Ch.16 Electric lighting design

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16.1 Big picture

- The design of an electric lighting system → the selection of lamps and luminaires of adequate number to meet the owner's project requirements (OPR).
- Conformance to the OPR for any proposed design solution → checked by manual or computerized analysis methods.
- Even though manual methods are increasingly less likely to be used in an office, manual (hand) methods are the focus of discussion in this chapter. Three reasons for this →
  - First, a manual method requires an explicit engagement with all important variables since they are unavoidably seen in the equations that represent the method.
  - Second, computerized software is often proprietary and set up as a black box—the workings of the software are often opaque.
  - Third, there are many lighting design software packages available, each with differences from the others.

16.2 Philosophy

- Lighting design is a combination of art and science (architectural engineering).
- The goal of lighting is to create an efficient and pleasing interior.
- The lighting designer should approach each problem with an open mind, bringing to it knowledge of current technology, as well as necessary background and experience
- An owner or designer is seldom satisfied with a carbon copy system from a previous design

16.3 Lighting design objectives

- Light can and should be used as a primary architectural material. Some underlying design objectives are:
  - Illuminance should be adequate for efficient seeing of the particular task involved. (시작업에 필요한 충분한 조도)
  - Lighting equipment (luminaires, etc.) should be unobtrusive, but not necessarily invisible. (야단스럽거나 요란하지 않은 조명기구, 그리고 반드시 감춰질 필요는 없음)
  - Lighting must have the proper quality and be deemed appropriate by users.
  - The lighting outcomes must be efficient in terms of cost and energy use and respectful of resources. Cost should be life-cycle cost (acquisition plus operation); energy should consider both cost and resource consumption. → This will be addressed in Project IV

Lighting design procedure

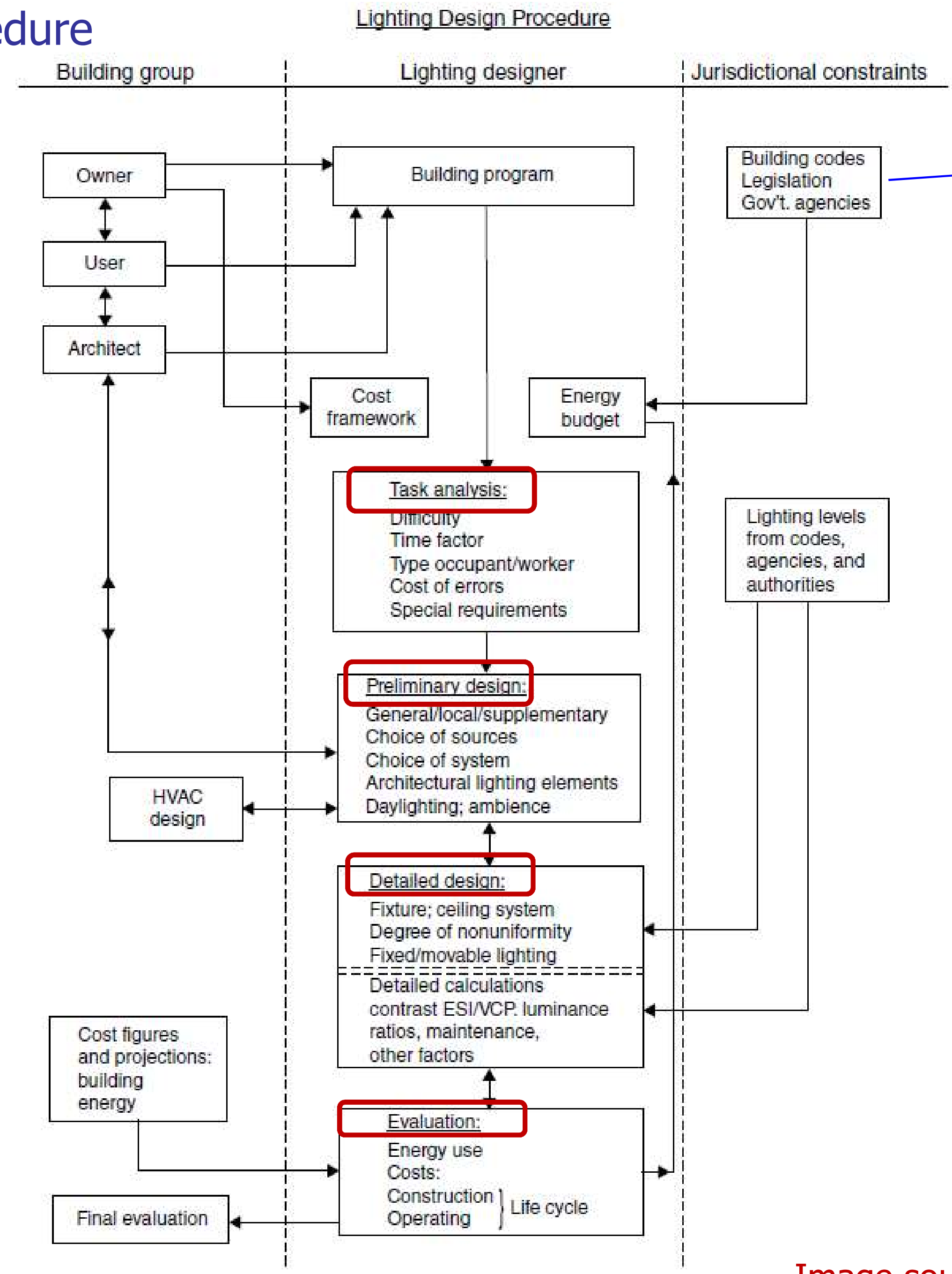


Fig. 15.1 Lighting design procedure chart.

DOE, GSA, NFPA, ASHRAE, IESNA, NIST

Image source: MEEB 12th Ed.

TABLE 16.1 Overview of the Lighting Design Process

Project Phase	Key Activities	Who is Involved	Comments
Pre-Design	Develop lighting OPR	Client, users, architect, engineer, lighting designer	OPR (or equivalent) is essential to success
Design	Select approach Select components Analyze proposal Evaluate proposal and iterate as needed	Architect, engineer, lighting designer	A system is proposed, evaluated, tweaked, reevaluated, and then put into contract documents
Construction	Verify submittals Verify installation	Lighting designer	Site observation is beneficial
Occupancy	Tune systems Do a POE Assist owner	Lighting designer, owner, users	Close the design loop by confirming in the field that OPR are met

Lighting OPR: issues, intent, criteria

- Lighting design issues
  - simply expressed as nouns that identify things related to lighting that should be considered during the design process.
  - Examples:
    - first cost, operating cost, flexibility, energy efficiency, maintainability, durability
- Lighting design intent
  - to convert each identified issue into a general direction to be pursued on the project
  - Examples:
    - Low first cost (or perhaps regional-average first cost)
    - Code-minimum energy efficiency (or perhaps exceptional energy efficiency)
    - Easily maintained (or perhaps maintained with some difficulty)

Lighting OPR: issues, intent, criteria

- Lighting design criteria
  - To convert the direction suggested by design intents into specific design targets (desired destinations)
  - usually quantitative and numeric but can be nonnumeric.
  - Examples
    - Code-minimum lighting power density (LPD)
    - LPD 10% less than code minimum
    - LPD 20% less than code minimum
    - Lamp luminous efficacy of 80 or more
    - Lamp luminous efficacy of 100 or more
    - Luminaire TER (Target Efficacy Rating) value of 40 or greater

16.6 Light distribution approach

- Uniform illuminance
  - to provide uniform, and generally diffuse, lighting throughout the area under consideration (e.g. a classroom with movable desks or an open plan office → the task may be located anywhere, thus this approach is appropriate)

- Local illuminance
  - light is only delivered to a task of limited size located in a larger space
  - rarely be found acceptable due to glare caused by excessive contrast
  - potentially very energy efficient, while being visually ineffective due to discomfort.

