(a) Physical arrangement

- M2 is effective (M4 is “dangerous”) (See Fig. 6.32).
- Offending zone

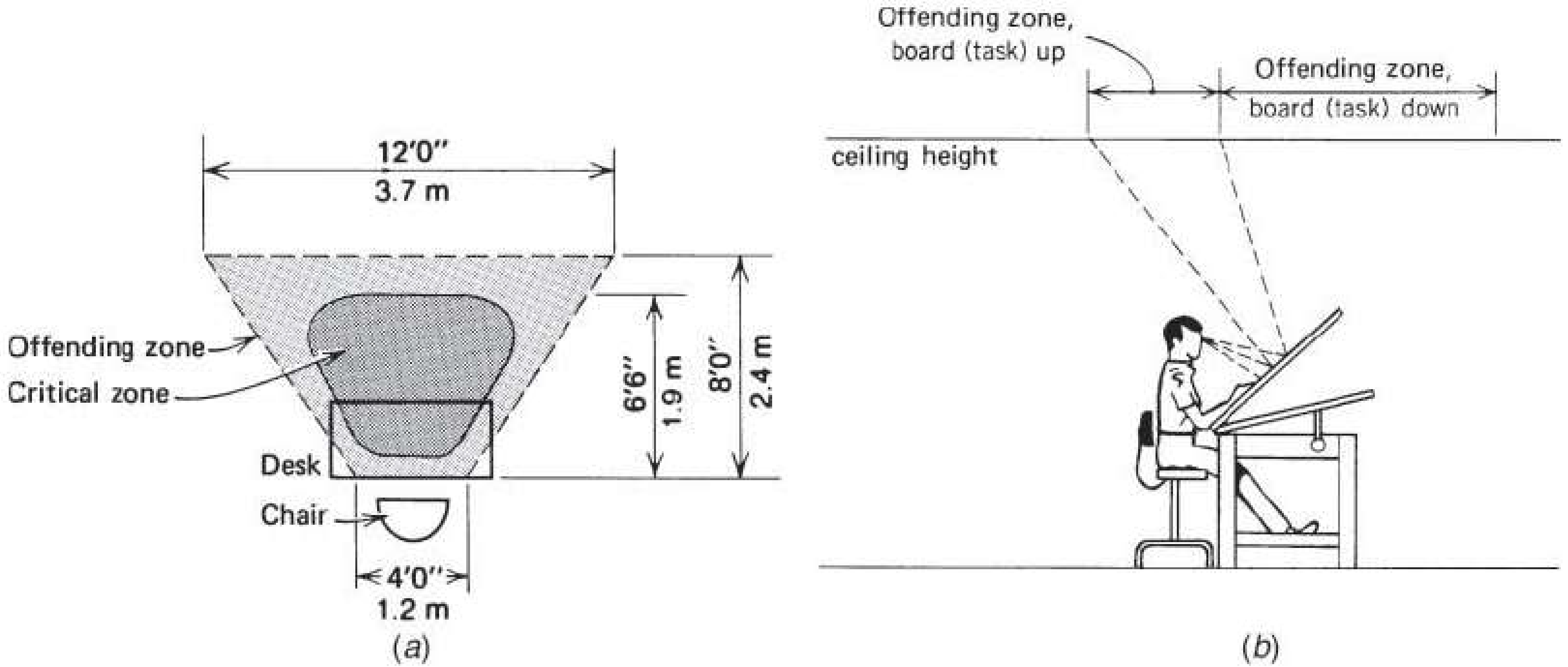


Fig. 16.24 (a) If luminaires are kept out of the trapezoidal offending zone, contrast will be excellent. If the bulk of one or more luminaires projects into this zone, especially into the critical zone, contrast will drop sharply. The dimensions shown are for a flat desk 3 ft × 5 ft (0.91 m × 1.5 m) and a 9-ft (2.7-m) ceiling height. (b) The dependence of the glare zone on table tilt is illustrated. The offending zone becomes smaller as the table is raised, so that with a table near the vertical position, glare is all but eliminated. (Ross and Baruzzini, Inc., 1975.)

Modular ceiling lighting fixture

- Fed from ceiling plug-in raceways (궤도, 트랙)
- (original) 18 fixtures, a total of 2,880W (160W/fixture), 28W/m^2, 900 lux
- (alternative) 13 fixtures, a total of 2,080W, 20.5W/m^2, 1,000 lux
- 800W reduced with an improvement in visibility

Grey-box represents rearranged lighting fixtures.

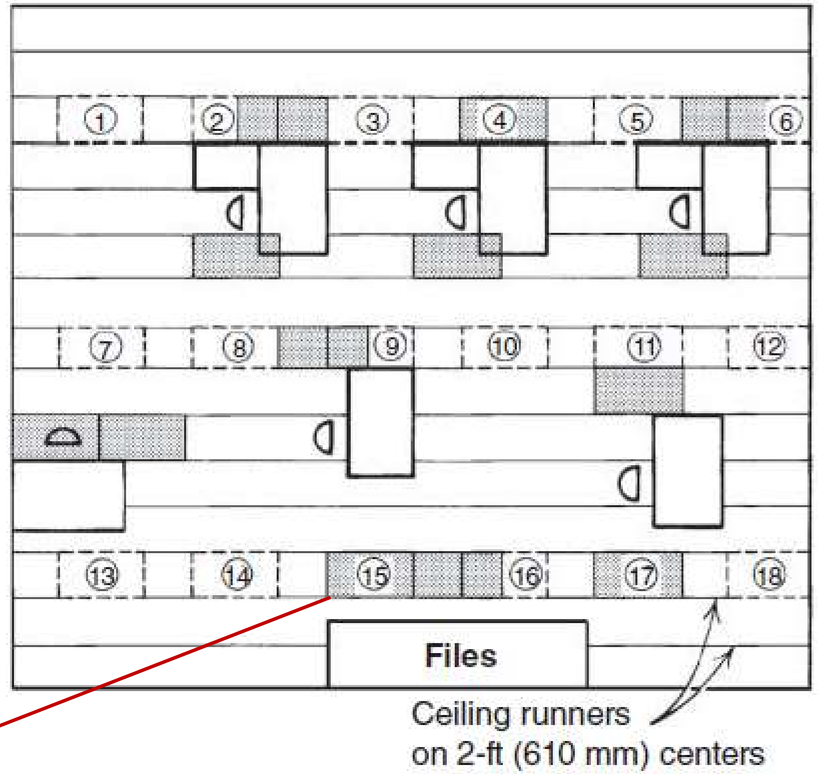


Fig. 16.25 An original uniform fixture layout utilized three rows of six 2 ft × 4 ft (0.6 m × 1.2 m), four-lamp fixtures, giving a total load of 2880 W, a load density of 2.6 W/ft2 (28 W/m2), and a uniform illuminance of approximately 90 (raw) fc (900 lux). The original layout is shown dotted and numbered. A rearranged layout uses 13 fixtures (shown shaded) for a total of 2080 W, a load density of 1.9 W/ft^2 (20.5 W/m^2), and more than 100 ESI fc (1000 lux) on each work surface. In addition, five fixtures are saved. Note: This level of illuminance is justified only for difficult visual tasks.

(b) Control of area brightness and eye adaptation level

- By increasing illuminance
- By increasing overall room illuminance (high energy consumption) vs. by adding a supplementary lighting (minimum energy use, complete control of lighting and psychological satisfaction)

Example of supplementary desk lamp

EXAMPLE 16.6 Recalculate the contrast reduction of the ink-on-paper visual task of Example ~~16.4~~, 6.4 assuming that a desk lamp raises the illuminance to 200 fc (2000 lux) and is positioned so as to be glare-free. Note: An adjustable lamp with 2 at 15-W fluorescent tubes would produce approximately that luminance on a desk.

SOLUTION

Contrast from Equation 6.9:

$$C = (L_{BD} + L_{BS}) - (L_{TD} + L_{TS}) \backslash L_{BD} + L_{BS}$$

where

$$L_{BD} = 200\,\text{fc} \times 0.71 = 142$$

$$L_{BS} = 2000\,\text{fL} \times 0.018 = 36$$

$$L_{TD} = 200\,\text{fc} \times 0.038 = 7.6$$

$$L_{TS} = 2000\,\text{fL} \times 0.021 = 42$$

and

$$C = (142 + 36) - (7.6 + 42) \backslash 142 + 36 = 0.72$$

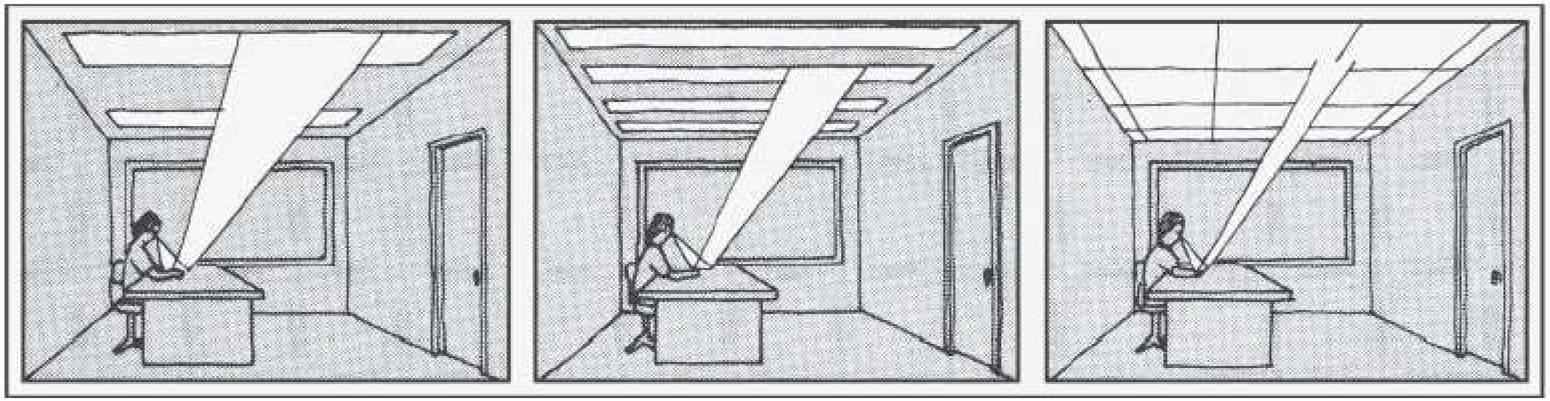
With this contrast (0.72), undesirable contrast reduction from a no-glare situation has been improved from the original 47% reduction (0.947 to 0.497) to a 24% reduction (0.947 to 0.72). However, because a contrast reduction of even 24% is unwanted, a change in task-source geometry or a change in source luminance would be required, assuming that the task itself must remain unchanged. ■

The effectiveness of a supplementary desk lamp is shown in this example!!

In general, any contrast reduction of more than 15% is undesirable.

