Step 1

- Step 1: dimensional data, reflectances of the room surfaces

STEP 1. Establish dimensional data for the room. Room length, width, and height are determined by the architectural design process. In offices, schools, and many other occupancies, the work plane is typically 30 in. (760 mm) above the finished floor (AFF). In shops, 42 to 48 in. (1066 to 1220 mm); in a carpet store at floor level. The location of the working plane and placement of the lighting fixtures relative to the ceiling plane will determine the three *h* terms, representing the heights of the zonal cavities. Estimate the initial reflectances of major room surfaces (selecting reflectances that conform to those suggested by the values in Table 16.5 is fine for preliminary design). Fill in the information in a sketch, as in Fig. 16.13.

TABLE 15.2 Approximate Reflectance Values for Paints

Medium-Value Colors	Reflectance (%)
White	80–85
Light gray	45–70
Dark gray	20–25
Ivory white	70–80
Ivory	60–70
Pearl gray	70–75
Buff	40–70
Tan	30–50
Brown	20–40
Green	25–50
Olive	20–30
Azure blue	50–60
Sky blue	35–40
Pink	50–70
Cardinal red	20–25
Red	20–40

From MEEB 12th Ed.

Step 2: Find CR, RCR, CCR

STEP 2. See again Fig. 16.13. Determine the three cavity ratios of the room by calculation.

The basic expression for a cavity ratio (CR) is:

$$\mathrm{CR} = 2.5 \times \frac{\text{area of cavity wall}}{\text{area of work plane}} \tag{16.11}$$

In a rectangular space, the area of a given cavity wall is $h \times (2l + 2w)$ or $2h(l + w)$; therefore,

$$\mathrm{CR} = \frac{2.5 \times 2h(l + w)}{\text{area of work plane}} \tag{16.12}$$

or

$$\mathrm{CR} = 5h \times \frac{l + w}{l \times w} \tag{16.13}$$

For other than rectangular rooms, the area can be calculated as required by geometry. For instance, in a circular room, the cavity wall area $= h \times 2\pi r$ and the work plane area is πr^2. Thus,

$$\mathrm{CR} = \frac{2.5 \times h \times 2\pi r}{\pi r^2} = \frac{5h}{r} \tag{16.14}$$

For each of the cavities in a rectangular room the cavity ratio is calculated as:

Room cavity ratio

$$\mathrm{RCR} = 5h_{\mathrm{RC}} \frac{l + w}{l \times w} \tag{16.15}$$

Ceiling cavity ratio

$$\mathrm{CCR} = 5h_{\mathrm{CC}} \frac{l + w}{l \times w} \tag{16.16}$$

Floor cavity ratio

$$\mathrm{FCR} = 5h_{\mathrm{FC}} \frac{l + w}{l \times w} \tag{16.17}$$

GENERAL INFORMATION

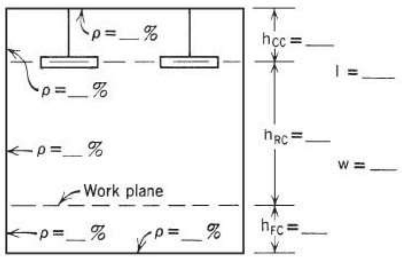
1. Project identification: ______________________________
(Give name of area and/or building and room number)

2. Average maintained illumination for design: ______ lux [footcandles]

Luminaire data:
3. Manufacturer: ______________________
4. Catalog number: ______________________

Lamp data:
5. Type and color: ______________________
6. Number per luminaire: ______________________
7. Total lumens per luminaire: ______________________

SELECTION OF COEFFICIENT OF UTILIZATION



8. Step 1: Fill in sketch at right.

9. Step 2: Determine Cavity Ratios by formulas.

9a. Room cavity ratio, RCR = ______________________
9b. Ceiling cavity ratio, CCR = ______________________
9c. Floor cavity ratio, FCR = ______________________

10. Step 3: Obtain effective ceiling cavity reflectance (ρ_{CC}) from Table 16.2. ρ_{CC} = __________

11. Step 4: Obtain effective floor cavity reflectance (ρ_{FC}) from Table 16.2. ρ_{FC} = __________

12. Step 5: Obtain coefficient of utilization (CU) from manufacturer's data. CU = __________

SELECTION OF LIGHT LOSS FACTORS

Unrecoverable		Recoverable	
13. Luminaire ambient temperature	________	17. Room surface dirt depreciation	________
14. Voltage to luminaire	________	18. Lamp lumen depreciation	________
15. Luminaire surface depreciation	________	19. Lamp burnouts factor	________
16. Other factors **(components)**	________	20. Luminaire dirt depreciation LDD	________

21. Total light loss factor, LLF (product of individual factors above): ______

CALCULATIONS

(Average maintained illumination level)

$$\text{Number of luminaires} = \frac{(\text{Illuminance}) \times (\text{Area})}{(\text{Lumens per luminaire}) \times (\text{CU}) \times (\text{LLF})}$$

22. = ______________________ =

$$\text{Lux [footcandles]} = \frac{(\text{number of luminaires}) \times (\text{lumens per luminaire}) \times (\text{CU}) \times (\text{LLF})}{(\text{area})}$$

23. = ______________________ =

24. Calculated by: ______________________ Date: __________

Fig. 16.13 *Zonal cavity method calculation form. (Courtesy of IESNA.)*

- Steps 3, 4: find ρ_{CC} , ρ_{FC}
  - Use ρ_w from Step 1
  - CCR = 0 for surface mounted or recessed fixtures
  - FCR = 0 for carpet stores (if the floor is the working plane)

- Step 5:select CU
  - From the manufacturers' data or Table 16.1 (MEEB 12th Ed.)
  - Interpolation may be necessary
  - For ρ_{Fc} other than 20%, refer to Table 16.6

- Step 6: calculate the illuminance and the number of fixtures

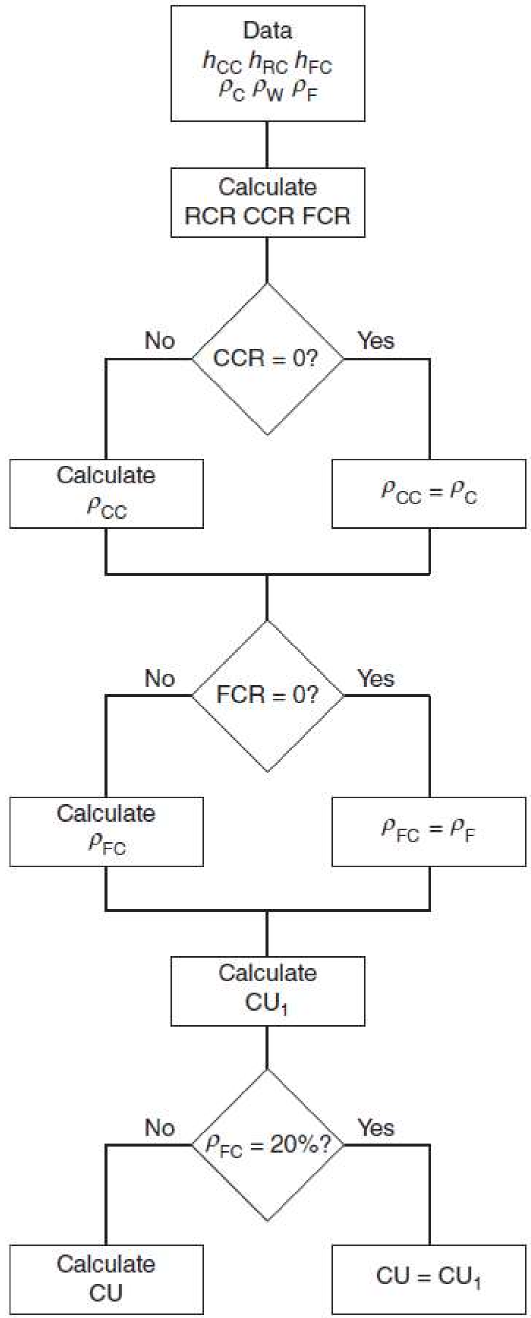
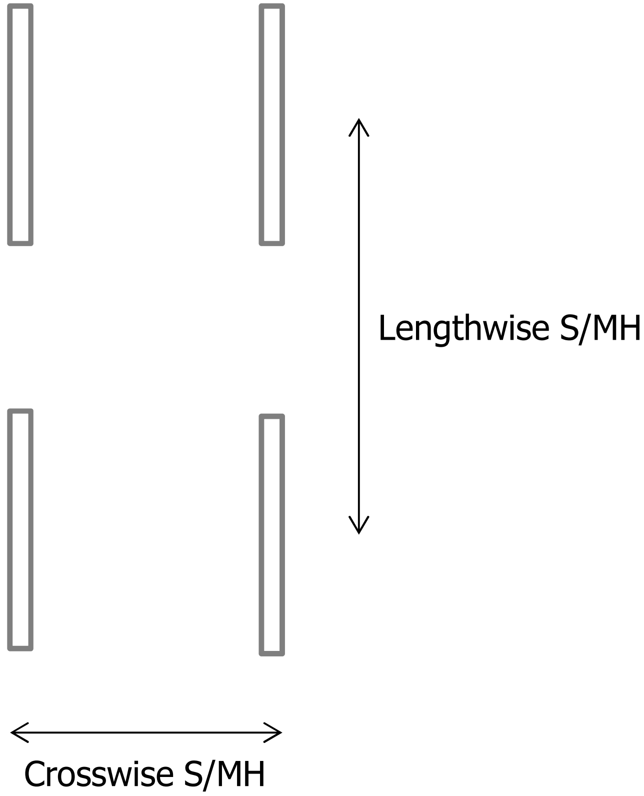


Fig. 16.12 Zonal cavity method flow chart.