16.6 Light distribution approach

- Supplemental illuminance
  - This is used where some high-lux tasks are found in a space with generally lower illuminance demands.
  - Uniform illuminance is provided for the space in general but is supplemented with additional light at the more demanding task locations.
  - glare potential is reduced by reducing contrast.
  - Fig. 16.1 shows typical supplementary lighting units
- Task-ambient illuminance
  - "task-ambient" means different things to different people.
  - Specifically refers to light delivered by a luminaire designed to provide both uniform and supplemental light components. A luminaire becomes part of the furniture layout of a space.
  - Although not common, this lighting approach can be architecturally interesting (freeing the ceiling from luminaires)

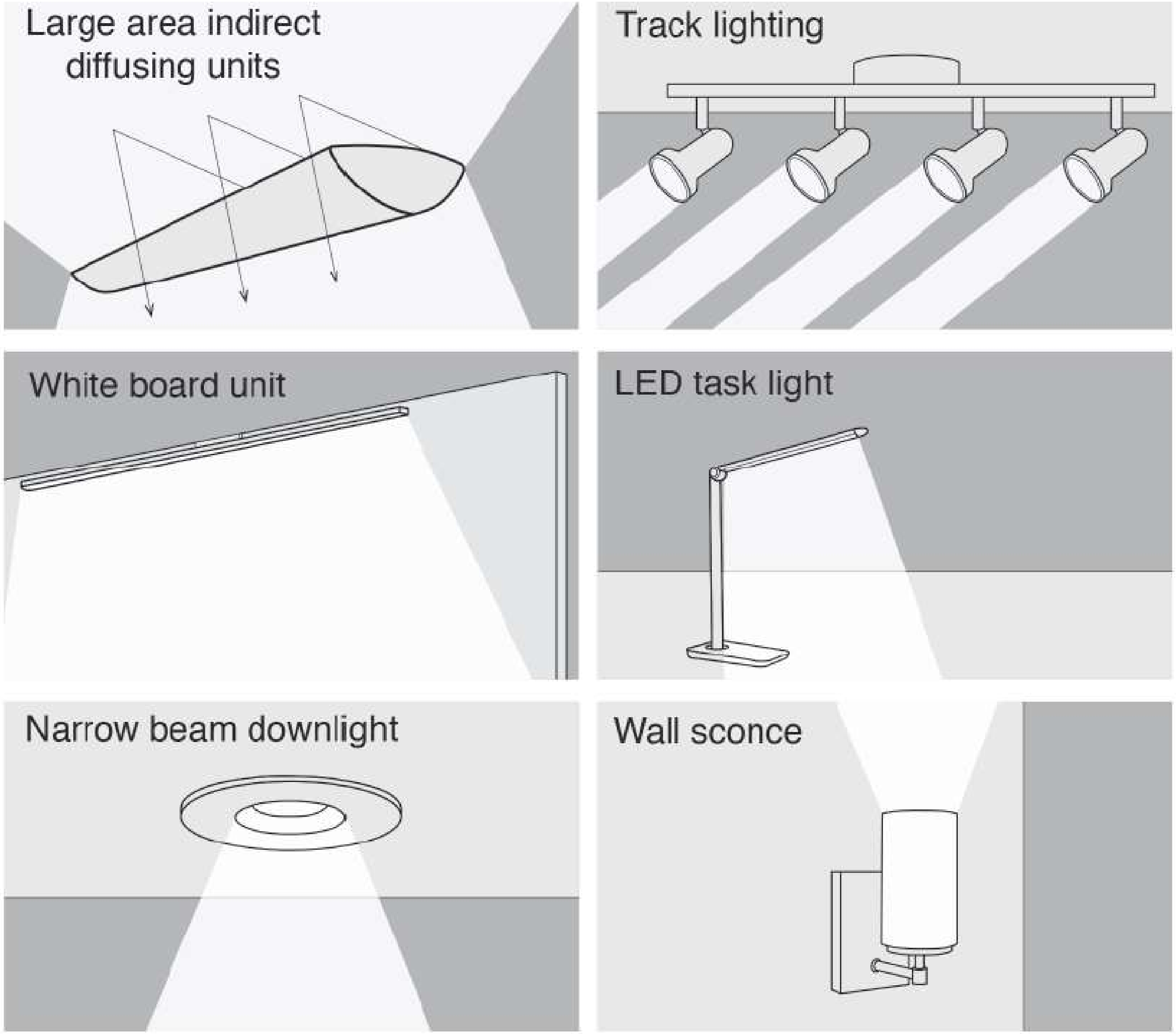
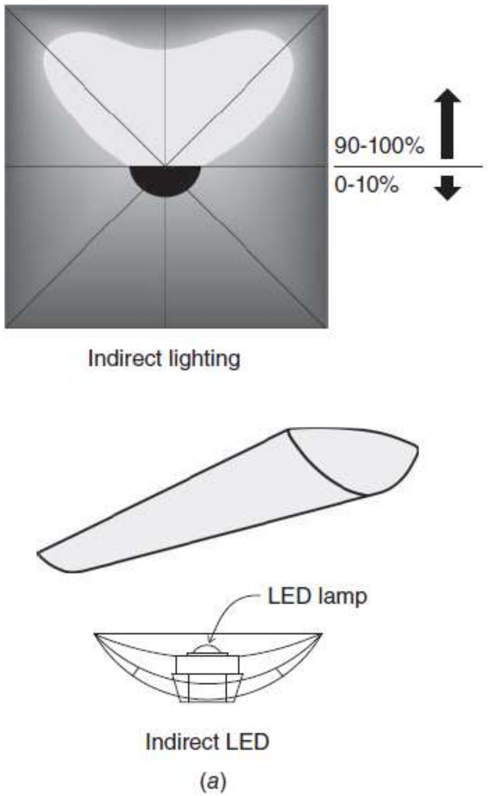


Fig. 16.1 Typical supplementary lighting units for incandescent, CFL, and linear fluorescent sources. (Drawn by Kelli Kimura; © Alison Kwok; all rights reserved.)

Light delivery options: Indirect delivery

- Between 90% and 100% of the light output of the luminaires (see Fig. 16.2a) is directed toward the ceiling and upper walls of the room.
- Practically all the light reaches a horizontal working plane indirectly, that is, via reflection from the ceiling and upper walls.
- The ceiling and upper walls become a secondary light source → high reflectance finishes. (Fig.16.2b)



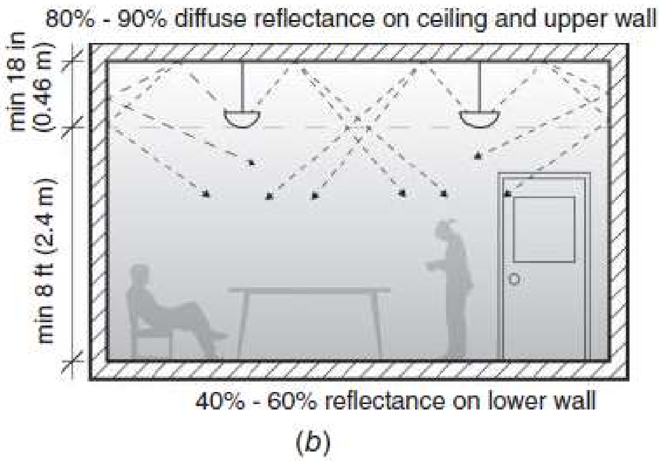


***Fig. 16.2** Indirect lighting. (a) The luminaires deliver 90–100% of their output above their own horizontal plane. The ceiling and upper wall surfaces of the space are directly illuminated, and by reflection become large secondary sources that illuminate the space below. When properly designed, this type of installation yields a substantially uniform bright ceiling. (b) Indirect delivery of light to a space involves multiple reflections from multiple surfaces and, if properly designed, provides nearly uniform, glareless illumination in the room. This type of delivery is particularly useful in spaces with digital screens. (Drawn by Kelli Kimura.)*

Indirect delivery

- The source must be suspended at least 12 in. (300 mm, single-lamp luminaire), and preferably 18 in (general). (450 mm) or more (24-36”) from the ceiling (depending on the fixture output) in order to avoid ceiling “hot spots,” this system requires a minimum ceiling height of 9 ft 6 in (2.85m).
- Indirect lighting is inherently inefficient, because much of the useful light reaches the working plane only after at least two reflections—within the luminaire and off the ceiling/upper wall.

