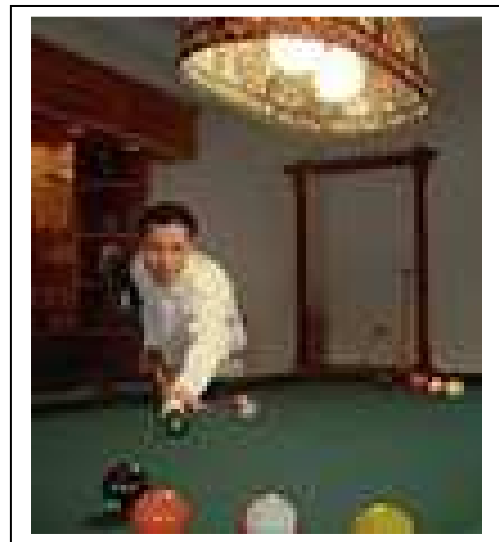


Methods for calculating illumination

The problem of the lighting designer at the functional level is to determine how many lights and where to place them to get the correct level of illumination for a given activity.

These calculations can be divided into two types

- We want to determine the illumination at a small specific location in the room from a point light source. **Accent** or **task** lighting. This not much more complicated than exercises we have already been doing



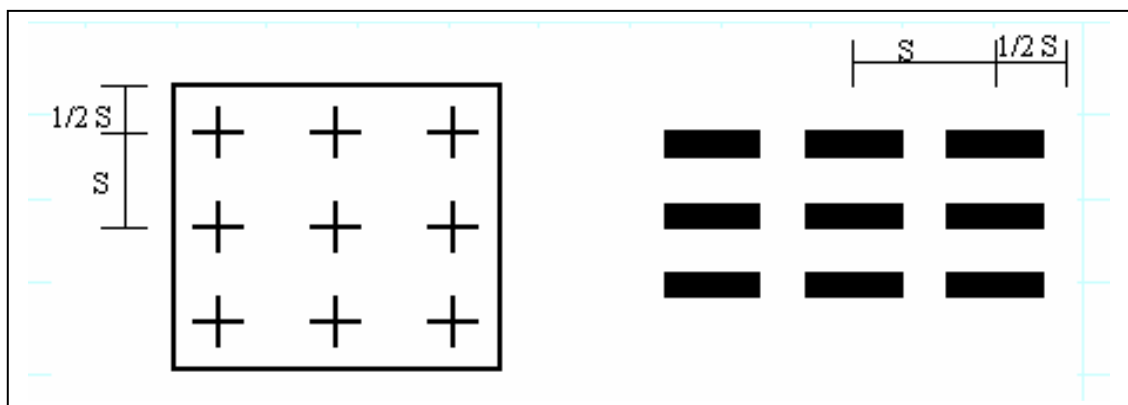
Simply get polar plot for luminaire and work out the illumination on surface for a given lamp. Called the **point** illumination method.

The lumen method

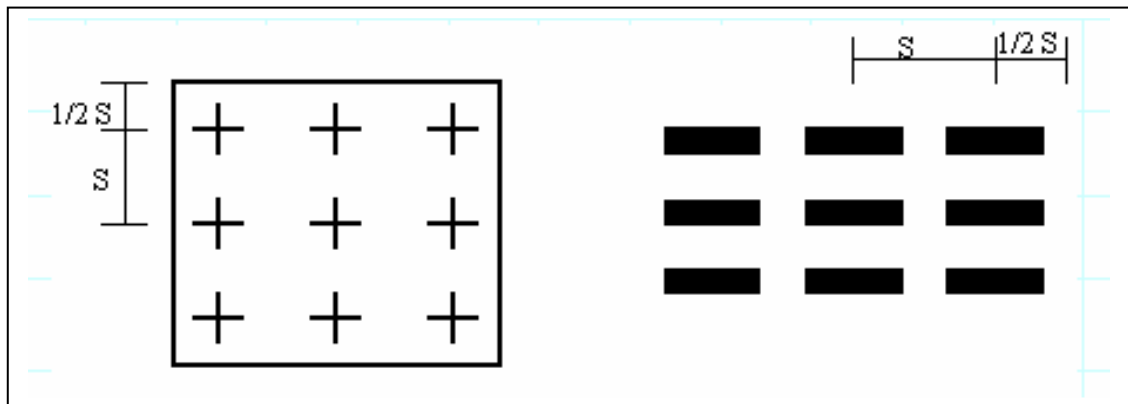
We want to estimate the illumination pattern from a set of diffuse lighting sources over a broad area in a room. This is a more complicated exercise. We will be using the **total flux method**, or **lumen method** to get rough and reasonable estimates of the lamps/luminaires needed.

