Design Considerations

1 **Illuminance Ratios,** $\frac{E_{WALLS}}{E_{WP}}$, $\frac{E_{ceiling}}{E_{WP}}$

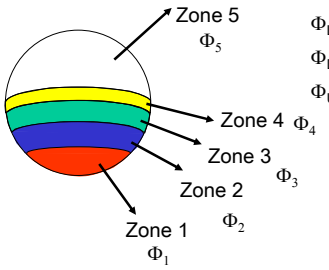
2 Illuminance on the working plane

3 Arrangement of luminaires

4 Discomfort Glare from installation

5 Modelling of flow of light from installation

CIE Flux Description of Flux Distribution from Luminaire



Φ_{LAMP}

$\Phi_{DOWN} = \Phi_1 + \Phi_2 + \Phi_3 + \Phi_4$

$\Phi_{UP} = \Phi_5$

CIE numbers: $\frac{\Phi_1}{\Phi_{DOWN}}, \frac{\Phi_1+\Phi_2}{\Phi_{DOWN}}, \frac{\Phi_1+\Phi_2+\Phi_3}{\Phi_{DOWN}}, \frac{\Phi_{DOWN}}{\Phi_{UP}+\Phi_{DOWN}}, \frac{\Phi_{UP}+\Phi_{DOWN}}{\Phi_{LAMP}}$

SPECIFYING the INSTALLATION

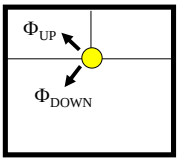
FFR - Flux Fraction Ratio

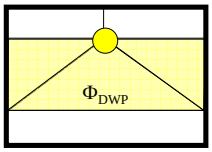
DR - Direct Ratio which is a function of BZ number

Description of Lighting Installation

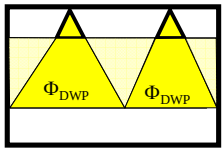
FFR - Flux Fraction Ratio = $\frac{\Phi_{UP}}{\Phi_{DOWN}}$

DR - Direct Ratio= $\frac{\Phi_{DIRECT\ to\ WP}}{\Phi_{DOWN}}$





Higher BZ lower DR



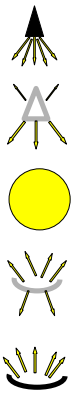
Lower BZ higher DR

1 Flux Fraction Ratio, FFR, = $\frac{\text{Light flux emitted upward from luminaire}}{\text{Light flux emitted downward from luminaire}}$

2

$\text{Direct Ratio} = \frac{\text{Light flux directly incident on WP from luminaires}}{\text{Total light flux emitted downward by the luminaires}}$

Proportion of Downward Light flux from luminaires directly incident on Working Plane



	DOWN %	UP %
DIRECT	100-90	0 - 10
SEMI-DIRECT	90- 60	10 - 40
GENERAL DIFFUSING	60 - 40	40 - 60
SEMI-INDIRECT	40 - 10	60 - 90
INDIRECT	10 - 0	90 - 100

Description	Light up %	Light down %	Characteristics
Indirect	100-90	0-10	Heightens room, draws attention to the ceiling, gives room a sense of spaciousness, working plane can appear dull, especially at low levels of illuminance, very flat lighting of objects, inefficient to light working plane.
Semi-indirect	90-60	10-40	Offsets some dullness because of the brightness of the luminaire itself, the luminaire is seen against a light ceiling and therefore glare is less of a problem, ceiling may still be the focus of attention.
Diffusing	60-40	40-60	No emphasis on any surface, may be glaring if light from luminaire shines directly in the eyes, size of source may be increased to reduce glare
Semi-Direct	40-10	60-90	The working plane will appear well lit, and the upward component will light the ceiling and tend to reduce discomfort glare. The cut-off angle may be important in reducing glare as directing the light downwards means that it could be quite bright.
Direct	10 - 0	90-100	Light concentrated on the working plane, other room surfaces may appear dark, the cut off from the luminaires may be prominent on the walls, may look cold and intense, especially if the luminaire is a low brightness luminaire, dark ceiling may introduce discomfort glare.

