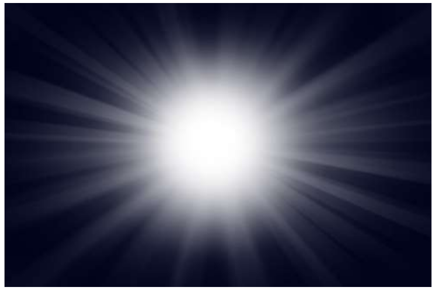
Direct glare


Small-size high-output

vs.


Large-area low-luminance

- Factors: luminance, size, and position of each light source in the vision field, the adaptation level of the eye (background luminance)
- Glare is proportional to a source's luminance and its apprehended *solid* angle.
  - Source luminance is more important than the number of sources. The reduction in glare by 0.5 *L* is greater than by 0.5 *n*. (10 lamps of 1.0 L vs. 20 lamps of 0.5 L)
  - A bare bulb vs. luminous ceiling
- The amount of direct glare is inversely proportional to the background luminance (eye adaptation level).
  - A ceiling fixture with a luminance of 4,000cd/m^2 with an eye adaptation level of 150cd/m^2 (indoor space) vs. with an eye adaptation level of a daylight condition (1,500cd/m^2)
  - An automobile's headlights at night vs. in daylight

Visual Comfort Probability (VCP)

- Defined as the percentage of normal-vision observers who will be *comfortable* in that specific visual environment.
- A set of standard conditions for VCP calculation (established by IESNA)
  - 1000-lux illuminance
  - Room reflectances: 0.8 for ceiling cavity, 0.5 for wall, 0.2 for floor cavity
  - Luminaire mounting height: 2.55, 3.0, 3.9, 4.8m (8.5, 10.0, 13.0, 16.0 ft)
  - Luminaires are fractionally apportioned over the ceiling according to a standard scheme
  - A given range of representative room dimensions including square, long narrow, and short wide rooms
  - An observation point: 1.2m(4ft) in front of the center of the rear wall and 1.2m(4ft) above the floor
  - A horizontal line of sight looking directly forward
  - A head-up field of view limited to 53° above and directly forward from the observer

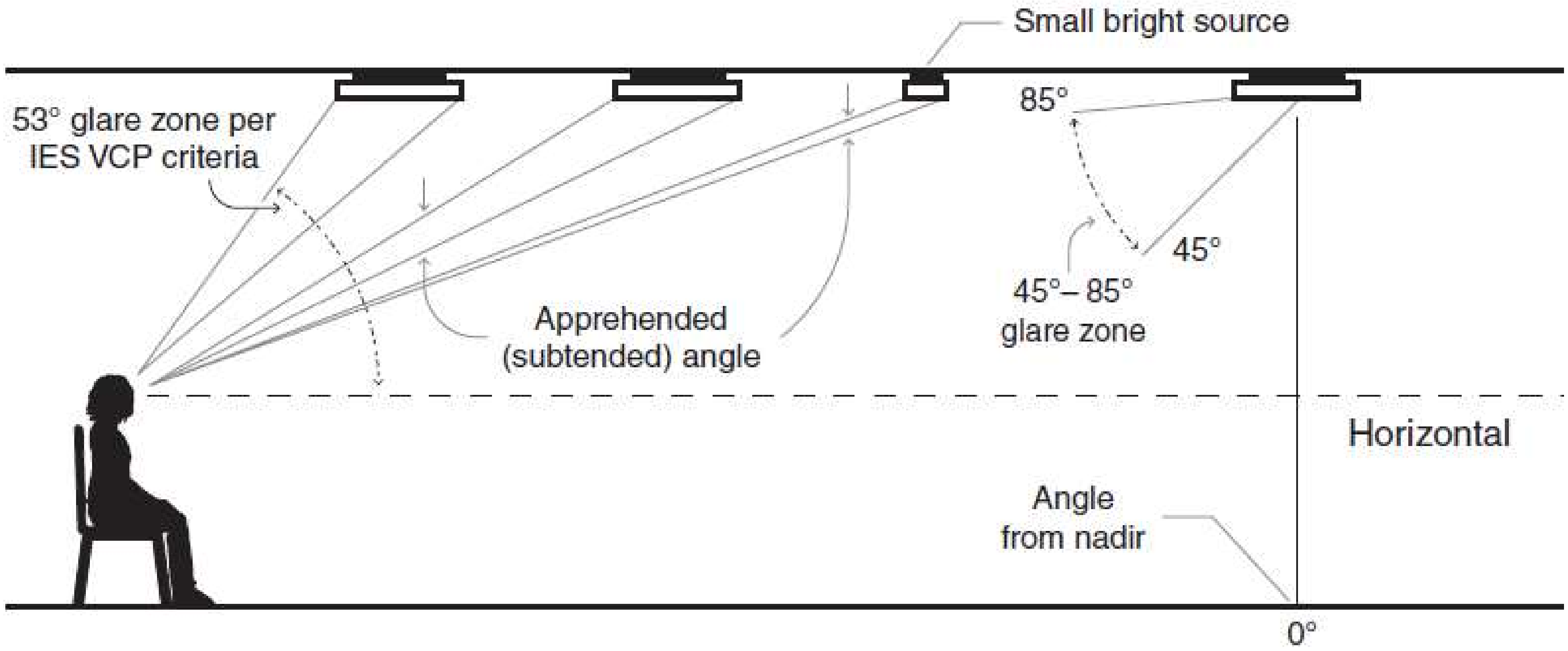
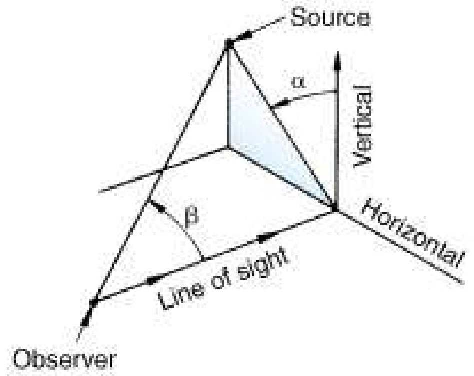


Fig. 6.24 *Evaluation of direct glare potential. The glare contribution of each source depends upon its size (subtended solid angle), luminance, and location in the field of view. Note that the solid angle of a small source is such that even with high luminance, it is not generally objectionable. Such sources are normally called sparkle. Glare is much more likely when a bright source is seen against a darker background; therefore, light-colored ceilings and upper walls are recommended. (Drawn by Martin Lee.)*

VCP calculation



$$P = \exp[(35.2 - 0.31889\alpha - 1.22e^{-2\alpha/9})10^{-3}\,\beta + (21 + 0.26667\alpha - 0.002963\alpha^2)10^{-5}\,\beta^2]$$

$$F_v = \frac{L_w\omega_w + L_f\omega_f + L_c\omega_c + \sum L_s\omega_s}{}$$

$$Q = 20.4\omega_s + 1.52\omega_s^{0.2} - 0.075$$

$$M = \frac{0.50 L_s Q}{P F_v^{0.44}}$$

$$\mathrm{DGR} = \left(\sum_{i=1}^{n} M_i\right)^{n^{-0.0914}}$$

n: number of sources

DGR= Discomfort Glare Rating

$$\mathrm{VCP} = \frac{100}{\sqrt{2\pi}} \int_{-\infty}^{6.374 - 1.3227 \ln \mathrm{DGR}} e^{-t^2/2}\,dt$$

Three conditions for avoidance of direct glare

- VCP ≥ 70
- Max(Luminaire L)/Average(Luminaire L) ≤ 5 (preferably 3) at 45°, 55°, 65°, 75°and 85° from the nadir, crosswise and lengthwise
- Max(Luminaire L) crosswise and lengthwise do not exceed:

Fig. 6.24

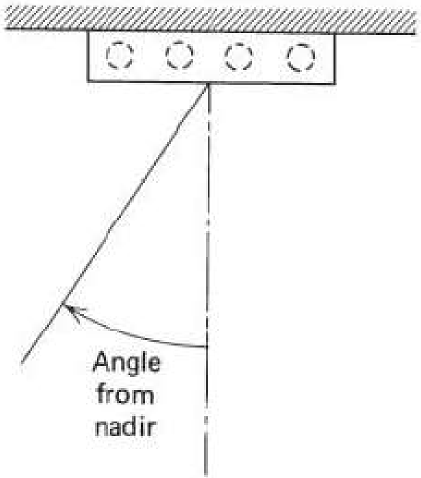
Angle Above Nadir (degrees)	Maximum Luminance (cd/m^2)
45	7710
55	5500
65	3860
75	2570
85	1695