For estimation of ρ_{CC} → use ρ_C, ρ_W, and CCR
For estimation of ρ_{FC} → use ρ_F, ρ_W, and FCR

TABLE 16.5 Percent Effective Ceiling or Floor Cavity Reflectance (ρ_{CC}, ρ_{FC}) for Various Reflectance Combinations

Percent Ceiling ρC or Floor Reflectance ρ_F:		90				80				70			50			30				10		
Percent Wall Reflectance ρ_W:		90	70	50	30	80	70	50	30	70	50	30	70	50	30	65	50	30	10	50	30	10
Ceiling or Floor Cavity Ratios—CCR or FCR	0	90	90	90	90	80	80	80	80	70	70	70	50	50	50	30	30	30	30	10	10	10
	0.2	89	88	86	85	79	78	77	76	68	67	66	49	48	47	30	29	29	28	10	10	9
	0.4	88	86	83	81	78	76	74	72	67	65	63	48	46	45	30	29	27	26	11	10	9
	0.6	88	84	80	76	77	75	71	68	65	62	59	47	45	43	29	28	26	25	11	10	9
	0.8	87	82	77	73	75	73	69	65	64	60	56	47	43	41	29	27	25	23	11	10	8
	1.0	86	80	74	69	74	71	66	61	63	58	53	46	42	39	29	27	24	22	11	9	8
	1.2	86	78	72	65	73	70	64	58	61	56	50	45	41	37	29	26	23	20	12	9	7
	1.4	85	77	69	62	72	68	62	55	60	54	48	45	40	35	28	26	22	19	12	9	7
	1.6	85	75	66	59	71	67	60	53	59	52	45	44	39	33	28	25	21	18	12	9	7
	1.8	84	73	64	56	70	65	58	50	57	50	43	43	37	32	28	25	21	17	12	9	6
	2.0	83	72	62	53	69	64	56	48	56	48	41	43	37	30	28	24	20	16	12	9	6
	2.2	83	70	60	51	68	63	54	45	55	46	39	42	36	29	28	24	19	15	13	9	6
	2.4	82	68	58	48	67	61	52	43	54	45	37	42	35	27	28	24	19	14	13	9	6
	2.6	82	67	56	46	66	60	50	41	53	43	35	41	34	26	27	23	18	13	13	9	5
	2.8	81	66	54	44	66	59	48	39	52	42	33	41	33	25	27	23	18	13	13	9	5
	3.0	81	64	52	42	65	58	47	38	51	40	32	40	32	24	27	22	17	12	13	8	5
	3.5	79	61	48	37	63	55	43	33	48	38	29	39	30	22	26	22	16	11	13	8	5
	4.0	78	58	44	33	61	52	40	30	46	35	26	38	29	20	26	21	15	9	13	8	4
	4.5	77	55	41	30	59	50	37	27	45	33	24	37	27	19	25	20	14	8	14	8	4
	5.0	76	53	38	27	57	48	35	25	43	32	22	36	26	17	25	19	13	7	14	8	4



The crosswise S/MH ratio is always considerably higher than the lengthwise S/MH ratio.(luminaire # 26, 28, 42 in Table 16.1)

TABLE 16.1 Coefficients of Utilization for Typical Luminaires with Suggested Maximum Spacing Ratios (*Continued*)

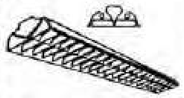
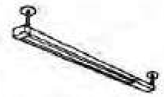
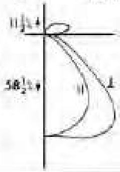
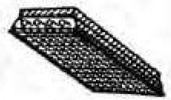
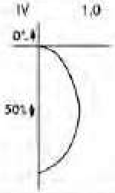
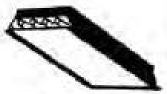
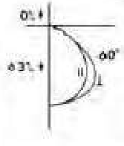
Typical Luminaire	Typical Distribution and Percent Lamp Lumens		ρ_{CC} →	80			70			50			0
			ρ_W →	50	30	10	50	30	10	50	30	10	0
	Maintenance Category	Maximum S/MH	RCR	Coefficients of Utilization for 20% Effective Floor Cavity Reflectance (ρ_{FC} = 20)									
26  Diffuse aluminum reflector with 35° crosswise shielding	II 	1.5/1.3	0	.95	.95	.95	.91	.91	.91	.83	.83	.83	.66
			1	.85	.82	.80	.82	.79	.77	.75	.73	.72	.59
			2	.76	.72	.68	.74	.70	.66	.68	.65	.62	.52
			3	.69	.63	.59	.66	.61	.57	.62	.58	.54	.46
			4	.62	.56	.51	.60	.54	.50	.56	.51	.47	.41
			5	.55	.49	.44	.53	.48	.43	.50	.45	.41	.36
			6	.50	.43	.39	.48	.42	.38	.45	.40	.36	.31
			7	.45	.38	.34	.43	.37	.33	.41	.36	.32	.27
			8	.40	.34	.29	.39	.33	.29	.37	.31	.28	.24
			9	.36	.30	.25	.35	.29	.25	.33	.28	.24	.20
28  Diffuse aluminum reflector with 35° crosswise, 35° lengthwise shielding	II 	1.5/1.1	0	.83	.83	.83	.79	.79	.79	.72	.72	.72	.56
			1	.75	.72	.70	.72	.69	.67	.65	.64	.62	.50
			2	.67	.63	.60	.65	.61	.58	.59	.57	.54	.45
			3	.61	.56	.52	.58	.54	.51	.54	.50	.48	.40
			4	.55	.49	.45	.53	.48	.44	.49	.45	.42	.36
			5	.49	.44	.40	.47	.42	.39	.44	.40	.37	.31
			6	.45	.39	.35	.43	.38	.34	.40	.36	.33	.28
			7	.40	.35	.31	.39	.34	.30	.36	.32	.29	.25
			8	.36	.31	.27	.35	.30	.26	.33	.28	.25	.21
			9	.33	.27	.23	.32	.26	.23	.29	.25	.22	.19
33  Luminous bottom-suspended unit with very-high-output lamp	VI 	N.A.	0	.77	.77	.77	.68	.68	.68	.50	.50	.50	.12
			1	.67	.64	.62	.59	.57	.54	.44	.42	.41	.10
			2	.59	.54	.50	.52	.48	.45	.38	.36	.34	.09
			3	.51	.46	.42	.45	.41	.37	.34	.31	.28	.07
			4	.45	.40	.35	.40	.35	.31	.30	.27	.24	.06
			5	.40	.34	.30	.35	.30	.27	.26	.23	.20	.05
			6	.36	.30	.26	.32	.27	.23	.24	.20	.18	.05
			7	.32	.26	.22	.28	.23	.20	.21	.18	.15	.04
			8	.29	.23	.19	.25	.21	.17	.19	.16	.13	.03
			9	.26	.20	.17	.23	.18	.15	.17	.14	.12	.03
35  Two-lamp prismatic wraparound; multiply by 0.95 for four lamps	V 	1.5/1.2	0	.81	.81	.81	.78	.78	.78	.72	.72	.72	.59
			1	.71	.69	.66	.69	.66	.64	.64	.62	.60	.50
			2	.64	.59	.56	.61	.58	.54	.57	.54	.51	.44
			3	.57	.52	.48	.55	.50	.47	.51	.48	.45	.38
			4	.51	.46	.41	.49	.44	.41	.46	.42	.39	.34
			5	.46	.40	.36	.44	.39	.35	.41	.37	.34	.29
			6	.41	.35	.31	.40	.35	.31	.38	.33	.30	.26
			7	.37	.31	.27	.36	.31	.27	.34	.29	.26	.23
			8	.33	.28	.24	.32	.27	.23	.30	.26	.22	.19
			9	.30	.24	.20	.29	.24	.20	.27	.23	.19	.17
38  Four-lamp, 610-mm (2-ft)-wide troffer with 45° plastic louver	IV 	1.0	0	.60	.60	.60	.58	.58	.58	.56	.56	.56	.50
			1	.54	.52	.50	.52	.51	.49	.50	.49	.48	.44
			2	.48	.45	.43	.47	.44	.42	.45	.43	.41	.39
			3	.43	.40	.37	.42	.39	.37	.41	.38	.36	.34
			4	.39	.35	.32	.38	.35	.32	.37	.34	.32	.30
			5	.35	.31	.28	.35	.31	.28	.34	.30	.28	.26
			6	.32	.28	.25	.32	.28	.25	.31	.27	.25	.23
			7	.29	.25	.22	.29	.25	.22	.28	.25	.22	.21
			8	.26	.22	.20	.26	.22	.20	.25	.22	.20	.18
			9	.24	.20	.17	.24	.20	.17	.23	.20	.17	.16
42  Fluorescent unit with flat prismatic lens, four-lamp, 610 mm (2 ft) wide	V 	1.4/1.2	0	.75	.75	.75	.73	.73	.73	.70	.70	.70	.63
			1	.67	.65	.63	.66	.64	.62	.63	.62	.60	.55
			2	.60	.57	.54	.59	.56	.53	.57	.54	.52	.49
			3	.54	.50	.47	.53	.49	.46	.52	.48	.45	.43
			4	.49	.44	.40	.48	.44	.40	.47	.43	.40	.37
			5	.44	.39	.35	.43	.38	.35	.42	.38	.34	.33
			6	.40	.34	.31	.39	.34	.31	.38	.34	.30	.29
			7	.36	.30	.27	.35	.30	.27	.34	.30	.27	.25
			8	.32	.27	.23	.32	.27	.23	.31	.26	.23	.22
			9	.29	.24	.20	.28	.23	.20	.28	.23	.20	.19

TABLE 16.6 CU Adjustment Factors for Effective Floor Cavity Reflectances Other Than 20% (Any Wall Reflectance)[a]

For 30% effective floor cavity reflectance, *multiply* the CU value for 20% floor cavity reflectance by the appropriate factor from the following table.
For 10% effective floor cavity reflectance, *divide* the CU value for 20% floor cavity reflectance by the appropriate factor from the following table.

	Percent Effective Ceiling Cavity Reflectance, ρ_{CC}			
Room Cavity Ratio	**80**	**70**	**50**	**10**
1	1.08	1.06	1.04	1.01
2	1.06	1.05	1.03	1.01
3	1.04	1.04	1.03	1.01
4	1.03	1.03	1.02	1.01
5	1.03	1.02	1.02	1.01
6	1.02	1.02	1.02	1.01
7	1.02	1.02	1.01	1.01
8	1.02	1.02	1.01	1.01
9	1.01	1.01	1.01	1.01
10	1.01	1.01	1.01	1.01

Source: Extracted from the *IESNA Lighting Handbook* (1993); reprinted with permission.
[a]For more precise data that address varying ρ_W values, see the current *IESNA Lighting Handbook*.

Example in 12th Ed.

Fluorescent lamp used

Example 16.1 (12^{th} Ed.)

EXAMPLE 16.1 It is suggested that the reader photocopy Fig. 16.35 and fill it in as the solution to this example is developed.

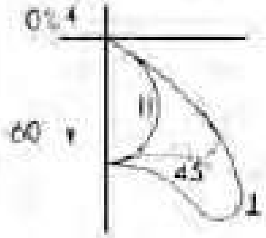
Given. Assume a classroom with dimensions of (W × L × H): 6 m × 8 m × 3.7 m (19.7 × 26.3 × 12.1 ft), at an elementary school. Initial reflectances are: ceiling 80%, entire wall 50%, floor 20%. (Note that the sketch in Fig. 16.35 can accommodate different reflectances for the upper, center, and lower wall sections.) The goal is to provide adequate illuminance using fluorescent fixtures. Assume yearly maintenance, lamp replacement at burnout, proper voltage and ballasts, and a medium clean atmosphere.

