BLDG 366
Acoustics and Lighting

Week 11: Lighting calculation (cont.)

March 18th, 2016

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Outline

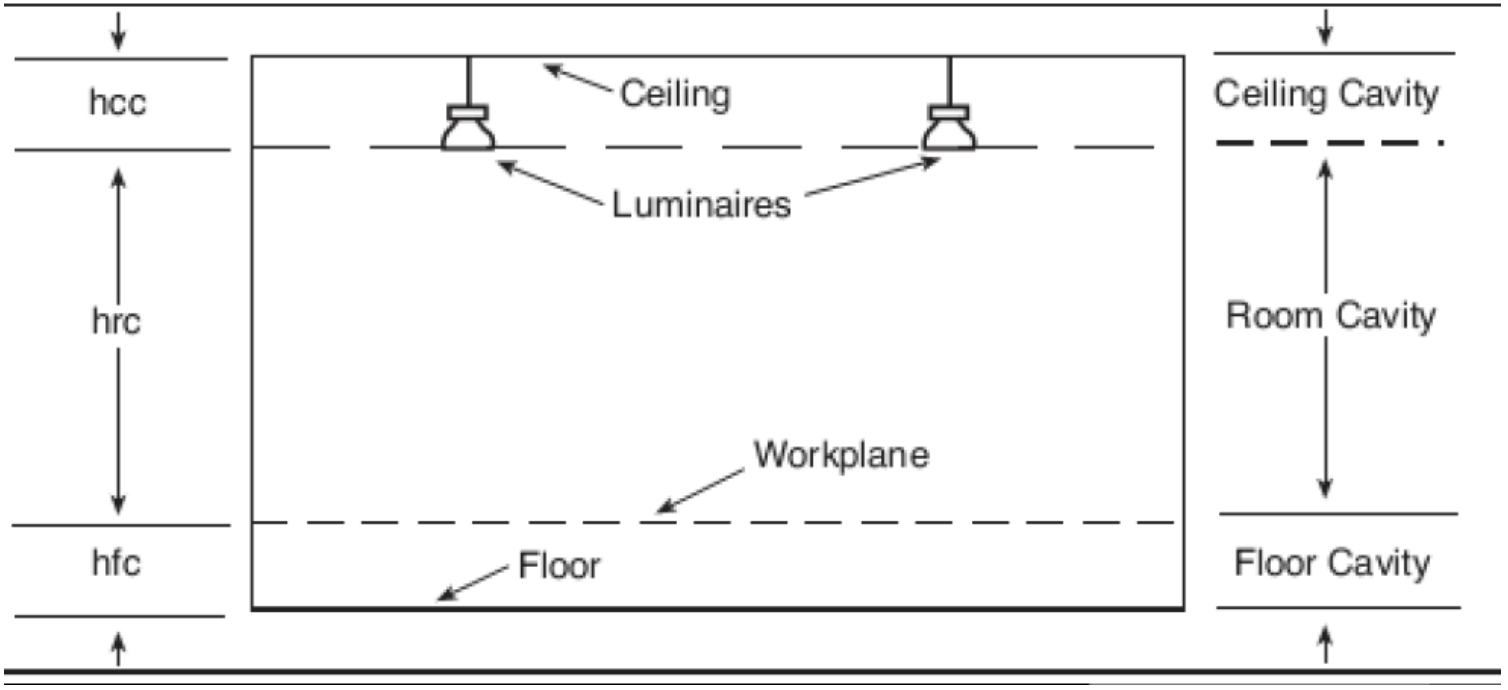
- Review of Lumen method
- Point-by-point method
- Lighting design

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

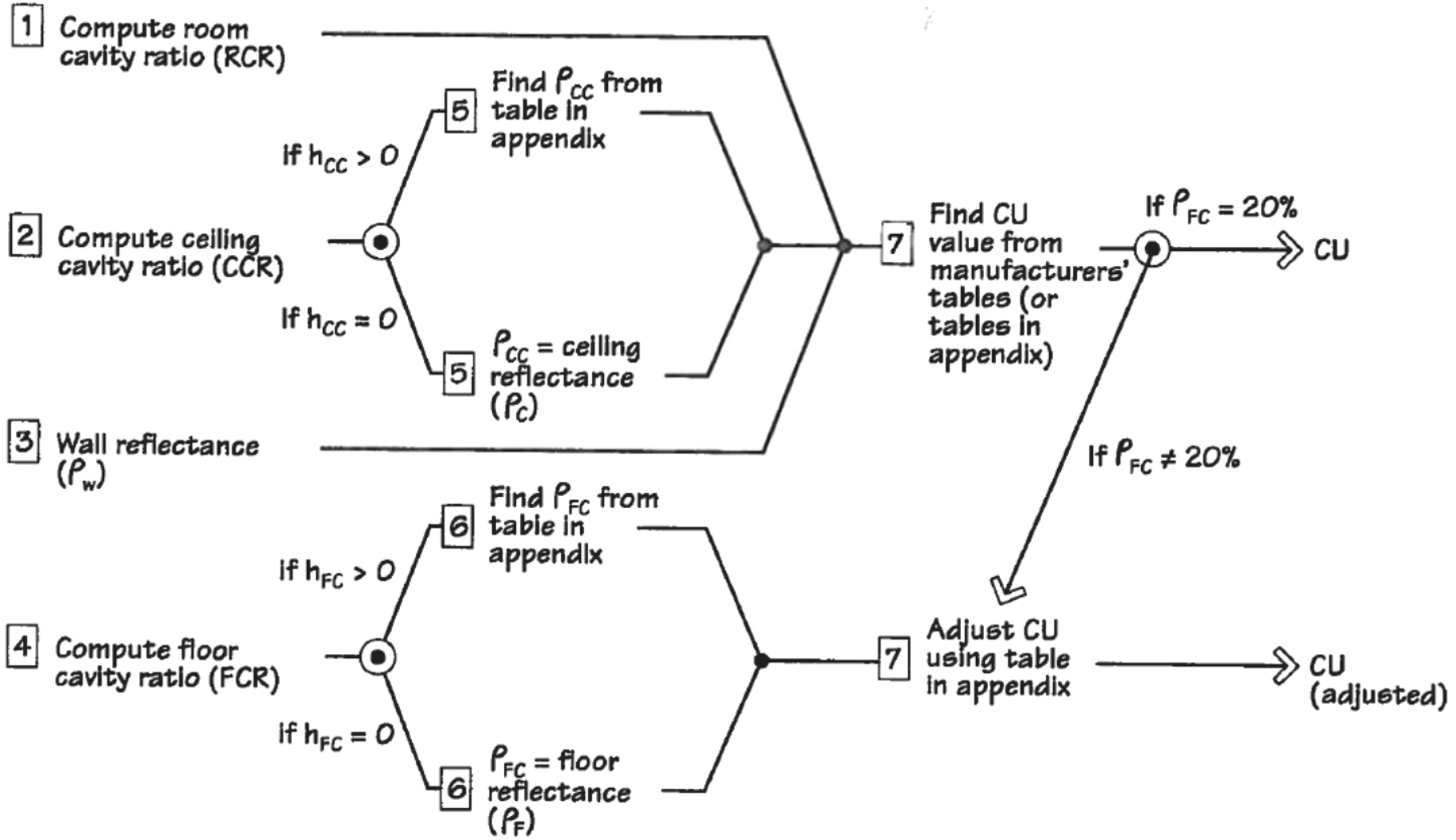
Determination of CU by zonal cavity method

- 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)

HOW TO FIND COEFFICIENT OF UTILIZATION



Symbols

- Steps
- All preceding steps to be evaluated
- Decision (i.e., must do one of the following steps)

D. Egan and V. Olgyay (2003)

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

- Step IV: determine the light loss factor (LLF)
  - 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
  - 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.
    - **Room surface dirt depreciation (RSDD):** takes into account that dirt accumulates on room surfaces and reduces surface reflectance
    - **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
    - **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

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

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

L is the total initial lumens per luminaire

N = number of luminaires

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

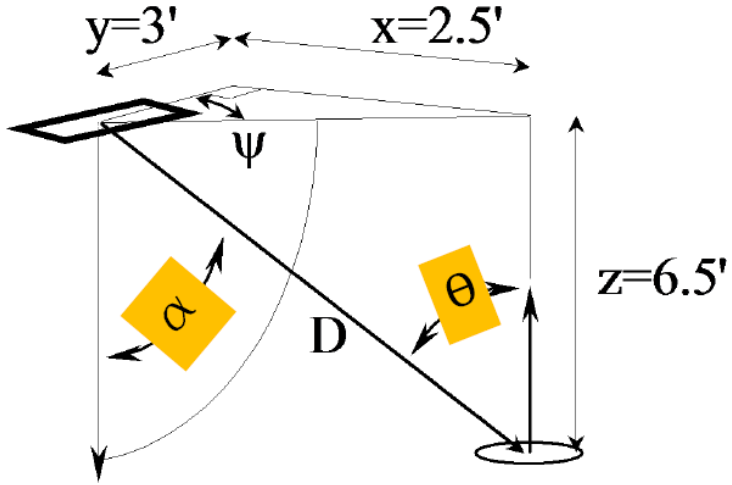
CU = coefficient of utilization

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

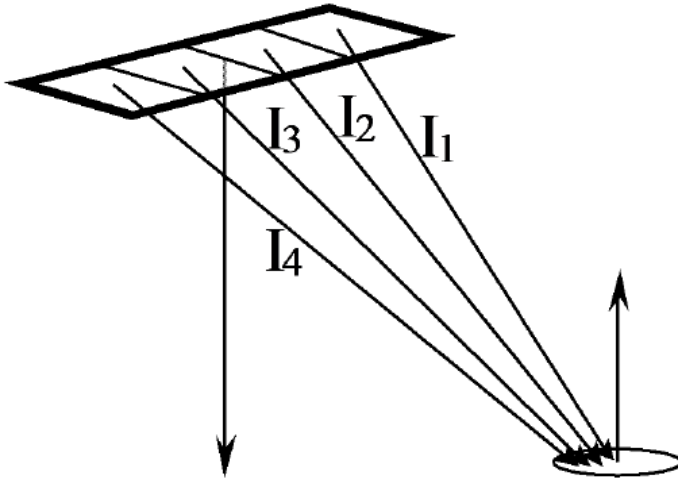
Point-by-Point Method

- Only applicable for
  - Point sources (e.g. incandescents, HID)
  - Perfectly diffused surfaces
    - Such as exterior lighting in parking lots, spot or flood lighting, or in interiors in which few luminaires are required and surface reflectances are negligible
- Cannot be used for area sources (such as fluorescent troffers) unless some modifications are made
  - The luminaires mounted high enough to act as point sources (**at least five times of the length of the luminaire**)
  - The luminaires must be divided into small clusters, each of which can be treated as a point source
  - To account for the room surface reflectances a number of separate calculations must be made by first evaluating the luminances and then treating them as groups of small sources

Point-by-Point Method



D=7.6’, length of the luminaire <1.5’



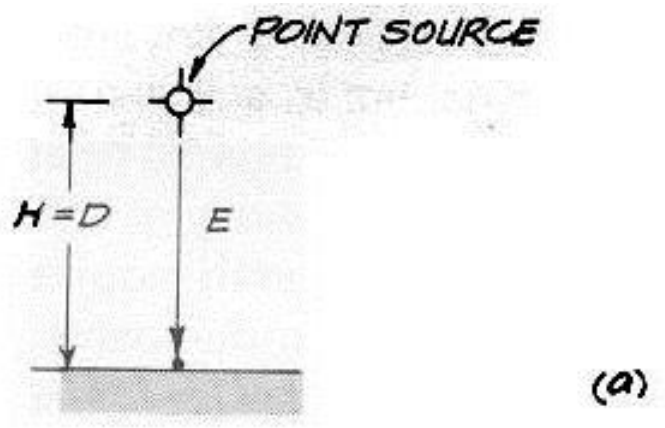
For distance less than 5L, break the luminaire into smaller clusters to satisfy the criteria as “point source”, then follow the procedure for “multi-point” source calculation

Point-by-Point Method

- Point-by-point method is based on the inverse-square law, which states that the illuminance at a point on a surface perpendicular to the light ray is equal to the luminous intensity of the source at that point, divided by the square of the distance between the source and the point of interest

$$E = I / D^2$$

E : illuminance [lux]
I : luminous intensity [candela]
D : distance [m]



$$E = \frac{I}{D^2}$$

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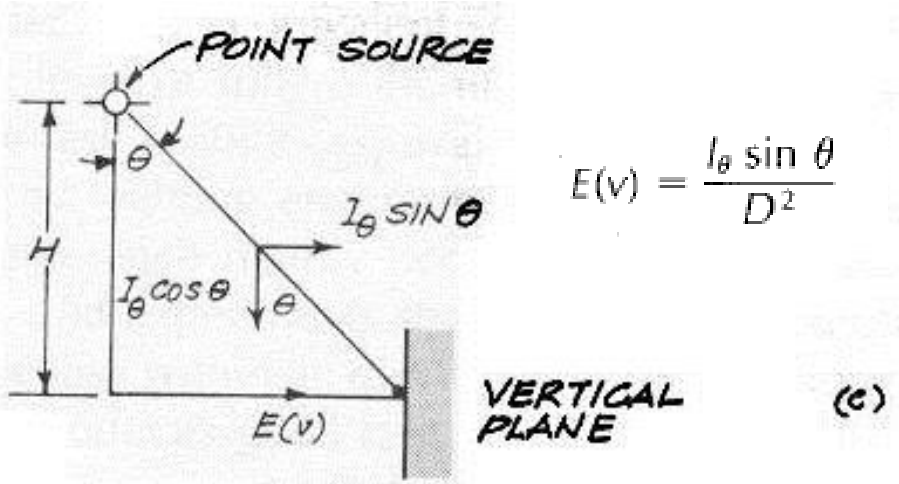
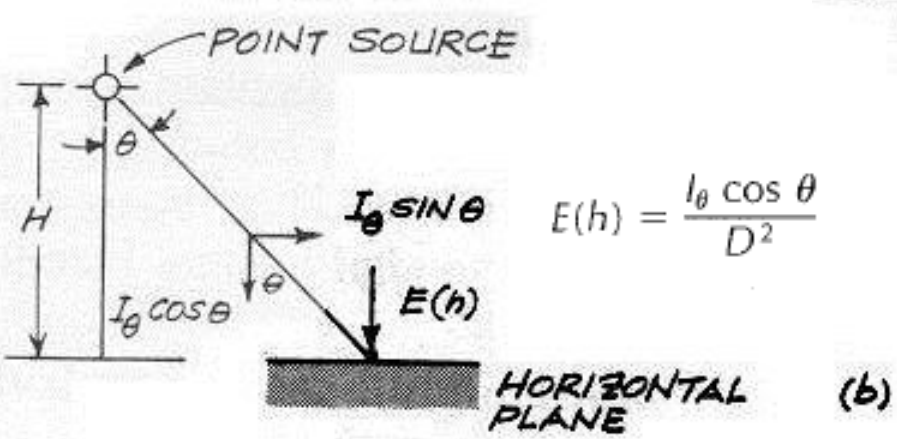
Point-by-Point Method