(c) Control of light source characteristics

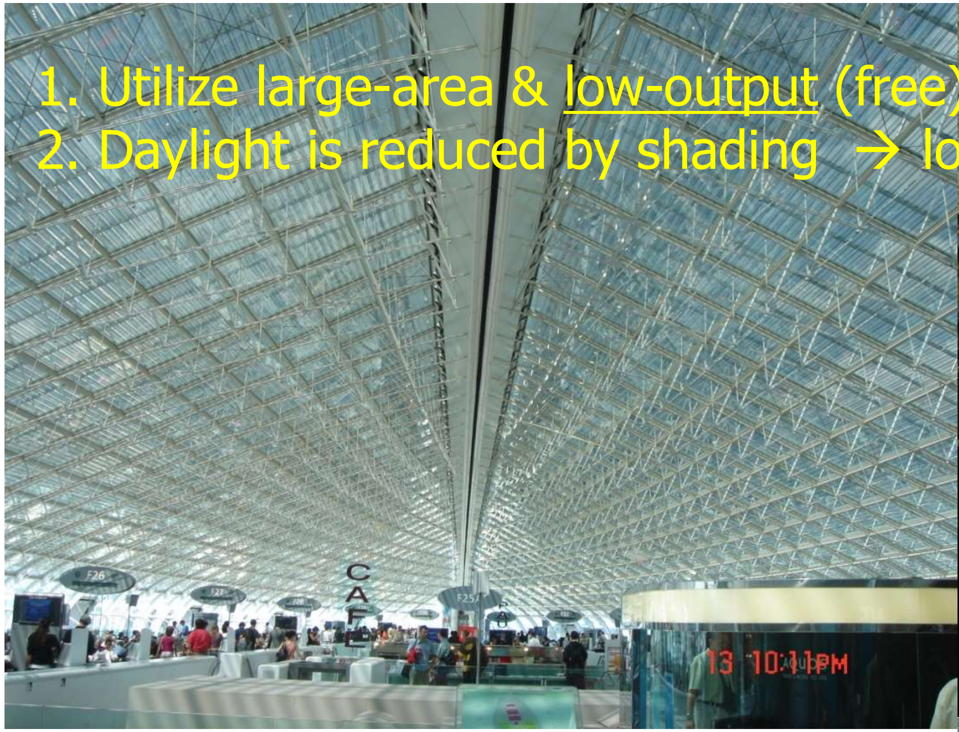
- Luminaire's luminance↓
- Four ways
  - (1) Reduce a lighting fixture's output in the critical portion of the ceiling glare zone, e.g. dimming or switching lamps
  - (2) Utilize larger-area, low-output sources in lieu of using a few small high-output sources (Fig. 16.26)
    - Disadvantage: increased lighting fixture cost



(a) (b) (c)

Fig. 16.26 A concentration of light in the glare zone (a) produces the largest amount of reflected glare. As the number of light sources is increased (b) in the glare zone, and luminance is decreased, reflected glare is decreased. The least glare is from an all-luminous ceiling (c), which also has the lowest luminance.

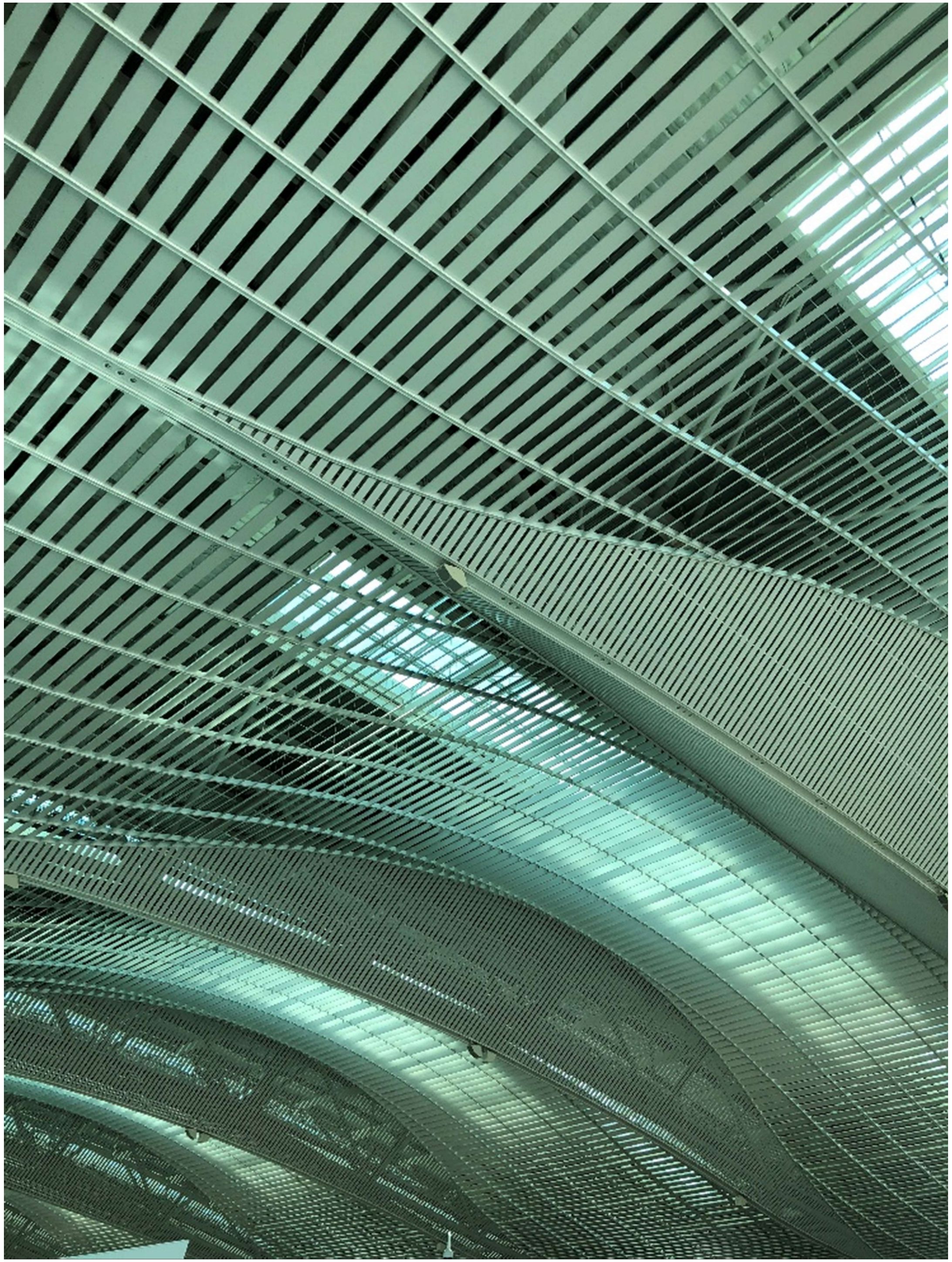
1. Utilize large-area & <u>low-output</u> (free) sources
2. Daylight is reduced by shading → low luminance ceiling is achieved



