Calculating Light

NOT SO SCARY LIGHTING MATH

Measuring Light / Light Metrics

• Hand Calculations
  – Point-by-Point
  – Lumen Method

The importance of Lighting Math:
• Calculations can determine the light levels
• Calculations can determine the required quantity of fixtures
• Calculations can verify uniformity

Methods to perform Lighting Math:
• By Hand - calculates a "quick" estimate of light levels, and verifies qty of fixtures
• By Computer - calculates a "detailed" estimate of light levels, and verifies qty of fixtures
Calculating Light

Target Illuminance / Light Levels

Who Defines Light Levels?
- IES of North America
  - Recommended Practices
  - Defines light levels and quality of illumination by task and application
- Codes and Regulations
- The Owner

Definitions:
- Task = the work performed
- Applications = the project type (i.e. School, Commercial etc.

Target Illuminance / Ages

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Standard Age Range is 40-55 years old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 40 years</td>
<td>Can reduce the light levels up to 1/3!</td>
</tr>
<tr>
<td>Over 55 years</td>
<td>Can increase the light levels up to 2/3!</td>
</tr>
</tbody>
</table>

Babies require 3 times more light than a 20 year old!
Calculating Light

IESNA Recommended Light Levels

QUALITY ISSUES FOR OFFICE LIGHTING

<table>
<thead>
<tr>
<th></th>
<th>Private Office</th>
<th>Openplan Office</th>
<th>Office Corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control of direct and reflected glare</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Light on walls and ceilings</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Physical relation of fixtures to users</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Uniformity / Reduces shadows and flicker</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Room surface characteristics</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Color rendering and color temperature</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Daylighting</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Lighting controls</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Quantity of light on task (footcandles)</td>
<td>≥ 40 ft-Lc</td>
<td>≥ 40 ft-Lc</td>
<td>≥ 35 ft-Lc</td>
</tr>
</tbody>
</table>

Very Important ● Important ○ Somewhat Important


IESNA Recommended Light Levels

QUALITY ISSUES FOR SCHOOL LIGHTING

<table>
<thead>
<tr>
<th></th>
<th>General Classroom</th>
<th>Computer Classroom</th>
<th>School Corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light on walls and ceilings</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Control of direct and reflected glare</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Uniformity</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Daylight</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Color rendering and color temperature</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Lighting controls</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Quantity of light (footcandles)</td>
<td>≥ 40 ft-Lc</td>
<td>≥ 40 ft-Lc</td>
<td>≥ 35 ft-Lc</td>
</tr>
</tbody>
</table>

Very Important ● Important ○ Somewhat Important

IESNA Recommended Light Levels

- IESNA Light Level recommendations are for footcandles (FC, fc) at the work plane - 2'6" AFF (30 inches)
- They have limited significance to us when we interpret the actual environment.
- Such factors as lighting walls, brightness accents, shadows, sparkle, and color have a greater influence on emotional reaction.
- IESNA's recommend light levels are for an age range of 40 – 55 years old
Calculating Light

Summary Horizontal Light Level (table 15)

<table>
<thead>
<tr>
<th>Activity</th>
<th>General Illumination</th>
<th>Direct or Average Illumination from a Fixture or Lamp</th>
<th>Recommended Spacing or Layout</th>
<th>Point-by-Point Light Level from a Fixture or Lamp Reaching a Specific Point</th>
<th>Recommended Spacing or Layout</th>
<th>Lumen Method Light Level in a Room from a Fixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>5 fc</td>
<td>5 fc</td>
<td>20 fc</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Corridor</td>
<td>5 fc</td>
<td>5 fc</td>
<td>20 fc</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lobby</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stair</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Service</td>
<td>5 fc</td>
<td>5 fc</td>
<td>20 fc</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Restrooms and Washrooms</td>
<td>5 fc</td>
<td>5 fc</td>
<td>20 fc</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kitchen</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Laundry</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Hand Methods to Calculate Light

Mnfrs Guides
- Direct or Average Illumination from a Fixture or Lamp
- Recommended spacing or layout

Point-by-Point
- Direct light level from a Fixture or Lamp reaching a specific point
- Candlepower info needed