Example of published VCP

4–40-W Lamps
Prismatic Lens Diffuser

Average Luminance Data cd/m²

Vertical Angles	*Across Axes*	*Along Axes*
60°	2000	1750
65°	1060	1075
70°	500	560
75°	410	380
80°	480	343
85°	560	420



IES Visual Comfort Probability Data

Room Size		*Luminaires Lengthwise*			*Luminaires Crosswise*		
		Ceiling Height (in ft)					
W (ft)	*L (ft)*	*8.5*	*10.0*	*13.0*	*8.5*	*10.0*	*13.0*
20 ×	20	80	77	76	79	75	72
	30	80	78	76	79	76	73
	40	82	79	77	79	77	74
	60	80	80	78	79	77	75
30 ×	20	84	80	77	82	78	74
	30	83	80	77	81	79	74
	40	82	80	78	81	79	75
	60	82	80	78	80	79	75
	80	82	80	78	80	78	76

Reflectances:
- Wall 50%
- Ceiling cavity 80%
- Floor cavity 20%

Work plane illumination: 1000 lux

Fig. 6.25 A typical set of a manufacturer's published VCP and luminance data.

Discussions

- Advantages of the standardized procedure (even before a specific lighting layout has been made)
  - Simplification of VCP calculations
  - Comparison between luminaires
- Limitations
  - In small spaces, VCP has little significance. In such rooms less than 6m in length and width, the luminaires are largely out of the view.
  - Tabulated VCP figures are given for worst viewing position. Because VCP varies dramatically with observer position, the VCP values given are lower than the space's average VCP.

Veiling reflections and reflected glare

- Veiling reflections vs. reflected glare. Two terms are interchangeable.
  - Veiling reflections: related to dull finish surfaces
  - Reflected glare: related to polished or mirror surfaces
- Nature of problem: Fig. 6.26

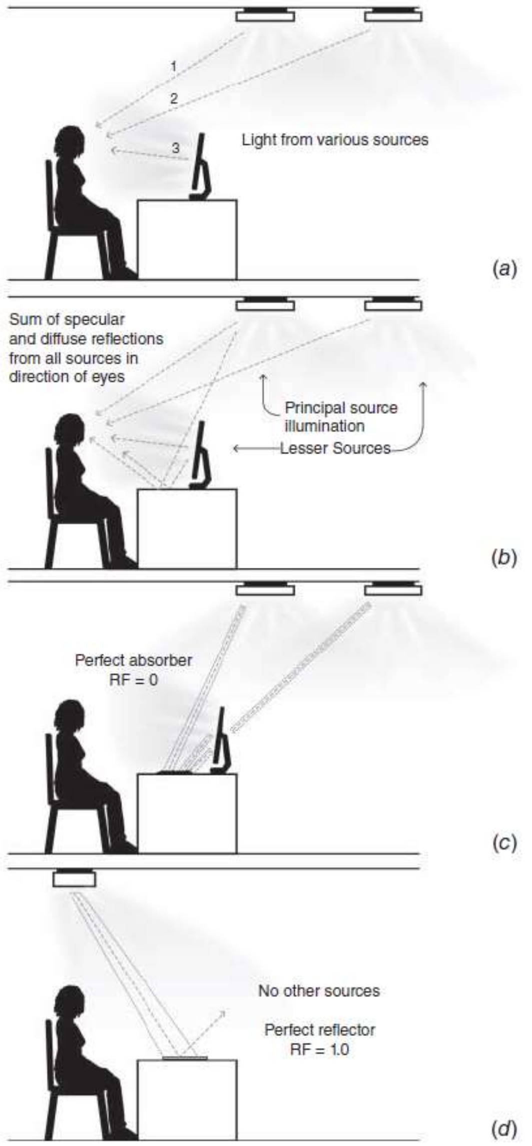


Fig. 6.26 (a) The nature of the seeing process requires that light from a source or sources be reflected by the task into the eye. (b) The light entering the eye is the sum of all the reflected light, specular and diffuse, from all sources in the direction of the eye. If the task is specular, all the sources will be seen reflected in the task. (c) A perfectly absorptive object is jet black because it reflects nothing. (d) A perfectly reflective object positioned as shown is also seen as black because geometrically it cannot reflect light into the eyes. (Drawn by Martin Lee.)

Geometry of reflected glare

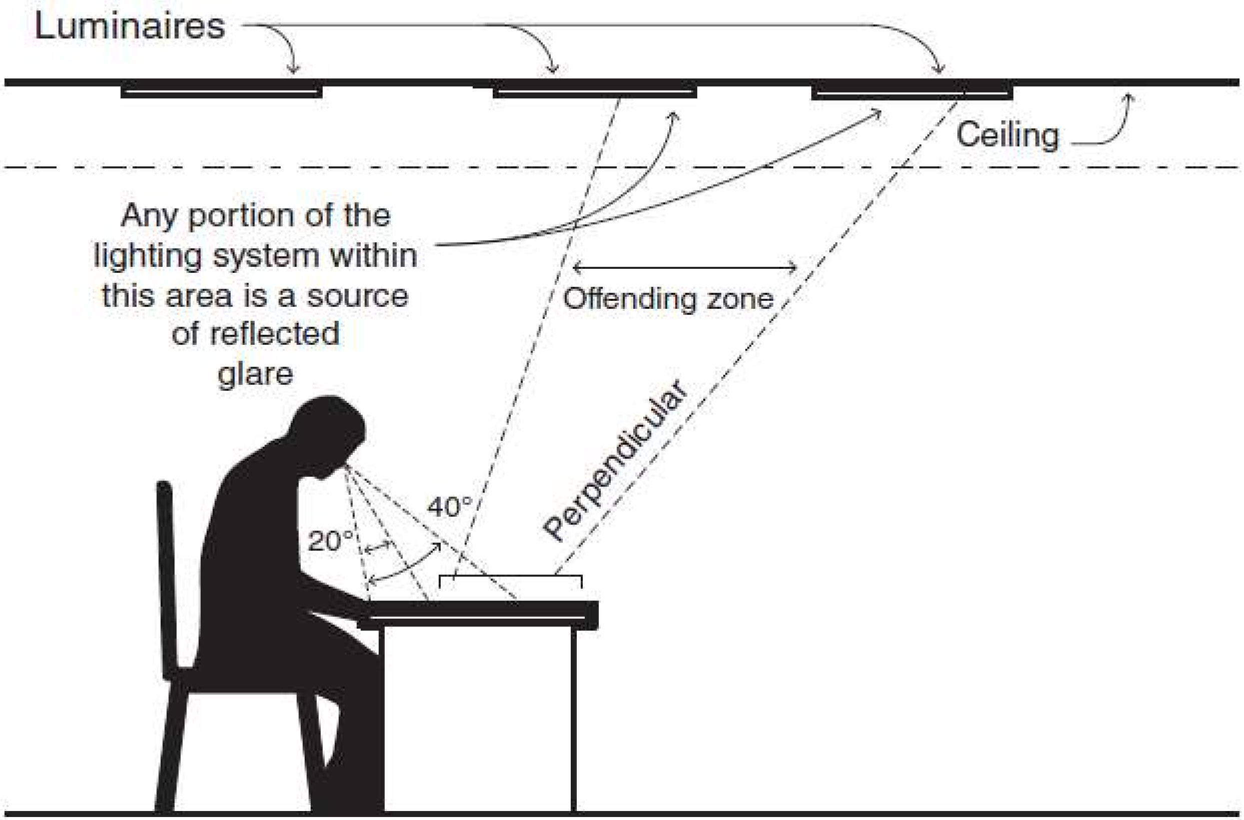


Fig. 6.27 Geometry of reflected glare. Because normal desktop, head-down viewing angles vary from 20° to 40° from the vertical, the offending zone (wherein light sources are likely to be reflected from tasks) is the area on the ceiling corresponding to specular reflection between these two angles. Note that the higher the ceiling, the larger this area becomes. Also note that the offending zone will move as the table tilt changes. (Drawn by Martin Lee.)