This method is used in areas where a *uniform* light intensity of the work area. Used for rectangular rooms with gridded luminaire pattern.

Uniform: For the present discussion we require the minimum illumination level to be at least 70% of the maximum illumination level.



The lumen method



What we have to do is solve an equation of the type

$$E = \frac{\Phi_{rec}}{A}$$

where E is the illumination level required at the work surface and A is the total area of the plane where the work is done. The factor Φ_{rec} is the flux of light received on the working surface. The factor Φ_{rec} is **not** the flux emitted by the lamps although it will be related to the flux emitted by the lamps.

The main issue is to determine how much flux needs to be installed, i.e. Φ_{inst} , to get the required amount of received flux Φ_{rec} .

Methods for calculating illumination

The first step is to determine how much flux is to be received.

$$\Phi_{rec} = EA$$

Multiply the illumination required by the surface area.

The received flux is related to the installed flux by a simple formula

$$\Phi_{rec} = MF \times UF \times \Phi_{inst}$$

where

MF = Maintenance factor (Light Loss Factor LLF)

UF = Utilization factor

The maintenance factor gives an estimate of how lighting conditions will deteriorate through use. Some factors are

- Dust and dirt inside luminaire surfaces
- Aging of light bulbs emitting less light
- Cleaning of room surfaces, e.g. ceiling

Without detailed knowledge of a maintenance plan, one sets $MF = 0.80$.

The utilization factor (UF)

This utilization factor is somewhat more complicated to determine than the maintenance factor.

The utilization factor will depend on the following

The luminaire properties. One needs the light output ratio (*LOR*). How much of the light emitted by the lamps actually leaves the luminaire? An enclosed lamp in a luminaire with low reflectivity will have a smaller *LOR* than a naked lamp.

The respective values of the ULOR and DLOR also have an impact. The light emitted downwards will probably reach the work area without reflections. However light emitted upwards can only reach the work area after reflection(s) from surfaces. A large *DLOR* usually means a higher *UF*.

The utilization factor (*UF*)

The reflectance of the room surfaces. Are the surfaces (walls, ceiling) light or dark in colour? The larger the *ULOR* the more important this factor becomes. Some typical reflectance values are

Colour	Reflectance
White, Off-white, light shades of gray, brown, blue	75-90%
Medium green, yellow, brown or gray	30-60%
Dark gray, medium blue	10-20%
Dark blue, green, wood panelling	5-10%

(A colour with strong chroma does not reflect other colours). Reflectances are available from manufacturers of paints and furniture finishings.

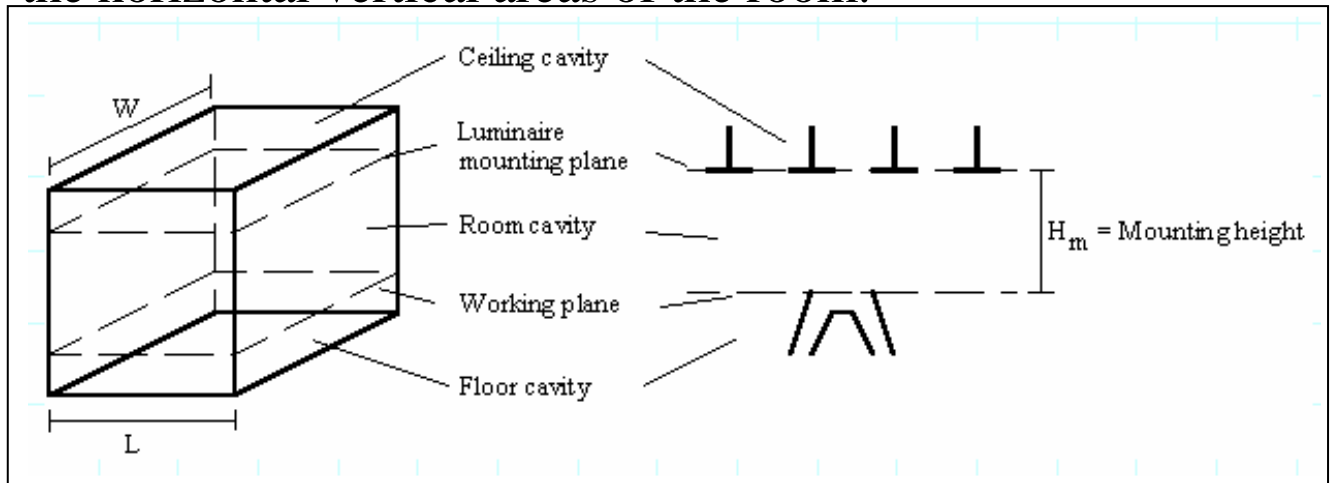
It is usual to make the reflectance of the ceiling highest, walls slightly lower and the floor darker. One typically recommends in offices

	Light
Ceiling	70-90%
Wall	50-70%
Floor	20-50%

Reflectances of desks should be 20-40%. Do not choose very dark wood, or bright surfaces.