- If the surface is not perpendicular to the light ray, the appropriate trigonometrical functions need to be applied to represent the component perpendicular to the surface



$$E(v) = \frac{I_\theta \sin\theta}{D^2}$$

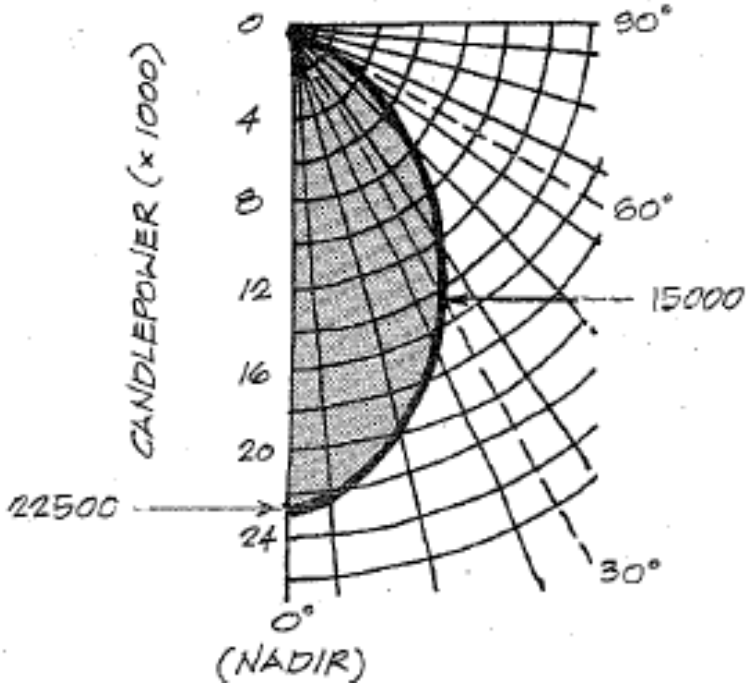


$$E(h) = \frac{I_\theta \cos\theta}{D^2}$$

Sorcar (1987)

Point-by-Point Method

- Ex. 1: The candle-power (candela) distribution curve of the luminaire is shown below. The distance is D=15ft, determine the illuminace for a horizontal plane at an angle of 0° and 30°, and the illuminace for a vertical plane at an angle of 30°

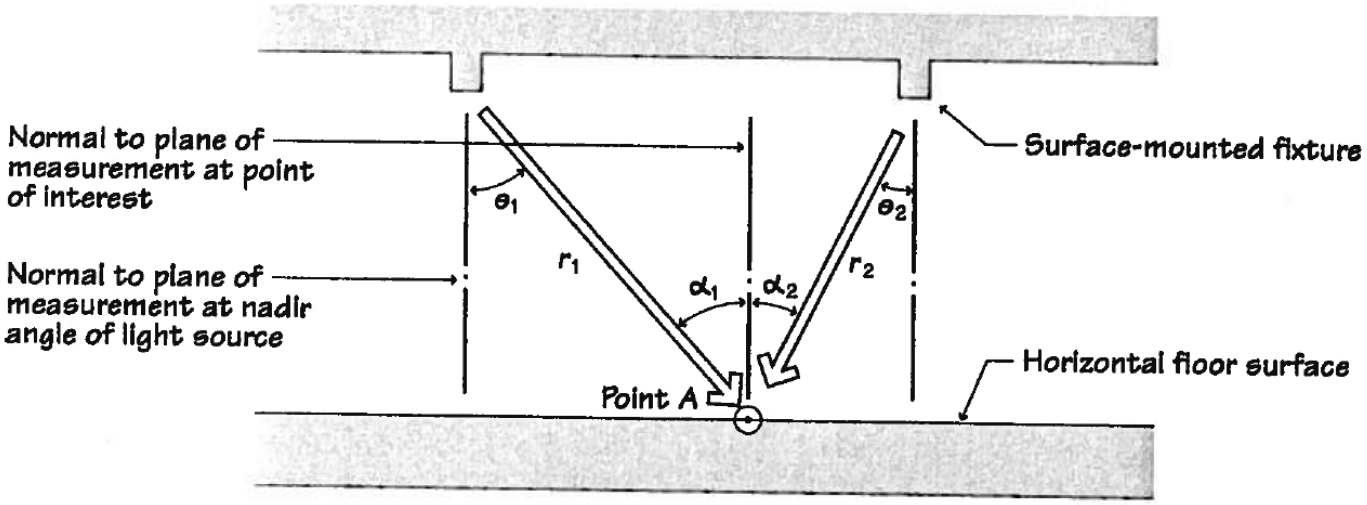


$$E = \frac{I}{D^2} = \frac{22{,}500}{15^2} = 100 \text{ fc}$$

$$E(v) = \frac{I_\theta \sin\theta}{D^2} = \frac{15{,}000 \times \sin 30^\circ}{15^2} = 33.3 \text{ fc}$$

$$E(h) = \frac{I_\theta \cos\theta}{D^2} = \frac{15{,}000 \times \cos 30^\circ}{15^2} = 57.7 \text{ fc}$$

Multi-point source



Illumination level at any point (e.g., point *A* shown below) is the sum of the illumination levels from all sources contributing light at that point. The illumination level can be computed by

$$E = \frac{CP}{r_1^2}\cos\alpha_1 + \frac{CP}{r_2^2}\cos\alpha_2 + \cdots$$

where E = illumination level (fc)
CP = candlepower of source of light, varies with angle θ from nadir (cd)
r = distance from source of light to point of interest (ft)
α = angle between ray of light and normal to surface (deg)

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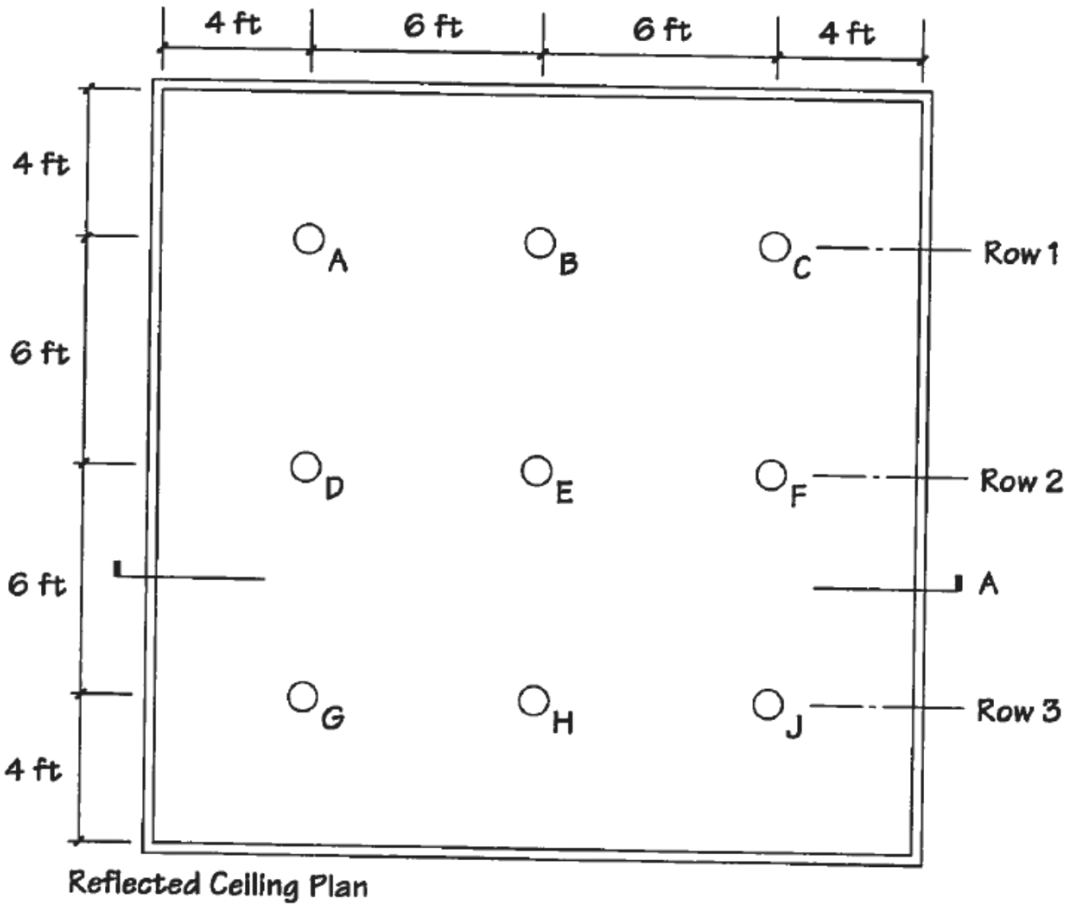
Multi-point source

Ex 2.

1. In the reflected ceiling plan shown below, nine downlight luminaires are arranged to highlight areas on the horizontal work surface.



Reflected Ceiling Plan

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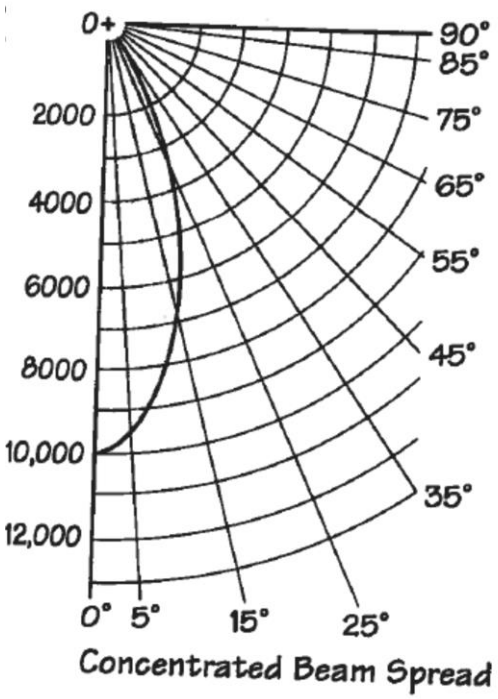
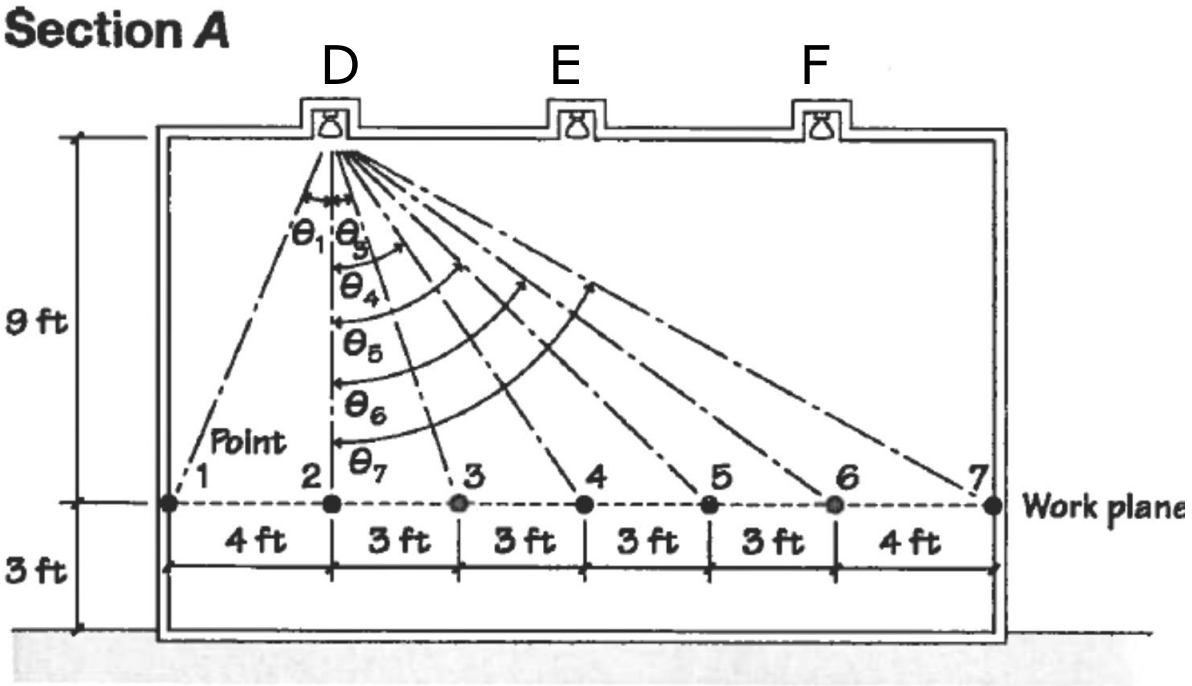
Multi-point source

Find the illumination at the seven points on the work plane under row 2. Assume work plane is 3ft above the floor.





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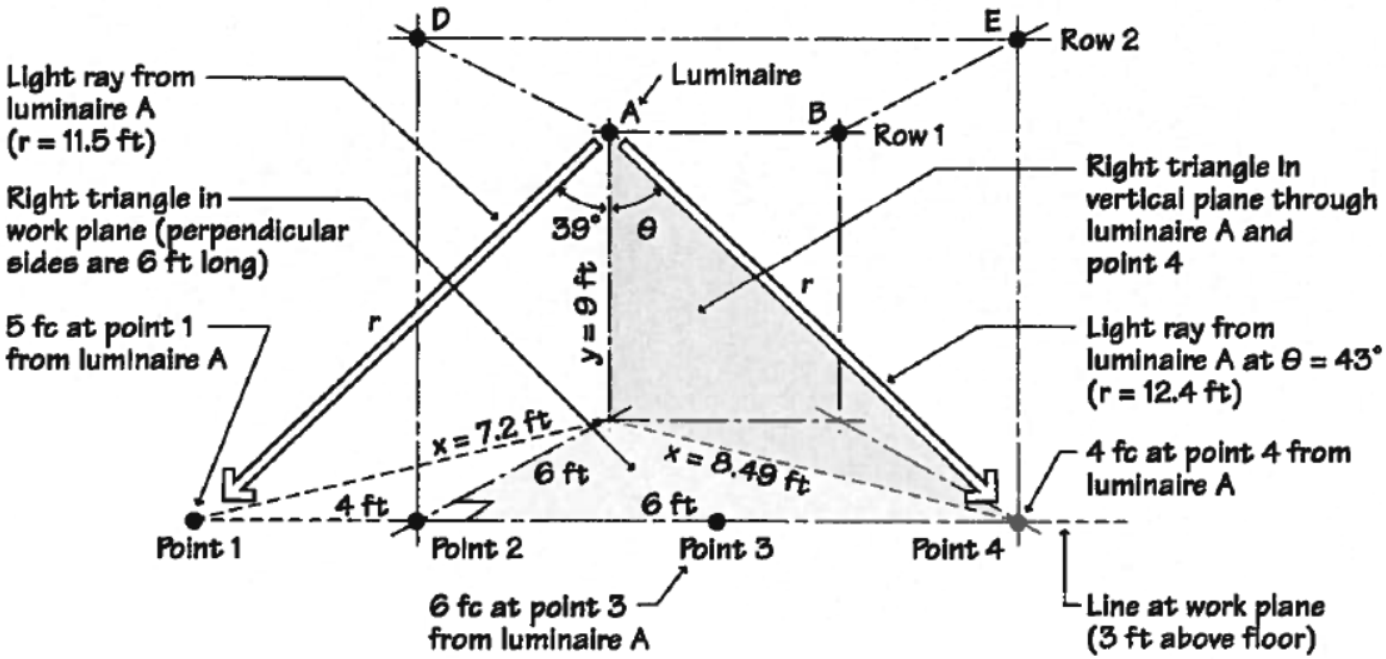
Multi-point source

3. The illumination at point 4 from luminaire A is found by determining the dimensions of the horizontal and vertical right triangles shown below. The bottom side of the vertical right triangle in the plane of luminaire A is $\sqrt{6^2 + 6^2} = 8.49$ ft by the pythagorean theorem. Angle θ is found from $\tan \theta = x/y = 8.49/9 = 0.9433$. From the table on page 283, $\theta = 43°$ and $\cos 43 = 0.7314$.

$$E = \frac{CP}{r^2} \cos \theta = \frac{800}{8.49^2 + 9^2} (0.7314) = 4 \text{ fc}$$



Multi-point source

2. The table below is used to determine illumination at seven points on the work plane under row 2 from luminaire D by solving $(CP/r^2) \cos \theta$.

