TABLE 16.1 Coefficients of Utilization for Typical Luminaires with Suggested Maximum Spacing Ratios

To obtain a coefficient of utilization (CU):

1. Determine the cavity ratios for the room, ceiling, and floor.
2. Determine the effective ceiling and floor cavity reflectances from Table 16.2. Use initial ceiling, floor, and wall reflectances.
3. Obtain the CU for a 20% effective floor cavity reflectance from the appropriate column for the luminaire type to be used. Interpolate, when necessary, to obtain the CU for the exact room cavity ratio for the nearest effective ceiling cavity reflectances above and below the reflectance obtained in step 2; interpolate between these CUs to obtain the CU for the step 2 ceiling cavity reflectance.
4. If the effective floor cavity reflectance differs significantly from 20%, obtain the multiplier from Table 16.3 and apply this to the CU obtained in step 3.
5. To obtain the CU for a ceiling cavity reflectance (ρ_{CC}) of 30 or 10%, multiply the figure for ρ_{CC} = 50% by 0.85 or 0.70, respectively. This is an approximation. For exact figures, see the IESNA Lighting Handbook (2000).
6. Use the figure in the last column (ρ_{CC} = 0; ρ_w = 0) for outdoor lighting, i.e., there are no walls or ceiling.
7. Legend:

ρ_{CC} = percent effective ceiling cavity reflectance

ρ_w = percent wall reflectance

RCR = room cavity ratio

Maximum S/MH guide = ratio of maximum luminaire spacing to mounting above work plane

Note: In some cases, luminaire data in this table are based on an actual typical luminaire; in other cases, the data represent a composite of generic luminaire types. Therefore, whenever possible, specific luminaire data should be used in preference to this table.

The polar intensity sketch (candlepower distribution curve) and the corresponding spacing-to-mounting height guide are representative of many luminaires of each type shown.

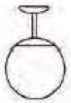
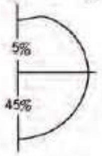
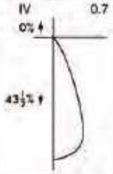
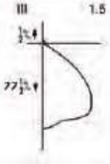
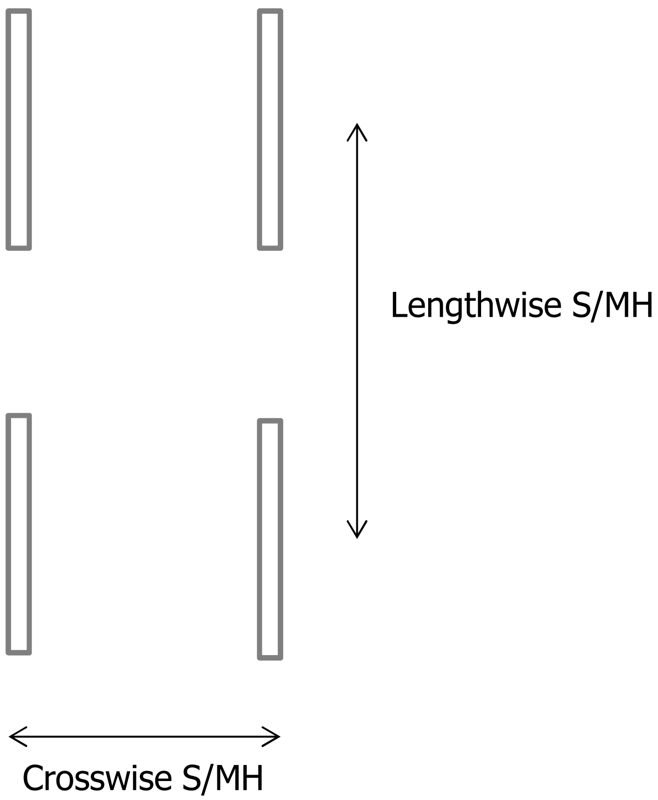
Typical Luminaire	Typical Distribution and Percent Lamp Lumens / Maintenance Category	Maximum S/MH	RCR	ρ_{cc} 80, ρ_w 50	80, 30	80, 10	70, 50	70, 30	70, 10	50, 50	50, 30	50, 10	0, 0
				Coefficients of Utilization for 20% Effective Floor Cavity Reflectance (ρ_{FC} = 20)									
1 	V 	1.5	0	.67	.87	.87	.81	.81	.81	.69	.69	.69	.44
			1	.71	.67	.63	.66	.62	.59	.56	.53	.50	.31
			2	.61	.54	.49	.56	.50	.46	.47	.43	.39	.23
			3	.52	.45	.39	.48	.42	.37	.41	.36	.31	.18
			4	.46	.38	.33	.42	.36	.30	.36	.30	.26	.15
			5	.40	.33	.27	.37	.30	.25	.32	.26	.22	.12
			6	.36	.28	.23	.33	.26	.21	.28	.23	.19	.10
			7	.32	.25	.20	.29	.23	.18	.25	.20	.16	.09
Pendant diffusing sphere with incandescent lamp			8	.29	.22	.17	.27	.20	.16	.23	.17	.14	.07
			9	.26	.19	.15	.24	.18	.14	.20	.15	.12	.06
3 	IV 	1.3	0	.99	.99	.99	.97	.97	.97	.92	.93	.93	.83
			1	.88	.85	.82	.86	.83	.81	.83	.80	.78	.72
			2	.78	.73	.68	.76	.72	.67	.73	.69	.66	.61
			3	.69	.62	.57	.67	.61	.57	.65	.60	.56	.52
			4	.61	.54	.49	.60	.53	.48	.58	.52	.48	.45
			5	.54	.47	.41	.53	.46	.41	.51	.45	.41	.38
			6	.48	.41	.35	.47	.40	.35	.46	.39	.35	.32
Porcelain-enameled ventilated standard dome with incandescent lamp			7	.43	.35	.30	.42	.35	.30	.41	.34	.30	.28
			8	.38	.31	.26	.38	.31	.26	.37	.30	.26	.24
			9	.35	.28	.23	.34	.27	.23	.33	.27	.23	.21
7 	IV 	0.7	0	.52	.52	.52	.51	.51	.51	.48	.48	.48	.44
			1	.49	.48	.48	.48	.48	.47	.47	.46	.46	.42
			2	.47	.46	.45	.46	.45	.44	.45	.44	.43	.41
			3	.45	.44	.43	.45	.43	.42	.44	.42	.42	.40
			4	.43	.42	.41	.43	.41	.40	.42	.41	.40	.38
EAR-38 lamp above 51-mm (2 in.)-diameter aperture (increase efficiency to 54½% for 76-mm (3 in.)-diameter aperture)			5	.42	.40	.39	.41	.40	.38	.41	.39	.38	.37
			6	.40	.39	.37	.40	.38	.37	.39	.38	.37	.36
			7	.39	.37	.36	.39	.37	.36	.38	.37	.35	.35
			8	.37	.36	.34	.37	.35	.34	.37	.35	.34	.33
			9	.36	.34	.33	.36	.34	.33	.35	.34	.33	.32
18 	III 	1.5	0	.93	.93	.93	.91	.91	.91	.87	.87	.87	.78
			1	.85	.82	.80	.83	.81	.79	.79	.78	.76	.70
			2	.77	.73	.70	.76	.72	.69	.73	.70	.67	.63
			3	.70	.65	.61	.68	.64	.60	.66	.62	.59	.56
			4	.63	.58	.53	.62	.57	.53	.60	.56	.52	.49
			5	.57	.51	.47	.56	.51	.47	.55	.50	.46	.44
			6	.51	.45	.41	.51	.45	.41	.49	.44	.40	.38
"High-bay" wide distribution ventilated reflector with clear HID lamp			7	.46	.40	.35	.45	.39	.35	.44	.39	.35	.33
			8	.41	.35	.31	.41	.35	.31	.40	.34	.31	.29
			9	.37	.31	.27	.37	.31	.27	.36	.30	.27	.25

Image source: MEEB 12th Ed.



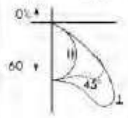
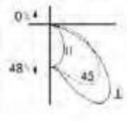
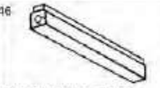
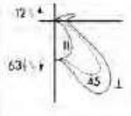
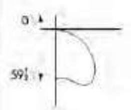
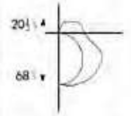
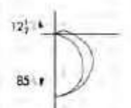
The crosswise S/MH ratio is always considerably higher than the lengthwise S/MH ratio.(luminaire # 26, 28, 42 in Table 16.1)

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

Typical Luminaire	Typical Distribution and Percent Lamp Lumens: Maintenance Category	Maximum S/MH	RCR	ρ_{cc} → 80, ρ_w → 50	80, 30	80, 10	70, 50	70, 30	70, 10	50, 50	50, 30	50, 10	0, 0
				Coefficients of Utilization for 20% Effective Floor Cavity Reflectance (ρ_{fc} = 20)									
26	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
Diffuse aluminum reflector with 35° crosswise shielding			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	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
Diffuse aluminum reflector with 35° crosswise, 35° lengthwise shielding			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	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
Luminous bottom-suspended unit with very-high-output lamp			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	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
Two-lamp prismatic wraparound; multiply by 0.95 for four lamps			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	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
Four-lamp, 610-mm (2-ft)-wide troffer with 45° plastic louver			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	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
Fluorescent unit with flat prismatic lens, four-lamp, 610 mm (2 ft) wide			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

Image source: MEEB 12th Ed.