- (a) illuminance target
  - IESNA handbook: 500 Lux
  - Lines 1, 2, and 8 of Fig 16.13

(b) Luminaire selection

- for a classroom situation
  - Low direct glare (high VCP): a large proportion of their time in a heads-up position
  - Low veiling reflections because of the seeing task
  - High efficiency and low energy use to meet ANSI/ASHRAE/IESNA Standard 90.1 and most governmental requirements
  - Minimum maintenance: poor cleaning and maintenance situation in many schools
- indirect lighting is not chosen (although the ceiling height is sufficient)
  - Indirect lighting depends on a highly reflective ceiling, requiring yearly cleaning and repainting at intervals not exceeding 5 years. This is not generally the case in public schools.
- Luminaire No. 44 from Table 16.1 (12^{th} Ed.) chosen
  - Two lamp fluorescent unit with louvers that exhibit 45° cutoff and crosswise batwing distribution

TABLE 16.1 Coefficients of Utilization for Typical Luminaires with Suggested Maximum Spacing Ratios (*Continued*)

Typical Luminaire	Typical Distribution and Percent Lamp Lumens / Maintenance Category	Maximum S/MH	RCR	ρ_{CC} → 80			70			50			0
			ρ_W →	50	30	10	50	30	10	50	30	10	0
				Coefficients of Utilization for 20% Effective Floor Cavity Reflectance (ρ_{FC} = 20)									
44 	IV 	N.A.	0	.71	.71	.71	.70	.70	.70	.66	.66	.66	.60
			1	.65	.63	.61	.63	.62	.60	.61	.59	.58	.54
			2	.59	.55	.53	.58	.55	.52	.56	.53	.51	.48
			3	.53	.49	.46	.52	.48	.45	.50	.47	.45	.42
			4	.47	.43	.40	.47	.43	.40	.45	.42	.39	.37
			5	.42	.38	.34	.42	.37	.34	.41	.37	.34	.32
			6	.38	.33	.30	.38	.33	.30	.37	.33	.30	.28
			7	.34	.29	.26	.33	.29	.26	.33	.28	.25	.24
Radial batwing distribution—louvered fluorescent unit			8	.30	.25	.22	.30	.25	.22	.29	.25	.22	.20
			9	.27	.22	.18	.26	.22	.18	.26	.21	.18	.17

(c) Steps

- For easy maintenance, the mounting height is 1.95m ($MH=h_{RC}$=1.95m=2.7m-0.75m)
- The recommended maximum S/MH: 1.5-2.0

STEP 1. The required data that should appear in the sketch in Fig. 16.35 are

$h_{CC} = 1.0$ m	$h_{RC} = 1.95$ m
$h_{FC} = 0.75$ m	$l = 8$ m
$\rho_C = 80\%$	$\rho_W = 50\%$
$\rho_F = 20\%$	$w = 6$ m

STEP 2. From Equations 16.8, 16.9, and 16.10

$$\frac{l + w}{l \times w} = 0.29$$

$$\mathrm{RCR} = 5h_{RC}\frac{l + w}{l \times w}$$

$$\mathrm{RCR} = 5\,(1.95)(0.29) = 2.84$$
$$\mathrm{CCR} = 5\,(1)(0.29) = 1.46$$
$$\mathrm{FCR} = 5\,(0.75)(0.29) = 1.09$$

STEP 3. From Table 16.2 obtain effective reflectances: For ρ_{CC} use $\rho_C = 0.8$, $\rho_W = 0.5$, and CCR = 1.46. Therefore,

$$\rho_{CC} = 0.61$$

STEP 4. For ρ_{FC} use $\rho_F = 0.2$, $\rho_W = 0.5$, and FCR = 1.09. Therefore,

ρ_{FC} = ~~0.18~~ 0.19 by interpolation

(c) steps

STEP 5. Interpolation between RCR of 2.8 and 3.0 is necessary. The CU for the selected luminaire—No. 44 of Table 16.1—can now be obtained by double interpolation.

$\rho W = 0.50$	CU		
$\rho CC \rightarrow$	**0.70**	**0.61**	**0.50**
RCR			
2.0	0.58		0.55
2.84		?	
3.0	0.52		0.50

Design CU = 0.52. No correction from Table 16.3 is required, as ρ_{FC} is close to 20%. At this stage, lines 9 through 12 of Fig. 16.35 can be filled in.

STEP 6. The LLF (see Section 16.20) results from establishing items 13 to 20 of Fig. 16.35. These are:

Items 13–16	0.88	
Item 17	0.92 (direct lighting)	
Item 18	0.85	(Fluorescent, replacement on burnout)
Item 19	0.95	(individual replacement on burnout)
Item 20	0.80	(Category IV ← Table 16.1)

Item 21: LLF = (0.88) 0.92 (0.85)(0.95)(0.80) = 0.54

$$N = \frac{(500 \text{ lux})(6 \times 8 \text{ m})}{2(3200 \text{ lm})(0.52)(0.54)} = 13.35$$

$$\frac{300 \text{ cm spacing}}{195 \text{ cm mounting height}} = 1.53$$

195 cm mounting height → h_{RC}

Luminaire layout

- the room be treated as a single (student area & teacher area)
- Two lengthwise rows for VCP
- The window wall row has a separate switch and is farther from the wall than the inside row due to the daylight.
- To prevent reflected glare, the sixth fixture in the outside row is off the line.
- For chalkboard lighting, two single lamp installed
- The number of fixtures: 11 + 0.5 + 0.5 =12
  - The number of required fixtures: 13.35
  - Actual minimum maintained lighting level: 12/13.35 * 500 = 450 Lux
  - The designer must decide if this is OK.

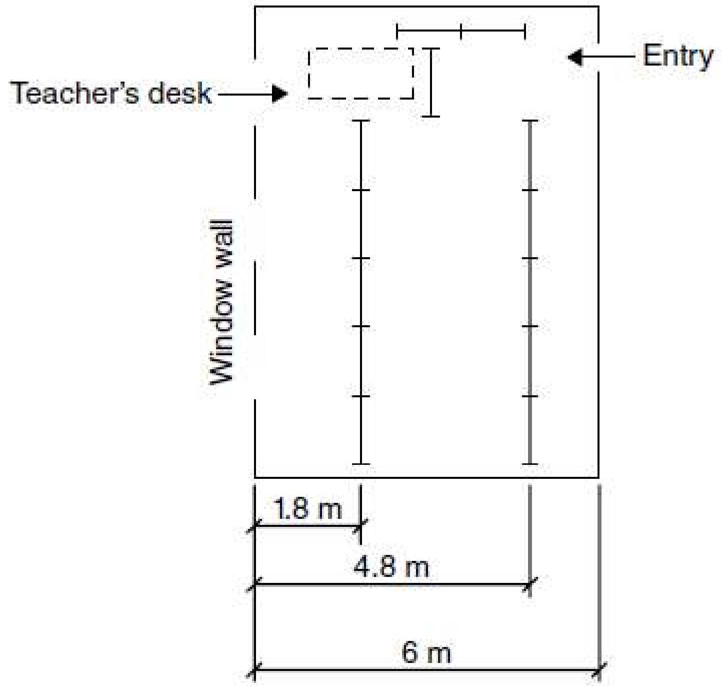


Fig. 16.36 *Layout of pendant parabolic aluminum reflector luminaires in a typical classroom. The units have a modified batwing distribution in the crosswise direction, which mandates their being hung with their long axis parallel to the line of sight, as shown. Furthermore, the fixtures have lower brightness in that direction, that is, VCP for students in the head-up position is excellent. Note that the distance between the outside fixture row and the window wall is more than one-half of the side-to-side spacing because of daylight contribution during school hours, whereas the inside fixture row to inside wall spacing is less than one-half of the side-to-side spacing in order to maintain sufficient illuminance near that wall. The single fixture to the right of the teacher's desk (to the teacher's left) was so placed to avoid the veiling reflections that would result from a fixture directly above the desk and to take advantage of the fixture's transverse batwing distribution characteristic.*

Example 16.2

EXAMPLE 16.2 Assume a large modern business office, with dimensions of (L × W × hung ceiling H) 60 ft × 100 ft × 8 ft (18 × 30 × 2.4 m). Initial reflectances are 0.80, 0.50, and 0.30. Provide general lighting using fluorescent lamps with high-efficiency ballasts in recessed troffer luminaires. The space is fully air-conditioned. Lamps are replaced on a burn-out basis, and the fixture is then cleaned.

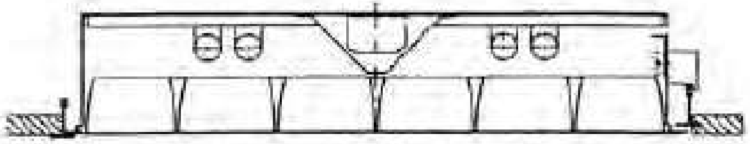
- Illuminance: 500 Lux
- Luminaires with parabolic diffusers, reflectors, and/ or baffles, which exhibit very low high-angle luminance.

- Office workstation: half-height partitions, varying viewing directions → Luminaire's directionality is negative.
- A specular parabolic baffled 2ft square unit selected: two 32W, T8, with 2,800 initial lumens (Fig. 16.37, CDC, CU)
- Category I

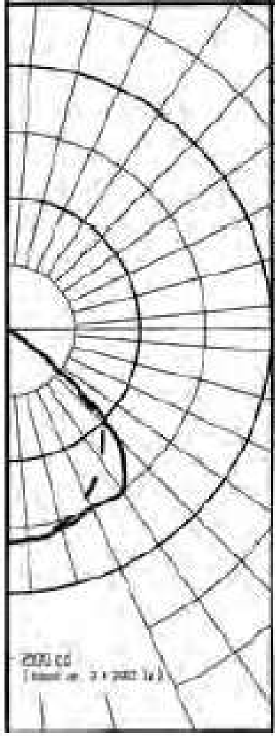
REK D/RIK-D 2/31-U

Recessed mounted luminaire with parabolic mirrored louver
(without mirrored reflector)

Shielding angle : Parl.: 60 - Norm.: 60



CANDLEPOWER



DEG.	Parl.	22.5	45	67.5	Norm.	Flux
0	1609	1609	1609	1605	1608	
5	1603	1603	1607	1606	1605	177
10	1577	1579	1589	1596	1600	
15	1534	1534	1551	1565	1584	506
20	1473	1480	1490	1522	1526	
25	1409	1412	1431	1481	1498	773
30	1312	1327	1365	1464	1502	
35	1212	1230	1311	1446	1501	904
40	1103	1141	1263	1328	1352	
45	970	1034	1138	1135	1149	802
50	599	572	617	521	535	
55	122	129	139	140	144	223
60	14	14	15	15	15	
65	12	5	11	7	19	10
70	3	3	2	3	4	
75	2	2	1	2	2	2
80	2	1	1	1	2	
85	1	1	1	2	2	2
90	2	2	2	2	2	
95	0	0	0	0	1	0
100-180	0	0	0	0	0	

COEFFICIENTS OF UTILIZATION

LUMINAIRE EFFICIENCY : 0.61

REFL. FACT.	80			70			50			30			10			0
CEILING ρ_{CC}	80			70			50			30			10			0
WALLS ρ_W	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0
FLOOR ρ_{FC}	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
ROOM CAVITY RATIO - RCR 1	64	61	59	62	60	58	60	58	56	57	56	54	55	54	53	52
2	57	54	51	56	53	50	54	51	49	52	50	48	50	48	47	45
3	53	49	46	53	49	46	51	48	45	49	47	44	48	45	44	42
4	49	45	42	49	45	41	47	44	41	46	43	40	45	42	40	39
5	45	41	38	45	41	37	44	40	37	42	39	37	41	39	36	35
6	42	37	34	41	37	34	40	36	33	39	36	33	38	35	33	32
7	38	34	30	38	33	30	37	33	30	36	33	30	35	32	30	29
8	35	31	28	35	31	28	34	30	27	33	30	27	33	30	27	26
9	33	29	26	33	28	26	32	28	25	31	28	25	31	28	25	24
10	30	26	23	30	26	23	30	26	23	29	26	23	29	25	23	22