Point	tan θ	θ	CP*	$x^2 + y^2$	r^2	$(CP/r^2) \times (\cos \theta)$	E (fc)
1	4/9 = 0.4444	24°	4,500	$4^2 + 9^2$	97	$^{4500}/_{97}(0.9135)$	42
2	—	0°	10,000	$0^2 + 9^2$	81	$^{10,000}/_{81}(1.0000)$	123
3	3/9 = 0.3333	18°	6,700	$3^2 + 9^2$	90	$^{6700}/_{90}(0.9511)$	71
4	6/9 = 0.6667	34°	2,000	$6^2 + 9^2$	117	$^{2000}/_{117}(0.8290)$	14
5	9/9 = 1.0000	45°	500	$9^2 + 9^2$	162	$^{500}/_{162}(0.7071)$	2
6	12/9 = 1.3333	53°	0	$12^2 + 9^2$	225	$0/_{225}(0.6018)$	0
7	16/9 = 1.7778	61°	0	$16^2 + 9^2$	337	$0/_{337}(0.4848)$	0

*Candlepower (cd) data from *concentrated beam spread* photometric curve on page 153.

Multi-point source

4. The table below is used to find the total footcandles at points 1 to 7 on the work plane under row 2. By symmetry, the illumination patterns from luminaires E and F are equal to those of D. Notice that luminaires located along rows 1 and 3 also contribute illumination at these points.

	Illumination level *E* at points under row 2						
Luminaire	**1**	**2**	**3**	**4**	**5**	**6**	**7**
D	42	123	71	14	2		
E		14	71	123	71	14	
F			2	14	71	123	42
A	5	14	6	4			
B		4	6	14	6	4	
C				4	6	14	5
G	5	14	6	4			
H		4	6	14	6	4	
J				4	6	14	5
Total (fc)	52	173	168	195	168	173	52

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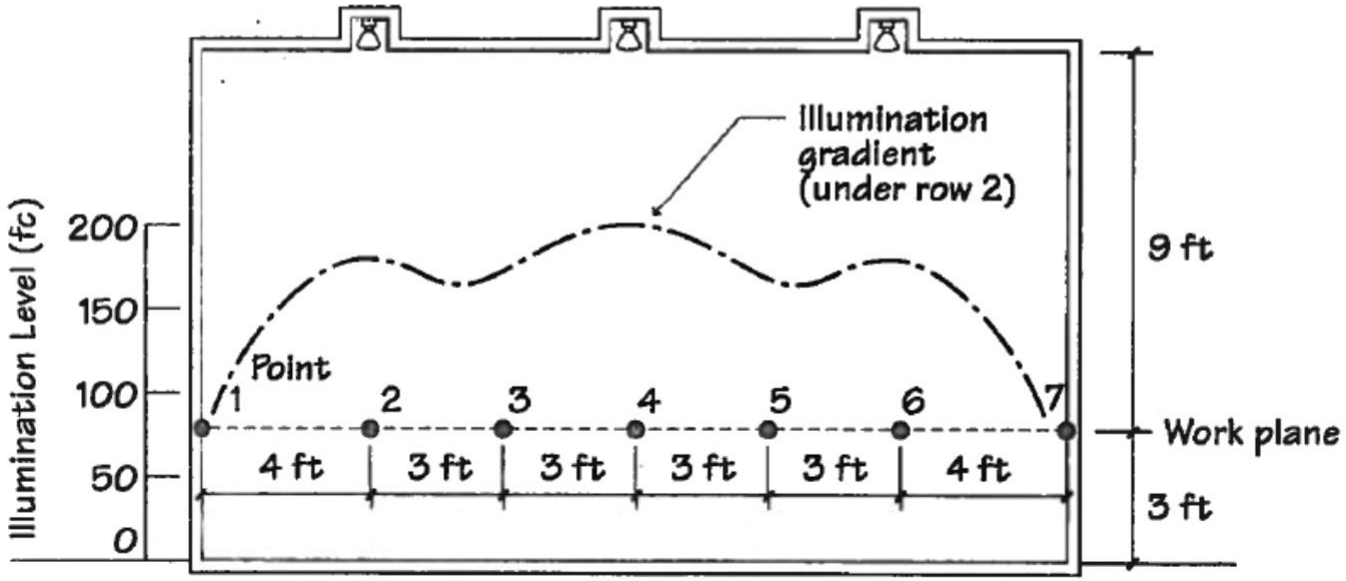
Multi-point source

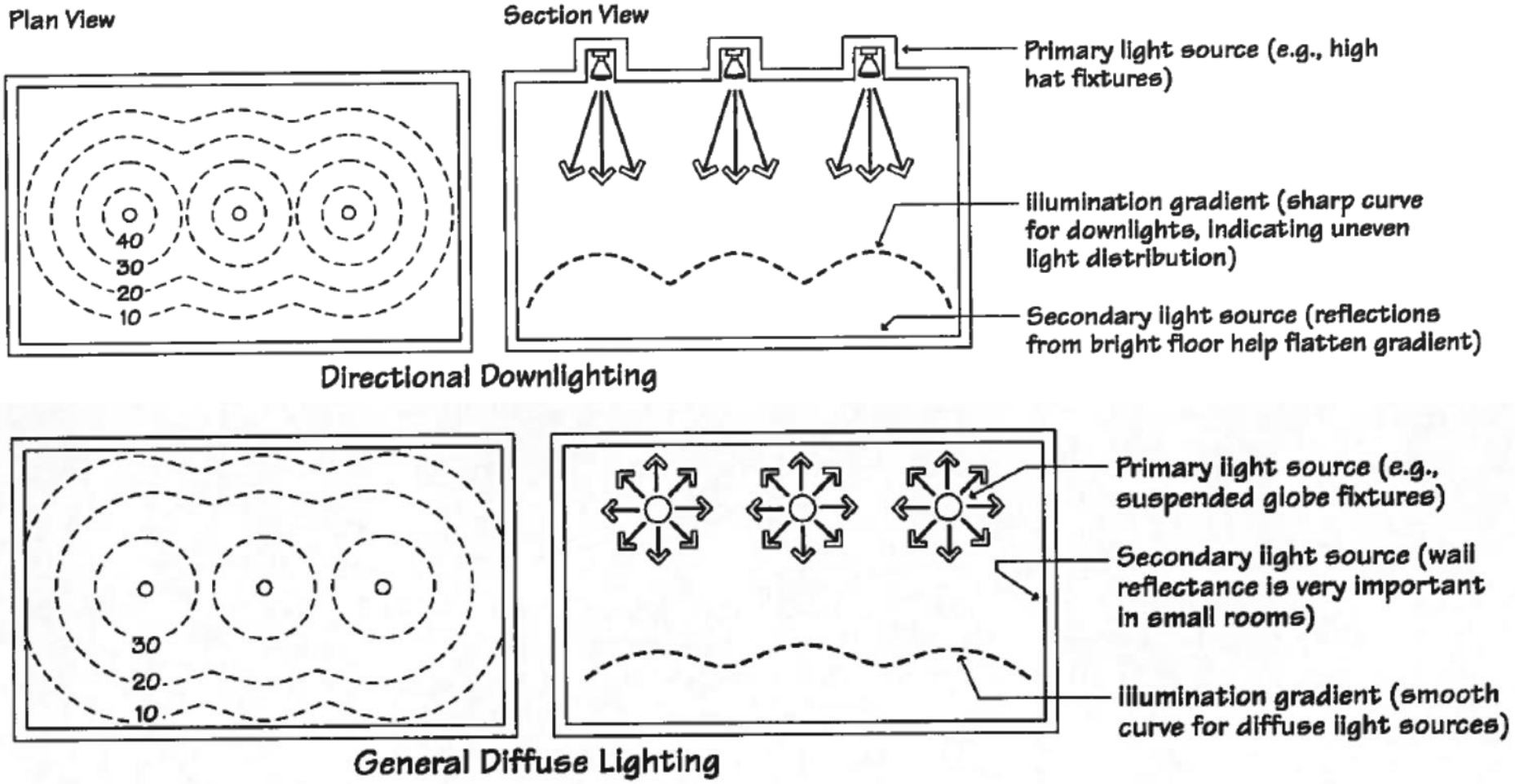
5. On section *A*, an illumination gradient is plotted, showing variations of direct light on the work plane from the nine luminaires. The point method does not account for interreflected light from room surfaces, but these components are usually negligible for downlights.

Section *A*



Illumination gradients and contours:

Graphical representation of the increase or decrease of illumination levels along an axis of measurement.



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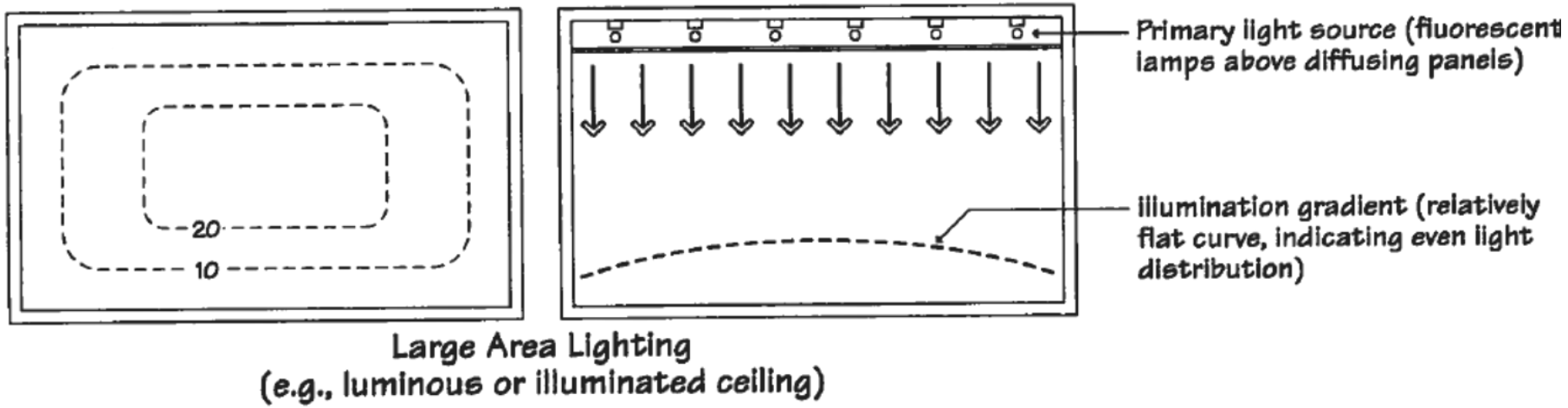
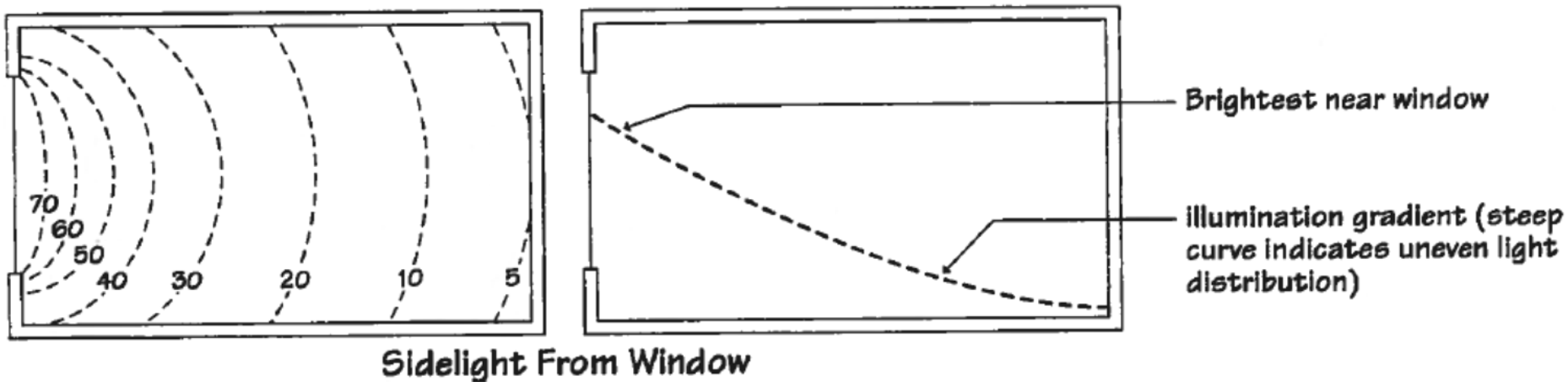
Illumination gradients and contours



Large Area Lighting
(e.g., luminous or illuminated ceiling)



Sidelight From Window

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COMPARISON CHART FOR ELECTRIC LIGHT SOURCES

	Incandescent (including tungsten-halogen)	Fluorescent	Low-pressure sodium	Mercury	Metal halide	High-pressure sodium
Basic description	High-intensity point source, compact size with one base	Low-intensity line source, bulky size with two bases plus ballast, temperature-sensitive	Low-pressure long line source, bulky ballast with one base	High-pressure point or short line source, moderately compact size with one base plus ballast	High-pressure point or short line source, moderately compact size with one base plus ballast	High-pressure point or short line source, moderately compact size with one base plus ballast
ANSI Designation		F		H	M	S
Length (in)	$\frac{3}{16}$–18	6–96	12–44	5–16	8–15	7–15
Wattage (W)	1–10,000	5–215	18–180	50–1000	32–1800	35–1000
Visible energy (%)	10	23	35	14	21	26
Efficacy (lm/W)	9–35	20–100	100–180	25–65	45–110	40–140
Typical average life (h)	750–4000 (varies with applied voltage)	8–20,000	18,000	16,000–24,000	1,500–20,000	≥24,000
Start and restart times (min)	Instantly	Immediately	6½–10 (start) 0–3 (restart)	3–9 5–10	3–5 4–20	½–1 3–4
Dimmability	Full-range adjustability	Dimmable with electronic ballasts	Not at present	Possible with special circuit plus auxiliary equipment	Possible with special circuit plus auxiliary equipment	Possible with special circuit plus auxiliary equipment
Color rendition	Excellent (continuous spectrum)	Good to excellent	Poor (spectrum predominantly monochrome yellow)	Poor to good (discontinuous spectrum) Low in red	Good to excellent (discontinuous spectrum)	Fair to good (discontinuous spectrum) Yellow cast, low in blue-green
Lumen loss over time	Fair to very good	Fair to very good	Very good	Fair	Good	Very good
Typical applications	• Accent • Residential • Museums	• Office • Educational • Retail • Industrial	• Parking lots • Roadways • Security	• Landscape • Street/pathways • Signs • Industrial • Security	• Building exteriors • Sports • Street • Industrial • Commercial	• Street • Outdoor • Industrial • Retail • Office • Security