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	ρcc → 80, ρw → 50	80, 30	80, 10	70, 50	70, 30	70, 10	50, 50	50, 30	50, 10	0, 0
				Coefficients of Utilization for 20% Effective Floor Cavity Reflectance (ρfc = 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	.55	.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—			8	.30	.25	.22	.30	.25	.22	.29	.25	.22	.20
louvered fluorescent unit			9	.27	.22	.18	.26	.22	.18	.26	.21	.18	.17
45 	V	N.A.	0	.57	.57	.57	.56	.56	.56	.53	.53	.53	.48
			1	.50	.48	.47	.49	.47	.46	.47	.46	.44	.41
			2	.44	.41	.38	.43	.40	.38	.41	.39	.37	.34
			3	.39	.35	.32	.36	.34	.31	.37	.33	.31	.29
			4	.34	.30	.27	.33	.29	.26	.32	.29	.26	.24
Radial batwing distribution—			5	.30	.25	.22	.29	.25	.22	.28	.24	.22	.20
four-lamp, 610-mm			6	.26	.22	.19	.26	.22	.18	.25	.21	.18	.17
(2 ft)-wide fluorescent unit			7	.23	.19	.16	.23	.19	.16	.22	.18	.16	.14
with flat prismatic lens			8	.21	.16	.13	.20	.16	.13	.19	.16	.13	.12
and overlay			9	.18	.14	.11	.18	.14	.11	.17	.14	.11	.10
46 	V	N.A.	0	.87	.87	.87	.84	.84	.84	.77	.77	.77	.64
			1	.76	.73	.70	.73	.70	.67	.67	.65	.63	.53
			2	.66	.61	.57	.64	.59	.56	.59	.56	.52	.44
			3	.59	.53	.48	.56	.51	.47	.53	.48	.44	.38
			4	.52	.45	.40	.50	.44	.40	.47	.42	.38	.32
Bilateral batwing distribu-			5	.46	.39	.34	.44	.38	.33	.41	.36	.32	.27
tion—one lamp, surface-			6	.41	.34	.29	.39	.33	.29	.37	.31	.27	.23
mounted fluorescent with			7	.36	.30	.25	.35	.29	.24	.33	.27	.23	.20
prismatic wraparound			8	.32	.26	.21	.31	.25	.21	.29	.24	.20	.17
lens			9	.29	.22	.18	.28	.22	.18	.26	.21	.17	.14
47 	V	1.7	0	.71	.71	.71	.69	.69	.69	.66	.66	.66	.60
			1	.62	.60	.58	.61	.59	.57	.59	.57	.55	.51
			2	.55	.51	.47	.53	.50	.47	.51	.48	.46	.42
			3	.48	.43	.39	.47	.43	.39	.45	.41	.38	.36
			4	.42	.37	.33	.41	.37	.33	.40	.36	.32	.30
Radial batwing distribution—			5	.37	.32	.27	.36	.31	.27	.35	.30	.27	.25
four-lamp, 610-mm (2-ft)-			6	.33	.27	.23	.32	.27	.23	.31	.26	.23	.21
wide fluorescent unit with			7	.29	.24	.20	.29	.24	.20	.28	.23	.20	.18
flat prismatic lens—			8	.26	.21	.17	.25	.20	.17	.25	.20	.17	.15
see note 2			9	.23	.18	.14	.23	.18	.14	.22	.17	.14	.13
48 	I	1.6/1.2	0	1.01	1.01	1.01	.96	.96	.96	.87	.87	.87	.68
			1	.85	.81	.77	.81	.77	.73	.73	.70	.67	.53
			2	.73	.66	.61	.69	.63	.58	.63	.58	.54	.42
			3	.63	.56	.50	.60	.53	.48	.55	.49	.44	.35
			4	.56	.47	.41	.53	.46	.40	.48	.42	.37	.29
			5	.49	.40	.34	.46	.39	.33	.42	.36	.31	.24
			6	.43	.35	.29	.41	.34	.28	.38	.31	.26	.20
			7	.39	.31	.25	.37	.29	.24	.34	.27	.23	.17
Two-lamp fluorescent strip			8	.34	.27	.21	.33	.26	.21	.30	.24	.19	.15
unit			9	.31	.23	.18	.30	.23	.18	.27	.21	.17	.12
49 	I	1.4/1.2	0	1.13	1.13	1.13	1.09	1.09	1.09	1.01	1.01	1.01	.85
			1	.96	.92	.88	.93	.89	.85	.87	.83	.80	.68
			2	.83	.76	.70	.80	.74	.68	.75	.69	.65	.55
			3	.73	.65	.58	.70	.63	.57	.66	.59	.54	.46
			4	.64	.55	.49	.62	.54	.48	.58	.51	.46	.39
			5	.56	.47	.41	.55	.46	.40	.51	.44	.38	.33
			6	.50	.41	.35	.49	.40	.34	.46	.38	.33	.28
Two-lamp fluorescent strip			7	.45	.36	.30	.44	.35	.30	.41	.34	.28	.24
unit with 235° reflector			8	.40	.32	.26	.39	.31	.25	.37	.30	.25	.21
fluorescent lamps			9	.36	.28	.22	.35	.27	.22	.33	.26	.21	.18

Case study

- Illuminance at P1 = higher than the average by 20-30% (because of other fixtures and inter-reflections)
  - P2 = 100% (room average)
  - P3 = 60%
  - P4 = 50%
- Designers' three choices
  - #1: Reduce the distance between the last row of fixtures and the wall to a third or less
  - #2: Provide continuous perimeter lighting or wall wash units → increase the wall illuminance
  - #3: a combination of #1 and #2
- Note: endwise illumination from linear fluorescent fixtures is considerably lower than crosswise illumination.
  - Terminate fixture rows no more than 1 ft from an end wall
  - Provide supplementary task lighting

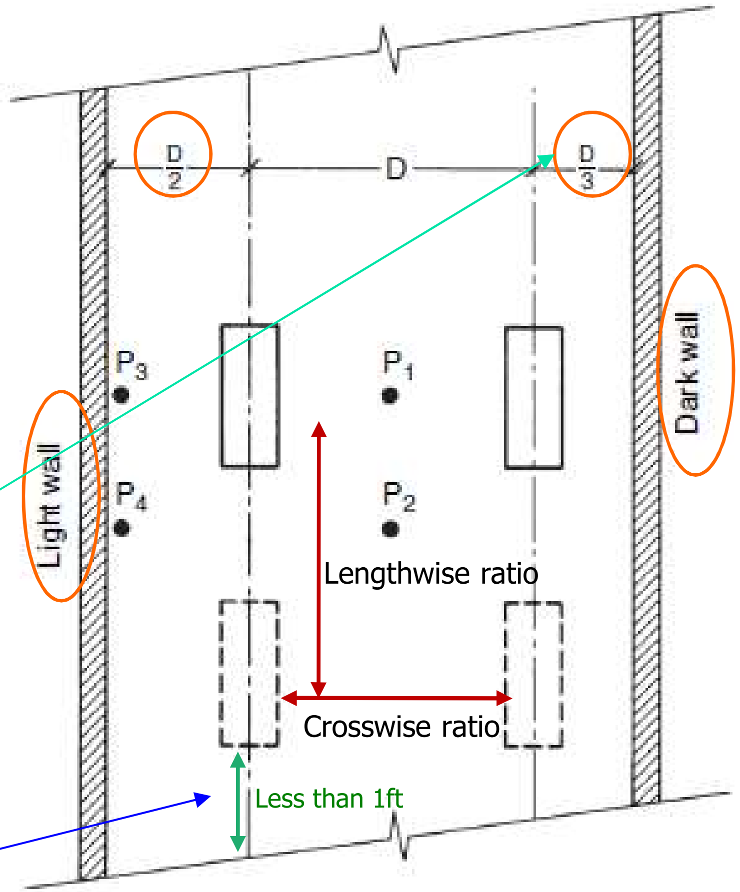


Fig. 15.42 The diagram shows lighting fixtures installed according to the manufacturer's recommended spacing criteria (ratio of spacing to mounting height above the work plane), with a row-to-row spacing, D, and a row-to-wall spacing, D/2, as shown at the left wall. Assuming a high-reflectance (light color) finish on the wall, illuminances P_3 and P_4 are at least one-half of the illuminance directly below a fixture. With a dark wall, as on the right, illuminance would fall below this value. Consequently, the right row of luminaires should be placed closer to the wall, as shown.

Determination of S/MH

- S/MH=spacing / mounting height (from the luminaire to the working plane)
- flat-bottomed curve → high S/MH
- S/MH not given by a manufacturer: refer to Fig. 15.43 for approximation

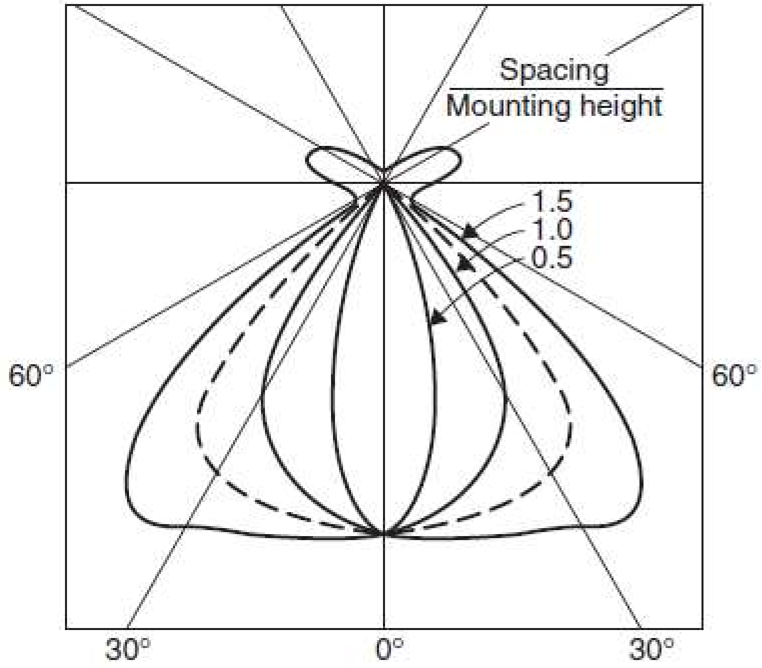


Fig. 15.43 *Curves for approximating the ratio of fixture spacing to mounting height (S/MH) above the working plane for typical direct distribution luminaires. These curves were developed for point sources such as incandescent (and HID) but can also be applied to asymmetric distribution luminaires using fluorescent lamps. The practical permissible S/MH is somewhat higher than the curves indicate because this is a semi-direct distribution, and the ceiling light component permits wider spacing between units. (After Odle and Smith, from* IESNA Journal, *January 1963.)*

Coefficient of Utilization (CU)

- CU: the ratio between the lumens reaching the horizontal work plane and the generated lumens
- In the absence of manufacturer's data: refer to Fig.15.46

- Fig. 15.46: variation of CU in terms of luminaire mounting height, room size, lighting systems (direct, indirect…)
  - Fig.15.46(a) Direct-indirect, general diffuse: CU influenced by room size and mounting height. For a small space, CU can vary by 20% depending on the pendant length
  - Fig.15.46(b) Indirect, semi-indirect: the mounting height is not that relevant to CU. Room size is more influential.

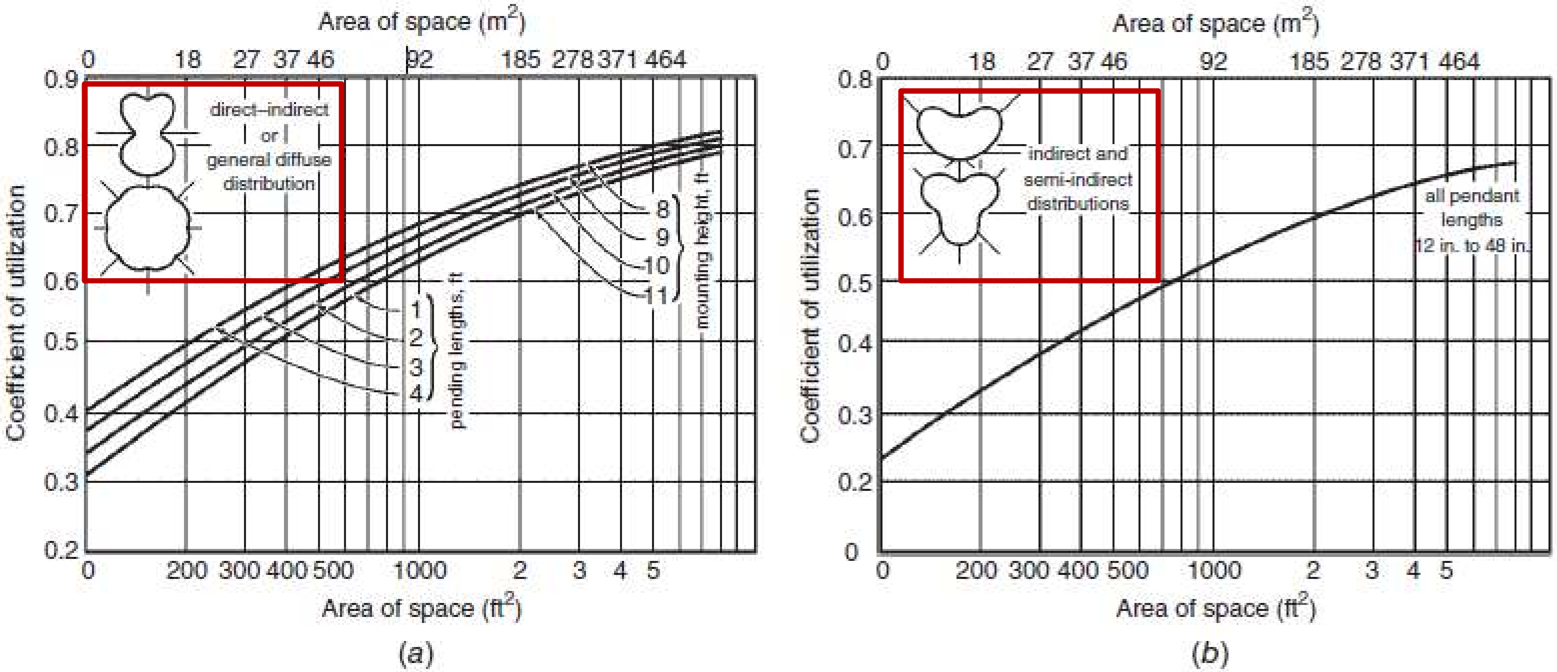


Fig. 15.46 Coefficient of utilization (CU) as a function of pendant length for various fixture distributions. With a substantial downward component, as in direct–indirect or general diffuse lighting (a), CU increases slowly as the fixture descends (pendant length increases). Maximum differentials occur in small rooms and can reach 20%. Where the ceiling is the light source, as in indirect and semi-indirect systems (b), the pendant length does not change the room illuminance. This curve can be used to estimate CU for indirect and semi-indirect luminaries in the absence of manufacturer's data. (Redrawn with SI units by Lisa Leal.)

