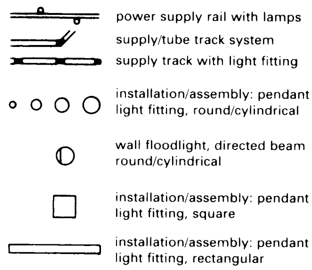
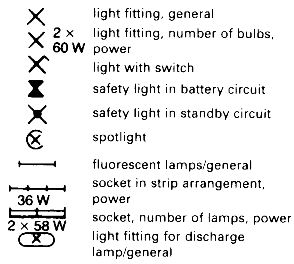
LIGHTING: LAMPS AND FITTINGS

radiation physics quantity	lighting technology quantity and symbol	lighting technology unit and abbreviation
radiation flux	luminous flux Φ	lumen (lm)
radiant intensity	light intensity I	candela (cd)
irradiance	illuminance E	lux (lx)
radiance	lighting density L	(cd/m^2)
radiant energy	quantity of light Q	(lm • h)
irradiation	light exposure H	(lx • h)

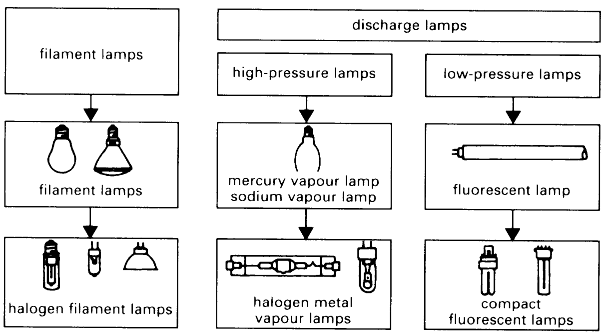
(1) **Quantities relating to radiation physics and lighting technology**



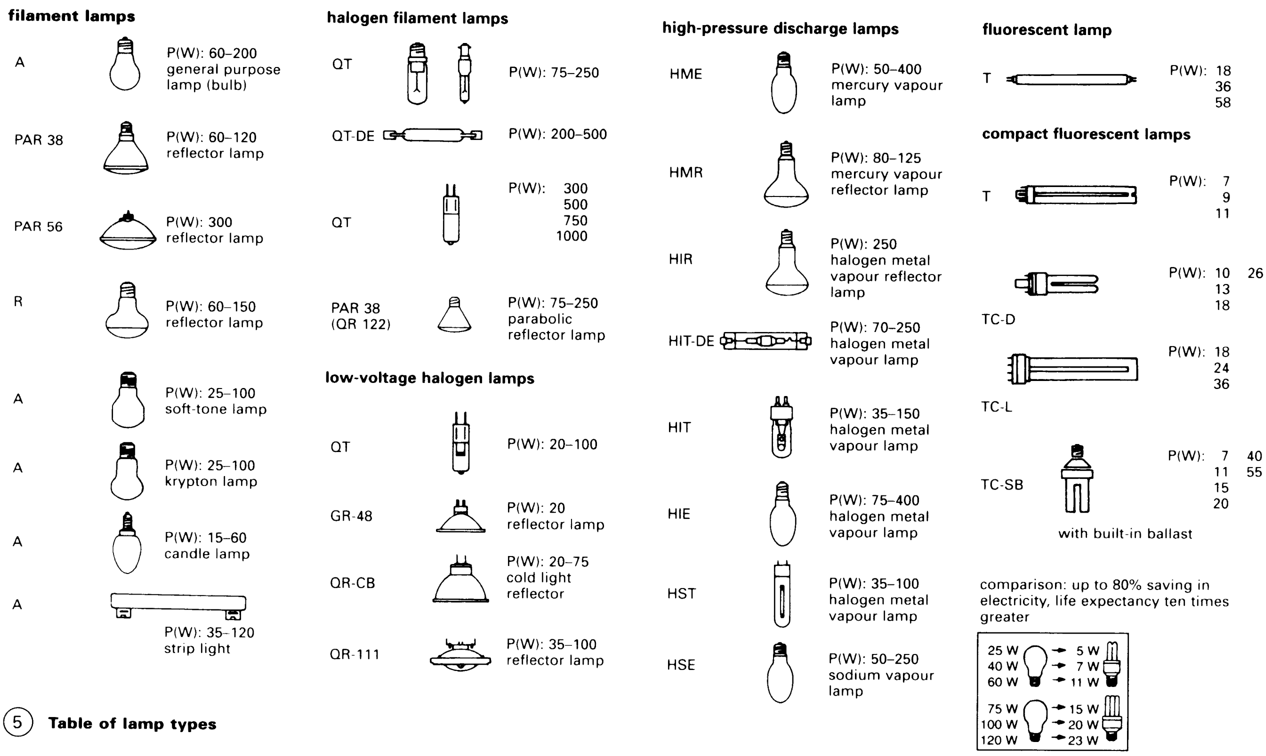
(2) **General lighting symbols for architectural plans**



(3) **Standard lighting symbols for architectural plans**



(4) **Diagrams of lamp types**



(5) **Table of lamp types**

Significant lighting parameters

The radiated power of light, as perceived by the eyes, is measured in terms of the luminous flux Φ. The luminous flux radiated per solid angle in a defined direction is referred to as the light intensity I. The intensity of a light source in all directions of radiation is given by the light intensity distribution, generally represented as a light intensity distribution curve (see following page). The light intensity distribution curve characterises the radiation of a light source as being narrow, medium or wide, and as symmetrical or asymmetrical.

The luminous flux per unit area is the lighting intensity or illuminance E. Typical values:

global radiation (clear sky)	max. 100000 lx
global radiation (cloudy sky)	max. 20000 lx
optimum sight	2000 lx
minimum in the workplace	200 lx
lighting orientation	20 lx
street lighting	10 lx
moonlight	0.2 lx

The lighting density L is a measure of the perceived brightness. For lamps it is relatively high and results in glare, which necessitates shielding for lights in indoor areas. The lighting density of room surfaces is calculated using the lighting intensity E and the degree of reflection.

Lamps

Lamps convert electrical power (W) into luminous power (lumen, lm). The light yield (lm/W) is a measure of efficiency.

For internal room lighting, filament and discharge lamps are used → (4).

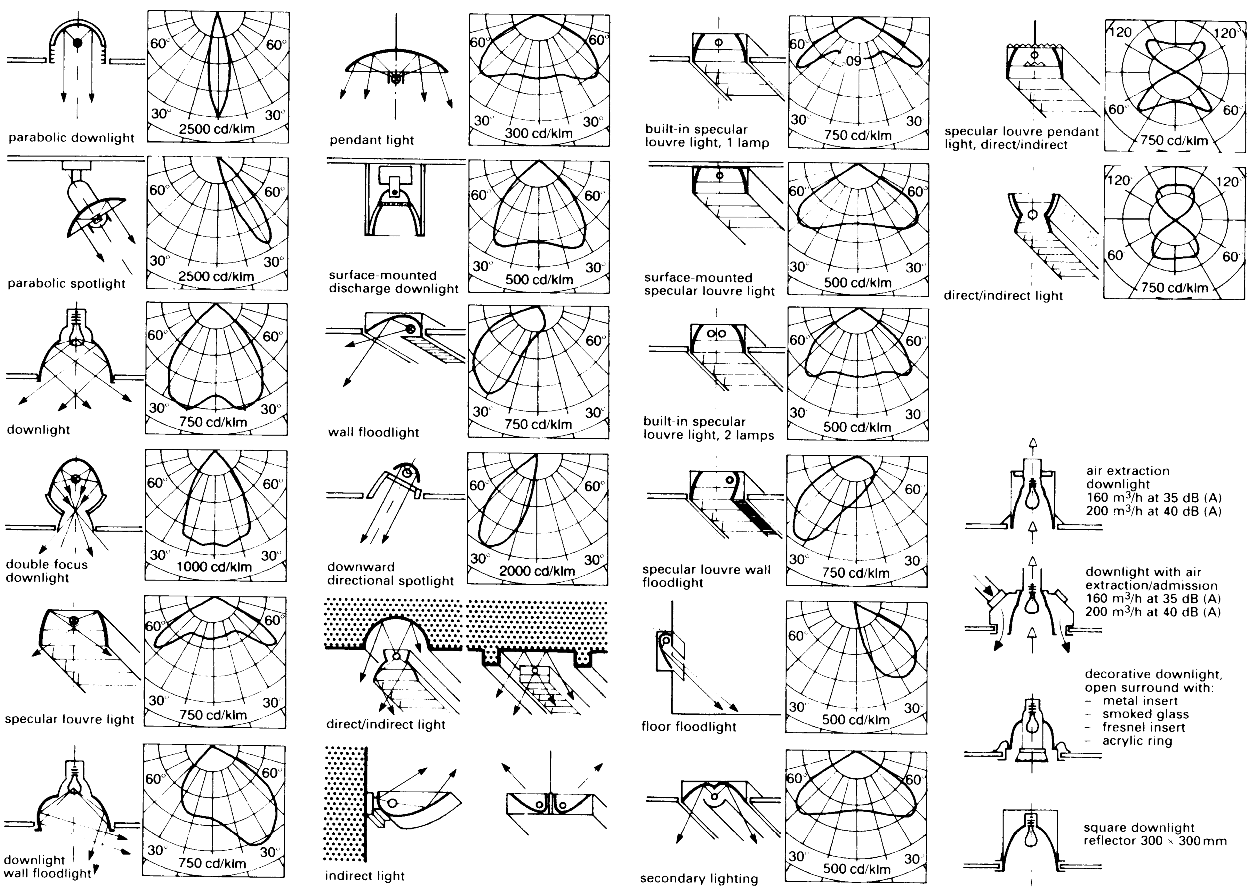
Filament lamps typically provide warm white light that is flicker-free, can be dimmed without restriction and give very good colour rendering. They offer high lighting intensity, particularly in the case of halogen bulbs, and their compact size allows small lighting outlines and very good focusing characteristics (e.g. spotlights). However, filament lamps also have a low lighting efficiency (lm/W) and a relatively short bulb life of between 1000 and 3000 hours.

