BLDG 366
Acoustics and Lighting

Week 10: Lighting calculation

March 12nd, 2016

Instructor: Dr. Hua Ge P. Eng.

Outline

- Review of lighting terminology
- Luminaires & description
- Lighting calculation
  - Lumen method
  - Point by point method

Lighting terminology

Quantity	Symbol	SI Unit	Abbr.	directional	Notes (& Imperial Units)
Luminous flux	**Φ**	**Lumen**	**lm**	No	**Also called luminous power (Lumen)**
Luminous efficacy		**Lumen per watt**	**lm/w**		**Ratio of luminous flux to radiant flux or power consumed by the source; max. possible is 683**
Luminous intensity	**I**	**Candela (lm/sr)**	**cd**	Yes	**An SI base unit (cd or Candela)**
Illuminance	**E**	**Lux (lm/m²)**	**lx**	No	**Used for light incident on a surface (fc or footcandels, lm/ft²)**
Luminance	**L**	**Candela per square metre**	**cd/m^2**	Yes	**Units are sometimes called nits (footlambert)**
Luminous exitance	**M**	**Lux (lm/m²)**	**lx**	no	**Used for light reflected or transmitted by a surface (Lumen per sq.ft.)**

http://ccrs.nrcan.gc.ca/resource/tutor/stereo/chap2/chapter2_4_e.php

Equations

Luminous Flux (Φ)

$$E = \frac{\Phi}{A}$$

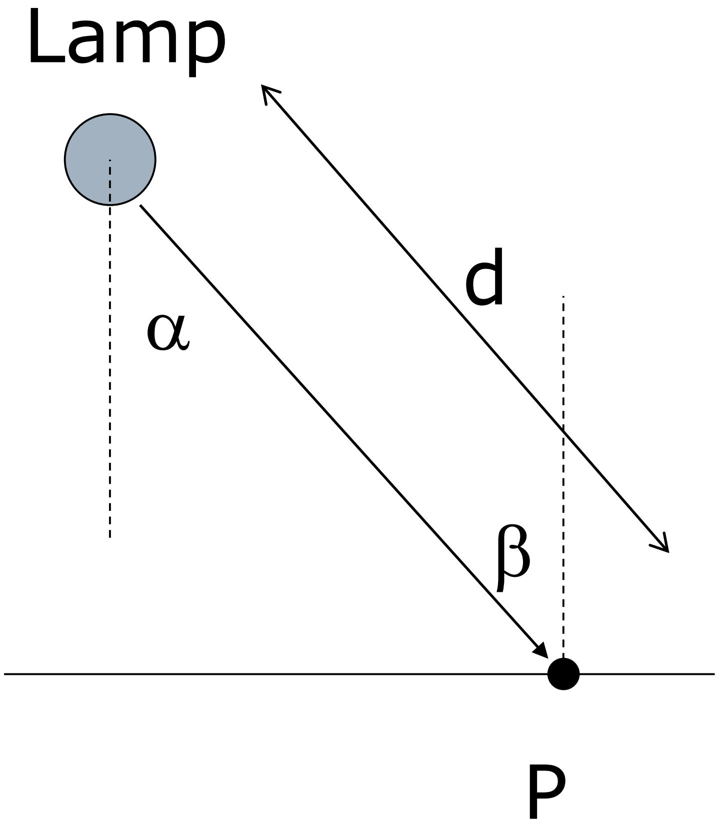
$$I = \frac{\phi}{4\pi}$$

E = I / D²

$$E = \frac{I \cos \beta}{d^2}$$

$$L = \frac{I}{A \cos \alpha}$$

$$M = \pi L$$



Exercises

1. Find the total luminous flux emitted by a lamp rated at 100 candelas; 1257 lumen

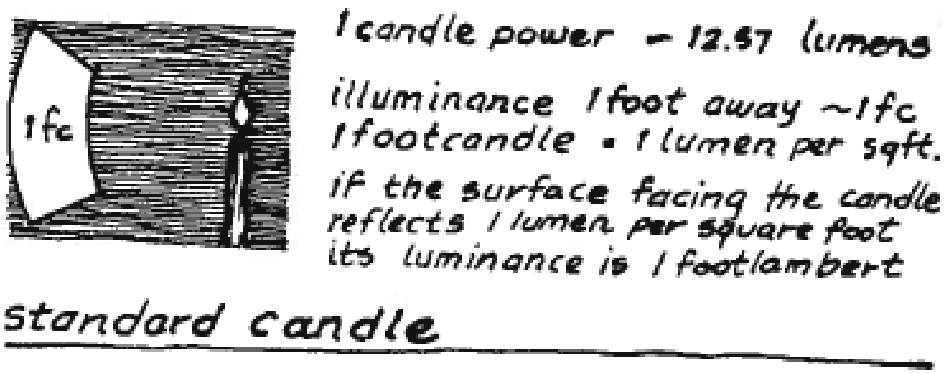
2. Find the illuminance (lux) @ 1 metre distance from a point light source rated at 100 candelas; 100 lux

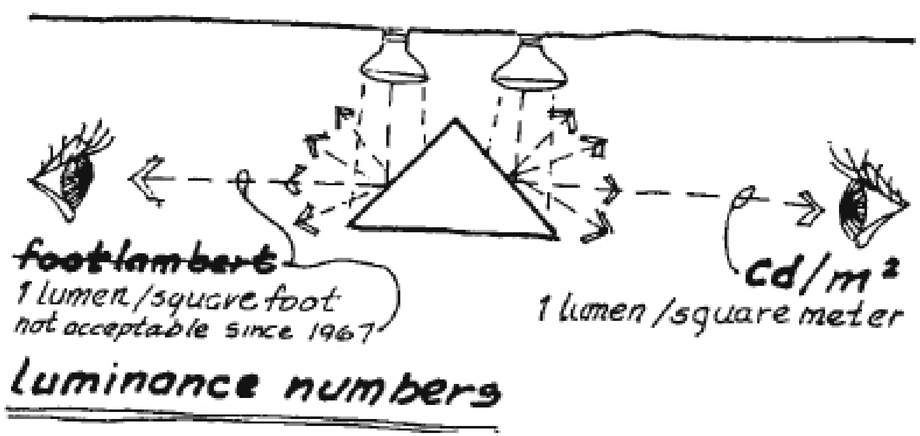
3. Find the illuminance (lux) @ 2 metres distance from a point light source rated at 100 candelas; 25 lux

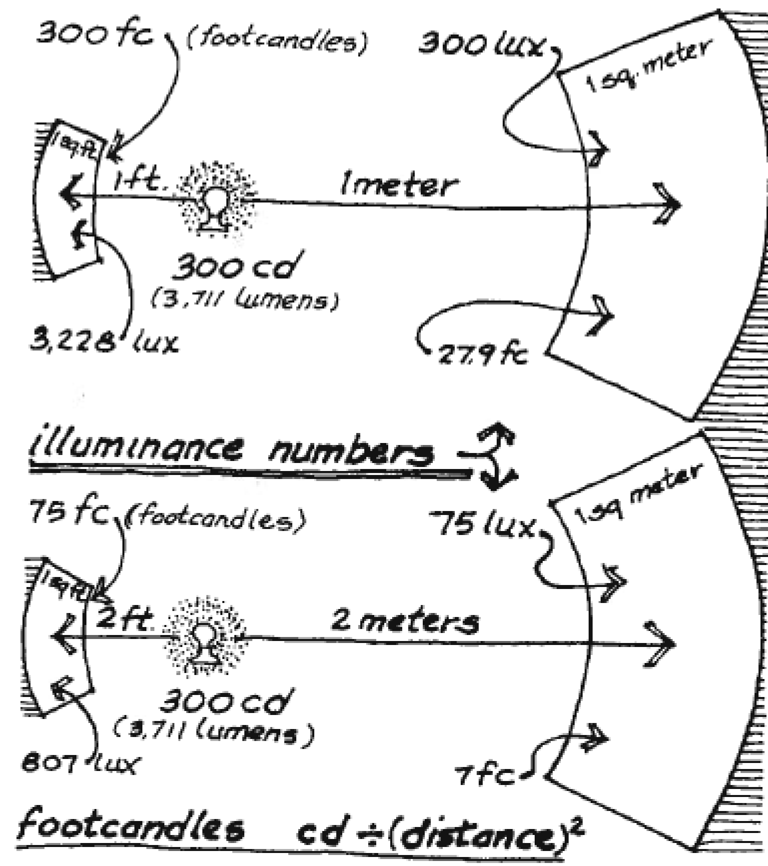
4. Find the illuminance (fc) @ 1 foot distance from a point light source rated at 100 candelas; 100fc

5. Find the illuminance (fc) @ 6.56 feet distance from a point light source rated at 100 candelas; 2.32fc

Lighting metrics







Light sources

- Light sources-lamps-used for illumination can be divided into three general classes:
  - **Incandescent** lamps: produce light by heating a filament until it glows. The glowing filaments are surrounded by either a vacuum or an inert gas which prevents the filament from oxidizing and “burning up”
  - **Discharge** lamps: produce light by ionizing a gas through electric discharge inside the lamp
  - **Solid-sate** lamps: convert electrical energy directly to light
- In addition to manufactured light sources, daylight provides illumination
  - Its primary characteristic is its variability

Discharge lamps

- Fluorescent lamps (low-pressure mercury electric-discharge lamp):

Produce light by emitting electrons from cathodes at their ends. This electron arc stream flows through the mercury vapour in the lamp, generating some visible light, but mostly UV radiation, which in turn excites the phosphor coating (i.e. fluorescent materials) on the inside of the bulb.

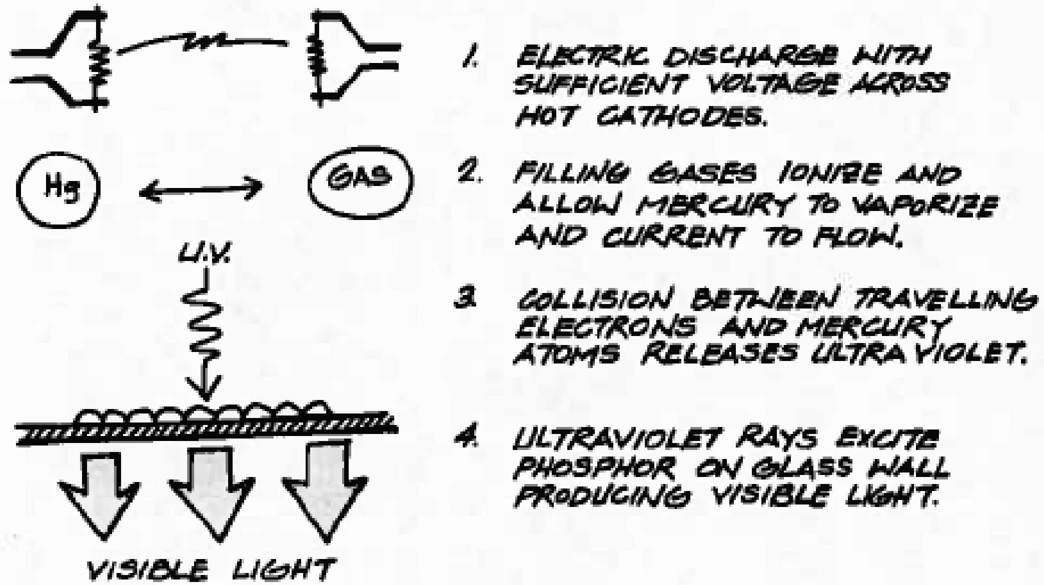


Figure 4-16. *Many cycles of operation inside a fluorescent lamp.*

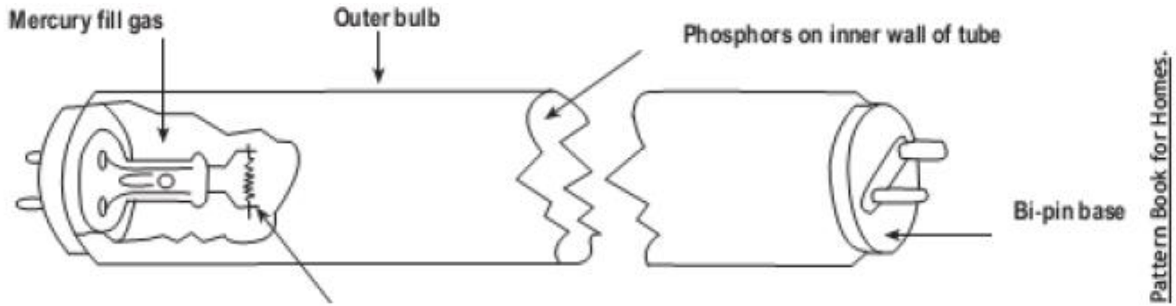
P. C. Sorcar (1987)

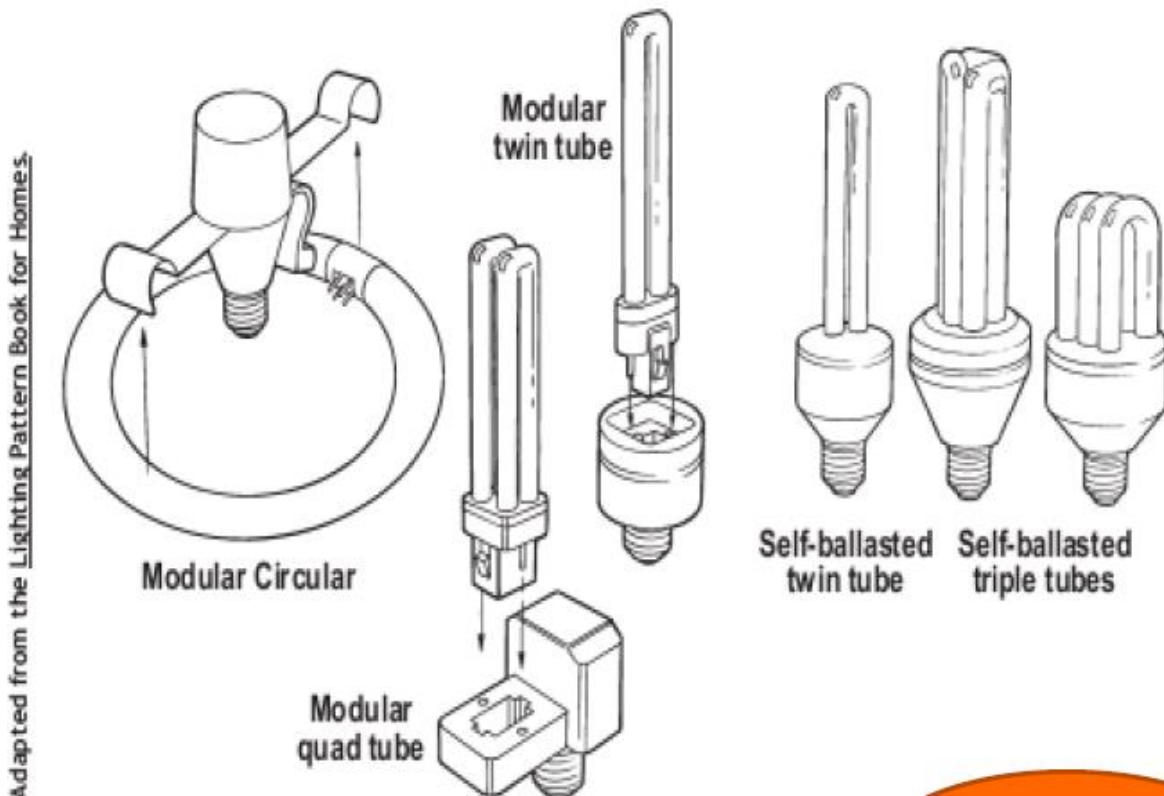
Filling gas: argon or mixture of argon & neon with a few drops of liquid mercury