HK airport terminal

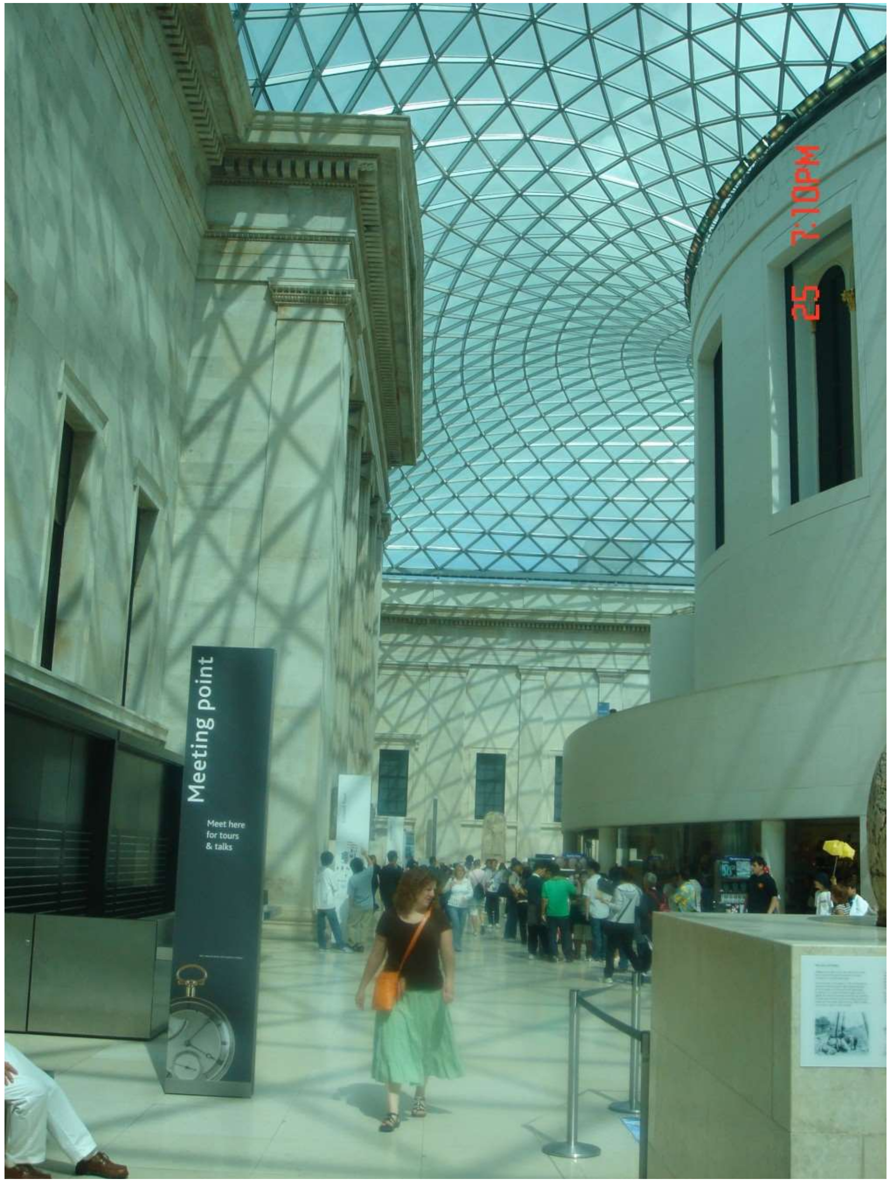

Q
一號客運大樓
Terminal 1
離港
Departures
餐廳及商店
Restaurants, Shops
洗手間
Toilets
6 11:46AM


6 11:46AM



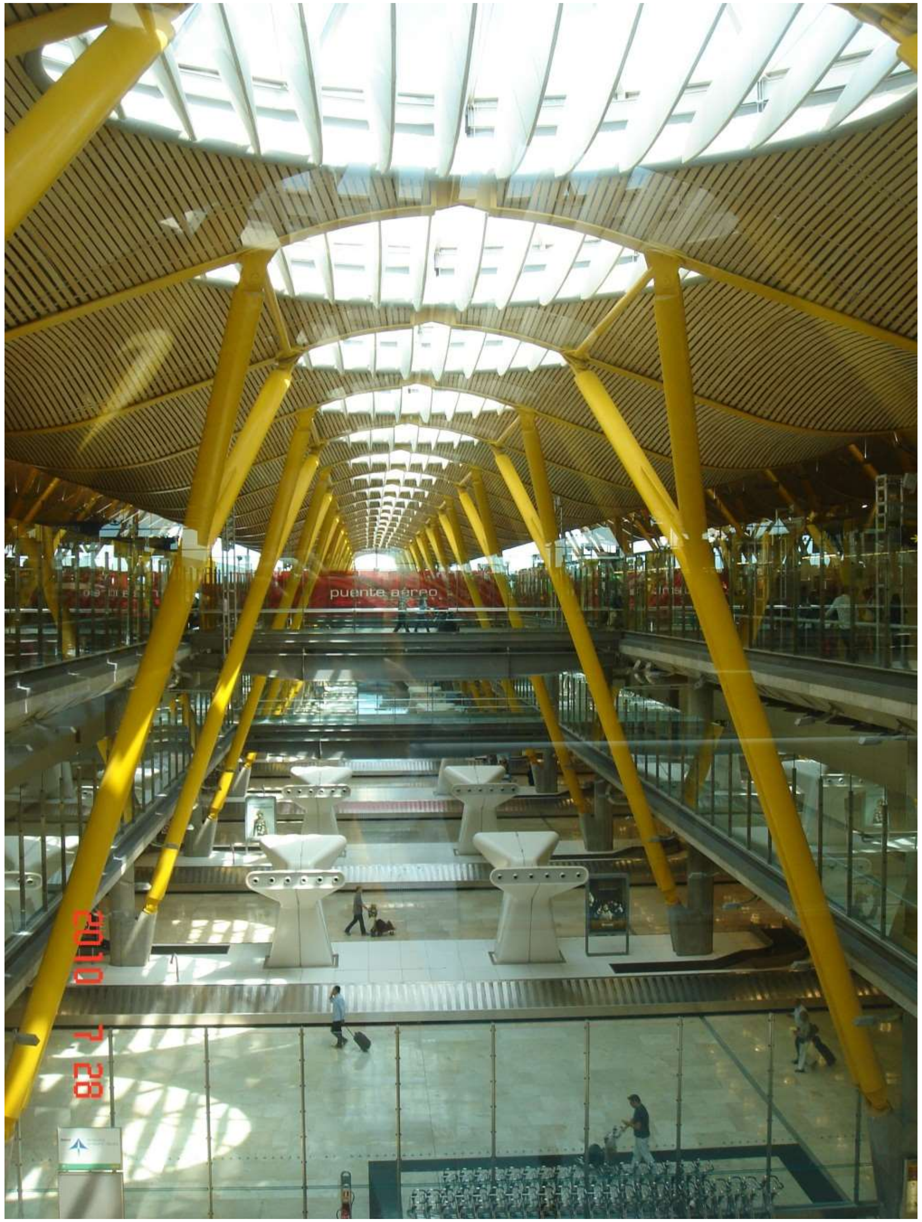
The British Museum

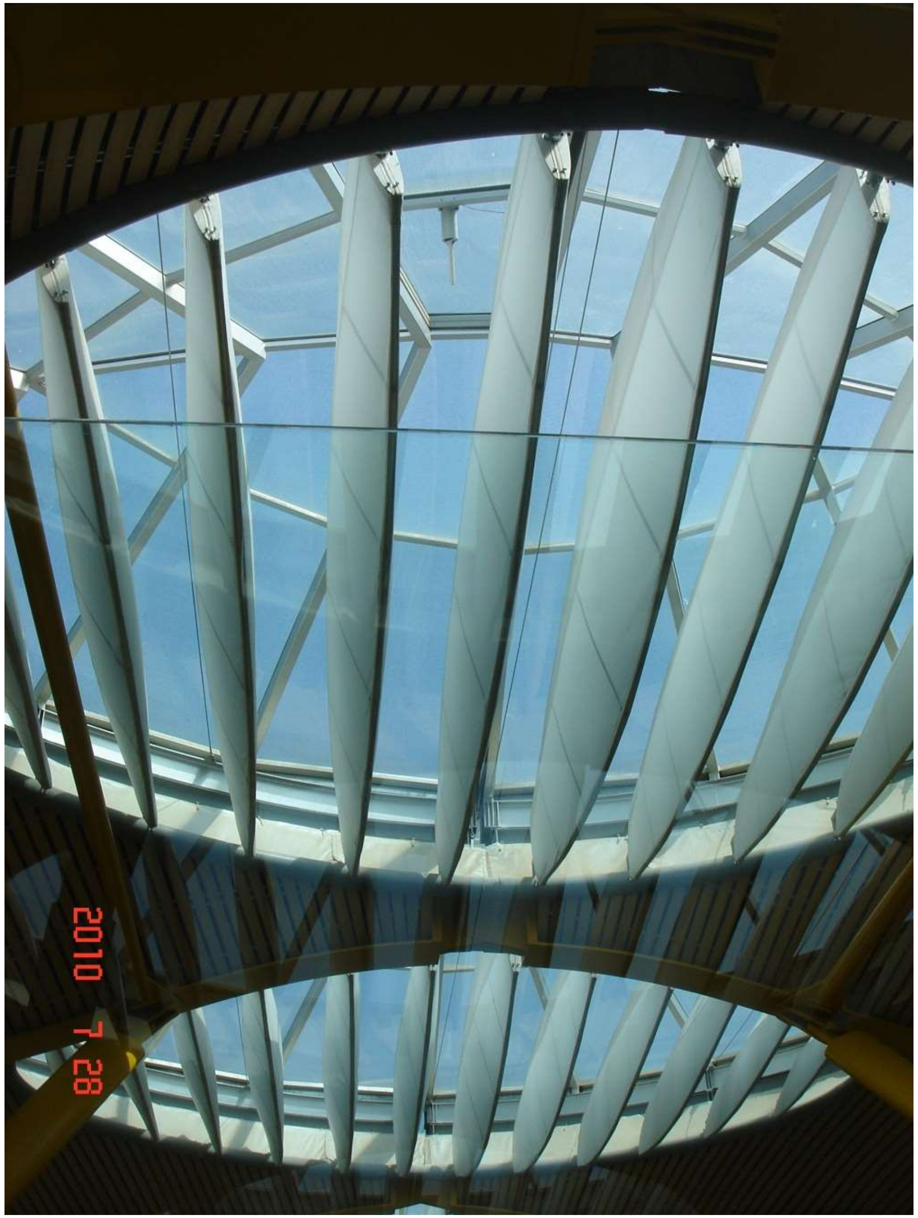
Audio tours
What's on
Shopping
Eating
25 6:17PM


25 7:10PM
Meeting point
Meet here
for tours
& talks


25 6:16PM
Tickets
Eating
Shopping
Lower floors
Ground floor
Upper floors


Barajas Airport (Madrid, Spain)
2010 7 28


puente aéreo
2010 7 28


2010 7 28

Estacion Zaragoza Delicias (Zaragoza, Spain)

A shopping mall in HK (2018.08.ICAE)

(c) Control of light source characteristics

- (3) Use the ceiling as a secondary source illuminated from high output indirect or semi-indirect fixtures
  - The space's ceiling height must be sufficient (to avoid "hot spots")
  - High reflective ceiling required

(Top) Athens PO building
(bottom) Sam Nunn Building

Example

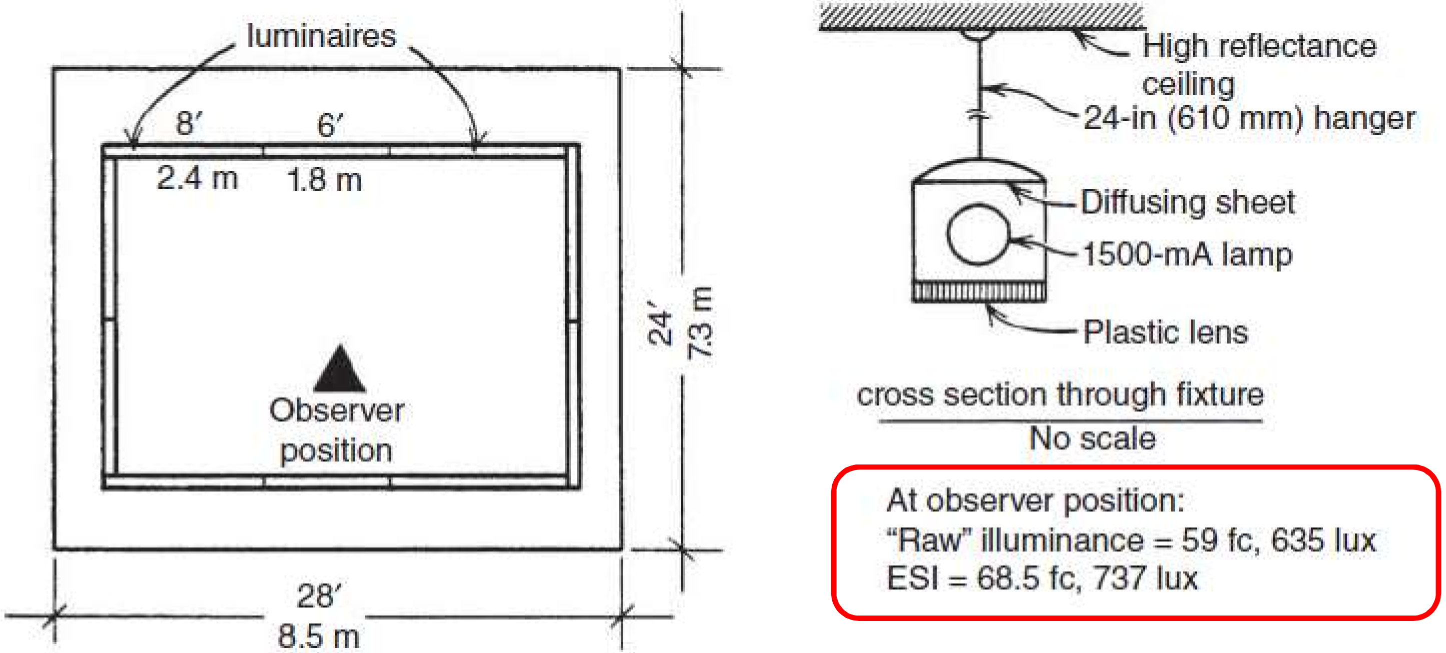
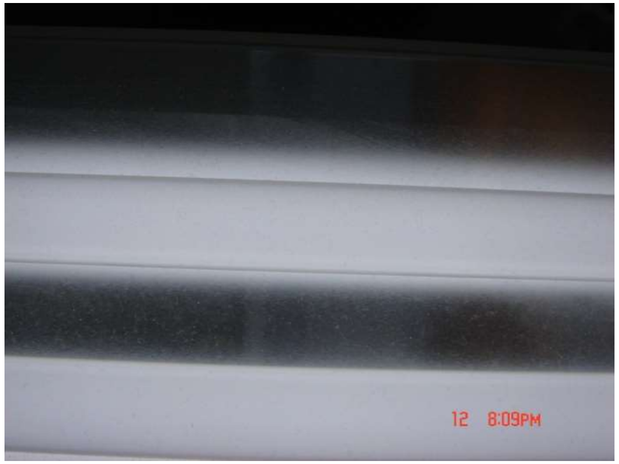


Fig. 16.27 *With a high-reflectance diffuse finish ceiling, this semi-direct perimeter lighting installation yields a higher ESI illuminance than raw illuminance at the viewing location illustrated, indicating excellent contrast rendering. The plastic lens at the bottom of the fixture provides perceived light source luminance and avoids the impression of gloominess, despite the satisfactory overall luminance level. (From Sampson, 1970.)*



FRESH company, Vaxjo, Sweden (2008)


BUS 89 325 62
Sortie
2
av. de France


20 6:25PM

20 6:25PM

20 6:26PM

20 8:23PM

the ceiling used as a secondary source.