Discharge lamps usually operate with a ballast device, and sometimes an ignition system, and offer high lighting efficiency with relatively long life (between 5000 and 15000 hours). The colour of the light depends on the type of lamp: warm white, neutral white or daylight white. Colour rendering is moderate to very good, but it is only possible to dim the lamps to a limited extent. Flicker-free operation can only be achieved by the use of an electronic ballast device.

LIGHTING: LAMPS AND FITTINGS

lighting type			flood lighting	spotlights	uplights	downlights	grid lighting: square grids	grid lighting: rectangular grids
	A	general purpose lamp 60–200W		○		○		
	PAR, R	parabolic reflector lamp reflector lamp 60–300W		○		○		
	QT	halogen filament lamp 75–250W	○	○	○	○		
	QT–DE	halogen filament lamp, sockets both sides 100–500W	○		○			
	QT–LV	low-voltage halogen lamp 20–100W		○		○		
	QR–LV	low-voltage halogen reflector lamp 20–100W		○		○		
	T	fluorescent lamp 18–58W	○		○		○	○
	TC TC–D TC–L	compact fluorescent lamp 7–55W	○	○	○	○	○	○
	HME	mercury vapour lamp 50–400W				○		
	HSE/ HST	sodium vapour lamp 50–250W				○		
	HIT HIT-DE	halogen metal vapour lamp 35–250W	○	○	○	○		

(1) **Allocation of lamp types and lighting types**



(2) **Light fittings and light distribution**

LIGHTING: PROVISION

room height	nominal illuminance	area	A ≤ 100 W	A > 100 W	PAR 38	PAR 56	R	QT ≤ 250 W	QT – DE	QT > 250 W	QT – LV	QR – CB – LV	QR –LV	T	TC	TC – D	TC – L	HME ≤ 80 W	HME > 80 W	HSE	HST	HIT – DE ≤ 70 W	HIT – DE > 70 W	HIT ≤ 70 W	HIT > 70 W	HIE
up to 3 m	up to 200 Lux	garage car parks, packing rooms												●				●		●	●					
		service rooms												●	●	●	●			●	●					
		workshops												●												
		restaurants	●				●				●	●	●													
		foyers	●	●	●						●	●			●	●										
	up to 500 Lux	standard offices, classrooms/lecture rooms, counters and cash desks												●		●	●									
		sitting rooms	●	●							●	●		●	●	●	●									
		workshops												●				●	●							
		libraries						●						●			●									
		sale rooms									●	●		●	●	●	●						●		●		
		exhibition rooms			●						●			●	●	●	●	●					●		●		
		museums, galleries, banqueting rooms	●	●	●	●	●	●		●	●	●	●	●			●									
		entrance halls	●	●				●			●			●	●	●	●									
	up to 750 Lux	data processing, standard offices with higher visibility requirements												●			●									
		workshops												●					●				●		●	
		shops												●			●	●								
		supermarkets												●												
		shop windows						●	●	●	●	●	●										●	●	●	●	
		hotel kitchens												●			●									
		concert stages				●		●	●																	
		drawing offices, large offices												●												
3 m up to 5 m	up to 200 Lux	storage rooms												●				●	●	●	●					
		workshops												●				●								
		industrial workshops												●				●		●	●	●		●		
		foyers	●	●	●						●				●	●										
		restaurants	●				●				●	●	●		●	●										
		churches	●	●	●			●								●										
		concert halls, theatres	●	●				●																		
	up to 500 Lux	workshops												●					●				●		●	
		industrial workshops												●					●				●		●	
		lecture halls, meeting rooms		●				●						●			●									
		sale rooms												●		●	●	●					●		●	
		exhibition rooms, museums, art galleries		●	●	●	●	●	●	●				●		●	●									
		entrance halls		●	●	●		●						●	●	●	●						●		●	
		restaurants														●	●									
		sports halls, multipurpose halls and gymnasiums						●						●					●				●		●	●
	up to 750 Lux	workshops												●				●	●				●		●	●
		art rooms												●			●									
		laboratories												●												
		libraries, reading rooms						●						●			●									
		exhibition rooms												●			●		●				●		●	●
		exhibition halls																	●							●
		shops												●			●						●		●	●
		supermarkets												●												
		large kitchens												●												
		concert stages			●	●		●	●																	
over 5 m	up to 200 Lux	industrial workshops, machine rooms, switchgear installations												●					●	●	●					●
		rooms for racked storage systems												●					●							
		churches		●		●		●																		
		concert halls, theatres		●		●		●																		
	up to 500 Lux	industrial workshops												●					●				●		●	●
		museums, art galleries				●		●						●			●									
		airports, railway stations, circulation zones												●			●		●	●	●		●		●	●
		banqueting halls				●		●																		
		sports and multipurpose halls						●						●									●		●	●
	up to 750 Lux	industrial workshops																	●	●	●					●
		auditoriums, lecture halls						●						●			●									
		exhibition rooms							●					●			●						●		●	●
		exhibition halls																	●				●		●	●
		supermarkets												●					●				●		●	●

A = general purpose lamps
PAR = parabolic reflector lamps
R = reflector lamps
QT = halogen filament lamps
QT – DE = halogen filament lamps, 2 sockets
QT – LV = low-voltage halogen lamps
QR – LV = low-voltage reflector lamps
QR – CB – LV = low-voltage reflector lamps, cold light
T = fluorescent lamps
TC = compact fluorescent lamps
TC – D = compact fluorescent lamps, 4 tubes
TC – L = compact fluorescent lamps, long
HME = mercury vapour lamps
HSE = sodium vapour lamps
HST = sodium vapour lamps, tubular
HIT = halogen metal vapour lamps
HIE = halogen metal vapour lamps, elliptical

(1) **Provision of lighting for internal areas**

LIGHTING: ARRANGEMENT

Forms of Lighting for Internal Areas

Direct, symmetrical lighting → ① is preferred for all general illumination of work rooms, meeting rooms, rooms in public use and circulation zones. The required level of illumination can be achieved with relatively little electrical power: standard values for specific loadings are given on p. 147. When designing a lighting system, an angle of illumination between 70° and 90° should be tried first.

Downlights (wall floods, louvre lighting) → ② can provide uniform wall illumination while the effect on the rest of the room is that of direct lighting. Wall floods on a power supply rail → ③ can also give uniform wall illumination over the required area, depending on the separation between the lamp and the wall; up to 500 lx can be achieved. Fluorescent lamps and halogen filament lamps can also be used.

Wall floods for ceiling installation → ④ can be sited so as to provide low room light or illumination of one wall. These can also make use of halogen filament lamps and fluorescent lamps.

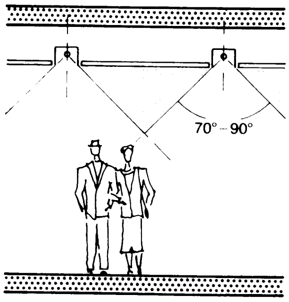
Downlighting with directed spotlights → ⑤ using a regular arrangement of lamps on the ceiling and swivelling reflectors can give different lighting levels in the room. Halogen filament lamps are most suitable, in particular those with low-voltage bulbs.

Indirect lighting → ⑥ can give an impression of a bright room free of glare even at low lighting levels, although the room must be sufficiently high and careful ceiling design is needed to give the required luminance. Energy consumption in this form of lighting is up to three times higher than for direct lighting so combinations are often used (e.g. 70% direct, 30% indirect) providing the room height is adequate (h≥3 m) → ⑦. Fluorescent lamps are usually used in direct/indirect lighting, but they may also be combined with filament lamps.

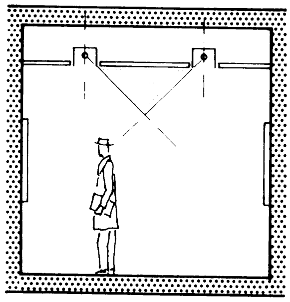
Ceiling and floor floods → ⑧ - ⑨ are employed to illuminate ceiling and floor surfaces. They usually use halogen filament or fluorescent lamps, although high-pressure discharge lamps are also a possibility.

Wall lights → ⑩ are principally used for decorative wall lighting and can also incorporate special effects (e.g. using colour filters or prisms). To a limited extent, they can also be used for the illumination of ceilings or floors.