ZONAL SUMMARY				AVG [cd/m²]			
ZONE	LUMENS	LAMP	FIXT	DEG.	NORM.	45°	PARL.
0 - 30	1456	25.1	41.0	45	5091	5041	4295
0 - 40	2420	41.7	68.2	50	3092	3009	2624
0 - 50	3312	57.1	93.3	55	766	759	665
0 - 60	3535	61.0	99.6	60	98	94	85
0 - 70	3549	61.1	99.9	65	75	81	66
0 - 90	3549	61.2	100.0	70	35	16	24
90 - 180	0	0.0	0.0	75	28	14	21
0 - 180	3550	61.2	100.0	80	31	21	31

Fig. 16.37 *Complete photometric data on a 2-ft (610-mm) square fixture with a 36-cell mirrored parabolic louver. The unit uses two T8 U-shaped 32-W fluorescent lamps. Note that the transverse distribution characteristic has a modified batwing shape typical of this type of louver. The louver's specular finish yields very low brightness at high angles, as can be seen from both the distribution curve and the luminance (cd/m²) data. (Courtesy of Zumtobel-STAFF.)*

Calculations. The reader should fill in a copy of Fig. 16.35 as we proceed. The working plane is taken as the desktop height (i.e., 30 in. or 2.5 ft).

STEP 1. $h_{CC} = 0$; $h_{RC} = 5.5$; $h_{FC} = 2.5$.

STEP 2. CCR = 0; RCR = 0.73; FCR = 0.33.

STEP 3. $\rho_W = 50\%$; $\rho_{CC} = 80\%$ (for a recessed fixture we use the ceiling reflectance).

STEP 4. From Table 16.2, $\rho_{FC} = 29\%$.

STEP 5. We find CU for $\rho_{FC} = 20\%$ by extrapolation:

RCR	CU	
0.73	?	
1.0	0.64	CU = 0.66
2.0	0.57	

STEP 6. From Table 16.3, the multiplier for ρ_{FC} = 30% (close to 29%) is 1.085.

STEP 7. Final CU = 1.085 (0.66) = 0.72.

STEP 8. LLF per Fig. 16.35:

1.0	0.92	(direct lighting)
1.0	0.85	(fluorescent, replacement on burnout)
0.9	0.95	(individual replacement on burnout)
0.92	0.88	(Category I)

LLF = 0.54

STEP 9.

$$\text{area/luminaire} = \frac{\text{lamps} \times \text{lumens/lamp} \times \text{CU} \times \text{LLF}}{\text{illuminance}}$$

$$= \frac{2(2800)(0.72)(0.54)}{500 / 10.76 \text{ lux per fc}} = 47 \text{ ft}^2$$

Zonal Cavity calculation by approximation

- reasonable approximation of Zonal Cavity Calculation (B.F. Jones, 1983)
- Assumptions
  - all rooms are square
  - RCR, ρ_{CC}, ρ_{FC}, LLF (refer to Fig.16.38)

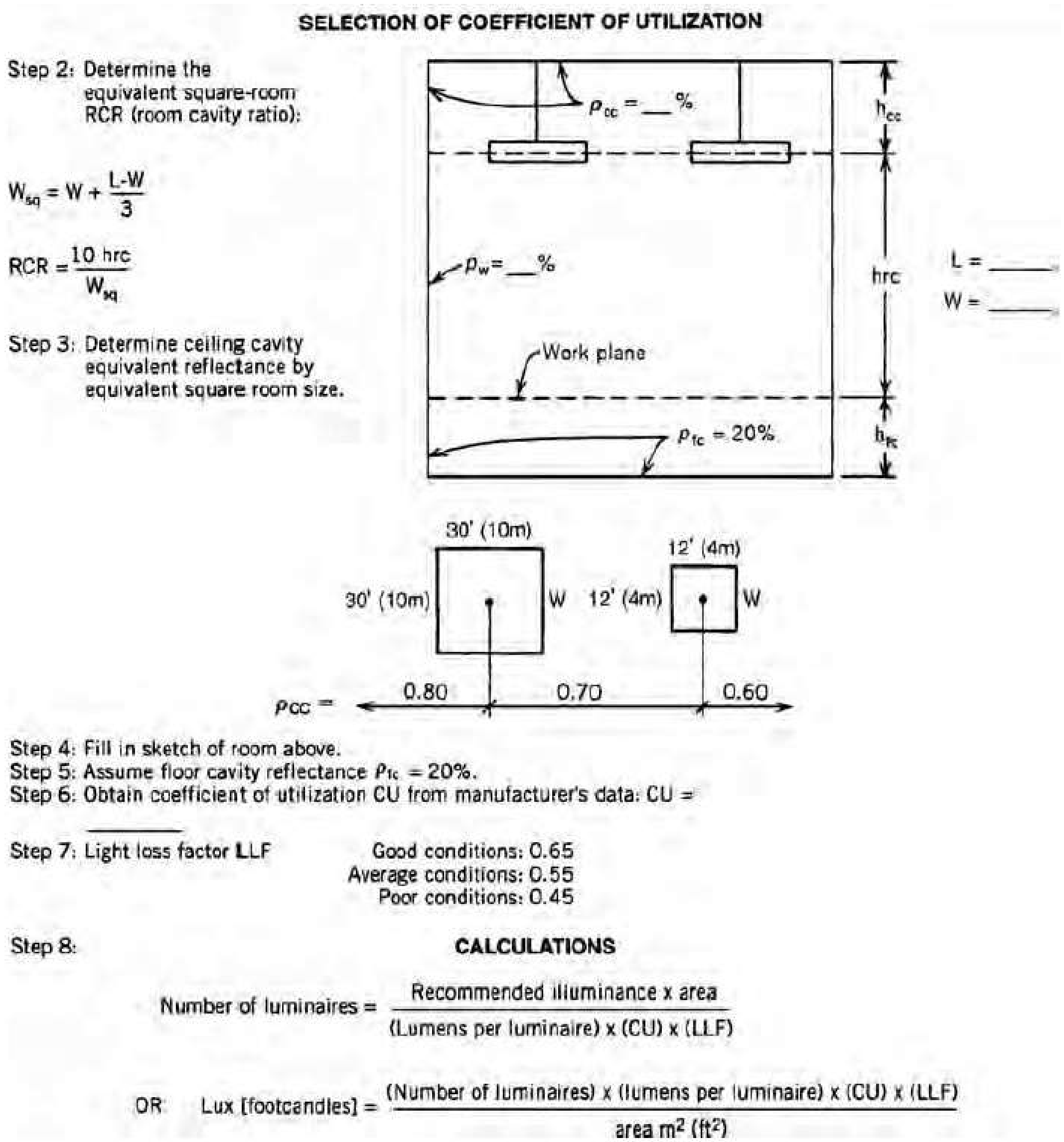


Fig. 16.38 Sheet for illuminance calculation using an approximate zonal cavity method (based on a method developed by B. F. Jones).

EXAMPLE 16.3 Classroom as in Example 16.1 by approximation.

1. "Square" the room.

$$w_{SQ} = 6 + \frac{8-6}{3} = 6\tfrac{2}{3}$$

2. Assume

$$\rho_{CC} = 70;\ \rho_W = 50;\ \rho_{FC} = 20$$

3. Calculate RCR

$$RCR = \frac{10 \times 1.95}{6\tfrac{2}{3}} = \frac{19.5}{6.66} = 2.93$$

4. Obtain CU from Table 16.1, fixture No. 44. CU = 0.52 by visual inspection.
5. Calculate fixtures

$$N = \frac{500(6 \times 8\text{ m})}{2(3200)(0.52)(0.55)}$$

$$= 13.11\text{ fixtures}$$

Thus, the result is substantially the same as the accurate calculation. Let us also check Example 16.2. ■

EXAMPLE 16.4 Office as in Example 16.2 by approximation.

1. $w_{SQ} = 60 + \frac{100-60}{3} = 73\text{ ft}$
2. $\rho_{CC} = 80;\ \rho_W = 50;\ \rho_{FC} = 20$
3. $RCR = \frac{10 \times 5.5}{73} = \frac{55}{73} = 0.75$
4. CU = 0.66 by inspection (mental interpolation)
5. LLF = 0.55
6. $\text{area / luminaire} = \frac{2 \times 2800 \times 0.66 \times 0.55}{50\text{ fc}}$

$$= 40.6\text{ sq ft } (3.8\text{ m}^2)$$

This result is within 5.5% of the more precise calculation. Thus, we see that these simple approximations give answers sufficiently accurate for most uses and are therefore recommended. ■

Conclusions

- For preliminary calculations of rectangular rooms: use the simple method (Fig. 16.38)
- For rooms where a high degree of accuracy is desired and actual reflectances are known, use the long method
- For rooms of unusual shape or rooms with special conditions (coffered ceilings, mixed-material walls, partial height partitions): use lighting simulation
- For spaces in which a number of different solutions are to be tried, use lighting simulation

Example in 13^{th} Ed.

LED used

Example 16.1 (p.783)

EXAMPLE 16.1 Fig. 16.13 is a compact and useful worksheet for zonal cavity calculations—using this worksheet to track these examples is recommended. To simplify this example, it is worked using only SI units; the exact same process would apply with I-P units.

Given. Assume a classroom with dimensions of (W × L × H): 6 m × 8 m × 3.7 m, in an elementary school. Initial surface reflectances are: ceiling 80%, entire wall 50%, floor 20%. (Note that the Fig.16.13 worksheet can accommodate different reflectances for the upper, center, and lower wall sections.) The basic lighting objective is to provide adequate illuminance using LED fixtures. Assume a yearly maintenance cycle, lamp replacement at burnout, proper voltage and ballasts, and a medium-clean dirt condition.

Considering the above, select luminaire *type a* from Table 16.4 as an initial informed trial fixture. This selection would meet requirements 1 through 4.

Although its distribution curve (see Table 16.4) shows no upward component, some fixtures of this basic design have slots in the top of the reflector to provide a 5% to 10% uplight component. In practice, such a unit would avoid an excessively dark ceiling and high luminance ratios between fixture and background. The mounting height is assumed as 2.7 m to permit an uplight component. The recommended maximum SC would be between 1.5 and 2.0. The work plane height is 750 mm.