Indirect delivery

- Approximately 750 lux (75 fc) is the maximum horizontal-plane illuminance attainable without exceeding an *overall* ceiling luminance of about 2,500 cd/m^2
  - Why 2,500cd/m^2 → a target limit for avoidance of direct glare
- If luminaires are correctly spaced, the resulting illuminance is uniform, and direct and reflected glare potentials are minimal.
- Indirect lighting is inherently inefficient but this inefficiency is offset by the glare-free nature of the indirect lighting.

Indirect delivery: applications

- The lack of shadow, low source brightness, and highly diffuse quality created by indirect lighting give a very quiet, cool ambience to a space, suitable for private offices, lounges, and waiting areas.
- Areas having specular visual tasks, such as an office with digital screens, use this system to great advantage. In such spaces, indirect fixtures *without* luminous bottoms or sides should be specified.

Semi indirect delivery

- 60-90% of the light toward the ceiling and upper walls of the room (see Fig.16.3)
- The ceiling remains the principal light source, and the diffuse character of room lighting remains.
- With both indirect and semi-indirect systems, it is often desirable to add accent lighting or downlighting to break the monotony inherent in these systems and establish visual points of interest.

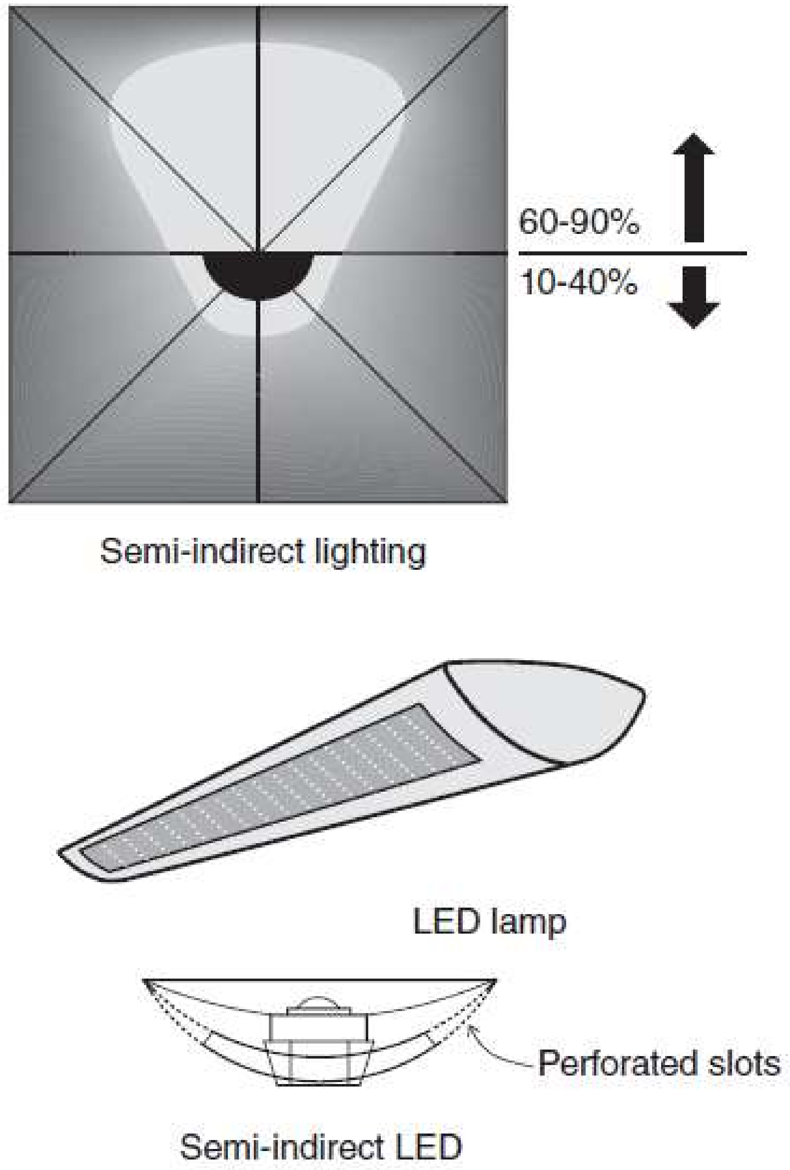


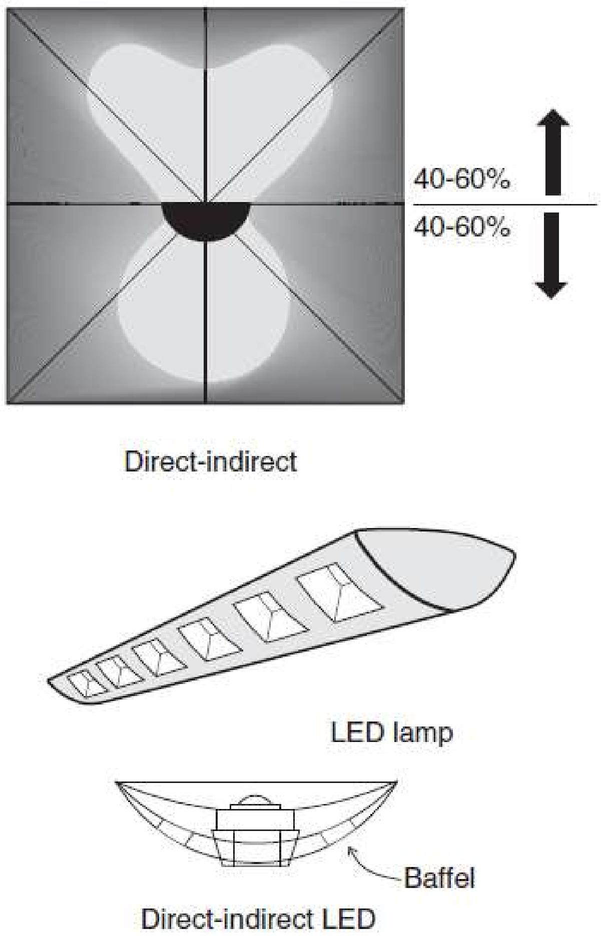
Fig. 16.3 Semi-indirect lighting. (Drawn by Kelli Kimura.)

Note

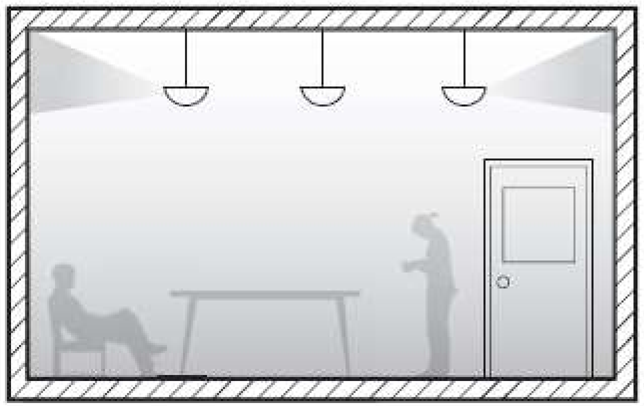
- The light in both indirect and semi-indirect lighting systems undergoes a number of ceiling and wall reflections before reaching the horizontal working plane.
- The use of colored paints, particularly on the ceiling, can serve to tint the room illumination slightly via selective absorption—to either good or bad effect, depending upon the space in question.

Direct-Indirect delivery

- an approximately equal distribution of light upward and downward, resulting in a fairly bright ceiling and upper wall



(*a*)



(*b*)

Fig. 16.4 *(a) Direct–indirect lighting. Upper and lower room surfaces are luminous, but the center of walls is not because of the lack of horizontal light output from fixtures (b). Most of the light on the working plane comes directly from the luminaire. (Drawn by Kelli Kimura.)*

General diffuse delivery

- This distributes light in all directions, whereas direct–indirect fixtures have little or no horizontal component.
- Suspension distances for direct-indirect & general diffuse should be adequate (generally not less than 12 in. [300 mm]) to avoid excessive ceiling brightness and hot spots.