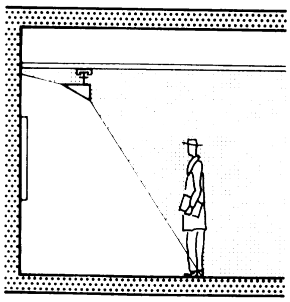
Wall floodlights and spotlights on power supply rails → ⑪ - ⑫ are particularly useful in sale rooms, exhibitions, museums and galleries. With wall floodlights, typical requirements are for vertical illumination levels of 50 lx, 150 lx or 300 lx; filament and fluorescent lamps are usually preferred. For spotlights, the basic light emission angles are 10° ('spot'), 30° ('highlight') and 90°('flood'). The angle of the light cone can be varied by passing the light through lenses (sculptured lenses, Fresnel lenses), and the spectrum of the light can be varied using UV and IR filters and colour filters. Shading can be arranged by means of louvres and anti-glare flaps.



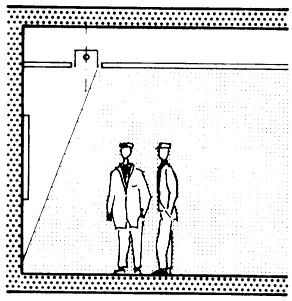
① Direct symmetrical illumination



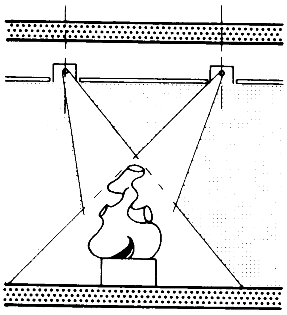
② Wall flood; direct illumination



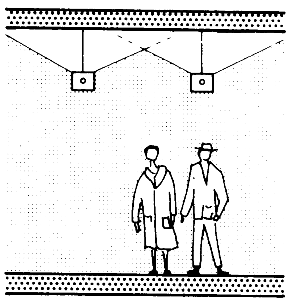
③ Wall flood on a power supply rail; partial room illumination



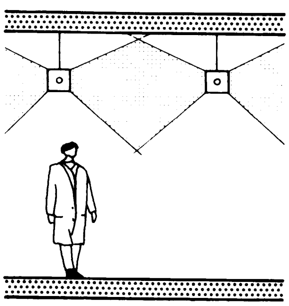
④ Wall floodlight



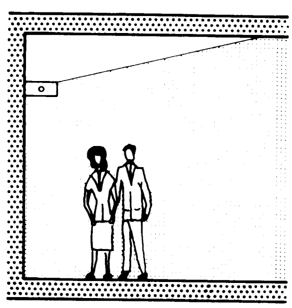
⑤ Directional spotlights



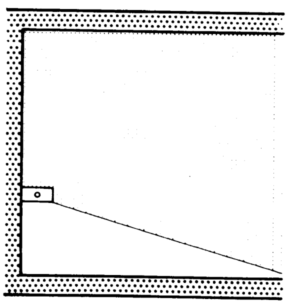
⑥ Indirect lighting



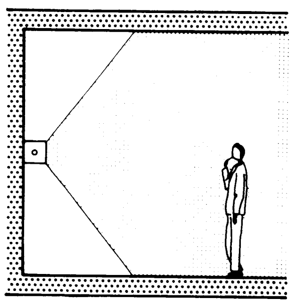
⑦ Direct/indirect lighting



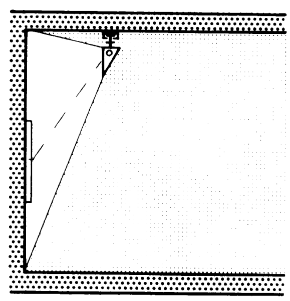
⑧ Ceiling floodlighting



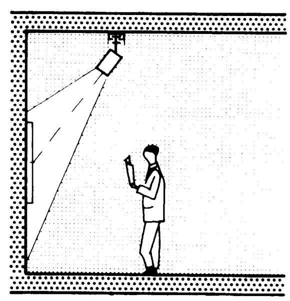
⑨ Floor floodlighting



⑩ Wall light; direct/indirect lighting



⑪ Wall flood on power supply rail



⑫ Spotlight on power supply rail

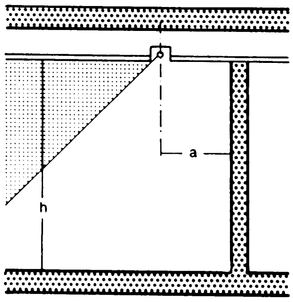
LIGHTING: ARRANGEMENT

Geometry of Lighting Arrangements

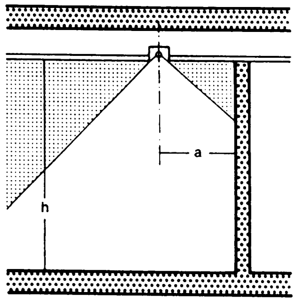
The spacing between light fittings and between the light fittings and the walls depends on the height of the room → ①-④.

The preferred incidence at which light strikes objects and wall areas is between 30° (optimum) and 40° → ⑤-⑨.

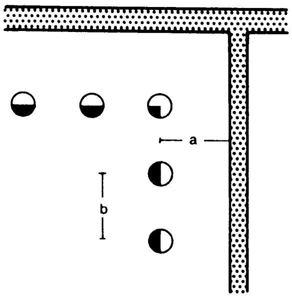
The shading angle of downward lighting lies between 30° (wide-angle lighting, adequate glare control) and 50° (narrow-angle lighting, high glare control) → ⑩, and between 30° and 40° in the case of louvred lighting.



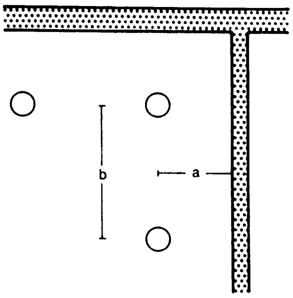
① **Downlight/wall floodlight, distance from wall: a ≈ 1/3h**



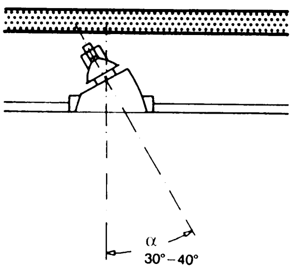
② **Downlight, distance from wall: a ≈ 1/3h**



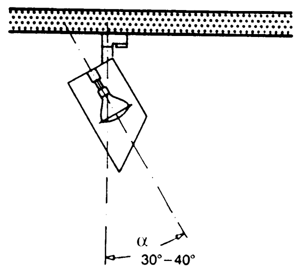
③ **Downlight/wall floodlight, separation between lights: b = 1–1.5a**



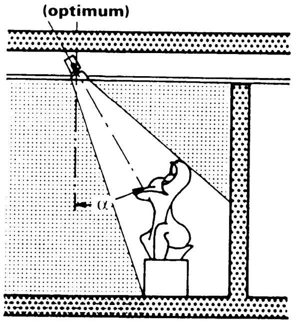
④ **Downlight, separation between lights: b ≈ 2a**



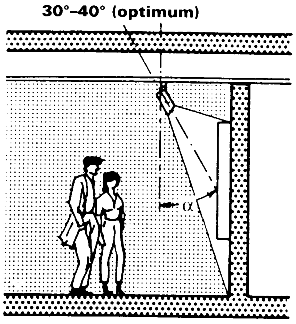
⑤ **Angle of inclination of directional spotlights and floodlights: α = 30°–40° (optimum)**



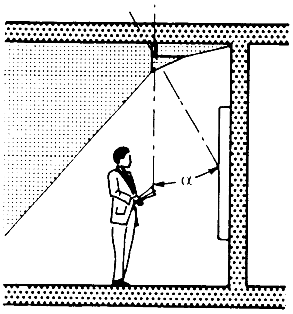
⑥ **Angle of inclination of spotlights illuminating objects and walls: α = 30°–40° (optimum)**



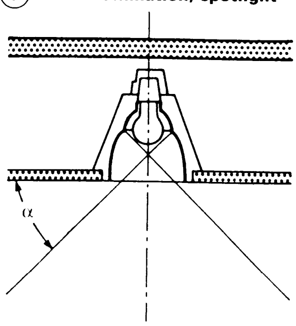
⑦ **Illumination of objects**



⑧ **Wall illumination, spotlight**



⑨ **Wall illumination, floodlight**



⑩ **Shading angle (= 30°/40°/50°)**

20 lx	necessary for the recognition of critical features. 20 lx is the minimum value of horizontal illuminance for internal areas, except work areas
200 lx	work areas appear dull with illuminance E < 200 lx, therefore 200 lx is the minimum value of illuminance for continually occupied work areas
2000 lx	2000 lx is recommended as the optimum illuminance for work areas
	the lowest perceptible change in illuminance is by factor of 1.5; therefore, the gradation of nominal illuminance levels for internal areas is: 20, 30, 50, 75, 100, 150, 200, 300, 500, 750, 1000, 1500, 2000 etc.