The utilization factor (UF)

The geometric proportion of the room. The geometric shape of the room will affect the UF. A factor called the **room index (RI)** is defined from the horizontal vertical areas of the room.



The horizontal areas are

$$Area_H = 2 \times Length \times Width = 2 \times L \times W$$

The vertical areas are

$$Area_V = 2 \times (Length + Width) \times Height_{Lum} = 2 \times (L + W) \times H_m$$

The mounting height, H_m is the vertical distance from the work place to the luminaire. The RI (the factors of 2 cancel) is

$$RI = \frac{Area_H}{Area_V} = \frac{L \times W}{(L + W) \times H_m}$$

The utilization factor (UF)

The Direct ratio. This is the proportion of the downward luminous flux that reaches the work area directly without reflection. It depends on

- **The shape of the room.** The Direct ratio has a low value with a tall narrow room (small RI) and a high value for a wide room (large RI).
- **The light distribution from the luminaires.** Luminaires that emit light through a larger solid angle will generally have a smaller direct ratio than luminaires that emit light in a narrower beam.

There exist data sheets of UF for rooms of different shapes and luminaires of a common type. Catalogues of luminaires often provide data sheets of UF for rooms.

Getting uniform illumination

As a rule of thumb, to achieve uniform lighting requires the spacing between the luminaires to be no larger than 1.5 times the mounting height.

$$LuminaireSpacing < 1.5H_m$$

The recipe for doing calculations

- Decide on Luminaire type and how many will be needed.
- Determine room index.
- Reflectances of ceiling, walls and floor estimated.
- Utilization factor for luminaire determined.
- DLOR for luminaire determined.
- Determine necessary flux

$$\Phi_{inst} = \frac{\Phi_{rec}}{MF \times UF} = \frac{E \times A}{MF \times UF}$$

- Geometry for uniform illumination to decide of number and size of luminaries. Trial and error. At this stage might change type of luminaire and repeat calculation.

A simple example (Szoklay, Example 2.7)

A general open plan office has dimensions $12 \times 8.5 \times 2.8$ m.

Using D.2.6 data sheet, visual class, means the illuminance required is 400 lux.

The reflectances of the ceiling are known as 0.70 and the reflectance of the wall is 0.50 m.

The work areas are at a height of 0.80 m.

The choice is made that an enclosed batten luminaire with diffuser should be used (D.2.7).

- The mounting height, $H_m = 2.8 - 0.8 = 2.0$ m.
- The RI is

$$RI = \frac{12 \times 8.5}{(12 + 8.5) \times 2.0} = \frac{102}{41} = 2.5$$

- From Table D.2.7, the luminaire DLOR = 0.50.

RI	C = 0.7	C = 0.7	C = 0.7	C = 0.5
	W = 0.5	W = 0.3	W = 0.1	W = 0.5
.....
2.0	0.52	0.47	0.44	0.44
2.5	0.55	0.51	0.48	0.50
....