Design Considerations

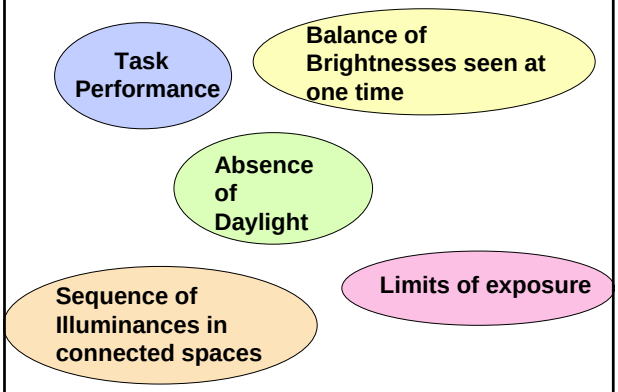
1 Illuminance Ratios, $\frac{E_{WALLS}}{E_{WP}}$, $\frac{E_{ceiling}}{E_{WP}}$

2 **Illuminance on the working plane**

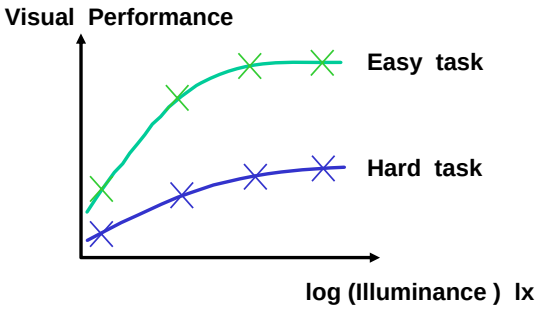
3 Arrangement of luminaires

4 Discomfort Glare from installation

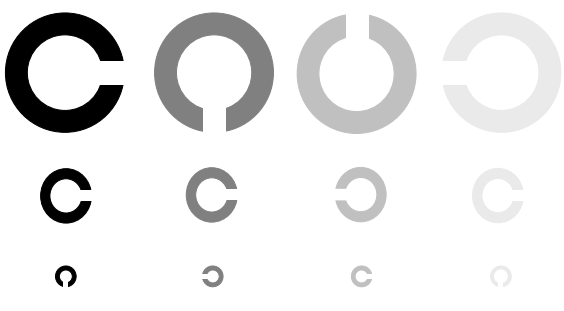
5 Modelling of flow of light from installation



CHOICE OF ILLUMINANCE



VISUAL PERFORMANCE

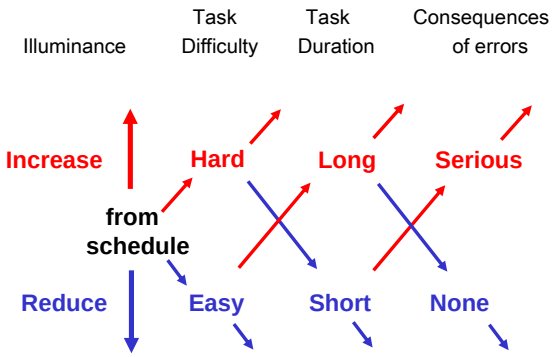


LANDOLT RINGS

ACTIVITY

Casual seeing with no need to see detail	50 lx
Occasional use and correct perceptions	100 lx
Long occupation and some detail seen	200 lx
Long occupation and easy tasks	300 lx
Moderately difficult tasks	500 lx
Difficult visual tasks	750 lx
Very difficult visual tasks, colour clear	1000 lx
Extremely difficult visual tasks	>1500 lx

STANDARD ILLUMINANCES from illuminance schedule



MODIFYING LIGHT LEVELS

Illuminance on Working plane

LUMEN METHOD

$$E_{AV} = \frac{\Phi_{Lamps} \times UF \times MF}{A_{WP}} \quad \text{lx}$$

E_{AV} = Average illuminance on the working plane

A_{WP} = Area of the working plane

Φ_{lamps} = Total lumen output from all lamps

UF = Utilization Factor - proportion of total lamp flux to WP

MF = Maintenance Factor - proportion of light after given time

Factors affecting Utilization Factor

1. Luminaire characteristics, LOR, FFR, DR
2. Reflectances of room surfaces
3. Shape of the room

$$\text{Room Index} = \frac{\text{Horizontal surface areas}}{\text{Vertical surface areas}} = \frac{2 \times Length \times Width}{2 \times H_M \times (Length + Width)} = \frac{LW}{H_M (L + W)}$$