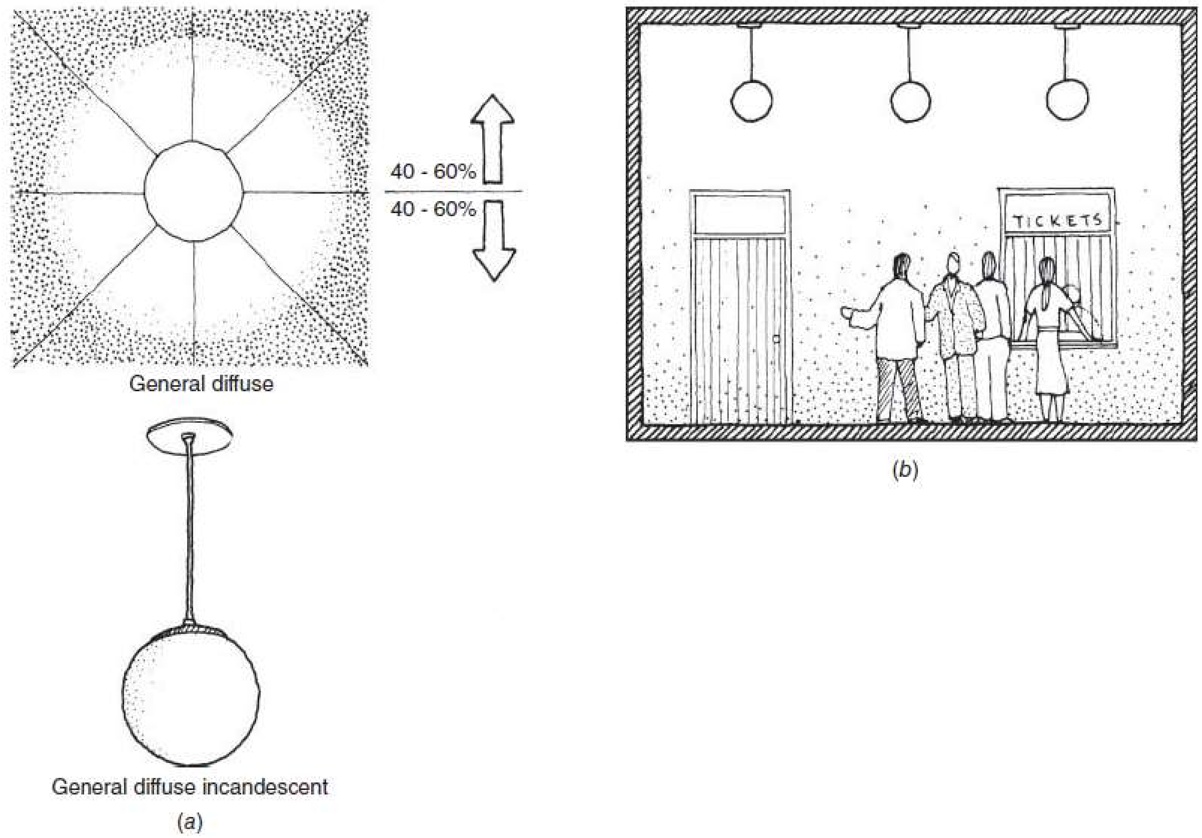


Fig. 16.5 (a) General diffuse lighting. (b) Note that all room surfaces are illuminated and become secondary sources, although those closest to the fixtures (ceiling, upper wall) are the brightest secondary sources. The primary source of illumination is the direct radiation from the fixture. The floor contribution to work plane illuminance is nominal due to its normally low reflectance.

Office, Fresh Vaxjo Sweden (2008.02)

Office, Fresh Vaxjo Sweden (2008.02)

2F, The Orlando Int’l airport (2010.01)

2F, The Orlando Int'l airport (2010.01)

- 1F, 2F plans are identical
- Depending on lighting system, luminous and architectural environment is quite different from each other
- 2F: luminaires too close to the ceiling (wrong design!!)
- 1F: use of downlights (yellow color)

2F, The Orlando Int'l airport (2010.01)

2F, The Orlando Int'l airport (2010.01)

1F, The Orlando Int'l airport (2010.01)

1F, The Orlando Int'l airport (2010.01)

Semi direct delivery

- 60-90% of the light directed downward
- the upward component is normally enough to minimize direct glare from the luminaires, depending on eye adaptation level.

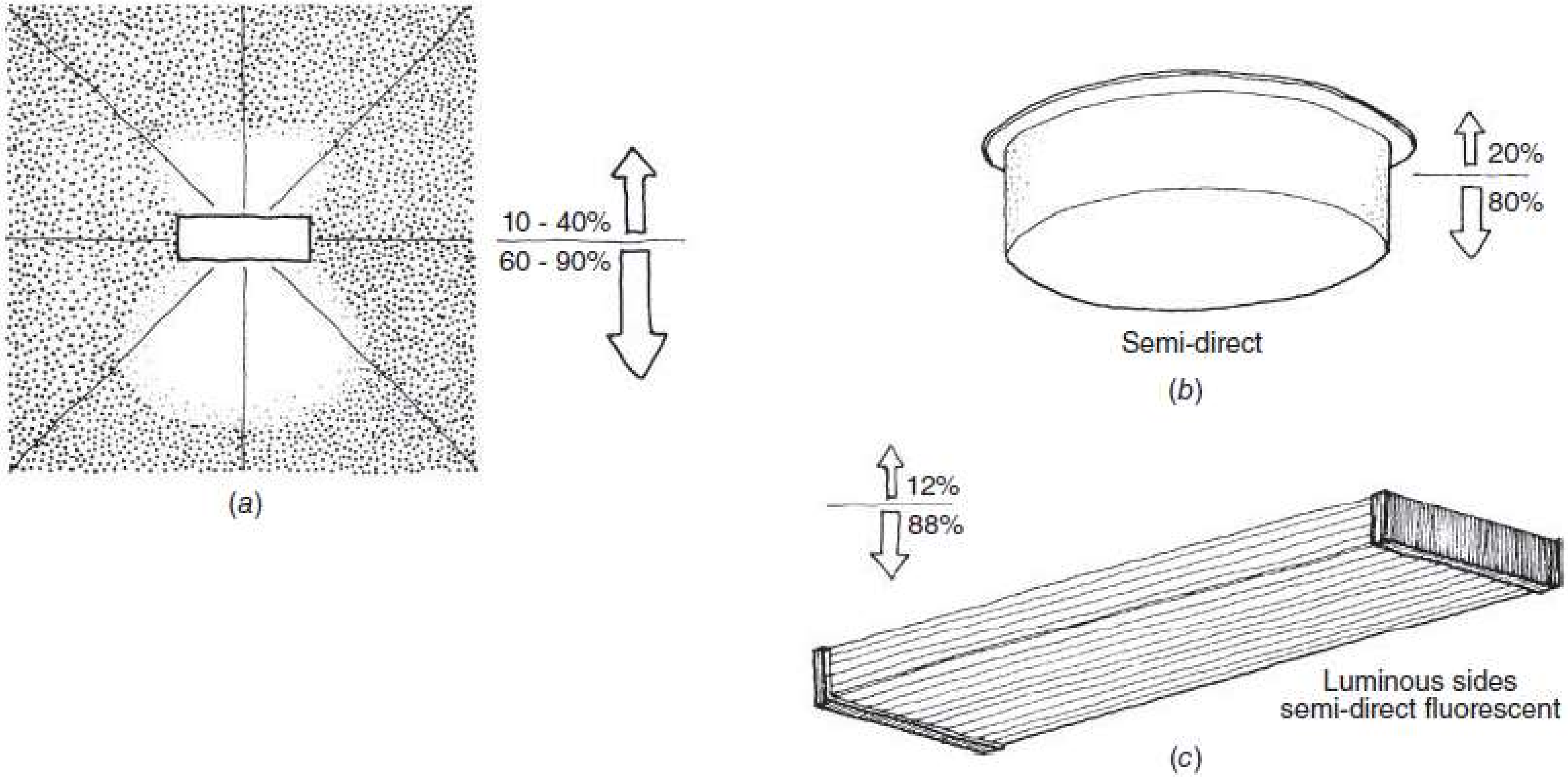


Fig. 16.6 Semi-direct light delivery provides its own ceiling brightness (a), with surface-mounted fixtures (b) or pendant/surface units (c) as illustrated. Other characteristics are like those for direct delivery.