City Chambers of Edinburgh (June, 2008)

(c) Control of light source characteristics

- (4) Reduce the luminaire luminance at the offending angles
  - Most horizontal task vision takes place between 20° and 40° from the vertical (Figs. 6.27-28)
  - Batwing diffusers

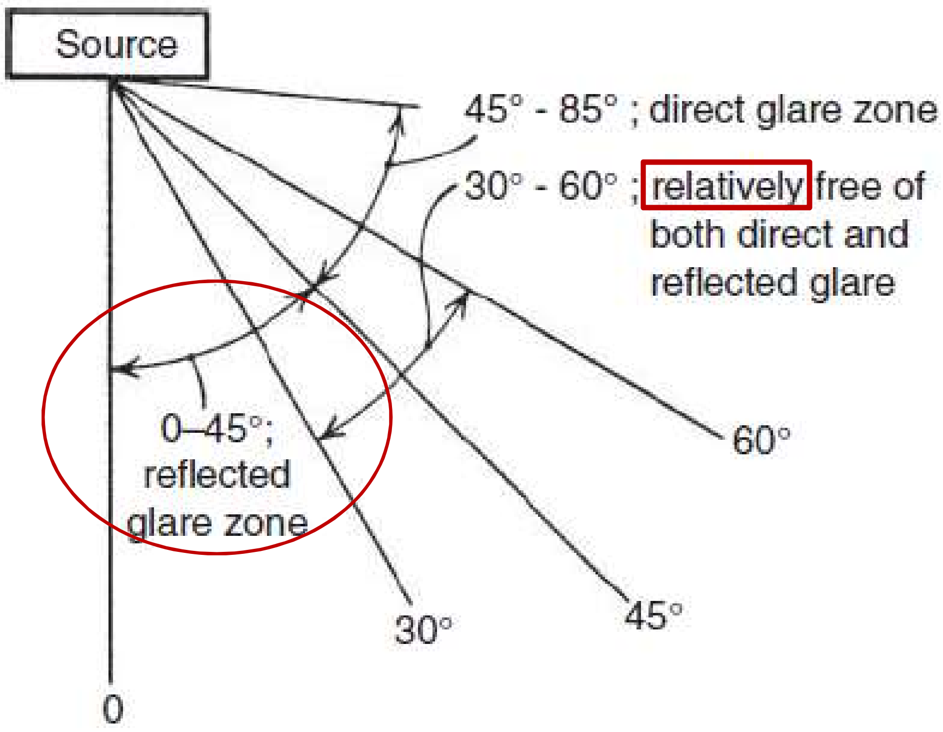
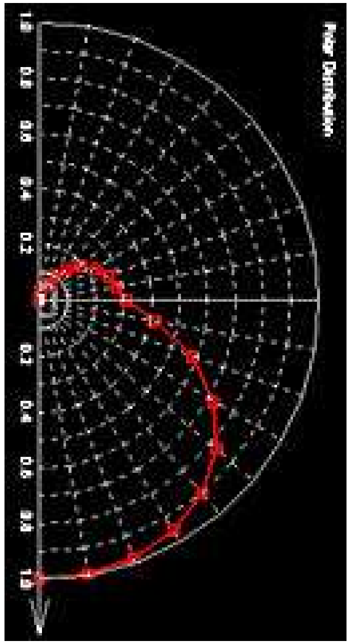


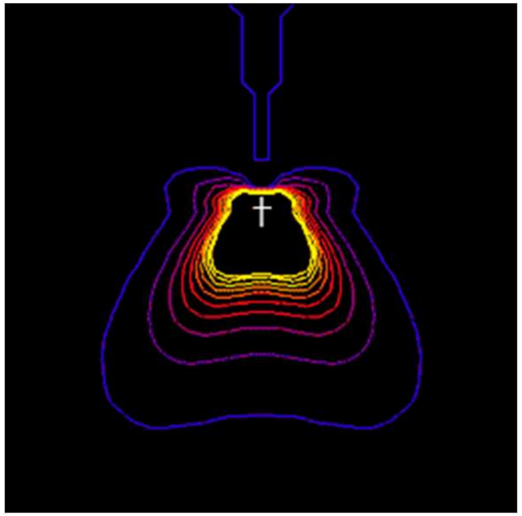
Fig. 16.28 *Glare zones are 0° to 45° and 45° to 85° for reflected and direct glare, respectively. Therefore, a diffuser that emphasizes the 30° to 60° zone will be least objectionable on both counts.*

Example



IES #46, BILATERAL BATWING,
SURFACE MTD W/ PRISMATIC
WRAPAROUND
LAMP=FLUORESCENT

< Batwing fixture>



Summit building, GA, USA

(d) Changing task quality

- Simply reducing the task specularity.
- It is often cheaper and always more economical in terms of energy use, to upgrade the task (in the visibility sense) than to change the lighting system.

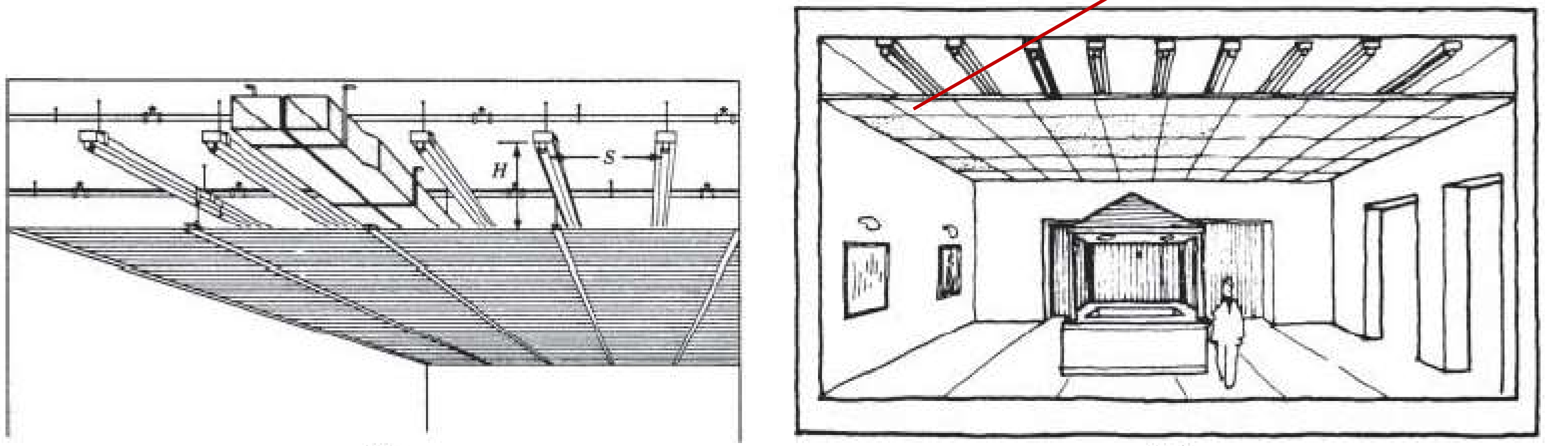
Qualitative design considerations

Size and pattern of luminaires

- Because of its luminance, each luminaire or other luminous source is a point of visual attention.
- Luminaire size should correlate with room size and ceiling height.
- Fluorescent fixtures larger than 2 ft × 4 ft (600 mm × 1200 mm) should not be used in ceilings lower than 10 ft (3m).

Size and pattern of luminaires

- Trans-illuminated ceiling (Fig.16.29, totally lighting fixtures) require a minimum of 12 ft (3.7 m) mounting height.
  - (a) for uniform illuminance: S<= 1.5H
  - (b) To relieve monotony of large unbroken expanses, clearly defined diffuser panels are used.



(a) (b)

Fig. 16.29 (a) The suspended diffusive material of a luminous ceiling—when properly designed—allows the designer to hide piping and ductwork, without affecting the ceiling's light distribution. As a rule, if uniform illuminance is desired, the spacing (S) of the strip fixtures should not exceed 1.5 times the height (H) between the fixtures and the diffusing element. (b) A luminous ceiling provides low-brightness, highly diffuse, uniform illuminance, generally exceeding 500 lux (45 fc). Such a lighting approach is particularly useful for specular tasks where supplemental lighting is impractical. To relieve the monotony of large, unbroken expanses, as in (a), designers frequently use clearly defined diffuser panels, as shown.

Coffer-type fixtures

- In place of a luminous ceiling, large-area, coffer-type fixtures can be utilized in order to give the impression of depth.

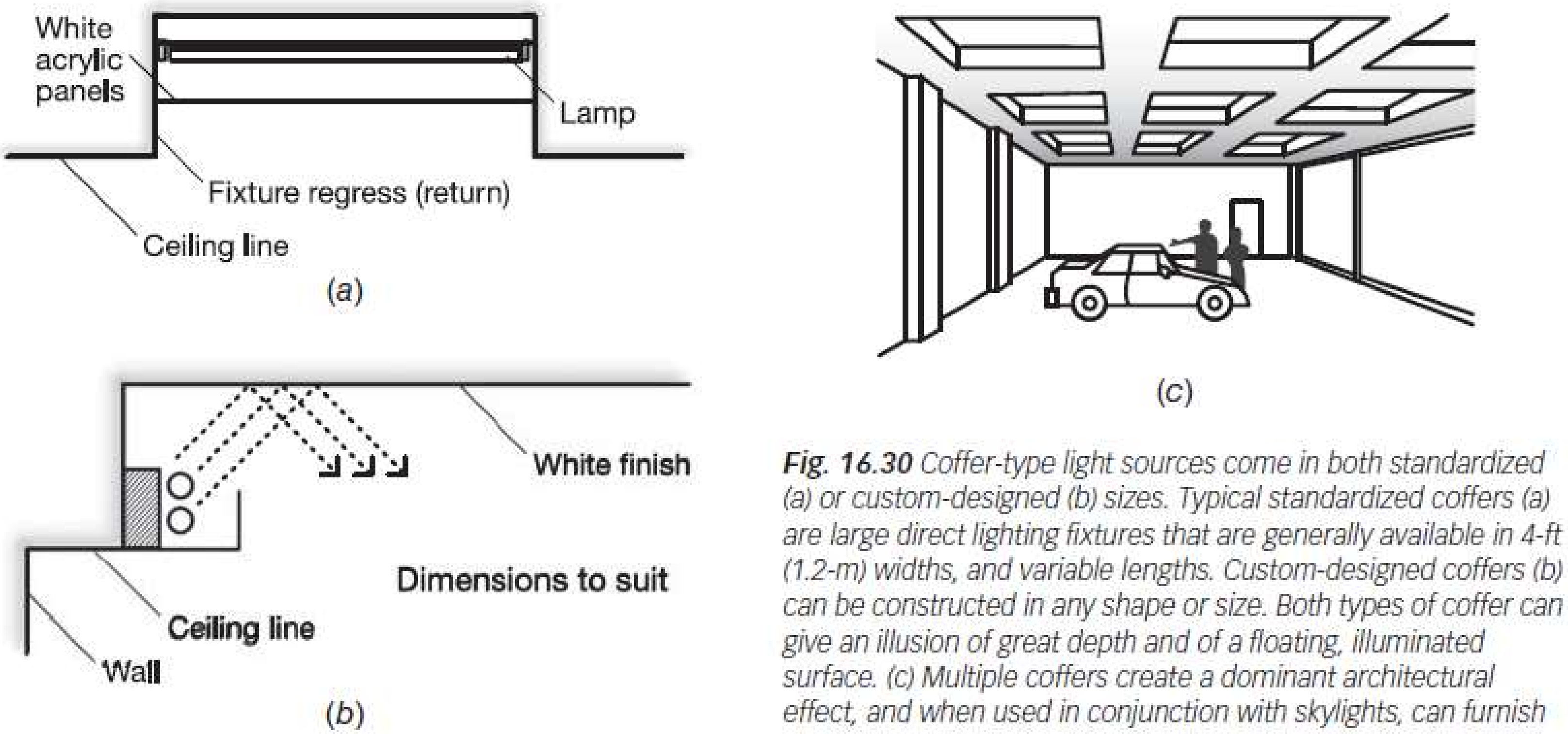


Fig. 16.30 Coffer-type light sources come in both standardized (a) or custom-designed (b) sizes. Typical standardized coffers (a) are large direct lighting fixtures that are generally available in 4-ft (1.2-m) widths, and variable lengths. Custom-designed coffers (b) can be constructed in any shape or size. Both types of coffer can give an illusion of great depth and of a floating, illuminated surface. (c) Multiple coffers create a dominant architectural effect, and when used in conjunction with skylights, can furnish soft, glare-free illumination throughout the day and night. (Drawn by Alisa Kwok.)