Discharge lamps

- HID Lamps: produce light by passing a high-pressure electron arc stream through a gas vapour. They require about 5 min. to warm up to full brightness.
- Four types of high-intensity discharge (HID) lamps are most widely available on today's market
  - High pressure mercury vapour lamps
  - Metal-halide lamps
  - High-pressure sodium lamps
  - Xenon lamps

Discharge lamps





P. C. Sorcar (1987)

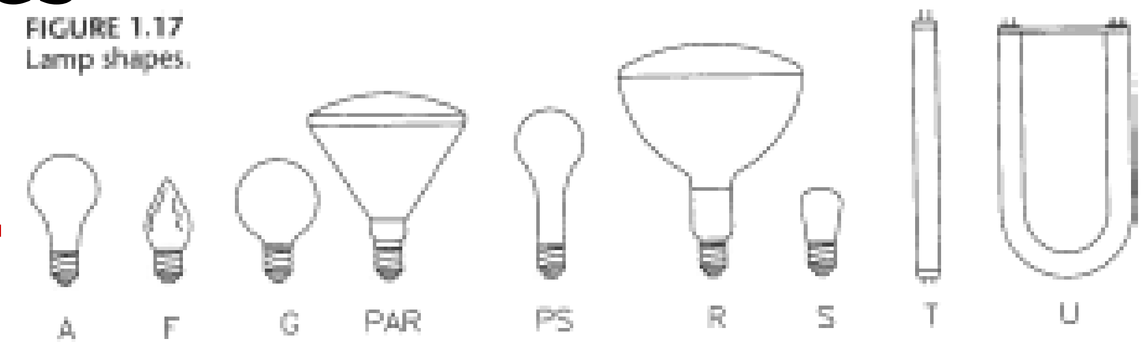
Solid-state lamps

- LED lamps
  - Use light-emitting diodes (LEDs) as the source of light
  - They offer long service life and high energy efficiency

http//Wikipedia.org

Lamp shapes

FIGURE 1.17
Lamp shapes.

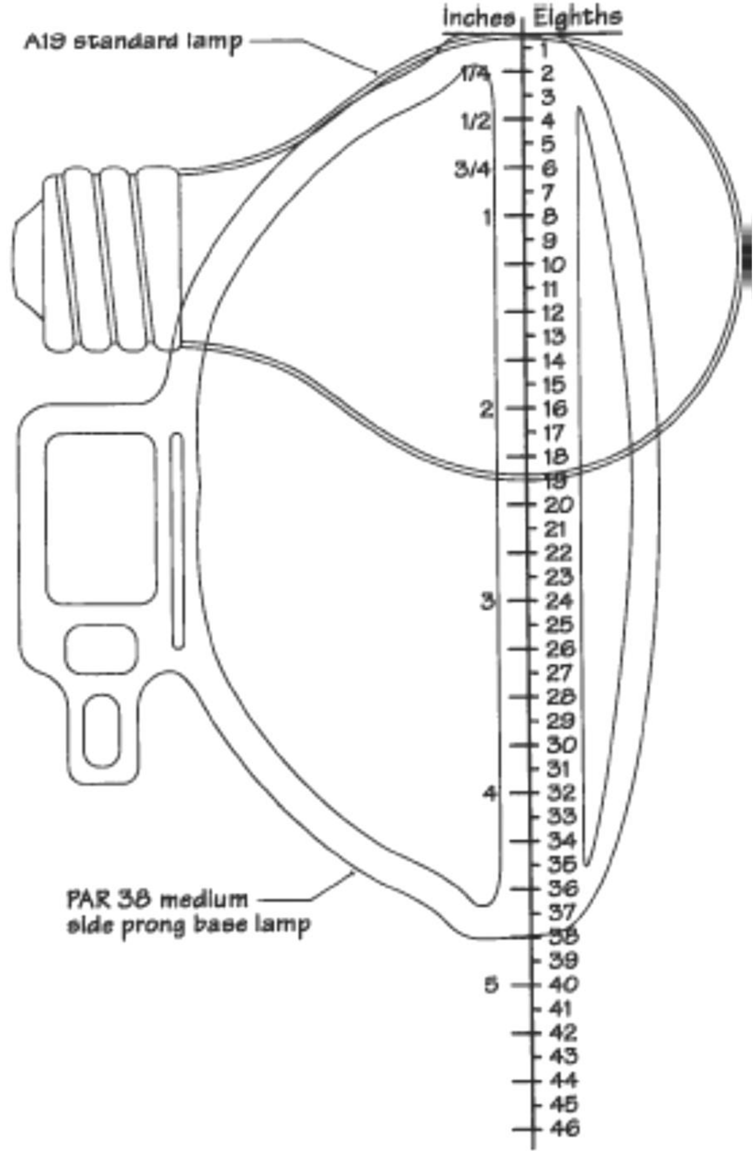


Letter	Lamp shape	Lamp description/use(s)
A	Arbitrary	Standard household light bulb
F	Flame	Decorative flame-shaped bulb used in electrically lighted holiday candles and chandeliers
G	Globe or round	Ball-shaped bulbs used in vanity mirrors and large lobbies
PAR	Parabolic reflector	Used for directed beam applications such as search lights and flood lights
PS	Pear straight-neck	Similar to an A-lamp bulb shape but with a longer neck, often used in workshops and maintenance rooms
R	Reflector	Bulb contains a highly reflective surface, resembles the front of a flashlight
S	Straight side	This lamp has a bulb with parallel straight sides; often used for decorative or small lamp applications
T	Tubular	Most common shape for fluorescent lamps but may also be used in incandescent lamps; the bulb is a tube with a base at either end
U	U-shaped	Similar to the tubular lamp, but bent into a U shape

D. Egan and V. Olgyay (2003)

Lamp designation

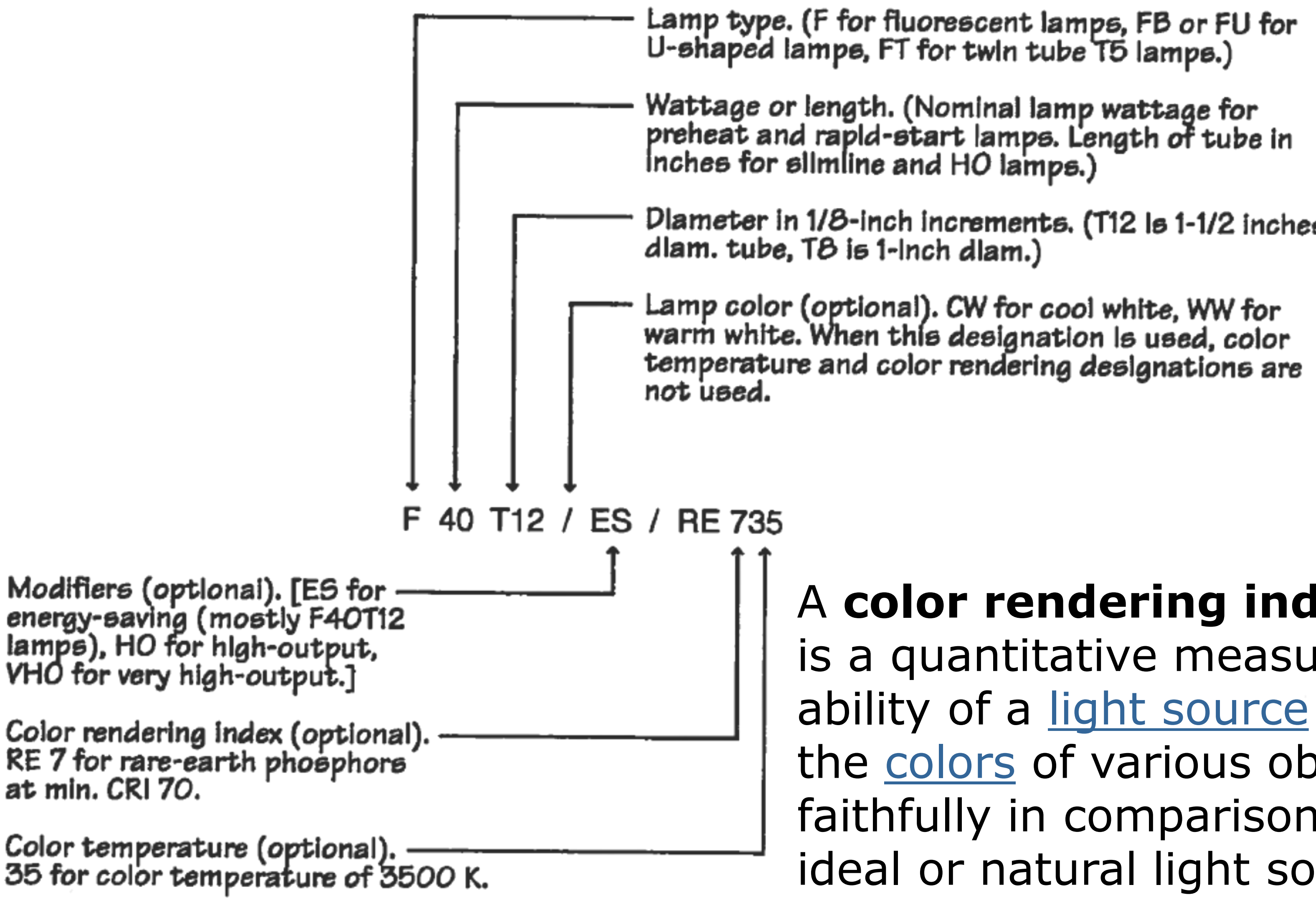
- standard abbreviations which refer to diameter, shape and wattage
- diameter is given in increments of 1/8 in. e.g. 16 refers to 2 in.
- additional information including length, color rendering or mounting



Lamps Superimposed on Ruler (Inches)

D. Egan and V. Olgyay (2003)

Lamp designation



A **color rendering index** (**CRI**) is a quantitative measure of the ability of a light source to reveal the colors of various objects faithfully in comparison with an ideal or natural light source. Range: Max. 100; florescent: 50-90; LED: 80+

D. Egan and V. Olgyay (2003)

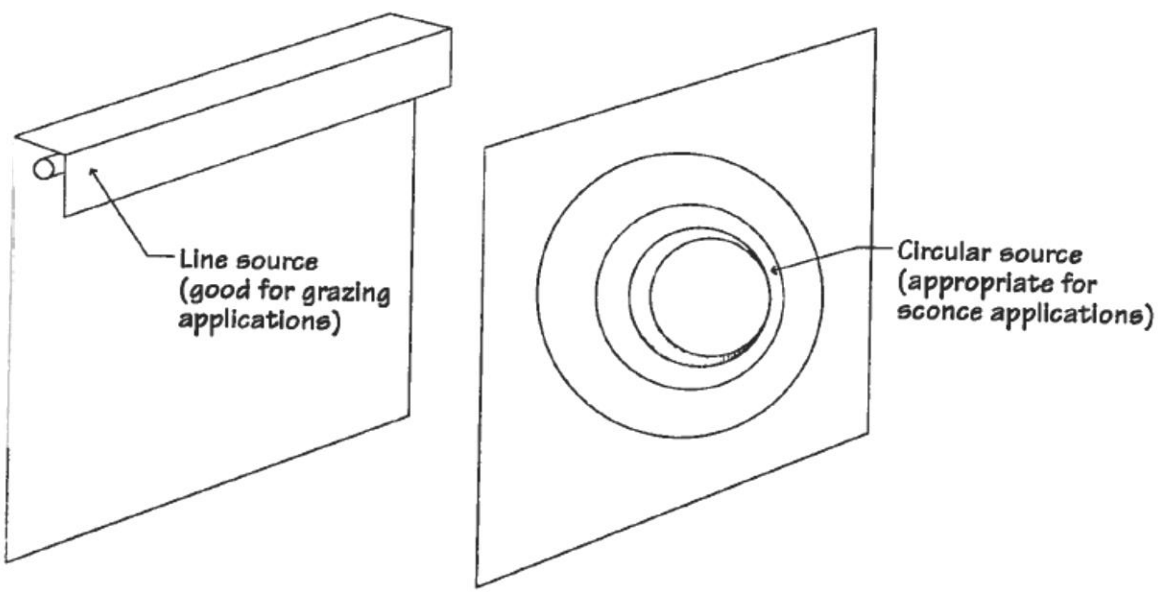
Lamp designation

Abbreviation	Description
200A23	200-W, A-shaped lamp, 2¾-in diameter
35MR16/NSP	35-W, multireflector, 2-in diameter, narrow spot
75PAR36SP	75-W, parabolic aluminized reflector, 4½-in diameter, spot
Q500T3/CL	Quartz tungsten halogen, 500-W, tubular, ⅜-in diameter, clear lamp
F40T12WW	Fluorescent, 40-W, tubular, 1½-in diameter, warm white
F48T12CW/HO	Fluorescent, 48-in, 63-W, tubular, 1½-in diameter, cool white, high-output
F32T8/RE735	Fluorescent, 32-W, tubular, 1-in diameter, rare earth, CRI 70–79, 3500K
F96T12CW	Fluorescent, 8-ft long, tubular, 1-in diameter, cool white
CFT13W/GX23/27	Compact fluorescent, 13-W, twin-tube, GX series, 2700K
MH175/C/U	Metal halide, 175-W, phosphor coated, universal mounting position
S54SB-100	High-pressure sodium, 100-W

D. Egan and V. Olgyay (2003)

Lamp form

- Typical form of lamps: **point source, line source and area source**
- Its physical form should be matched to its intended application. E.g. a line source may be best choice for grazing a wall while a circular source might be better used in a sconce
- Up close, a large point source can be like an area source, from distance a series of small point sources can be perceived as a line source

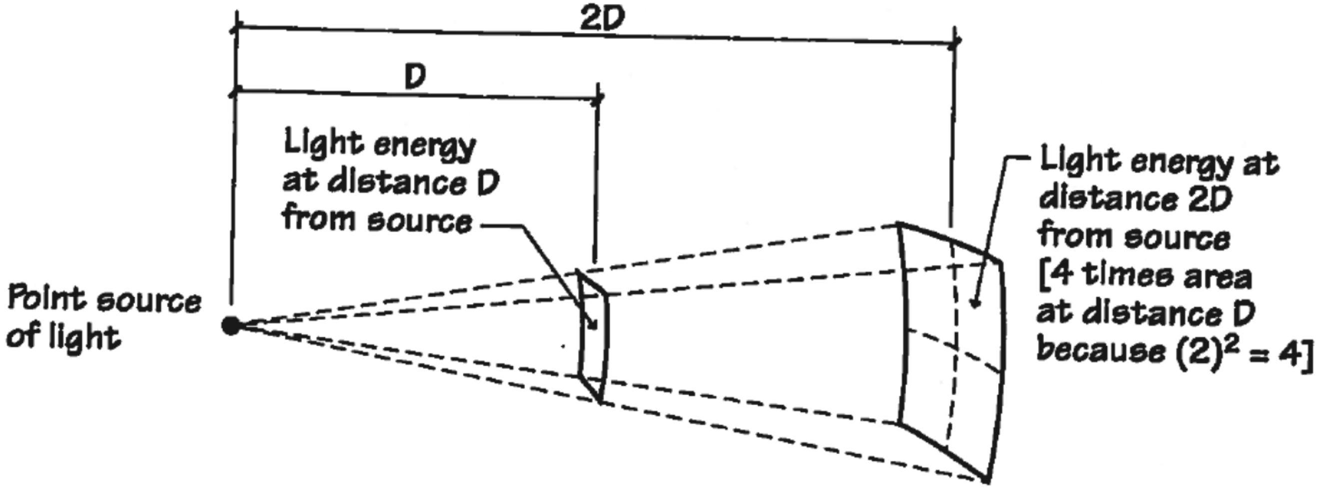


D. Egan and V. Olgyay (2002)

Lamp form

- Point source:

Light which originates from a single point (such as the familiar incandescent A lamp) is known as a *point source*. Point sources produce the sharpest shadows. A point source will behave as an area source when very close to the observer; and similarly, an area source will behave as a point source when sufficiently far away. For practical purposes, this distance can be considered to be about 5 to 10 times the largest dimension of the source. Therefore a 2-ft by 2-ft fluorescent panel will appear to be a point source when viewed from more than 20 ft away.

