Lighting Calculations

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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](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

- Direct
- Semi-Direct
- General Diffuse
- (IES) Direct-Indirect
- Semi-Indirect
- Indirect
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

Ceiling cavity reflectance 0.6 minimum
Relative ceiling illuminance 0.3 to 0.9

Effective wall reflectance 0.3 to 0.7
Relative wall illuminance 0.5 to 0.6

Task illuminance 1.0

Effective floor cavity reflectance 0.3 to 0.7

Window wall reflectance 0.6 minimum

[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/m²), 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 1.2 m
  - Vertical (e.g. on wall surface)
  - Inclined
- Analyse light distribution
  - Using light distribution curves, illumination and isolux diagrams
    - Illuminance (lux) or luminance (cd/m²)
Light distribution curves, illumination and isolux diagrams*

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

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

[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 \((\text{m}^2)\)
Lumen Method

- **Room index (K)**: a measure of the proportions of the room, for rectangular room
  - \( K = \frac{L \times W}{L + W} \) \( h_m \)
    - \( L \) = 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)** = \( \frac{L \times W}{L + W} \) \( h = K \times \frac{h_m}{h} \)
    - \( h \) = 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.

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

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)
  - \(MF = LLMF \times LSF \times LMF \times RSMF\)
    - 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

<table>
<thead>
<tr>
<th>Environmental condition</th>
<th>Maintenance factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean</td>
<td>0.9</td>
</tr>
<tr>
<td>Average</td>
<td>0.8</td>
</tr>
<tr>
<td>Dirty</td>
<td>0.7</td>
</tr>
</tbody>
</table>

The graph illustrates the depreciation of light output over time, categorized into three conditions:

- **Luminaire light O/P depreciation**
- **Lamp lumen depreciation**
- **Luminaire cleaned**
- **Luminaire cleaned and re-lamped**
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_{\text{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 \(\text{SHR}_{\text{max}}\)
  • Calculate illumininance 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)
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

The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity.
Cosine Law for lighting calculations

**COSINE LAW (Illuminance on Tilted Surface)**

- Horizontally directed Light Source F lumens flux
- Vertical Surface A receiving the Light
- Tilted Surface B receiving the Light
- Angle Z made by the Surface B with the direction of the Light

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

\[
\frac{A}{B} = \cos(Z) \quad B = \frac{A}{\cos(Z)} \quad \text{Illuminance } E_A = \frac{F}{A}
\]

\[
E_B = \frac{F}{B} = \frac{F}{\left( \frac{A}{\cos(Z)} \right)} = \frac{F}{A} \cdot \cos(Z) = E_A \cdot \cos(Z)
\]

\[
E = \frac{I}{D^2} \quad \text{when the incident angle is 0 degrees.}
\]

The general equation becomes

\[
E = \frac{I}{D^2} \cdot \cos(Z)
\]

<table>
<thead>
<tr>
<th>Cosine Values of Angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1.000</td>
</tr>
</tbody>
</table>
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

- **Example:** 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’
- **Wall washing:** 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**

- Beam diameter
- Distance (m): 0, 1, 2, 3
- Emax (lux): 0, 8500, 2100, 940
- Imax
- Beam angle (24°)

**Wall-washing luminaire**

- E1, E2, E3
- Height
- Width
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
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 design data

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

[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](http://iarc.uncg.edu/elight/learn/learn.html)
  - Establish design criteria [http://iarc.uncg.edu/elight/learn/establish/est.html](http://iarc.uncg.edu/elight/learn/establish/est.html)
  - Record architectural constraints [http://iarc.uncg.edu/elight/learn/record/record.html](http://iarc.uncg.edu/elight/learn/record/record.html)
  - Determine visual functions and tasks [http://iarc.uncg.edu/elight/learn/determine/deter.html](http://iarc.uncg.edu/elight/learn/determine/deter.html)
  - Design light distribution [http://iarc.uncg.edu/elight/learn/design/design.html](http://iarc.uncg.edu/elight/learn/design/design.html)
  - Qualitative and quantitative results [http://iarc.uncg.edu/elight/learn/qualitative/qual.html](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
References

  - Chapter 6: Lighting design

  - Chapter 12: Photometric datasheets
  - Chapter 13: Indoor lighting calculations
  - Chapter 14: Outdoor lighting calculations