To achieve the uniformity of illumination desirable for general lighting, regular spacing is required. However, various effects may be obtained within said regularity.

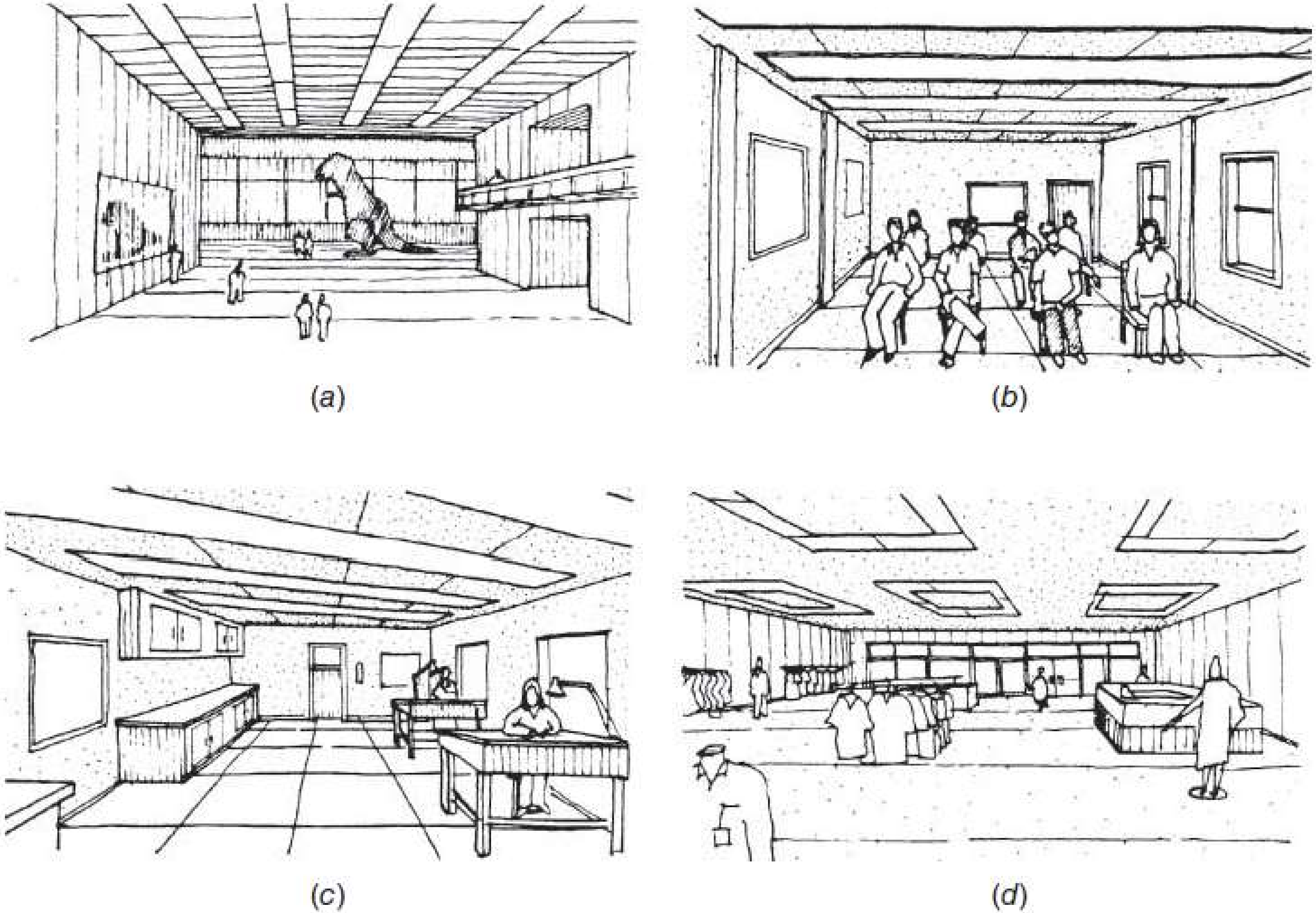


Fig. 16.31 *(a) Longitudinal lines in the direction of the sight line increase apparent length, direct traffic flow, and decrease direct glare. (b) Lines perpendicular to the line of sight shorten and widen a space but also increase direct glare. (c) Diagonal lines minimize shadows and break rectangular patterns. (d) Rectangular pattern is architecturally dominant.*

It is often recommended that the pattern of lighting ought to either reinforce an architectural form (Fig.16.32(a)) or remain neutral (Fig.16.32(b, c)).

(a)

(b)

(c)

Fig. 16.32 Lighting designs for various spaces with high ceilings. The fixtures in (a) and (b) follow structural beams. (b) Floor reflection and daylight provide ceiling and wall illumination. (c) Lighting in this space was handled by recessing fixtures into the lattice ceiling pattern. Metal-halide HID lamps and tungsten-halogen lamps were used. (a: by M. B. Warren; b by L. Reens; c: courtesy of GTE/Sylvania, Inc.)


13 8:47PM


13 8:47PM

Generally, downlights are not visually dominant, and regularity of placement is not essential (Fig.16.33).

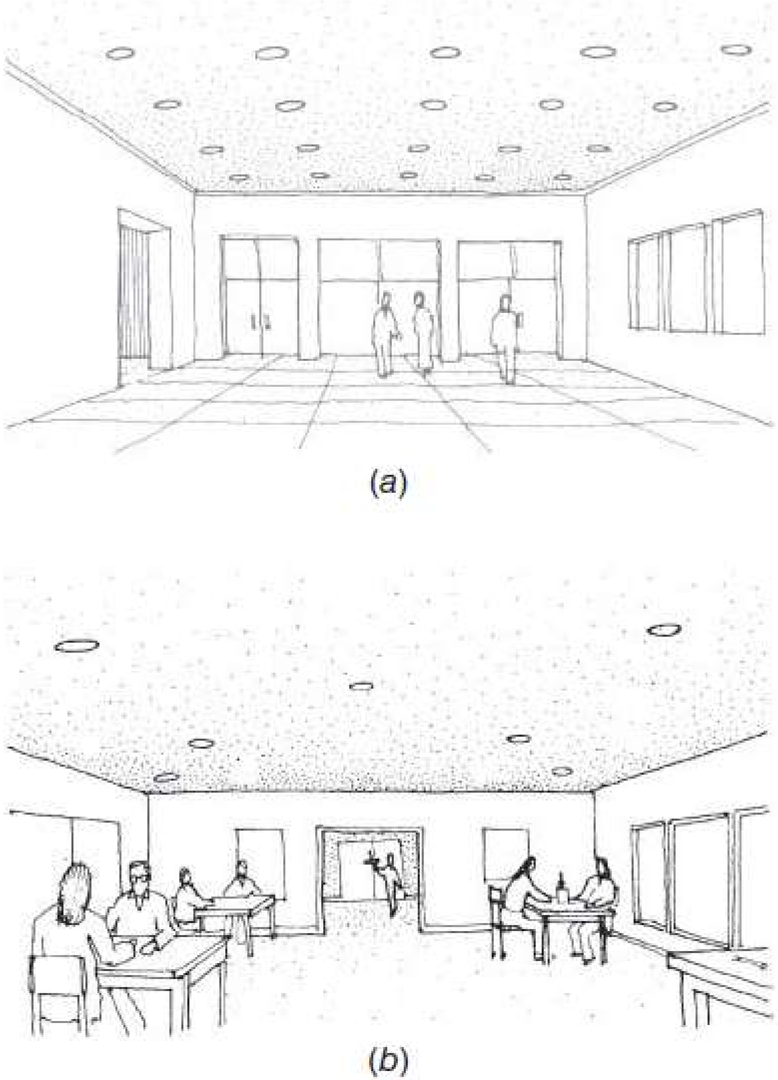


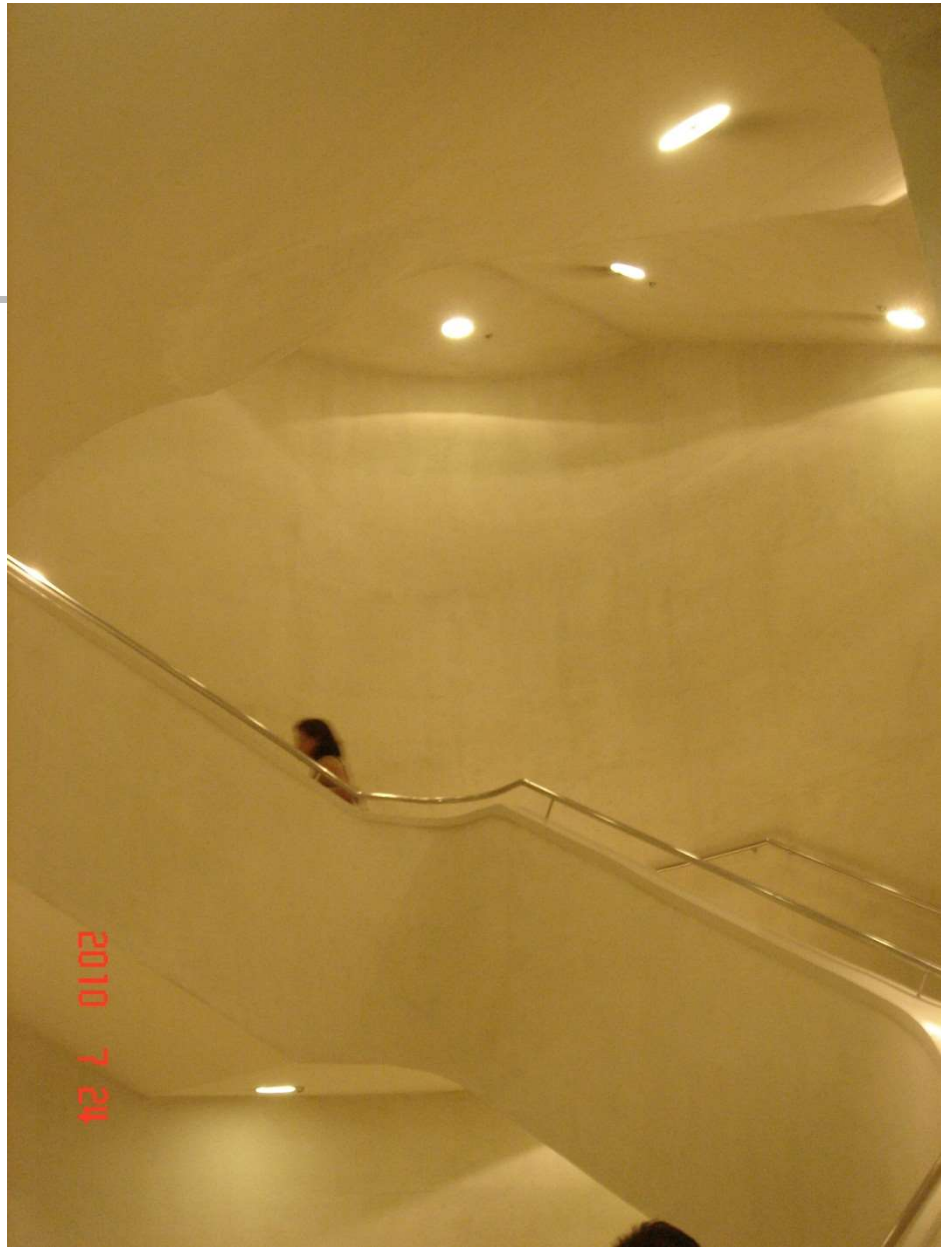
Fig. 16.33 Downlights are unobtrusive light sources. They can be spaced evenly throughout a room (a) or unevenly (b).