Direct delivery

- 90-100% of the light downward
- Spread type (Fig.16.7) vs concentrating type (Fig.16.8)
- The effect of direct lighting depends greatly on whether the luminaire light distribution is spread out or concentrated.
- Direct glare and veiling reflections may arise under direct lighting.

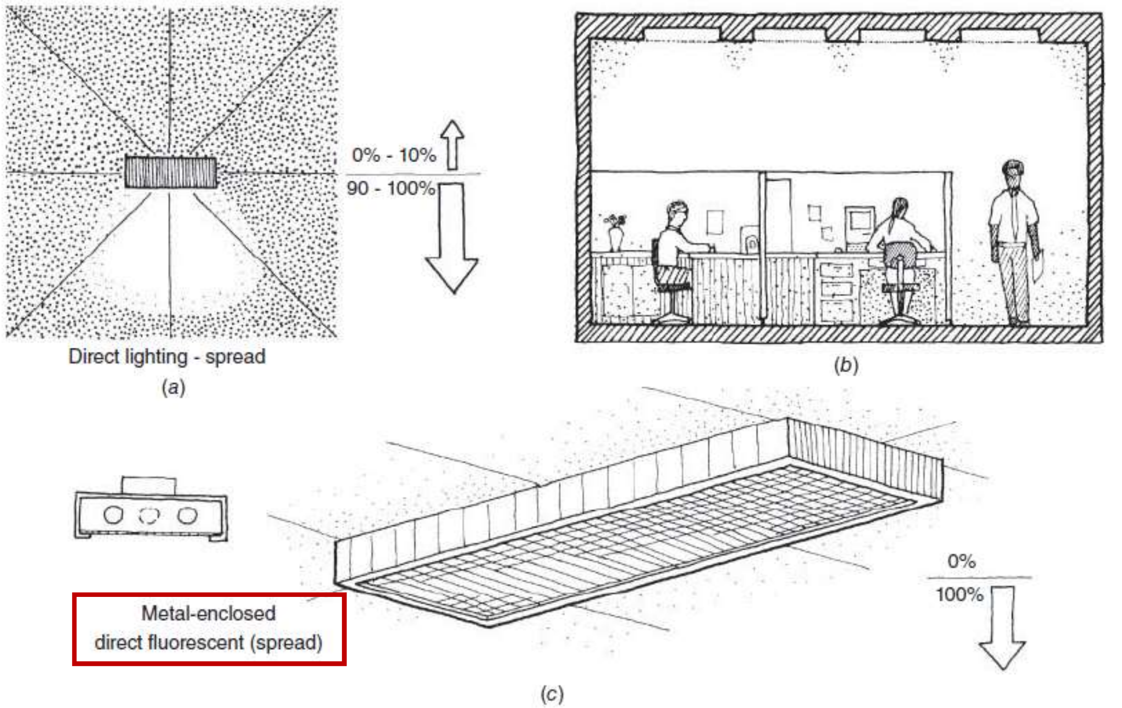


Fig. 16.7 Spread-type direct light delivery (a) illuminates all room surfaces except the ceiling, which is only illuminated by reflection from the floor. Some diffuseness is evident. The most common fixture in this category is the direct fluorescent unit, either troffer-type, recessed in the ceiling (b), or surface-mounted (c).

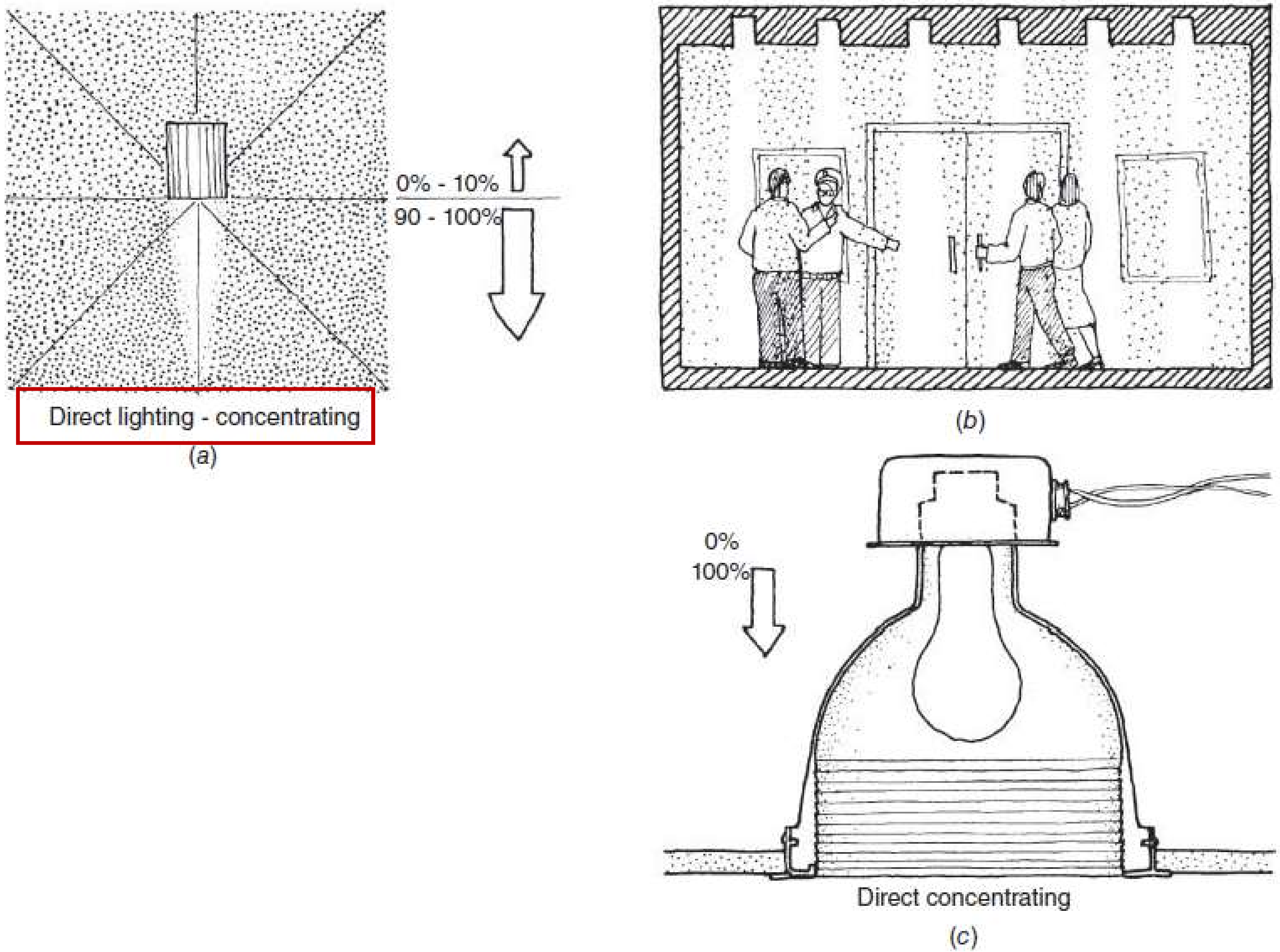


Fig. 16.8 *(a) With concentrated direct delivery, the floor is the only luminous surface (b) other than the ceiling fixture. Diffuseness is absent. Walls are dark. Incandescent downlights (c) and, to a lesser extent, CFL downlights are of this type unless equipped with spread-type lenses.*

spread vs. concentrating

- Spread type: suitable for general lighting (office)
- Concentrating type: creating sharp shadow and a theatrical environment, thus used for highlights, local and supplementary lighting, and specialized privacy-atmosphere installations.
- Fig.16.9(a), (b): equal illuminance. The apparent illuminance in (b) greater due to wall wash in the background.