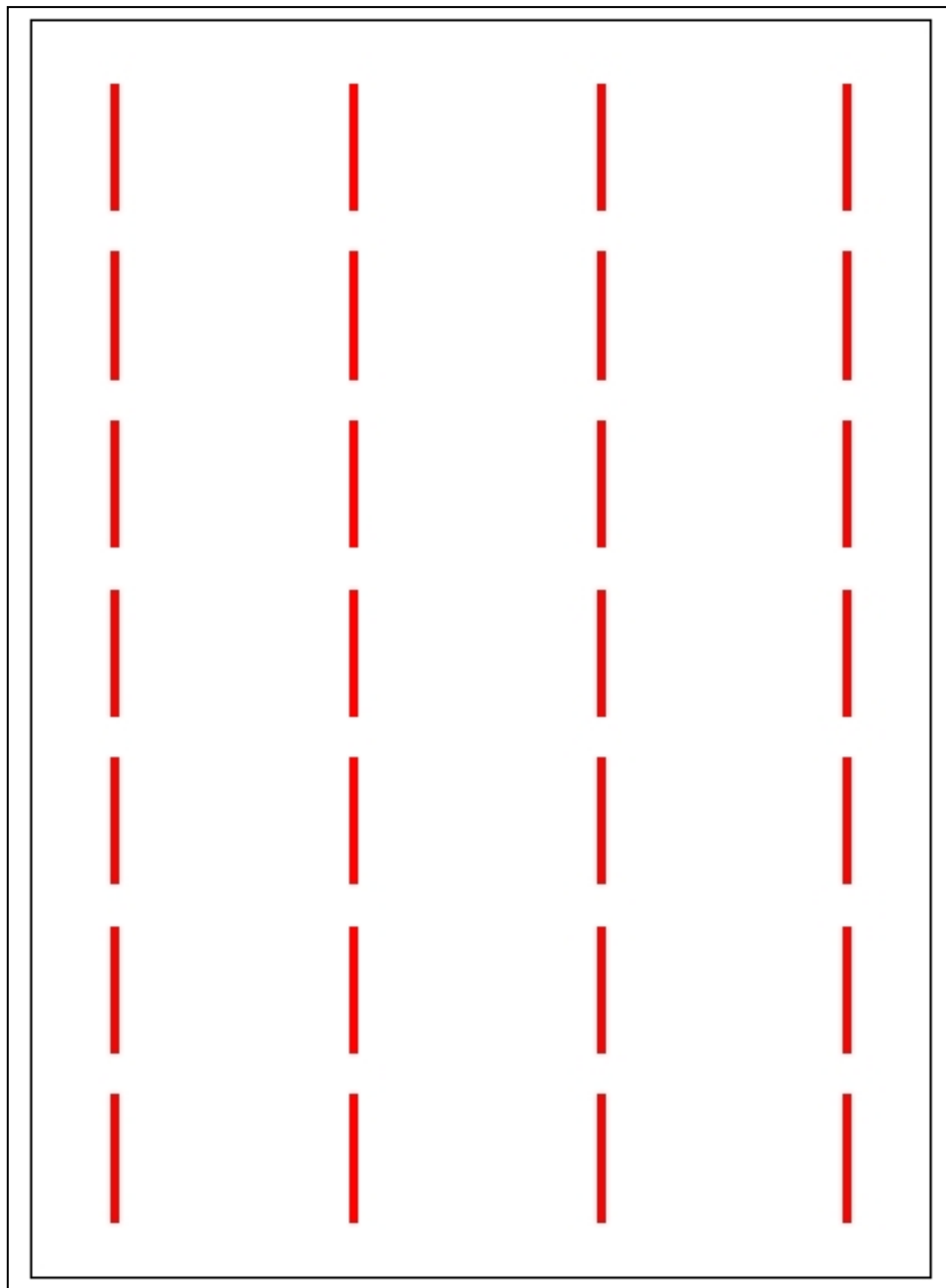
- Utilization factor, choose entry in $C = 0.7, 0.5$ column. $UF = 0.55$.

- So we need a total installed luminous flux of

$$\Phi_{inst} = \frac{E \times A}{MF \times UF} = \frac{400 \times 12 \times 8.5}{0.55 \times 0.80} = 98,000 \text{ lm}$$

- For uniform lighting, need minimum spacing of $1.5 \times H_m = 3.0$ m between luminaires.
- Table D2.9. Choose 1.20 m long fluorescent lamps (middle size) of 40 W. (Rule of middle size). Go for a middle quality lamp Kolor-rite (CRI index = 1B). Flux output = 1800 lumen.
- Number of lamps needed = $98,000/1800 = 55$. Round up to 56 since want two lamps per luminaires.

- Geometric experiment, decide on a layout of 7 rows of 4 luminaires. Spacing of 1.60 m along 12.0 m length (with 0.60 m from walls and 0.40 m between ends). Spacing along width is 2.30 m between centres, with a 0.80 m gap from the walls. Make gap between last lamp to wall equal to half spacing between luminaires.