Factors affecting Maintenance Factor

1. Length of time lamps have been burning
2. Level of pollution in external environment
3. Cleanliness of interior room surfaces
4. Frequency of cleaning installation
5. Policy on changing extinguished lamps

Design Considerations

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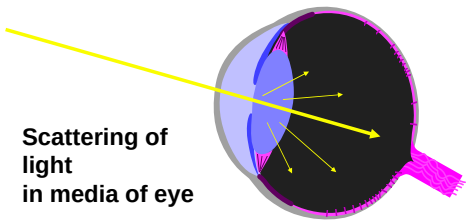
DISABILITY GLARE

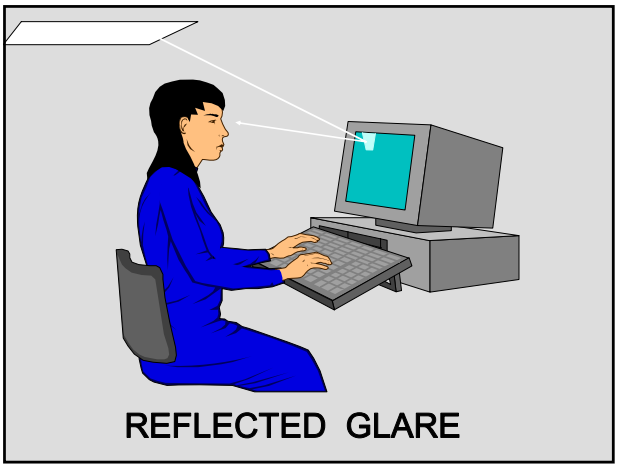


Scattering of light in media of eye

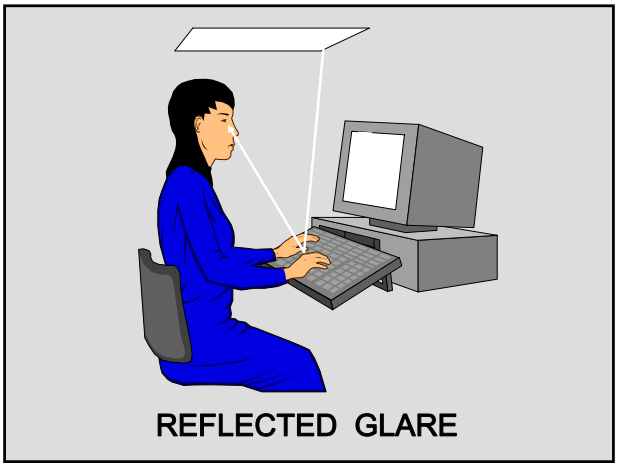
casts a veil of light over the retina

DISABILITY GLARE

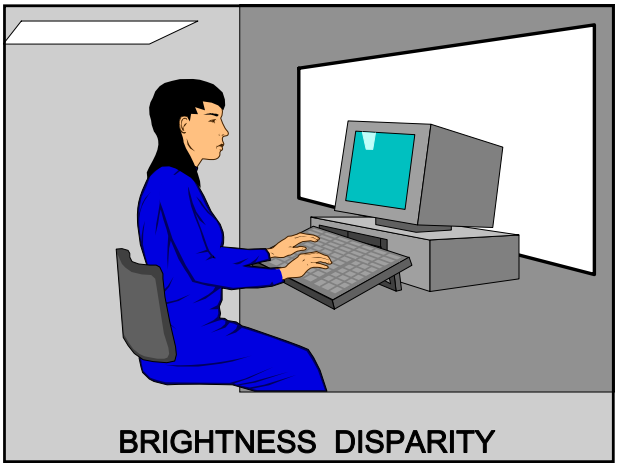
$$M_v = k\frac{E_v}{\theta^2}\ \text{asb}$$



