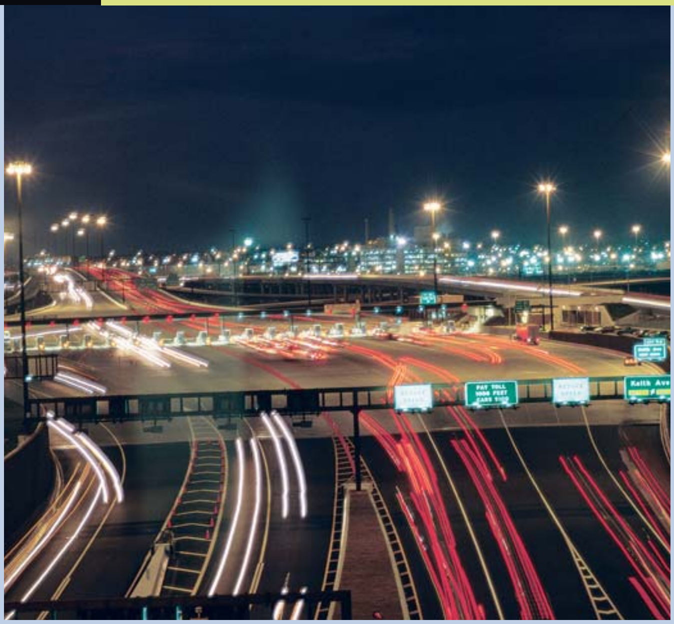
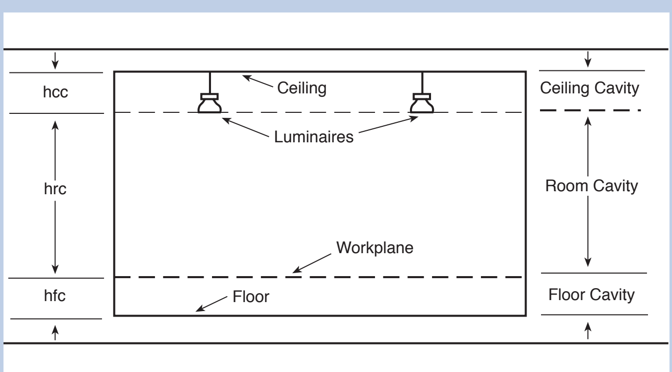
Zonal Cavity Method for Indoor Calculations





Methods of calculating illuminance

In order to design a luminaire layout that best meets the illuminance and uniformity requirements of the job, two types of information are generally needed: average illuminance level and illuminance level at a given point. Calculation of illuminance at specific points is often done to help the designer evaluate the lighting uniformity, especially when using luminaires where maximum spacing recommendations are not supplied, or where task lighting levels must be checked against ambient.

If average levels are to be calculated, two methods can be applied:

1. For indoor lighting situations, the Zonal Cavity Method is used with data from a coefficient of utilization table.
2. For outdoor lighting applications, a coefficient of utilization curve is provided, the CU is read directly from the curve and the standard lumen formula is used.

The following two methods can be used if calculations are to be done to determine illuminance at one point.

1. If an isofootcandle chart is provided, illuminance levels may be read directly from this curve.
2. If sufficient candlepower data are available, illuminance levels may be calculated from these data using the point-to-point method.

The following sections describe these methods of calculation.

Zonal Cavity Method

The Zonal Cavity Method (sometimes called the Lumen Method) is the currently accepted method for calculating average illuminance levels for indoor areas, unless the light distribution is radically asymmetric. It is an accurate hand method for indoor applications because it takes into consideration the effect that inter-reflectance has on the level of illuminance. Although it takes into account several variables, the basic premise that footcandles are equal to luminous flux over an area is not violated.

The basis of the Zonal Cavity Method is that a room is made up of three spaces or cavities. The space between the ceiling and the fixtures, if they are suspended, is defined as the "ceiling cavity"; the space between the work plane and the floor, the "floor cavity"; and the space between the fixtures and the work plane, the "room cavity."

Once the concept of these cavities is understood, it is possible to calculate numerical relationships called "cavity ratios," which can be used to determine the effective reflectance of the ceiling and floor cavities and then to find the coefficient of utilization.

There are four basic steps in any calculation of illuminance level:

1. Determine cavity ratios
2. Determine effective cavity reflectances
3. Select coefficient of utilization
4. Compute average illuminance level

Step 1: Cavity ratios for a rectangular space may be calculated by using the following formulas:

$$\text{Ceiling Cavity Ratio (CCR)} = \frac{5\ hcc\ (L+W)}{L \times W}$$

$$\text{Room Cavity Ratio (RCR)} = \frac{5\ hrc\ (L+W)}{L \times W}$$

$$\text{Floor Cavity Ratio (FCR)} = \frac{5\ hfc\ (L+W)}{L \times W}$$

Where:

hcc = distance in feet from luminaire to ceiling
hrc = distance in feet from luminaire to work plane
hfc = distance in feet from work plane to floor
L = length of room, in feet
W = width of room, in feet

An alternate formula for calculating any cavity ratio is:

$$\text{Cavity Ratio} = \frac{2.5 \times \text{height of cavity} \times \text{cavity perimeter}}{\text{area of cavity base}}$$

1970s: The Revolutionary High Mast Systems
Holophane develops the first lighting system to raise and lower for ground-level servicing.

