surface with light
    - Achieve illumination on vertical or horizontal surfaces
  - Design issues
    - Appearance during daytime
    - Glare from the installation
    - Decorative lighting
    - Lighting for specific outdoor activities e.g. sports
  - Applications:
    - Building façade, sports, road lighting

Legislative Council Building (now Court of Final Appeal) at daytime and night-time

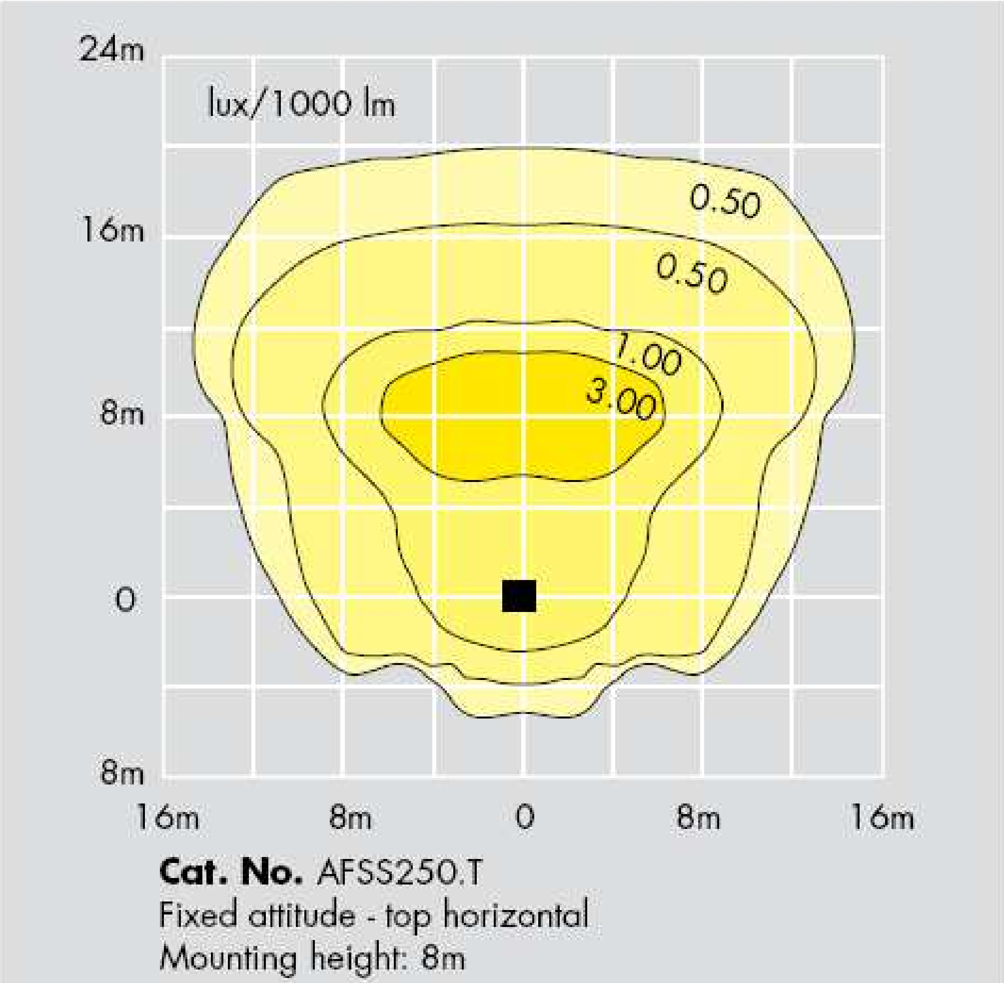


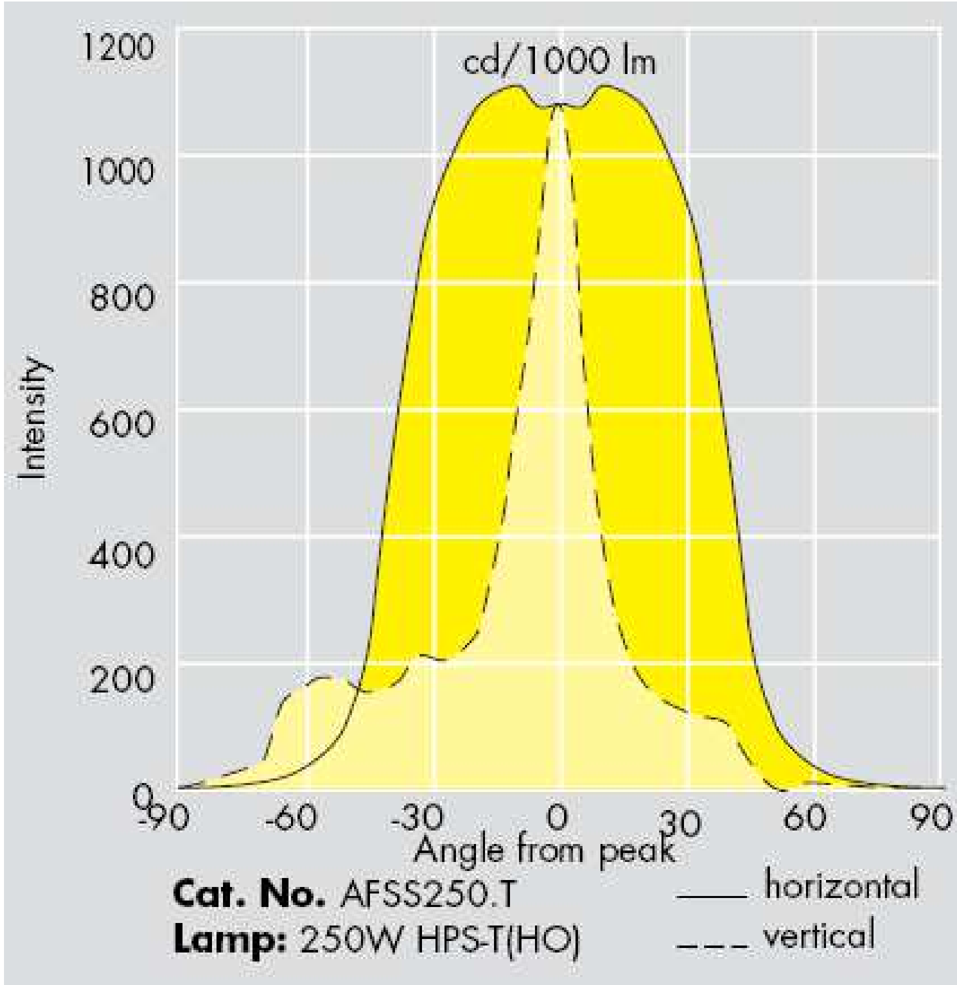


Outdoor Lighting

- Outdoor lighting (cont'd)
  - Floodlighting a building
    - Requires a sense of drama and colour
    - Select locations for putting floodlights & aiming points
      - Peak intensity & beam angle
    - Usually all the beams from each floodlight shall overlap
      - Uniformity ratio (max : average) about 5:1
  - Floodlighting a horizontal open area
    - Use isolux diagram (horizontal illumination plots)
      - Or isocandela and zonal flux diagram
    - Calculate using inverse square law and cosine law