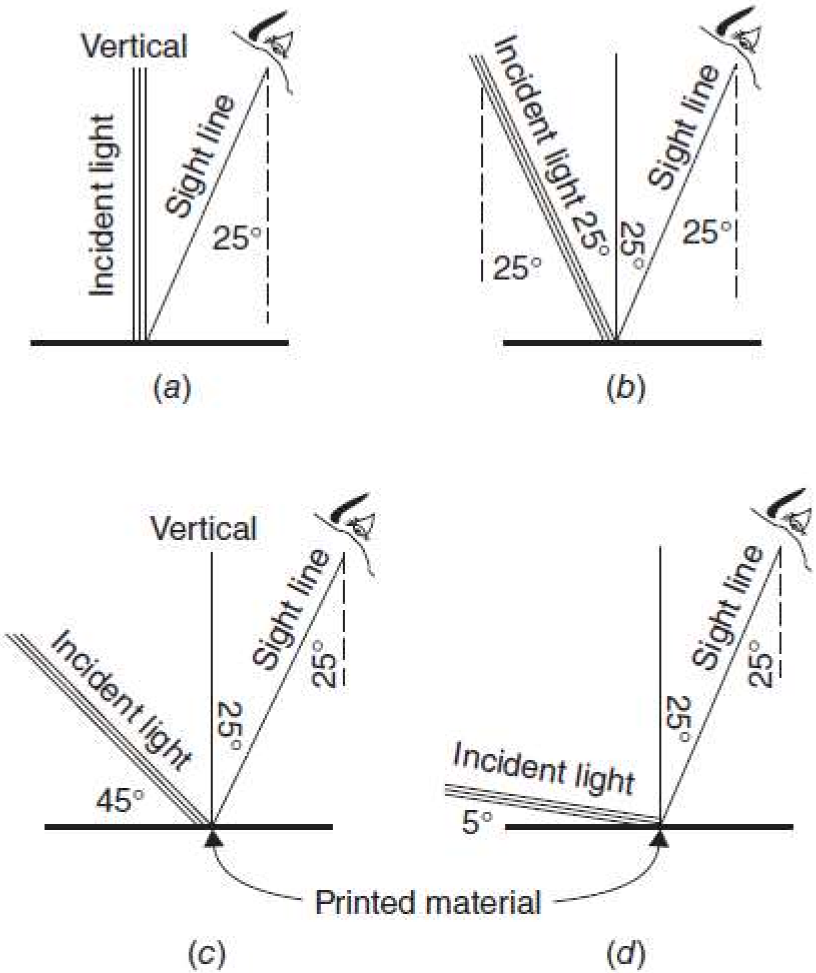


Fig. 6.28 *The usual viewing angle to a horizontal surface is between 20° and 40° from the vertical—25° is the most common viewing angle. With vertical incident light on a diffuse surface (such as a textbook page) (a), the print can appear dark and clear. When the angle of light incidence is equal to the viewing angle (b), a mirrorlike reflection can make the page illegible. Even with a diffuse paper, the print is light at best and almost invisible at worst. As the angle of incidence becomes larger (c), reflected glare decreases. When the incident light is at a very low angle (d), there is little reflected glare, and the print appears lighter.*

Contrast reduction

- The principal effect of the reflection of a light source in a visual object is to reduce contrast between the object and background, thus reducing visibility: 광원의 반사가 contrast를 줄임으로, visibility를 감소시킴
- Contrast reduction increases:
  - (1) When the incident angle approaches the viewing angle, the specularly reflected component of this light becomes more and more pronounced, and task contrast drops.
  - (2) When the specular reflectance of the task and background is high, as with the glass screen of a visual display terminal.

$$C = \frac{(L_{BD} + L_{BS}) - (L_{TD} + L_{TS})}{L_{BD} + L_{BS}} \qquad (6.9)$$

contrast: considering specular and diffuse reflection both

L_{BD} = Background luminance caused by diffuse reflectance
L_{BS} = Background luminance caused by specular reflectance
L_{TD} = Task luminance caused by diffuse reflectance
L_{TS} = Task luminance caused by specular reflectance

TABLE 6.4 Typical Reflectances

Material	Reflectance	
	Specular	Diffuse
Matte black paper	0.0005	0.04
Matte white paper	0.0030	0.77
Newspaper	0.0065	0.68
Very glossy white photo paper	0.048	0.83
Metallic paper—copper	0.11	0.28
Dull black ink	0.006	0.045
Super gloss black ink	0.039	0.016

Source: Courtesy of IESNA.

Why are the values so small?
Many surfaces and finishes used in architecture exhibit a reflectance that is sufficiently diffuse to be considered perfectly diffuse (IESNA handbook, 2001)

EXAMPLE 6.4 Assume an interior space lit to an average illuminance of 75 fc (750 lux) using bare bulb fluorescent fixtures (with luminance = 7000 cd/m² [2000 fL]). The task is drawing with ink on paper. Reflectances are:

	Specular	Diffuse
Ink (Task)	0.021	0.038
Paper (Background)	0.018	0.71

Calculate the task contrast without and with reflec- specular
tion of the 2000 fL source on the work. L_s

SOLUTION

1. Without specularity, using Equation 6.7 for diffuse reflection only:

$$C = \frac{R_B - R_T}{R_B} = \frac{0.71 - 0.038}{0.71} = 0.947$$

2. With specularity, using Equation 6.9,

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

where

$$L_{BD} = 75 \text{ fc} \times 0.71 = 53.25$$

$$L_{BS} = 2000 \text{ fL} \times 0.018 = 36.0$$

$$L_{TD} = 75 \text{ fc} \times 0.038 = 2.85$$

$$L_{TS} = 2000 \text{ fL} \times 0.021 = 42.0$$

and

$$C = \frac{(53.25 + 36) - (2.85 + 42)}{53.25 + 36} = 0.497$$

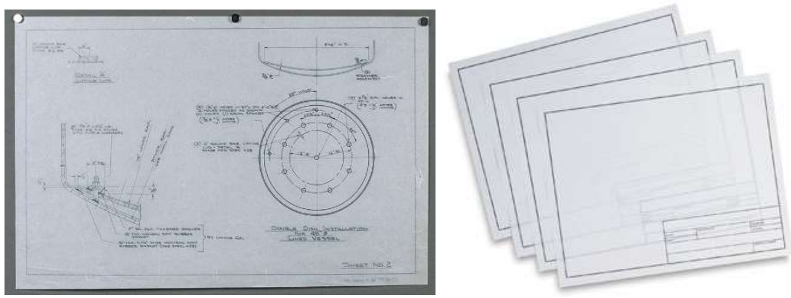
which is roughly half of the previous contrast. If the contrast is normalized to the maximum contrast (as is usually done), the contrast reduction R can be expressed as:

$$R = 1 - \frac{C}{C_{MAX}} \qquad (6.10)$$

Thus, in this case, contrast reduction would be:

$$R = 1 - \frac{0.497}{0.947} = 0.47 \text{ or } 47\%$$

■



Vellum paper

From Ch.16

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

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

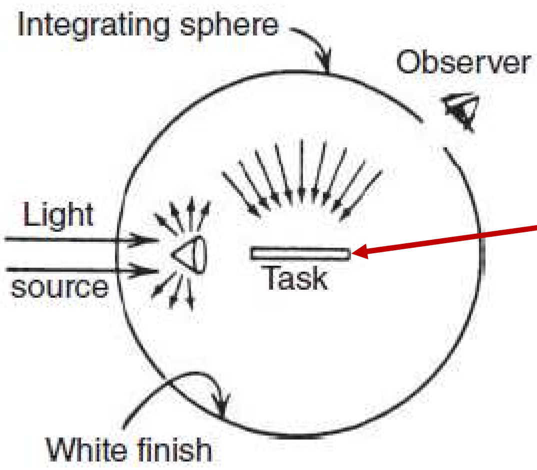
With this contrast (0.72), undesirable contrast reduction from a no-glare situation has been improved from the original 47% reduction (0.947 to 0.497) to a 24% reduction (0.947 to 0.72). However, because a contrast reduction of even 24% is unwanted, a change in task-source geometry or a change in source 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.