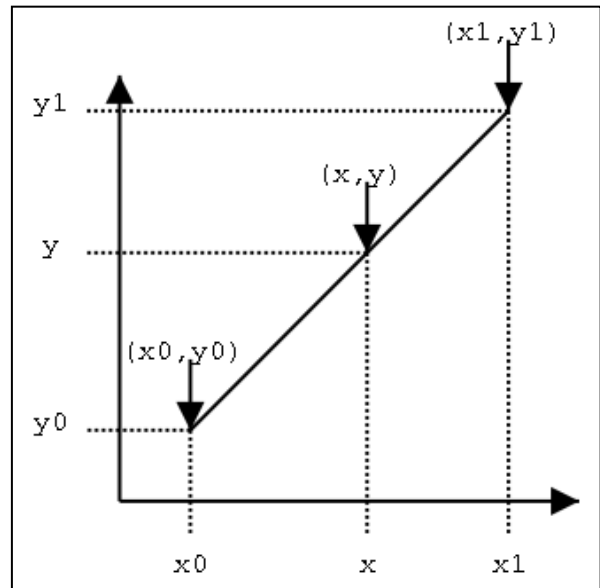
Linear Interpolation

Will be using table of values for utilization factors. Particular RI data for luminaries might not be read from table exactly (e.g. as in example of Szokolay).

Determine slope

$$m = \frac{y_1 - y_0}{x_1 - x_0}$$

How far along?



So

$$y = y_0 + m(x - x_0)$$

Suppose the RI was 2.70 (refer to Szokolay).

For $RI=2.5$ $UF = 0.55$; and for $RI = 3.0$ $UF = 0.58$

So $m = (0.58-0.55)/(3.0-2.5) = 0.060$

So $RI = 0.55 + 0.060*(2.7-2.5) = 0.55+0.012 = 0.56$

The space to height ratio (SHR)

The spacing to height ratio (**SHR** or **S/H_m**) is the ratio of the centre-to-centre distance between adjacent luminaires, to their height above the working plane. Used to estimate if lighting is uniform. For a rectangular arrangement of luminaires

$$SHR = \frac{1}{H_m} \times \sqrt{\frac{A}{N}}$$

A = total floor area

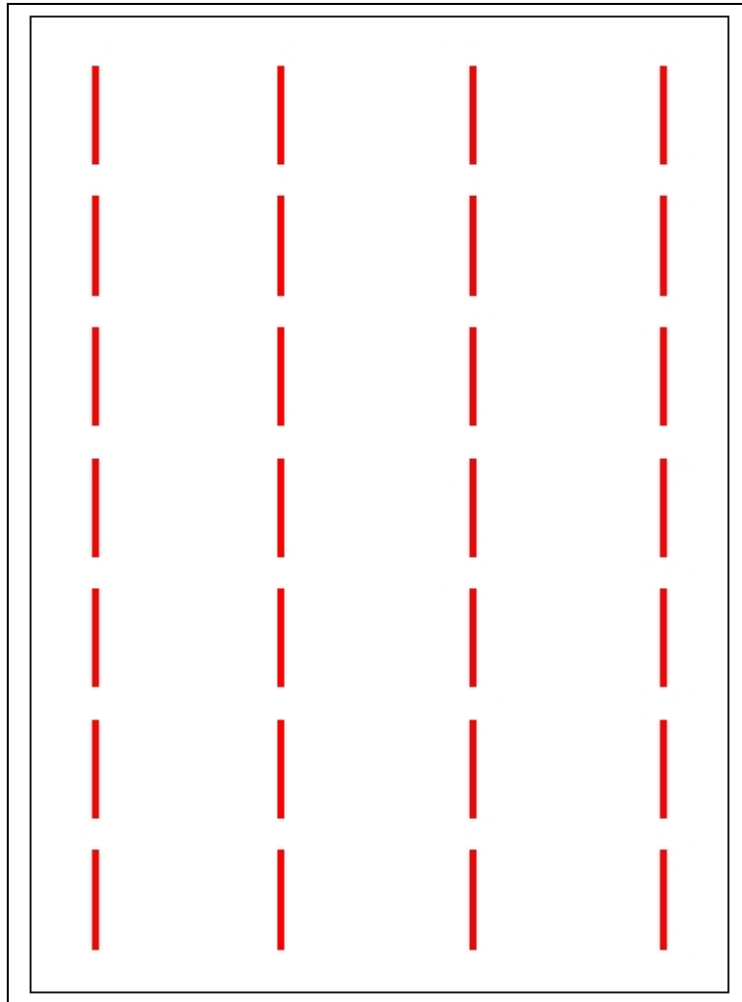
N = number of luminaires

More precise criteria for uniform lighting.