Floodlight Data

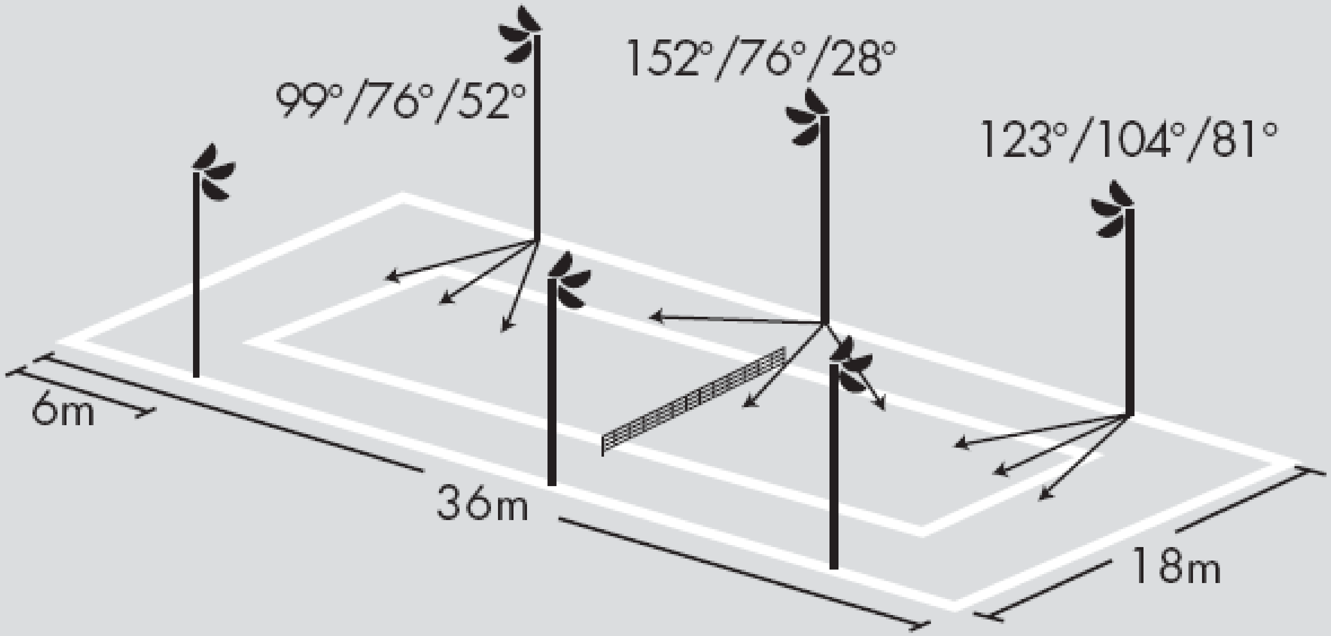




Floodlight design data

[Source: Thorn Lighting, UK]