Equivalent Spherical Illumination (ESI)

- In order to approach the problem of contrast reduction (reflected glare), it was required to define glare-free lighting (reference lighting). Thus, ESI was developed.
- ESI: diffuse and glare-free illuminance out of its total illuminance

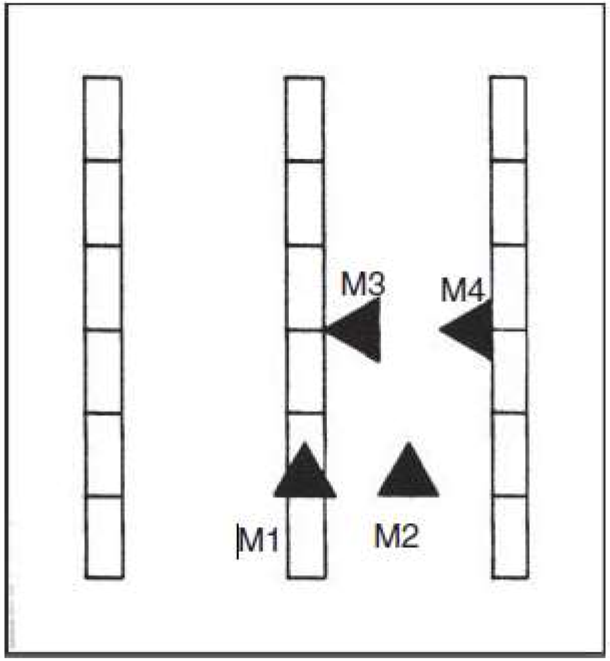


The illuminance falling on this surface is entirely uniform and diffuse.

Fig. 6.31 Spherical illumination is produced by illuminating an object by diffuse reflection from the inside walls of an integrating sphere. The light source and observer are normally external.

There are no high-luminance sources reflected in it.

This is glare-free illuminance!!



		Observer Position			
		M1	*M2*	*M3*	*M4*
TI	2L	108	92	125	118
	4L	215	185	250	235
CRF	2L	0.75	1.00	0.82	1.01
	4L	0.76	1.00	0.83	1.03
ESI	2L	17.8	91.9	31.5	127.8
	4L	28.4	185.3	58.1	308.3

TI–Task illuminance
2L–2 lamps (inside pair)
4L–4 lamps
CRF–Contrast Rendition Factors

Fig. 6.32 *A test classroom illuminated by three widely spaced rows of four-lamp fixtures with lens-type wraparound diffusers. Observer positions are shown by arrows. The row of fixtures in front of position M4 is too far forward to be in the offending zone. (From Sampson, 1970.)*

10 feet spacing, see Fig. 16.24

Luminance ratios

- Contrast is desirable in the object of view. But, high contrast (or high luminance ratio) is not always desirable (Fig. 6.33).
- Thus, the recommended maximum luminance ratios are suggested → Table 6.5

TABLE 6.5 Recommended Maximum Luminance Ratios[a]

Note: To achieve a comfortable brightness balance, limit luminance ratios between areas *of appreciable size* as seen from normal viewing positions as follows:

1 to one-third	Between task and adjacent surroundings
1 to one-tenth	Between task and more remote darker surfaces
1 to 10	Between task and more remote lighter surfaces
20 to 1	Between luminaires (or fenestration) and surfaces adjacent to them
40 to 1	Anywhere within the normal field of view

[a]These ratios are recommended as maximums; lesser ratios are generally beneficial.

light, diffuse linoleum placed over the dark desktop

dark, specular[polished] desktop

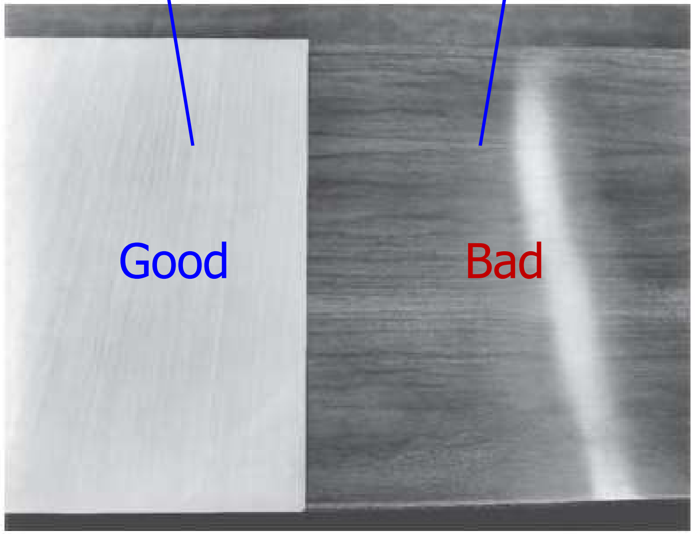


Fig. 6.33 The reflected glare from luminaires disappears when a piece of light, diffuse linoleum is placed over the dark, polished desktop. Light-colored desktops with 35% to 50% reflectance result in task-to-background ratios within the 3:1 recommended range. Before the linoleum was placed, a reflection like the one seen on the right also existed on the left of the desk due to another luminaire. (Courtesy of IESNA.)

Control of reflected glare

- Will be addressed in detail in Ch.16

Color Temperature (CT)

- When a blackbody is heated, it first glows deep red, then cherry red, then orange, until it becomes blue-white hot.
- The color of the light radiated is related to its temperature.
- By developing a blackbody Color Temperature (CT) scale, we can compare the color of a light source to this scale.
- 3400°K for halogen lamp, 4200 °K for fluorescent tubes.

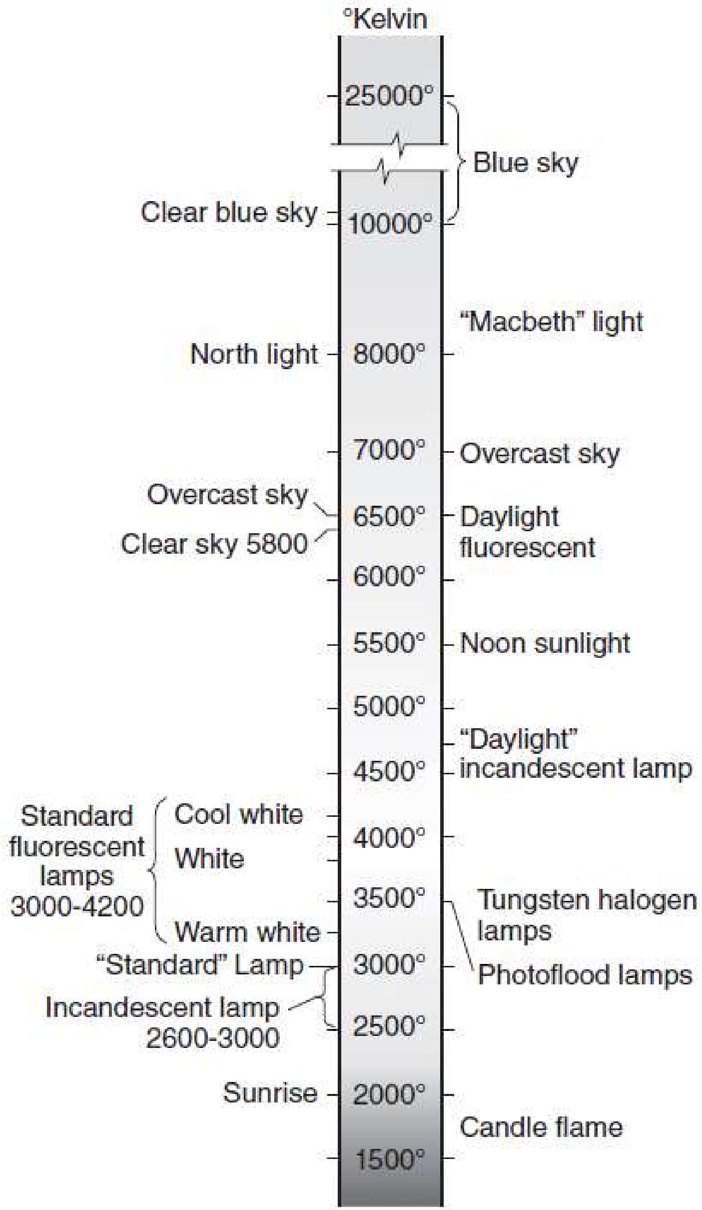


Fig. 6.34 Approximate color temperatures of common illuminants.