Lighting fixtures appraisal

- Photometric and design data: CDC, CU, luminance data from 45° to 85°, VCP, LER, recommended S/MH
- Construction and installation: quality of materials and finish, ease of installation, installation instruction sheets
- Maintenance: should be ‘simply & quickly relampable’, resistant to dirt collection, and simple to clean.

Coefficient of Utilization

- Some of the generated lumen output of the lamp can be lost because of internal reflections inside a luminaire. (→ lamp efficacy alone is not sufficient)
- Some of the generated lumen output of the luminaire can be lost because of internal reflections in the room (→ Similarly, luminaire efficiency alone is not sufficient).
  - Case I: a room with a high, dark ceiling
    - a high efficiency (say, 80%) indirect lighting unit → most of the light directed upward would be lost (absorbed), and the actual illuminance on the working plane would be very low.
  - Case II: the same room illuminated with 50% efficiency direct-lighting units utilizing the same wattage
    - The illuminance on the working plane would be considerably higher than Case I

Coefficient of Utilization

- Lamp efficacy vs. luminaire efficiency vs. room system efficiency
- CU: the ratio between the lumens reaching the horizontal workplane and the generated lumens
- Can be regard as a measure of the overall luminous efficiency of a particular unit in a particular space.
- CU is a factor that combines fixture efficiency and distribution with room proportions, mounting height, and surface reflectances
- Refer to Table 16.1 (from MEEB 12th Ed.) → only for generic fixture types. In an actual job, refer to the manufacturer's catalog.

LER (Luminaire Efficacy Rating)

- A measure of luminaire energy efficiency
- Expressed in lumen/watt (luminaire efficacy)
- takes into account all power used by a luminaire, including ballast
- LER= photometric efficiency * ballast factor / luminaire input watts
- Described in NEMA - National Electrical Manufacturers Association (http://www.nema.org/)

TER (Target Efficacy Rating)

- TER = (EFF × TLL × BF)/input watts
  - EFF = Energy Effectiveness Factor (which includes
  - an averaged CU value)
  - TLL = total initial lamp lumens
  - BF = Ballast Factor
- TER is the currently preferred performance metric.

LER vs. lighting energy

Category	Input and Output	Sam Nunn	Russell	Peachtree Summit	MLK	Rome	William Augustus	Stephens	Newnan	PO-CT	Federal Record Center
Energy (PI1)	Selected space	15F (SE)	9F	19F	2F	3F	2F (an office)	2F	2F	2F (East)	entrance lobby
	Total number of the luminaires	38	515	104	394	91	8	590	403	37	12
	# of lamps/luminaire	3	3	2	4	3	4	1	1	2	3
	lumen/lamp	2710	2710	2800	2710	2800	2710	2580	2710	2580	2710
	Input watt per luminaire	89	89	60	162	89	110	30	30	55	89
	P (capacity for lighting amartures in kW)	3.4	45.8	6.2	63.8	8.1	0.9	17.7	12.1	2.0	1.1
	Lighting control	central on/of	central on/of	centrral on/o	centrral on/o	room switch	room switch	room switch	central on/of	room switch	room switch
	Number of burning hours per year	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
	Occupancy sensor	no	no	no	no	no	no	no	no	no	no
	Area of selected room (m2)	311	2,833	624	2,424	432	49	1,593	1,009	411	56
	Result (kWh/m2)	24.1	35.6	20.9	57.9	39.2	40.4	24.4	26.4	10.7	43.0
LER (PI2)	Selected space	15F (SE)	9F	19F	2F	3F	2F (an office)	2F	2F	2F (East)	entrance lobby
	Photometric efficiency of luminaires	0.62	0.75	0.78	0.63	0.78	0.78	0.79	0.64	0.86	0.75
	Total lumens (# lamps*lumen)	8130	8130	5600	10840	8400	10840	2580	2710	5160	8130
	Ballast factor (0-1)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.8	0.88
	Input watt per luminaire	89	89	60	162	89	110	30	30	55	89
	Result (Lumen/watt)	50.1	60.5	64.1	37.1	64.8	67.6	56.1	50.7	60.2	60.5

Lighting control

Lighting and energy

Refer to the next slide

1.3.6 1995 Commercial *Delivered* End-Use Energy Consumption Intensities, by Principal Building Type (1)

	Consumption (10^3 Btu/SF)					
Building Type	Space Heating	Space Cooling	Water Heating	Lighting	Total (2)	Percent of Total Consumption
Office	24.3	9.1	8.7	28.1	97.2	19%
Mercantile and Service	30.6	5.8	5.1	23.4	76.4	18%
Education	32.8	4.8	17.4	15.8	79.3	12%
Health Care	55.2	9.9	63.0	39.3	240.4	11%
Lodging	22.7	8.1	51.4	23.2	127.3	9%
Public Assembly	53.6	6.3	17.5	21.9	113.7	8%
Food Service	30.9	19.5	27.5	37.0	245.5	6%
Warehouse and Storage	15.7	0.9	2.0	9.8	38.3	6%
Food Sales	27.5	13.4	9.1	33.9	213.5	3%
Vacant (3)	38.0	1.4	5.5	4.5	30.1	3%
Public Order and Safety	27.8	6.1	23.4	16.4	97.2	2%
Other (4)	59.6	9.3	15.3	26.7	172.2	3%
All Buildings	29.0	6.0	13.8	20.4	90.5	100%

Note(s): 1) Further detail can be found in Table 7.4.1. Parking garages and commercial buildings on multibuilding manufacturing facilities are excluded from CBECS 1995. 2) Includes all end-uses. 3) Includes vacant and religious worship. 4) Includes mixed uses, hangars, crematoriums, laboratories, and other.

Source(s): EIA, Commercial Building Energy Consumption and Expenditures 1995, April 1998, Table EU-2, p. 311.

From 2002 BUILDINGS ENERGY DATABOOK published by U.S. DEPARTMENT OF ENERGY OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY

Lighting and energy

1.3.9 Aggregate Commercial Building Component Loads (1)

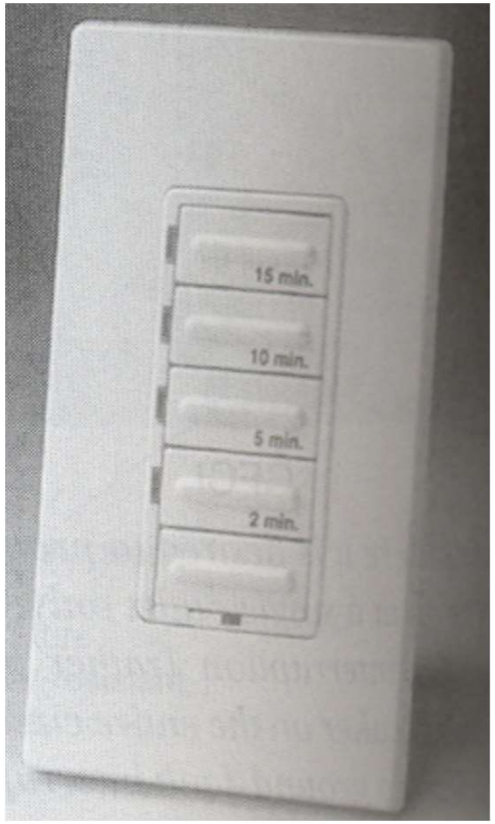
Component	Heating (quads)	Heating (%)	Cooling (quads)	Cooling (%)
	Loads (quads) and Percent of Total Loads			
Roof	-0.103	12%	0.014	1%
Walls (2)	-0.174	21%	-0.008	-
Foundation	-0.093	11%	-0.058	-
Infiltration	-0.152	18%	-0.041	-
Ventilation	-0.129	15%	-0.045	-
Windows (conduction)	-0.188	22%	-0.085	-
Windows (solar gain)	0.114	-	0.386	32%
Internal Gains				
Lights	0.196	-	0.505	42%
Equipment (electrical)	0.048	-	0.207	17%
Equip. (non-electrical)	0.001	-	0.006	1%
People	0.038	-	0.082	7%
NET Load	-0.442	100%	0.963	100%

Note(s): 1) "Loads" represents the thermal energy losses/gains that, when combined, will be offset by a building's heating/cooling system to maintain a set interior temperature (which then equals *site* energy). 2) Includes common interior walls between buildings.

Source(s): LBNL, Commercial Heating and Cooling Loads Component Analysis, June 1998, Table 24, p. 45 and Figure 3, p. 61.

Why lighting control?

- Two purposes
  - Flexibility: modifications of luminances and patterns
  - Economy: a proper lighting control can save up to 60% over a simple on/off control. (reduced energy use, reduced air-conditioning costs, longer lamp and ballast life due to lower operating temperatures and lower output, lower labor costs)
- Lighting control: manual, automatic, or combined controls
- Control functions: switching and dimming
- Control devices: the means for switching and dimming
  - simple wall switch, time switch, dimmer, occupancy sensor, photocell, assembly of control and signal equipment (microprocessor, programmable controller)



Time-out switch for supply closets

Lighting control: switching

- Switching: simple on/off → multiple discrete lighting levels (Fig.15.47)
  - All ballast on : 100% illumination
  - Two-lamp ballast on : 66% illumination
  - ½ of two lamp ballast (split wired) : 33% illumination
  - All ballast off : 0% illumination
- Two level ballast (0, 50, 100%): 0%, 17%, 33%, 50%, 66%, 83%, 100%

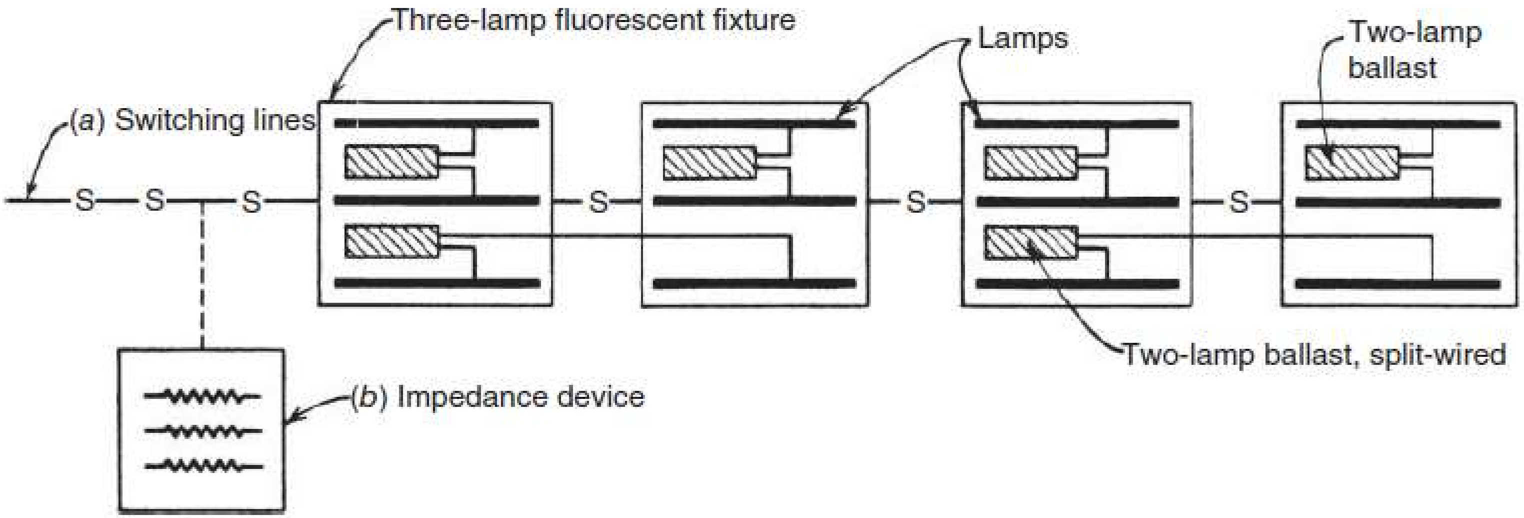


Fig. 15.47 Schematic diagram of switching arrangements to achieve multiple discreet lighting levels with three-lamp fluorescent lighting fixtures. Two-lamp ballasts are used in the interest of energy conservation and financial economy. In scheme (a) ballasts are switched, thus removing either one or two lamps from service. Finer control is achieved by using two-level ballasts or by introducing impedance (b) into the circuit, either in a block for an entire circuit or distributed in each fixture.