Step 2: Effective cavity reflectances must be determined for the ceiling cavity and for the floor cavity. These are located in Table A (see below) under the applicable combination of cavity ratio and actual reflectance of ceiling, walls and floor. The effective reflectance values found will then be ρ_{cc} (effective ceiling cavity reflectance) and ρ_{fc} (effective floor cavity reflectance) . Note that if the luminaire is recessed or surface mounted, or if the floor is the work plane, the CCR or FCR will be 0 and then the actual reflectance of the ceiling or floor will also be the effective reflectance.

Step 3: With these values of ρ_{cc}, ρ_{fc}, and ρ_{w} (wall reflectance), and knowing the room cavity ratio (RCR) previously calculated, find the coefficient of utilization in the luminaire coefficient of utilization (CU) table. Note that since the table is linear, linear interpolations can be made for exact cavity ratios and reflectance combinations.

The coefficient of utilization found will be for a 20% effective floor cavity reflectance. Thus, it will be necessary to correct for the previously determined ρ_{fc}. This is done by multiplying the previously determined CU by the factor from Table B (pg.12).

CU final = CU (20% floor) x Multiplier for actual ρ_{fc}. If it is other than 10% or 30%, interpolate or extrapolate and multiply by this factor.

Step 4: Computation of the illuminance level is performed using the standard Lumen Method formula.

$$\text{Footcandles (maintained)} = \frac{\text{\# of fixtures x lamps per fixture x lumens per lamp x CU x LLF}}{\text{area in square feet}}$$

When the initial illuminance level required is known and the number of fixtures needed to obtain that level is desired, a variation of the standard lumen formula is used.

$$\text{\# of luminaires} = \frac{\text{maintained footcandles desired x area in sq. ft.}}{\text{lamp/fixture x lumen/lamp x CU x LLF}}$$

The total light loss factor (LLF) consists of three basic factors: lamp lumen depreciation (LLD), luminaire dirt depreciation (LDD) and ballast factor (BF). If initial levels are to be found, a multiplier of 1 is used. Light loss factors, along with the total lamp lumen output, vary with manufacturer and type of lamp or luminaire and are determined by consulting the manufacturer's published data.

Ballast factor (BF) is defined as the ratio between the published lamp lumens and the lumens delivered by the lamp on the ballast used. Typical HID ballast factors vary between .9 and .95. Holophane ballasts are designed to have a BF=1.0.

Occasionally, other light loss factors may need to be applied when they are applicable. Some of these are luminaire ambient temperature, voltage factor and room surface dirt depreciation.

Table A
Percent effective ceiling or floor cavity reflectance for various reflectance combinations.

% Ceiling or floor reflectance	90				80				70			50				30			10		
% Wall reflectance	90	70	50	30	80	70	50	30	70	50	30	70	50	30	70	50	30	10	50	30	10
Cavity ratio																					
0.2	89	88	86	85	78	78	77	76	68	67	66	49	48	47	30	29	29	28	10	10	09
0.4	88	86	84	81	77	76	74	72	67	65	63	48	47	45	30	29	28	26	11	10	09
0.6	87	84	80	77	76	75	71	68	65	63	59	47	45	43	30	28	26	25	11	10	08
0.8	87	82	77	73	75	73	69	65	64	60	56	47	44	40	30	28	25	23	11	10	08
1.0	86	80	75	69	74	72	67	62	62	58	53	46	43	38	30	27	24	22	12	10	08
1.2	85	78	72	66	73	70	64	58	61	57	50	45	41	36	30	27	23	21	12	10	07
1.4	85	77	69	62	72	68	62	55	60	55	47	45	40	35	30	26	22	19	12	10	07
1.6	84	75	67	59	71	67	60	53	59	53	45	44	39	33	29	25	22	18	12	09	07
1.8	83	73	64	56	70	66	58	50	58	51	42	43	38	31	29	25	21	17	13	09	06
2.0	83	72	62	53	69	64	56	48	56	49	40	43	37	30	29	24	20	16	13	09	06
2.2	82	70	59	50	68	63	54	45	55	48	38	42	36	29	29	24	19	15	13	09	06
2.4	82	69	58	48	67	61	52	43	54	46	37	42	35	27	29	24	19	14	13	09	06
2.6	81	67	56	46	66	60	50	41	54	45	35	41	34	26	29	23	18	14	13	09	06
2.8	81	66	54	44	65	59	48	39	53	43	33	41	33	25	29	23	17	13	13	09	05
3.0	80	64	52	42	65	58	47	37	52	42	32	40	32	24	29	22	17	12	13	09	05
3.2	79	63	50	40	65	57	45	35	51	40	31	39	31	23	29	22	16	12	13	09	05
3.4	79	62	48	38	64	56	44	34	50	39	29	39	30	22	29	22	16	11	13	09	05
3.6	78	61	47	36	63	54	43	32	49	38	28	39	29	21	29	21	15	10	13	09	04
3.8	78	60	45	35	62	53	41	31	49	37	27	38	29	21	28	21	15	10	14	09	04
4.0	77	58	44	33	61	53	40	30	48	36	26	38	28	20	28	21	14	09	14	09	04
4.2	77	57	43	32	60	52	39	29	47	35	25	37	28	20	28	20	14	09	14	09	04
4.4	76	56	42	31	60	51	38	28	46	34	24	37	27	19	28	20	14	09	14	08	04
4.6	76	55	40	30	59	50	37	27	45	33	24	36	26	18	28	20	13	08	14	08	04
4.8	75	54	39	28	58	49	36	26	45	32	23	36	26	18	28	20	13	08	14	08	04
5.0	75	53	38	28	58	48	35	25	44	31	22	35	25	17	28	19	13	08	14	08	04