However, when downlights are surface-mounted (a generally inadvisable procedure), the result can be far from visually neutral (Fig.16.34)

Fig. 16.34 *The array of large, cylindrical, surface-mounted downlights dominates the area's appearance despite the high ceiling.*

Architects: Jacques Herzog & Pierre de Meuron
Caixa Forum, Madrid, Spain (2010.07)

Caixa Forum, Madrid, Spain (2010.07)



Caixa Forum, Madrid, Spain (2010.07)

Nonuniform layouts with large fixtures can create a pattern problem since they are often too large to be neutral—the nonuniformity can create visual confusion.

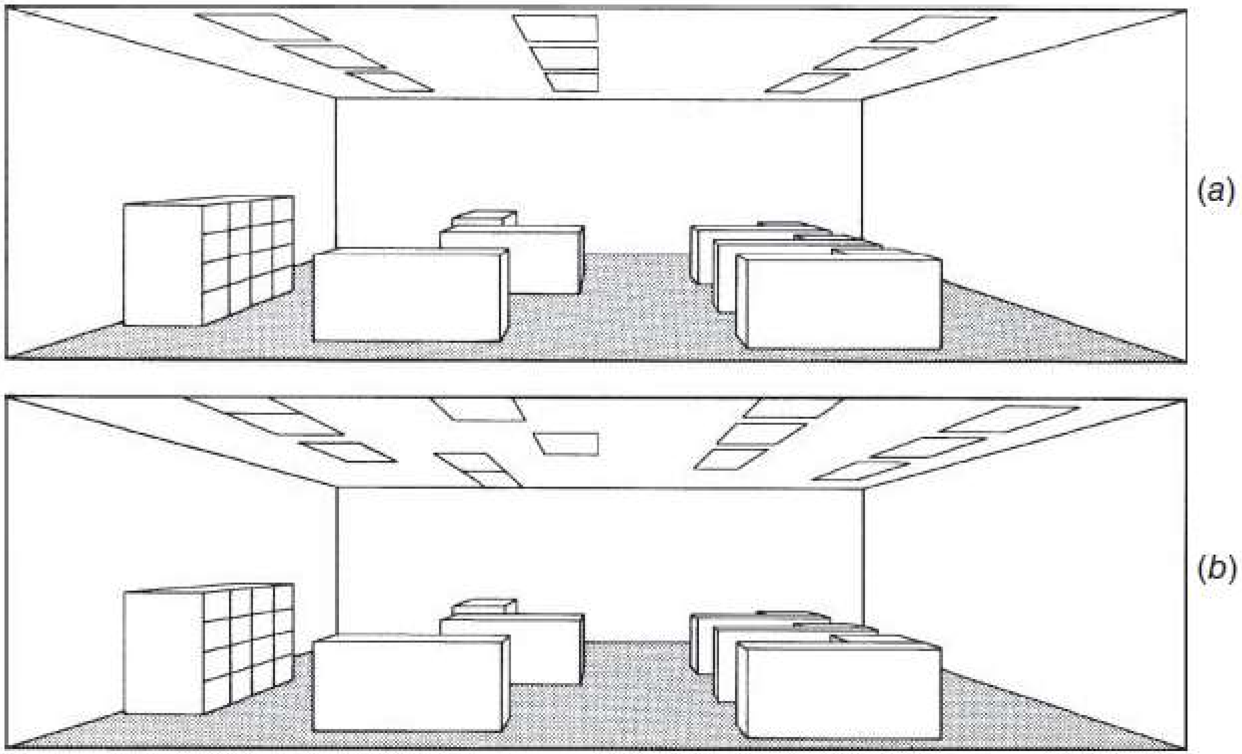


Fig. 16.35 *(a) The layout of the lighting fixtures is economical and may provide uniform illuminance. (b) The nonuniform layout lacks integration with the functions below and may not provide the illuminance needed for the task locations.*

Architects: Jacques Herzog & Pierre de Meuron
Caixa Forum, Madrid, Spain (2010.07)

Caixa Forum, Madrid, Spain (2010.07)

The MAXXI: Museum of XXI Century Arts, in Rome, Italy, features slot fixtures that reinforce movement through space and skylights with controllable louvers to illuminate the gallery space. Lighting patterns are often used as formal directional markers. (Fig. 16.37)

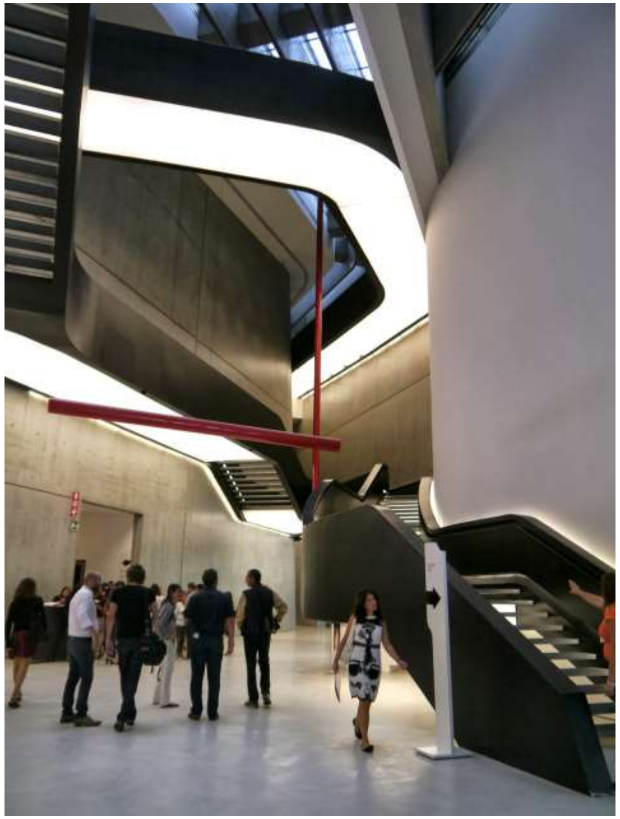


Image source: https://laviebohemetravel.wordpress.com/2013/09/27/maxxi/

Fig. 16.37 *Linear slot lighting emphasizes the curvilinear form of the gallery, further reinforcing a directional flow of traffic through the space. (© Donald Corner; used with permission.)*

Architect: Zaha Hadid

Patterns of luminance

- Patterns of luminance = patterns of light and shadow in a space
- Purely diffuse lighting is monotonous and not conducive.
- Some directional lighting is often introduced, e.g. uplighting or downlighting. As seen in Fig. 16.40, directional light is what creates shape and is precisely the characteristic best used to influence architectural space and form.
- Most useful in lobbies, waiting areas, recreational spaces, restaurants, etc.

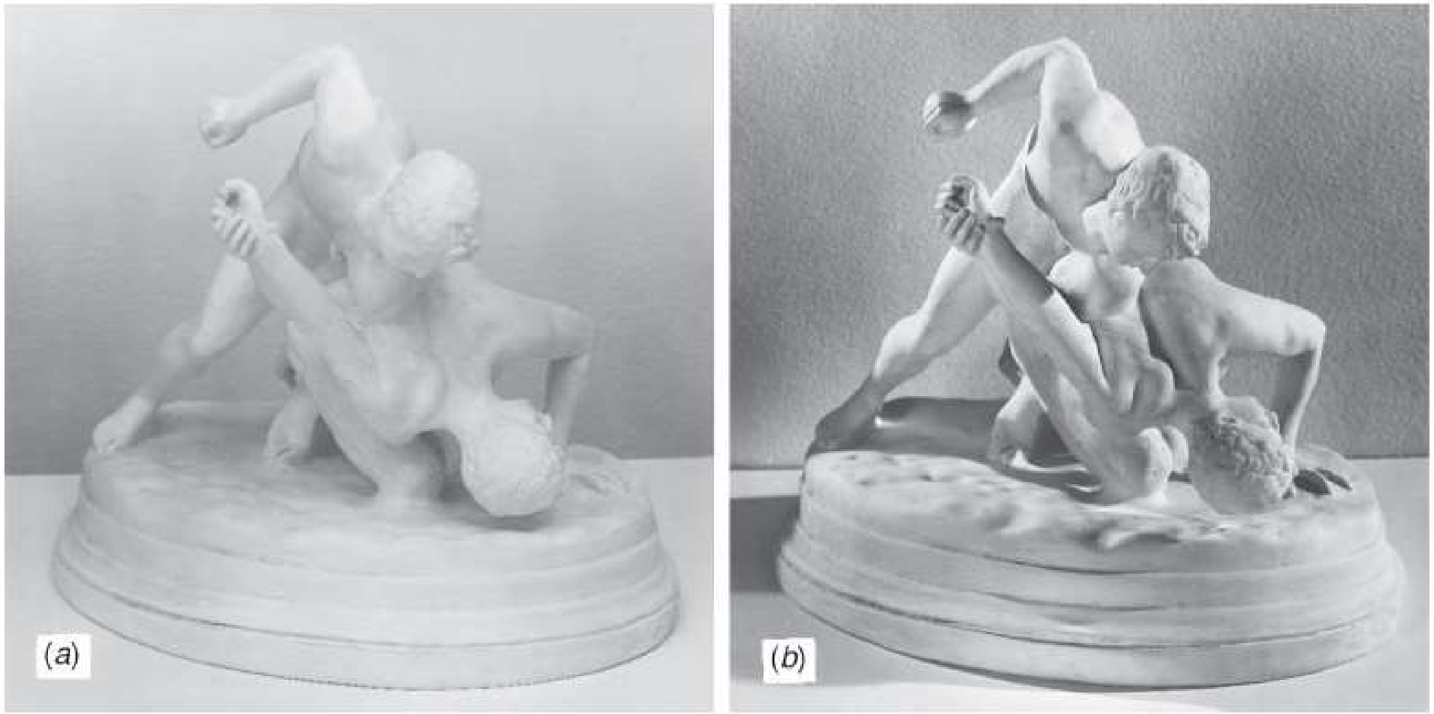


Fig. 16.40 *Totally diffuse lighting (a) destroys texture, whereas a combination of diffuse and directional lighting (b) produces the required modeling shadows. (Courtesy of Holophane.)*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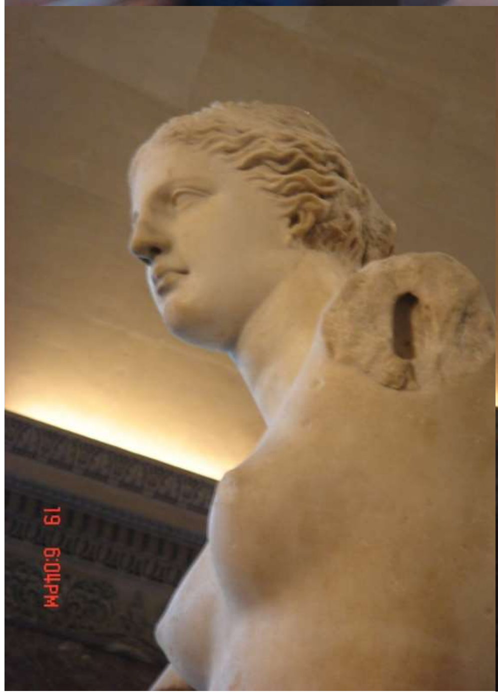
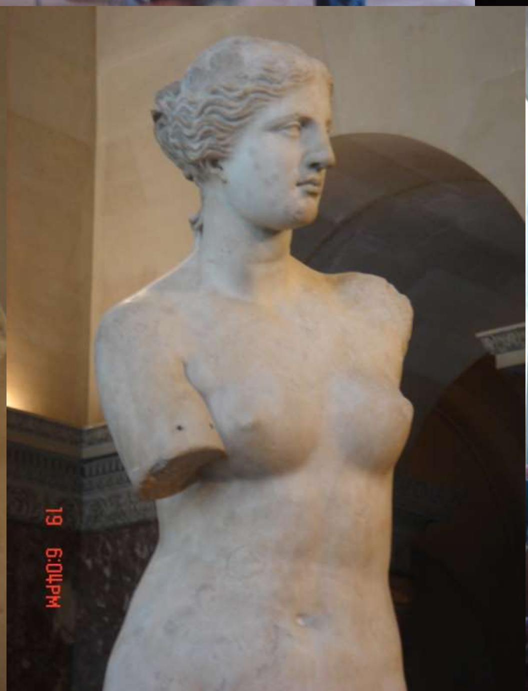
19 6:05PM