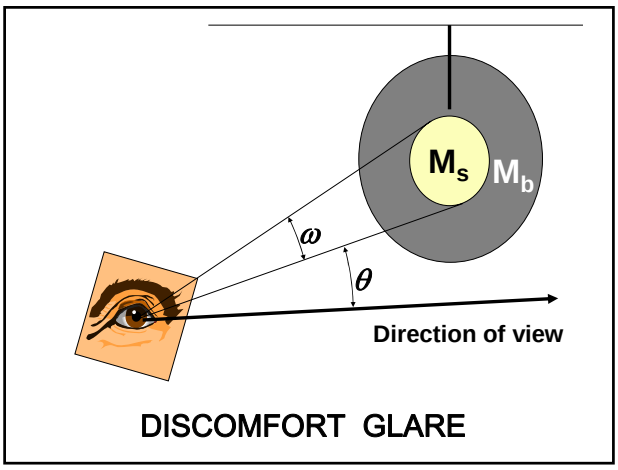
REFLECTED GLARE



REFLECTED GLARE



BRIGHTNESS DISPARITY



DISCOMFORT GLARE

Discomfort Glare

$$\text{Discomfort Glare} \propto \frac{M_{SOURCE}^{1.6} \times \omega^{0.8}}{M_{BACKGROUND} \times \theta^2}$$

M_{SOURCE}	Luminous exitance of the Glare Source
$M_{BACKGROUND}$	Average Luminous exitance of the background
ω	Solid angle of glare source in steradians= $\frac{A_{projected}}{D^2}$
θ	Angle of glare source from line of sight in radians

Design Considerations

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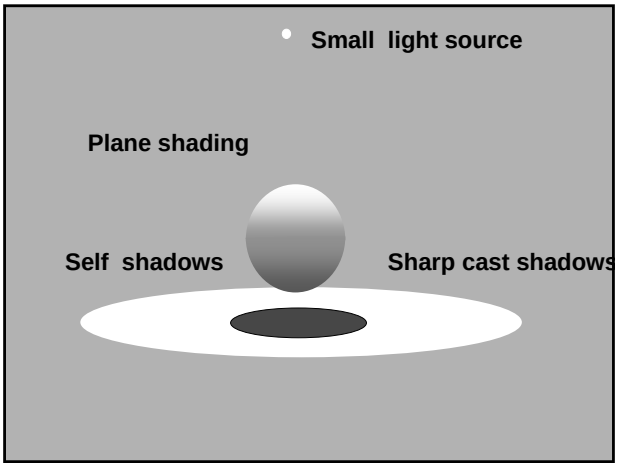
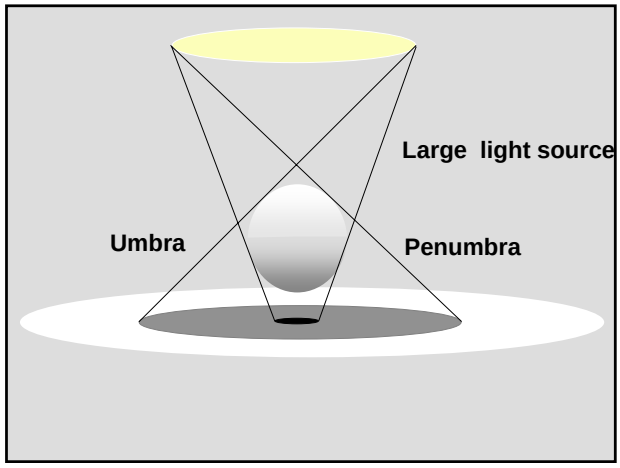
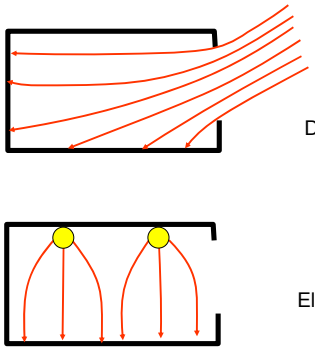
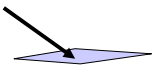


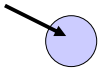


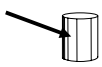


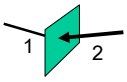
Difference in Flow of light for daylight and electric light