⑪ **Range of illuminance values for internal areas**

recommended illuminance			area/activity
20	30	50	paths and work areas in the open air
50	100	150	for orientation in rooms for short-stay periods
100	150	200	for work areas not in constant use
200	300	500	for visual tasks of little difficulty
300	500	750	for visual tasks of moderate difficulty
500	750	1000	for visual tasks with higher demands, e.g. office work
750	1000	1500	for visual tasks of great difficulty, e.g. fine assembly work
1000	1500	2000	for visual tasks of considerable difficulty, e.g. inspection
over 2000			additional lighting for difficult and special visual tasks

⑫ **Recommended illuminance values in accordance with CIE (Commission International de l'Eclairage)**

identifying letters: IP	example IP 44
first identifying digit 0 – 6	degree of protection against contact and foreign bodies
second identifying digit 0 – 8	degree of protection against ingress of water

first digit	area of protection
0	no protection
1	protection against large foreign bodies (>50 m)
2	against medium-sized foreign bodies (>12 mm)
3	against small foreign bodies (<2.5 mm)
4	against granular foreign bodies (<1 mm)
5	against dust deposits
6	against entry of dust

first digit	area of protection
0	no protection
1	protection against vertical drops of water
2	against drops of water at an incidence of up to 15°
3	against water splashing
4	against water spraying
5	against water jets
6	against ingress of water due to flooding
7	against dipping in water
8	against immersion in water

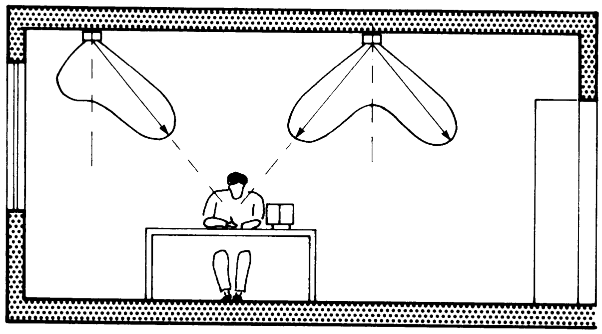
⑬ **Types of protection required for lighting**

stage	index Ra	typical areas of application
1A	> 90	paint sampling, art galleries
1B	90 > RA > 80	living accommodation, hotels, restaurants, offices, schools, hospitals, printing and textile industry
2A 2B	80 > RA > 70 70 > RA > 60	industry
3	60 > RA > 40	industrial and other areas with low demands for colour rendering
4	40 > RA > 20	ditto

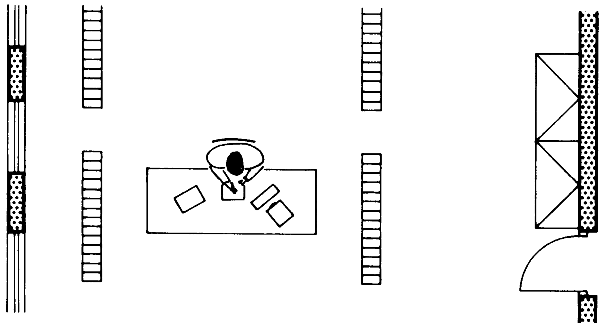
⑭ **Colour reproduction of lamps**

LIGHTING: ARRANGEMENT

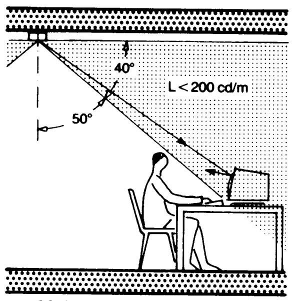
Lighting Quality Characteristics



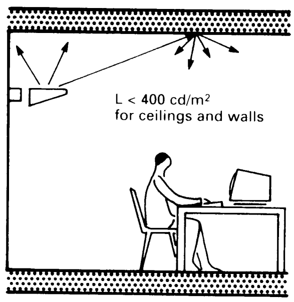
① Correct arrangement of lights in relation to work position: light from the side



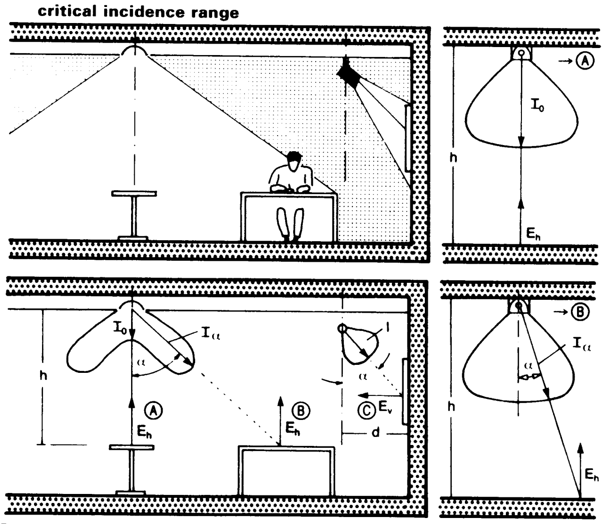
② Working surfaces, monitor screens, keyboards and paper should have matt surfaces



③ Lights which can generate reflections should have low luminance levels in the critical incidence range



④ Luminance of indirect lighting

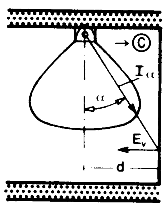


⑤ Illuminance at a point

Ⓐ $E_h = \frac{I_0}{h^2}$

Ⓑ $E_h = \frac{I_\alpha}{h^2} \cdot \cos^3\alpha$

Ⓒ $E_v = \frac{I_\alpha}{d^2} \cdot \cos^3(90-\alpha)$



⑥ Photometric distance principle

Any good lighting design must meet functional and ergonomic requirements while taking cost-effectiveness into account. In addition to the following quantitative quality criteria, there are qualitative, in particular architectural, criteria which must be observed.

Level of illumination

A mean level of between 300 lx (individual offices with daylight) and 750 lx (large rooms) is required in work areas. Higher illumination levels can be achieved in uniform general lighting through the addition of lighting at workplace positions.

Light direction → ①

Ideally, light should fall on a working position from the side. The prerequisite for this is a wing-shaped light distribution curve (p. 142).

Limitation of glare → ②–③

Direct glare, reflected glare and reflections from monitor screens should all be limited. Limiting direct glare is achieved by using lights with shading angles ≥ 30°.

Limiting reflected glare is achieved by directing light from the side onto the working position, in conjunction with the use of matt surfaces on the surrounding areas. → ②.

Limiting reflections from monitor screens requires the correct positioning of the screen. Lighting which nevertheless still reflects on a screen must have a luminance of ≤ 200 cd/m² in these areas.

Distribution of luminance

The harmonic distribution of luminance is the result of a careful balance of all the degrees of reflection in the room → ⑦. Luminance due to indirect lighting must not exceed 400 cd/m².

Colour of light and colour rendering

The colour of the light is determined by the choice of lamp. A distinction is made between three types: warm white light (colour temperature under 3300 K), neutral white light (3300–5000 K) and white daylight (over 5000 K). In offices, most light sources are chosen in the warm white or neutral white ranges. For colour rendering, which depends on the spectral composition of the light, stage 1 (very good colour rendering) should generally be sought.

Calculation of point illuminance levels → ⑥

The illuminance levels (horizontal E_h, vertical E_v), which are generated by individual light sources, can be determined from the luminous intensity and the spatial geometry (height h, distance d and light incidence angle α) using the photometric distance principle.

	reflection factor (%)		reflection factor (%)
lighting materials			
aluminium, pure, highly polished	80 to 87	plaster, light	40 to 45
aluminium, anodised, matt	80 to 85	plaster, dark	15 to 25
aluminium, polished	65 to 75	sandstone	20 to 40
aluminium, matt	55 to 76	plywood, rough	25 to 40
aluminium coatings, matt	55 to 56	cement, concrete, rough	20 to 30
chrome, polished	60 to 70	brick, red, new	10 to 15
vitreous enamel, white	65 to 75	**paints**	
lacquer, pure white	80 to 85	white	75 to 85
copper, highly polished	60 to 70	light grey	40 to 60
brass, highly polished	70 to 75	medium grey	25 to 35
nickel, highly polished	50 to 60	dark grey	10 to 15
paper, white	70 to 80	light blue	40 to 50
silvered mirror, behind glass	80 to 88	dark blue	15 to 20
silver, highly polished	90 to 92	light green	45 to 55
other materials		dark green	15 to 20
oak, light, polished	25 to 35	light yellow	60 to 70
oak, dark, polished	10 to 15	brown	20 to 30
granite	20 to 25	light red	45 to 55
limestone	35 to 55	dark red	15 to 20
marble, polished	30 to 70		

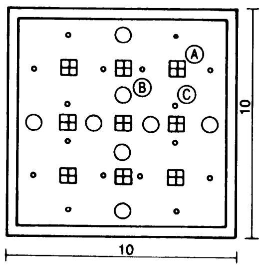
⑦ Reflection factors for various materials

specific connected load P* W/m² for 100 lx for height 3 m, area > 100 m² and reflection 0.7/0.5/0.2	
A	12 W/m²
QT	10 W/m²
HME	5 W/m²
TC	5 W/m²
TC-L	4 W/m²
T26	3 W/m²

① **Specific connected load P* for various lamp types**

correction factor k				
height H	area A(m²)	reflection factor 070502	050201	000
		bright	medium	dark
up to 3 m	20	0.75	0.65	0.60
	50	0.90	0.80	0.75
	≥ 100	1.00	0.90	0.85
3–5 m	20	0.55	0.45	0.40
	50	0.75	0.65	0.60
	≥ 100	0.90	0.80	0.75
5–7 m	50	0.55	0.45	0.40
	≥ 100	0.75	0.65	0.60