Lighting control: dimming

- For fluorescent lamps: dimming down to 40% of output is possible without reducing efficacy
- Due to efficacy reduction below 40% output, a combination of dimming and switching is economical.

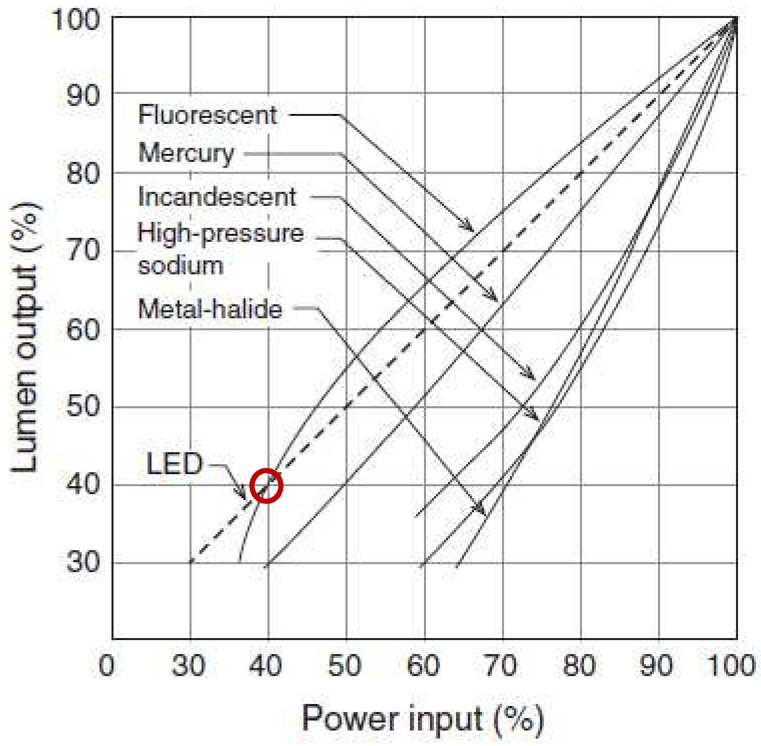
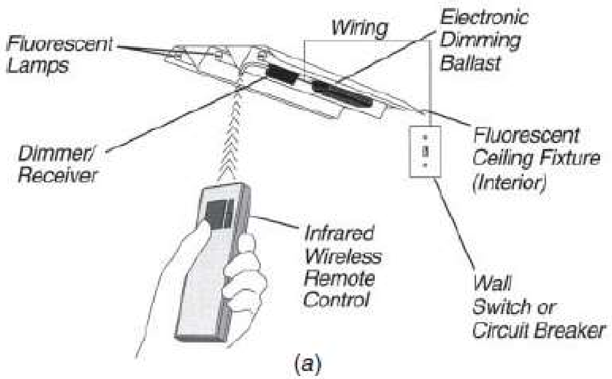


Fig. 15.48 Typical dimming curves for generic light source types. Note that fluorescent lighting is efficient and approximately linear down to 40% output. LED lamp dimming is similar to that of fluorescent. All other sources have reduced efficacy when dimmed. (Drawing revised by Martin Lee.)

Lighting control: control initiation (manual control)

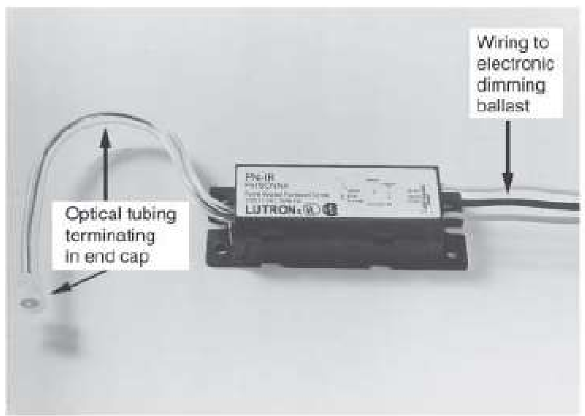
- Numerous studies dating back at least 50 years have indicated increased employee satisfaction & increased work output when at least a degree of control of the working environment is in his or her hands.
- Manual control has been demonstrated to be wasteful ← the tendency to leave lights on when daylight is sufficient or when leaving a room for an extended period.
- Manual dimming in multiple occupancy spaces: personnel dissatisfaction & friction
  - remote-control manual dimming (Fig. 15.49): can control single or multiple luminaires closest to his or her workstation

- Fig. 15.49: open multiple occupancy space
  - can control single or multiple luminaires closest to the occupant.
  - direct glare, reflected glare reduced. Good for VDT work.



(a)

(b) Handheld IR remote control



(c) IR-activated receiver/dimmer

(d) Electronic dimming ballast

Fig. 15.49 *(a) Ceiling-mounted fluorescent fixtures within an 8-ft (2.4-m) radius of the optical sensor can be dimmed by remote control and restored almost instantaneously. (b) The handheld IR remote-control device for continuous dimming and for dimming override for maximum or minimum light. (c) The IR-activated receiver/dimmer, which fits into a 4-in (100-mm) square standard outlet box, can be mounted inside the luminaire as in (a) or adjacent to it. (d) High-frequency electronic dimming ballast for one to four lamps can provide full-range dimming down to 1–5% of output or down to 10% of output, depending on the type. The optical tube that carries the IR signal must be exposed on the ceiling. It may be mounted on the underside of an open luminaire or close by. (Courtesy of Lutron Electronics Co.)*

Lighting control: control initiation (automatic control)

- Two types exist
  - Open-circuit control, open loop control, static control → not dependent on state variables. simple.
  - Close-loop control, feedback control, dynamic control → dependent on state variables

Static control, open control

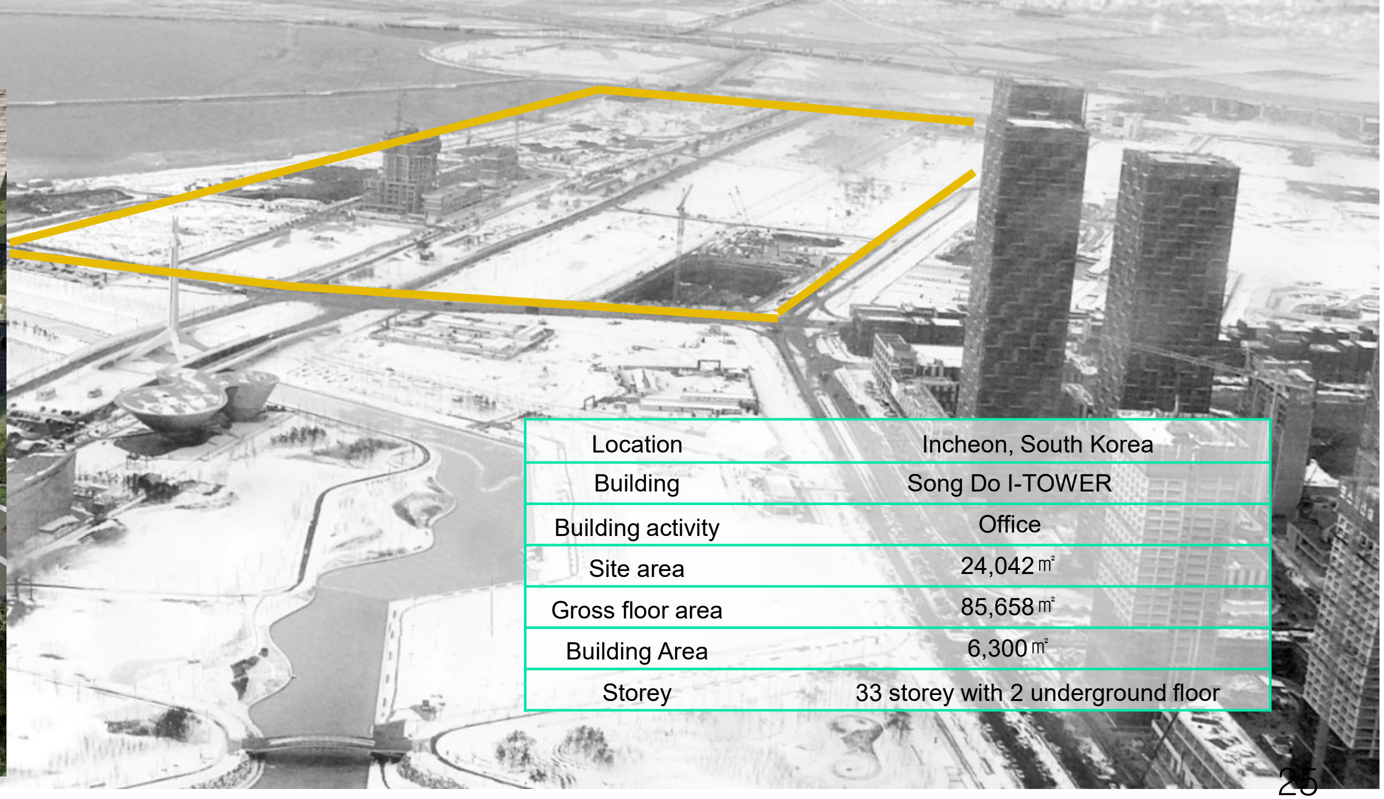
- Based on the time-base controller.
- Insensitive to field conditions
- e.g. a timer set to shut off a row of fixtures adjacent to windows between 10:00 a.m. and 3:00 p.m.
- Local override must be provided to accommodate the following cases
  - Rainy dark days, overtime work, etc.
- Applications: facilities with regular, repetitive schedules and few exceptional situations

Dynamic control, closed-loop control

- Respond to sensor data.
- Feedback loop.
- Inputs: illuminance, time, system kW demand, kWh usage in a time period, or space occupancy, singly or in combination

Examples: blind control + lighting control

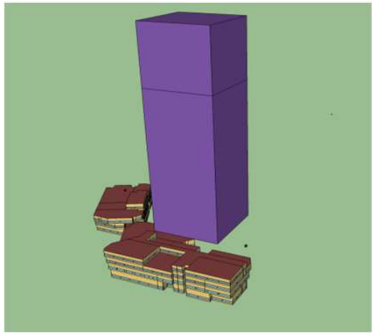
- Energy analysis: T社
  - Alt A: manual blind (blind angle: 0^o, 45^o, 90^o, 135^o)
  - Alt B: motorized smart blind (integrated to dimming control)
- Simulation tool: EnergyPlus EMS (Energy Management System)