Example 16.1 (p.783)

STEP 1. The information that should appear in the sketch in Fig. 16.13 is:

$h_{CC} = 1.0\,\text{m}$
$h_{FC} = 0.75\,\text{m}$
$\rho_C = 80\%$
$\rho_F = 20\%$

$h_{RC} = 1.95\,\text{m}$
$l = 8\,\text{m}$
$w = 6\,\text{m}$
$\rho_W = 50\%$

STEP 2. Determine the three cavity ratios as follows:

$$\frac{l+w}{l \times w} = 0.29$$

$$\text{RCR} = 5h_{RC}\frac{l+w}{l \times w}$$

$$\text{RCR} = 5(1.95)(0.29) = 2.84$$

$$\text{CCR} = 5(1)(0.29) = 1.46$$

$$\text{FCR} = 5(0.75)(0.29) = 1.09$$

STEP 3. Obtain effective reflectances from Table 16.5. For ρ_{CC} use $\rho_C = 0.8$, $\rho_W = 0.5$, and CCR = 1.46.

Thus,

$$\rho_{CC} = 0.61$$

STEP 4. To determine ρ_{FC} use $\rho_F = 0.2$, $\rho_W = 0.5$, and FCR = 1.09. Thus,

ρ_{FC} = ~~0.18~~ 0.19 (by interpolation)

STEP 5. With a room cavity ratio of 2.84, the CU for the selected luminaire—*type a* (direct distribution)—can be extracted from Table 16.4 by interpolation.

$\rho_W = 0.50$	CU		
$\rho_{CC} \rightarrow$	**0.70**	**0.61**	**0.50**
RCR			
2.0	0.94		0.91
2.84		?	
3.0	0.85		0.82

Significant improvement in CU compared to FL !!

The CU = 0.85. No correction from Table 16.6 is required, as ρ_{FC} is close to 20%. At this point, lines 9 through 12 of Fig. 16.13 can be filled in.

STEP 6. The LLF (see *light loss factor* subsection) is established by estimating items 13 to 20 in Fig. 16.13. These are assumed as:

Items 13–16 (collectively)	0.88
Item 17	0.92 (direct lighting)
Item 18	0.87 (LED, replacement on burnout)
Item 19	0.95 (individual replacement on burnout)
Item 20	0.80 (Category IV)

Item 21: LLF = (0.88)((0.92)(0.87))(0.95)(0.80) = 0.535

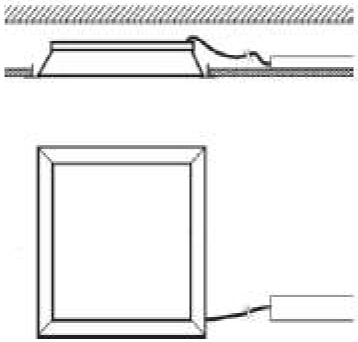
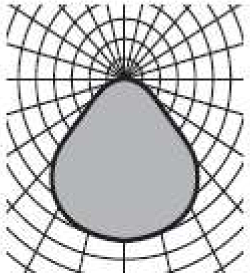
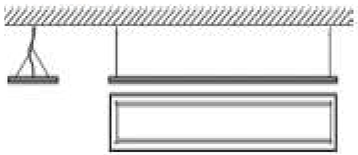
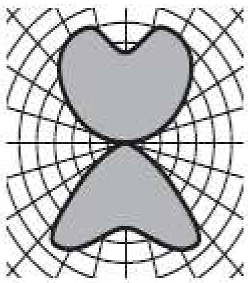
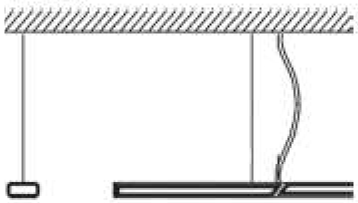
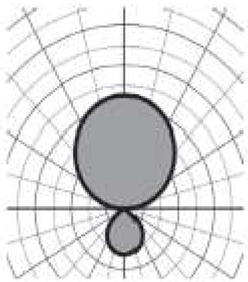
STEP 7. Complete the illuminance calculation. A typical classroom normally consists of a student seating area and a teacher's area. The illuminance requirement is approximately the same for both, so the room can be treated as a single entity for visual task purposes. Assuming 7900 lumens (at 4000K and 80 CRI) per luminaire, the number *N* of luminaires required to provide design illuminance is:

$$N = (500\,\text{lx})(6 \times 8\,\text{m}) / (7900\,/\text{m})(0.85)(0.54)$$
$$= 6.6$$

The use of 6.6 fixtures is not possible, so the designer would need to decide whether 6 fixtures would be adequate (this would provide a maintained illuminance of 455 lux—substantially below the design target) or whether 7 or 8 fixtures should be used. Eight fixtures would simplify luminaire layout in the ceiling plane but result in substantially more illuminance than required; an eight-fixture layout might also better conform to the recommended SC limits for the luminaire. Perhaps a similar fixture with somewhat lower lumen output could be used. Lighting design does not stop with the fixture count.

The remaining lines of Fig. 16.13 can now be completed. ■

ABLE 16.4 Coefficients of Utilization for Three Typical LED Luminaires

uminaire Type	Photometric Distribution	RCC→	80	80	80	70	70	70	50	50	50	30	30	30	10	10	10	
		RW→	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	
		RFC→	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
		RCR↓																WDRC↓
. direct 		0	119	119	119	116	116	116	111	111	111	106	106	106	102	102	102	—
		1	107	103	100	105	101	99	101	98	96	97	95	93	93	91	90	0.301
		2	96	90	85	94	89	84	91	86	82	87	84	81	84	82	79	0.288
		3	86	79	74	85	78	73	82	76	72	79	75	71	77	73	69	0.270
		4	77	70	64	76	69	64	74	68	63	72	66	62	70	65	61	0.255
		5	69	61	55	68	61	55	66	60	55	64	59	54	63	58	54	0.242
		6	63	55	49	62	54	49	60	53	48	59	52	48	57	52	47	0.227
		7	57	49	43	56	48	43	54	47	42	53	47	42	52	46	42	0.214
		8	51	43	37	50	43	37	49	42	37	48	41	37	47	41	37	0.204
		9	46	38	32	45	38	32	44	37	32	43	37	32	42	36	32	0.194
		10	42	34	29	41	34	29	40	33	28	39	33	28	38	32	28	0.184
. direct-indirect 		0	105	105	105	96	96	96	79	79	79	64	64	64	49	49	49	—
		1	93	89	86	85	82	79	70	68	66	57	55	54	44	43	43	0.138
		2	82	76	71	75	70	66	62	59	56	51	48	46	40	38	37	0.130
		3	72	65	60	66	61	56	55	51	48	45	42	40	36	34	32	0.121
		4	64	57	51	59	53	48	50	45	41	41	37	34	32	30	28	0.114
		5	57	49	44	53	46	41	44	39	35	36	33	30	29	26	24	0.108
		6	51	43	38	47	40	35	40	34	30	33	29	26	26	23	21	0.101
		7	46	38	32	42	35	30	36	30	26	29	25	22	23	21	18	0.095
		8	41	33	28	38	31	26	32	27	23	26	22	19	21	18	16	0.090
		9	37	29	24	34	27	23	29	23	20	24	20	17	19	16	14	0.086
		10	33	26	21	31	24	20	26	21	17	21	17	15	17	14	12	0.081
. indirect 		0	100	100	100	89	89	89	68	68	68	48	48	48	31	31	31	—
		1	88	85	82	78	76	73	60	58	57	43	42	41	28	27	27	0.058
		2	78	72	68	69	65	61	53	50	48	39	37	35	25	24	24	0.057
		3	69	62	57	61	56	51	48	44	41	35	33	31	23	22	21	0.054
		4	61	54	48	55	49	44	43	38	35	31	29	27	21	19	18	0.051
		5	54	47	41	49	42	38	38	34	30	28	25	23	19	17	16	0.049
		6	49	41	36	44	37	33	34	30	26	25	23	20	17	16	14	0.046
		7	44	36	31	39	33	29	31	26	23	23	20	18	16	14	13	0.044
		8	39	32	27	36	29	25	28	23	20	21	18	16	14	12	11	0.042
		9	36	29	24	32	26	22	25	21	18	19	16	14	13	11	10	0.041
		10	32	26	21	29	23	19	23	19	16	17	14	12	12	10	9	0.039

bbreviations: RCC = effective reflectance of ceiling cavity; RW = average reflectance of wall surfaces; RFC = effective reflectance of floor cavity; RCR = room cavity ratio; WDRC = wall direct radiation efficient

ese values and images were extracted by the authors from data generously provided by TRILUX gmbH & Co. for the following luminaires: type a-direct: ArimoS Sky; type b-direct-indirect: LuceoS H1-L; d type c-indirect: Parelia H-L.

WDRC

- WDRC: The ratio of the wall illuminance caused by that component of light from luminaires in a room cavity that arrives without being reflected by room surfaces to the quotient of the total lamp flux divided by the floor area.

Example 16.2 (p.784)

EXAMPLE 16.2 Assume a large business office, with dimensions of (L × W × hung ceiling H) 60 ft × 100 ft × 8 ft. Initial reflectances (ceiling, wall, floor) are 0.80, 0.50, and 0.30. Provide uniform illuminance using LED fixtures. Lamps are replaced on a burnout basis, and the fixture is then cleaned.

SOLUTION

Because of the low ceiling height specified, a direct luminaire (such as *type a* in Table 16.4) will be required; this luminaire will be installed in the ceiling plane and will have only a direct distribution component. A section through such a fixture, and its characteristic lumen distribution curve, are shown in Table 16.4.

Calculations. This example is developed using only I-P units; the procedure would be the same using SI units. The working plane is taken as the desktop height (i.e., 30 in. or 2.5 ft).

STEP 1. $h_{CC} = 0$; $h_{RC} = 5.5$; $h_{FC} = 2.5$.

STEP 2. CCR = 0; RCR = 0.73; FCR = 0.33.

STEP 3. $\rho_W = 50\%$; $\rho_{CC} = 80\%$ (for a recessed or surface mounted fixture there is no ceiling cavity and the ceiling reflectance is ρ_{CC}).

STEP 4. From Table 16.5, $\rho_{FC} = 29\%$.

STEP 5. For a RCR of 0.73 and a ρ_{FC} of 20%, the CU can be found by extrapolation:

RCR	CU
0	119
0.73	?
1.0	107

For a RCR of 0.73, CU is interpolated from Table 16.4 as 110. Even though this value is mathematically correct, it is physically impossible. A luminaire cannot deliver more light than it produces. The problem in this case is that the CU tables for LED fixtures give quirky results at low RCR values due to the procedures used to develop the tables. As a workaround, it is suggested that a CU value of 95 (0.95) be used in this case—as a compromise between the data and reality.

STEP 6. From Table 16.6, the multiplier for ρ_{FC} = 30% (close enough to 29% to avoid interpolation) is 1.085.

110 119

STEP 7. Final CU = 1.085 ~~(0.95)~~ = ~~1.0~~ (rounded down to not mess with the laws of physics).

STEP 8. LLF following the steps in Fig. 16.13:

1.0	0.92 (direct lighting)
1.0	0.87 (LED, replacement on burnout)
0.9	0.95 (individual replacement on burnout)
0.92	0.80 (Category IV)

LLF = 0.503

STEP 9. Using the area per luminaire approach for this large space:

area/luminaire = (7900 lm) (1.0 CU) (0.54 LLF) / 50 fc design target

area/luminaire = ~~85 ft²~~ 79.4 ft²

An area of 85 ft² per fixture feels excessive and might lead to non-uniformity of illuminance. As in Example 16.1 (the school classroom), finding an LED luminaire with lower lumen output would increase the required number of fixtures and decrease the area served per fixture. ■

Zonal Cavity calculation by approximation

EXAMPLE 16.3 Consider the classroom as in Example 16.1, but by approximation.