② **Table of correction factors**

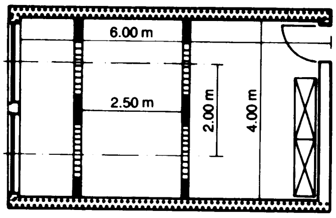


③ **Calculation of illuminance for internal areas**

example
room area A = 100 m²
room height H = 3 m
reflection factor 0.5/0.2/0.1 (medium reflection)
type of light
P* = 4 W/m² · (compact fluorescent lamp)
P* = 9 · 45 W = 405 W
type of light
P* = 12 W/m² · (general purpose lamp)
P* = 8 · 100 W = 800 W
type of light
P* = 10 W/m² · (halogen filament lamp)
P* = 16 · 20 W = 320 W
formula

$$E_n = \left(\frac{100 \cdot 405}{100 \cdot 4} + \frac{100 \cdot 800}{100 \cdot 12} + \frac{100 \cdot 320}{100 \cdot 10}\right) \cdot 0.9$$

E_n = 180 lx

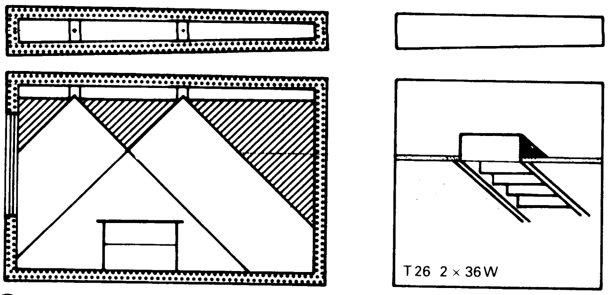


A = 24 m²
K = 0.75 (bright reflection)
P = 4 · 90 W = 360 W

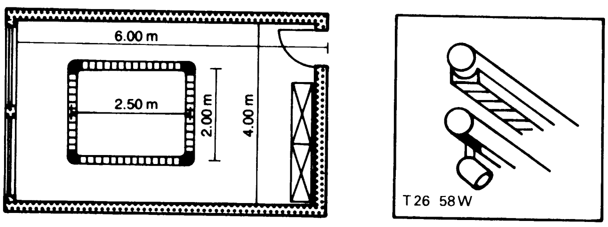
$$E_n = \frac{100 \cdot 4 \cdot 90}{24.3} \cdot 0.75$$

E_n = 375 lx

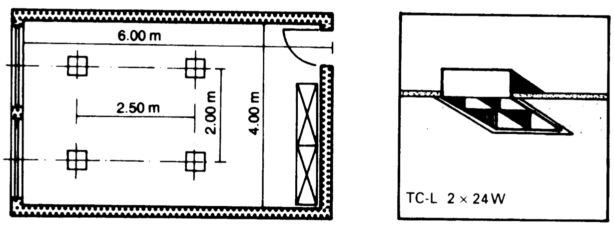
④ **Calculation for offices**



⑤ **Built-in louvred lighting**



⑥ **Structured lighting**



⑦ **Built-in louvred lighting**

Calculation of mean illuminance

In practice, it is often necessary to obtain an estimate of the mean intensity of illuminance (E_n) for a given level of electrical power supplied, or the electrical power P required for a given level of illumination. E_n and P can be estimated from the formula in → ⑧. The specific power P* required for this calculation depends on the type of lamps used → ①, and relates to direct illumination. The correction factor k depends on the size of the room and the reflection levels of the walls, ceiling and floor → ②.

If the calculation is to be made for rooms with different types of lighting, the components are calculated individually and then added together → ③.

Calculation of the illumination using the specific power is also applicable to offices. In the example, a rectangular room with an area of 24 m² is equipped with 4 lights. From → ⑧, with 2 × 36 W lamps (connected value, including 90 W ballast), an illuminance of ca. 375 lx is achieved.

In offices, in addition to conventional louvred mirror lighting, square louvred lighting with compact fluorescent lamps → ⑦, or structured lighting → ⑥, are frequently installed. Lighting structures use a combination of power supply rails to carry spotlights.

Floodlighting buildings

The luminous flux required for lamps used to floodlight a building can be calculated from the formula in → ⑨. The luminance should be between 3 cd/m² (free-standing objects) and 16 cd/m² (objects in very bright surroundings).

$$E_n = \frac{100 \cdot P}{A \cdot P^*} \cdot k$$

$$P = \frac{E_n \cdot P \cdot P^*}{100} \cdot \frac{1}{k}$$

E [illegible]

E_n nominal illuminance (lx)
P connected load (W)
P* specific connected load (W/m²) → ①
A room floor area
k correction factor → ②

⑧ **Formula for mean illuminance E_n and connected load P**

calculation formula for luminous flux

$$\Phi = \frac{\pi \cdot L \cdot A}{\eta_B \cdot \varrho}$$

luminance for a floodlit object	(cdm²) L
free standing	3 – 6.5
dark surroundings	6.5 – 10
moderately bright surroundings	10 – 13
very bright surroundings	13 – 16

lighting efficiency factor object	η_B
large area	0.4
small area	
large distance	0.3
towers	0.2

Φ = luminous flux required
L = mean luminance (cd/m²)
A = surface to be floodlit
η_B = lighting efficiency factor
ϱ = reflection factor for the material

level of reflection from illuminated materials	ϱ
brick, white vitrified	0.85
white marble	0.6
plaster, light	0.3–0.5
plaster, dark	0.2–0.3
light sandstone	0.3–0.4
dark sandstone	0.1–0.2
light brick	0.3–0.4
dark brick	0.1–0.2
light wood	0.3–0.5
granite	0.1–0.2

⑨ **Luminous flux required for floodlighting**

LIGHTING: REQUIREMENTS

		warm white					neutral white				daylight white			
light colours (Philips)	76	29	827	927	830	930	25	33	840	940	950	865	965	54
colour rendering level		3	1B	1A	1B	1A	2A	2B	1B	1A	1A	1B	1A	2A
sales areas														
foodstuffs			●		X				X					
meat	X								X					
textiles, leather goods				X	●	X			●	X				
furniture, carpets			X	X	X	X								
sports, games, paper goods					X				X					
photography, watches, jewellery					X	●			X	●				
cosmetics, hairdressing			●	X	●	X			●	X				
flowers	●					X				X				X
bakery goods			X											
refrigerated counters, chests			X											
cheese, fruit, vegetables			X											
fish			X											
department stores, supermarkets			X	X	X				X	X				
trade and industry														
workshops							●		X					
machinery, electrical manufacture							●		X			X		
textile manufacture									X			X		
printing, graphic trades									●	X	X	●	X	
paint shops											X		X	
varnishing shops									X		●	X	●	
warehousing, dispatch								●	X					
plant growing														X
woodworking									X		X	X		
forging, rolling		●					●							
laboratories					X						X	X		
colour testing											X		X	
offices and administration														
offices, corridors					X				X					
meeting rooms			X		X									
schools, places of education														
lecture theatres, classrms, play schools					X				X					
libraries, reading rooms			X		X									
social spaces														
restaurants, pubs, hotels			X	X										
theatres, concert halls, foyers			X											
event spaces														
exhibition halls			X						X					
sports and multipurpose halls					X				X					
galleries, museums			X			X								
clinics, medical practices														
diagnosis and treatment						●				●				
wards, waiting rooms			●	X	●	X								
domestic														
living room			X			X								
kitchen, bathroom, workroom, cellar			X			X			X	X				
external lighting														
roads, paths, pedestrian areas		X						X						
illumination of signs														X

X = recommended ● = possible

(1) **The correct use of fluorescent lamps**

recommended lighting levels for working areas

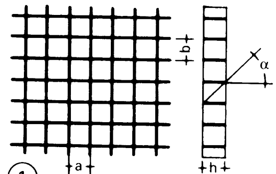
table of nominal levels of illuminance: standard values for working areas

type of area type of activity	(lx)
general rooms:	
circulation zones in storage buildings	50
storerooms	50
storerooms with access requirements	100
storerooms with reading requirements	200
gangways in storage racking systems	20
operating platforms	200
dispatch areas	200
canteens	200
break rooms	100
gymnasiums	300
changing rooms	100
washrooms	100
toilet areas	100
first-aid areas	500
machinery rooms	100
power supply installations	100
postrooms	500
telephone exchanges	300
circulation zones in buildings:	
for persons	50
for vehicles	100
stairs	100
loading ramps	100
offices, administration rooms:	
offices with workstations near windows	300
offices	500
open-plan offices	
- high reflection	750
- moderate reflection	1000
technical drawing	750
conference rooms	300
reception rooms	100
rooms for public use	200
data processing	500
chemical industry:	
facilities with remote controls	50
facilities with manual operations	100
continuously occupied technical processing facilities	200
maintenance facilities	300
laboratories	300
work requiring a high degree of visual acuity	500
colour testing	1000
cement industry, ceramics, glass works:	
working positions or areas at furnaces, mixers, pulverising plant	200
rollers, presses, forming operations	300
glass blowing, grinding, etching, glass polishing, glass instrumentation manufacture	500
decorative work	500
hand grinding and engraving	750
fine work	1000
iron and steel works, rolling mills, large foundries:	
automated production facilities	50
production facilities, manual work	100
continuously occupied work positions in production facilities	200
maintenance	300
control stations	500