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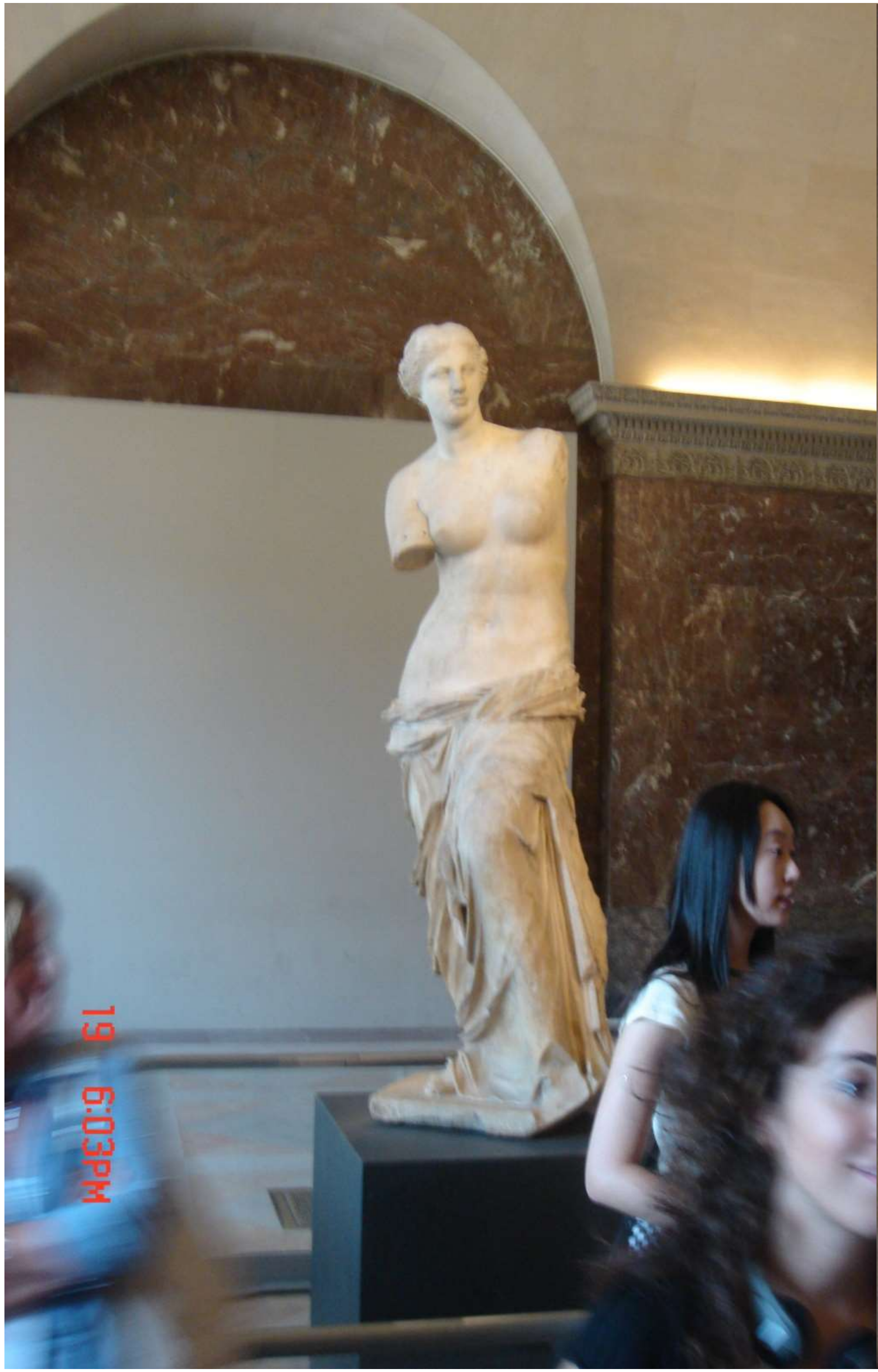
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Other evaluation considerations

Tasks

Costs

Lighting power budget

Energy

Task analysis

- Multitasking
  - If there are several tasks to be performed at the same location and the most difficult one occurs infrequently, it may be reasonable to provide supplementary portable lighting or even to suggest moving the task to another location.
- Variation in task difficulty
  - Particularly common in spaces in public buildings.
  - A school gym can be used for athletics, band concerts, testing, and town meetings: it is common to treat the space as essentially four different spaces and to design a lighting system appropriate for each, while maximizing common equipment usage.

Task analysis

- Viewing time
  - prolonged intensive work or rapidly changing task: illumination to be raised one (or more) levels
- Viewer condition
  - If there is likely to be a high percentage of older workers, lighting should be increased. This compensates for the decreased ability of an aging eye.

Task analysis

- Cost of errors
  - Economic trade-off between savings that result from improved visual acuity (accuracy) and the cost of improved lighting to reach the higher accuracy
  - Tasks where the costs of errors is a serious concern include inspection, proofreading, textile matching, very fine machining, and precision manufacturing.
- special requirements
  - Large tasks: the angle of seeing varies from 20° to 70° (glare!!)
  - 3D tasks: undercuts and reveals
  - Tools: tools can cast shadows below and in front when lighted from above and behind.
  - Non-horizontal tasks
  - Task observed from various positions: illumination must be adequate for all viewing angles.

Costs

- First cost(initial cost), operating cost, life cycle cost
  - Incandescent lamps and fixtures are low in first cost and high in operating cost.
- The impact of lighting energy on the operating cost of the entire building must be studied and an apportionment of costs determined. The only practical means of accomplishing this is by using a computer simulation
  - to reflect the effect of the lighting system on building costs and, in particular, on HVAC first cost and operating costs.

Relationship: lighting vs. HVAC

- The impact of lighting system design on HVAC & building energy
  - HVAC system sizing, heating and cooling energy cost, lighting power consumption
  - Lighting simulation must be employed to analyze the aforementioned relationship.
- Sam Nunn building
  - Constructed in 1998: central on/off lighting control
  - 2004-2005: retrofit (w/ occupancy sensor)

Sam Nunn Atlanta Federal Center

Atlanta Federal Center (total floor area = 145,000 m2)

Arch. Design: Kohn Pederson Fox Associates

HVAC design: Newcomb & Boyd

Energy consumer	Average	
Heating	8,553,494	7.6%
Fans	9,090,290	8.0%
Lighting	54,949,602	**48.6%**
Pumps	4,579,134	4.0%
Cooling	30,225,076	**26.7%**
Humidifying	4,006,742	3.5%
Domestic hot water	1,691,157	1.5%
Total	**113,095,495**	**100.0%**

Annual energy saving calculation

	From	To	**Savings in MBTU/year**	**$/year**
Orientation	SE-NW	South-North	1,300	16,877
Windows ratio	40%	30%	3,583	46,507
Lighting control	Central on/off	Daylight switch	10,407	135,082
Total			**15,290**	**196,913**

* Energy bill in 2003: 1.45 million $

- **accurate prediction (8.6%)**
- **instructive information for better energy-efficient buildings**
- **annual energy saving opportunities**

With an input of 3-4 hours (!) per building the PI's assess the building's technical performance.

Lighting Power budget

- ASHRAE/IESNA 90.1-2019 Energy Standard for Buildings Except Low-Rise Residential Buildings
  - Accounts for lighting, HVAC, electrical, power, water, envelope, energy management, etc.
  - Two options
    - Option #1: lighting power density (W/m^2)
      - building area method or space by space method
    - Option #2: whole building energy use by building simulation ($kwh/m^2.yr$)

TABLE 9.3.1.1
Lighting Power Densities Using the Building Area Method

Building Area Type[a]	Lighting Power Density (W/ft^2)
Automotive Facility	1.5
Convention Center	1.4
Court House	1.4
Dining: Bar Lounge/Leisure	1.5
Dining: Cafeteria/Fast Food	1.8
Dining: Family	1.9
Dormitory	1.5
Exercise Center	1.4
Gymnasium	1.7
Hospital/Health Care	1.6
Hotel	1.7
Library	1.5
Manufacturing Facility	2.2
Motel	2.0
Motion Picture Theater	1.6
Multi-Family	1.0
Museum	1.6
Office	1.3
Parking Garage	0.3
Penitentiary	1.2
Performing Arts Theater	1.5
Police/Fire Station	1.3
Post Office	1.6
Religious Building	2.2
Retail	1.9
School/University	1.5
Sports Arena	1.5
Town Hall	1.4
Transportation	1.2
Warehouse	1.2
Workshop	1.7

Building Area method

TABLE 9.3.1.2
Lighting Power Densities Using the Space-by-Space Method

Building Type	Space-by-Space Method LPDs																
	Common Space Types and LPDs (W/ft^2)																
	Office—Enclosed	Office—Open Plan	Conference Meeting/Mulitpurpose	Classroom/Lecture/Training	Audience/Seating Area	Lobby	Atrium—first three floors	Atrium—each additional floor	Lounge/Recreation	Dining Area	Food Preparation	Restrooms	Corridor/Transition	Stairs—Active	Active Storage	Inactive Storage	Electrical/Mechanical
Athletic Facility Buildings																	
Gymnasium	1.5	1.3	1.5		0.5	1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Exercise Center	1.5	1.3	1.5		0.5	1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Civil Service Buildings																	
Courthouse	1.5	1.3	1.5	1.6	1.6	1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Police Stations	1.5	1.3	1.5	1.6	1.6	1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Fire Stations	1.5	1.3	1.5	1.6		1.8			1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Post Office	1.5	1.3	1.5	1.6		1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Town Hall	1.5	1.3	1.5	1.6	1.6	1.8				1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Convention Center Buildings																	
Convention Center	1.5	1.3	1.5	1.6	0.5	1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Educational Buildings																	
School/University	1.5	1.3	1.5	1.6		1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Library	1.5	1.3	1.5	1.6		1.8	1.3	0.2		1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Food Service Buildings																	
Dining: Bar Lounge/Leisure	1.5	1.3	1.5			1.8	1.3	0.2	1.4	1.2	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Dining: Family	1.5	1.3	1.5			1.8	1.3	0.2	1.4	2.2	2.2	1.0	0.7	0.9	1.1	0.3	1.3
Dining: Cafeteria	1.5	1.3	1.5			1.8	1.3	0.2	1.4	1.4	2.2	1.0	0.7	0.9	1.1	0.3	1.3

Space by Space method

Table 16.9 shows two things

- the differences in “expectations” between various space types
- a clear trend of increasing stringency over a decade-long period.

