The importance of Lighting Math:

- Calculations can determine the light levels
- Calculations can determine the required quantity of fixtures
- Calculations can verify layout

Methods to perform Lighting Math:

- By Hand
- By Computer
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.)

- IESNA Light Level recommendations are for Footcandles at the work plane (2'6" AFF)
- 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
Lighting Math

Ages

Standard Age Range is 40-55 years old

Less than 40 years old...
Can reduce the light levels up to 1/3!

Over 55 years old...
Can increase the light levels up to 2/3!

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

IESNA Recommended Light Levels

IESNA Lighting Design Guide

Interior Locations and Tasks

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<th>Accounting and Office</th>
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| Business and Finance | Conference Rooms | Design 

3
Lighting Math

Summary Light Level (table 15)

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<td>Halls and hallways</td>
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<td>Hallways, for general</td>
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<td>Kitchen, general washing,</td>
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<tr>
<td>Laundry</td>
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</tbody>
</table>

**Luminance**
- Measures how easy something is to see, or how bright a surface is – emitting light energy.
- Examples: backlit signage, a full moon, glowing wall.
- **Measured in:** Foot-Lamberts (US) or Candelas per meter squared (metric)
  \[ 1 \text{ Foot-Lambert} = 3.426 \text{ Candelas/m}^2 \]

**Illuminance**
- Measures how much light there is to see by, the light level to perform a task – arriving lighting energy.
- Examples: emergency light level on the floor.
- **Measured in:** Foot-Candles (US) and Lux (Metric).
Lighting Math

Light – 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).

Light – 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
Light – 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

CIE Luminaire Types / Distributions

Direct Semi-Direct General Diffuse

(IES) Direct-Indirect Semi-Indirect Indirect
Lighting Math

Candlepower Distribution Curve

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

Asymmetrical Distribution Curve

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

- Candlepower Distribution for perpendicularly oriented fixtures.

Candlepower Distribution for parallelly oriented fixtures.
Lighting Math

**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**

**Lumens versus Candelas**

- **Lumen** is an amount of **ENERGY**
- **Candela** is an amount of **INTENSITY**

- Light output from lamps and fixtures be measured in **Lumens** and **Candelas**.
- Fixtures alter **Lumen** and **Candela** output (Their values can only be found in Photometry Reports)

**Bare Lamp**
100 watt A-lamp = 1650 Lumens

**Lamp in a Fixture**
Fixature = 1240 Lumens
Fixature is approx 75% efficient
Lighting Math

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

Photometry Reports: sample 1

- Open Downlight
Photometry Reports: sample 2

- Indirect Pendant

Photometry Reports: sample 3

- Ceiling Fixture
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

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

### Point-by-Point

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

- Ceiling height = 9ft
- Light Level at Floor

\[ FC = \frac{2651 \text{ candelas}}{9 \text{ ft}^2} \]
\[ FC = \frac{2651}{81} \]
\[ FC = 32.7 \text{ foot-candles} \]
Lighting Math

Point-by-Point

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

- Ceiling Fixture Example

FC = \text{candelas / ft}^2

FC = \text{foot-candles}

Determine the Light Level at Table

Ceiling height = 9ft

Corridor Width = 6 ft

Eye Level = 5.5ft

Determine the Light Level at the Wall
Point-by-Point

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

To solve for \( D \), you can:
1. Scale the Drawing, or
2. Use Trigonometry

\[ A^2 + B^2 = C^2 \]
\[ 2.5^2 + 3^2 = C^2 \]
\[ 6.25 + 9 = C^2 \]
\[ C = \sqrt{6.25 + 9} \]
\[ C = 3.9 \text{ (approx 4 ft)} \]

Ceiling height = 8 ft
Corridor Width = 6 ft
Eye Level = 5.5 ft

Determine the Light Level at the Wall

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

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

\[ \tan(\text{Angle}) = \frac{\text{Opp}}{\text{Adj}} \]
\[ \text{Angle} = \tan^{-1}\left(\frac{\text{Opp}}{\text{Adj}}\right) \]

\[ \text{Angle} = \tan^{-1}\left(\frac{3}{2.5}\right) \]
\[ \text{Angle} = 50 \text{ degrees} \]
Lighting Math

Point-by-Point

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

- Ceiling Fixture Example

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

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

Determine the Light Level at the Wall

Corridor Width = 6 ft

Ceiling height = 8 ft

Eye Level = 5.5 ft

Point-by-Point Factors

- Calculated Levels are Facing the Light Fixture
  - With the exception of directly below
Point-by-Point Factors

- You need to factor an adjustment if you want levels at other angles (IE Horizontal, Vertical Angles)
  - COSINE Adjusted!!

COSINE Adjustments

Foot-candle = \( \frac{\text{Candle Power}}{\text{Distance}^2} \times \text{COS(} \text{Angle of Incidence} \text{)} \)

Light Source

Incidence

Reflectance

\[ \theta \]
Lighting Math

Point-by-Point… with COSINE Adjustment

- Ceiling Fixture Example

**FC = CP/D² x COS(angle)**

What is the Angle of Incidence?

**FC = 7.25 x COS (___ deg)**

**FC = ____ foot-candles**

Corridor Width = 6 ft

Ceiling height = 8 ft

Determine the Light Level at the Wall

Methods to Calculate Light

**Point-by-Point**
- Direct Illumination from a Fixture or Lamp
  - You need….
    - Photometry
    - Distances from Fixture or Lamp

**Lumen Method**
- Average Light Level in a Room from a Fixture
  - You need….
    - Photometry
    - Room Dimensions and Surface Reflectance's
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.

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
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).
  - 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.

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!

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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
**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.

**Room Cavity Ratio**

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

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

Room Cavity Ratio

RCR = \frac{5 \times MH \times (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.

Room Cavity Ratio

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

- The RCR can vary depending on the height of the fixture....as shown here with Wall Brackets or Sconces.
Room Cavity Ratio

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

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

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

Room Cavity Ratio

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

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

RCR =
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:

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

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

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

**Lumen Method Example 1**

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

Example:
- Room Width: 128 ft
- Room Length: 15 ft
- Ceiling Height: 10 ft
Coefficient of Utilization

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

Lumen Method Example 2

How many fixtures do I need to achieve 30-foot-candles at table height?