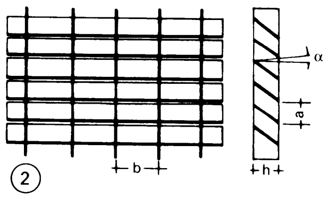
type of area type of activity	(lx)
metal processing/working:	
forging of small components	200
welding	300
large/medium machining operations	300
fine machining work	500
control stations	750
cold rolling mills	200
wire drawing	300
heavy sheet working	200
light sheet working	300
tool manufacture	500
large assembly work	200
medium assembly work	300
fine assembly work	500
drop forging	200
foundries, cellars, etc.	50
scaffolding, trestling	100
sanding	200
cleaning castings	200
work positions at mixers	200
casting houses	200
emptying positions	200
machine forming operations	200
manual forming operations	300
core making	300
model construction	500
galvanising	300
painting	300
control stations	750
tool assembly, fine mechanics	1000
motor body operations	500
lacquering	750
night-shift lacquering	1000
upholstery	500
inspection	750
power stations:	
charging equipment	50
boiler house	100
pressure equalising chambers	200
machine rooms	100
adjoining rooms	50
switchgear in buildings	100
external switchgear	20
control rooms	300
inspection work	500
electrical industry:	
manufacture of wire and cable, assembly work, winding thick wire	300
assembly of telephone equipment, winding medium-thick wire	500
assembly of fine components, adjustment and testing	1000
assembly of fine electronic components	1500
repair work	1500
jewellery and watchmaking:	
manufacture of jewellery	1000
preparation of precious stones	1500
optical and watchmaking workshops	1500
wood preparation and woodworking:	
steam treatment	100
saw mills	200
assembly	200
selection of veneers, lacquers, model woodworking	500
woodworking machinery	500
wood finishing	500
defect control	750

type of area type of activity	(lx)
paper manufacture and processing, printing:	
pulp factory	200
paper- and boardmaking machinery	300
book-binding, wallpaper printing	300
cutting, gilding, embossing, plate etching, work on blocks and plates, printing machines, stencil manufacture	500
hand printing, paper sorting	750
retouching, lithographics, hand and machine composition, finishing	1000
colour proofing in multicolour printing	1500
steel- and copper-plate engraving	2000
leather industry:	
vat operations	200
skin preparation	300
saddle making	500
leather dyeing	750
quality control, moderate demands	750
quality control, high demands	1000
quality control, extreme demands	1500
colour inspection	1000
textile manufacture and processing:	
work in dyeing vats	200
spinning	300
dyeing	300
spinning, knitting, weaving	500
sewing, material printing	750
millinery	750
trimming	1000
quality control, colour check	1000
foodstuffs industry:	
general work positions	200
mixing, unpacking	300
butchery, dairy work, milling	300
cutting and sorting	300
delicatessen, cigarette manufacture	500
quality control, decoration, sorting	500
laboratories	1000
wholesale and retail trades:	
salerooms, continuously occupied work positions	300
cashier's positions	500
trades (general examples):	
paint shops	200
pre-assembly of heating and ventilation equipment	200
locksmiths	300
garages	300
joinery	300
repair workshops	500
radio and television workshops	500
service operations:	
hotel and restaurant receptions	200
kitchens	500
dining rooms	200
buffet	300
lounges	300
self-service restaurants	300
laundries, washrooms	300
ironing machines	300
hand ironing	300
sorting	300
inspection	1000
hairdressers	500
beauty salons	750

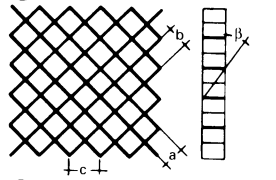
LIGHTING: REQUIREMENTS



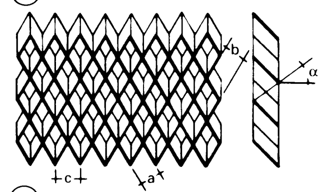
①



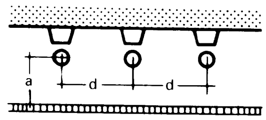
②



③



④



⑤

Lattice diffuser designs:

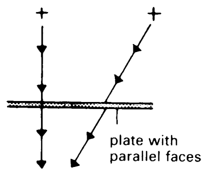
① **Parallel lattice**

② **Parallel slanting lattice**

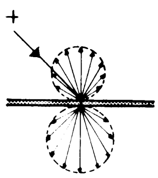
③ **Diagonal lattice**

④ **Diagonal slanting lattice**

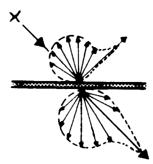
⑤ **Arrangement of lamps a ≥ 2/3d**



⑥ **Directional permeability of clear glass, showing displacement of slanting radiation**



⑦ **Scattered permeability of frosted glass, alabaster, etc.**



⑦ **Mixed permeability of ornamental glass, silk, light frosted glass, etc.**

material	scatter	thick-ness (mm)	reflec-tion (%)	permea-bility (%)	absorp-tion (%)
clear glass	none	2 – 4	6 – 8	90 – 92	2 – 4
ornamental glass	minimal	3.2 – 5.9	7 – 24	57 – 90	3 – 21
clear glass, frosted outside	minimal	1.75 – 3.1	7 – 20	63 – 87	4 – 17
clear glass, frosted inside	minimal	1.75 – 3.1	6 – 16	77 – 89	3 – 11
frosted glass: group 1	good	1.7 – 3.6	40 – 66	12 – 38	20 – 31
group 2	good	1.7 – 2.5	43 – 54	37 – 51	6 – 11
group 3	good	1.4 – 3.5	65 – 78	13 – 35	4 – 11
plated frosted glass: group 1	good	1.9 – 2.9	31 – 45	47 – 66	3 – 10
group 2	good	2.8 – 3.3	54 – 67	27 – 35	8 – 11
frosted glass, colour-plated					
red		2 – 3	64 – 69	2 – 4	29 – 34
orange		2 – 3	63 – 68	6 – 10	22 – 31
green		2 – 3	60 – 66	3 – 9	30 – 31
opaline glass	minimal	2.2 – 2.5	13 – 28	58 – 84	2 – 14
porcelain	good	3.0	72 – 77	2 – 8	2 – 21
marble, polished	good	7.3 – 10	30 – 71	3 – 8	24 – 65
marble, impregnated	good	3 – 5	27 – 54	12 – 40	11 – 49
alabaster	good	11.2 – 13.4	49 – 67	17 – 30	14 – 21
cardboard, impregnated	good		69	8	23
parchment, uncoloured	good		48	42	10
parchment, light yellow	good		37	41	22
parchment, dark yellow	good		36	14	50
silk, white	moderate		28 – 38	61 – 71	1
silk, coloured	moderate		5 – 24	13 – 54	27 – 80
cotton lining	good		rd.68	rd.28	rd.4
Formica, tinted	good	1.1 – 2.8	32 – 39	20 – 36	26 – 48
Pollopas, light colour	good	1.2 – 1.6	46 – 48	25 – 33	21 – 28
Perspex, white (frosted)	good	1.0	55	17	28
Perspex, yellow (frosted)	good	1.0	36	9	55
Perspex, blue (frosted)	good	1.0	12	4	84
Perspex, green (frosted)	good	1.0	12	4	84
mirror glass (plate)		6 – 8	8	88	4
wire-reinforced glass		6 – 8	9	74	17
crude glass		4 – 6	8	88	4
insulating glass (green)		2	6	38	56

⑨ **Relevant characteristics of materials permeable to light**

Fluorescent Tubes for Advertising Displays

Every type of text and arbitrary line styles can be reproduced using fluorescent tubes, including ornamental and figured representations. Control is simple using rheostats or regulating transformers. Fluorescent tubes are commonly used for cinemas, theatres, sales advertising and publicity. In offices and businesses, louvred or gridded ceilings may be installed under fluorescent tubes to provide predominantly downward lighting → ① – ⑤.

Strip-lights and elongated lighting panels allow soft uniform lighting to be achieved, which approximates daylight and has shadow effects.

High-pressure mercury vapour lamps with fluorescent gas are used for the illumination of factories and workshops as well as for external lighting.

Mixed-light lamps with fluorescent gas produce light similar to daylight, with good colour reproduction. These lamps have standard fittings, without a ballast device (e.g. general-purpose lamps).

Transparent and Translucent Materials

In determining the size, colour, window dimensions and lighting of a room, a knowledge of the translucence, scatter and reflected radiation of the materials to be used in the room is required. This is particularly important for effective artistic and economic design.

A distinction is made between materials which reflect light → ⑨ with direct, totally scattered or partially scattered return radiation, and translucent materials with direct → ① – ⑥, scattered → ⑦ or mixed translucence → ⑧.

Note: Frosted glass with inside surface frosting (preferred owing to fewer soiling problems) absorbs less light than the same glass with external surface frosting → ⑨.

Coloured silk lampshades with white linings which minimally reduce translucence absorb around 20% less light than those without linings and with greater translucence.