1. "Square" the room.

$$W_{SQ} = 6 + \frac{8-6}{3} = 6^2/_3$$

2. Assume:

$$\rho_{CC} = 70;\ \rho_W = 50;\ \rho_{FC} = 20$$

3. Calculate RCR.

$$RCR = \frac{10 \times 1.95}{6^2/_3} = \frac{19.5}{6.66} = 2.93$$

4. Obtain CU from Table 16.4, fixture *type a*. CU = 0.85 by visual inspection.
5. Calculate required number of fixtures (N).

$$N = (500)(6 \times 8\,m)/(7900)(0.85)(0.55) = 6.5$$

Thus, the approximate result (6.5) is substantially the same as from the more detailed calculations (6.6). Next, consider the analysis in Example 16.2 by approximation. ■

EXAMPLE 16.4 Consider the office as in Example 16.2, but by approximation.

1. $W_{SQ} = 60 + \frac{100-60}{3} = 73\,ft$
2. $\rho_{CC} = 80; \rho W = 50; \rho_{FC} = 20$
3. $RCR = \frac{10 \times 5.5}{73} = \frac{55}{73} = 0.75$
4. CU = 1.0 by inspection (eyeball interpolation); reduced to 0.95 as discussed in Example 16.2
5. LLF = 0.55
6. area/luminaire = (7900)(0.95)(0.55) / 50 fc

$$= 82.6\,ft^2$$

This approximate result (82.6) is within 5% of the more precise calculation result (85). Thus, these simple approximations give answers sufficiently accurate for most uses.

Step 1: **GENERAL INFORMATION**

(a) Project identification: ______________________
(Give name of area and / or building and room number)

(b) Average maintained illumination for design: ______ lux [footcandles]

Luminaire data: ______________________
(c) Manufacturer: ______________________
(d) Catalog number: ______________________

Lamp data: ______________________
(e) Type and color: ______________________
(f) Number per luminaire: ______________________
(g) Total lumens per luminaire: ______________________

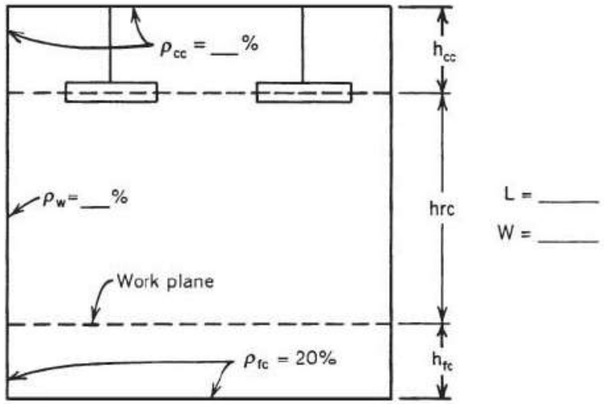
SELECTION OF COEFFICIENT OF UTILIZATION

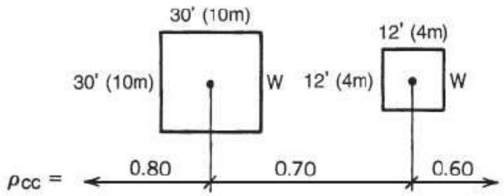
Step 2: Determine the equivalent square-room RCR (room cavity ratio):

$$W_{sq} = W + \frac{L-W}{3}$$

$$RCR = \frac{10\ hrc}{W_{sq}}$$

Step 3: Determine ceiling cavity equivalent reflectance by equivalent square room size.





Step 4: Fill in sketch of room above.
Step 5: Assume floor cavity reflectance ρ_{fc} = 20%.
Step 6: Obtain coefficient of utilization CU from manufacturer's data: CU =

____

Step 7: Light loss factor LLF

Good conditions: 0.65
Average conditions: 0.55
Poor conditions: 0.45

Step 8: **CALCULATIONS**

$$\text{Number of luminaires} = \frac{\text{Recommended illuminance x area}}{\text{(Lumens per luminaire) x (CU) x (LLF)}}$$

OR

$$\text{Lux [footcandles]} = \frac{\text{(Number of luminaires) x (lumens per luminaire) x (CU) x (LLF)}}{\text{area } m^2\ (ft^2)}$$

Fig. 16.14 *Worksheet for illuminance calculation using an approximate zonal cavity method (based on a method developed by B. F. Jones).*

Effect of cavity reflectances on illuminance (1)

- N = X / CU
  - No. of luminaires = E * Area / (lamps per fixture * initial lumens per lamp * CU * LLF)
- The impact of the reflectances of the various room cavities on CU
  - Fig. 16.15: semi-indirect
  - Fig. 16.16: direct-indirect
  - Fig. 16.17: direct (spread)
- For indirect lighting: ceiling cavity reflectance
- For direct lighting: floor reflectance

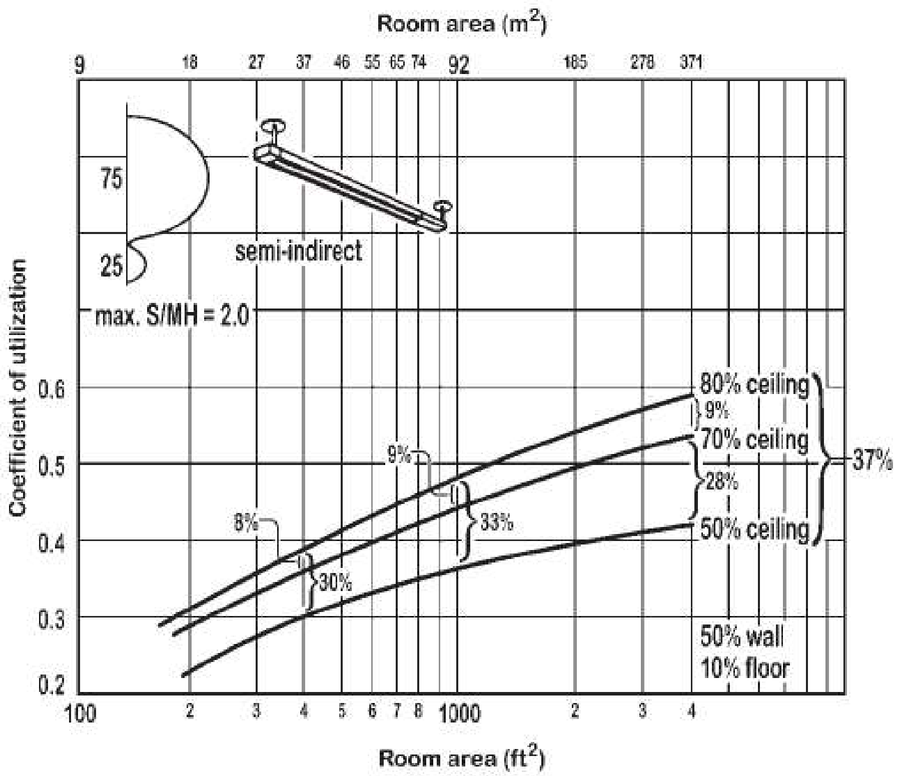
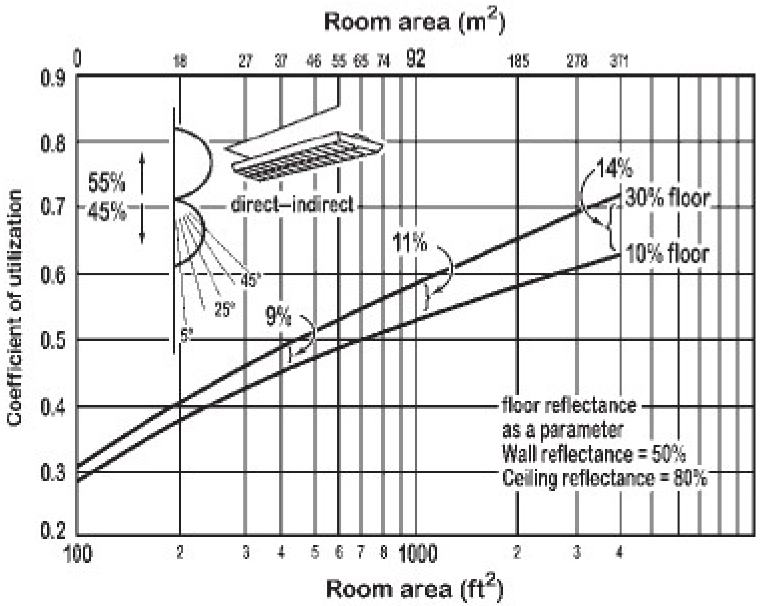


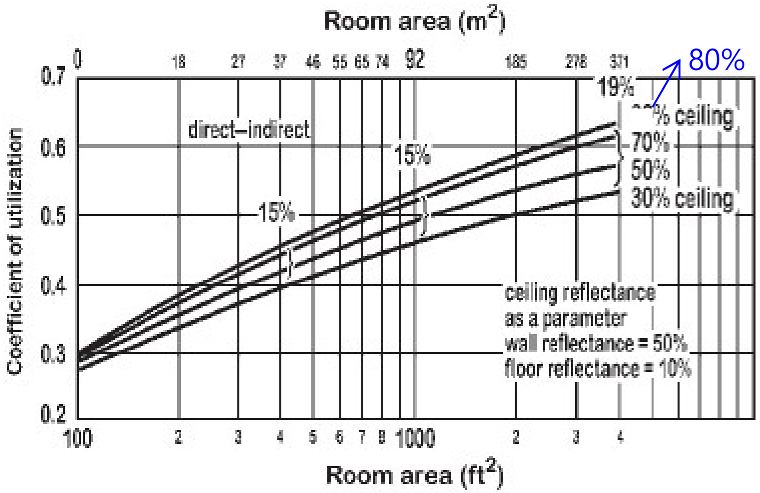
Fig. 16.15 *Effect of surface reflectances on the CU of a luminaire with semi-indirect distribution. As expected, because the ceiling becomes the secondary light source, its reflectance has the most pronounced effect. With this particular fixture having a 25% downward component, the floor finish also has an appreciable effect, increasing the CU by an average of 10% for a 30% reflectance floor. The effect of wall reflectance increases as rooms become smaller and the proportion of wall surface becomes larger. The change in CU between a 30% and a 50% reflectance wall varies from 15% for a 400-ft² (37-m²) room to 5% for a 4000-ft² (372-m²) room. (Redrawn with SI units by Lisa Leal.)*

- For indirect and semi-indirect: the ceiling reflectance has the most pronounced effect.
- The floor finish also has an appreciable effect: increasing CU by 10% for a 30% reflectance floor.
- The effect of wall reflectance naturally increases as rooms become smaller.
- The change in CU between a 30% and a 50% wall reflectance varies from 15% for a 400ft² (37m²) room to 5% for a 4,000 ft² (372m²) room.