Lumen Method
- Average Light Level in a Room from a Fixture
- Lumen info needed (Can be used to determine quantity needed)
Calculating Light

Manufactures Guides: Beam Guides

Manufactures Guides: Printed Literature
Calculating Light

Manufactures Guides: Printed Literature

Manufactures Guides: On-Line Calculations
Calculating Light

Computer Calculation Example

Computer Calculation Example
Calculating Light

### Seeing Light

**Illuminance: We do Not See Light Arriving**

Measures how much light is present, the light level to perform a task – *arriving lighting energy*

- Examples: emergency light level on the floor, on the desk, on a book
- Measured in: Foot-Candles (US) and Lux (Metric)

**Luminance: We See Brightness of Surfaces**

Measures how easy something is to see, or how bright a surface is – *emitting or reflected light energy*

- Examples: backlit signage, the moon, a glowing wall, the contrast on steps
- Measured in: Foot-Lamberts (US) or Candelas per meter squared (metric)
- \( 1 \text{ Foot-Lambert} = 3.426 \text{ Candelas/m}^2 \)

### Light Metric – The Foot-candle

**Foot-candle** is known as a unit of light - direct illumination light level

Derived from one candle placed at a distance of one foot from a surface is defined as a **foot-candle**

(abbreviation = fc or FC)
Calculating Light

**Light Metric – The Lumen**

The energy of light from a candle falling on a one foot square area is One Lumen (abbreviation = lm)

The total amount of light energy coming out of the candle is approximately 13 lumens.

The total amount of light energy coming out of 100-watt A-lamp is approximately 1650 lumens.

NOT DEFINED BY DISTANCE

**Efficiency vs Efficacy**

- **Watts** is the amount of energy used to Produce Light
- Light output from lamps and fixtures be measured in units of Lumens and Candelas.
- The ratio Lumens emitted by a lamp or fixture measures Efficiency and Efficacy

**Bare Lamp**

100 watt A-lamp = 1650 Lumens

Efficacy = Lumens/Watt
= 1650/100
= 16.5 L/W

**Lamp in a Fixture**

Fixture = 1240 Lumens

Efficiency = Fixture Lumens/Lamp Lumens
= 1240/1650
= 75%

25% is lost
Calculating Light

**Light Metric – The Candela**

*Candle Power* is the intensity value at any given direction. *(unit is Candela, abbreviated as cp)*

*Distribution Curve* represents the total light intensity pattern produced by a source.

**Light Measurement**

Measures the candlepower distribution of a particular lamp or luminaire.

Information is generated in a -- Photometric report

Integrating Sphere  
Gonio-Photometer  
The Spectro-Radiometer
Calculating Light

Photometry Reports

- Plot of candlepower values
- Summary of candlepower values in different planes
- Fixture Efficiency
- Lumen Summary
- Luminance summary
- Spacing criteria (SC) or Spacing/Mounting Height (S/MH) for uniformity
- Coefficient of Utilization Table
- Guides

Hand Methods to Calculate Light

Matris Guides
- Direct or Average Illumination from a Fixture or Lamp
- Recommended spacing or layout

Point-by-Point
- Direct light level from a Fixture or Lamp reaching a specific point
- Candlepower info needed

Lumen Method
- Average Light Level in a Room from a Fixture
- Lumen info needed (Can be used to determine quantity needed)
Calculating Light

Point-by-Point: FC at a Point

CIE Luminaire Types / Distributions

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

Photometry Reports: sample 1

- Downlight
Calculating Light

Photometry Reports: sample 2

- Indirect Pendant

Lighting Systems Silhouette® Luminous Indirect SC

Page 2 of 2

2 Light T5 Per 4’ (nominal) Section

Performance

CANDLES/POWER

ZONES: 0 20 40 67 90

WALL REFL.

% EFFECTIVE CEILING CAVITY REFLECTANCE

ROOM CAVITY REFL.