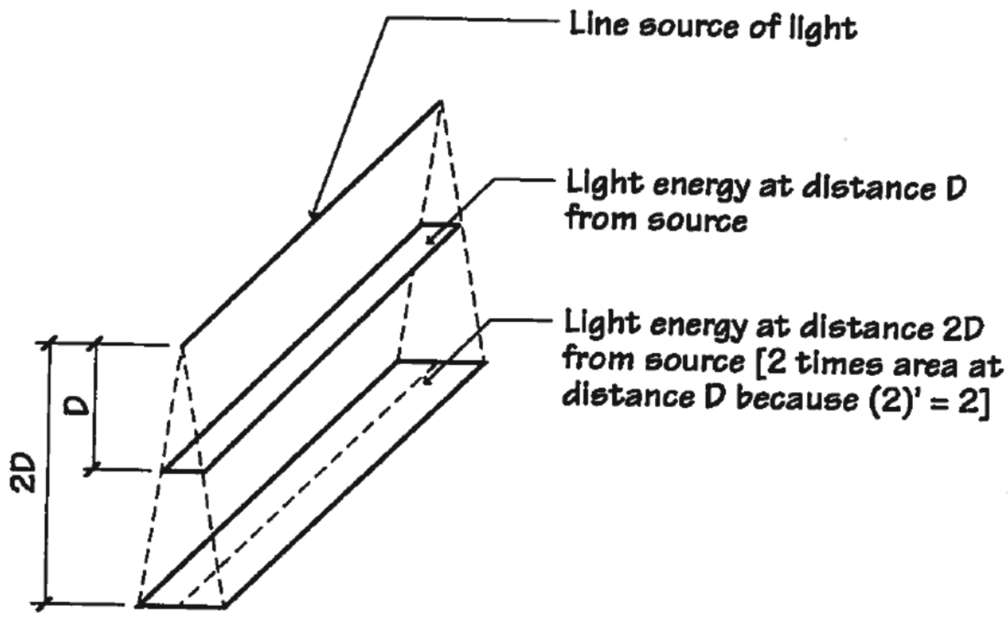


D. Egan and V. Olgyay (2003)

Lamp form

- Line source:

When a point source of light is extended along one axis, it becomes a line source. A row of fluorescent lamps is a line source. Line sources produce shadows perpendicular to their axis; shadows parallel to the axis of line sources are weak and washed out.

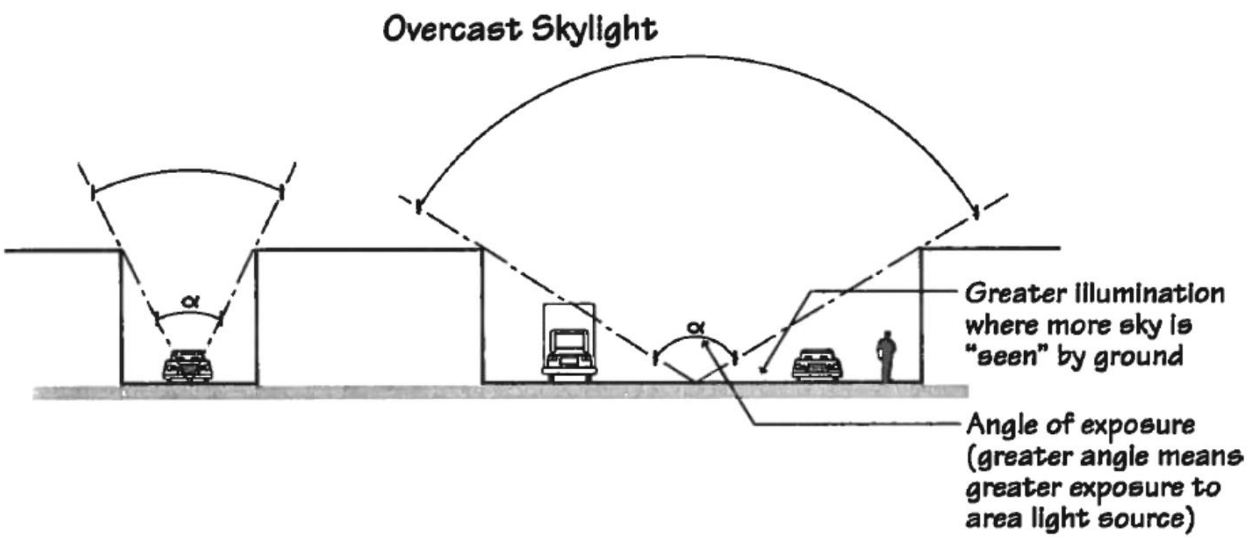


D. Egan and V. Olgyay (2003)

Lamp form

- area source:

Extending a light source along two perpendicular axes creates an area light source. Examples of area sources include uniformly overcast skies, luminous ceilings, most indirect light sources, and large luminous panels. For area sources, the light level at a given point is the amount of the source "seen" (exposed to the given point of interest) and the candlepower of the source. The amount seen is measured by the solid angle subtended between the source and the observation point.

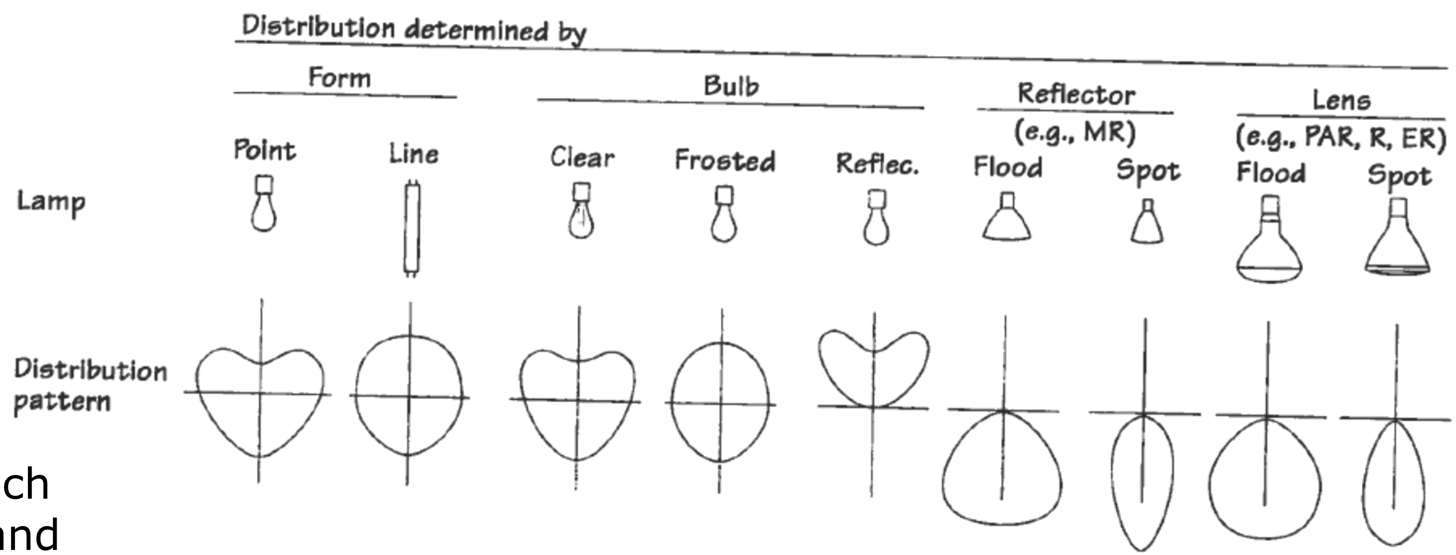


D. Egan and V. Olgyay (2003)

Distribution

- The optics of a lamp are determined by form (point, line, or area)
- Characteristics of the bulb (inside frosted, clear, lensed)
- Use of a reflector as part of the lamp i.e. multireflector (MR), parabolic aluminized reflector (PAR) and reflector (R) to direct the light and reduce trapped light inside
- Lamps without optical controls will depend on the fixture to control and distribute light

Parabolic shape direct output in parallel rays, which are fairly broad and soft-edge



Note: All distributions are shown parallel to the lamp's axis with the exception of the line source, which is shown perpendicular to the lamp's axis.

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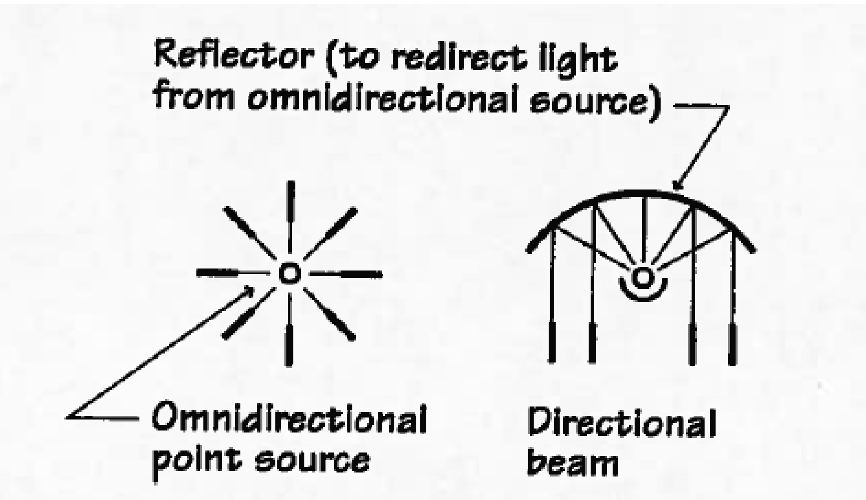
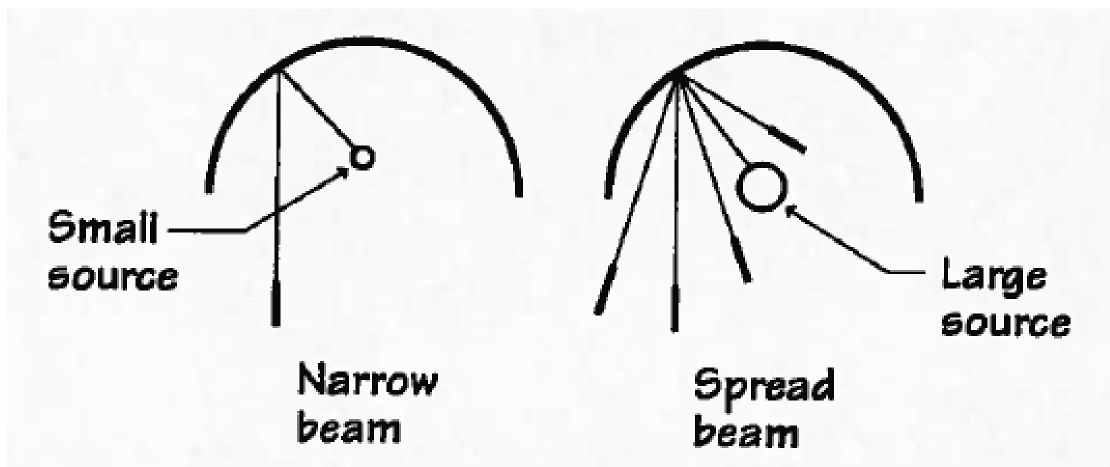
Distribution: reflector





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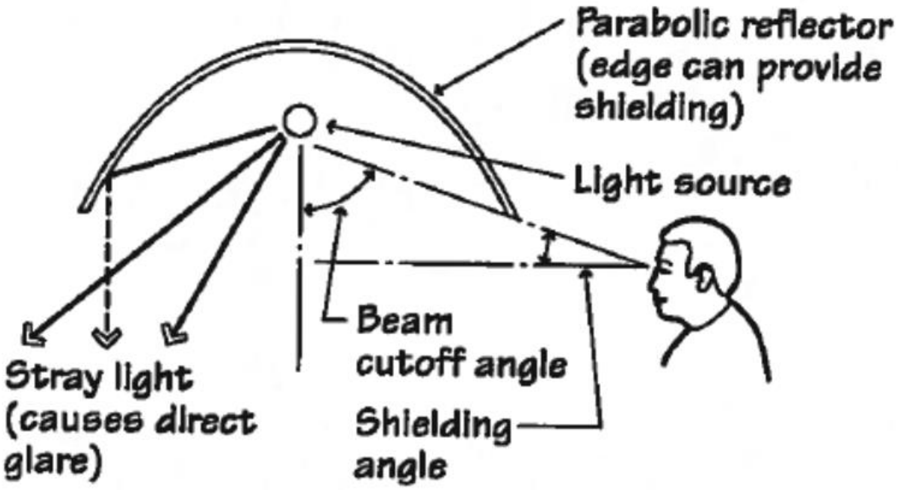
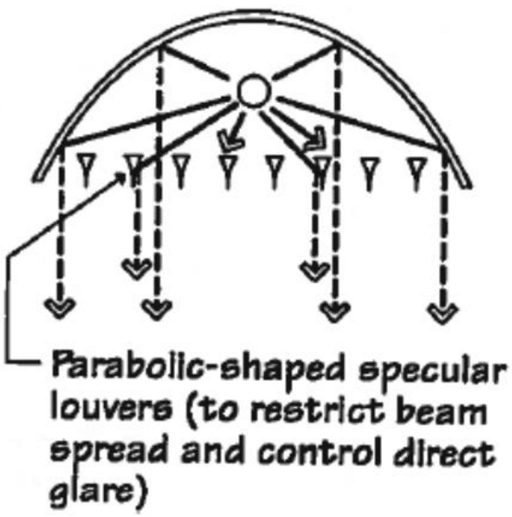
Distribution

Reflectors, lenses, and diffusing elements can be used to achieve a wide variety of light distribution and brightness characteristics.