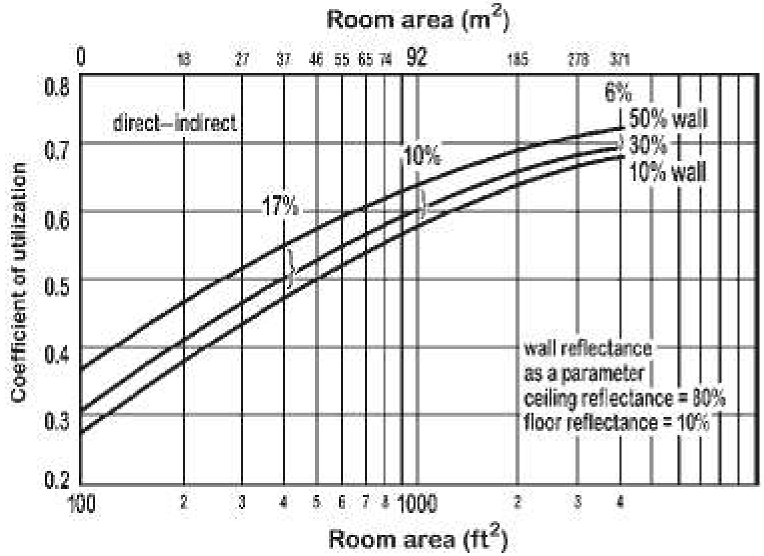
- Fig. 16.16 (direct—indirect)
  - The effects of the ceiling and floor are most pronounced. (Fig.16.16(a) & Fig.16.16(b))
  - The wall reflectance effect is appreciable in small rooms. (Fig.16.16(c))



(a)



(b)



(c)

Fig. 16.16 *Effect of surface reflectances (a: floor, b: ceiling, c: wall) on the CU of a luminaire with direct–indirect distribution. With such distribution, the effects of the ceiling and floor are most pronounced, with an appreciable wall effect only in small rooms. (Redrawn with SI units by Lisa Leal.)*

- Fig. 16.17 (direct spread)
  - Floor finish is most important
  - Wall reflectance is important only in small rooms.
  - As these fixtures have no upward component, all ceiling illumination is derived from reflection. Thus, in a room with floor reflectance of less than 20%, ceiling finish has no effect on room illumination.

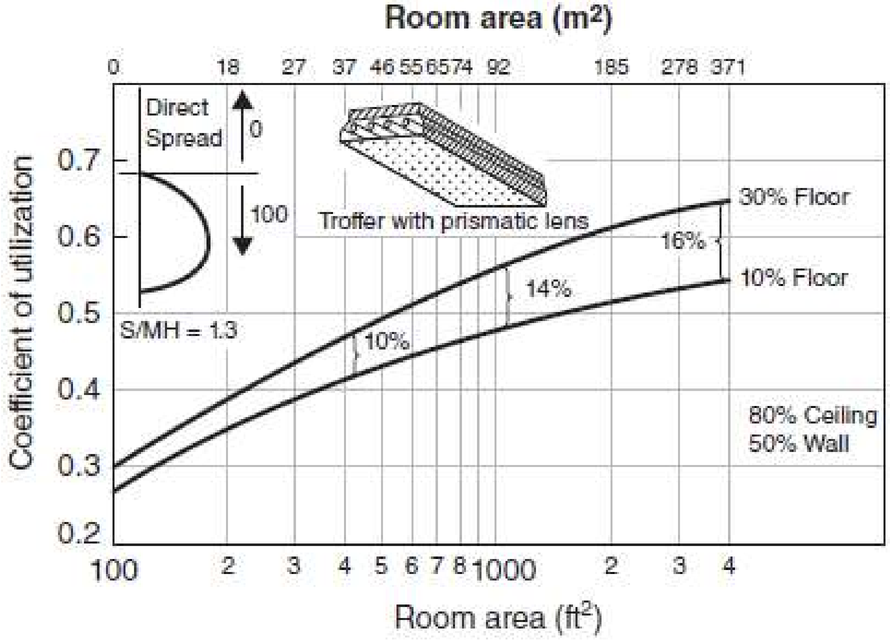


Fig. 16.17 *Effect of surface reflectances on the CU of a luminaire with direct (spread) distribution. Floor finish is most important, with wall reflectance important only in small rooms. As these fixtures have no upward component, all ceiling illumination is derived from reflection. Thus, in a room with floor reflectance of less than 20%, ceiling finish has no effect on room illumination.*

Effect of cavity reflectance on illuminance (2)

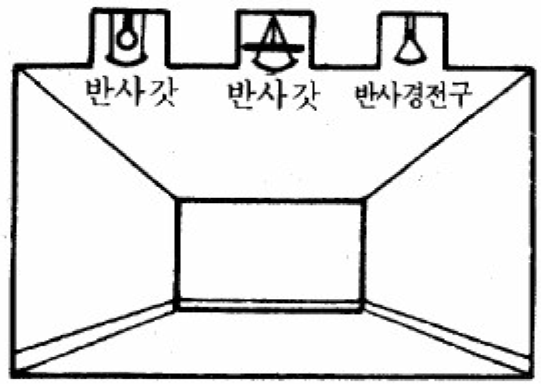
- Lighting costs amount to 3-5% of the total construction cost, such as offices.
- A 20% differential in lighting fixtures can amount to as much as 1% of the total construction cost.
  - N =X/CU (→ CU increased by 25%, N decreased by 20%)
- Reduced number of lighting fixtures
  - Reduced construction cost, reduced electricity use, reduced maintenance cost (relamping), reduced internal heat generation, HVAC system downsizing, reduced fan energy, reduced cooling energy
- Performance assessment in stakeholder dialogues
  - Stakeholders: lighting designer, HVAC designer, architect, construction manager, owner, occupant, etc.
  - Blind belief should be avoided. → uncertainty analysis & sensitivity analysis

Calculating illuminance at a point

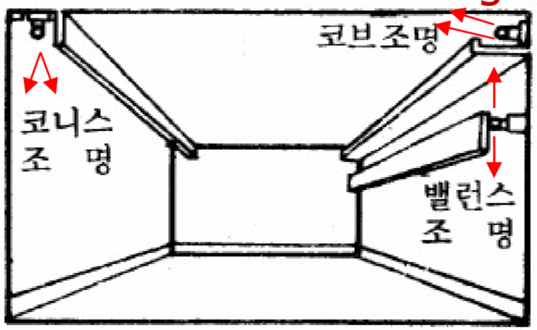
- The IESNA lumen method: uniform illuminance assumed.
- The lumen method is inapplicable to the following:
  - Nonuniform lighting layout
  - Other than horizontal (e.g., wall-washers)
  - Architectural lighting elements (e.g. coves, valances, etc.)
  - Nonstandard light sources (CU data are not available).
- Three methods
  - Design aids: isolux charts, illuminance “cone” charts, illuminance tables and charts.
  - Longhand calculation: Fig.16.22
  - Lighting simulation tools

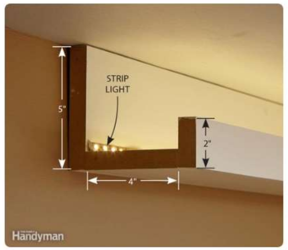
Architectural lighting

Refer to Ch.17: residential lighting



coffered lighting





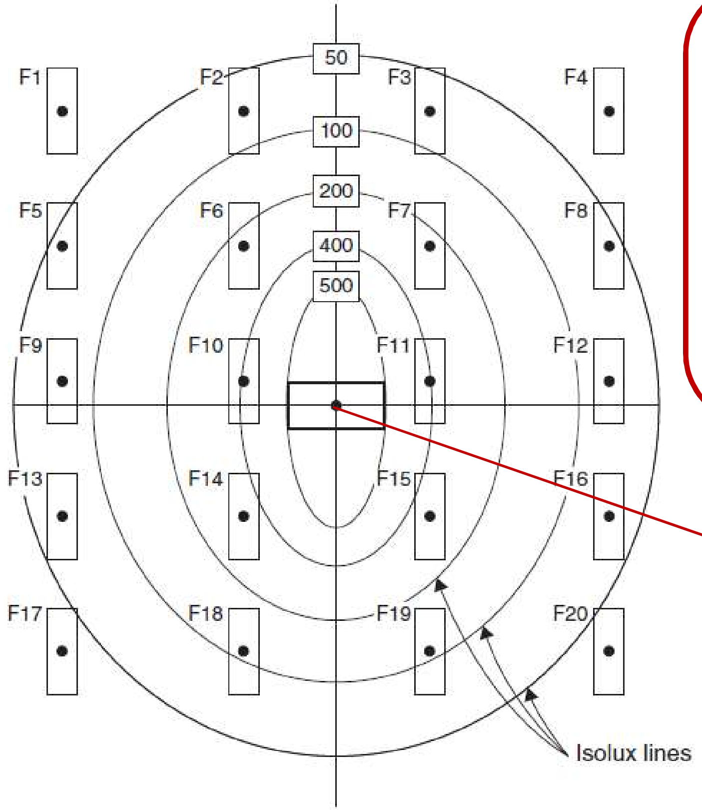
Examples of cove lighting

Design aids

- Curves, charts, plots and tables prepared by the luminaire manufacturer, designer
- Types
  - Isolux charts (Fig.16.19)
  - Illuminance "cone" charts (Fig. 16.20)
  - Illuminance tables and charts (Fig. 16.21)

Isolux charts

- Called isofootcandle charts
- Use of an isolux diagram for a single luminaire (Fig 16.19 either calculated or measured)
- A sum of the illuminance contribution of every other luminaire



Luminaire	Contribution (Lux)
F2, F3	75 × 2
F5, F8	50 × 2
F6, F7	225 × 2
F9, F12	75 × 2
F10, F11	400 × 2
F13, F16	60 × 2
F14, F15	300 × 2
F18, F19	100 × 2
	2570 lux total

Calculated illuminance at the given point

Fig. 16.19 *The ellipses represent isolux lines for a single luminaire at a given height above the work plane. They are centered on the point (the work area of a desk) for which the illuminance must be determined. The total illuminance at that point is the sum of the individual luminaire contributions. The center of the luminaire is the point of reference. Therefore, when two or more isolux lines pass through a fixture, its contribution is determined by the interpolated isolux line passing through its center. Note the symmetry around the vertical axis, necessitating a plot of only half of the ellipses. Note that the chart could be plotted with isofootcandle lines.*

Illuminance "cone" charts

- Max. E at center, 0.5E at the circumference
- Only two values (E, 0.5E) are given in contrast to the isolux diagram (Fig. 16.19)