Measures of Illuminance

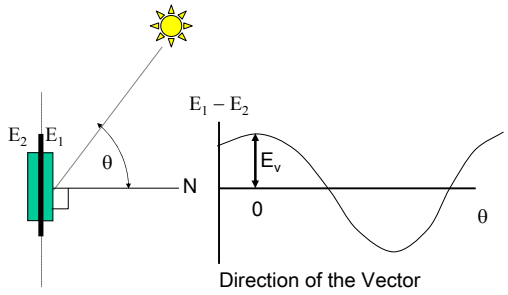
Planar illuminance  $E_P = \frac{\delta\Phi}{\delta A_{Plane\ surface}}$

Scalar illuminance  $E_S = \frac{\delta\Phi}{\delta A_{Surface\ of\ sphere}}$

Cylindrical illuminance  $E_C = \frac{\delta\Phi}{\delta A_{Surface\ of\ cylinder}}$

Illumination Vector 

$E_V = |E_1 - E_2|_{MAX}$



Illuminance Vector

Strength of Modelling

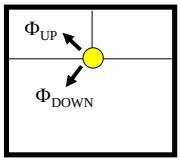
Vector Scalar ratio = $\frac{E_S}{E_V}$

Maximum value = 4 → $E_S = \frac{\Phi}{4\pi r^2}$, $E_V = \frac{\Phi}{\pi r^2}$, $\frac{E_V}{E_S} = \frac{\Phi}{\pi r^2}\frac{4\pi r^2}{\Phi} = 4$

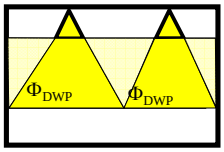
Minimum value = 0 → ←

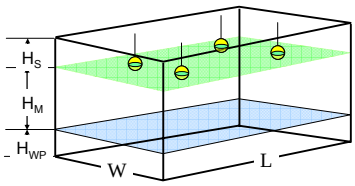
Description of Lighting Installation

FFR - Flux Fraction Ratio = $\frac{\Phi_{UP}}{\Phi_{DOWN}}$



DR - Direct Ratio= $\frac{\Phi_{DIRECT\,to\,WP}}{\Phi_{DOWN}}$





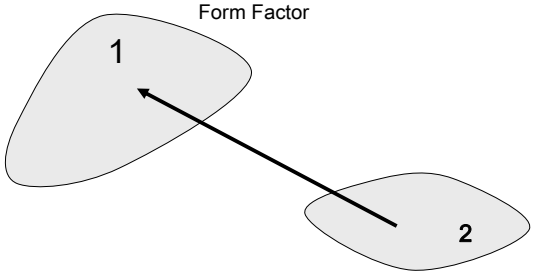
Room Index $= \frac{L \times W}{H_M (L+W)}$

$A_{Walls} = 2H_M (L+W)$

$A_{WP} = L \times W$

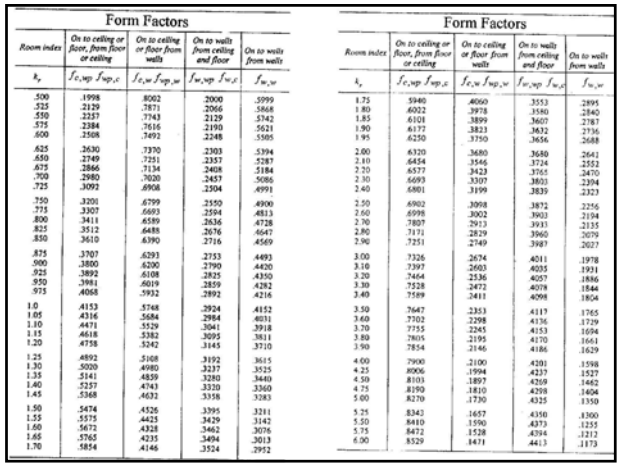
$\frac{A_{WP}}{A_{Walls}} = \frac{L \times W}{2H_M (L+W)} = \frac{RoomIndex}{2} = \frac{RI}{2}$

Form Factor



$f_{1,2} = \frac{\text{Illuminance on Surface 1}}{\text{Luminous Exitence of Surface 2}} = \frac{E_1}{M_2}$