TABLE 16.9 Evolution of Lighting Power Density Values for Selected Space Types

SPACE TYPE	2016 LPD LIMIT	2013 LPD limit	2010 LPD limit	2007 LPD limit	2001 LPD limit
Dormitory	0.61 W/ft^2	0.57 W/ft^2	0.6 W/ft^2	1.0 W/ft^2	1.5 W/ft^2
Hotel	0.75 W/ft^2	0.87 W/ft^2	1.0 W/ft^2	1.0 W/ft^2	1.7 W/ft^2
Office	0.79 W/ft^2	0.82 W/ft^2	0.9 W/ft^2	1.0 W/ft^2	1.3 W/ft^2
Retail	1.06 W/ft^2	1.26 W/ft^2	1.4 W/ft^2	1.5 W/ft^2	1.9 W/ft^2

Source: Reprinted with permission; ©ASHRAE, www.ashrae.org. ASHRAE Standard 90.1–2016, ASHRAE Standard 90.1–2013, ASHRAE Standard 90.1–2010, ASHRAE Standard 90.1–2007, and ASHRAE Standard 90.1–2001.

For LPD values in W/m^2, multiply the given values by 10.76.

Energy

- Energy considerations must pervade every aspect of the design process.
- Lighting consumes approximately 25% of the electric power generated in the United States. In terms of *resources*, this amounts to approximately 4 million barrels (462,500 kL) of oil per day.

Lighting energy

- In commercial buildings, lighting consumes about 20% to 30% of electric energy; the percentage is greater in residences and lower in industrial facilities.
- A reduction of 40% to 50% in lighting energy is attainable through judicious design.
- Translated into resources, such a reduction can readily amount to more than 1 million barrels (115,630kL) of oil per day.

The question to be answered

- What design guidelines can be followed in order to achieve energy-conscious design?
  - ASHRAE Standard 90.1 (ASHRAE, 2019)
  - *The Advanced Energy Design Guides* published by ASHRAE (various dates)
  - LEED (USGBC, 2013).
  - For lighting effectiveness guidelines refer to *The Lighting Handbook* (IESNA, 2011).

Conceptual-level approaches for energy-conscious lighting design

- (a) Design lighting for expected activity
  - It is energy-wasteful to light any surface to a higher illuminance than required.
  - Nonuniform lighting is recommended where high illuminance levels are required for selected tasks in multi-task spaces.
  - Providing overall high-lux illumination with a provision for switching to reduced lighting levels is not advisable because of the increased first cost and the psychological impetus to operate at maximum levels.

- 1. Place tasks with similar lighting requirements in the same general location.
- 2. Place the most severe seeing tasks at the best daylighting locations
- 3. If possible, improve the quality of difficult visual tasks. This is more economical in terms of energy-use than providing additional light.
- 4. The advantages of nonuniform lighting increase as the space between workstations increases.
- 5. When using a task-based design approach, keep in mind that a nonuniform ceiling layout may give a chaotic appearance to a space. Therefore, the preferred approach is to use uniform ambient lighting and localized supplemental lighting.

Conceptual-level approaches for energy-conscious lighting design

- (b) Use effective, high-quality, efficient, low maintenance, thermally controlled luminaires.
  - “Effective” means providing useful light and minimizing direct glare.
  - In cases where much of the viewer’s time is spent in a head-up position, as in schools: the design should lean toward achieving high visual comfort probability (VCP).
  - Where work and viewing position are fixed, and most of the viewer’s time is spent head-down: the design should lean toward low reflected glare.

1. Use of high-quality luminaire

- high-quality luminaire is made with permanent finishes such as Alzak® or multi-coat baked enamel or any of the high-quality permanent aluminum finishes currently available.
- This ensures that its performance after 8 to 10 years of service will be comparable to the original.

2. Use of *energy-efficient* luminaire

- high luminaire efficacy rating (LER).
- This is expressed in lumens per watt (lumens output per watt input), it uses the same descriptive term used for light sources (i.e., *efficacy*).
- This metric takes into account all power used by a luminaire, including ballast & lamp.

3. Use of *low-maintenance* luminaire

- Must remain clean for extended periods and is designed so that all reflecting surfaces can be easily and rapidly cleaned without demounting.
- Enclosed fixtures should be gasketed. Nongasketed units collect and retain dust, thus causing rapid lumen output depreciation.

4. Relamping should be simple and rapid

5. Use of *thermally controlled* luminaire

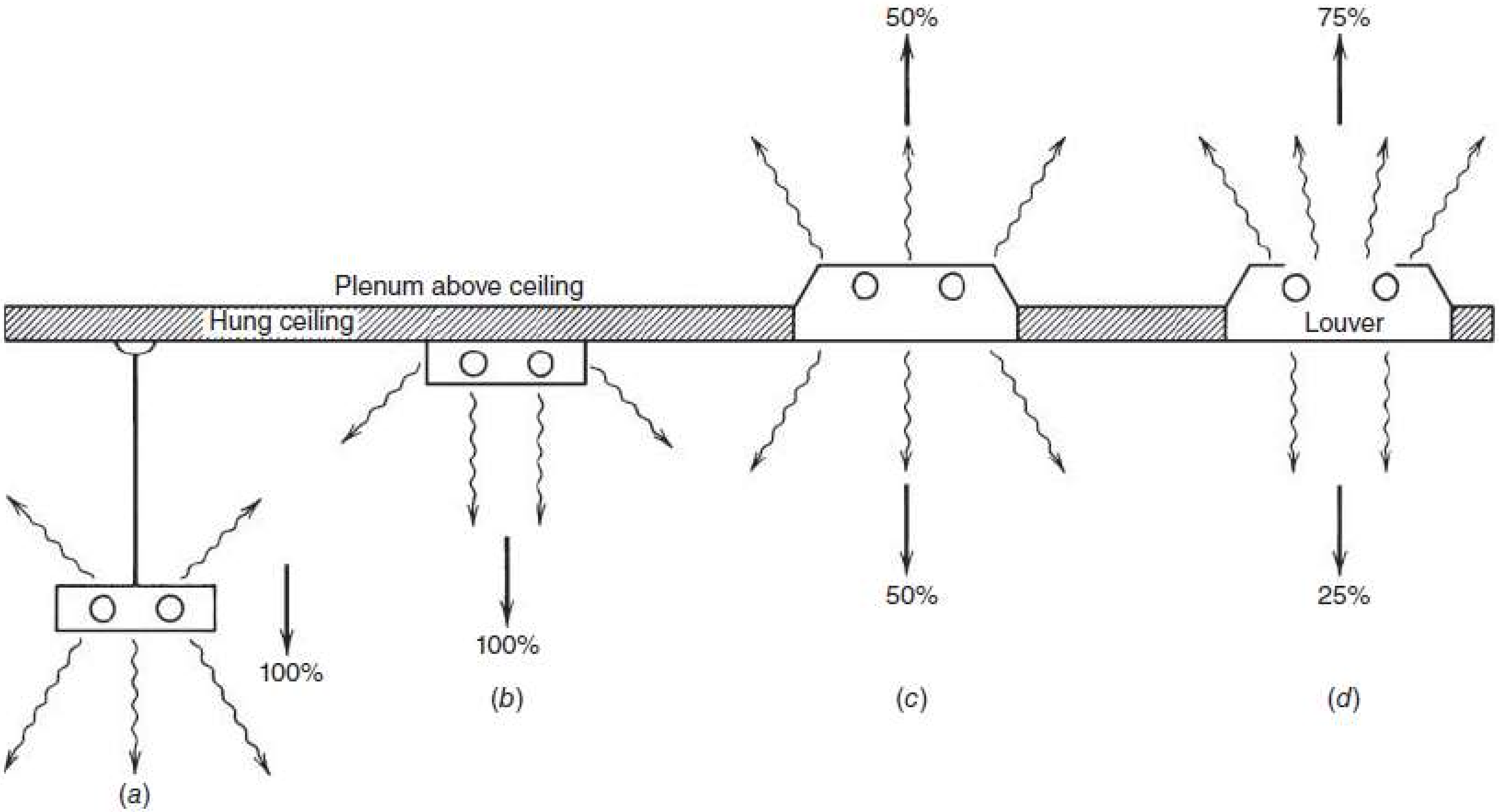

Fig. 16.41 *Method of fixture installation controls the transfer of heat from a luminaire. (a) Suspended units transfer all heat to the space while remaining fairly cool. (b) Surface-mounted fixtures also transfer all heat to the space but, because of blocked transfer upward, run hot. (c) Completely enclosed recessed units transfer about 50% of their heat to the plenum. (d) Open-louvered, baffled units transfer about 75% of their heat. When they are ducted, heat transfer upward can be as high as 85%.*

- 6. Use *efficient light sources and accessories:* high efficacy, high CRI light sources

Conceptual-level approaches for energy-conscious lighting design

- Select *an appropriate lighting system*
  - Six approaches to light delivery: indirect, semi-indirect, direct-indirect, general diffuse, semi-direct, direct
  - Detailed in Section 16.6
- *Use daylight, and use it properly.*
  - Daylight must be considered as a basic light source that is subject to both weather variations and time
  - variations.
  - Window luminance can cause severe and even disabling glare

Conceptual-level approaches for energy-conscious lighting design

- *Use energy-efficient lighting control strategies* (dimming, occupancy sensing, daylight control, etc.)
  - Without reducing lighting effectiveness, proper controls can reduce energy consumption as much as 60%.
- *Use light finishes on ceilings, walls, floors, and furnishings.*
  - Benefit #1: Producing higher illuminance levels
  - Benefit #2: Decreasing uncomfortable luminance ratios between luminaire and upper wall, or task and background.
  - Recommended reflectance ranges → ceiling: 80-90%, walls: 50-60%, floors: 20-40%, furniture: 25-45%

Other lighting design recommendations: ASHRAE/IESNA 90.1 standard (textbook p.809)

1. Buildings shall have some form of automatic lighting shutoff control.
2. Where applicable, occupancy sensors and automatic daylight compensation controls should be used.
3. Separate spaces must have separate controls.
4. Enclosed rooms should have controls that allow for at least two lighting levels.
5. Where supplemental lighting is used, in order to avoid uncomfortable luminance ratios, the ambient level should not be lower than a third of the task level.
6. Accent lighting should not exceed five times the ambient lighting level. In merchandising areas where contrast between ambient and task levels is critical, ambient levels should be reduced as much as is practical.
7. Before specifying superreflective aluminum in luminaires, establish that the high reflectance will be maintained in the application being considered and that recommended luminaire maintenance procedures can and will be implemented.
8. Utilize low-energy/low-maintenance exit signage where permitted by local codes; such equipment is readily available.

Design evaluation

- Three aspects: lighting, cost, energy
- Lighting
  - quantity, quality, luminance ratios, mood, ambience, texture, color, variation, psychological impressions, orientations, daylight use, etc.
- Cost
  - initial cost, life cycle cost, annual operating cost, operating budgets, construction budgets
- Energy
  - HVAC system sizing, heating & cooling energy, lighting energy
- Architectural engineer: lighting design, HVAC design, energy and cost consulting, etc.