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Light and form

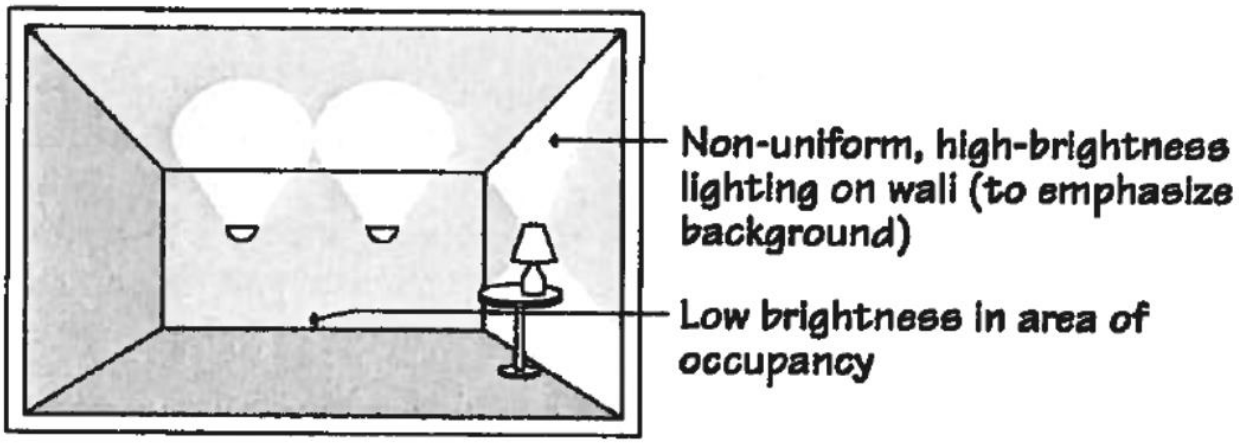
Flynn's luminance patterns

- Research by Prof. J. Flynn at Pennsylvania State University revealed that specific luminance patterns have a consistent and definable effect on an occupant's subjective impression of a space
- Primary categories of impressions based on luminance patterns:
  - Privacy
  - Relaxation
  - Visual clarity
  - Spaciousness

Light and form

Privacy

Privacy is somewhat like being in the shadows. Lighting patterns which are overall low-illuminance, nonuniform, and darker in the zone of the occupant than in the surroundings will reinforce an impression of privacy. Vertical rather than horizontal surfaces should be lit.



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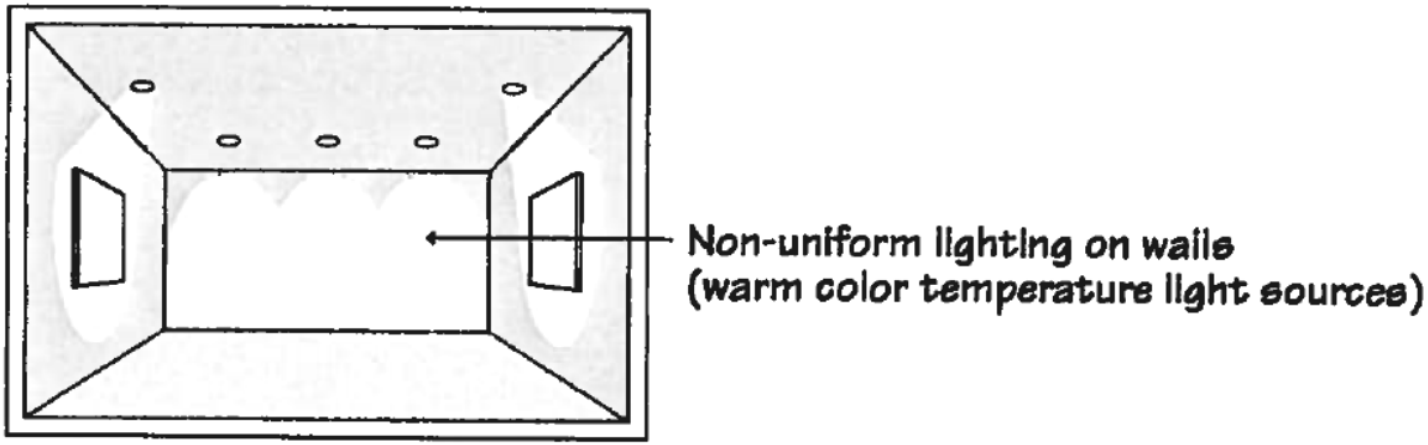
Light and form

Relaxation

Relaxation also implies nonuniform lighting, with nonuniform wall lighting contributing to this impression. Warm color sources contribute to a relaxing feeling. Aspects of the patterns for relaxation can be effectively combined with those for visual clarity to create effective and comfortable work environments.



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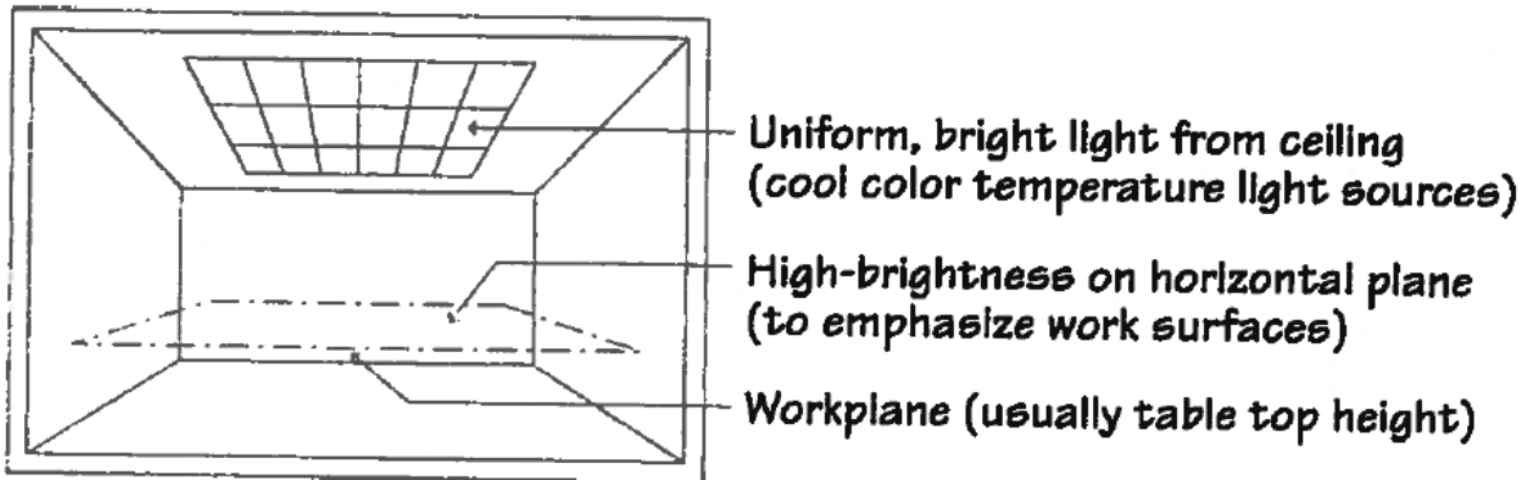
Light and form

Visual Clarity

Visual clarity refers to the crispness and distinctness of the visual environment, rather than how well a task can be seen. Visual clarity is reinforced by shadows, by emphasis on horizontal surfaces such as the work plane and the ceiling, and by higher luminance in the center of the room.



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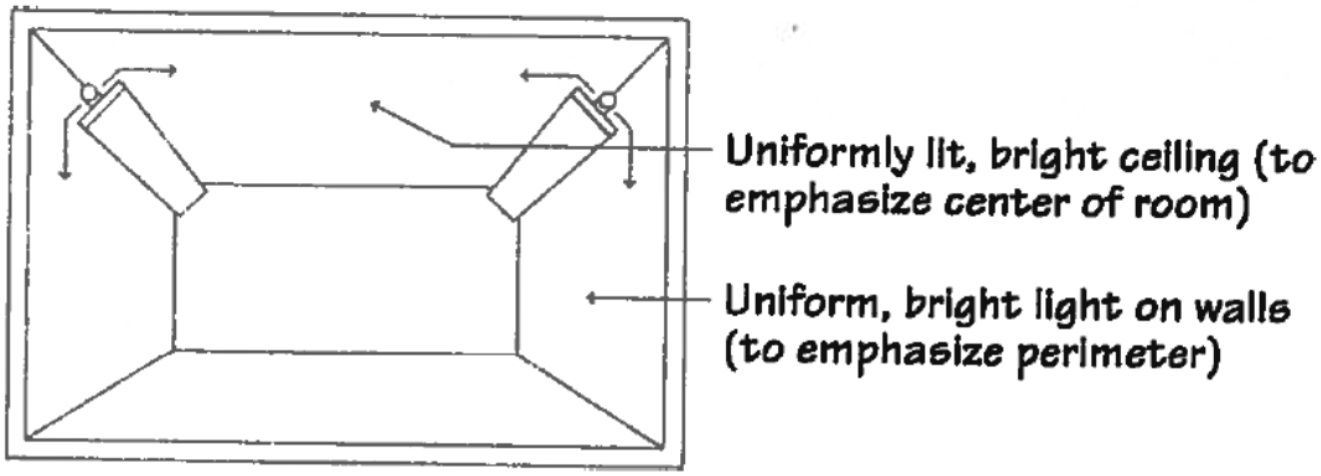
Light and form

Spaciousness

Relatively bright ceilings and walls are particularly important to reinforce a sense of spaciousness. Uniform illumination also helps make a room feel spacious.



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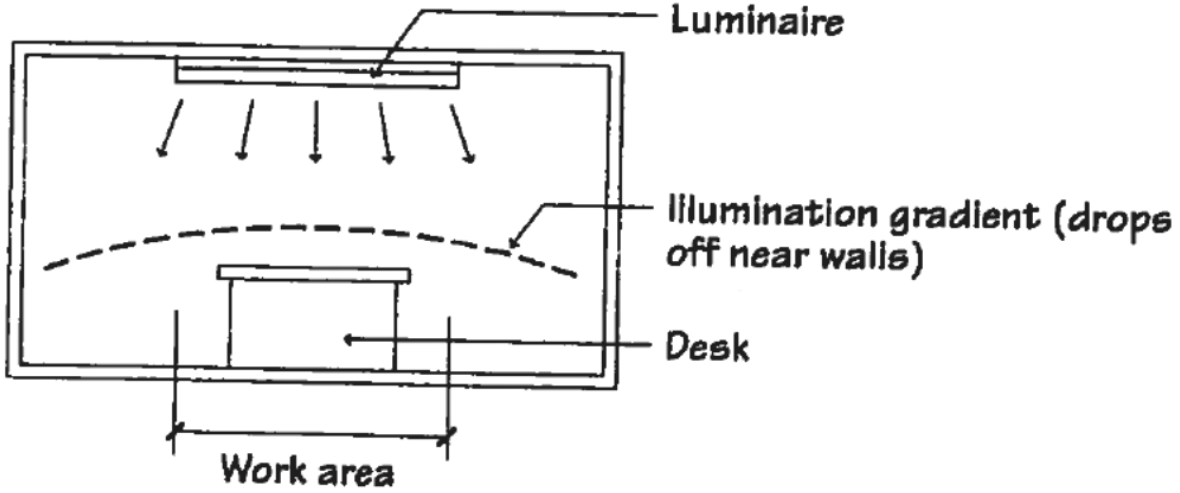
Light distribution strategies

General or Ambient Lighting

General lighting provides uniform illumination over the entire area of a room, allowing flexibility in the placement of workstations. *Localized general lighting* also provides approximately uniform illumination, but luminaires are located in a pattern that responds to the specific arrangement of workstations.



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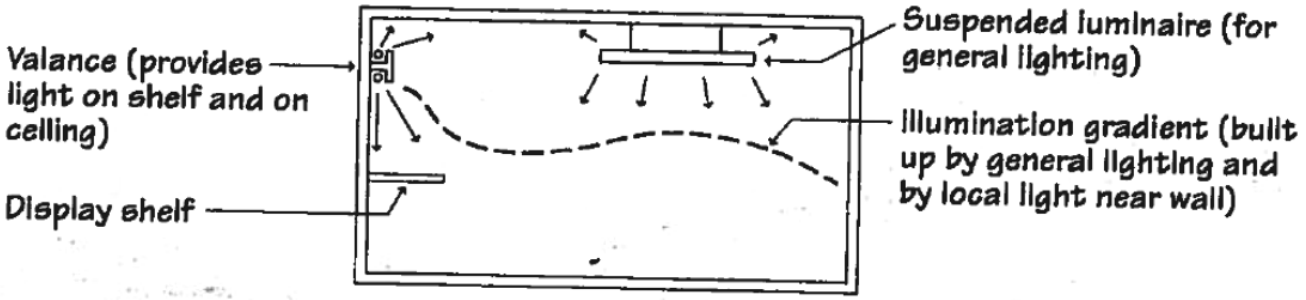
Light distribution strategies

Local Lighting

Local lighting provides high illumination on relatively small areas. It can be too bright and uncomfortable unless surrounding surfaces are also illuminated, as shown below. Local lighting used with general lighting is called *supplementary lighting.*



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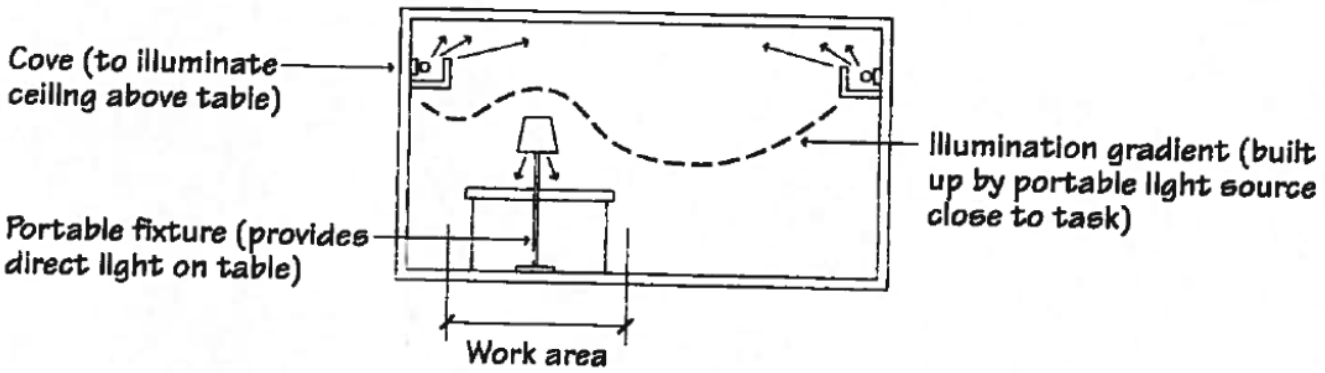
Light distribution strategies

Task-Ambient Lighting

Task-ambient lighting provides high illumination on the *task* from light sources located close to the work area, supplemented by *ambient* illumination, usually from indirect light sources (e.g., furniture-integrated fixtures which direct light toward the ceiling).