$E_1 = M_2 f_{1,2} = E_2 \rho_2 f_{1,2}$

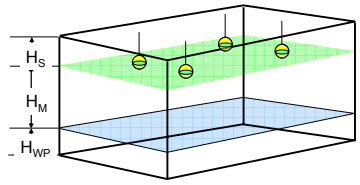


Form Factors

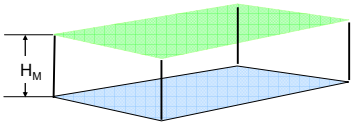
Room index	On to ceiling or floor, from floor or ceiling	On to ceiling or floor from walls	On to walls from ceiling and floor	On to walls from walls
k_r	$f_{c,wp}$ $f_{wp,c}$	$f_{c,w}$ $f_{wp,w}$	$f_{w,wp}$ $f_{w,c}$	$f_{w,w}$
.500	.1998	.8002	.2000	.5999
.525	.2129	.7871	.2066	.5868
.550	.2257	.7743	.2129	.5742
.575	.2384	.7616	.2190	.5621
.600	.2508	.7492	.2248	.5505
.625	.2630	.7370	.2303	.5394
.650	.2749	.7251	.2357	.5287
.675	.2866	.7134	.2408	.5184
.700	.2980	.7020	.2457	.5086
.725	.3092	.6908	.2504	.4991
.750	.3201	.6799	.2550	.4900
.775	.3307	.6693	.2594	.4813
.800	.3411	.6589	.2636	.4728
.825	.3512	.6488	.2676	.4647
.850	.3610	.6390	.2716	.4569
.875	.3707	.6293	.2753	.4493
.900	.3800	.6200	.2790	.4420
.925	.3892	.6108	.2825	.4350
.950	.3981	.6019	.2859	.4282
.975	.4068	.5932	.2892	.4216
1.0	.4153	.5748	.2924	.4152
1.05	.4316	.5684	.2984	.4031
1.10	.4471	.5529	.3041	.3918
1.15	.4618	.5382	.3095	.3811
1.20	.4758	.5242	.3145	.3710
1.25	.4892	.5108	.3192	.3615
1.30	.5020	.4980	.3237	.3525
1.35	.5141	.4859	.3280	.3440
1.40	.5257	.4743	.3320	.3360
1.45	.5368	.4632	.3358	.3283
1.50	.5474	.4526	.3395	.3211
1.55	.5575	.4425	.3429	.3142
1.60	.5672	.4328	.3462	.3076
1.65	.5765	.4235	.3494	.3013
1.70	.5854	.4146	.3524	.2952

Form Factors

Room index	On to ceiling or floor, from floor or ceiling	On to ceiling or floor from walls	On to walls from ceiling and floor	On to walls from walls
k_r	$f_{c,wp}$ $f_{wp,c}$	$f_{c,w}$ $f_{wp,w}$	$f_{w,wp}$ $f_{w,c}$	$f_{w,w}$
1.75	.5940	.4060	.3553	.2895
1.80	.6022	.3978	.3580	.2840
1.85	.6101	.3899	.3607	.2787
1.90	.6177	.3823	.3632	.2736
1.95	.6250	.3750	.3656	.2688
2.00	.6320	.3680	.3680	.2641
2.10	.6454	.3546	.3724	.2552
2.20	.6577	.3423	.3765	.2470
2.30	.6693	.3307	.3803	.2394
2.40	.6801	.3199	.3839	.2323
2.50	.6902	.3098	.3872	.2256
2.60	.6998	.3002	.3903	.2194
2.70	.7807	.2913	.3933	.2135
2.80	.7171	.2829	.3960	.2079
2.90	.7251	.2749	.3987	.2027
3.00	.7326	.2674	.4011	.1978
3.10	.7397	.2603	.4035	.1931
3.20	.7464	.2536	.4057	.1886
3.30	.7528	.2472	.4078	.1844
3.40	.7589	.2411	.4098	.1804
3.50	.7647	.2353	.4117	.1765
3.60	.7702	.2298	.4136	.1729
3.70	.7755	.2245	.4153	.1694
3.80	.7805	.2195	.4170	.1661
3.90	.7854	.2146	.4186	.1629
4.00	.7900	.2100	.4201	.1598
4.25	.8006	.1994	.4237	.1527
4.50	.8103	.1897	.4269	.1462
4.75	.8190	.1810	.4298	.1404
5.00	.8270	.1730	.4325	.1350
5.25	.8343	.1657	.4350	.1300
5.50	.8410	.1590	.4373	.1255
5.75	.8472	.1528	.4394	.1212
6.00	.8529	.1471	.4413	.1173