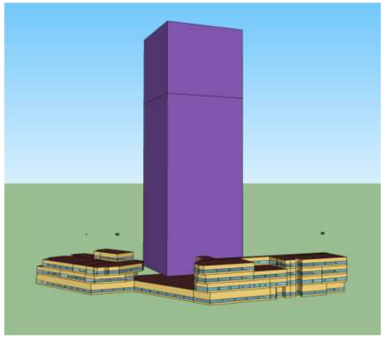


Location	Incheon, South Korea
Building	Song Do I-TOWER
Building activity	Office
Site area	24,042㎡
Gross floor area	85,658㎡
Building Area	6,300㎡
Storey	33 storey with 2 underground floor

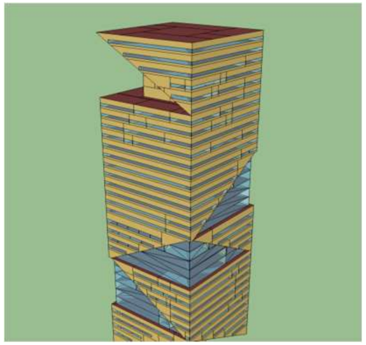
Modeling process

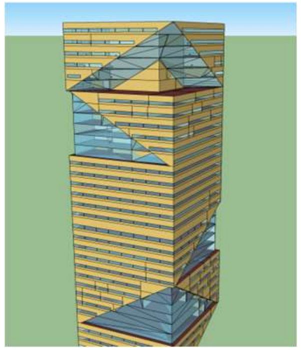
Lower (1-4F)



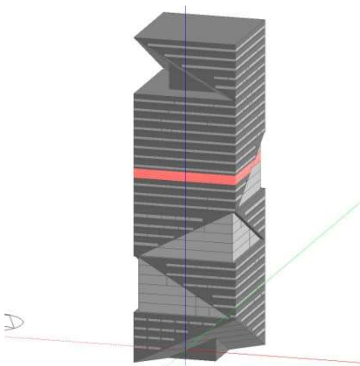


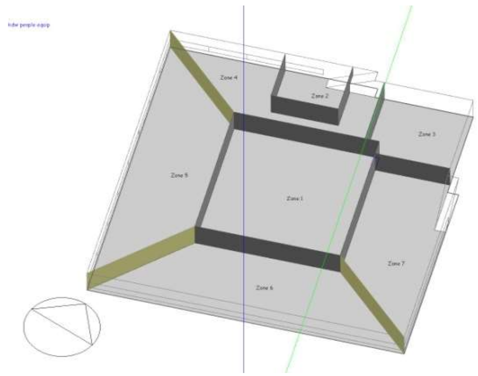
High (5-33F)