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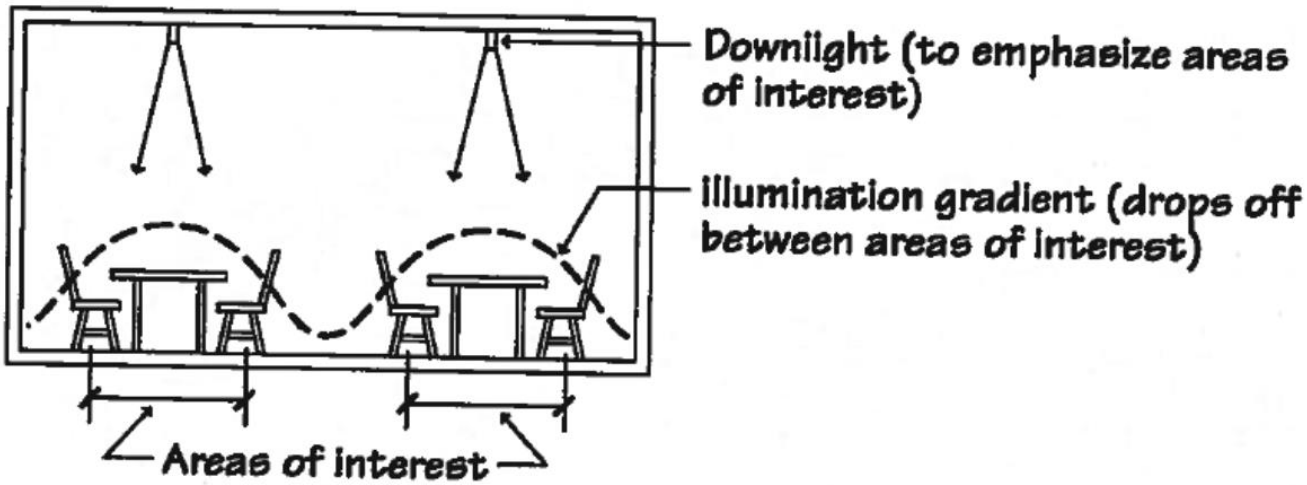
Light distribution strategies

Highlighting

Highlighting emphasizes areas of interest, such as tables in restaurants or artwork in galleries. *Spill* from the highlighted areas may provide sufficient ambient illumination.



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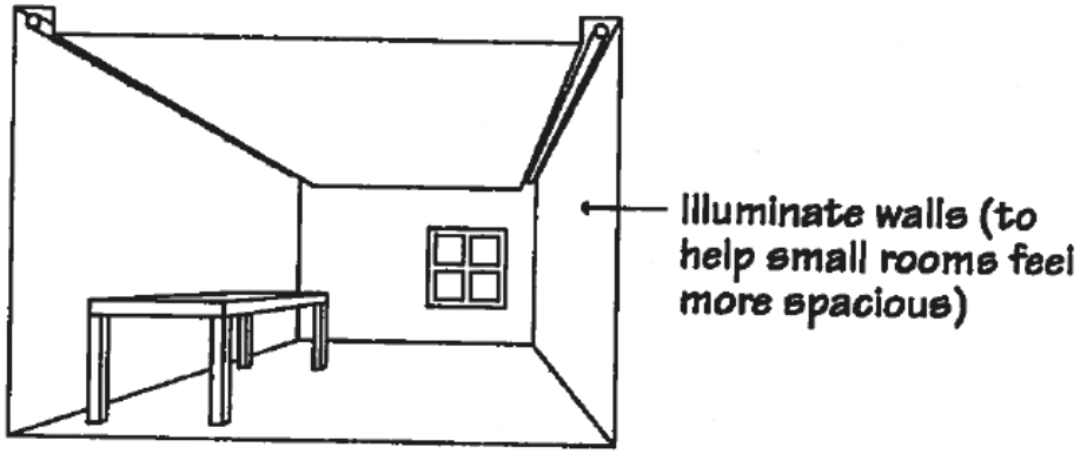
Light distribution strategies

Small Rooms

Light can be used to make small rooms feel spacious by emphasizing the vertical surfaces. Walls are more important than the ceiling (e.g., a 10-ft by 10-ft by 8-ft room has 320 ft^2 of wall surface, but only 100 ft^2 of ceiling).



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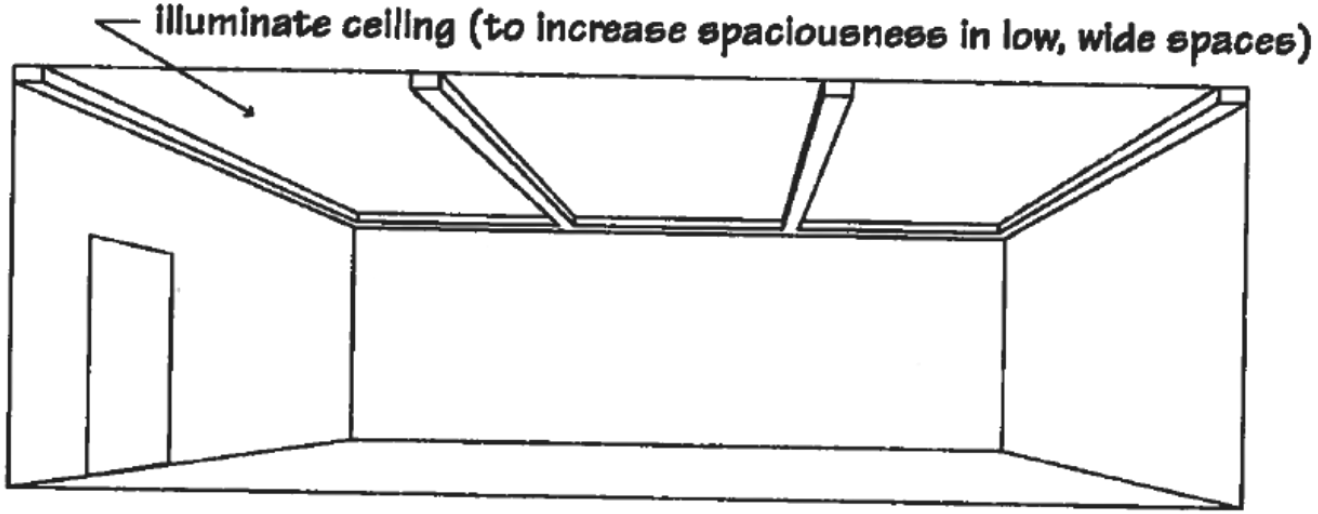
Light distribution strategies

Large Rooms

Large rooms have proportionately more horizontal than vertical surfaces. For example, a 100-ft by 100-ft by 10-ft room only has 4000 ft² of wall surfaces compared to 10,000 ft² of ceiling. Therefore, the dominant lighting opportunities are horizontal surfaces, that is, ceiling and work surfaces.



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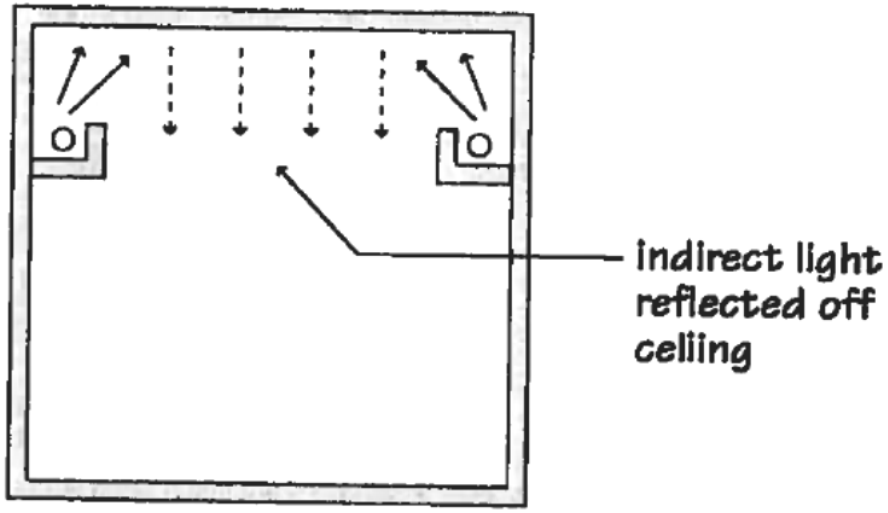
Light distribution strategies

Illuminated ceilings emphasize space by illuminating ceiling surfaces and can be biologically satisfying. However, they can be distracting if unevenly lit. Illuminated ceilings can provide very even illumination on horizontal planes, and they are often the best solution for glare control. Illuminated ceilings may be less efficient than direct lighting and imperfections of the ceiling may be highlighted.



Ceiling Illuminated by Indirect Light

Ceiling as a source of indirect light

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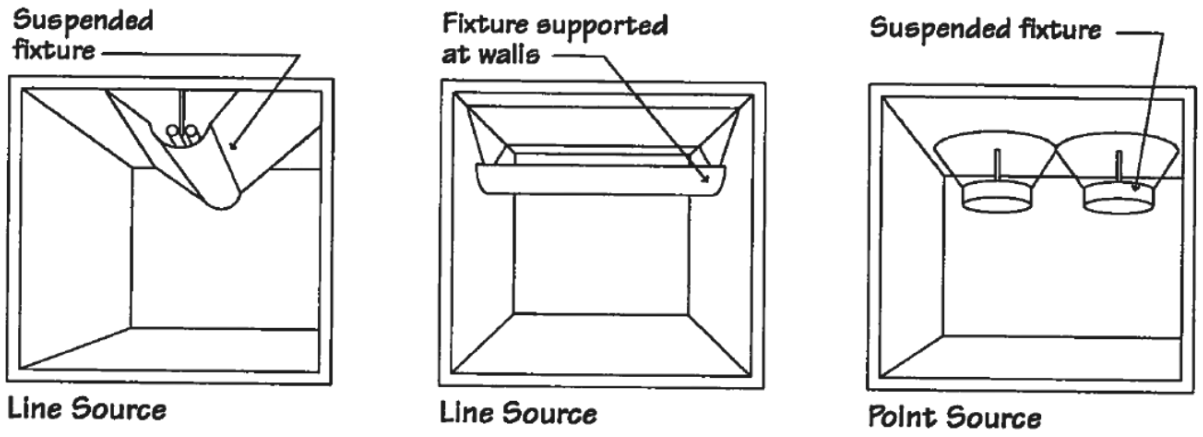
Light distribution strategies



Suspended fixtures to illuminate the ceiling

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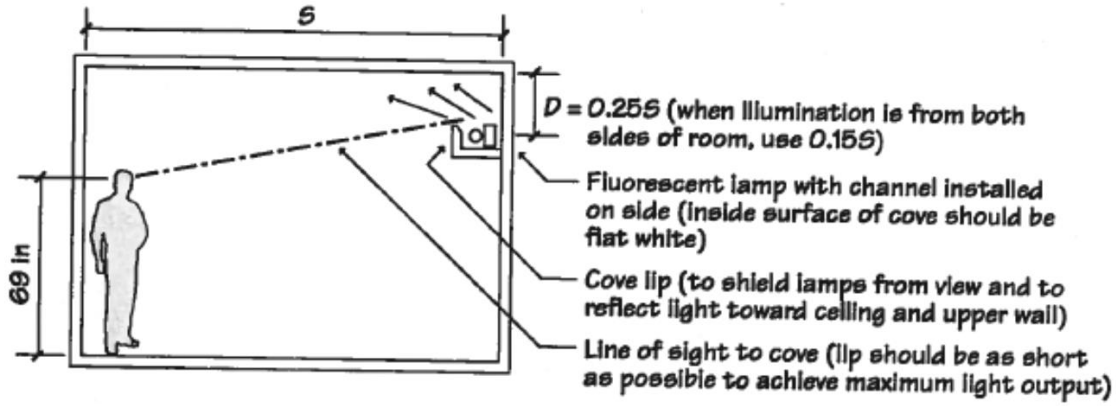
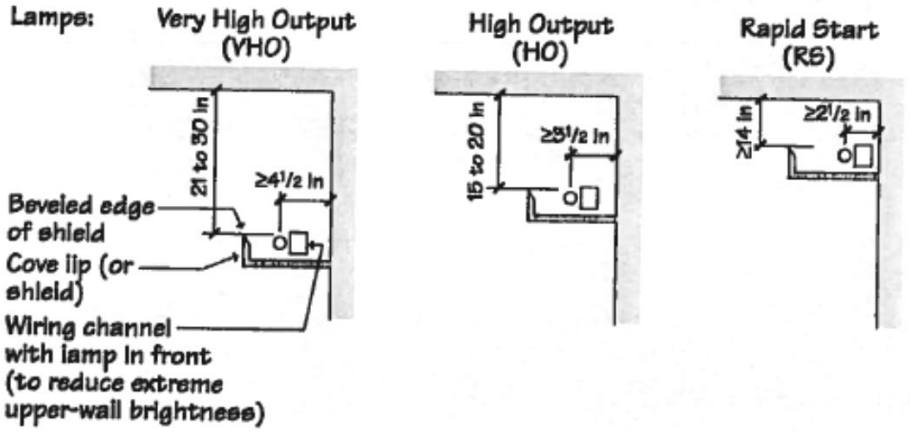
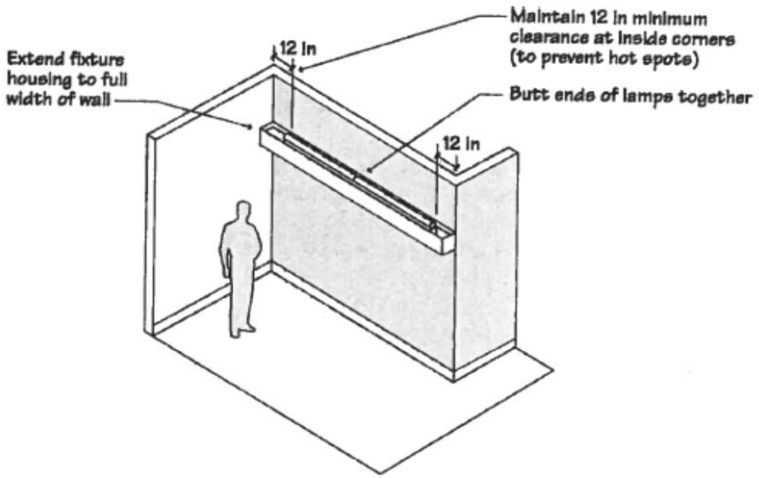
Light distribution strategies



Cove lighting: coves can be used to direct light toward ceilings, providing overall diffuse illumination, called ambient luminescence.