1980s: The GranVille® Sparks a Romance with Historically Styled Street Lighting
The acorn, a turn-of-the-century replica, offers the look of yesteryear with state-of-the-art technology.

Table B
Multiplying factors for other than 20 percent effective floor cavity reflectance

% Effective ceiling cavity reflectance, ρ_{cc}	80				70				50			30			10		
% Wall reflectance, ρ_w	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10
For 30 per cent effective floor cavity reflectance (20 per cent = 1.00)																	
Room cavity ratio																	
1	1.092	1.082	1.075	1.068	1.077	1.070	1.064	1.059	1.049	1.044	1.040	1.028	1.026	1.023	1.012	1.010	1.008
2	1.079	1.066	1.055	1.047	1.068	1.057	1.048	1.039	1.041	1.033	1.027	1.026	1.021	1.017	1.013	1.010	1.006
3	1.070	1.054	1 042	1.033	1.061	1.048	1.037	1.028	1.034	1.027	1.020	1.024	1.017	1.012	1.014	1.009	1.005
4	1.062	1.045	1.033	1.024	1.055	1.040	1.029	1.021	1.030	1.022	1.015	1.022	1.015	1.010	1.014	1.009	1.004
5	1.056	1 038	1.026	1.018	1.050	1.034	1.024	1.015	1.027	1.018	1.012	1.020	1.013	1.008	1.014	1.009	1.004
6	1.052	1.033	1.021	1.014	1.047	1.030	1.020	1.012	1.024	1.015	l.009	1.019	1.012	1.006	1.014	1.008	1.003
7	1.047	1.029	1.018	1.011	1.043	1.026	1.017	l.009	1.022	1.013	1.007	1.018	1.010	1.005	1.014	1.008	1.003
8	1.044	1.026	1.015	1.009	1.040	1.024	1.015	1.007	1.020	1.012	1.006	1.017	1.009	1.004	1.013	1.007	1.003
9	1.040	1.024	1.014	1.007	1.037	1.022	1.014	1.006	1.019	1.011	1.005	1.016	1.009	1.004	1.013	1.007	1.002
10	1.037	1.022	1.012	1.006	1.034	1.020	1.012	1.005	1.017	1.010	1.004	1.015	1.009	1.003	1.013	1.007	1.002
For 10 per cent effective floor cavity reflectance (20 per cent=1.00)																	
Room cavity ratio																	
1	.923	.929	.935	.940	.933	.939	.943	.948	.956	.960	.963	.973	.976	.979	.989	.991	.993
2	.931	.942	.950	.958	.940	.949	$\boxed{.957}$	.963	.962	$\boxed{.968}$	.974	.976	.980	.985	.988	.991	.995
3	.939	.951	.961	.969	.945	.957	.966	.973	.967	.975	.981	.978	.983	.988	.988	.992	.996
4	.944	.958	.969	.978	.950	.963	.973	.980	.972	.980	.986	.980	.986	.991	.987	.992	.996
5	.949	.964	.976	.983	.954	.968	.978	.985	.975	.983	.989	.981	.988	.993	.987	.992	.997
6	.953	.969	.980	.986	.958	.972	.982	.989	.977	.985	.992	.982	.989	.995	.987	.993	.997
7	.957	.973	.983	.991	.961	.975	.985	.991	.979	.987	.994	.983	.990	.996	.987	.993	.998
8	.960	.976	.986	.993	.963	.977	.987	.993	.981	.988	.995	.984	.991	.997	.987	.994	.998
9	.963	.978	.987	.994	.965	.979	.989	.994	.983	.990	.996	.985	.992	.998	.988	.994	.999
10	.965	.980	.965	.980	.967	.981	.990	.995	.984	.991	.997	.986	.993	.998	.988	.994	.999

Example:

A typical lecture hall is 60' long and 30' wide with a 14' ceiling height. Reflectances are: ceiling 80%, walls 30%, floor 10%. Four-lamp Prismawrap (coefficients of utilization shown below) is to be used on 4' stems, and the work plane is 2' above the floor. Find the illuminance level if there are 18 luminaires in the room.