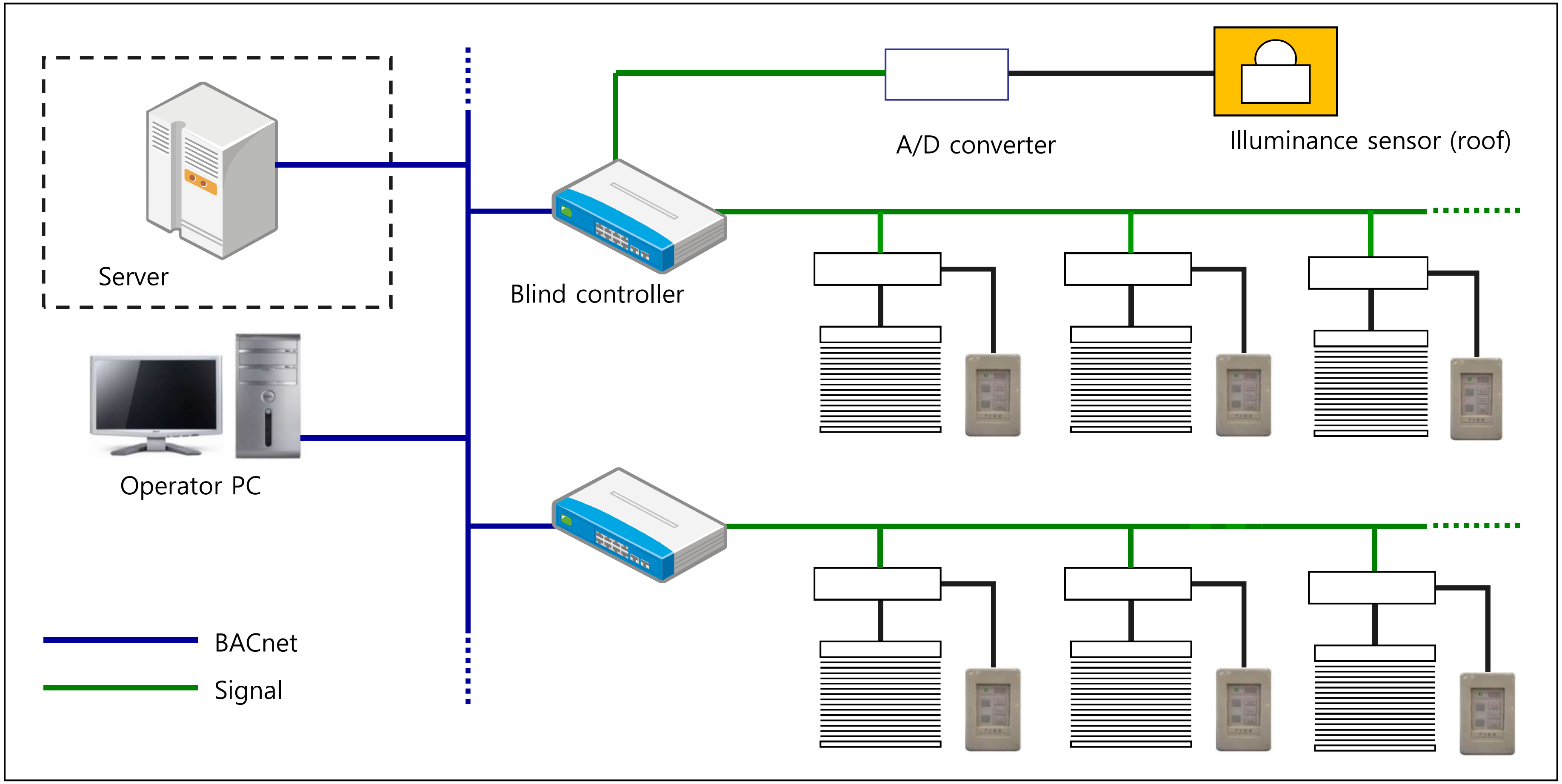


Typical floor

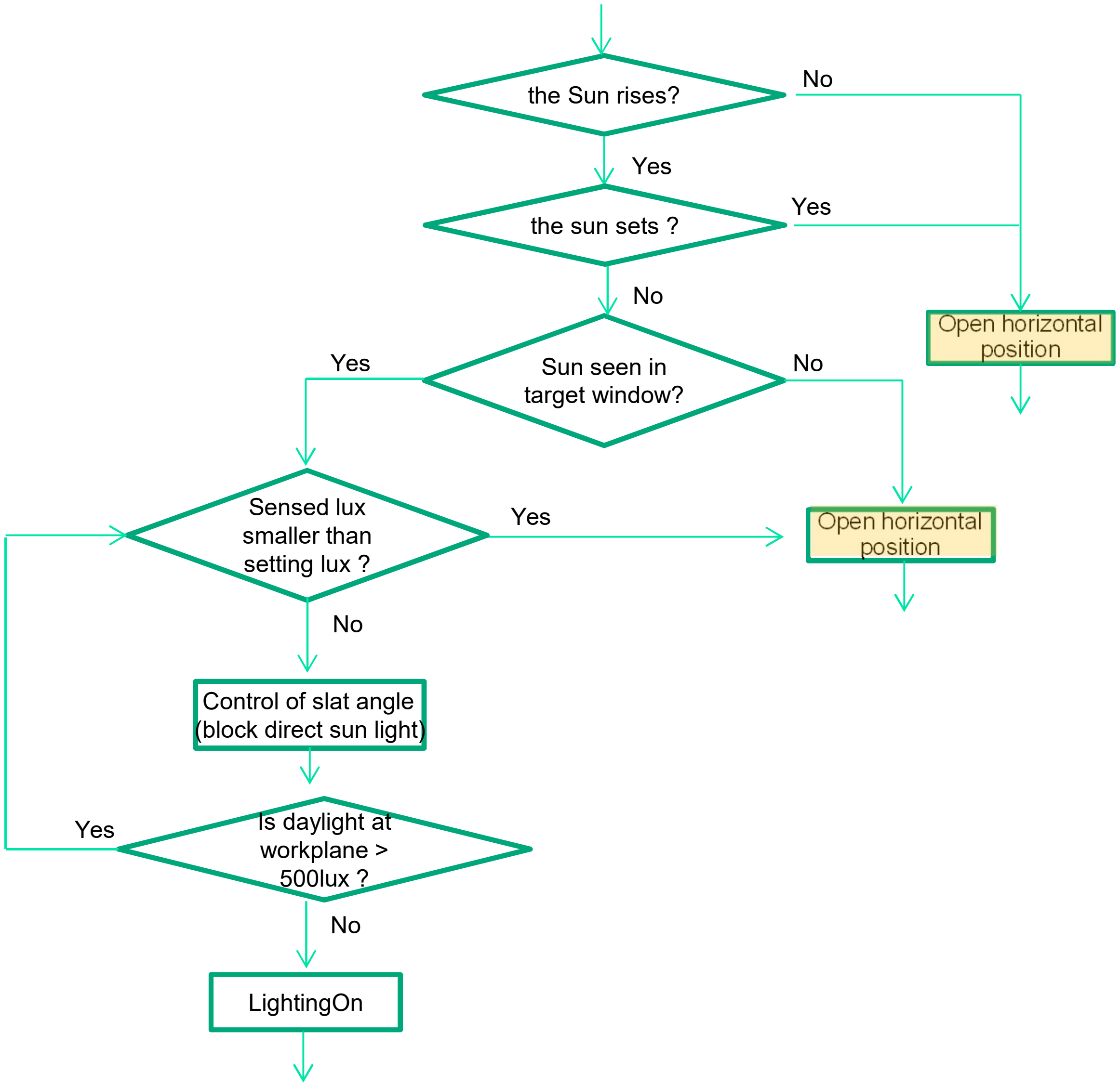


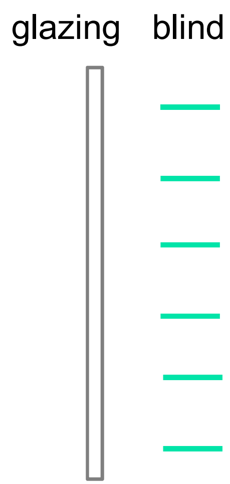


T社 system configuration

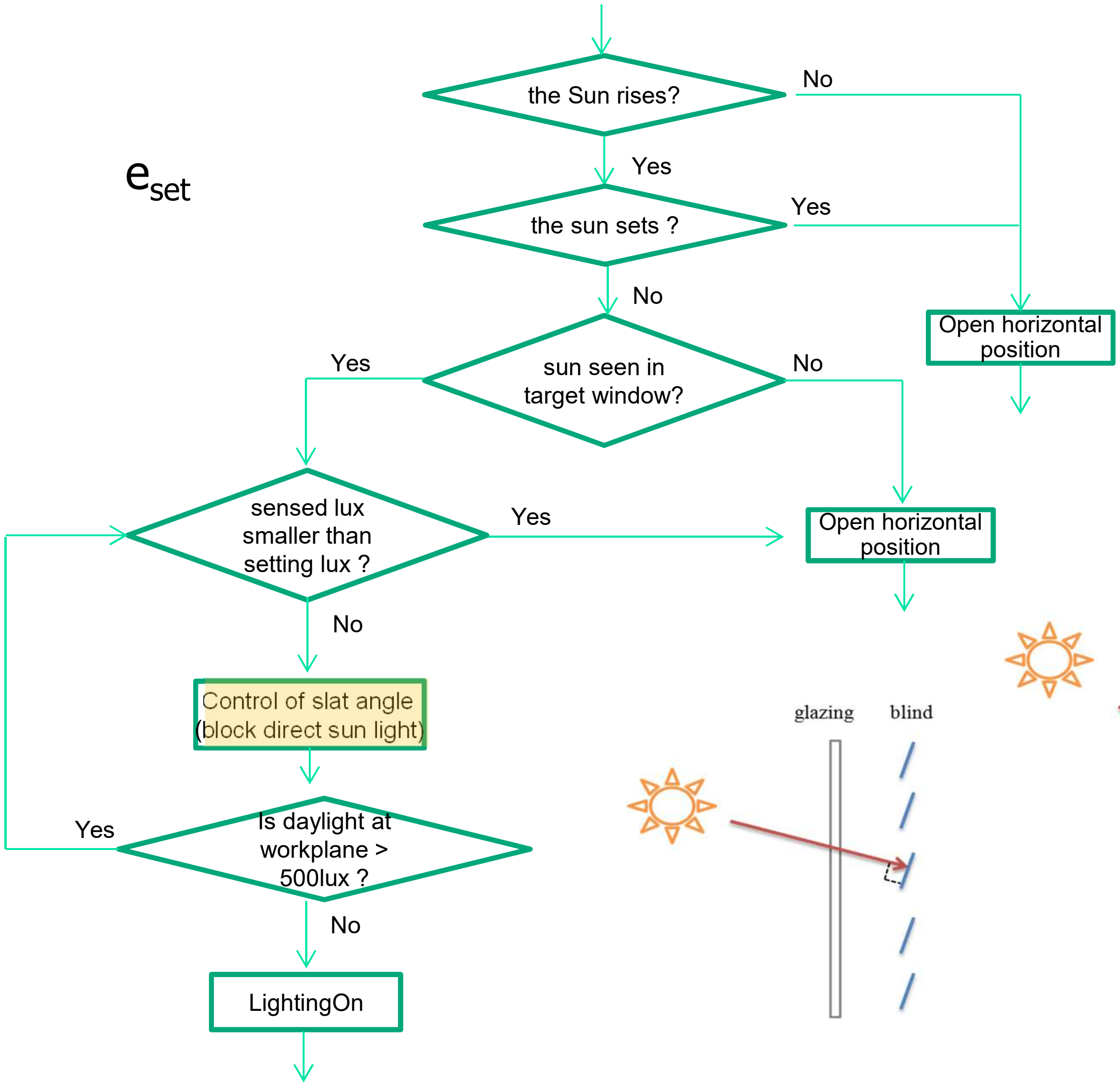


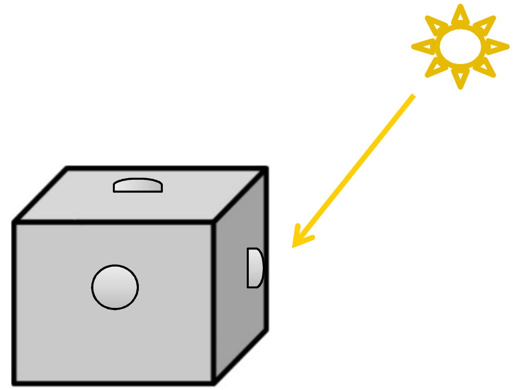
Logic #1: blind open (kept horizontal)



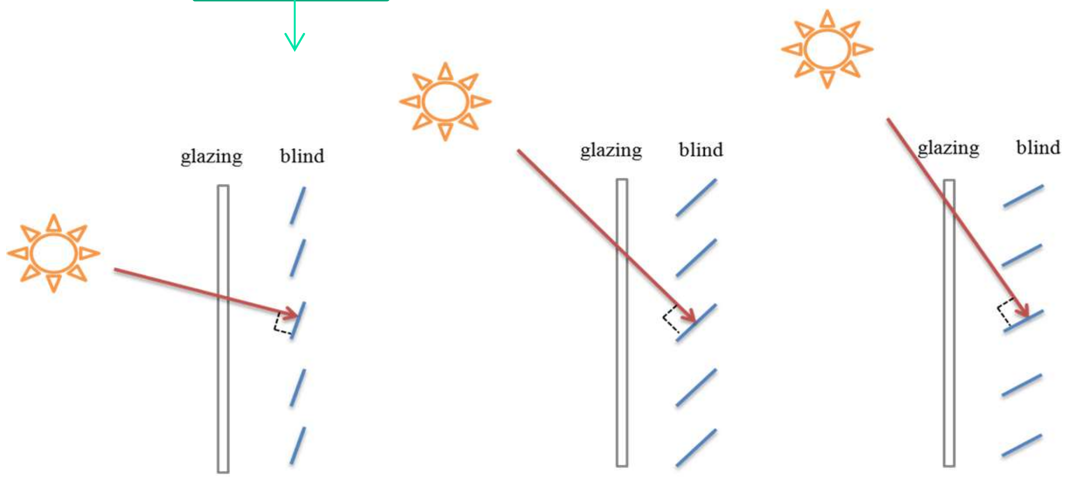


Logic #2: direct solar radiation blocked

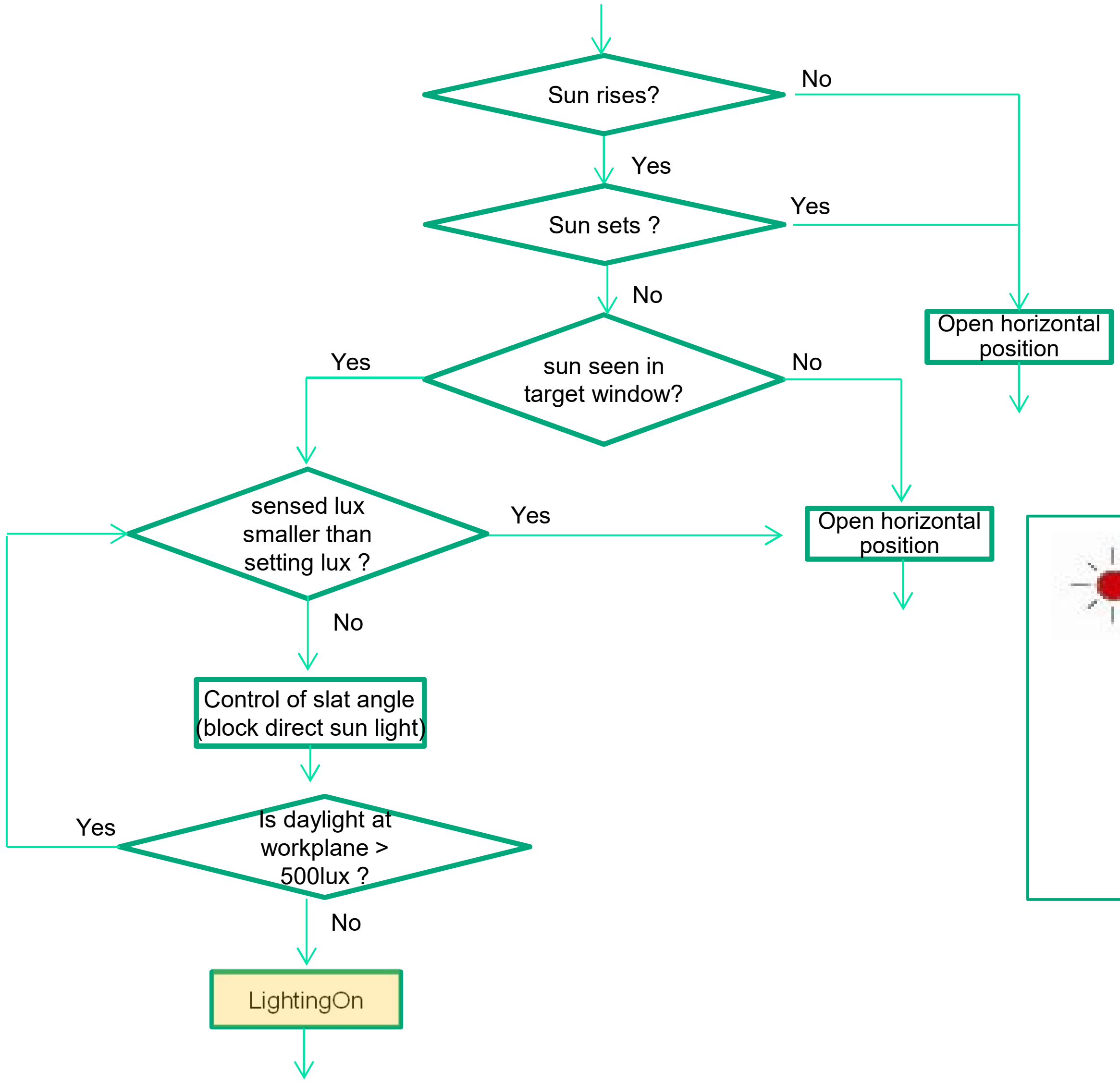


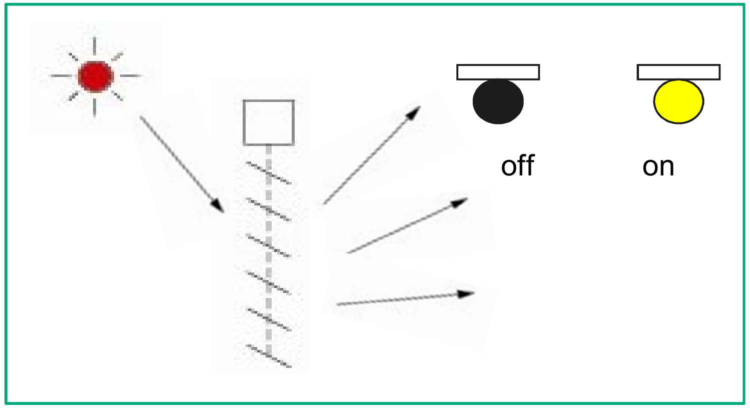


$E_{measured}$ (10,000 Lux) > E_{set} (2000 Lux)



Logic #3: daylighting control (dimming control)



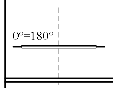
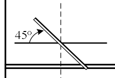
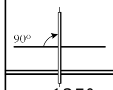
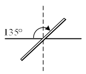


EMS

```
EnergyManagementSystem:Program,
  myCalc,               !- Name
  if my_DayType ==1 || my_DayType ==8 || my_DayType ==7,   check holidays
                 set my_a_slat_1=0,     !- Program Line 2
                 set my_a_slat_2=0,     !- A4
                 set my_a_slat_3=0,     !- A5
                 set my_a_slat_4=0,     !- A6

  else,             !- A7
                 if Solar_Alt > 0, the Sun rises?
                        if a_vp_1 > 0 && a_vp_1 < 90,  (east) the sun is seen ?
                               if sense_a_L_1 > set_L,        Sensed lux is greater than Setting lux ?
                                      set my_a_slat_1=a_hp_1,
                                      set a_state_1=1,
                               else,
                                      set my_a_slat_1=90,
                                      set a_state_1=0,
                               endif,
                        else,               open, if sun is not seen
                               set my_a_slat_1=90,
                        endif,

                        if a_vp_2 > 0 && a_vp_2 < 90, (west) the sun is seen ?
                               if sense_a_L_2 > set_L,        Sensed lux is greater than Setting lux ?
                                      set my_a_slat_2=a_hp_2,
                                      set a_state_2=1,
                               else,
                                      set my_a_slat_2=90,
                                      set a_state_2=0,
                               endif,
                        else,          open, if the sun is not seen
                               set my_a_slat_2=90,
                        endif,

                          :
                          :
                          :
                 else,         the sun sets ?
                        set Sun_state=0,
                        set my_a_slat_1=0,       open status
                        set my_a_slat_2=0,
                        set my_a_slat_3=0,
                        set my_a_slat_4=0,
                        endif,
  endif;
```