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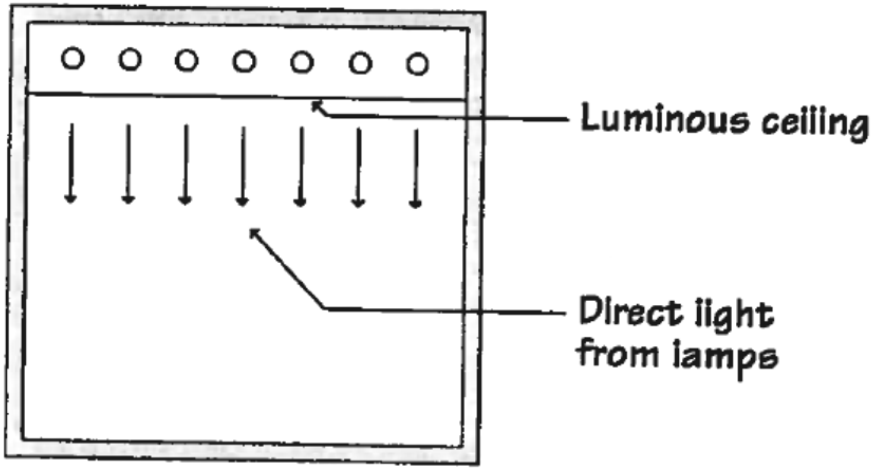
Light distribution strategies

The ceiling also can be used as a direct source of light, either as a surface on which to fasten light fixtures or, with the addition of baffles or diffusing lenses, as a single large light fixture. These continuous lensed fixture ceilings are generally referred to as *luminous ceilings*. Luminous ceilings can provide extremely even illumination on horizontal planes. However, since they are usually the brightest element in the space (even at very low luminance), the ceiling will be emphasized to the exclusion of objects of visual interest, such as artwork or horizontal tasks.



Direct Light from Luminous Ceiling

Ceiling as a source of direct light

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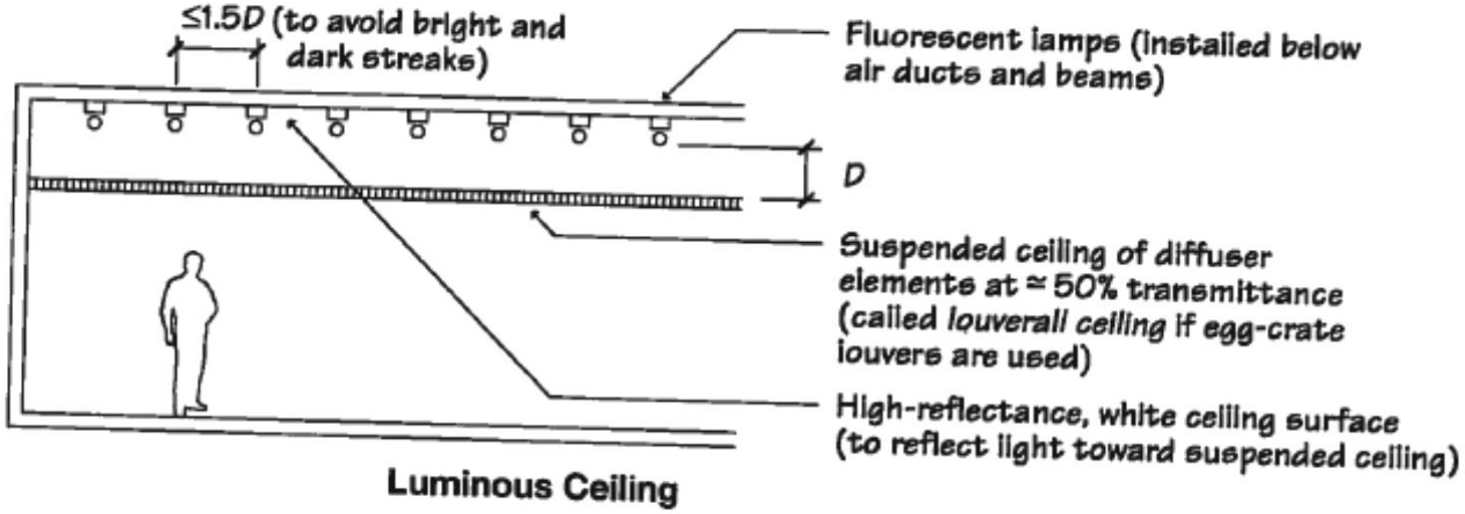
Light distribution strategies



Luminous ceiling: provide even illumination at low luminance; it appears visually as an overcast sky at low elevation, can be dull and gloomy due to its static nature. It often emphasize maintenance problems by showing dirt and uneven joints. It can be used to conceal mechanical services and structural elements.

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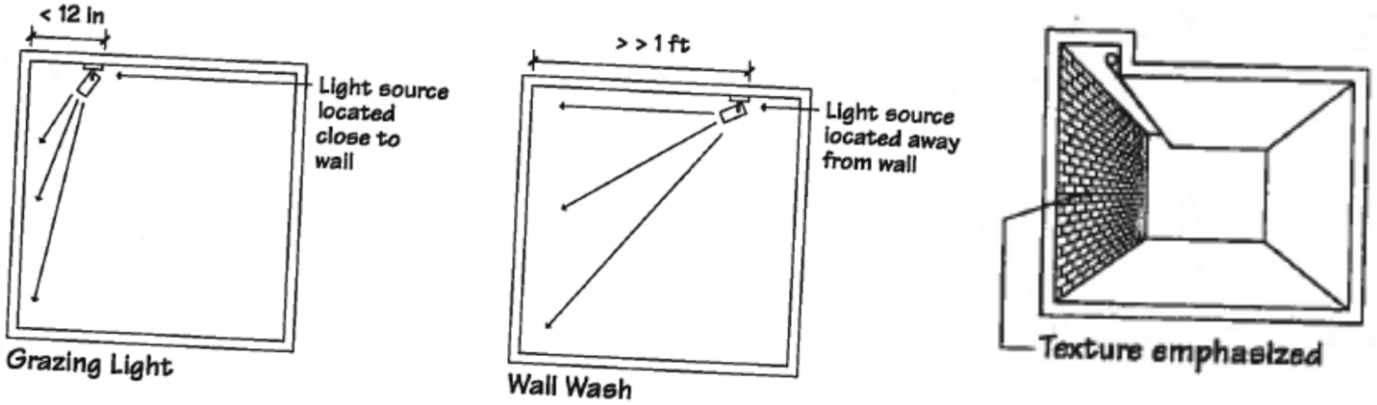
Light distribution strategies

Illuminated walls:
- human eye perceives vertical surfaces more readily than horizontal surfaces.
- Illuminated vertical surfaces give the impression of a larger space
- Illuminated walls are most effective as a source of indirect illumination when the surface has a light, matte finish;
- it can be a source of glare when highly reflective surfaces are lit



Wall washing: a smooth even distribution of light over a wall; luminaire located 12” or more away from the wall; the farther away the luminaire, the flatter and more even the wall will appear

Grazing light: located within 6 to 12”; emphasizes the wall texture;

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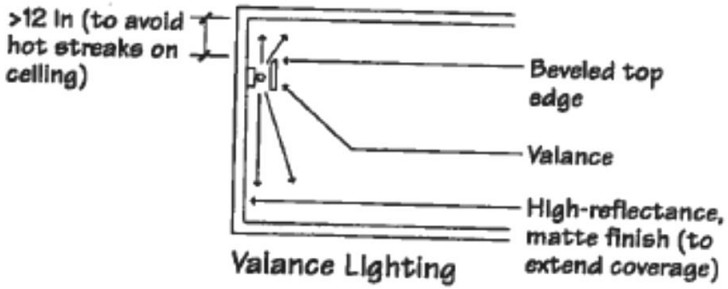
Light distribution strategies

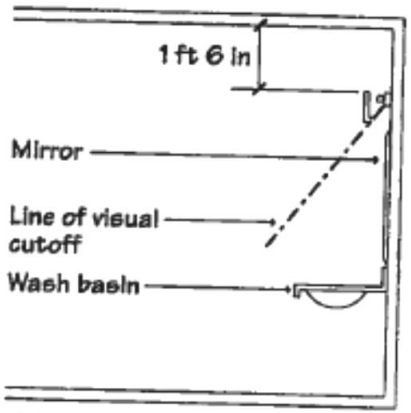
Line sources for illuminating walls: Valance and cornice lighting

Valance Lighting: Because valance lighting illuminates above and below the shielding board, both the ceiling and the wall are lighted.

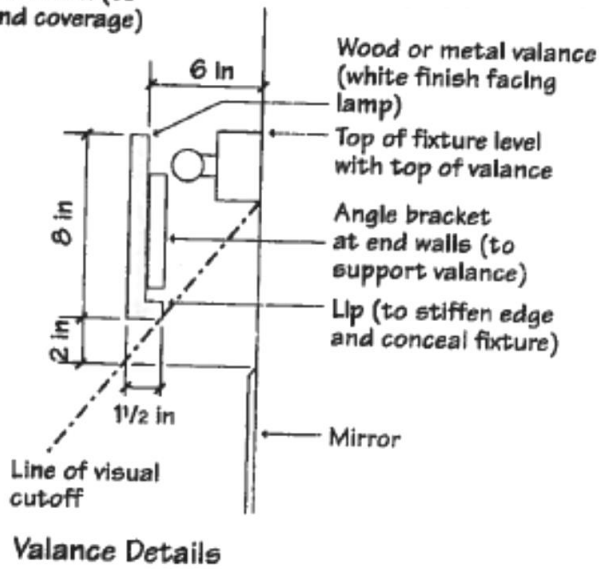
1. Size valance to completely shield light sources from view.
2. Locate valance at least 12 in below ceiling to avoid excessive ceiling brightness.
3. Extend valance the full length of the wall.
4. Butt the ends of the lamps together for maximum uniformity of illumination.
5. Leave a minimum of 12 in between lamps and end walls to avoid hot spots.



Valance Lighting



Valance Above Mirror



Valance Details

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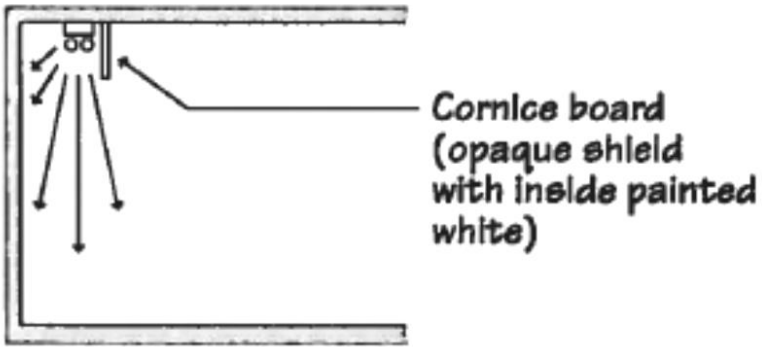
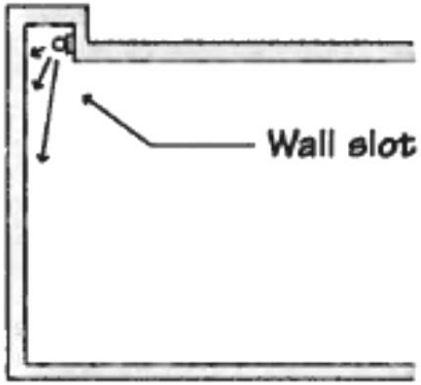
Light distribution strategies

Cornice and Wall Slot Lighting: Cornice lighting illuminates the wall below the fixture. Excessive brightness ratios occur when the wall is much brighter than the ceiling. Shadows behind the cornice lamp shielding board can be lessened if the wall and other surfaces are light in color and bounce some light up to the ceiling. Specular wall materials such as polished marble may act as a mirror to reflect the lamp image and cause glare. Use a matte finish material from at least 12 in below the slot or cornice up to the fixture.

Wall slots are cornices which are recessed into the ceiling. This seamlessly integrates lighting and architecture. Wall slots can have the pleasant effect of making the ceiling appear to float free from the wall.





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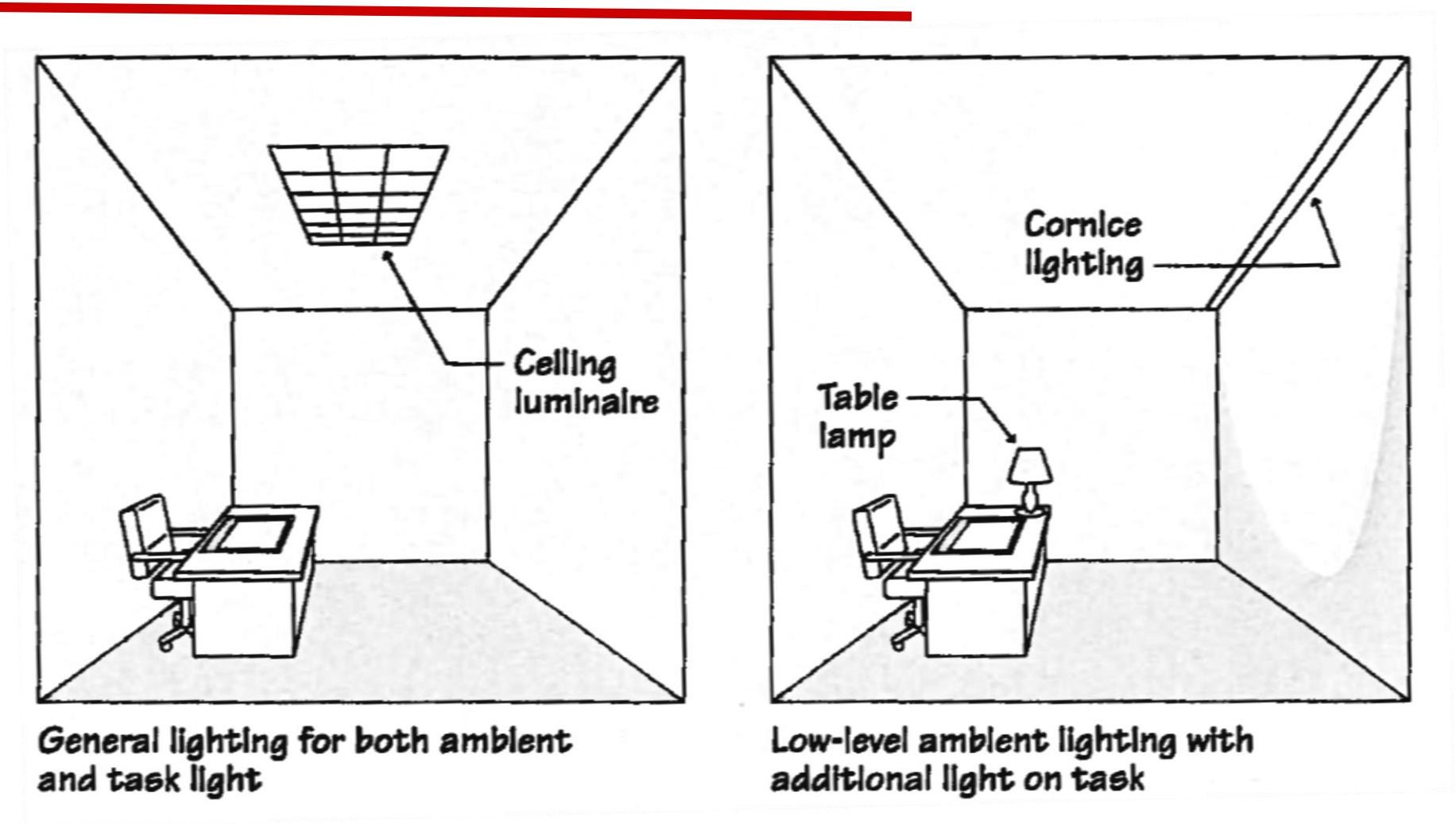
Building applications: office lighting