DISTRIBUTION

Calculations are for 26 watt T5 lamps, for 54 watt T5 lamps multiply by 1.7

Photometry Reports: sample 3

- Ceiling Fixture

Specification Decorative Discus™ 6700MS213U

Ceiling or “ADA” Wall Mounted 2 Lt. 13W Compact Fluorescent

...
Calculating Light

Point-by-Point: FC at a Point

Asymmetrical Distribution Curve

- Rectangular Tubular Fluorescent fixture
  - 90 deg Perpendicular
  - 0 deg Parallel

Candlepower Distribution

- Candlepower distribution curves provides intuitive information on how a luminaire will perform
- Candela values are used in calculations to predict light levels at a specific point

Candle Power Distribution

- Distribution angles
  - 0 deg 10 20 30 90 deg
  - Candela 300 600 900 1200 1500
Calculating Light

Point-by-Point

Foot-candle = \( \frac{\text{Candle Power}}{\text{Distance}^2} \)

\[ FC = \frac{\text{candelas}}{\text{ft}^2} \]

Calculate the Level at the Table

Ceiling height = 11' - 6"

Distance = 9 ft

\[ FC = \text{foot-candles} \]

Calculate the Level at the Table

Ceiling height = 9 ft

Distance = 9 ft

\[ FC = \text{foot-candles} \]

Point-by-Point

• Ceiling Fixture Example

Ceiling height = 11' - 6"

Distance = 9 ft

\[ FC = \text{foot-candles} \]
Calculating Light

Beam Study

To solve for any component, you can:
1. Scale the Drawing, or
2. Use **Trigonometry**

![Diagram of a triangle with labels A, B, C, W, H, and θ.]

Ceiling height = 9ft

\[ A^2 + B^2 = C^2 \]

Beam Study

To solve for any component, you can:
1. Scale the Drawing, or
2. Use **Trigonometry**

![Diagram of a triangle with labels A, B, C, W, H, and θ.]

Ceiling height = 9ft

Sine θ = Opposite / Hypotenuse
Cosine θ = Adjacent / Hypotenuse
Tangent θ = Opposite / Adjacent

Remember this by the name of the Indian Princess: soh-cah-toa
Calculating Light

**Point-by-Point**

$$\text{Foot-candle} = \frac{\text{Candle Power}}{\text{Distance}^2}$$

- **Ceiling Fixture Example**

  $$\text{FC} = \frac{\text{candelas}}{\text{ft}^2}$$

  $$\text{FC} = \text{foot-candles}$$

  Ceiling height = 9ft

  \[ \text{Determine the Light Level at the center of the Table} \]

**Hand Methods to Calculate Light**

**Mnfrs Guides**
- Direct or Average Illumination from a Fixture or Lamp
- Recommended spacing or layout

**Point-by-Point**
- Direct light level from a Fixture or Lamp reaching a specific point
- Candlepower info needed

**Lumen Method**
- Average Light Level in a Room from a Fixture
- Lumen info needed (Can be used to determine quantity needed)
Calculating Light

Lumen Method: Room Reflectance

- Room comprised of Walls, Ceiling, and Floor.
- Walls typically have Doors and Windows
- All surfaces have a reflectance value to bounce light.
- Light from Light Fixture bounces off of all surfaces.

Lumen Method: Room Reflectance

- Surfaces with less reflectance will bounce less light
- Typical Reflectance Values:
  - 75%-90% White, Off White, Grey, Light tints of Blue or Brown
  - 30%-60% Medium Green, Yellow, Brown, or Grey
  - 10%-20% Dark Grey, Medium Blue
  - 5%-10% Dark Blue, Brown, Dark Green, and many wood finishes
Calculating Light

Calculations using Lumens

Lumen Method Calculation
- Calculates the Average Illumination for a room.
- Takes into account the room surface reflectance’s – but assumes the surfaces are diffuse (not shiny!).
- Assumes an empty room (without furniture).
- The formula can also be used to determine the required Quantity of Fixtures needed for a target light level.
- Does not determine light fixture layout or location – you must following mnfrs spacing criteria.

The Steps:
1. You need Room Dimensions and the Fixture Mounting Height.
2. You need to select a Light fixture
3. Determine the rooms Room Cavity Ratio (RCR).
4. Look-up the fixtures Coefficient of Utilization for the RCR.
5. Calculate!