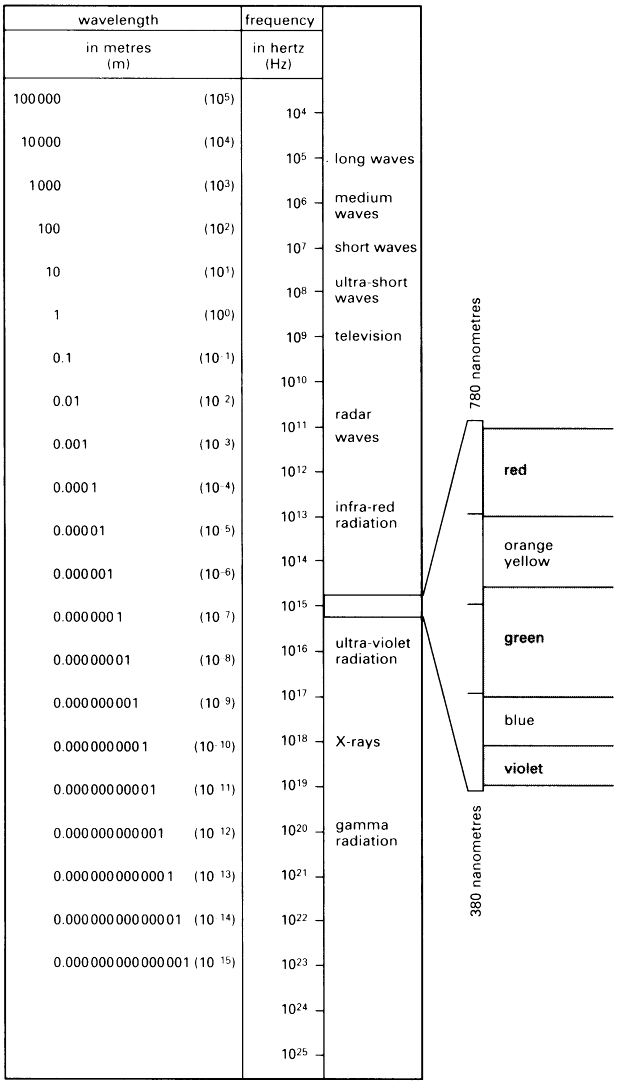
Daylight glass which filters electric light to simulate sunlight absorbs approximately 35% of the total light. Glass which comes close to copying the scattered light of the sky must absorb 60–80%.

Clear window glass is translucent to between 65 and 95% of light. If poor-quality clear glass is used, particularly in the case of double or triple glazing, so much light is absorbed that it is necessary to increase the window size. This increase is not compensated for by the improved thermal insulation of the multi-paned window assembly.

Sheet glass is made mechanically, and is ready for use without further processing. It is a clear, transparent glass which is colourless and uniformly thick. Both sides have even plane surfaces, and its transparency to light is 91–93%.

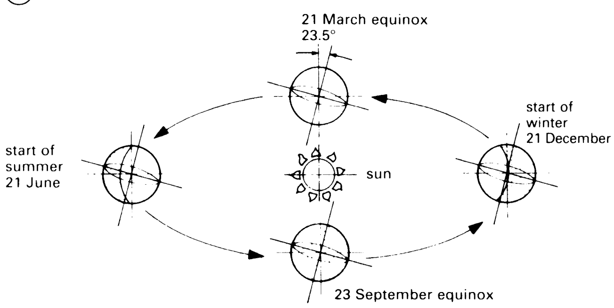
Classification: Type 1: Best commercial quality product for rooms (living accommodation, offices).
Type 2: Structural glass for factories, storerooms, cellars and glass floors.

Glass of one type only should be used for glazed items which are sited next to each other. Such applications include window glazing, shop windows, doors, dividing walls, furniture construction, laminated safety glass and double-glazing units. Further processing might entail polishing, etching, frosting, stoving, silvering, painting, bending or arching. Special-purpose glass, such as silvered glass, dry plate glass, glass for automobiles and safety glass, is made in all thicknesses (→ pp. 166–173).

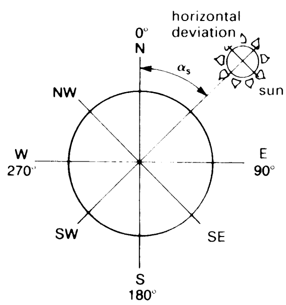


(1 nanometre = 1 × 10⁻⁹ metres)

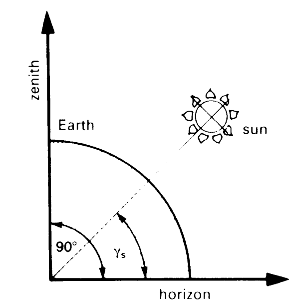
(1) **Spectrum of electromagnetic radiation**



(2) **Seasons of the year, northern hemisphere**



(3) **Azimuth (α_s)**



(4) **Angle of elevation (γ_s)**

DAYLIGHT

General requirements for daylight illumination of internal areas

All rooms which are to be used for permanent occupation must be provided with adequate natural light. In addition, appropriate visual links with the outside world must be safeguarded.

Light, wavelength, light colour

Within the electromagnetic spectrum → (1), visible light occupies a relatively small band, namely 380–780 nm. Light (daylight and artificial light) is the visible band of electromagnetic radiation between ultra-violet and infra-red. The spectral colours which occur in this range each have corresponding wavelengths, e.g. violet is short wave and red is long wave. Sunlight contains relatively more short-wave radiation than a filament lamp, which has more long-wave radiation, i.e. a greater red light component. However, daylight is perceived by the human eye as being white, apart from at sunrise and sunset, when it appears red.

The unit of measurement for illuminance (particularly artificial light) is the lux (lx). The level of daylight in rooms is given as a percentage (see later).

Astronomical fundamentals: position of the sun

The radiation and light sources which give rise to daylight are not constant. The sun is the 'primary light source' of daylight → (2) whatever the condition of the sky. The axis of inclination of the Earth (23.5°), the daily rotation of the Earth around its own axis and the rotation of the Earth around the sun over a period of 1 year determine the position of the sun as a function of the time of year and the day for each point on the surface of the Earth → (2).

The position of the Earth is defined by two angles: the azimuth, α_s, and the angle of elevation, γ_s. On a plan view → (3), the azimuth is the horizontal deviation of the position of the sun from 0°, where 0° = north, 90° = east, 180° = south and 270° = west as seen by the observer. On a vertical projection → (4), the angle of elevation is the position of the sun over the horizon as seen by the observer.

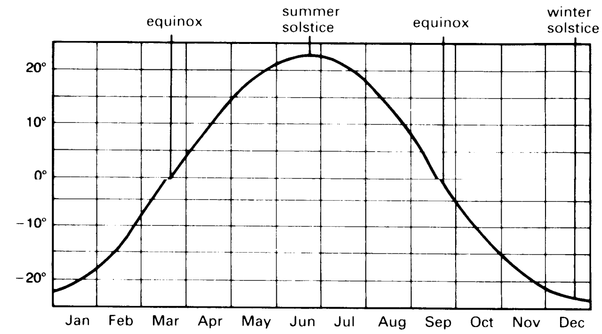
A number of measuring methods are used to determine the position of the sun at a given location, for example determination of the degree of latitude and the angle of elevation.

The declination of the sun during the annual cycle results in four main seasons in the year. The equinoxes are on 21 March and 23 September; this is when the declination of the sun is 0°. The winter solstice occurs on 21 December (the shortest day), when the declination of the sun is –23.5°; the summer solstice occurs on 21 June (the longest day), when the declination of the sun is +23.5° (see next page, → (5)).

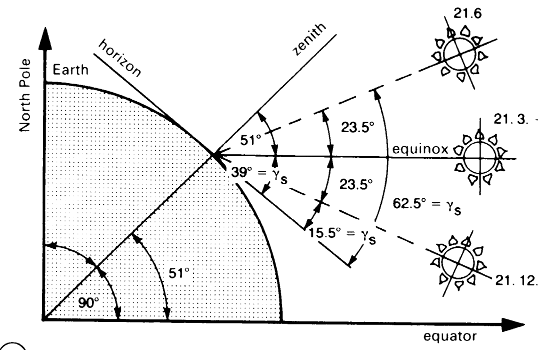
The position of the sun is given by the degree of latitude. On 21 March and 23 September, at 12.00 (α_s = 180°), the zenith angle of the sun at any latitude is of the same magnitude as the angle of latitude. For example, at 51° north (Brighton), the zenith angle at 12.00 (α_s = 180°) is 51° (see next page, → (6)). The angle of elevation of the sun above the horizontal is 90° – 51° = 39°.

On 21 June, at midday, 12.00 (α_s = 180°), the sun is 23.5° higher than on 21 March and 23 September: 39° + 23.5° = 62.5°. On the other hand, on 21 December the sun is 23.5° lower than at the equinox: 39° – 23.5° = 15.5°. These deviations are the same for all degrees of latitude.

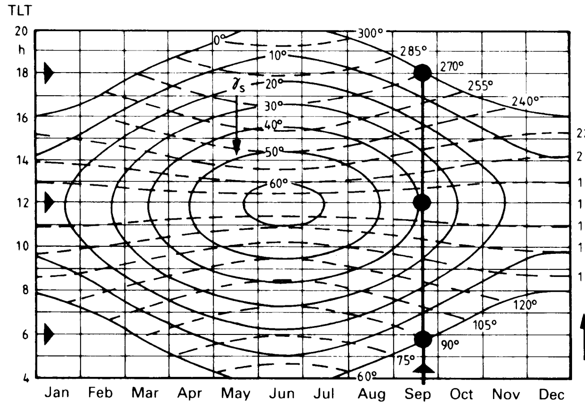
Thus, the angle of elevation of the sun, corresponding to the time of year, can be determined for all degrees of latitude.