Specular Reflector



Louvers (or Baffles)



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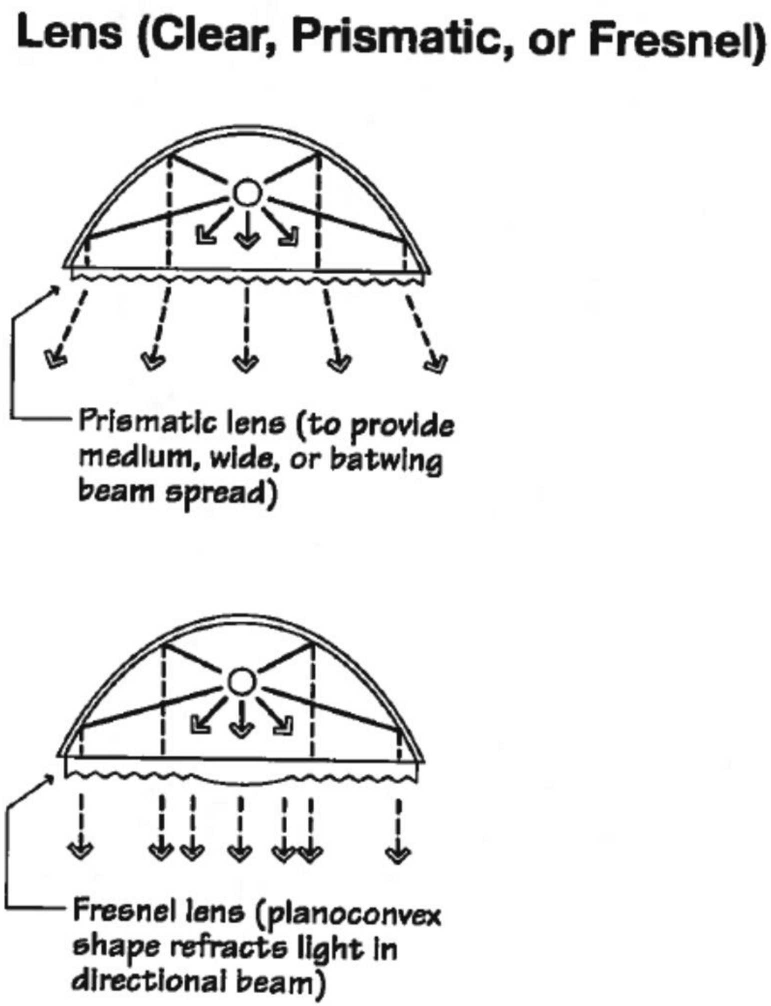
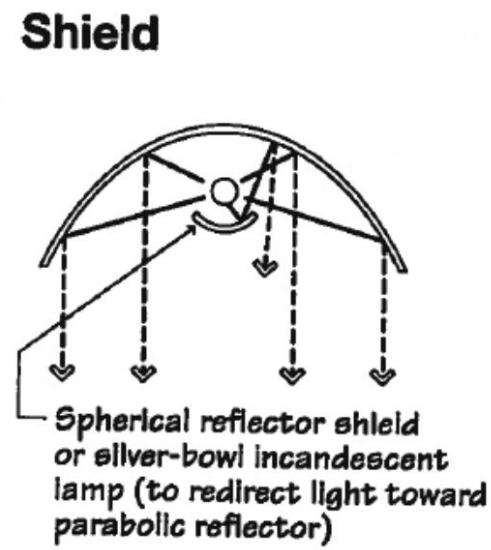
Distribution





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Lamps description

Reference Tables for:

- **Candlepower**
- **Lumen**
- **Luminance**
- **Coefficient of Utilization**

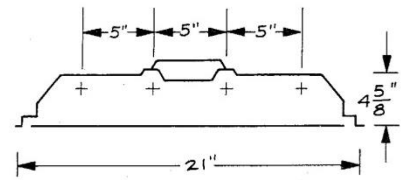
Photometric Report for Sorcar Lighting Co., Product Catalog No. XYZ

Three-Plane Photometry

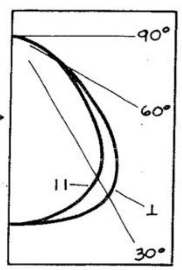
(A) → Luminaire. Metal troffer, synthetic enamel
Clear prismatic plasic lens No. 12,
acrylic

Lamps. Four F40T12/CW, 3200 lm each

Reflectance. 0.87



(B) →



CANDLEPOWER

Angle	Along	45·	Across
0	3500	3500	3500
5	3468	3478	3484
15	3387	3434	3478
25	3220	3347	3473
35	2696	2956	3122
45	1949	2100	2388
55	1183	950	1335
65	568	376	600
75	291	210	254
85	88	132	86
90	0	0	0 ← (C)

ZONAL LUMEN SUMMARY

Zone	Lumens	% Lamp	% Fixture
0–30	2850	22.3	34.8
30–60	4464	34.8	54.5
60–90	876	6.9	10.7
0–90	8190	64.0	100.0
90–180	0	0	0
0–180	8190	64	100

↑ (D)

(E) → Efficiency. 64%

(G) → CIE-IES type. Direct

(H) → Shielding angle. across 90°
along 90°

(I) → SC. 1.4 (⊥), 1.35 (∥)

COEFFICIENTS OF UTILIZATION: ZONAL CAVITY

Pfc	20%													
Pcc	80%				70%				50%			30%		
Pw	70%	50%	30%	10%	70%	50%	30%	10%	50%	30%	10%	50%	30%	10%
1	71	68	66	64	69	67	65	63	64	63	61	62	61	59
2	66	62	58	55	64	60	57	54	58	56	53	56	54	52
(J) → 3	61	56	51	48	60	55	51	47	53	49	47	51	48	46
4	57	50	45	42	55	49	45	42	48	44	41	46	43	40
5	52	45	40	36	51	45	40	36	43	39	36	42	38	36
6	49	41	36	32	47	40	36	32	39	35	32	38	34	32
7	45	37	32	28	44	37	32	28	36	31	28	35	31	28
8	41	33	28	25	41	33	28	25	32	28	25	31	27	24
9	38	30	25	22	37	30	25	22	29	25	21	28	24	21
10	35	27	22	19	35	27	22	19	26	22	19	26	22	19

LUMINANCE SUMMARY — (F)

	Average (f-L)		Maximum (f-L)		Footlambert Ratio	
Degree	Parallel	Normal	Parallel	Normal	Parallel	Normal
0	1682	1682	2855	2855	1.7	1.7
45	1324	1623	1884	2296	1.4	1.4
55	991	1118	1354	1737	1.4	1.6
65	646	682	736	942	1.1	1.4
75	539	472	559	677	1.0	1.4
85	487	473	589	559	1.2	1.2

Figure 5-1. *A photometric report.*

P. C. Sorcar (1987)

Lamps description

Photometric Report for Sorcar Lighting Co., Product Catalog No. XYZ

Three-Plane Photometry

Ⓐ → Luminaire. Metal troffer, synthetic enamel
Clear prismatic plasic lens No. 12,
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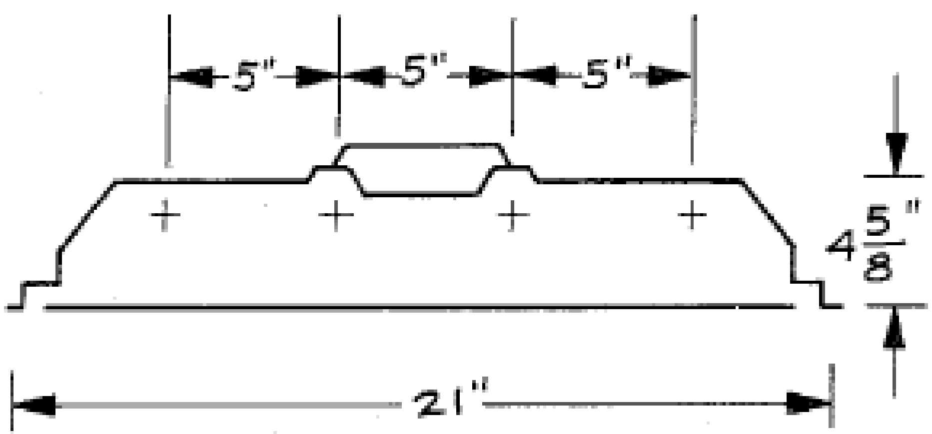
Lamps. Four F40T12/CW, 3200 lm each

Reflectance. 0.87



P. C. Sorcar (1987)

Lamps description

- Candela distribution table
  - A tabular listing of the candela readings at each given angle
  - The lumens (flux) column is a summary of the lumens (flux) emitted within a zone centred around the corresponding vertical angle

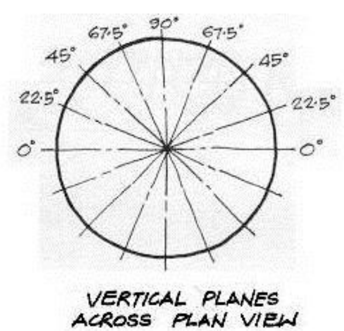
Lateral Angles

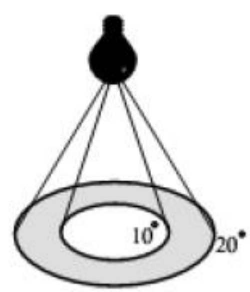
CANDELA DISTRIBUTION

Vertical Angles	0.0	22.5	45.0	67.5	90.0	FLUX
0	1401	1401	1401	1401	1401	
5	1399	1396	1393	1391	1390	132
15	1321	1313	1283	1267	1260	363
25	1198	1156	1124	1170	1199	538
35	1034	977	1050	1177	1252	682
45	803	789	979	1167	1277	763
55	508	557	706	823	921	597
65	82	103	123	107	97	125
75	18	20	21	21	21	24
85	0	0	0	0	0	3
90	0	0	0	0	0	

The lumens (flux) column is a summary of the lumens (flux) emitted within a zone centered around the corresponding vertical angle.

Ex. The vertical angle 15° has 363 lumens in a cone ranging from 10° to 20°.





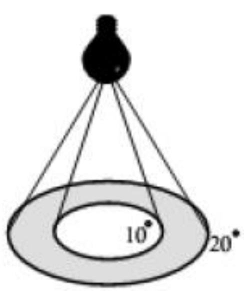
Lamps description

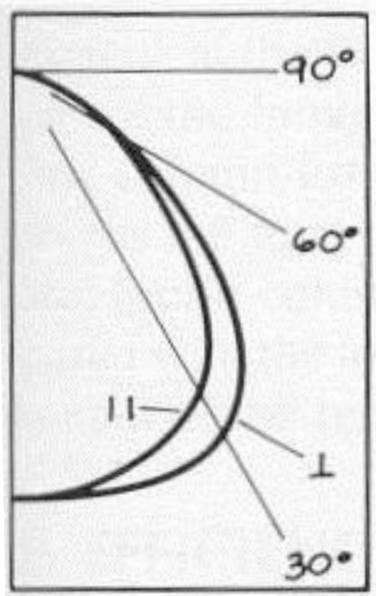
- Polar Candela Plot:

Graphical representation of the candela distribution table

Candlepower (Candela) Table ©

B





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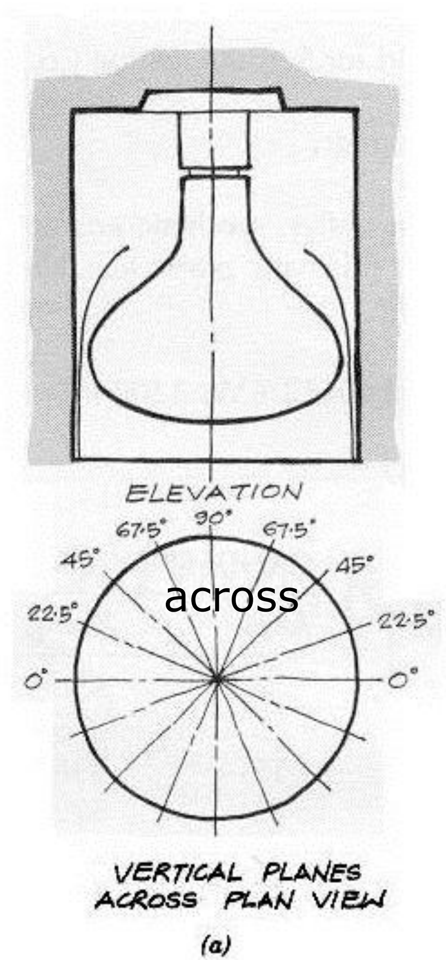
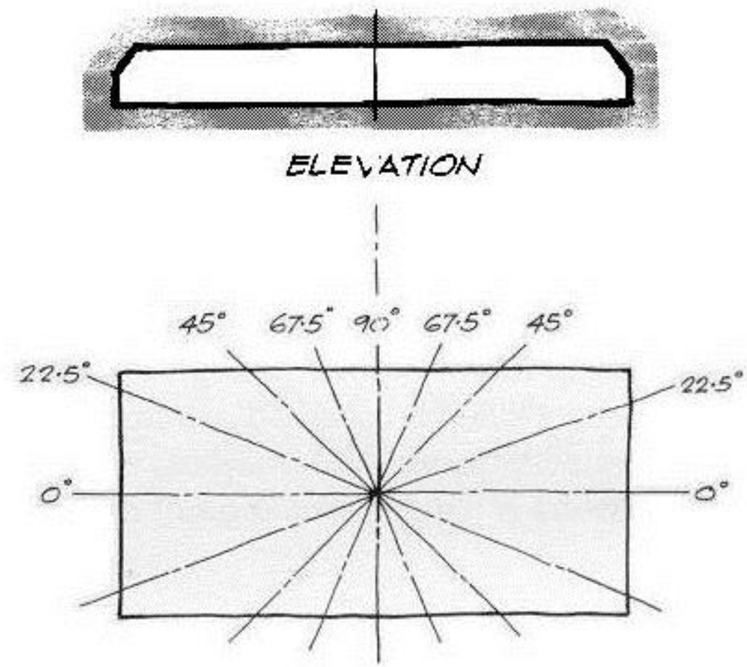
P. C. Sorcar (1987)