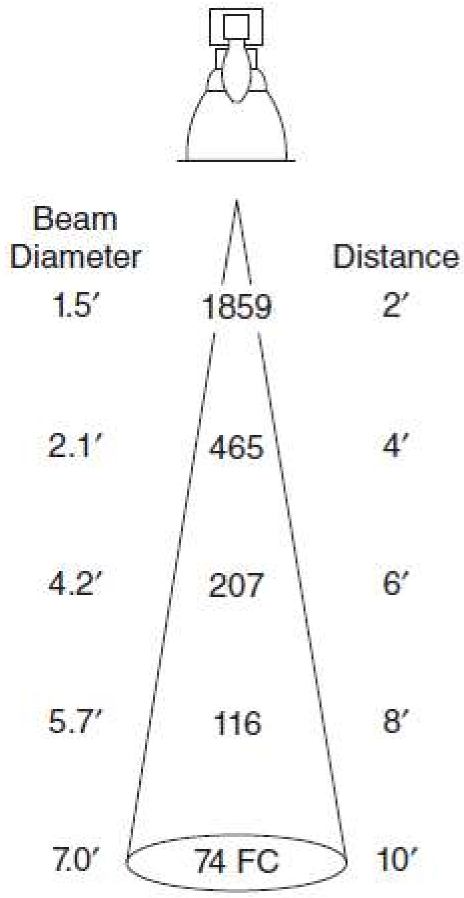
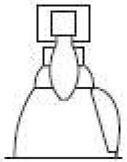


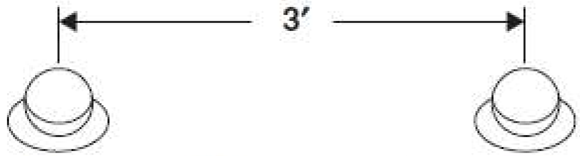
Fig. 16.20 *For downlights with symmetrical circular distribution, a "cone of light," as shown, can be drawn. The illuminance at varying distances on the beam centerline directly below the luminaire is given in the center column. A circle with a circumference at which the illuminance is half of this maximum is drawn at each distance from the downlight (2 ft, 4 ft, etc.). The numbers in the left column show the diameter of this (beam) circle. Similar diagrams are available in SI units. (Courtesy of Zumtobel-STAFF.)*

Illuminance tables and charts

- The illuminance pattern on a wall is shown in Fig.16.21
- Similar charts are available for other luminaire spacings.

Wallwash Lighting Data Chart





Wall — 3′ — Elevation

Elevation	0′	1′	2′	3′
ceiling				
1′	38	38	38	38
2′	44	44	44	44
3′	51	51	51	51
4′	56	58	58	56
5′	59	61	61	59
6′	58	57	57	58
7′	52	49	49	52
8′	42	42	42	42
9′	18	18	18	18
floor	33	33	33	33

Fig. 16.21 *Addition of an interior reflector to the downlight of Fig. 16.44 converts it to a dual-purpose downlight and wallwash unit. In this I-P unit example, the wall illuminances (in fc) produced by multiple units spaced 3 ft apart and ceiling-mounted 3 ft from the wall are given in the chart. Similar charts are available for other luminaire spacings (and in SI units). (Courtesy of Zumtobel-STAFF.)*

Calculating illuminance from a point source

The basis of point source calculations is the inverse square law:

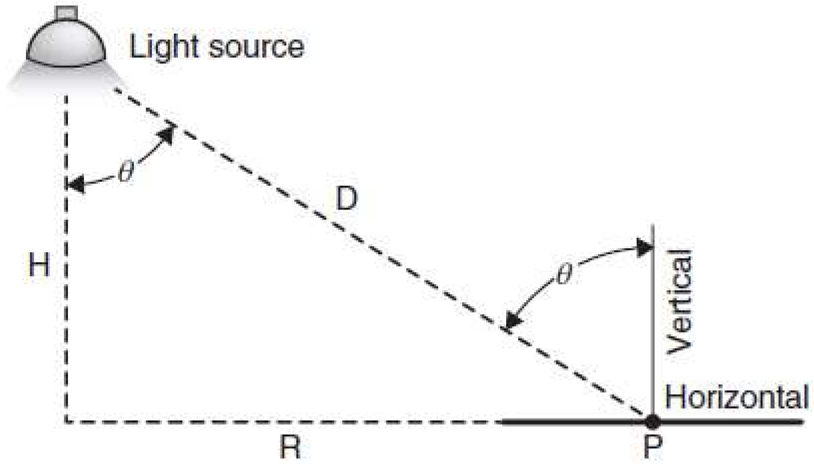
$$fc = \frac{cp}{D^2}$$

where *fc*, *cp*, and *D* are footcandle illuminance, candlepower intensity, and distance, respectively. Refer to Fig. 16.22. The horizontal illuminance at a point *P* as shown in Fig. 16.22 is:

$$\text{horizontal}\ E = \frac{cp}{D^2}\cos\theta$$

and the vertical illuminance at that same point is

$$\text{vertical}\ E = \frac{cp}{D^2}\sin\theta$$



Horizontal illuminance at point P

$$E_H = \frac{CP \times \cos\theta}{D^2} = \frac{CP}{H^2}\cos^3\theta$$

Vertical illuminance at point P

$$E_V = \frac{CP \times \sin\theta}{D^2} = \frac{CP}{R^2}\sin^3\theta$$

Fig. 16.22 *Relationship between intensity in candlepower (cp) and illuminance when the source can be considered a point source—that is, when the inverse square law applies. The source's major dimension must not exceed 0.2D to be considered a point source. Using feet yields fc; using meters yields lux. (Redrawn by Martin Lee.)*

Example 16.5

EXAMPLE 16.5 Referring to Fig. 16.22 and the candlepower distribution curve of Fig. 16.23, find the horizontal and vertical illuminance at point *P*, which is 10 ft below and 12 ft horizontally distant from the source. The same analysis process would apply if using SI dimensions.

SOLUTION

$$H = 10\text{ ft}\ R = 12\text{ ft}$$

$$\theta = \tan^{-1}\frac{12}{10} = 50°$$

$$\sin\theta = 0.766 \quad \cos\theta = 0.643$$

$$cp\text{ at }50° = 6600\ (\text{from Fig. 16.23})$$

$$\text{Horizontal illuminance: } \frac{6600}{10^2} \times (0.643)^3 = 17.5\text{ fc}$$

$$\text{Vertical illuminance: } \frac{6600}{12^2} \times (0.766)^3 = 20.8\text{ fc}$$

■

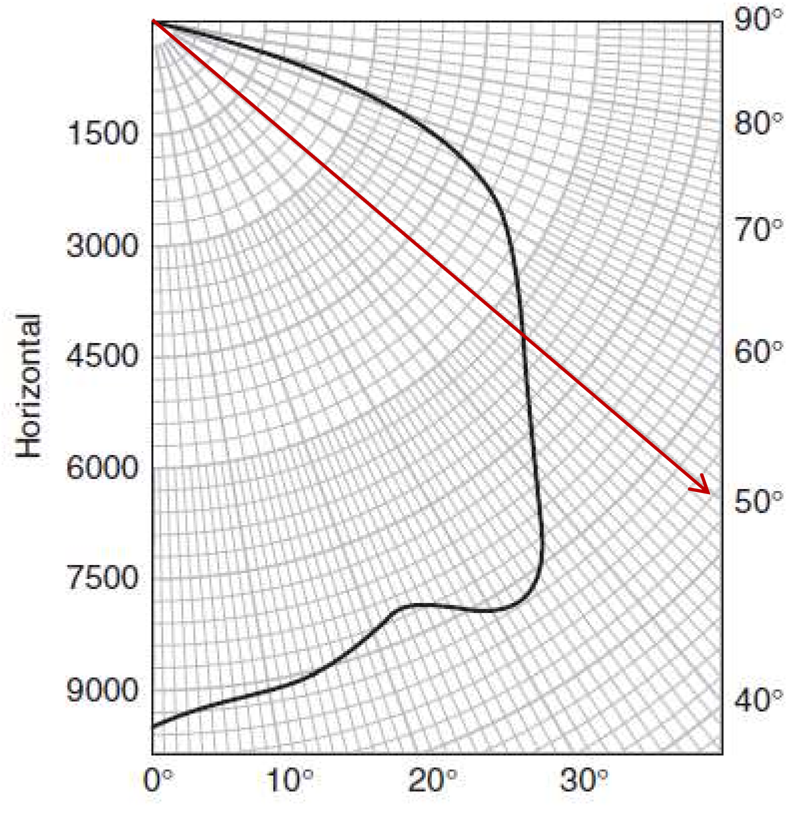
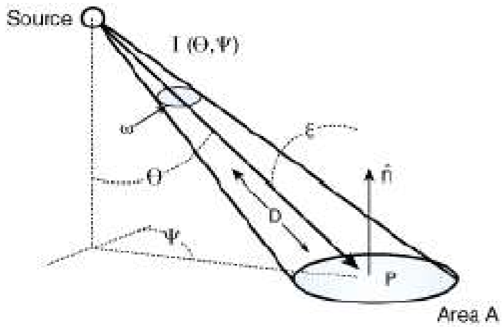


Fig. 16.23 *Typical candlepower distribution plot.*

Calculating illuminance from linear and area sources

- from a point source to a point



$$E = \frac{I(\theta, \psi)\cos\xi}{D^2}$$

- from a point source to a receiving area

$$\Phi = \int \frac{I(\theta, \psi)\cos\xi}{D^2}\, dA$$

Φ: flux transferred from a point source to a differential area

$$\Phi = \sum_{i=1}^{n} I(\theta_i, \psi_i)\cos\xi_i \frac{a_i}{D_i^2}$$

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

E: Average illuminance

Calculating illuminance from linear and area sources

- from a diffuse area source to a point
- from a diffuse area source to a receiving area
- from a non-diffuse area source to a point

Integration over the surface of the luminaire gives

$$E = \frac{1}{A}\int \frac{I(\theta, \psi)\cos\xi}{D^2}\,dA \qquad E = \frac{1}{A}\sum_i I(\theta_i, \psi_i)\cos\xi_i \frac{a_i}{D_i^2}$$

where the summation is over all the discrete pieces of the luminaire, and

$I(\theta_i,\psi_i)$ = intensity of the ith piece of the luminaire surface to point P,
ξ_i = incident angle for flux from the ith piece of the luminaire surface,
a_i = area of the ith piece of the luminaire surface,
D_i = distance between the ith piece of the luminaire surface and point P,
A = area of the luminaire surface.

- from a non-diffuse area source to a receiving area

Calculating illuminance from linear and area sources

- These manual methods are laborious and frequently less than reliable.
- Lighting simulation is strongly recommended for point-by-point illuminance calculation.

Simulation-based lighting design

- The calculations are performed accurately and rapidly.
- The designer can change design parameters with less effort than hand calculations.
- List of lighting simulation tools: https://www.buildingenergysoftwaretools.com/ → lighting simulation

Evaluating glare potential

- Direct Glare
  - Control of direct glare is addressed (see Ch.6)
- In Ch.16, reflected glare is a focus.

Control of reflected glare

- No perfect solution to the reflected glare so far.
- Several techniques to minimize
  - (a) Physical arrangement of sources, task, and observer
  - (b) Adjusting brightness (eye adaptation level)
  - (c) Design of the light source so that it causes minimal reflected glare.
  - (d) Changing the task quality