- The SHR should not exceed maximum spacing to height ratio (**SHRMAX**) of the given luminaire as quoted by the manufacturer, and
- The geometric mean spacing to height ratio of the luminaire layout should be within the range of nominal spacing to height ratio (**SHRNOM**) of the given luminaire as quoted by the manufacturer, i.e.

$$\sqrt{SHR(length) \times SHR(width)} = SHRNOM \pm 0.5$$

The space to height ratio: Example



$$\text{SHR}(\text{length}) = 1.6/2.0 = 0.80$$

$$\text{SHR}(\text{length}) = 2.3/2.0 = 1.15$$

For linear fluorescent luminaire, $\text{SHRNOM} = 1.7$.
So everything is OK.

Lighting layouts

For uniform lighting patterns a regular arrangement of lights is desired.

Generally, for linear luminaires, keep the long luminaire parallel to the long room axis. A diagonal luminaire arrangement can be distracting, and the order of room disjointed from order of light source.

Issues.

With little variation, lighting is monotonous and flat. This refers to the degree of shadow. The stronger the shadows the less flat the light. Luminaires with diffusers produce flatter light.

All parts of room, even where no visual tasks are performed receive same amount of light. Provide general illumination of 200 lux, and maybe localized illuminance of 600 where difficult tasks occur. Requires flexibility in electrical trunking supply so luminaires can be moved.

The maintenance factor

The details of the maintenance factor depends on a number of different inputs.

$$MF = LLMF \times LMF \times RSMF$$

LLMF = Lamp Lumen maintenance factor. How well does the lamp maintain its light output as it ages. Obtained from manufacturer catalogs.

LMF = Luminaire maintenance factor. Main issue is dust or grime being deposited on luminaire surface.

RSMF = Room surface maintenance factor. How clean is the room kept, dirt on walls and ceilings reducing reflectivity and illumination.

Lamp Type		Hours	
LLMF	6000	10000	12000
Fluorescent, tri-phosphor With electronic ballast	0.99	0.96	0.95
Metal halide	0.72	0.66	0.63
High Pressure sodium	0.91	0.88	0.87

The maintenance factor

$$MF = LLMF \times LMF \times RSMF$$

The *LMF* and *RSMF* depend on what is going on in the room. Rooms divided into a number of categories. IES handbook. Very Clean (VC), Clean (C), Medium (M), Dirty (D), Very Dirty.

The *LMF* further depends on the type of luminaire. Whether it is a naked bulb, whether it has diffusers, reflectors, uses louvres.

Cleaning interval	1 year			2 years			3 years		
Environment	C	N	D	C	N	D	C	N	D
PERLUCE	0.94	0.90	0.86	0.91	0.86	0.81	0.90	0.84	0.79
IP 20 luminaire	0.88	0.82	0.77	0.83	0.77	0.71	0.79	0.73	0.65

C = clean (clean rooms, computer centres, hospitals)

N = normal (offices, shops, schools, restaurants)

D = dirty (chemical plants, wood processing plants, welding shops)

According to CIE text 97 "Maintenance of indoor electrical lighting systems", 1995 edition, ISBN 3 900 734 34 8

Luminaire	PERLUCE	IP 20 LUMINAIRE
Lamp lumen maintenance factor: LLMF	0.92	0.92
Lamp life survival factor: LSF	0.96	0.96
Room surface maintenance factor: RSMF	0.95	0.95
Luminaire maintenance factor: LMF	0.84	0.73
Maintenance factor: MF	0.70	0.61

The control of glare

Glare occurs in both natural (daylight) and in interior lighting situations. It is most annoying in the interior light environment where the lighting is under human control.

The glare annoyance depends on a number of factors

- In a supermarket people are on the move and not always looking in same direction
- In a classroom students are usually looking in a fixed direction
- In a classroom, students are reading, this is a moderately difficult visual task.
- Students are fixed for a long period of time.

Standards for glare depend on the use of the visual environment.

The glare index

There is quantity called the discomfort glare constant (g) which is

$$g = 0.45 \times \frac{L_s^{1.6}}{L_B} \frac{\omega^{0.8}}{P^{1.6}}$$

In this relation

L_s = luminance of the source of glare.

L_B = average luminance of the background sources.

P is called the position index. This gives an indication of the position of where the light index is located in the field of view. P is small when light is in field of view.

Area of Glare Source

$$\omega = \frac{\text{Area of Glare Source}}{(\text{Distance from source})^2} = \text{solid angle of glare}$$

Besides this, there is something called the glare index

$$GI = 10 \log_{10}(g)$$

Glare index	Reaction
0 - 10	Imperceptible
10 - 16	Noticeable
16 - 22	Acceptable
22 – 28	Uncomfortable
> 28	Intolerable

More visually demanding tasks with high illuminance levels are less tolerant of glare.