Lamps description

along



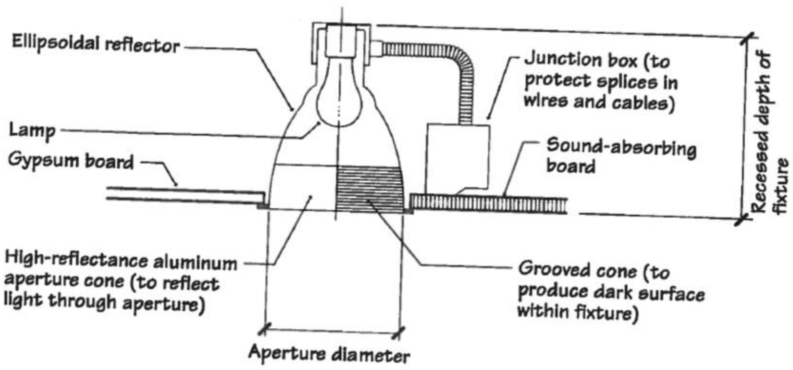
along

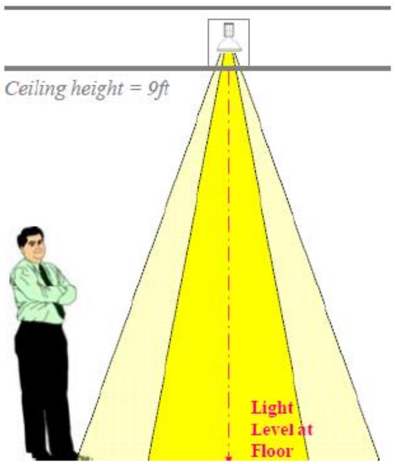


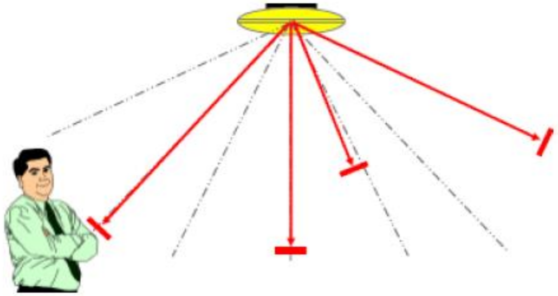
across

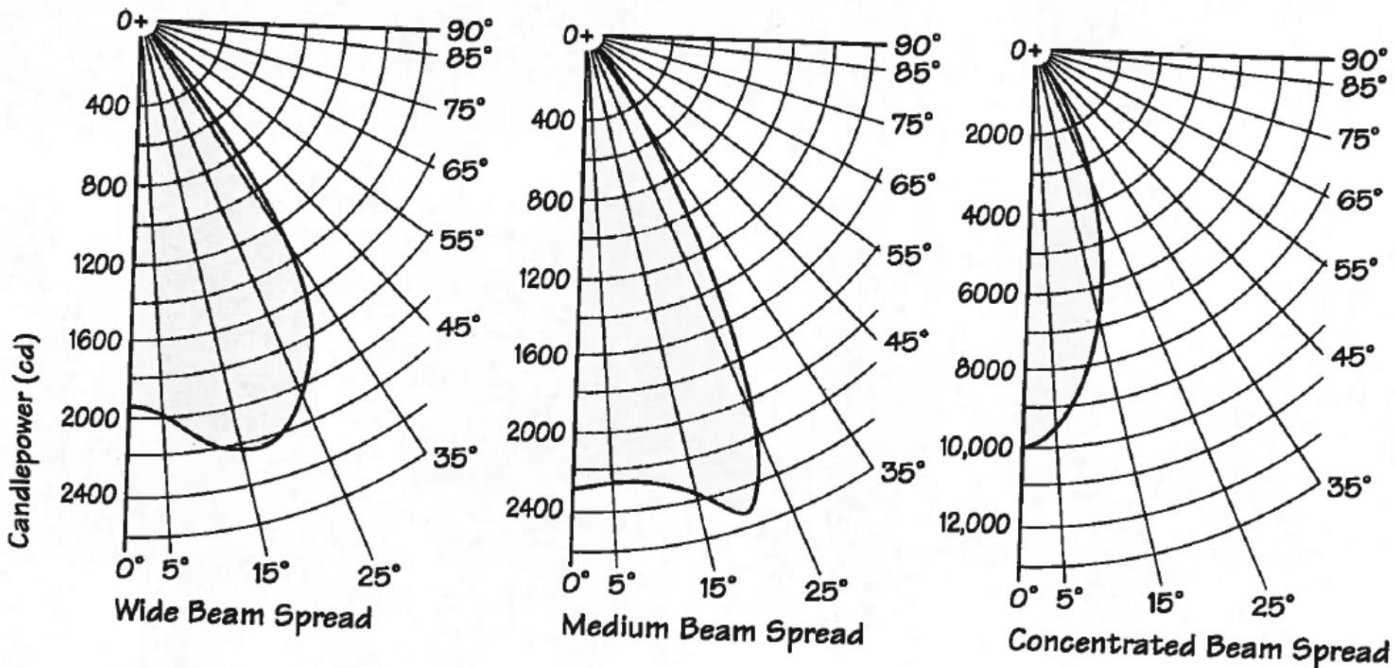
P. C. Sorcar (1987)

Luminaires





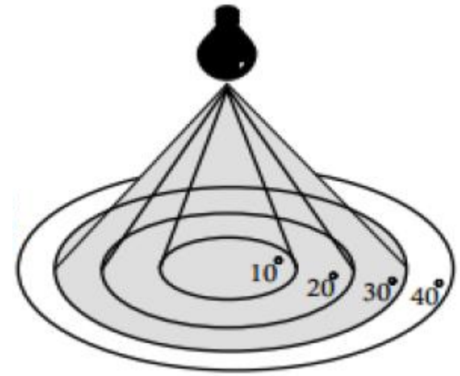




Note: When light output is symmetric about the nadir angle (0°), only one-half of the candlepower distribution curve is normally shown.

D. Egan and V. Olgyay (2003)

Lamps description



- Provides the lumen concentration summary at a key zone
  - Light emitted at 0 to 45° is usually called the direct light zone because it falls onto the task without causing any direct glare to the viewer
  - The 45 to 90° zone is known as the direct glare zone. The degree of brightness caused by the luminaire is usually dependent on the candela values at those angles.
  - Total lumen at the 90 to 180° zone represents light in the upper hemisphere and that at 0 to 90° represents the lower hemisphere
  - The lumens at the 0 to 180° zone represent the total output of the luminaire

ZONAL LUMEN SUMMARY

Zone	Lumens	% Lamp	% Fixture
0–30	2850	22.3	34.8
30–60	4464	34.8	54.5
60–90	876	6.9	10.7
0–90	8190	64.0	100.0
90–180	0	0	0
0–180	8190	64	100

D

- % lamp: the lumen sum within the given zone as a percentage of the total rated lamp lumens
- % fixture: the lumen sum within the given zone as a percentage of the total luminaire lumen output

Lamps description

Ⓔ ⟶ Efficiency. 64%

ZONAL LUMEN SUMMARY

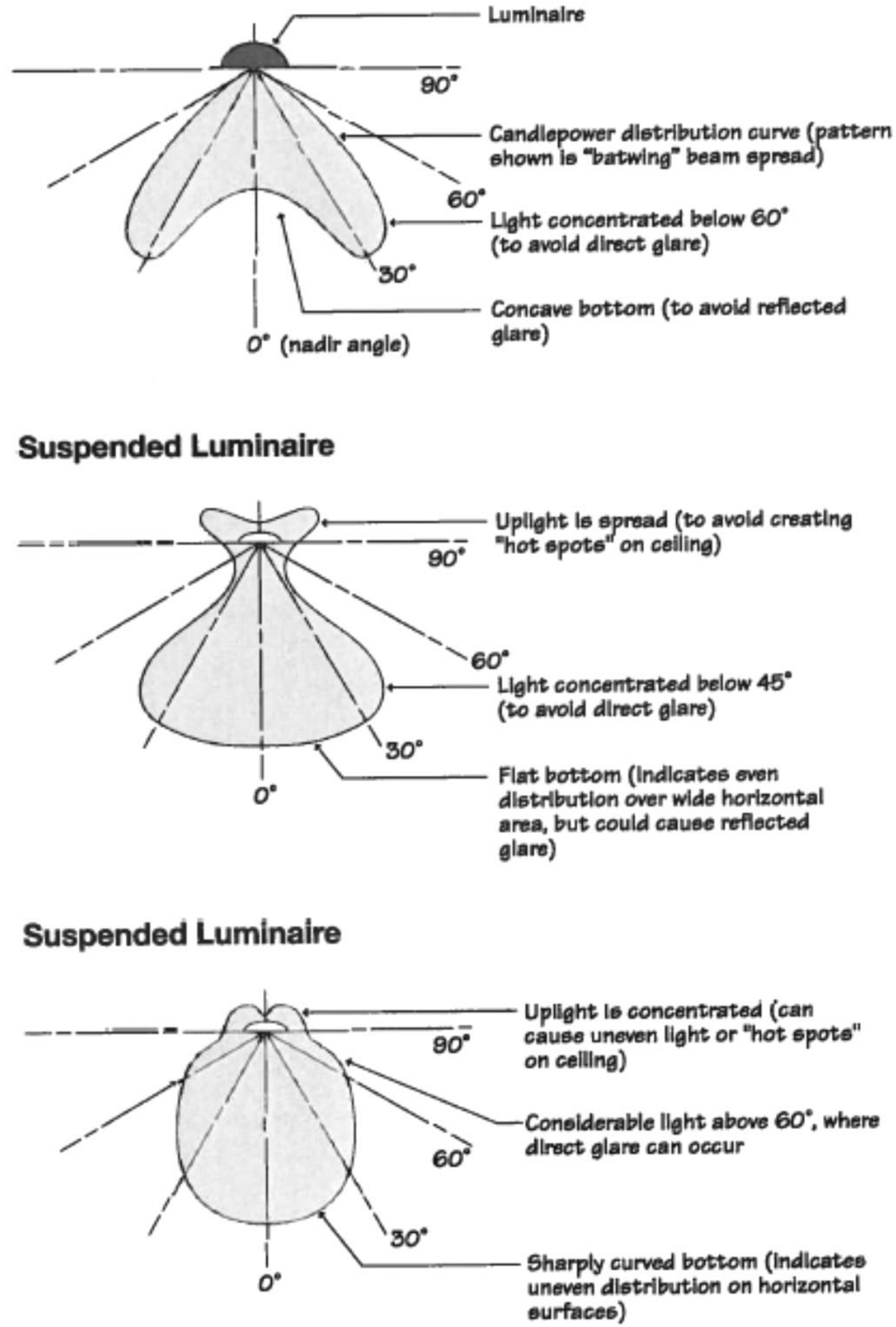
Zone	Lumens	% Lamp	% Fixture
0–30	2850	22.3	34.8
30–60	4464	34.8	54.5
60–90	876	6.9	10.7
0–90	8190	64.0	100.0
90–180	0	0	0
0–180	8190	64	100

↑ Ⓓ

- Efficiency of a luminaire is the ratio of the total number of lumens emitted by the luminaire to the total number of lumens produced by the bare lamps

Shape of candlepower distribution curves:

can be used to indicate where potential problems from direct and reflected glare might occur and where “hot spot” may be created on room surfaces



D. Egan and V. Olgyay (2003)

Lamps description

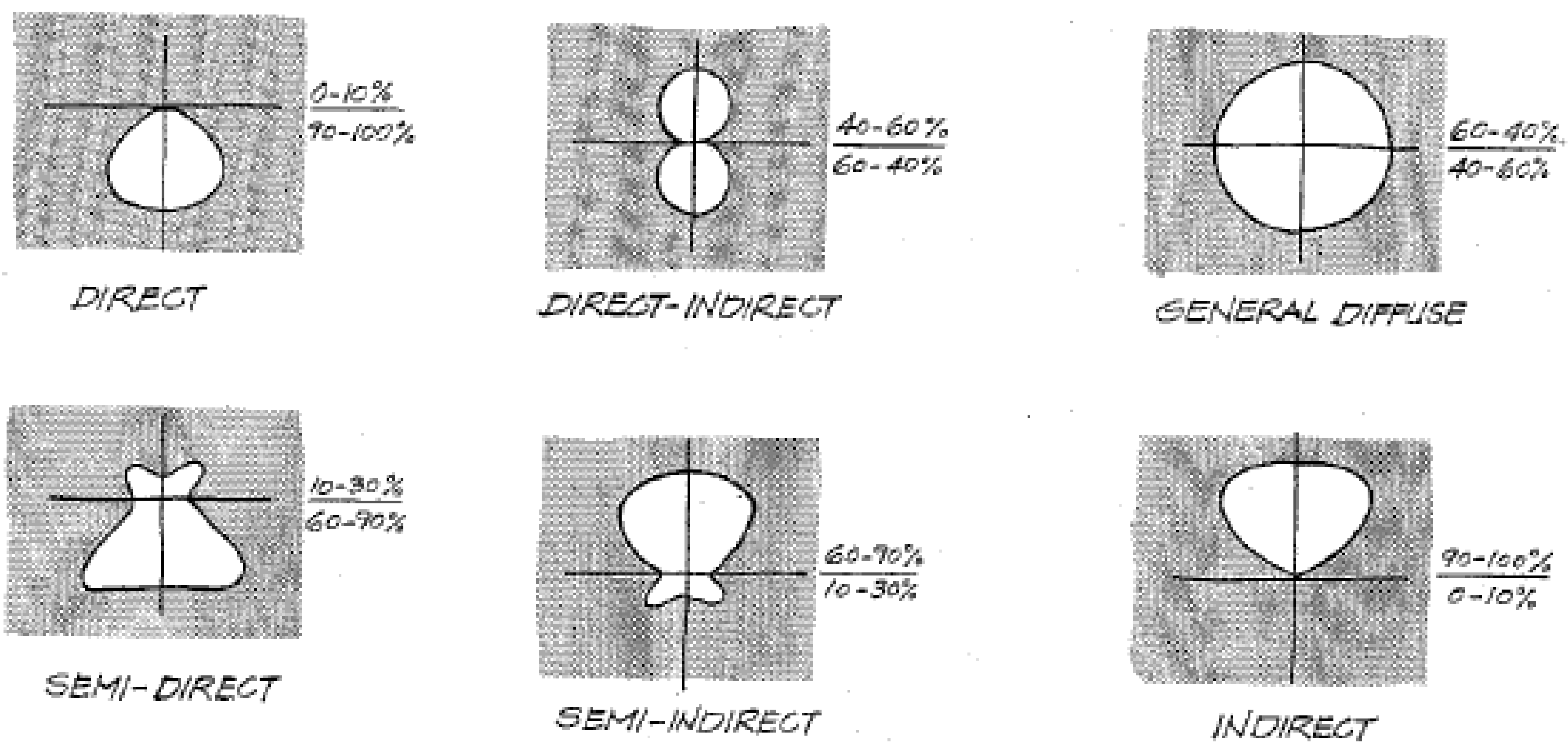
ⓒ → CIE-IES type. Direct

- CIE-IES type: A classification system specified by the International Commission on Illumination (CIE), which uses luminous intensity or flux distribution of the indoor luminaire to categorize it in one of the following six categories:
  - Direct: 90-100% of flux is directed downward
  - Semi-direct: 60-90% of the flux is directed downward. The remainder of the flux is above the 90^{o} vertical angle
  - General diffuse/direct-indirect: both upward and downward flux are comparable
  - Semi-indirect: 60-90% of flux is directed upward
  - Indirect: 90-100% of flux is directed upward above the 90^{o} vertical angle

Lamps description

Ⓒ → CIE-IES type. Direct

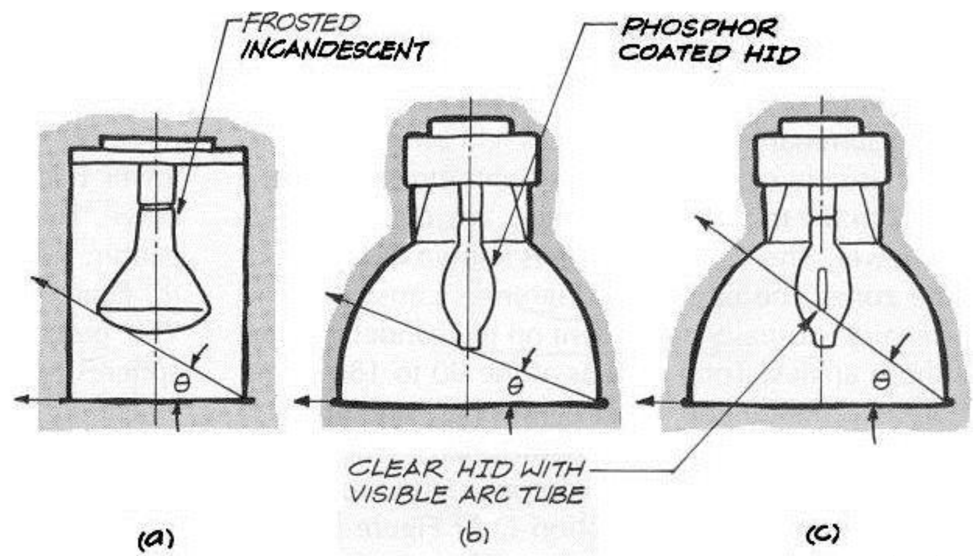
$$\%\ \text{total output} = \frac{\text{lumen produced in upper and lower hemispheres} \times 100}{\text{total lumens produced at 0 to 180°}}$$