spread

Concentrating

(*a*) (*b*)

Fig. 16.9 *Large-dimension lighting fixtures may be used in a low-ceilinged room if the apparent sizes of the units can be reduced. Here at a mounting height of 7.5 ft (2.3 m), 4 ft × 4 ft (1.2 × 1.2 m) units are acceptable because the lattice on the face of each unit gives the impression of reduced fixture size. Note also that the apparent illuminance in (b) is greater than in (a) although both are exactly equal on the table surface because of the wall wash in the background. The eye perceives vertical surface illuminance more readily than horizontal illuminance and retains the impression for the entire space.*

Illuminance targets

- Illuminance levels:
  - Tremendous efforts have been made to answer: "How much light must I provide for the specific visual task at hand?"
- Extensive tests determined the conditions under which small differences in contrast could be detected for specific degrees of accuracy, under variable task luminance, size, and exposure time.
- The idea behind the tests was that visual acuity could be defined as the ability to distinguish differences in contrast.
- Visual task studies indicate that, assuming good contrast, required luminances for various categories of tasks, are roughly as follows:

Category of Visual Task	Required Luminance cd/m^2 (fl)
Causal	10–20 (3–6)
Ordinary	20–100 (6–29)
Moderate	100–200 (29–58)
Difficult	200–400 (58–117)
Severe	Above 400 (117)

Illuminance and luminance

- Recommended Illuminance was derived from luminance values by IESNA.
  - $L(cd/m^2) = E * \rho / \pi$ (in SI unit)

Assuming uniform, diffuse task reflectance and uniform illuminance

$$L = \frac{E \times RF}{\pi}$$

Category of Visual Task	Required Luminance cd/m² (fl)
Causal	10–20 (3–6)
Ordinary	20–100 (6–29)
Moderate	100–200 (29–58)
Difficult	200–400 (58–117)
Severe	Above 400 (117)

Category of Visual Task	Required E lux[a] (fc)	
	R = 50%	R = 10%
Casual	62–125 (6–12)	300–625 (28–58)
Ordinary	125–625 (12–58)	625–3125 (58–290)
Moderate	625–1250 (58–116)	3125–6250 (290–580)
Difficult	1250–2500 (116–230)	6250–12,500 (580–1161)
Severe	>2500 (230)	>12,500 (1161)

E (lux)	RF	Luminance (cd/m2)
500	0.7	111.4
500	0.5	79.6
500	0.1	15.9

A single illumination scheme is often inadequate !!

Remark

- Several reservations about this process of developing recommended task illuminances have been voiced by researchers.
- These will not be addressed in the textbook, but they suggest that the IESNA illuminance recommendations are best seen as guidelines and not as set-in-stone doctrine.

Illuminance recommendations

- Three factors: task characteristics, task importance (described in the previous slide, e.g. causal, ordinary, moderate, difficult, severe), and observer characteristics (in the form of “visual age” of the observers).
- In Table 16.2, lettered categories (A-Y) progress from less demanding, primarily exterior lighting applications to highly demanding, primarily interior applications.

IESNA illuminance recommendations

TABLE 16.2 Recommended Illuminance Categories

Category		*Recommended Illuminance Targets lux (fc) Visual Ages of Observers (years) where at least half are*			Some Typical Application and Task Characteristics
		<25	25 to 65	>65	
INTERIOR and EXTERIOR applications	A[a]	0.5 (.05)	1 (0.1)	2 (0.2)	Dark adapted situations
	B[a]	1 (0.1)	2 (0.2)	4 (0.4)	Basic convenience situations Very-low-activity situation
	C[a]	2 (0.2)	4 (0.4)	8(0.7)	Slow-paced situations Low-density situations
	D[a]	3 (0.3)	6 (0.6)	12 (1.1)	Slow-to-moderate-paced situations
	E[a]	4 (0.4)	8 (0.7)	16 (1.5)	Moderate-to-high-density situations
	F[a]	5 (0.5)	10 (1)	20 (2)	Moderate-to-fast-paced situations
	G[a]	7.5 (0.7)	15 (1.4)	30 (3)	High-density situations
	H[a]	10 (1)	20 (2)	40 (4)	Some indoor very subdued circulation situations Some indoor social situations
INTERIOR and EXTERIOR	I[a]	15 (1.4)	30 (3)	60 (6)	Congested and significant outdoor intersections, important decision-points, gathering places, and key points of interest Some indoor social situations Some indoor commerce situations
INTERIOR and EXTERIOR applications	J[b]	20 (2)	40 (4)	80 (8)	Some outdoor commerce situations
	K[b]	25 (2.5)	50 (5)	100 (10)	Some indoor social situations
	L[b]	37.5 (3.5)	75 (7)	150 (15)	Some indoor commerce situations
	M[b]	50 (5)	100 (10)	200 (18.58)	
	N[b]	75 (7)	150 (15)	300 (30)	
	O[b]	100 (10)	200 (20)	400 (40)	
	P[c]	150 (15)	300 (30)	600 (60)	Some indoor social situations Some indoor education situations Some indoor commerce situations Some indoor sports situations
	Q[c]	200 (20)	400 (40)	800 (80)	Some indoor education situations
	R[c]	250 (25)	500 (50)	1000 (100)	Some indoor commerce situations
	S[c]	375 (37)	750 (75)	1500 (150)	Some indoor sports situations Some indoor industrial situations
	T[d]	500 (50)	1000 (100)	2000 (200)	Some sports situations
	U[d]	750 (75)	1500 (150)	3000 (280)	Some indoor commerce situations
	V[d]	1000 (100)	2000 (200)	4000 (380)	Some indoor industrial situations
	W[e]	1500 (150)	3000 (280)	6000 (560)	Some sports situations Some indoor industrial situations Some health care procedural situations
INTERIOR applications	X[e]	2500 (235)	5000 (470)	10000 (930)	Some health care procedural situations
	Y[e]	5000 (470)	10000 (930)	20000 (1860)	

Source: Illuminating Engineering Society of North America, *The Lighting Handbook*, 10th ed. © 2011; used with permission. The I-P unit soft conversions were developed by the authors of this book.

[a]Orientation, relatively large-scale, physical (less-cognitive) tasks—visual performance is typically not work-related, but related to dark sedentary social situations, senses of safety and security, and casual circulation based on landscape, hardscape, architecture, and people as visual tasks.

[b]Common social activity and large and/or high-contrast tasks—visual performance involves higher-level assessment of landscape, hardscape, architecture, and people and can be work related.

[c]Common, relatively small-scale, more cognitive or fast-performance visual tasks—visual performance is typically daily life- and work-related, including much reading and writing of hardcopies and electronic media consecutively and/or simultaneously.

[d]Small-scale, cognitive visual tasks—visual performance is work- or sports-related, close and distant fine inspection, very small detail, high-speed assessment and reaction.

[e]Unusual, extremely minute and/or life-sustaining cognitive tasks—visual performance is of the highest order in respective fields of health care, industrial, and sports.

A sample of IESNA illuminance recommendations for a library: targets for horizontal surfaces (E_h) and vertical surfaces (E_v) are organized by task and visual ages of the users.