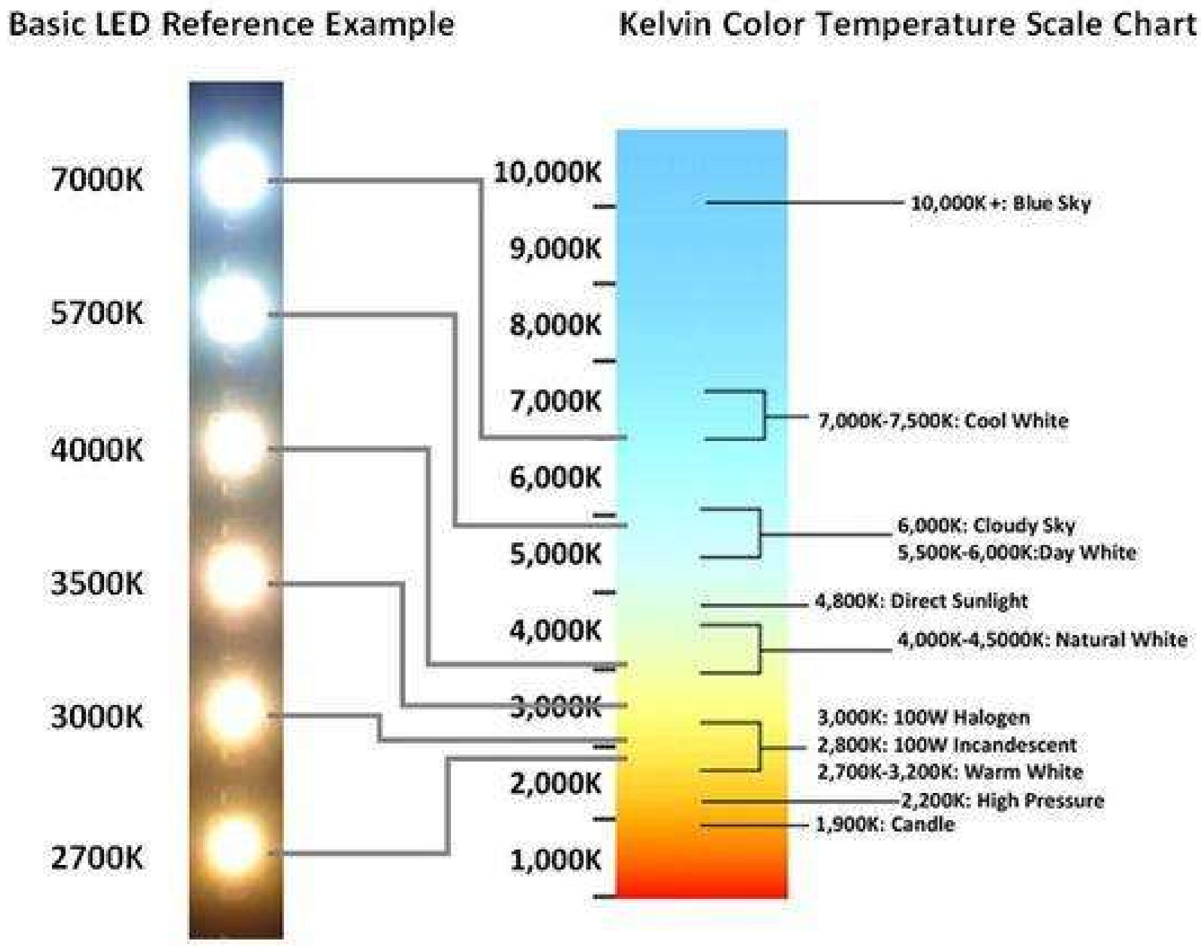


Image source: https://richbrilliantwilling.com/blogs/light-reading/7988231-understanding-color-temperature-of-led-lighting

CCT (Correlated Color Temperature)

- Why CCT?
  - Strictly speaking, CT can be assigned only to a light source that produces light by heating, such as incandescent lamp (필라멘트 온도는 3,000°C까지 상승).
  - CCT is for other sources such as fluorescent and LED lamps because there is no relation whatever between operating temperature of the light sources and the color of the light produced.
- Correlated Color Temperature (CCT): the temperature of a black body whose chromaticity most nearly matches that of the light source.

Object color

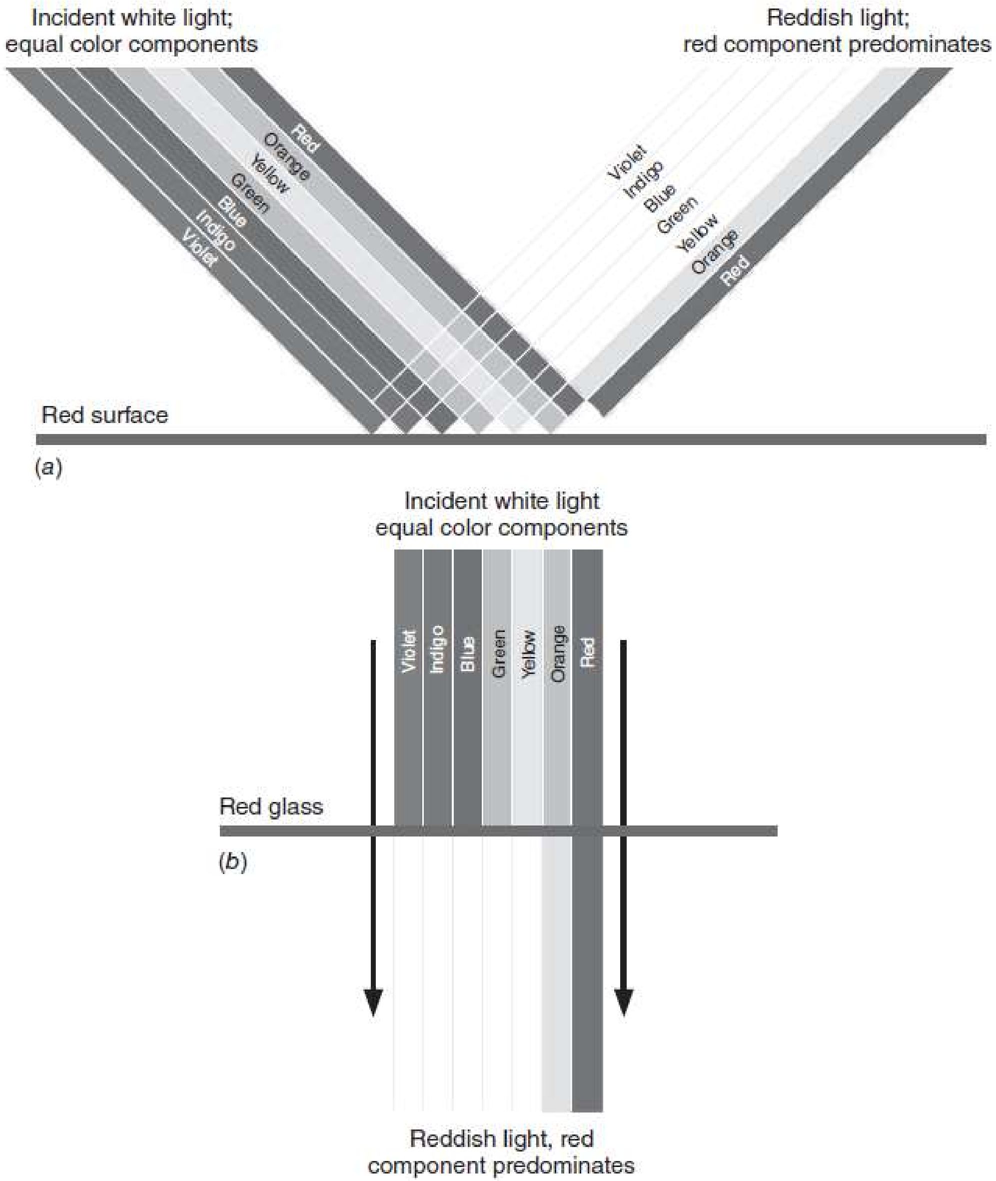


Fig. 6.40 Selective absorption of materials relative to (a) reflected light and (b) transmitted light.