Photometry Reports
- Plot of candlepower values
- Summary of candlepower values in different planes
- Fixture Efficiency
- Lumen Summary
- Luminance summary
- Spacing Criteria (SC) or Spacing/Mounting Height (S/MH) for uniformity
- Coefficient of Utilization Table
- Guides
Calculating Light

**Coefficient of Utilization**

- Also known as **CU**
- Defines the percentage of light output that is expected from a fixture
- The value is determined by a CU table
- **For commercial Reflectance of 80/50/20**, the actual CU value is this.

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Reflectance</th>
<th>CU Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>80%</td>
<td>0.8</td>
</tr>
<tr>
<td>50</td>
<td>50%</td>
<td>0.5</td>
</tr>
<tr>
<td>20</td>
<td>20%</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Step Room Cavity Ratio**

\[ RCR = \frac{5xMH(L+W)}{Room \ Area} \]

- The **RCR** can vary depending on the height you want to calculate… **as shown here with the calculation height at the floor.**
Calculating Light

Room Cavity Ratio  

\[ RCR = \frac{5xMHx(L+W)}{Room\ Area} \]

- Room Cavity Ratio (aka RCR) is the volume between the Fixture and Height of Calculation.
- Workplane height is typically 30-inches above the floor.
- A room's RCR will always be between 1 and 10.

The RCR can vary depending on the height of the fixture, as shown here with Wall Brackets or Sconces.
Calculating Light

Room Cavity Ratio

RCR = \frac{5 \times MH \times (L + W)}{\text{Room Area}}

- The RCR can vary depending on the height of the fixture... as shown here with Pendants.

Example:
Room Width: 12ft
Room Length: 15ft
Ceiling Height: 10ft

RCR = \frac{5 \times (\_\_\_) \times (\_\_ + \_\_)}{\_\_ \times \_\_}

RCR =
Calculating Light

Lumen Method Formula

To Calculate Foot-candle level:

\[ FC = \frac{\text{Qty of Fixtures} \times \text{Number of Lamps per Fixture} \times \text{Lumens per Lamp} \times \text{CU}}{\text{Area of the Room}} \]

To Calculate number of Fixtures:

\[ FC = \frac{\text{Total Lumens in the Room} \times \text{CU}}{\text{Area of the Room}} \]

\[ \text{Qty of Fixtures} = \frac{FC \times \text{Area of the Room}}{\text{Number of Lamps per Fixture} \times \text{Lumens per Lamp} \times \text{CU}} \]

\[ \text{Qty of Fixtures} = \frac{FC \times \text{Area of the Room}}{\text{Total Lumens in the Room} \times \text{CU}} \]

Layout and Pattern

10ft x 10ft Office

Four Ceiling Lights:

10ft x 10ft Office

One Pendant:
Calculating Light

Lumen Method Example 1

What is the resulting Foot-candle Level at table height from four ceiling lights?

Target Illuminance = 30FC

Example:
- Room Width: 10ft
- Room Length: 15ft
- Ceiling Height: 10ft

Lumen Method Calculation

Calculation:
- Foot-candle Level: \( \frac{\text{Lumen per Lamp} \times \text{Room Area}}{\text{Room Surface Area}} \)

Example:
- Room Width: 10ft
- Room Length: 15ft
- Ceiling Height: 10ft
- Target Illuminance = 30FC

Lumen Method Example 1

What is the resulting Foot-candle Level at table height from four ceiling lights?
Calculating Light

Lumen Method Example 2

What is the resulting Foot-candle Level at table height from one pendant?

Target Illuminance = 30FC

Example:
Room Width: 10ft
Room Length: 10ft
Ceiling Height: 10ft

Lumen Method Calculation

<table>
<thead>
<tr>
<th>Project</th>
<th>Room Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Room</th>
<th>Room Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ceiling Height (ft)</th>
<th>Room Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Room Cavity Ratio</th>
<th>Room Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ROM = Lumen/Area</th>
<th>Area = Lumen/ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R =</th>
<th>W =</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lamp</th>
<th>Lamps per Room</th>
<th>Lamps per Lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FC =</th>
<th>QFC =</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q Of Pictures</th>
<th>QFC x ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q of Pictures</th>
<th>QFC x ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q of Pictures</th>
<th>QFC x ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q of Pictures</th>
<th>QFC x ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>