TABLE 16.3 Library Facility Illuminance Recommendations

		Recommended Maintained Illuminance Targets Lux (fc)							
		Horizontal (E_h) Targets				*Vertical (E_v) Targets*			
		Visual Ages of Observers (years) where at least half are				*Visual Ages of Observers (years) where at least half are*			
Application and Tasks	**Notes**	**Category**	**<25**	**25–65**	**>65**	**Category**	**<25**	**25–65**	**>65**
Book Lending—Book Stacks									
General[3]	E_h @ floor of book stacks proper	O	100 (10)	200 (20)	400 (40)				
Shelving @ 2′6″ (760 mm) AFF[a]	E_h and E_v @ front face of shelving	P	150 (15)	300 (30)	600 (60)	O	100 (10)	200 (20)	400 (40)
Lending Desk									
Self-service[a]	E_h @ 2′6″ (760 mm) AFF; E_v @ 5′ (1.5 m) AFF	P	150 (15)	300 (30)	600 (60)	M	50 (5)	100 (10)	200 (20)
Staffed[a]	E_h @ 2′6″ (760 mm) AFF; E_v @ 5′ (1.5 m) AFF	R	250 (25)	500 (50)	1000 (100)	O	100 (10)	200 (20)	400 (40)
Periodicals									
Shelving @ 1′0″ (305 mm) AFF	E_v @ front face of shelving					M	50	100 (10)	200 (20)
Computer Center[a]	CSA/ISO Type I and II positive polarity screens. E_h @ 2′6″ (760 mm); E_v @ 4′ (1.2 m) AFF	P	150 (15)	300 (30)	600 (60)	M	50 (5)	100 (10)	200 (20)
Reading Areas									
Grand Reading Room[a]	E_h @ 2′6″ (760 mm) AFF; E_v @ 4′ (1.2 m) AFF	R	250 (25)	500 (50)	1000 (100)	O	100 (10)	200 (20)	400 (40)
Stack Reading Areas[a]	E_h @ 2′6″ (760 mm) AFF; E_v @ 4′ (1.2 m) AFF	R	250 (25)	500 (50)	1000 (100)	M	50 (5)	100 (10)	200 (20)
Study Carrels[a]	E_h @ 2′6″ (760 mm) AFF; E_v @ 4′ (1.2 m) AFF	R	250 (25)	500 (50)	1000 (100)	O	100 (10)	200 (20)	400 (40)
Tables and Chairs[a]	E_h @ 2′6″ (760 mm) AFF; E_v @ 4′ (1.2 m) AFF	R	250 (25)	500 (50)	1000 (100)	O	100 (10)	200 (20)	400 (40)
Special Collections									
Archival Storage	E_h and E_v @ 3′ (910 mm) AFF	P	150 (15)	300 (30)	600 (60)	M	50 (5)	100 (10)	200 (20)
Rare Books	E_h and E_v @ 3′ (910 mm) AFF	P	150 (15)	300 (30)	600 (60)	M	50 (5)	100 (10)	200 (20)

Source: Illuminating Engineering Society of North America, *The Lighting Handbook*, 10th ed. © 2011; used with permission. The I-P unit soft conversions were developed by the authors of this book.

[a] Combination of daylighting and electric lighting strategies can be employed to achieve target values during daylight hours. Daylighting may require unconventional approaches.

Note

- The IESNA recommended illuminance values are not directly applicable to installations where a visual task is not the deciding factor (e.g., lighting for safety, mood, merchandizing, theater, display, etc.)

Detailed design procedure of the zonal cavity method

- Step 1: Selection of luminaires
  - Based on CDC, CU, luminance between 45° and 85°, VCP, LER, S/MH
- Step 2: calculation of the number of luminaires
  - Lumen method, Flux method: simplest and most applicable
- Assumptions
  - the space is empty
  - all surfaces are perfect diffusers
  - All surface reflectances are estimates, usually with an accuracy of no more than ±10%.
  - Maintenance conditions are prognoses of future actions, at best ±10% accurate

Zonal cavity method (1)

- the zonal cavity method also called the lumen method
- Calculation for the *average* maintained illuminance on the working plane
- Presupposition: luminaires will be spaced so that the illumination is uniform over the space.
- Procedures
  - Lux (fc) = lumens/area (m^2, ft^2)
  - Lumens on the working plane = lamp lumens * CU
  - Initial illuminance (E) = lamp lumens * CU / area
    - CU provided by the manufacturer
    - In the absence of the CU: approximation using the generic fixture types in Table 16.1 (from MEEB 12^{th} Ed.)
  - Maintained illuminance (E) = lamp lumens * CU * LLF/ area
    - LLF: effect of temperature and voltage variations, dirt accumulation on luminaires and room surfaces, lamp output depreciation, maintenance conditions

Lumen method (2)

- Maintained E = lamp lumens * CU * LLF/ area
  - Lamp lumens = No. of luminaires * lamps per luminaire * initial lumens per lamp
- No. of luminaires = Maintained E * Area / (lamps per luminaire * initial lumens per lamp * CU * LLF)
- For large areas:
  - Area per luminaire = (lamps per luminaire * initial lumens per lamp * CU * LLF) / maintained E
  - To maintain 600 lux
    - A: 7 m^2 per luminaire
    - B: for 1,800 m^2 floor, 257 luminaires
    - A is convenient.

Calculation of LLF

- recoverable loss: can be improved by maintenance
- non-recoverable loss: can't be improved

Non-recoverable loss factors

- (a) Luminaire ambient temperature
  - fluorescent fixtures are sensitive to ambient temperature
  - For normal indoor: use 1.0.
  - For others: refer to technical data on the luminaire
- (b) Voltage
  - At the rated voltage: 1.0
- (c) Luminaire surface depreciation
  - proportional to age (not by dirt but by age)
  - Depending on the surface type.
- (d) Components
  - ballast factor, ballast-lamp photometric factor, equipment operating factor, lamp position (tilt) factor, thermal factor by the reflector.
  - In general: use 0.92
- Overall factor: (a)*(b)*(c)*(d). In general, use 0.88

Recoverable loss factors

- (e) Room surface dirt depreciation
  - Light arriving after surface reflections
  - Assuming a 24-month cleaning cycle and normal condition of cleanliness:
    - direct lighting: 0.92 $\pm$ 5%
    - semi-direct lighting : 0.87 $\pm$ 8%
    - direct-indirect lighting: 0.82 $\pm$ 10%
    - semi-indirect lighting: 0.77 $\pm$ 12%
    - indirect lighting: 0.72 $\pm$ 17%

Recoverable loss factors

- (f) Lamp lumen depreciation:
  - Two factors: the type of lamp and the replacement schedule

	Group Replacement	Replacement on Burnout
Incandescent	0.94	0.88
Tungsten–halogen	0.98	0.94
Fluorescent	0.90	0.85
Mercury-vapor	0.82	0.74
Metal–halide	0.87	0.80
High-pressure sodium	0.94	0.88
LED	0.94	0.87

- (g) Burnouts:
  - Group replacement procedures: 1.0
  - Individual replacement on burnouts: 0.95 (meaning 5% produces no output)
- Note
  - (f) accounts for lumen depreciation
  - (g) accounts for the ratio of the working lamps to the total lamps

Recoverable loss factors

- (h) Luminaire dirt depreciation (LDD)
  - With the passage of time, dirt accumulates on the lamps and the surfaces of the luminaires.
  - Depending on luminaire design, room condition, maintenance schedule
  - From the manufacturer's data or from Table 16.1 (refer to maintenance category) → Fig.16.10
  - The luminaire maintenance category for a specific fixture is obtained from the manufacturer.
  - LDD is an indication of its proneness to dirt accumulation.

LDD factor

This is the determinant (Table 16.1)

This is not the determinant. Only to show examples.