Limiting GI	Occupations
16	Drawing offices, very fine visual inspections
19	Offices, libraries, keyboard and VDT work (reflections from screen).
22	Kitchen, reception area, fine assembly
25	Stock rooms, assembly line for easy tasks
28	Indoor car park, rough industrial work

(At present time, do not require you to calculate the glare index, require you to know what it is and when it is most important to eliminate.)

Control of glare

Consider the factors in that arise in the glare formulae.

First of all, glare from all sources is additive

$$GI = 10 \log_{10} (g_1 + g_2 + g_3 + \dots)$$

People get annoyed by all sources of discomfort glare.

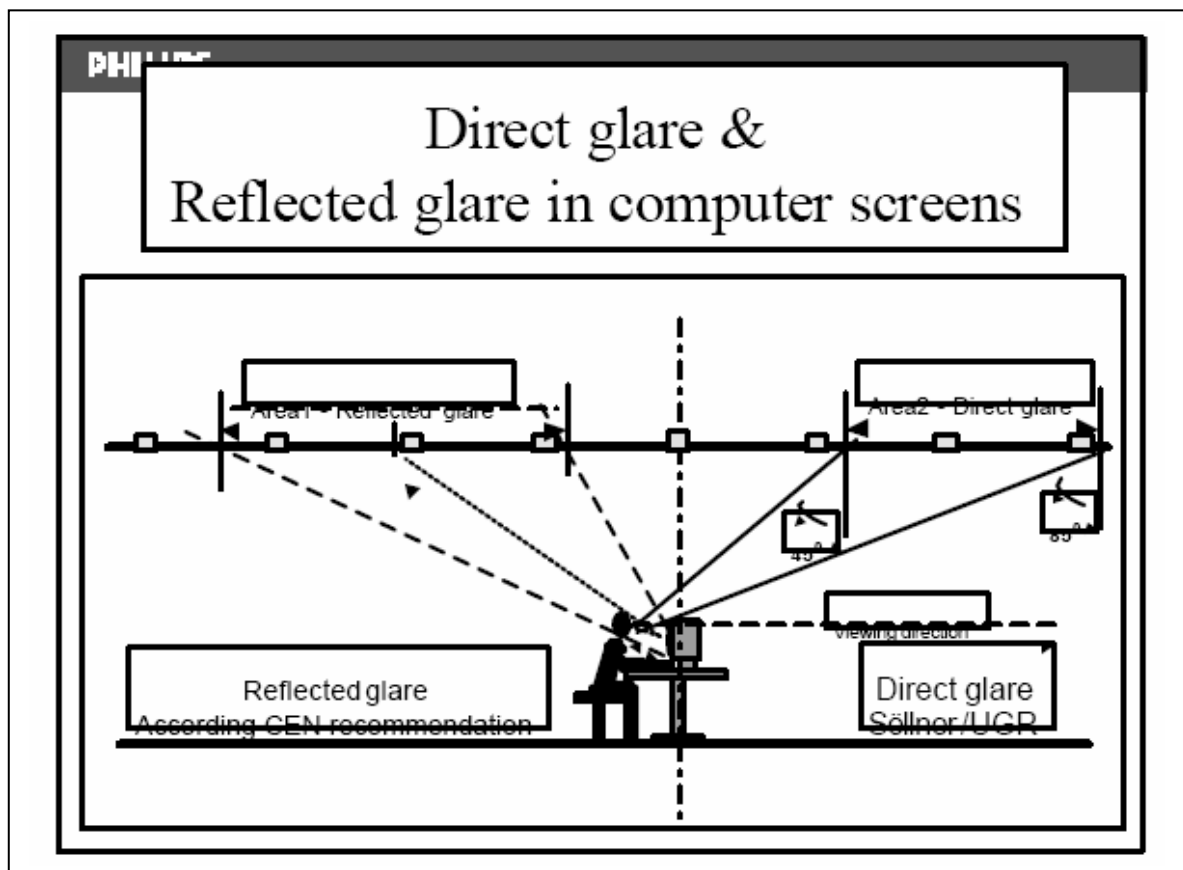
$$g = 0.45 \times \frac{L_s^{1.6}}{L_B} \frac{\omega^{0.8}}{p^{1.6}}$$

Obviously, cutting down the illuminance of the glare source, L_s is a good idea. **This does not mean reducing the light level in the room.** The higher the illumination of the background, the smaller the glare constant. So rather than having one very bright luminaire, have a number of dimmer luminaires.