Troika

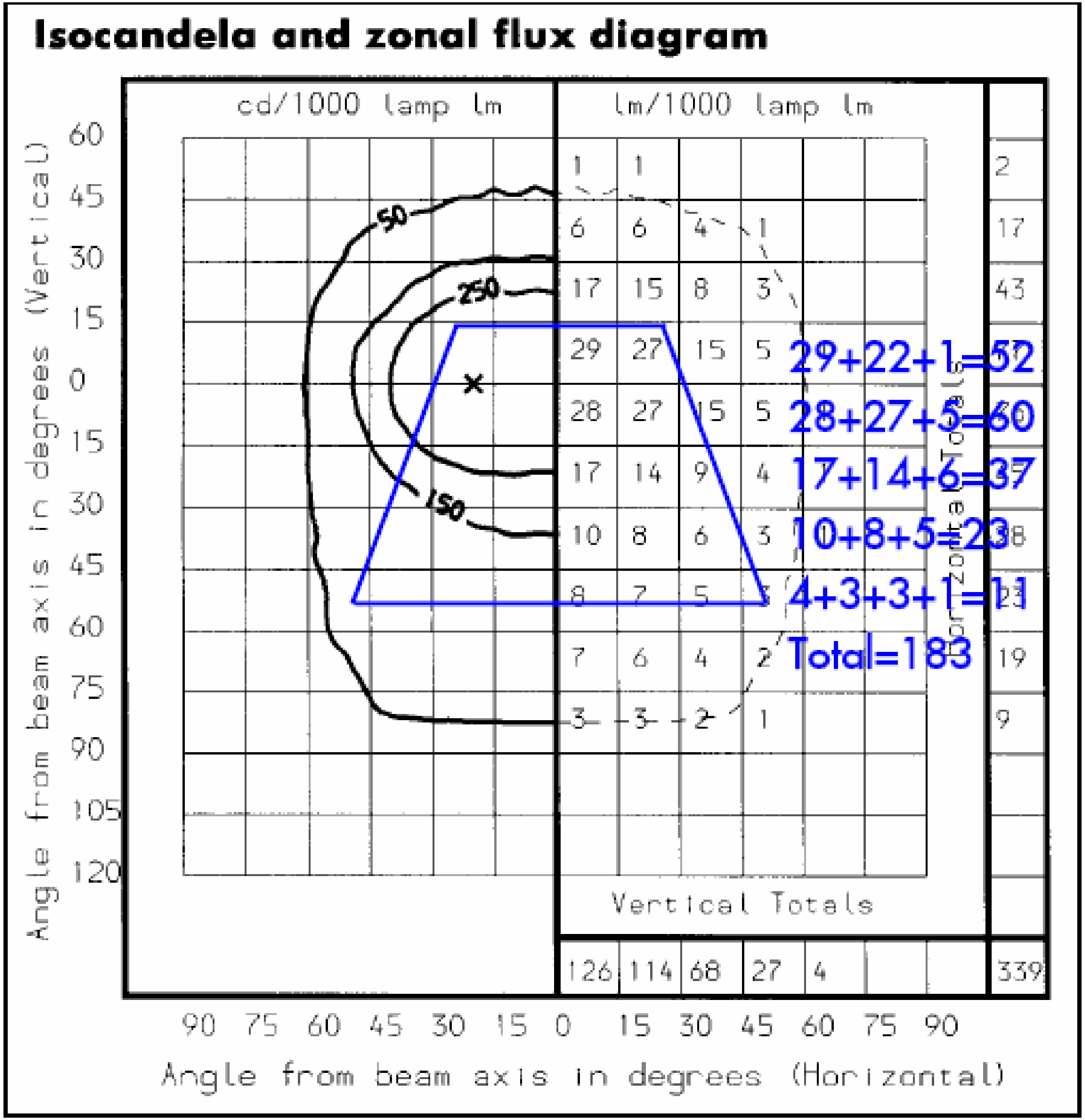


Aiming angles given

Class 2 Competition
Mounting height: 8m
Maintenance factor: 0.8

Cat. No: QTKA2540MSE40
+ CON2HQI-T400.4
Lamp: 18 x HIT 400W
Lumens: 38000
Lux: 300 aug
Lamp position: 1
Uniformity: 0.8
Glare rating: 41

Sample floodlight design for a tennis court
[Source: Thorn Lighting, UK]



[Source: Thorn Lighting, UK]

Further Reading

- e-light: LEARN: the different stages of the lighting design process http://iarc.uncg.edu/elight/learn/learn.html
  - Establish design criteria http://iarc.uncg.edu/elight/learn/establish/est.html
  - Record architectural constraints http://iarc.uncg.edu/elight/learn/record/record.html
  - Determine visual functions and tasks http://iarc.uncg.edu/elight/learn/determine/deter.html
  - Design light distribution http://iarc.uncg.edu/elight/learn/design/design.html
  - Qualitative and quantitative results http://iarc.uncg.edu/elight/learn/qualitative/qual.html

Further Reading

- Lighting Design Calculation in a Building – Step by Step
  - http://www.electricaltechnology.org/2017/03/lighting-design-calculation-in-building.html
- The installer's guide to lighting design, Good Practice Guide 300
  - http://www.cibse.org/getmedia/0276ac78-dc41-4694-9378-8f984ef924f2/GPG300-The-Installers-Guide-to-Lighting-Design.pdf.aspx

References

- SLL, 2009. *The SLL Lighting Handbook*, Society of Light and Lighting (SLL), Chartered Institution of Building Services Engineers, London.
    - Chapter 6: Lighting design
- Raynham, P., 2012. *The SLL Code for Lighting*, Society of Light and Lighting (SLL), London.
    - Chapter 12: Photometric datasheets
    - Chapter 13: Indoor lighting calculations
    - Chapter 14: Outdoor lighting calculations