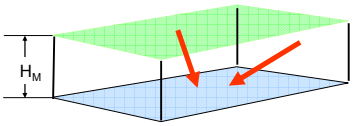


Effective ceiling plane



Working plane

Effective ceiling plane



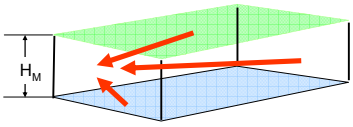
Working plane

Illuminance reflected onto working plane= light from ceiling + light from walls

$$E_{R_{WP}} = M_C \times f_{WP,C} + M_W \times f_{WP,W}$$

$$E_{R_{WP}} = E_C \times \rho_C \times f_{WP,C} + E_W \times \rho_W \times f_{WP,W}$$

Effective ceiling plane

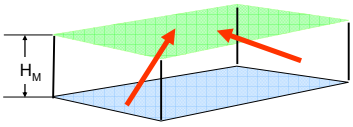


Working plane

Illuminance reflected onto walls= light from c. + light from wp+light from w.

$$E_{R_W} = E_C \times \rho_C \times f_{W,C} + E_{WP} \times \rho_{WP} \times f_{W,WP} + E_W \times \rho_W \times f_{W,W}$$

Effective ceiling plane



Working plane

Illuminance reflected onto Ceiling = light from working plane + light from walls

$$E_{R_C} = E_{WP} \times \rho_{WP} \times f_{C,WP} + E_W \times \rho_W \times f_{C,W}$$

	reflectance	E ratio	Final Illuminnance		Reflected light on surfaces					
					WP		Ceiling		Walls	
S	ρ	$\frac{E_S}{E_{WP}}$	E_S	M_S	$f_{WP,S}$	MSfwp,s	$f_{C,S}$		$f_{W,S}$	
WP	0.2	1	1	0.2			0.7326	0.147	0.4011	0.08
C	0.7	0.2	0.2	0.14	0.7326	0.102			0.4011	0.056
W	0.5	0.5	0.5	0.25	0.2674	0.067	0.2674	0.067	0.1978	0.049
					E_R	0.169		0.204		0.185

Final Illuminance = Direct Illuminance + Inter-reflected Illuminance

Direct Illuminance = Final Illuminance - Inter-reflected Illuminance

$$E_D = E - E_R$$

$$FFR = \frac{\Phi_{UP}}{\Phi_{DOWN}} = \frac{A_C E_{DC}}{A_{WP} E_{DWP} + A_W E_{DW}}$$

where:

E_{DC} = direct illuminance on the ceiling

E_{DWP} = direct illuminance on the working plane

E_{DW} = direct illuminance on the walls

Dividing by A_w,

$$FFR = \frac{\frac{A_C}{A_W} E_{DC}}{\frac{A_{WP}}{A_W} E_{DWP} + E_{DW}}, \text{ and as } \frac{A_{WP}}{A_W} = \frac{RI}{2}$$

$$FFR = \frac{\frac{RI}{2} E_{DC}}{\frac{RI}{2} E_{DWP} + E_{DW}}$$

$$DR = \frac{\Phi_{WP}}{\Phi_{DOWN}} = \frac{A_{WP} E_{DWP}}{A_{WP} E_{DWP} + A_W E_{DW}}$$

where:

E_{DC} = direct illuminance on the ceiling

E_{DWP} = direct illuminance on the working plane

E_{DW} = direct illuminance on the walls

Dividing by A_w,

$$DR = \frac{\frac{A_{WP}}{A_W} E_{DWP}}{\frac{A_{WP}}{A_W} E_{DWP} + E_{DW}}, \text{ and as } \frac{A_{WP}}{A_W} = \frac{RI}{2}$$

$$DR = \frac{\frac{RI}{2} E_{DWP}}{\frac{RI}{2} E_{DWP} + E_{DW}}$$

LUMEN METHOD

$$\mathrm{E_{AV}} = \frac{\Phi_{Lamps} \times UF \times MF}{A_{WP}} \quad \mathrm{lx}$$