The color of an object is its ability to modify the color of light incident on it by selective absorption.

An object is technically said to be colorless when it does not exhibit selective absorption, reflecting and absorbing the various components of the incident light nonselectively. Thus, white, black and all shades of gray are colorless, neutral, achromatic, or more precisely, lack hue.

Spectral distribution of light sources

- 물체의 선택적 흡수와 반사에 의해 우리는 색을 인지하므로, 물체의 색을 보기 위해서는 광원이 그 색을 가지고 있어야 함
- It is necessary that the illuminant (lighting source) contain the color of the object in order for us to see the object’s color.

Discharge lamp

The principal difference is the amount of blue in their spectrum.
A blue object will be bright under "cool white" and dull under "warm white".

실제적으로 연속된 선이 아님!

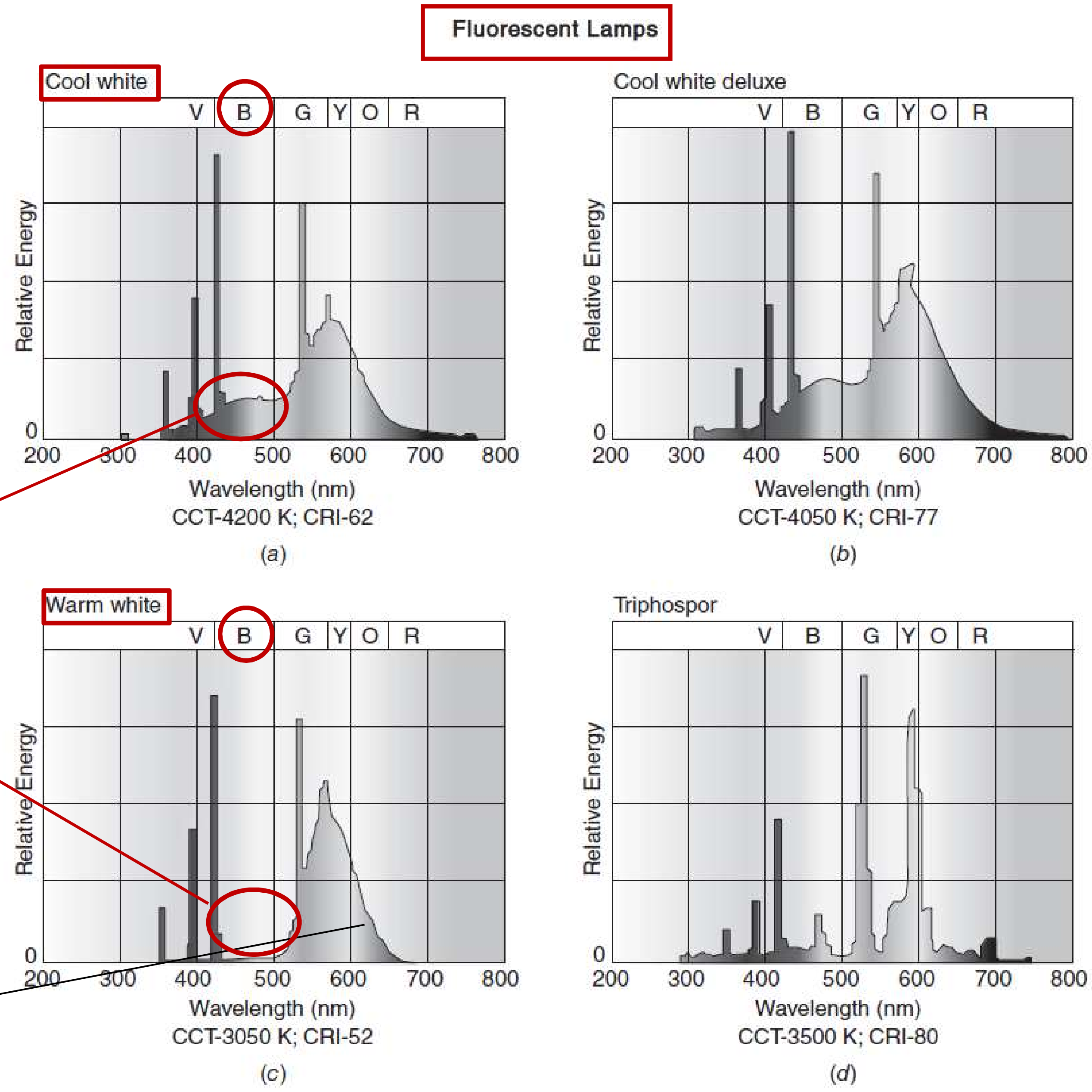


Fig. 6.37 Spectral energy distribution of several fluorescent lamp types with their correlated color temperatures (CCT) and color rendering indices (CRI). The curves are not truly continuous, but consist of individual color lines; they are shown connected for simplicity. These graphs are generic and show patterns of wavelength distribution; consult manufacturers' data for the output spectrum of a specific lamp.

Discharge lamp

Low-pressure sodium lamps (저압나트륨등)의 분광분포

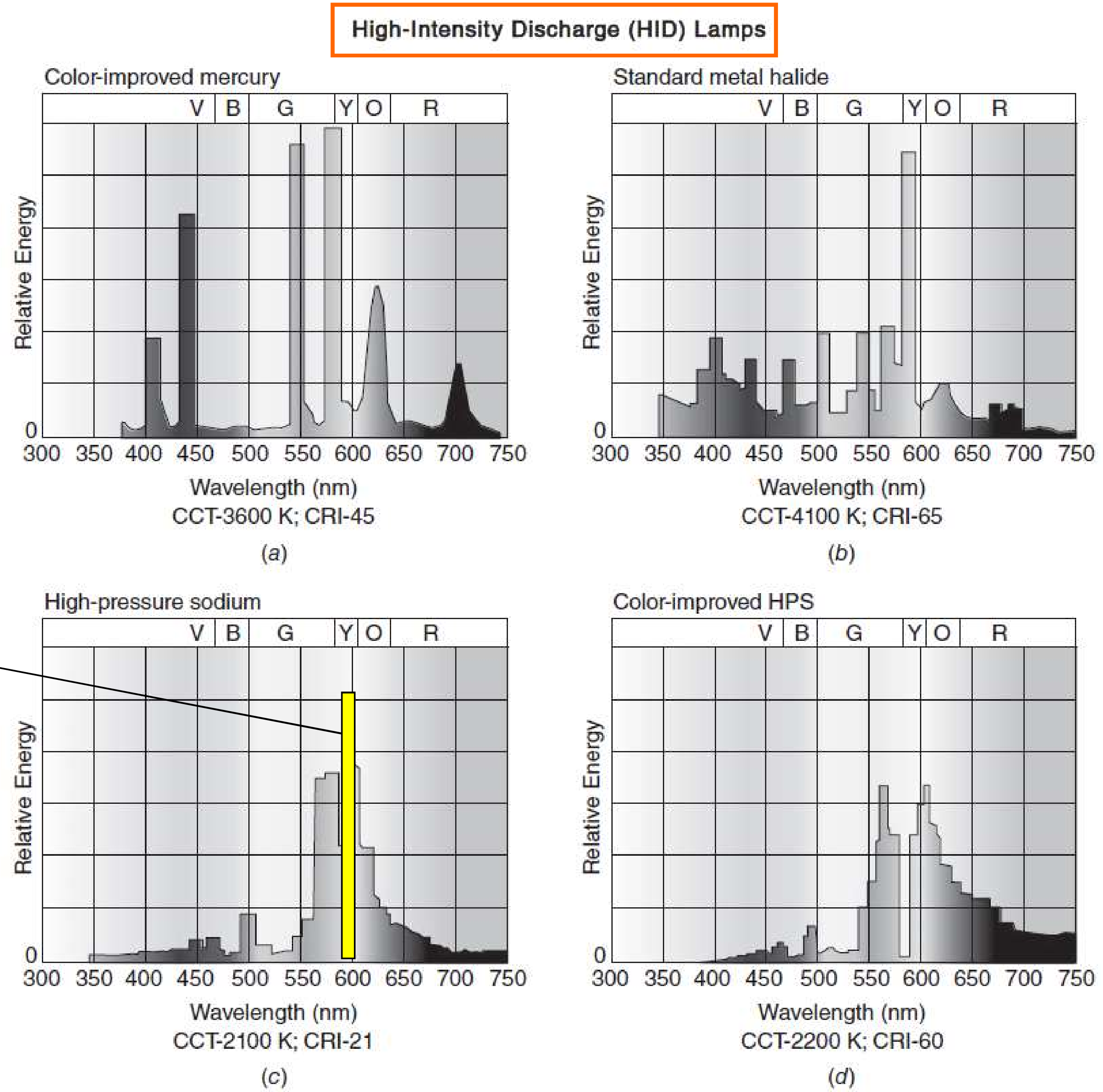


Fig. 6.38 Spectral energy distribution of typical high-intensity discharge (HID) lamps with their CCT and CRI. These graphs are generic and show patterns of wavelength distribution; consult manufacturers' data for the output spectrum of a specific lamp.