Most of the visual tasks involve looking horizontally or slightly down. So keep luminaires out of the low angle vision. (The factor p in the formula takes this into account). So do not give walls too high a reflectance. Do not give the floors too high reflectance (no glossy light floors!).

Control of glare

Computer screens. Since computer screens have shiny surfaces, very susceptible to glare, and can be disability glare.



Do not want have batten luminaires with lighting diffusing out the sides.

Keep light sources high, away from field of view.

Computer labs in Bld 29 have troffers with small ice-cube tray size louvres. The CIE have developed a **Unified Glare Rating (UGR)**. A relatively simple way to determine a glare index.

Glare

The glare index

$$g = 0.45 \times \frac{L_s^{1.6}}{L_B} \frac{\omega^{0.8}}{P^{1.6}}$$

L_s Keep luminance of source down. Use of diffusers and louvres. Problem, cutting down glare also cuts down total light emitted. Note, reflected light can also be a source of glare.

P Keep luminaires out of field of view. High ceilings are good. Field of view is roughly horizontal and about 1.2 m above floor.

ω Keep area of source small. Note, connected with L_s .

To cut down glare, avoid luminaires that emit light to sides (e.g. battern luminaire with a diffuser at the sides), light emitted more in downward direction avoids visual discomfort.

Uplighting

In this form of lighting, lighting is directed upwards to the ceiling. Reflected light from the ceiling provides the general illumination in the room.

Advantages, elimination of glare is one of the major advantages. Re-introduction driven by the increasing use of computers.

Disadvantage, it is somewhat inefficient. Low conversion of electrical energy into usable light. Ceiling is quite bright, less visual emphasis on other areas of room, furniture, floors.



Keep ceiling luminance below 500 cd/m^2 average and 1500 cd/m^2 maximum.

To get an even illumination on the ceiling requires that you have a high ceiling.

Uplighting

You either like it or not. It is possible to use combinations of direct diffuse and indirect lighting.

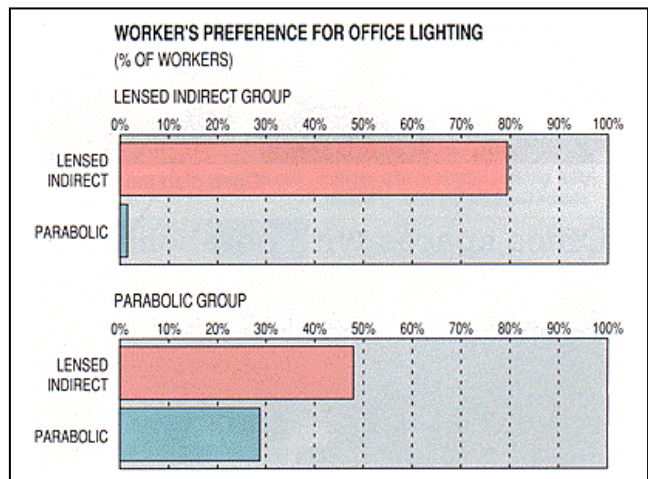
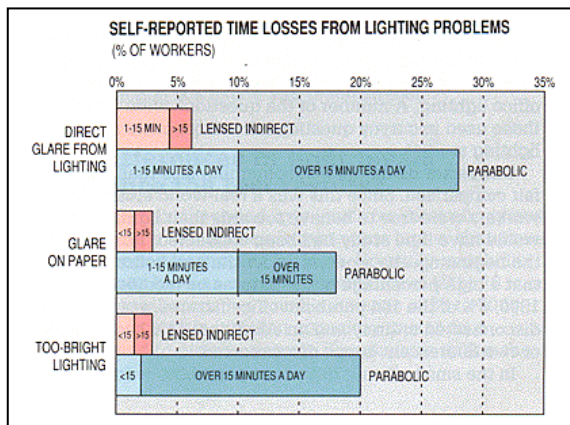
Illumination can be calculated using lumen method in conjunction with **transfer function** tables.



Need to maintain a uniform illumination on ceiling.
Eliminates light hot-spots that can result in glare.
Harder with low ceiling.

Computer workers prefer diffuse lighting

Workers in computerised office divided into two groups, half received illumination from parabolic (PAR) downlights. (PAR lights can be used to task lighting and cut down electricity bill). Other half had diffused light sources.



Besides less glare, concentrated beam downlights result in a darker ceiling. This can result in an oppressive psychological effect.