Results (not integrated with lighting control)

- T社 blind control: 5.2-5.9% energy saving → 20-30K USD savings
- 5.7% saved compared to the averages of four cases (0º, 45º, 90º, 135º)

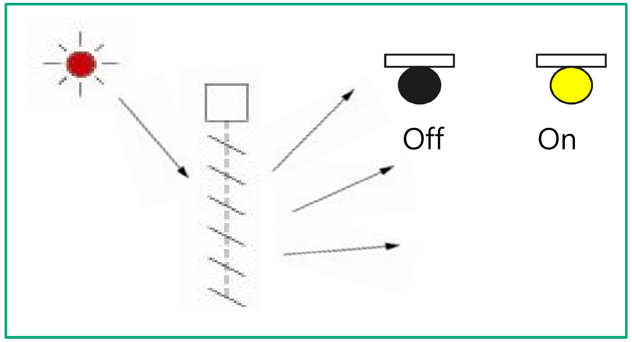
Blind angle		Manual blind: energy use (kWh/yr)	T社 blind: energy use (kWh/yr)	Energy saved (kWh/yr)	Energy savings (%)	CO_2 saved (Kg)	Energy cost (KRW/yr)	Carbon tax saving (KRW/yr)	Total cost saving (KRW/yr)
0°	Cooling	6,311,377	5,938,148	373,229		158,249	23,066,794	4,573,555	27,640,350
	Heating	74,536	69,805	4,731		946	339,749	27,346	367,096
	Total	6,385,913	6,007,953	377,960	5.9	159,195	23,406,544	4,600,901	**28,007,445**
45°	Cooling	6,291,652	5,938,148	353,504		149,886	21,827,328	4,331,849	26,159,177
	Heating	73,275	69,805	3,470		694	249,193	20,057	269,251
	Total	6,364,928	6,007,953	356,974	5.6	150,580	22,076,521	4,351,907	26,428,428
90°	Cooling	6,260,925	5,938,148	322,777		136,857	20,143,748	3,955,314	24,099,062
	Heating	78,750	69,805	8,944		1,789	642,326	51,700	694,026
	Total	6,339,675	6,007,953	331,721	**5.2**	138,646	20,786,074	4,007,014	**24,793,088**
135°	Cooling	6,310,105	5,938,148	371,957		157,710	23,131,819	4,557,973	27,689,791
	Heating	77,405	69,805	7,600		1,520	545,781	43,929	589,710
	Total	6,387,511	6,007,953	379,557	5.9	159,230	23,677,599	4,601,902	28,279,501
	Average	**6,369,507**	**6,007,953**	**361,553**	**5.7**	**151,913**	**22,486,684**	**4,390,431**	**26,877,116**

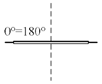
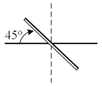
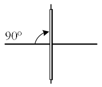
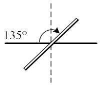
Electricity: 0.424 kg CO_2/kWh, Gas: 0.2 kg CO_2/kWh

Carbon tax: 28,901(KRW/ton. CO_2)

Results (integrated with lighting control)

- Energy saving: 5.7-18.8%→ 40 - 160k USD
- Lighting/cooling saved (heating energy increased)
- 11.4% saved compared to the averages of four cases (0°, 45°, 90°, 135°)



Blind angle		Manual blind: energy use (kWh/yr)	T社 blind: energy use (kWh/yr)	Energy saved (kWh/yr)	Energy savings (%)	CO_2 saved (Kg)	Energy cost (KRW/yr)	Carbon tax saving (KRW/yr)	Total cost saving (KRW/yr)
0° 	Cooling	5,447,705	4,917,440	530,265		224,832	32,683,671	6,497,876	39,181,547
	Heating	96,429	97,351	-923		-185	-66,262	-5,333	-71,595
	Lighting	5,227,258	4,989,108	238,150		100,975	13,178,671	2,918,291	16,096,961
	Total	10,771,392	10,003,900	767,492	7.1	325,623	45,796,080	9,410,833	55,206,913
45° 	Cooling	5,358,184	4,917,440	440,744		186,875	27,064,097	5,400,887	32,464,983
	Heating	95,736	97,351	-1,616		-323	-116,033	-9,339	-125,372
	Lighting	5,150,534	4,989,108	161,425		68,444	8,932,924	1,978,111	10,911,035
	Total	10,604,454	10,003,900	600,554	5.7	254,997	35,880,988	7,369,658	43,250,646
90° 	Cooling	6,119,043	4,917,440	1,201,603		509,480	74,706,978	14,724,468	89,431,446
	Heating	88,228	97,351	-9,124		-1,825	-655,212	-52,737	-707,949
	Lighting	6,115,300	4,989,108	1,126,191		477,505	62,320,938	13,800,375	76,121,313
	Total	12,322,570	10,003,900	2,318,670	18.8	985,160	136,372,705	28,472,106	164,844,811
135° 	Cooling	5,820,159	4,917,440	902,719		382,753	56,124,318	11,061,941	67,186,259
	Heating	91,827	97,351	-5,525		-1,105	-396,757	-31,935	-428,692
	Lighting	5,702,723	4,989,108	713,614		302,572	39,489,838	8,744,647	48,234,485
	Total	11,614,709	10,003,900	1,610,809	13.9	684,220	95,217,399	19,774,653	114,992,052
	Average	**11,328,281**	**10,003,900**	**1,324,381**	**11.4**	**562,500**	**78,316,793**	**16,256,812**	**94,573,606**

15.37 Lighting control strategies

- System “tuning”
- Variable time schedule
- Occupancy sensing
- Lumen maintenance
- Daylight compensation

(a) System tuning

- A difference between the design intent and the field result always exists.
  - Reasons for performance gap: assumptions in calculation, differences between specified and installed equipment, equipment location changes, etc.
- Lighting designer “tunes” the lighting system in the field to attain the intended design.
- Usually means reducing lighting levels in non-task areas
- System tuning should not be confused with lumen maintenance, described in Section 15.37d, which is a control strategy designed to compensate for normal system output decline and its corollary—initial system overdesign.

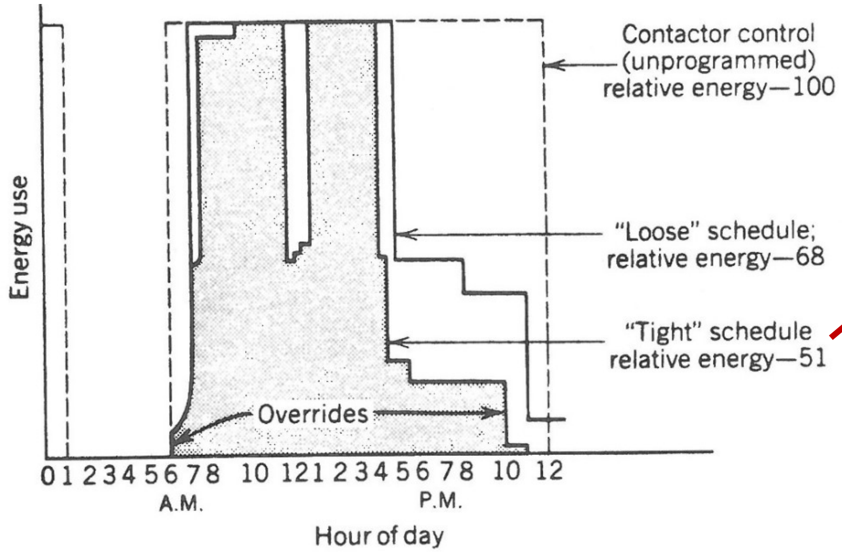
(a) System tuning

- The tuning action is a reduction in illuminance.
  - Replacing existing lamps with lower wattage lamps → lower light output
  - Multi-level ballasts (0, 50, 100%)
  - Dimming
  - Replacing standard wall switches with timeout switches
- This tuning can result in an energy reduction of 20% to 30%
- Lighting tuning is also required when the function of an entire space is changed.

(b) Variable time schedule

- No normal task area has a constant 24-hour, 365-day lighting requirement: coffee and lunch breaks, shift changes, cleaning periods, unoccupied periods
- Use of programmed time schedule-based control → can readily save 10% to 25% of the energy use, compared to manual control.
- Payback: 1.5-5 years
- Fig. 15.27 (from 10th Ed.): World trade center building → tight schedule with user override (occupant override per 1,000ft^2)

< three controls (contactor control, loose control, tight control) vs. energy use >



Tight schedule:
- lighting only in restricted areas during lunch time.
- With user override.
- After-hours lighting only in occupied areas rather than whole floors.

Fig. 15.27 *Actual plot of energy usage on a typical floor of a high-rise building in New York City, with three degrees of lighting control. Note the importance of override by occupants when tight scheduling is used. Override was provided on a 1000-ft²- (93-m²) zone basis. (Data extracted from Peterson and Rubenstein, 1982.)*

(c) Occupancy sensing

- Within a normal 9 a.m. to 5 p.m. working schedule, commercial offices unoccupied for 30-60% of the time
  - Coffee breaks, conference, work assignment, illness, vacation, etc.
- Occupancy sensors:
  - Turn off lights after a preset minimum period of 10 minutes or dim the light to a minimum
  - occupancy sensors can also turn off FCU, HVAC, fan, etc.
  - occupancy sensors should provide automatic override to schedule systems, thus relieving the occupant of using a manual override

Three types of occupancy sensors

- IR (Infrared): reacts to the "motion" of a heat source (Fig. 15.52) (it will not alarm to a stationary heat source)
- Disadvantages
  - Small movements may not be detected. A person sitting (not moving) may not be detected.
  - Very slow movements may not be detected.
  - The IR detector must "see" the heat source. A heat source blocked by furniture will not be detected. Direct line-of-sight.
  - The beams have a discrete width and depth → "dead spots"

IR occupancy sensors

(a)

(b)

(c)

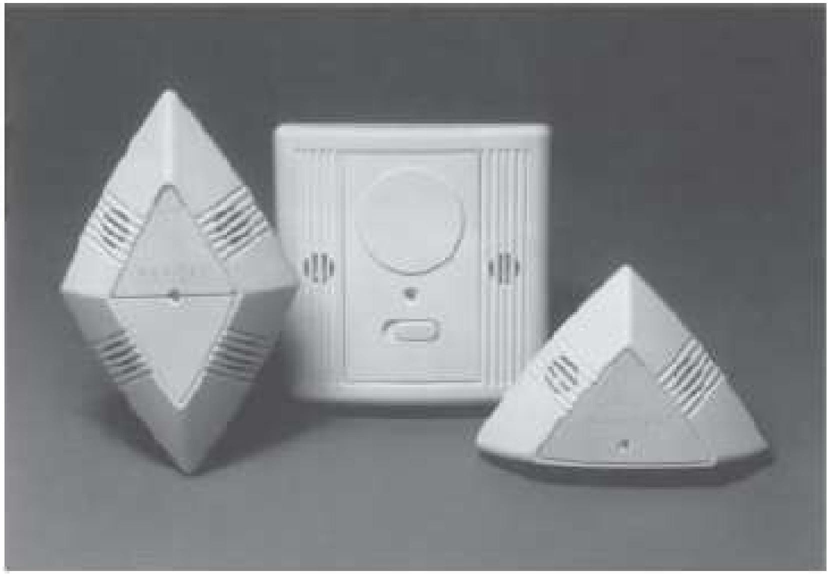
Fig. 15.52 *Passive infrared (PIR) occupancy sensors. All sensors can be equipped with an adjustable override to prevent turning on lighting when ambient light is sufficient. All units have adjustable delayed-off timing and a flashing LED that indicates sensor operation. (a) Flush-mounted ceiling unit. The 360° circular pattern of the lens indicates omnidirectional coverage. The unit is approximately 4 in. (100 mm) in diameter. (b) Flush-mounted combination wall switch and PIR occupancy sensor. Operation of the switch overrides the sensor function. (c) Surface-mounted wall PIR occupancy sensor. The semicircular shape of the lens indicates wide horizontal coverage. (Photos courtesy of Leviton Manufacturing Co.)*