A continuous line: the spectrum of a light source that produces light as a result of heating.

As wattage increases, the color changes from orange-red to white.

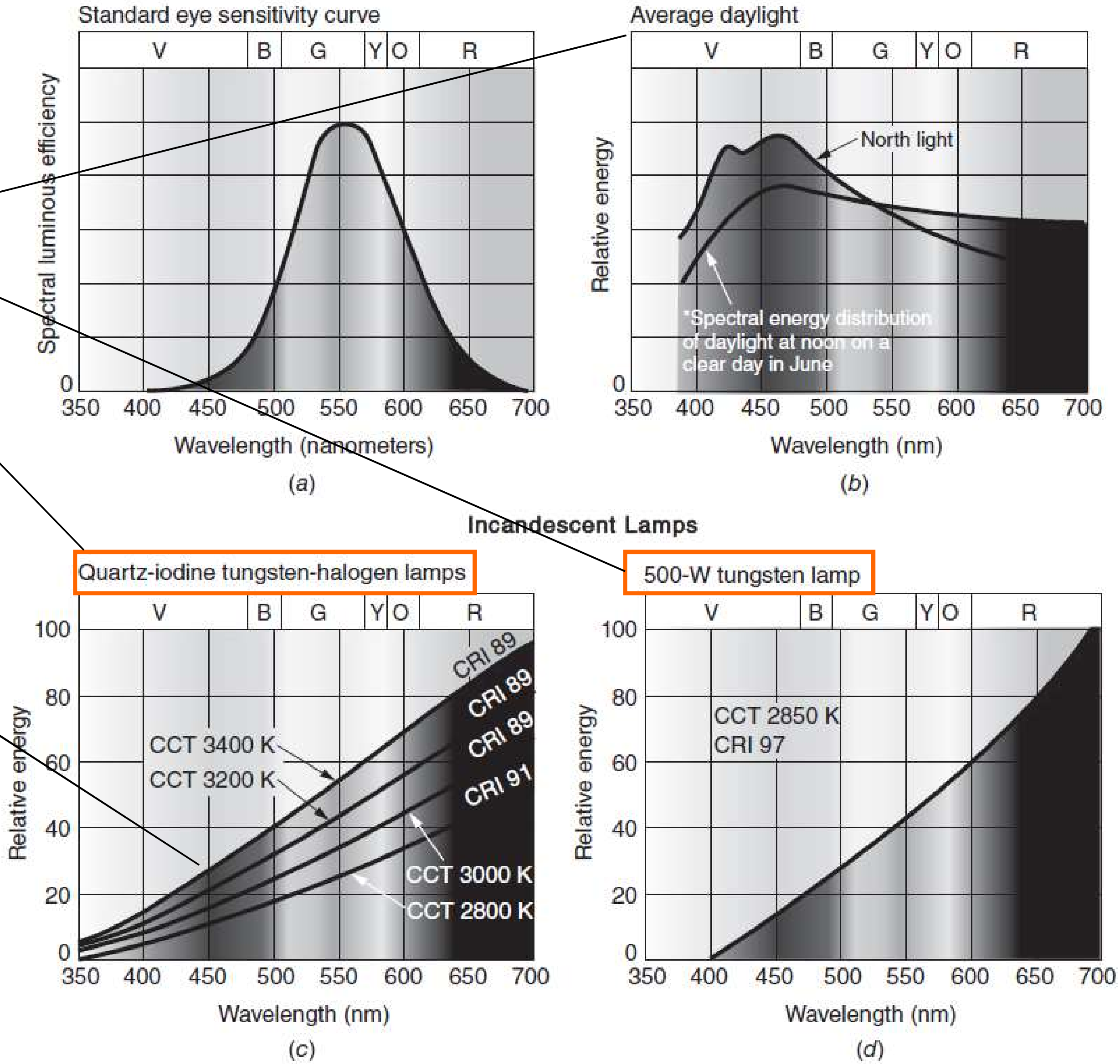


Fig. 6.39 (a) Standard photopic (cone-based) eye sensitivity curve. Note that maximum sensitivity occurs in the daylight range of 500–750 nm. (b) Spectral energy distribution of two specific types of daylight. North light, with a color temperature of 8000 K to 10,000 K, peaks in the blue range, whereas noon daylight contains all spectral colors in roughly equal proportions. (c) Tungsten-halogen lamps are incandescent sources and therefore contain all spectral colors. As wattages increase, the color changes from orange-red to white, and the CRI drops slightly. (d) A simple filament-type incandescent lamp is very close to being a blackbody radiator (i.e., its actual temperature and CCT are almost the same). This is reflected in its high CRI (97).

Color Rendering Index (CRI)

- CRI is a measure of how closely the illuminant (lighting source) approaches daylight of the same color temperature.
- CRI of 100 indicates an illuminant whose spectral content is equal to daylight of that temperature.
- Two sources cannot be compared unless their color temperatures are equal or quite close.
- Refer to Table 6.6

- CRI: a metric to quantify the color rendering properties of a particular light source.
- If CRI =100 → the object color under the artificial light appears equal to that under the daylight of the same color temperature.

Criticism

- Current CRI is not a perfect solution for measuring the quality of illumination.
- Various CCTs must be adopted: scoring 100 at one CCT does not imply equal illumination quality as scoring 100 at another CCT.
  - The "warmer" light colors (a 2700K incandescent bulb) vs. a neutral white light (4800K direct sunlight).
  - Please refer to the figure in the next slide.