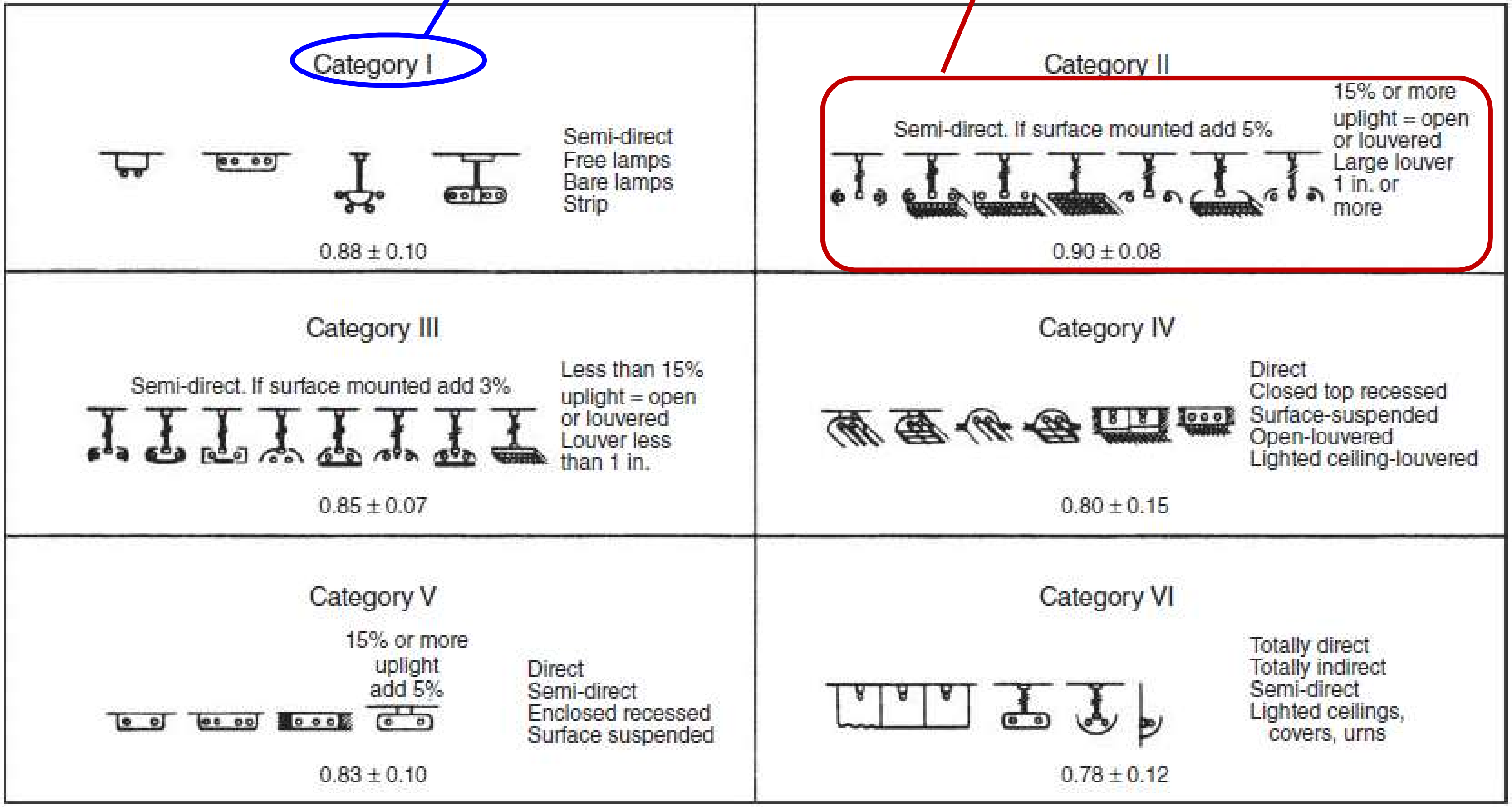


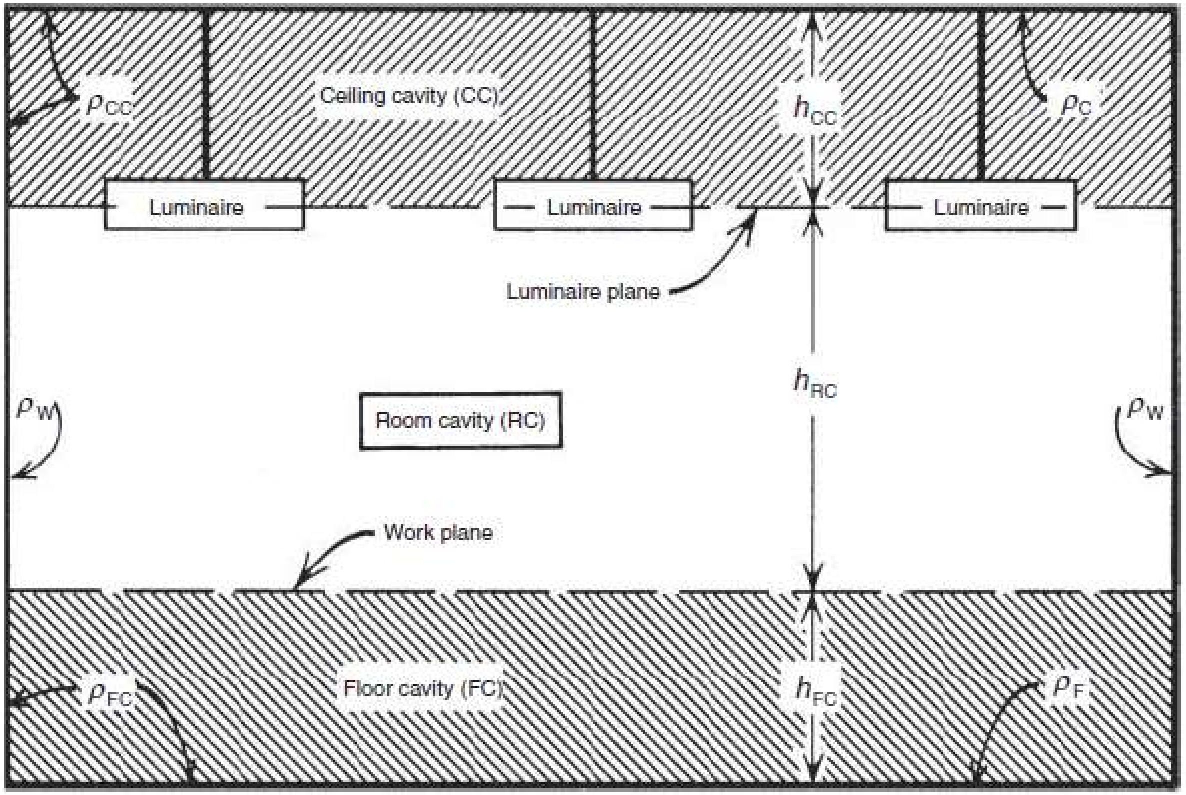
Fig. 16.10 *The LDD factor is determined from the category of luminaire (which is an indication of its proneness to dirt accumulation) plus knowledge of room ambient conditions.*

Calculation of LLF

- LLF = a * b * c * d * e * f * g * h
- Comparison
  - Case I: Fluorescent, group lamp replacement, …….. : LLF = 0.8
  - Case II: same as Case I but replacement on burnouts, no cleaning : LLF = 0.55
  - 0.55/0.8 = 0.69, 31% between Case I and Case II
- If difficult to estimate LLF: use the factors in pp. 785-786 (refer to Fig.16.14)
  - good condition=0.65
  - average condition=0.55
  - poor condition=0.45

Determination of CU by Zonal Cavity Method

- CU connects a particular fixture to a particular space (size, reflectances)
- Three cavities
  - ceiling cavity: above the fixture
  - floor cavity: below the working plane
  - room cavity: between the ceiling cavity and the floor cavity



Legend:

ρ_C = ceiling reflectance
ρ_{CC} = ceiling cavity reflectance
ρ_W = wall reflectance
ρ_F = floor reflectance
ρ_{FC} = floor cavity reflectance
h = height in feet or meters
h_{RC} = height of room cavity (etc.)

Fig. 16.11 *Room cavities as used in the zonal cavity method.*

- Work plane:
  - Offices, schools, etc.: 30″ AFF (above the finished floor)
  - Drafting rooms: 36-38″
  - Shops: 42-48″
  - Carpet stores, sail-cutting rooms: 0′
- ρ_C, ρ_W, ρ_F : Table 15.2 (MEEB 12th Ed)
- ρ_{CC}, ρ_{FC} : Table 16.5