Solutions:

(1) Calculate cavity ratios as follows:

$$CCR = \frac{5(4)(30+60)}{30 \times 60} = 1.0$$

$$RCR = \frac{5(8)(30+60)}{30 \times 60} = 2.0$$

$$FCR = \frac{5(2)\ (30+60)}{30 \times 60} = 0.5$$

(2) In Table A, look up effective cavity reflectances for these ceiling and floor cavities. ρ_{cc} for the ceiling cavity is determined to be 62%, while ρ_{fc} for the floor cavity is 10%.

(3) Knowing the room cavity ratio (RCR), it is now possible to find the coefficient of utilization for the Prismawrap luminaire in a room having an RCR of 2.0 and effective reflectances as follows:

ρ_{cc} = 62%; ρ_w = 30%; ρ_{fc} = 20%. By interpolation between boxed numbers in the table this CU is .55. Note that this CU is for an effective reflectance of 20% while the actual effective reflectance of the floor ρ_{fc} is 10%. To correct for this, locate the appropriate multiplier in Table B for the RCR already calculated (2.0). It is .962 and is found by interpolating between the boxed number in Table B for 70% ρ_{cc}, 30% ρ_w, and 50% ρ_{cc}, 30% ρ_w at an RCR of 2.0.

Then:

$$\text{CU final} = .55 \times .962 = .53$$

Note that all interpolations only need to be of the approximate, "eyeball" type, giving a credible degree of accuracy to the calculation.

(4) Illuminance level can now be calculated if we know the number of units to be used and the lamp lumen rating.

$$\text{FC initial} = \frac{\text{\# of fixtures x lamps/fixture x lumens/lamp x CU}}{\text{area}}$$

$$\text{FC initial} = \frac{18 \times 4 \times 3150 \times .53}{60 \times 30}$$

$$\text{FC initial} = 67$$

Check spacing of luminaires.

A possible arrangement for these fixtures is three columns of six fixtures spaced ten feet on center in each direction. The Spacing Criterion is 1.4, making the maximum allowable spacing 11.2 feet. The actual spacing is less than the maximum allowable spacing. Therefore, the illumination on the work plane should be uniform.

Table C: Four-lamp Prismawrap luminaire coefficients of utilization

Spacing Criterion 1.4

ρ_{cc}	80%					70%			50%			30%			10%		
ρ_w (RCR)	70%	50%	30%	10%	70%	50%	30%	10%	50%	30%	10%	50%	30%	10%	50%	30%	10%
0	.78	.78	.78	.78	.75	.75	.75	.75	.70	.70	.70	.66	.66	.66	.62	.62	.62
1	.72	.69	.67	.64	.69	.67	.65	.63	.63	.61	.59	.59	.58	.56	.56	.55	.53
2	.66	.62	.58	.55	.64	.60	$\boxed{.56}$	.53	.56	$\boxed{.54}$	.51	.53	.51	.49	.50	.48	.47
3	.61	.55	.51	.47	.59	.54	.50	.46	.51	.47	.44	.48	.45	.43	.46	.43	.41
4	.57	.50	.45	.41	.55	.48	.44	.40	.46	.42	.39	.44	.40	.38	.41	.39	.36
5	.52	.45	.39	.35	.50	.43	.38	.35	.41	.37	.34	.39	.36	.33	.37	.34	.32
6	.48	.40	.35	.31	.47	.39	.34	.31	.37	.33	.30	.36	.32	.29	.34	.31	.28
7	.45	.36	.31	.27	.43	.35	.30	.27	.34	.29	.26	.32	.28	.25	.31	.27	.25
8	.41	.33	.27	.23	.40	.32	.27	.23	.30	.26	.23	.29	.25	.22	.28	.24	.22
9	.38	.29	.24	.20	.36	.28	.23	.20	.27	.23	.20	.26	.22	.19	.25	.21	.19
10	.35	.26	.21	.18	.34	.26	.21	.18	.25	.20	.17	.24	.20	.17	.23	.19	.16

1990s: Energy Concerns and Green Lights Program
Holophane offered lighting solutions to companies to meet the EPA requirements and earn rebates.