P. C. Sorcar (1987)

Lamps description

Ⓗ ⟶ Shielding angle. across 90°
along 90°



P. C. Sorcar (1987)

- Shield angle: measured from a horizontal line drawn at the bottom of the luminaire to the line of first sight of the source. It is at this angle that the source is concealed from direct viewing
  - For sources with visible filaments the angle is measured between the horizontal line and the filament
  - For area sources like the one in the example given this angle is 90° (viewed directly from beneath the luminaire)

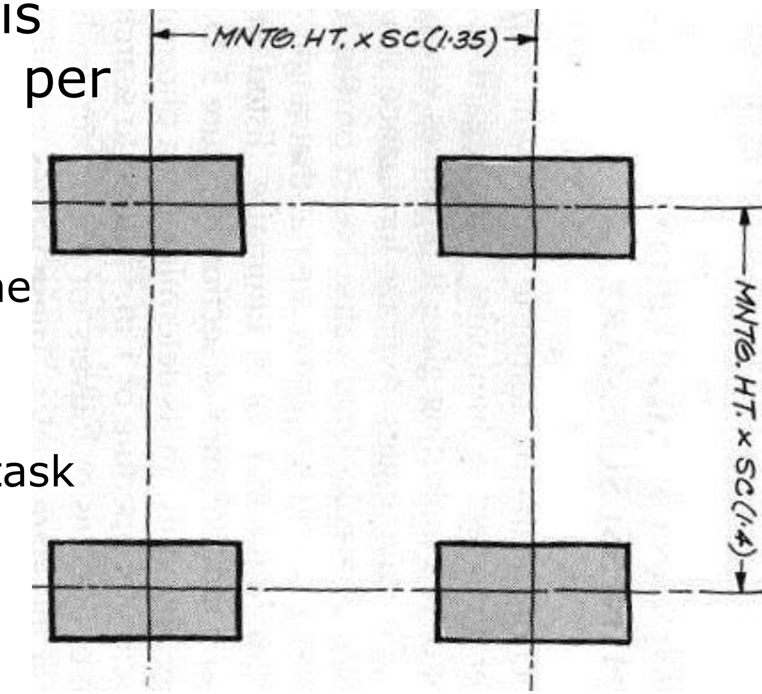
Lamps description

① → SC. 1.4 (⊥), 1.35 (||)

- Spacing criterion: is a ratio used to estimate the farthest spacing of luminaires that will still yield a relatively uniform illumination on the floor. This ratio is presented in units of spacing per mounting height

Ex 1. What is the max. mounting spacing in both directions if the lamps were mounted 8ft above the floor?

Ex. 2. What is the max. mounting spacing in both directions to achieve uniform illumination on the task level 2.5ft above the floor while the lamps were mounted 8ft above the floor?



P. C. Sorcar (1987)

Lamps description

- Coefficient of Utilization (CU): represents the portion of the total light that would fall on the work plane (the level of interest). In general, light appearing on the work plane is accumulated from two kinds of ray, the direct ray and the ray that hits the room surfaces, bounces back and forth, and finally reaches the work place.
  - CU depends on the candela distribution of the luminaire, its mounting height above the work plane, room proportions, and surface reflectance

COEFFICIENTS OF UTILIZATION: ZONAL CAVITY

Pfc	20%													
Pcc	80%				70%				50%			30%		
Pw	70%	50%	30%	10%	70%	50%	30%	10%	50%	30%	10%	50%	30%	10%
1	71	68	66	64	69	67	65	63	64	63	61	62	61	59
2	66	62	58	55	64	60	57	54	58	56	53	56	54	52
→ 3	61	56	51	48	60	55	51	47	53	49	47	51	48	46
4	57	50	45	42	55	49	45	42	48	44	41	46	43	40
5	52	45	40	36	51	45	40	36	43	39	36	42	38	36
6	49	41	36	32	47	40	36	32	39	35	32	38	34	32
7	45	37	32	28	44	37	32	28	36	31	28	35	31	28
8	41	33	28	25	41	33	28	25	32	28	25	31	27	24
9	38	30	25	22	37	30	25	22	29	25	21	28	24	21
10	35	27	22	19	35	27	22	19	26	22	19	26	22	19

P. C. Sorcar (1987)

Lighting calculation

- A simplified calculation to determine an average lighting level on an interior plane.
- Solve for the average illuminance *E* (in lux or fc)

$$E = \frac{\Phi}{A}$$

- Using the following variables:
  - Luminaire candlepower distribution, Efficiency, Room size, Room Shape, Surface reflectances, Luminaire mounting height, Coefficient of utilization & Light loss factor
  - **Two Methods : Cavity (or Lumen) Method & point-by-point method**

Cavity (Lumen) method

$$E = \frac{\Phi \times CU \times LLF}{A} \qquad E = \frac{(L \times N) \times CU \times LLF}{A}$$

Where,

Φ, the total flux in lumen on the area

E is the required average illuminance in footcandels (or lux)

L is the total initial lumens per luminaire

N = number of luminaires

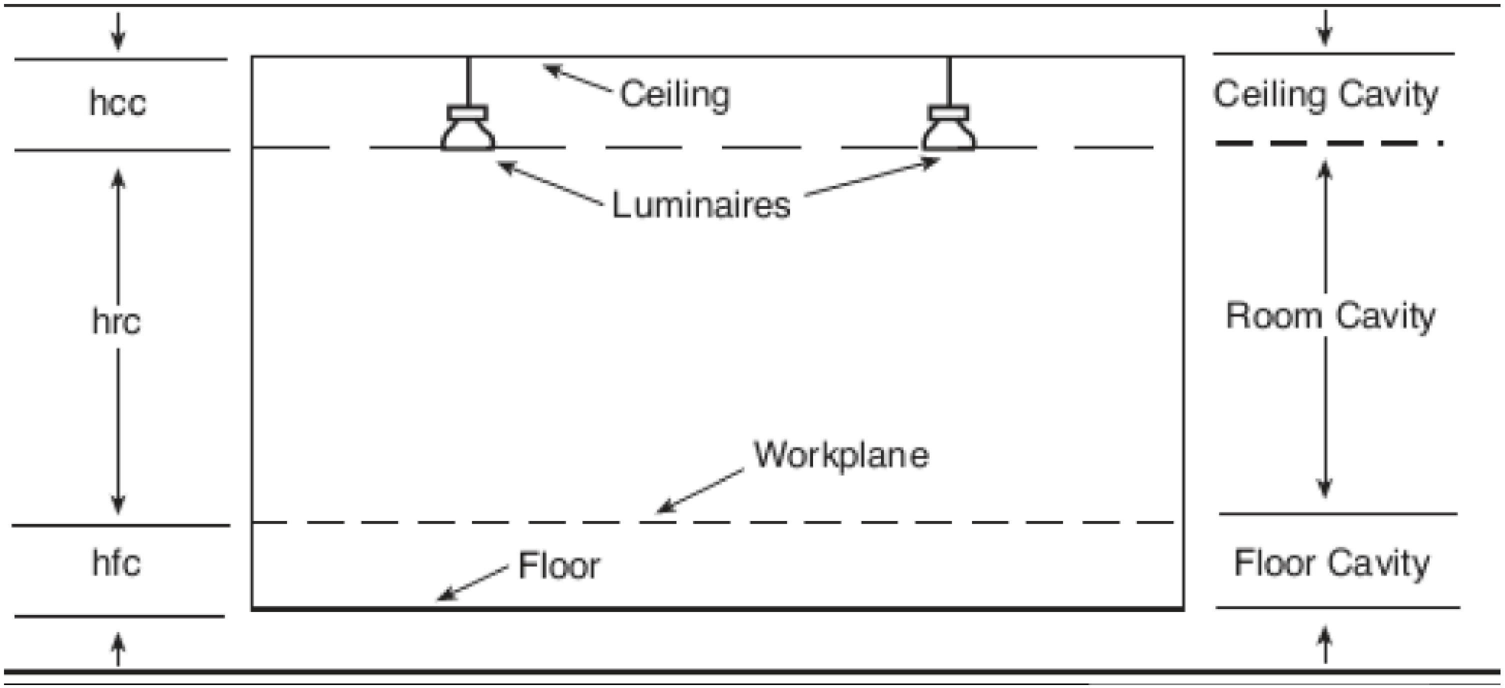
CU = coefficient of utilization

LLF = light-loss factor, due to dirt accumulation and depreciation in lumen output

A = is the floor area in sq.ft. (sq.m.)

Determination of CU by zonal cavity method

- Step I: determine cavity ratios
  - Ceiling cavity: the space between the luminaire mounting plane and the ceiling
  - Room cavity: the space between work plane and the luminaire mounting plane
  - Floor cavity: the space between the work plane and the floor



P. C. Sorcar (1987)

Step I: determine cavity ratios

- Cavity ratios represent the geometric proportions of the ceiling, room and floor cavities, can be determined:

  - For rectangular or square-shaped room with flat ceiling

$$cavity\_ratio = \frac{5h(roomlength + roomwidth)}{roomlength * roomwidth}$$

  - For irregular shapes

$$cavity\_ratio = \frac{2.5h * perimeter\_of\_room}{area\_of\_cavity\_base}$$

$h = h_{cc}$, h_{rc} or h_{fc}

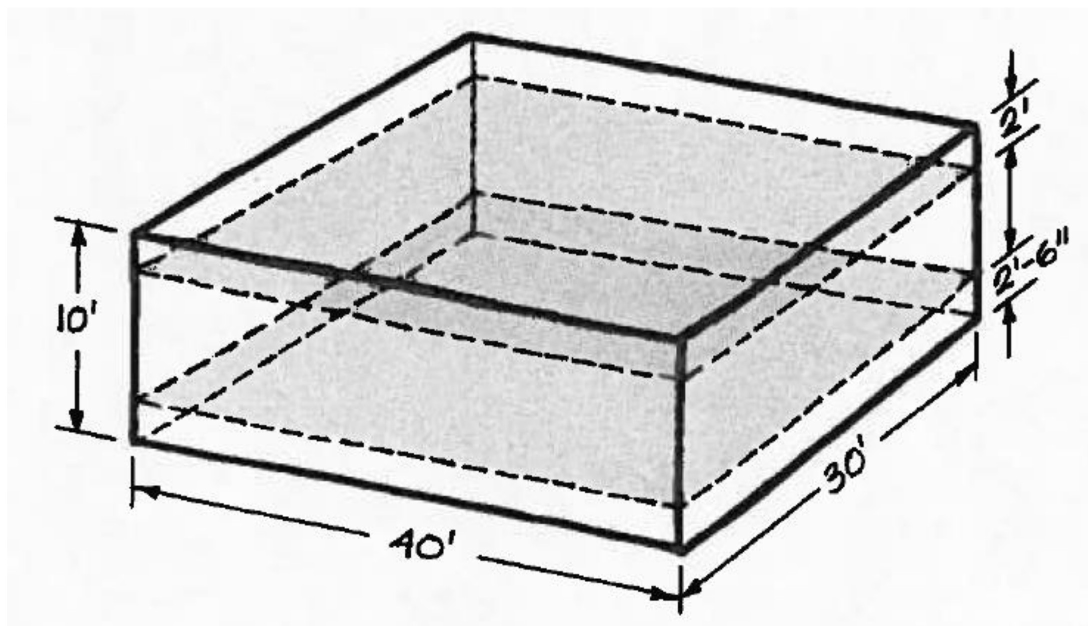
Determination of CU by zonal cavity method

Ex.3: Determine the ceiling cavity ratio (CCR), room cavity ratio (RCR), and the floor cavity ratio (FCR) for a rectangular room of length L=40′, width W=30′, and height H=10′. The luminaire mounting plane is 2′ below the ceiling and the work plane is 2.5′ above the floor.

CCR=?

RCR=?

FCR=?



Determination of CU by zonal cavity method

Ex.4: in the preceding example, a part of the room is used for a different purpose than the remaining area and requires a different illumination level. Determine the cavity ratios.

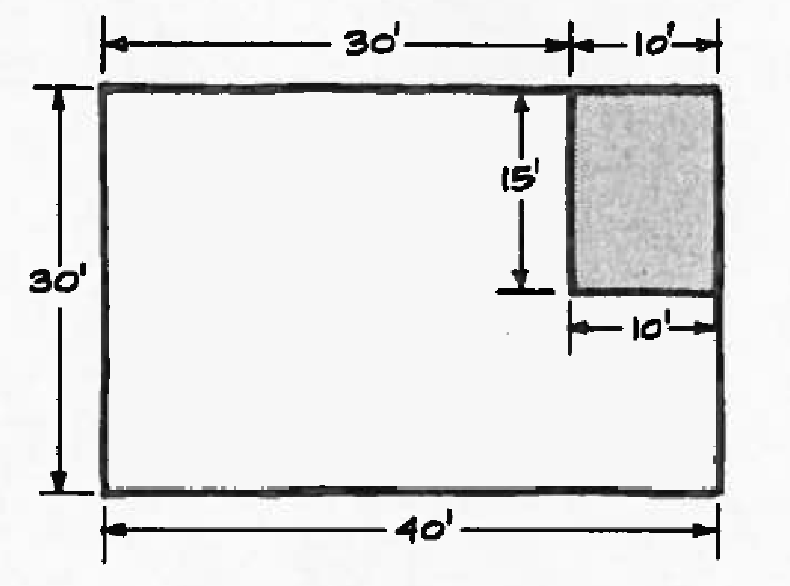
- For the shaded area:

CCR=?

RCR=?

FCR=?

- For the L-shaped room



Step II: determine effective cavity reflectances

1. Determine the weighted average reflectance of the wall, ceiling or floor

$$\rho = \frac{\rho_1 A_1 + \rho_2 A_2 + \rho_3 A_3 + \cdots}{A_1 + A_2 + A_3 + \cdots}$$

where ρ = the weighted average reflectance

$A_1, A_2, A_3 \cdots$ = areas of different surfaces

$\rho_1, \rho_2, \rho_3 \cdots$ = surface reflectances of $A_1, A_2, A_3 \cdots$

Ex.5: A specific wall of a room has 90ft^2 of white paint (80% reflectance), 160ft^2 of dark wood paneling (20% reflectance), 40ft^2 of wall paper (50% reflectance), and 30ft^2 of bookshelves of approximately 15% reflectance. Find the weighted average reflectance of the wall.