Ultrasonic sensors

- It emits energy in the 25 to 40 kHz range, which is well above the range of human hearing (Fig. 15.53).
- The waves immediately fill a space by reflecting and re-reflecting off all hard surfaces, establishing a pattern that is detected by the sensor.
- Any movement within the space disturbs this pattern.
- Advantages
  - No need for direct line-of-sight exposure
  - They detect small movements.
- disadvantages
  - The movement of curtains and even air movement can often trigger a sensor → false sensing

Ultrasonic sensors

(*a*)



(*b*)

Fig. 15.53 *Ultrasonic occupancy detectors. (a) Ceiling-mounted sensors, bidirectional on the left and unidirectional on the right. (Courtesy of Leviton Manufacturing Co.) (b) Sensors in various designs, intended for differing applications. Left to right: Ceiling-mounted two-way sensor intended for large rooms of up to 2800 ft^2 (260 m^2). Dual-function sensor and wall switch designed for rooms of up to 300 ft^2 (28 m^2); wall mounted on a single- or double-gang wall box. One-way ceiling-mounted sensor designed for use in rooms of up to approximately 1250 ft^2 (116 m^2). (Courtesy of Novitas Inc.)*

Hybrid

- IR + ultrasonic: dual technology sensors
  - Combines the characteristics of both sensors
  - In general: when both sensors detect movements: lighting off → lighting on
  - when both sensors don't detect movements: lighting on → lighting off:
  - Once lights on → a reaction in either sensor keeps the lights on

Placement of sensors

- can be wall-mounted or ceiling mounted.
- cover a maximum area of 25-100 m^2 per unit
- Reducing the minimum "on" period below 10 minutes is counterproductive.
- Payback period: 6 months - 3 years
- 'Smart' system: It learns a user(space)'s occupancy pattern and preference (lighting, temperature, air diffusion, etc.) and is programmed to react accordingly.

(d) Lumen maintenance

- Light depreciation is a continuous and very gradual process.
- Initial illuminance, E = lamp lumens * CU / area
- Maintained illuminance, E = lamp lumens * CU * LLF / area
  - LLF= Light Loss Factor
  - If LLF=0.6 & required E = 300 lux → Initial E = 500 Lux (40% initial overlighting. Initial overdesign).
- Control strategy known as "lumen maintenance"
  - reduces the initial overlighting by the required amount (as measured in the field, e.g. using dimming control)
  - and gradually restores it as the system ages.
- Local light sensors (photocells) measures the light and the controller raises or lowers the light output.

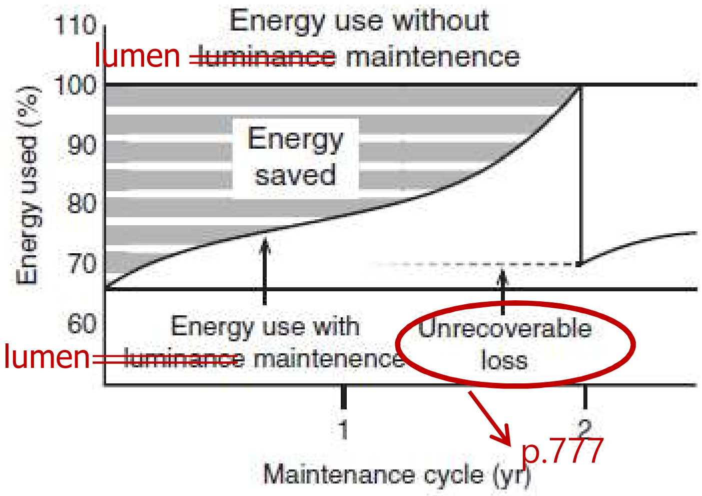


Fig. 15.54 Energy use pattern of a system that reduces the initial illuminance to compensate for necessary overdesign and gradually increases light output as system elements depreciate. In subsequent cycles the energy savings are reduced slightly because of unrecoverable light losses. (Redrawn by Martin Lee.)

Advantages of lumen maintenance

- Interior zones
  - Lighting reduction does not exceed 30% to 40%.
- Perimeter zones
  - daylight often provides all of the required light. → full range dimming, dimming plus switching, multi-level switching
- Shorter payback periods obtained by using multilevel switching rather than dimming because of its lower first cost

(e) Daylight compensation

- Daylight: minute by minute variation → on/off, multilevel switching can be annoying → automatic continuous dimming must be the choice
- Energy saving: Fig. 15.55

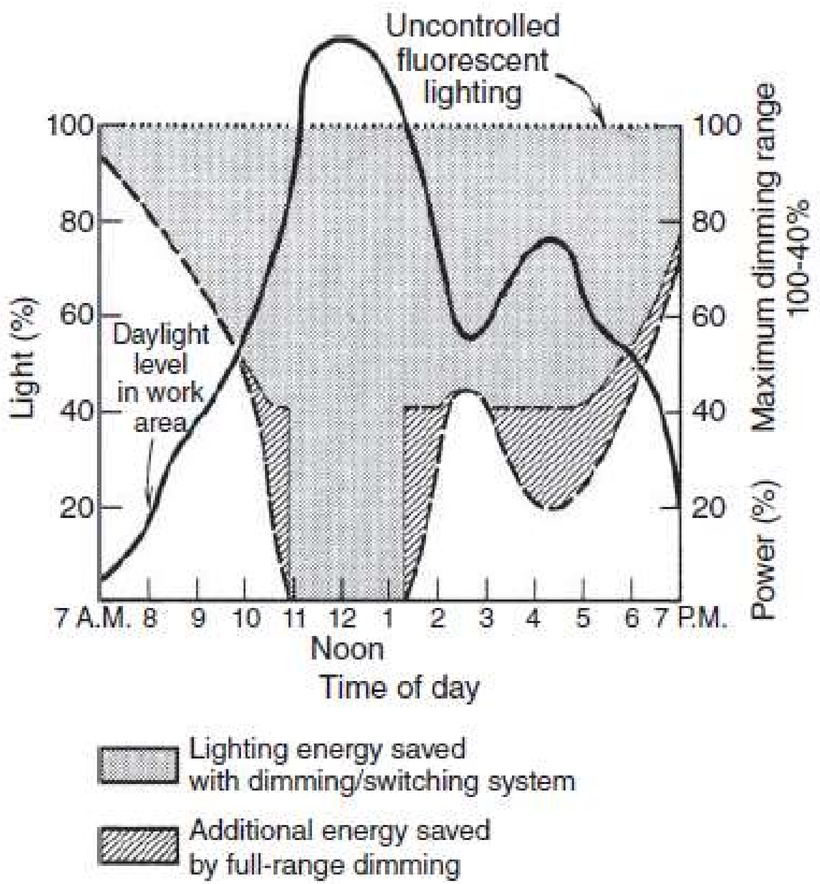


Fig. 15.55 *Energy savings typical of a daylight-compensating lighting control. A full-range dimming system is more effective than one that dims down to only 40%, because daylight often supplies most of the required illuminance. An economic analysis is required to determine whether the additional cost of such a system is justified.*

Why daylight compensation?

- can reduce energy use in perimeter areas by up to 60%, depending on latitude, climate, the ratio of perimeter to total floor area, hours of building use, initial lighting power density (W/m^2)
- Extended lamp and ballast life, reduced cooling costs, and reduced maintenance costs.
- payback period: always short and therefore financially attractive (three months to three years)

Daylight compensation

- Crucial design element: establishment of zone areas
- The south, east and west windows receive sufficient daylight
- The north: a narrow perimeter zone (Fig.16.56)
- Determination of zone depth: receiving at least half of its illuminance from daylight for several hours a day. ←daylight simulation

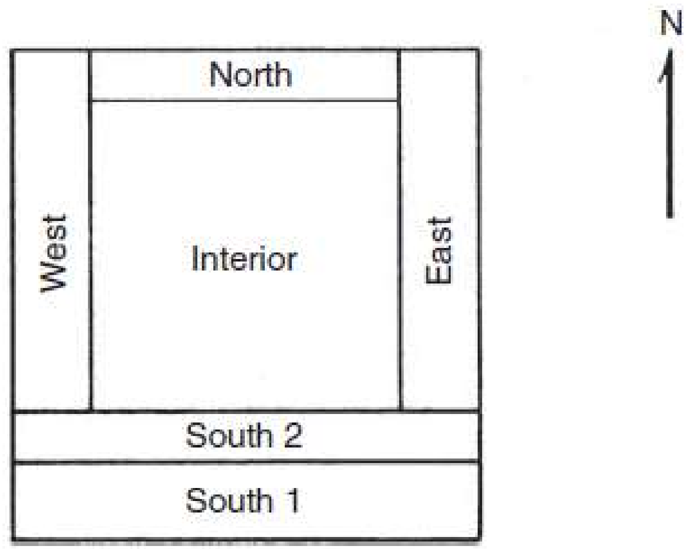


Fig. 15.56 *Typical building plan showing approximate daylight perimeter zones. Exact delineation of zones depends upon latitude, climate, window design, and cost of electric energy.*

Placement of photocells

- Determine points A, B, C
- Find the ratios of daylight (A, B, C) → the ratios of their Daylight Factors
- If the ratio of daylight between point A and B is 20/10=2, and 500 lux of daylight is required at point B: 1,000 lux is required at point A.
  - Daylight switching will be initiated with settings at 1,000 lux at point A.
- 500 lux required at point C and A:C=5:1 → two single level photocells or a multilevel unit installed at point A (with settings at 1,000 and 2,500 lux)

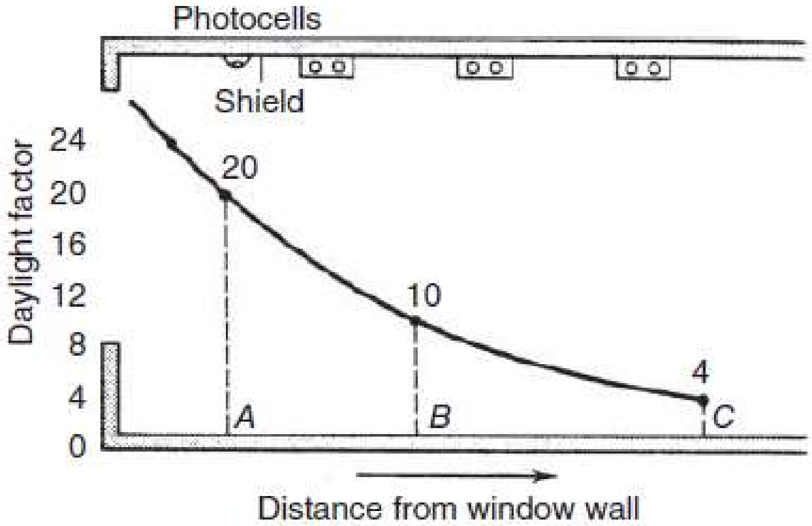


Fig. 15.57 *Typical daylight factor curve plotted on a room section with unilateral sidelighting. The photocell control technique for daylight compensation described in the text assumes a constant daylight factor (DF) distribution indoors—that is, from a fixed-luminance sky and no direct sun.*