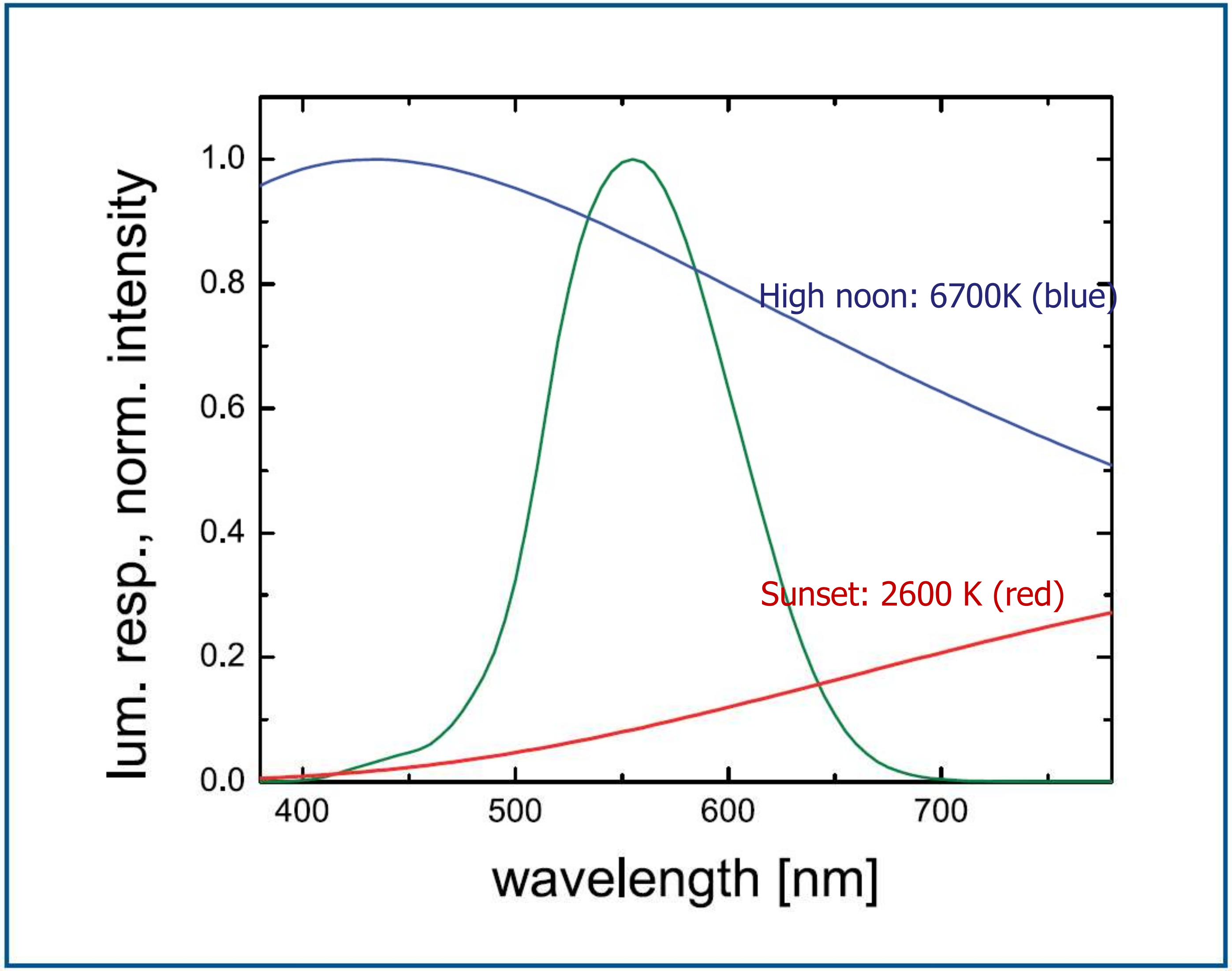


Fig. 1. *Visual response curve of the human eye (green), and the spectral power distribution of black body sources with a temperature of 6,700 K (blue) and 2,600 K (red). The 6,700 K curve is normalized to its peak value, for the 2,600 K curve we have assumed an overall power equal to that of the 6,700 K source.*

Source: Basics of Lighting: Efficacy, Color Rendering, and Color Temperature
https://en.wikipedia.org/wiki/High-CRI_LED_lighting

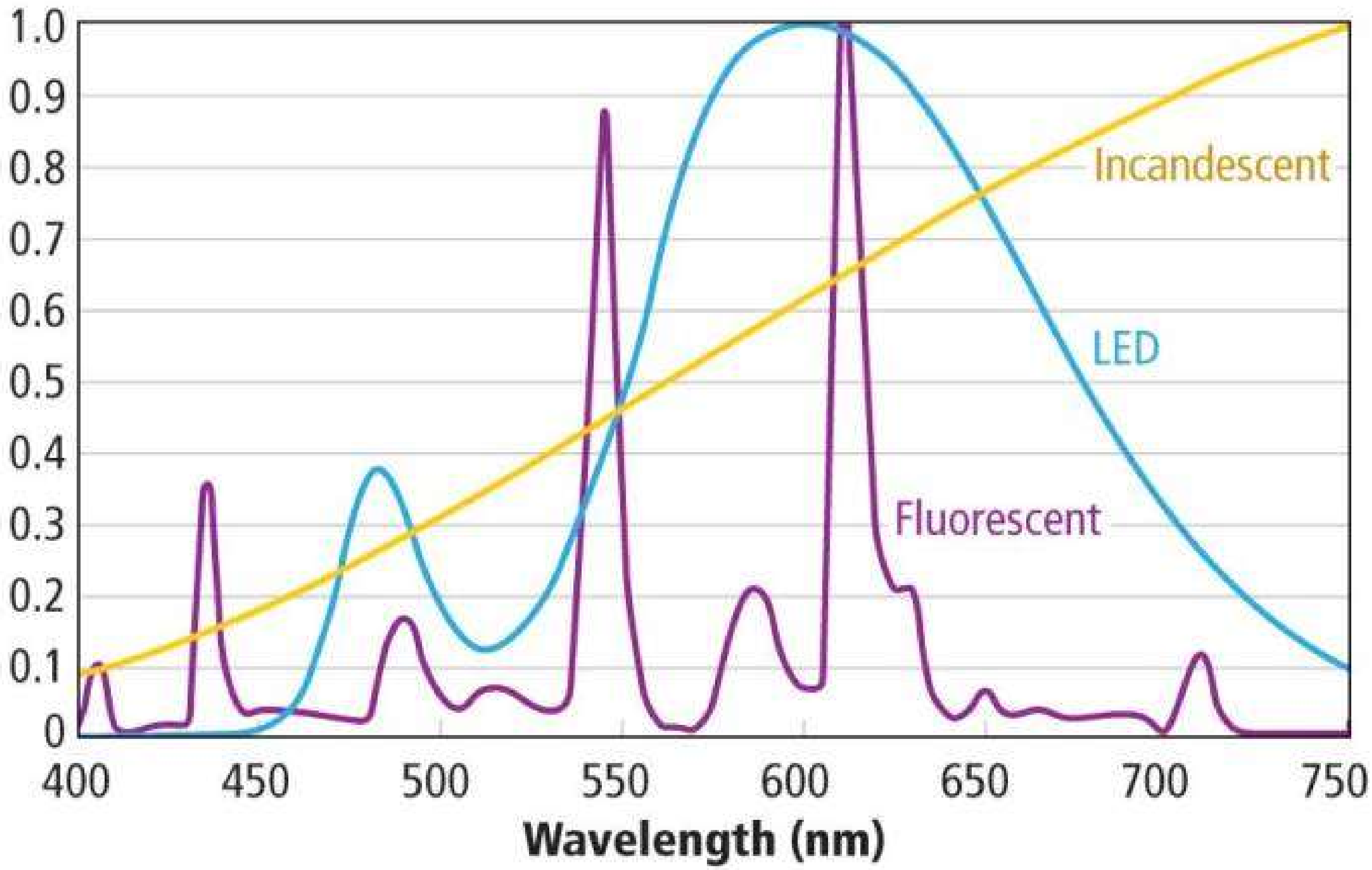


Image source: http://www.ledsmagazine.com/articles/print/volume-10/issue-2/features/understand-color-science-to-maximize-success-with-leds-part-4-magazine.html

TABLE 6.6 Effect of Illuminant on Object Colors

Lamp	CRI (approximate)	CCT (K)	Whiteness	Colors		Notes
				Enhanced	Grayed	
			FLUORESCENT			
Warm white	52	3050	Yellowish	Orange, yellow	Red, blue, green	
Cool white	62	4200	White	Yellow	Red	
	Orange Blue					
Cool white deluxe	77	4050	White	Green Orange Yellow	Red	
Triphosphor	75	2800	Yellowish	Red Orange	Deep red, blue	
	80	3000	Pale yellowish	Red Orange Green	Deep red	
			MERCURY			
Clear	20	7000	Blue–Green	Blue Green	Red Orange	Poor overall color rendering
Deluxe	45	3700	Pale purplish	Deep blue, red	Blue– green	Shift over life to greenish
			METAL–HALIDE			
Clear	65	4000	White	Blue Green Yellow	Red	May shift to pinkish over life
Phosphor-coated	80	4200	White	Blue Green Yellow	None	Shifts to pinkish over life
			HIGH-PRESSURE SODIUM			
Standard	21	2100	Yellowish	Yellow Green	Red, blue	
Color-corrected	60	2200	Yellowish-white	Red Green Yellow	Blue	CRI decreases slightly over life
			INCANDESCENT			
Incandescent	99+	2900	Yellowish	Red, orange, yellow	Blue, green	
LED						
High-CRI LED	99	4990		All colors Blue		
Mid-CRI LED	80	5000		Orange, Green, blue	Red	
RGB LED	73	5090				
DAYLIGHT						
Daylight	99+	5000		All colors		