Surface Reflectances

TABLE 1C GENERAL SURFACE REFLECTANCE ARBITRARY ASSIGNMENT CHART

REFLECTANCE:	100%	70%	50%	30%	0%
Color	White	Light shades	Full shades	Deep shades	Black
Texture	Smooth	Semismooth	Grainy	Mild-coarse	Coarse
Luster	Glossy	Semiglass	Eggshell	Satin	Flat

Determination of CU by zonal cavity method

TABLE 6-2. APPROXIMATE SURFACE REFLECTANCE OF TYPICAL BUILDING INTERIOR FINISHES

Building Finishes	App. Reflectance (%)
Ceilings	
White paint (plain plaster surface)	80
White paint on acoustic tile	70
White paint on smooth concrete	60
White paint on rough concrete	50
Walls	
White paint on plaster tiles	80
Medium blue-gray, yellow-gray	50
Light gray concrete	40
Bricks (other than rough gray)	30
Unfinished cement, rough tile	25
Wood panel (light)	25
Wood panel (dark)	20
Rough brick	15
Floors	
Light wood	35
Medium wood	25
Dark wood	20
Light tile	30
Dark tile	20
Light carpet (gray, orange, medium-blue)	20
Dark carpet (dark gray, brown)	15

P. C. Sorcar (1987)

Step II: determine effective cavity reflectances

2. Determine the effective ceiling and floor cavity reflectances ($\boldsymbol{\rho}_{cc}$, $\boldsymbol{\rho}_{fc}$)

- Is the ratio of the total flux out of the cavity opening to the total flux into the cavity opening
- Depend on their cavity depths, surface reflectances, and cavity ratios; the deeper the cavity, the poorer light reflected; some of the reflected light at the ceiling or floor is bounced off the walls

Ex. 6: A room has 80, 50 and 30% ceiling, wall and floor surface reflectances, respectively; CCR and FCR of the room are 1.6 and 0.5, respectively. Determine the effective ceiling and floor cavity reflectances by referring to Table 6-3.

($\boldsymbol{\rho}_{cc}$=60%; $\boldsymbol{\rho}_{fc}$=28%)

Effective cavity reflectance

- A simple approximating expression is:

$$\rho_{\text{eff}} = \frac{1}{1 + \left(\frac{A_s}{A_0}\right)\left(\frac{1-\rho}{\rho}\right)}$$

where A_s is the area of the cavity surfaces, A_0 is the area of the cavity opening, and ρ is the reflectance of the cavity surfaces. If the cavity is made up o surfaces having different reflectances, ρ must be the weighted-average reflectance of these surfaces.

For a rectangular ceiling cavity with walls of area A_w and reflectance ρ_w and a base of area A_b and reflectance ρ_b, the weighted average ρ is given by

$$\rho_{\text{ave}} = \frac{\rho_w A_w + \rho_b A_b}{A_w + A_b} \tag{7.9}$$

Insertion of Eq. (7.9) into Eq. (7.8) yields, following some manipulation,

$$\rho_{\text{eff}} = \frac{1}{\dfrac{[1 + (A_w/A_b)]^2}{\rho_b + \rho_w(A_w/A_b)} - \dfrac{A_w}{A_b}} \tag{7.10}$$

For a ceiling cavity $A_b = A_c$ and $\rho_b = \rho_c$. For a floor cavity $A_b = A_f$ and $\rho_b = \rho_f$.

Step III: select coefficient of utilization from manufacturer's data sheet

COEFFICIENTS OF UTILIZATION: ZONAL CAVITY

Pfc	20%													
Pcc	80%				70%				50%			30%		
Pw	70%	50%	30%	10%	70%	50%	30%	10%	50%	30%	10%	50%	30%	10%
1	71	68	66	64	69	67	65	63	64	63	61	62	61	59
2	66	62	58	55	64	60	57	54	58	56	53	56	54	52
3	61	56	51	48	60	55	51	47	53	49	47	51	48	46
4	57	50	45	42	55	49	45	42	48	44	41	46	43	40
5	52	45	40	36	51	45	40	36	43	39	36	42	38	36
6	49	41	36	32	47	40	36	32	39	35	32	38	34	32
7	45	37	32	28	44	37	32	28	36	31	28	35	31	28
8	41	33	28	25	41	33	28	25	32	28	25	31	27	24
9	38	30	25	22	37	30	25	22	29	25	21	28	24	21
10	35	27	22	19	35	27	22	19	26	22	19	26	22	19

Figure 5-1. *A photometric report.*

P. C. Sorcar (1987)

Step III: select coefficient of utilization from manufacturer's data sheet

- The effective floor cavity reflectance ρ_{fc} is normally 20%. If this value varies from20%, a correction factor is used to modify the CU, as shown in Table 6-4

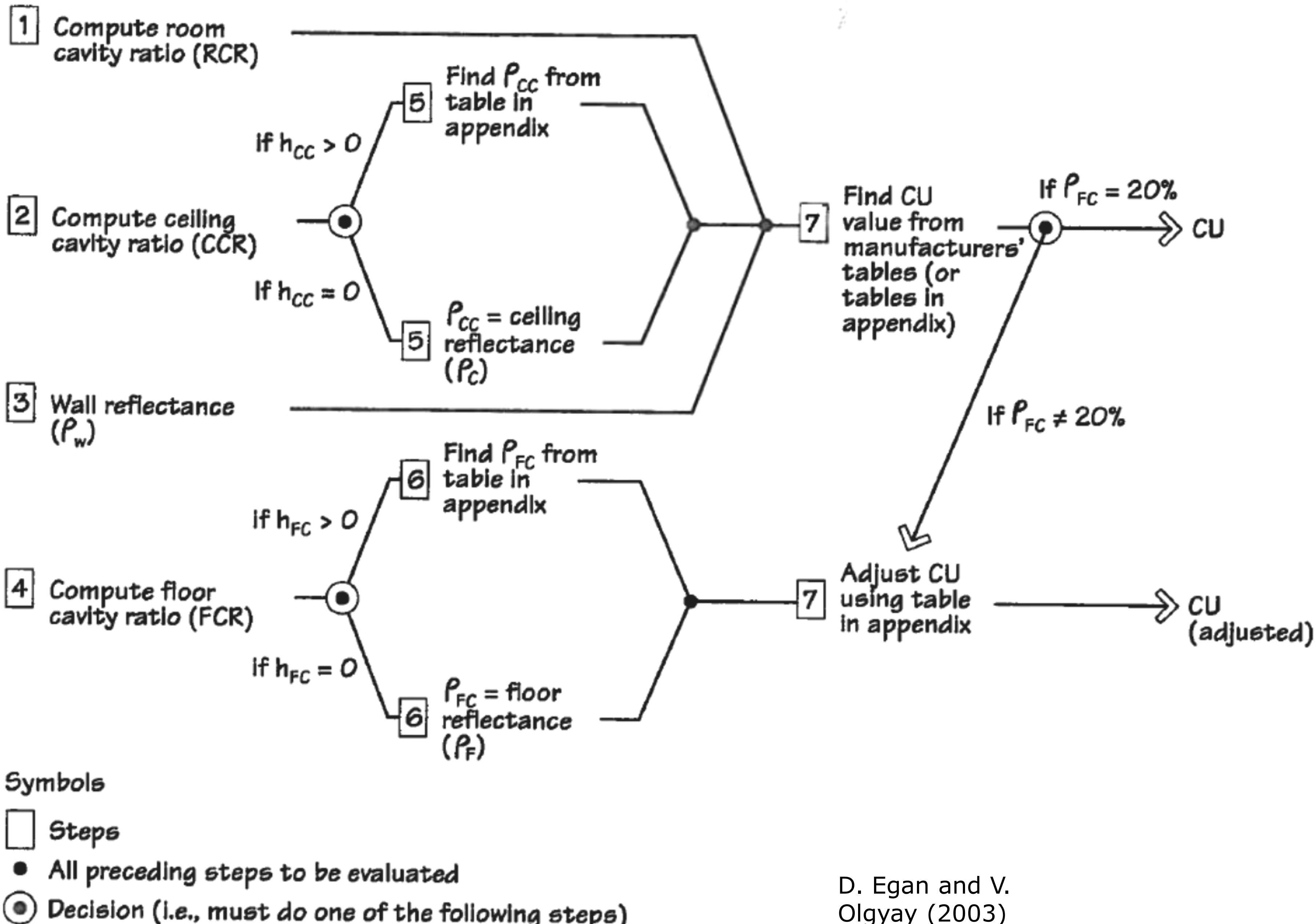
TABLE 6-4. MULTIPLYING FACTORS FOR OTHER THAN 20% EFFECTIVE FLOOR CAVITY REFLECTANCE[a]

% Effective Ceiling Cavity Reflectance, ρ_{CC}	80				70				50			30			10		
% Wall Reflectance, ρ_W	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10
For 30 Per Cent Effective Floor Cavity Reflectance (20 Per Cent = 1.00)																	
Room Cavity Ratio																	
1	1.092	1.082	1.075	1.068	1.077	1.070	1.064	1.059	1.049	1.044	1.040	1.028	1.026	1.023	1.012	1.010	1.008
2	1.079	1.066	1.055	1.047	1.068	1.057	1.048	1.039	1.041	1.033	1.027	1.026	1.021	1.017	1.013	1.010	1.006
3	1.070	1.054	1.042	1.033	1.061	1.048	1.037	1.028	1.034	1.027	1.020	1.024	1.017	1.012	1.014	1.009	1.005
4	1.062	1.045	1.033	1.024	1.055	1.040	1.029	1.021	1.030	1.022	1.015	1.022	1.015	1.010	1.014	1.009	1.004
5	1.056	1.038	1.026	1.018	1.050	1.034	1.024	1.015	1.027	1.018	1.012	1.020	1.013	1.008	1.014	1.009	1.004
6	1.052	1.033	1.021	1.014	1.047	1.030	1.020	1.012	1.024	1.015	1.009	1.019	1.012	1.008	1.014	1.008	1.003
7	1.047	1.029	1.018	1.011	1.043	1.028	1.017	1.009	1.022	1.013	1.007	1.018	1.010	1.005	1.014	1.008	1.003
8	1.044	1.026	1.015	1.009	1.040	1.024	1.015	1.007	1.020	1.012	1.006	1.017	1.009	1.004	1.013	1.007	1.003
9	1.040	1.024	1.014	1.007	1.037	1.022	1.014	1.006	1.019	1.011	1.005	1.016	1.009	1.004	1.013	1.007	1.002
10	1.037	1.022	1.012	1.006	1.034	1.020	1.012	1.005	1.017	1.010	1.004	1.015	1.009	1.003	1.013	1.007	1.002

Determination of CU by zonal cavity method

Ex.7: An office room with dimensions L=50ft, W=30ft, and H=8.5ft has a work plane 2.5ft above the floor. Ceiling, wall and floor reflectances are 80, 50 and 20%, respectively. Luminaires are 2x4 ft with four lamps and acrylic prismatic lenses. Determine the CU values if the luminaires are a) suspended 1.5ft below the ceiling (0.66) and b) recessed in the ceiling (0.65). Use the CU table in Figure 5-1.

HOW TO FIND COEFFICIENT OF UTILIZATION



D. Egan and V. Olgyay (2003)

Cavity (Lumen) method

$$E = \frac{\boldsymbol{\Phi} \times CU \times LLF}{A} \qquad E = \frac{(L \times N) \times CU \times LLF}{A}$$

Where,

$\boldsymbol{\Phi}$, the total flux in lumen on the area

E is the required average illuminance in footcandels (or lux)

L is the total initial lumens per luminaire

N = number of luminaires

CU = coefficient of utilization

LLF = light-loss factor, due to dirt accumulation and depreciation in lumen output

A = is the floor area in sq.ft. (sq.m.)

Step IV: determine the light loss factor

- LLF: takes into account that light output diminishes with time and must be considered in the lighting calculation to make up for the expected loss in the lighting system
  - Non-recoverable factors: represent the conditions of a lighting system that may reduce light output when nothing in terms of periodic maintenance can be done to recover the loss; these factors are unpredictable, for calculation purposes 1.0 used for all non-recoverable factors
    - **Luminaire ambient temperature**: fluorescents lamp directly affected by ambient temperature: 1% loss in light for every 2°F that the ambient temperature around the lamp exceeds 77°F
    - **Voltage variation:** light output changes with voltage variation, e.g. for incandescents each 1% variation in voltage produces a change in lumens of about 3%
    - **Luminaire surface depreciation:** change of surface characteristics of the luminarie
  - recoverable factors: can be predicted
    - **Luminaire dirt depreciation (LDD)**: mainly due to the accumulation of atmospheric dirt on lamps, lens, louvers and reflecting surfaces. Three factors must be considered in its determination: type of luminaire, atmospheric conditions and maintenance interval.

Light Loss Factors

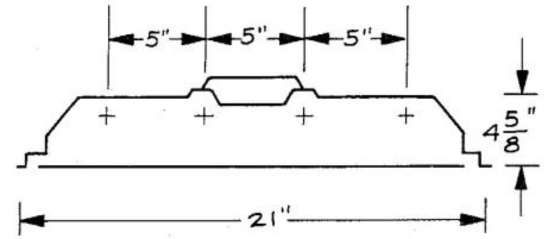


TABLE 6-5. LUMINAIRE CLASSIFICATION BASED ON SIX MAINTENANCE CATEGORIES [a]

Maintenance Category	Top Enclosure	Bottom Enclosure
I	1. None	1. None
II	1. None	1. None
	2. Transparent, with 15% or more up-light through apertures.	2. Louvers or baffles
	3. Translucent, with 15% or more up-light through apertures.	
	4. Opaque, with 15% or more up-light through apertures.	
III	1. Transparent, with less than 15% upward light through apertures.	1. None
	2. Translucent, with less than 15% upward light through apertures.	2. Louvers or baffles
	3. Opaque, with less than 15% up-light through apertures.	
IV	1. Transparent, unapertured.	1. None
	2. Translucent, unapertured.	2. Louvers
	3. Opaque, unapertured.	
V	1. Transparent, unapertured.	1. Transparent, unapertured
	2. Translucent, unapertured.	2. Translucent, unapertured
	3. Opaque, unapertured.	
VI	1. None	1. Transparent, unapertured
	2. Transparent, unapertured.	2. Translucent, unapertured
	3. Translucent, unapertured.	3. Opaque, unapertured
	4. Opaque, unapertured.	