- **Tasks**: a wide variety of tasks i.e. written communication, telephone conversation, reading, work at computers and conferences. It is best to respond to the illumination needs of each task individually, rather than assume that a single solution will work for all tasks.
- **Lighting**:
  - ambient light should be generally uniform but also provide visual relief and spatial definition
  - Avoidance of glare: locating light source behind the task or to the side will minimize reflected glare; vertical surfaces require different lighting than horizontal surfaces; reflected glare can be lessened by indirect lighting
- **Daylight**: best integrated with indirect uplighting system, where a high-reflectance ceiling can become the primary source of indirect illumination

Building applications: office lighting



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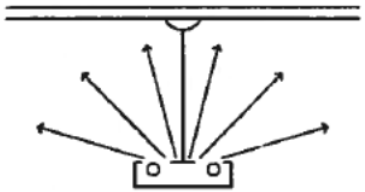
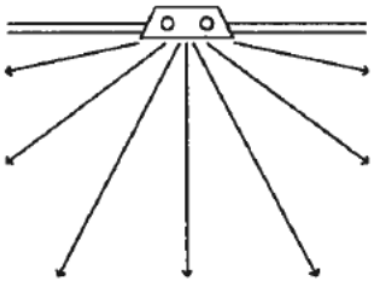
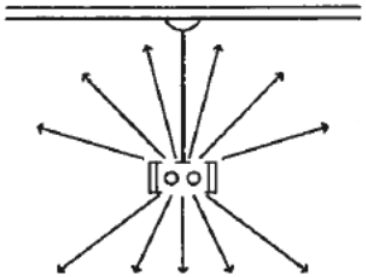
Comparison Chart for Office Lighting







	Indirect	Direct	Direct/Indirect
Emphasis on:	Ceilings	Work surfaces (desks, tables) and floors	Balanced (bi-directional light)
Compatibility with VDTs:	Good (limit ceiling brightness to <80 cd/ft^2)	Medium (limit fixture brightness to <80 cd/ft^2 at 65° from vertical)	Very good (balance brightnesses of ceiling and underside of fixture, and limit brightness of downward component to <80 cd/ft^2)
Glare potential:	Low (underside of fixture should be light-colored finish)	High (when lenses and diffusers are too bright)	Medium (shield downward component)
Other characteristics:	• Hot spots on ceiling if fixtures spaced too far apart • Softens sharp shadows • Can be monotonous	• De-emphasizes ceiling • Can cause sharp shadows • Scallop prone	• Can balance brightness of fixture and ceiling • Hot spots on ceiling if fixtures are poorly located

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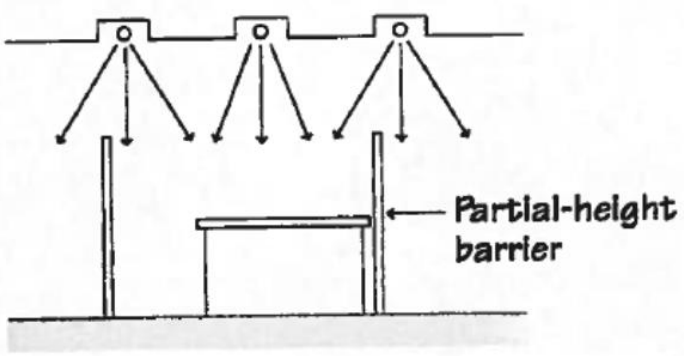
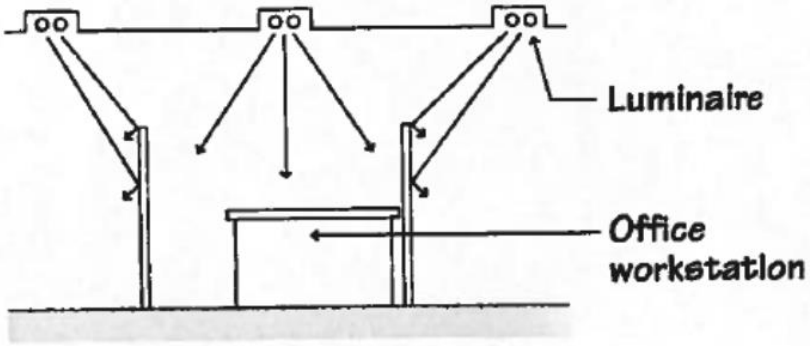
Guideline for office lighting

1. Fixture spacing affects light level and uniformity. For best results with downlights, be sure fixtures are not too widely spaced.



Preferred Luminaire Spacing



Luminaire Spacing Too Wide

2. Use appropriate surface reflectances by following recommendations of IESNA.

IESNA Recommendations for Offices

Surface	Reflectance (%)
Ceiling	>80
Walls	50 to 70
Floor	20 to 40
Partition	40 to 70
Furniture	25 to 45

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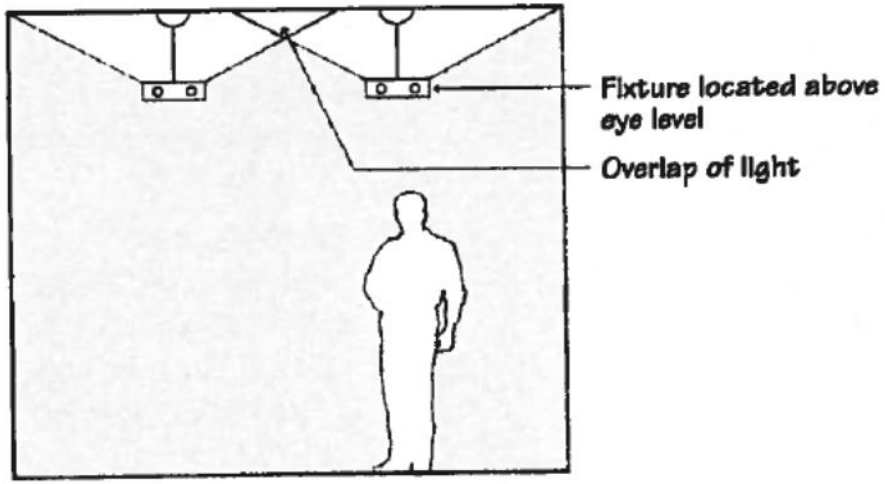
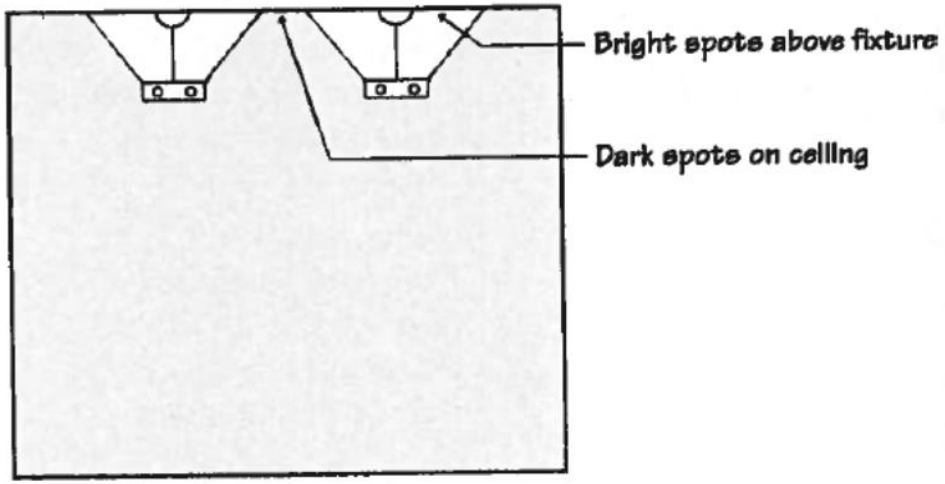
Guideline for office lighting

3. For good uniformity, layout indirect fixtures to have overlapping beam spreads. Uniform lighting tends to reduce unwanted contrast. Contrast between ceiling and luminaires should not exceed 8:1 (4:1 is preferred).



Good Uniformity



Poor Uniformity

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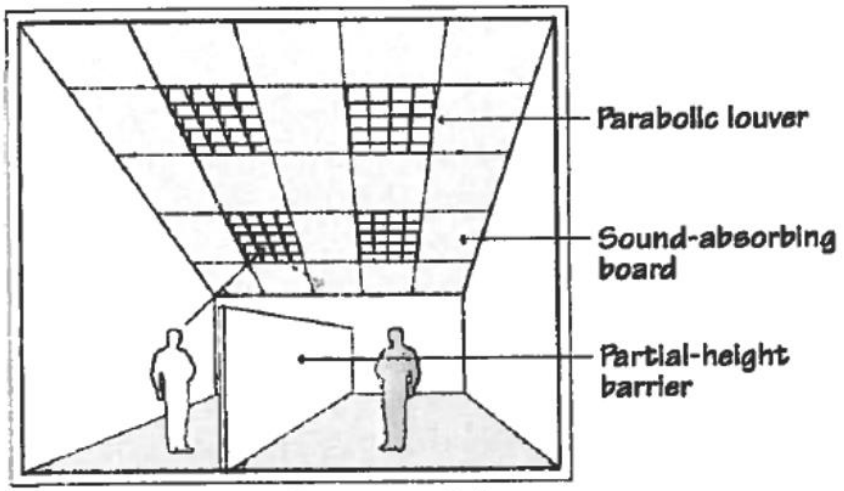
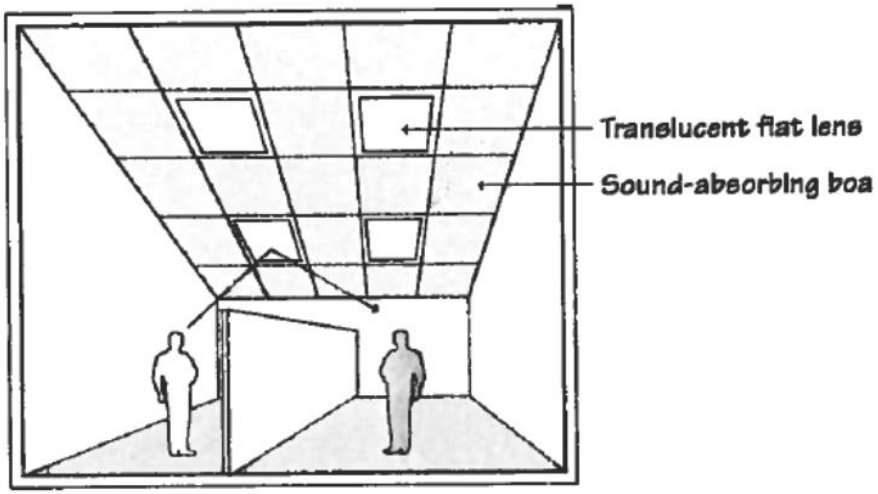
Guideline for office lighting

4. When acoustical privacy is required in open-plan offices, use deep-cell parabolic fixtures or indirect lighting. Hard surfaces such as lensed luminaires can reflect sound over partial-height barriers, destroying acoustical privacy.



Acoustical Privacy (from speech for seated persons)



Poor Acoustical Privacy

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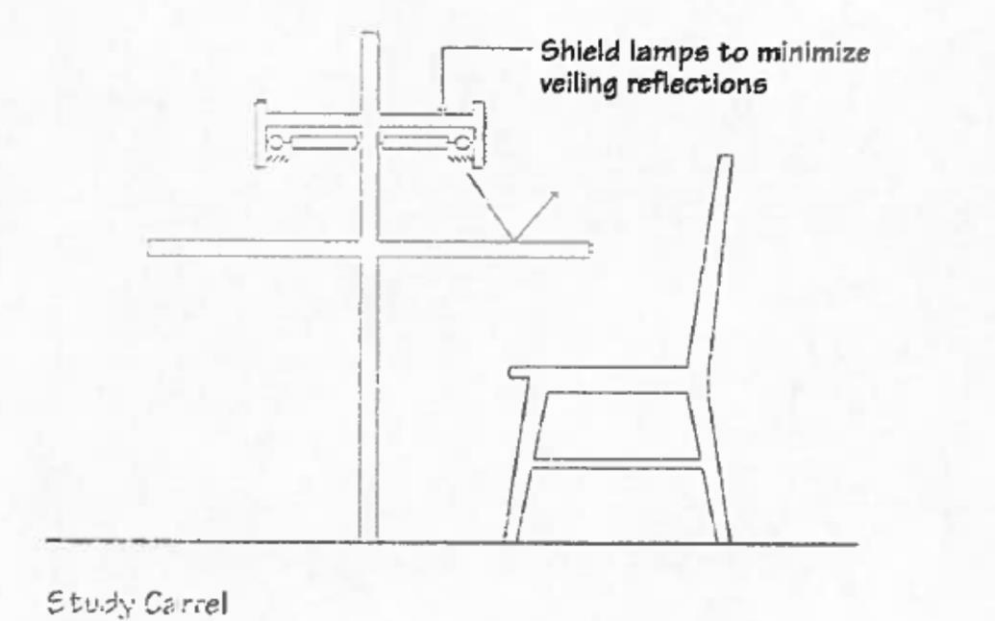
Library lighting

- A wide variety of lighting needs such as reading areas, office and circulation, exhibits and displays, and computer workstations. Two areas specific to libraries which requires special attention are: the study carrels and the book stacks.