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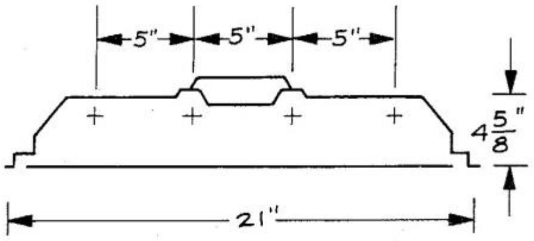
Light Loss Factors



- Type of atmosphere:
  - Very clean, VC
  - Clean, C
  - Medium, M
  - Dirty, D
  - Very dirty, VD

TABLE 1D CONDITIONS OF IMPURITIES WITHIN A SPACE

CONDITION:	VERY CLEAN	CLEAN	MEDIUM	DIRTY	VERY DIRTY
Airborne impurities	None	Little	Visible	Rapid accumulation	Constant accumulation
Ambient impurities	None	Little	Moderate	Heavy	Dense with no exclusion
Filtration and ventilation	Highly efficient	Above average	Below average	Blowers and no filters	None
Impurity adhesiveness	None	Small	Visible over time	High	Very high

1. Amount of airborne impurities produced
2. Amount of ambient airborne and surface impurities*
3. Method(s) and efficiency of filtration and exhaust ventilation
4. Impurity adhesiveness'

P. C. Sorcar (1987)

Light Loss Factors

For clean office environment, category V luminaire, maintenance interval at 24 month: LDD: 0.835

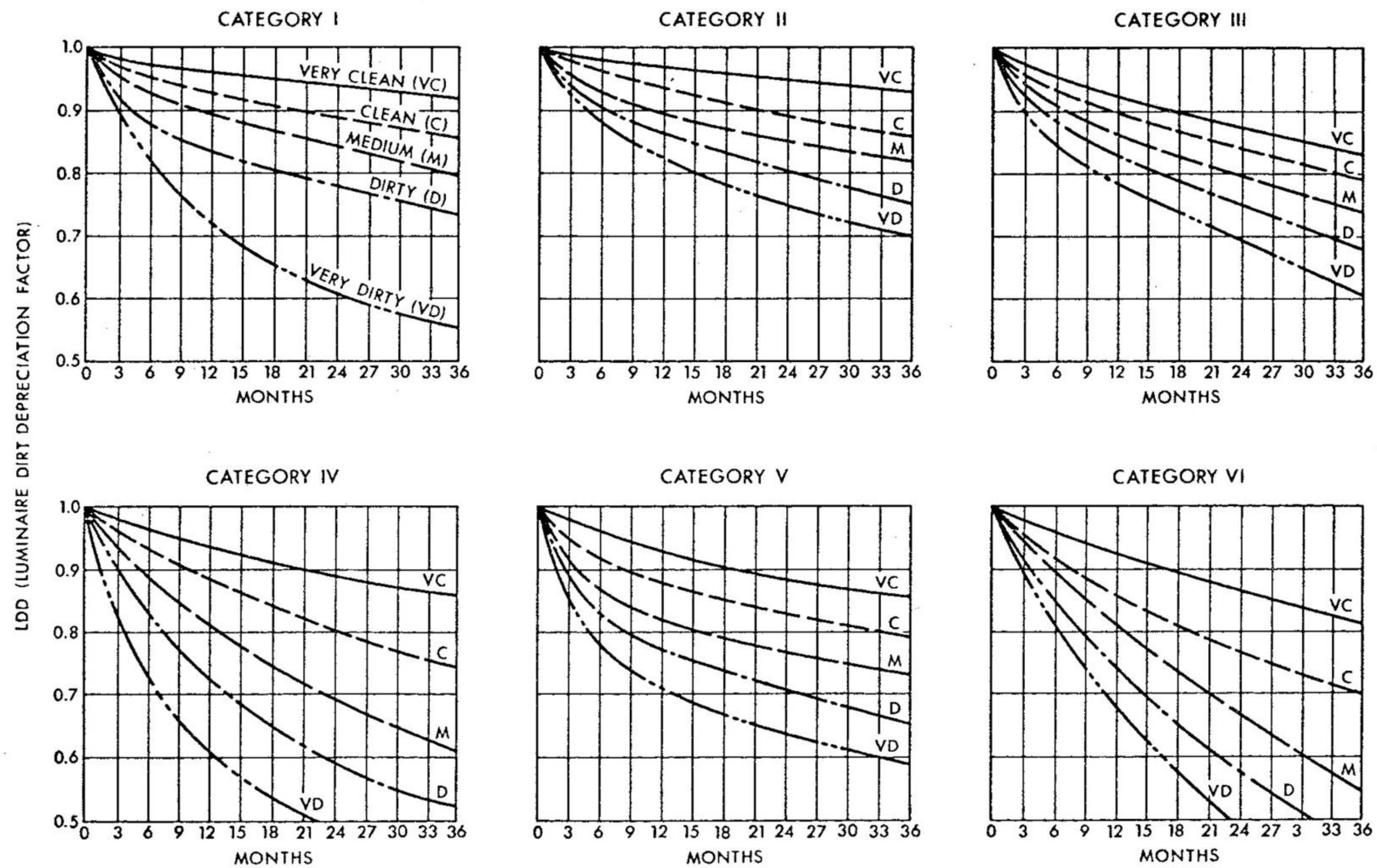


Figure 6-13. *Luminaire dirt depreciation factors for six luminaire categories. (Reprinted with permission from the IES Lighting Handbook, 1981, Reference Volume.)*

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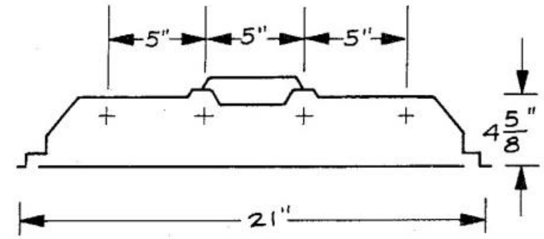
Light Loss Factors

- Expected dirt depreciation:

For a clean environment and at 24 month maintenance intervals, expected dirt depreciation: 18%



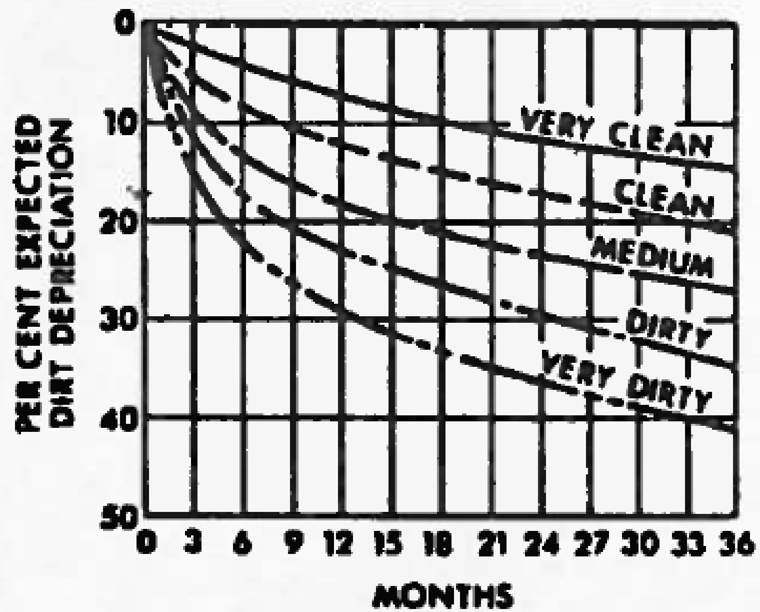


Figure 6-14. *Per cent expected dirt depreciation because of cleaning interval and atmospheric conditions. (Reprinted with permission from the IES Lighting Handbook, 1981, Reference Volume.)*

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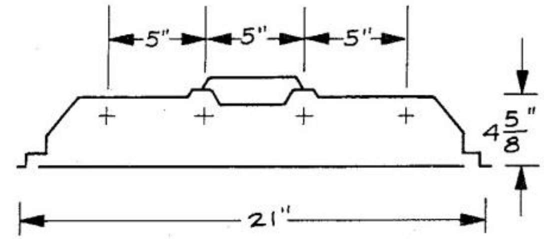
Light Loss Factors



- Room surface dirt depreciation (RSDD): takes into account that dirt accumulates on room surfaces and reduces surface reflectance (0.97)

RCR=1.6

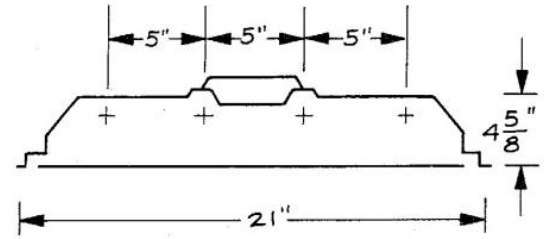
TABLE 6-6. ROOM SURFACE DIRT DEPRECIATION FACTORS [a]

		Luminaire Distribution Type																		
		Direct				Semi-Direct				Direct-Indirect				Semi-Indirect				Indirect			
Per Cent Expected Dirt Depreciation		10	20	30	40	10	20	30	40	10	20	30	40	10	20	30	40	10	20	30	40
Room Cavity Ratio	1	.98	.96	.94	.92	.97	.92	.89	.84	.94	.87	.80	.76	.94	.87	.80	.73	.90	.80	.70	.60
	2	.98	.96	.94	.92	.96	.92	.88	.83	.94	.87	.80	.75	.94	.87	.79	.72	.90	.80	.69	.59
	3	.98	.95	.93	.90	.96	.91	.87	.82	.94	.86	.79	.74	.94	.86	.78	.71	.90	.79	.68	.58
	4	.97	.95	.92	.90	.95	.90	.85	.80	.94	.86	.79	.73	.94	.86	.78	.70	.89	.78	.67	.56
	5	.97	.94	.91	.89	.94	.90	.84	.79	.93	.86	.78	.72	.93	.86	.77	.69	.89	.78	.66	.55
	6	.97	.94	.91	.88	.94	.89	.83	.78	.93	.85	.78	.71	.93	.85	.76	.68	.89	.77	.66	.54
	7	.97	.94	.90	.87	.93	.88	.82	.77	.93	.84	.77	.70	.93	.84	.76	.68	.89	.76	.65	.53
	8	.96	.93	.89	.86	.93	.87	.81	.75	.93	.84	.76	.69	.93	.84	.76	.68	.88	.76	.64	.52
	9	.96	.92	.88	.85	.93	.87	.80	.74	.93	.84	.76	.68	.93	.81	.75	.67	.88	.75	.63	.51
	10	.96	.92	.87	.83	.93	.86	.79	.72	.93	.84	.75	.67	.92	.83	.75	.67	.88	.75	.62	.50

[a] Reprinted from the *IES Lighting Handbook*, 1981, Reference Volume.

P. C. Sorcar (1987)

Light Loss Factors



- Lamp lumen depreciation (LLD): takes into account that lamp lumens decrease with age
  - Its value can be determined by manufacturer's lumen depreciation chart or diving the maintained lumen by the initial lamps at 70% of the average rated life (0.88)

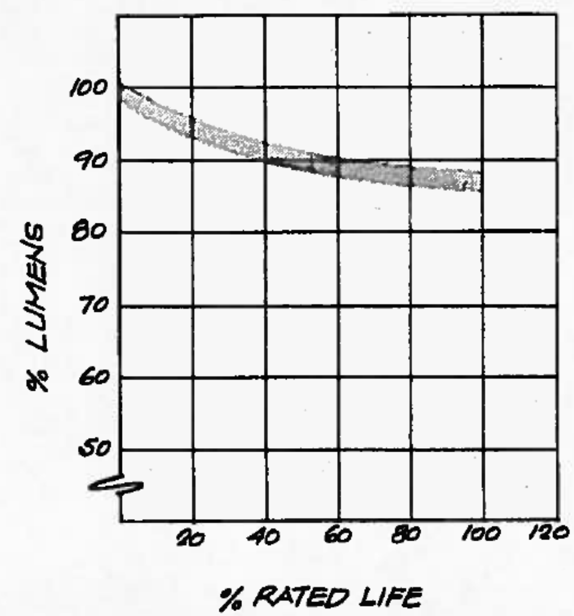
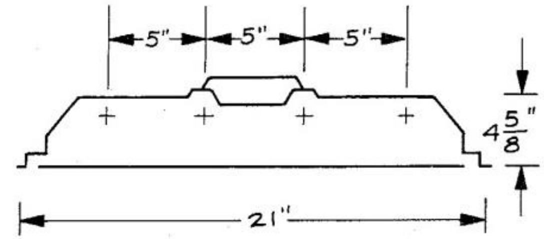


Figure 4-22. Approximate lumen maintenance of various types of cool white fluorescent lamps.

P. C. Sorcar (1987)

Light Loss Factors



- Lamp Burnout (LBO): predicts the no. of lamps that will burn out before the time of scheduled replacement, it is the ratio of the lamps remaining on to the total lamps used.
  - LBO is 1.0 when it is known that burned out lamps will be replaced promptly

LLF=(nonrecoverable factor)*(LDD*RSDD*LLD*LBO)

= 1.0 *(0.835*0.97*0.88*1.0)

=0.71

Step V: determine the no. of luminaires required

$$E = \frac{(L \times N) \times CU \times LLF}{A}$$

$$N = \frac{E \times A}{L \times CU \times LLF}$$

Ex.8: Find the number of luminaires required in Ex. 7 to produce 70fc (**maintained**) at the task level if the lamps are rated at 3200lm with an efficiency of 64% and the luminaires are recessed in the ceiling (28). Check the luminaire spacing and determine the initial illuminace (70/0.71=99fc).

Maintained illumination level represents the illuminance level at the time of lamp replacement and cleaning, typically 70% of rated life time to ensure that the required illumination level won't fall below the recommended value at any time.

Lighting calculation by zonal cavity method

- Step I: determine cavity ratios
  - Ceiling cavity: the space between the luminaire mounting plane and the ceiling
  - Room cavity: the space between work plane and the luminaire mounting plane
  - Floor cavity: the space between the work plane and the floor
- Step II: determine effective cavity reflectances
  - Depend on their cavity depths, surface reflectances, and cavity ratios; the deeper the cavity, the poorer light reflected; some of the reflected light at the ceiling or floor is bounced off the walls
- Step III: select coefficient of utilization from manufacturer's data sheet
  - The effective floor cavity reflectance $\boldsymbol{\rho}_{fc}$ is normally 20%. If this value varies from20%, a correction factor is used to modify the CU
- Step IV: determine light loss factor (LLF)
- Step V: determine no. of luminaires required and layout

Illuminance category	Ranges of illuminance maintained in service, lux (fc)	Type of activity
General illuminance throughout room:		
A	20–30–50 (2–3–5)	Public spaces with dark surroundings
B	50–75–100 (5–7.5–10)	Simple orientation for short temporary visits
C	100–150–200 (10–15–20)	Working spaces where visual tasks are only occasionally performed
Illuminance on task:		
D	200–300–500 (20–30–50)	Performance of visual tasks of high contrast or large size: reading printed material, typed originals, handwriting in ink, and good xerography; rough bench and machine work; ordinary inspection; rough assembly
E	500–750–1000 (50–75–100)	Performance of visual tasks of medium contrast or small size: reading medium pencil handwriting, poorly printed or reproduced material; medium bench and machine work; difficult inspection; medium assembly
F	1000–1500–2000 (100–150–200)	Performance of visual tasks of low contrast or very small size: reading handwriting in hard pencil on poor-quality paper and very poorly reproduced material; highly difficult inspection
Illuminance on task, obtained by a combination of general and local (supplementary) lighting:		
G	2000–3000–5000 (200–300–500)	Performance of visual tasks of low contrast and very small size over a prolonged period: fine assembly; very difficult inspection; fine bench and machine work
H	5000–7500–10,000 (500–750–1000)	Performance of very prolonged and exacting visual tasks: the most difficult inspection; extra-fine bench and machine work; extra-fine assembly
I	10,000–15,000–20,000 (1000–1500–2000)	Performance of very special visual tasks of extremely low contrast and small size: for example, surgical procedures

Courtesy of Illuminating Engineering Society of North America.

Egan, Architectural lighting

References

- M. David Egan and V. Olgyay. Architectural Lighting. McGraw Hill, 2002
- P. C. Sorcar, 1987. Architectural Lighting for commercial interiors. John Wiley & Sons. TH7900S67