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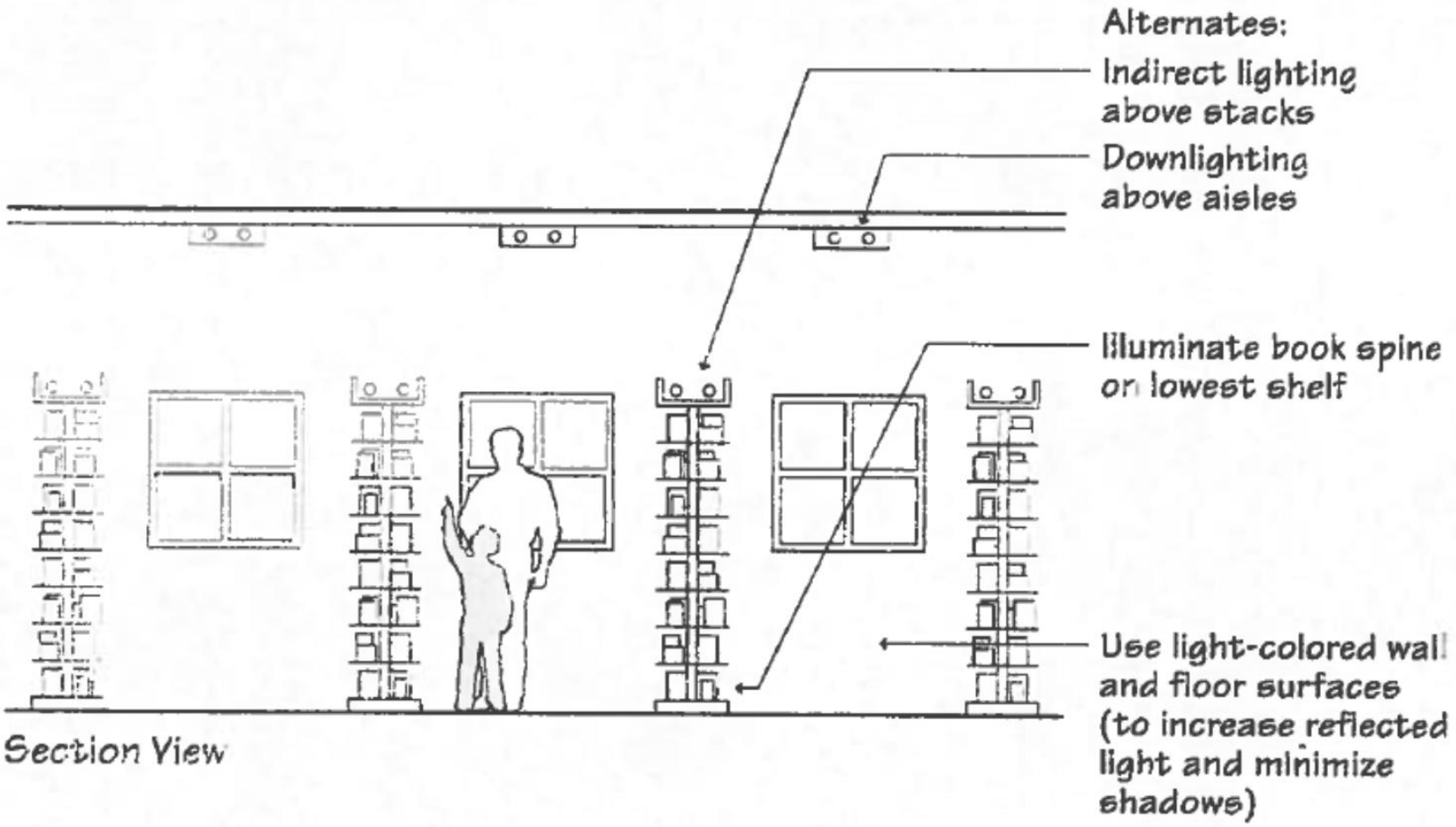
Library lighting



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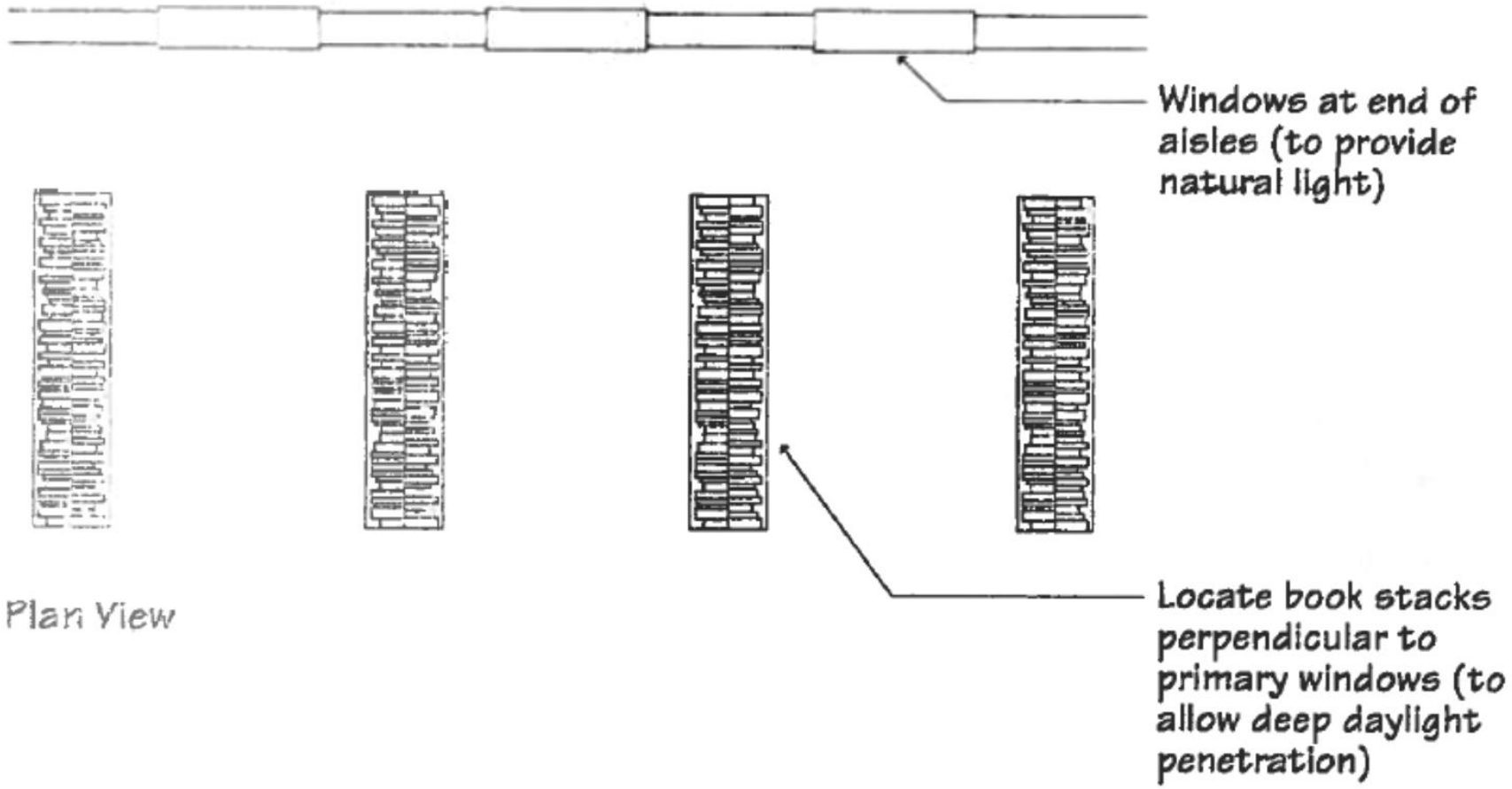
Library lighting



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Residential lighting

- **Light sources**: lighting is used to provide an appropriate atmosphere, crate a comfortable environment and help create moods
  - There are many diverse tasks in residence, most tasks are not critical. Flexibility in light placement and level control is important, uniformity is undesirable
  - Residential light levels tend to be low, which encourages use of warm color lamps

- **Daylight**: can be used to provide the majority of the ambient daytime illumination

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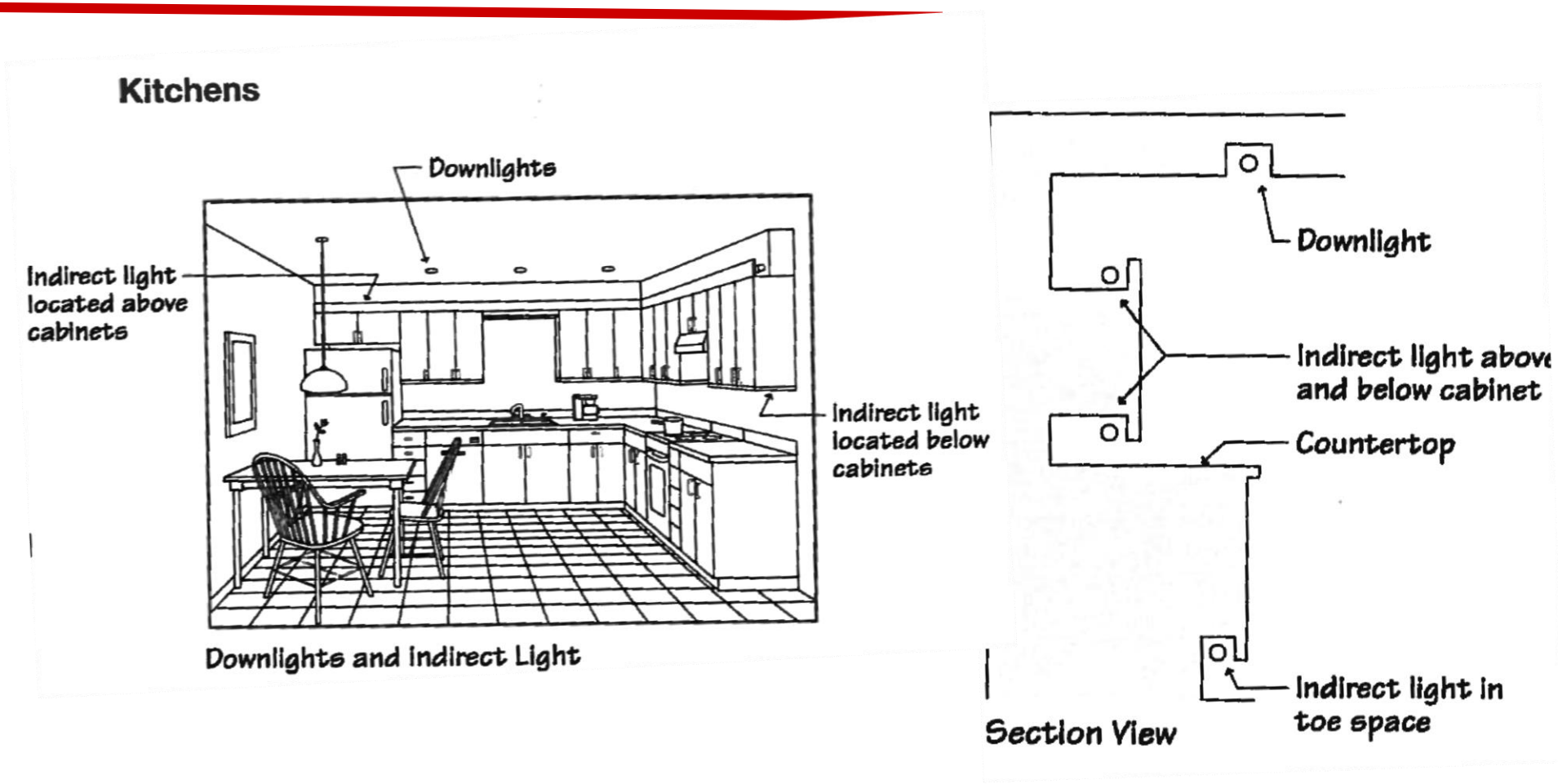
Residential lighting



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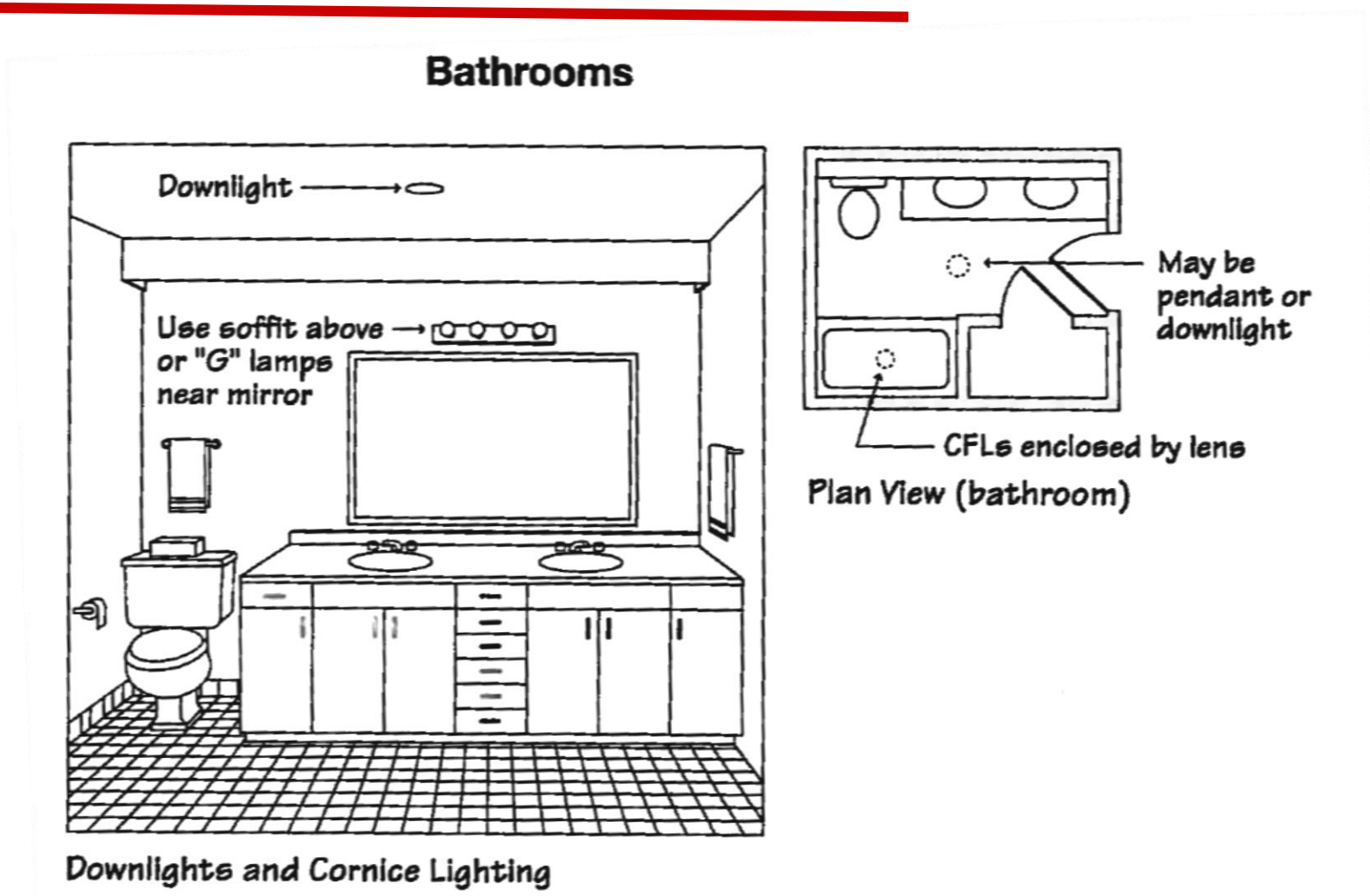
Residential lighting



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- P. C. Sorcar, 1987. Architectural Lighting for commercial interiors. John Wiley & Sons. TH7900S67