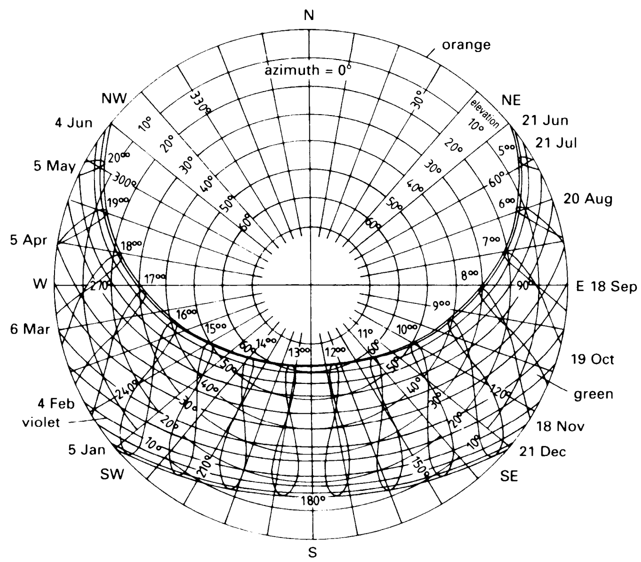
(5) **Annual variation of the declination of the sun**



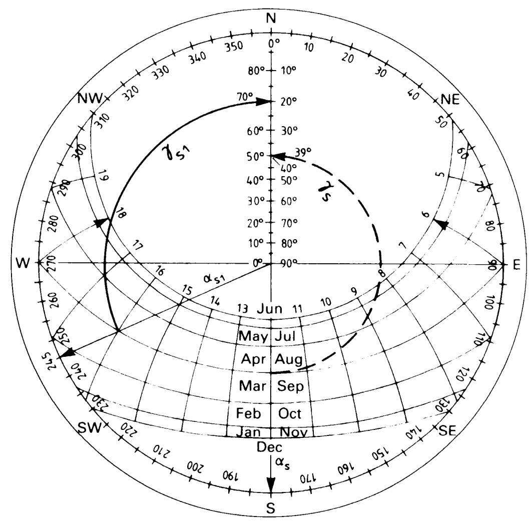
(6) **Degree of latitude and angle of elevation γ_s**



(7) **Solar azimuth α_s and solar elevation γ_s at 51° latitude (English south coast: Southampton, Brighton) as a function of time of year and time of day**



(8) **Solar position chart for latitude 49°52′N, longitude 8°39′, time reference meridian: longitude 15°00′**



(9) **Stereographic projection of the path of the sun, e.g. for latitude 51° on 21 March and on 23 September: sunrise at 6.00, sunset at 18.00, γ_s = 39° at 12.00**

Solar position diagrams

An example is shown of a solar position diagram for 51°N → (7). The diagram shows the plan projection of the position of the sun, in terms of azimuth and elevation, at true local time, e.g. for Brighton on 23 September, sunrise is at 6.00 at α_s = 90° (east); on the same date at 12.00, α_s = 180° (south) and the elevation angle is 39°; sunset is at 18.00, α_s = 270°, on the same day.

To determine the local course of the sun, a coloured solar position chart is used → (8). The chart contains the plan projection of the azimuth α_s and the angle of elevation γ_s of the sun as a function of time of year and time of day for the appropriate angle of latitude and reference meridian.

In order to determine the position of the sun, loop-shaped curves are given for each hour of the day. In these, violet is used for the first half of the year and green for the second. The looped shape of the hourly curves is attributable to the elliptical path of the Earth and the inclination of the ecliptic. The times shown relate to the given time reference meridian, i.e. to the time zone of the location in question.

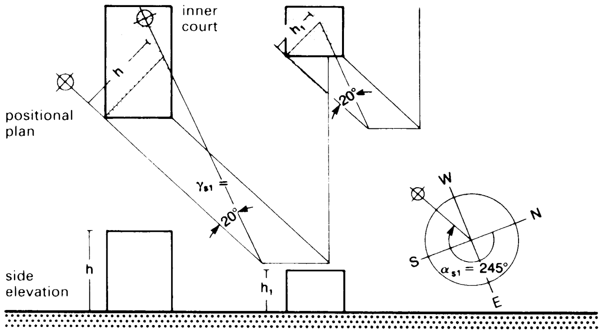
The intersection points of the daily curves with hourly curves of the same colour mark the position of the sun at any hour of the day. On the orange coloured polar diagram, the position of the sun can be read off as an angle of direction of the sun (azimuth) and angle of elevation of the sun (height) → (8).

Projection of the solar path

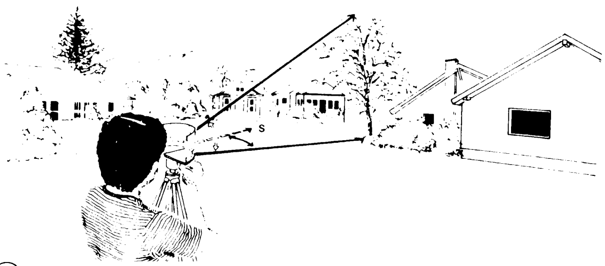
By using a stereographic projection → (9), the path of the sun can be determined for each degree of latitude (for the 21st day of each month) as a function of time of year and time of day.

Solar position, clock time and determination of time

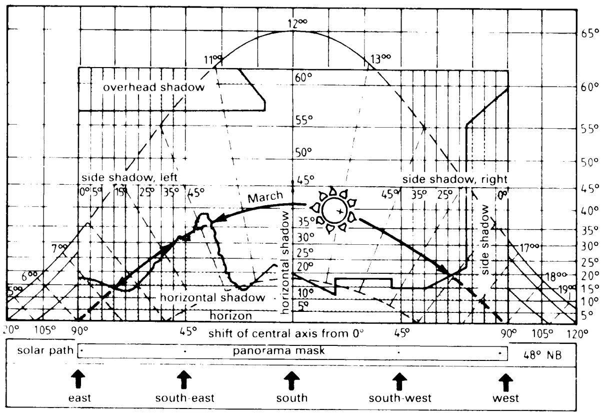
The position of the sun determines the daylight conditions according to the time of day and time of year. The true local time (TLT) is the usual reference for time of day (e.g. in the solar position charts) in determining daylight. Each location is allocated to a time zone, within which the same time (zone time) applies. If the time zone input is of interest, then the TLT must be converted to the appropriate time zone.



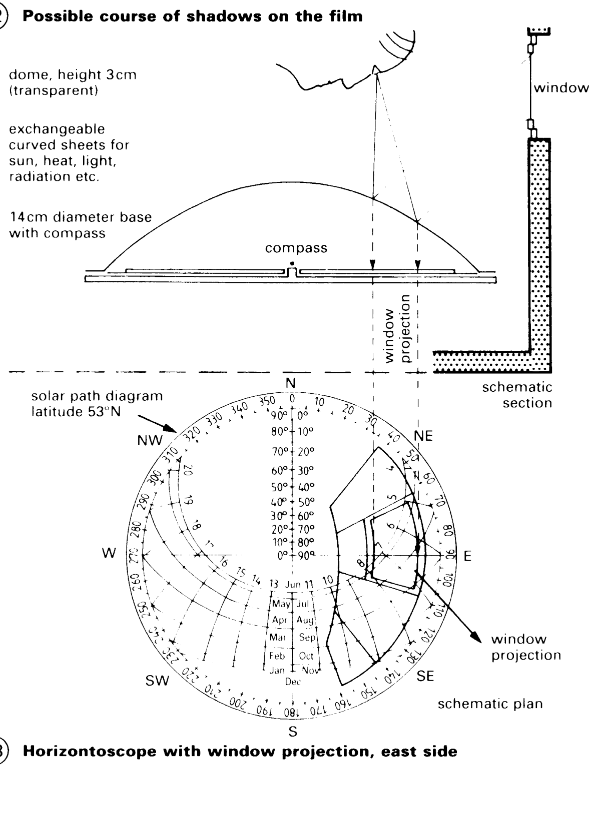
(10) **Graphical shadow construction**



(11) **Panorama mask (curved) in position**



(12) **Possible course of shadows on the film**



(13) **Horizontoscope with window projection, east side**

Position of the sun: shadows, methods employed

The following methods are employed to determine and verify the actual solar radiation and shadow, both inside and outside buildings, as a function of geographical location, time of year and time of day, structural features and surrounding conditions.

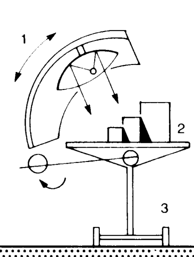
Graphical construction of shadows. Determination of the shadows cast by a building can be accomplished using the projected (apparent) course of the sun, represented in → (9) (see previous page), by means of a plan and an elevation. As an example, the shadows in a courtyard in Brighton, latitude 51°N, will be constructed for 21 March, at 16.00. The sun appears at this time at an azimuth angle (α_{s1}) of 245° and an elevation (γ_{s1}) of 20° → (9) + (10). The positional plan is orientated with the north. The directions of the shadows are determined by the horizontal edges of the building, that is, a parallel shift of the direction of the sunshine (α_{s1} = 245°) due to the corners of the building. The length of the shadow is determined by the vertical edges of the building, that is, a rotation of the true height of the building (h) and application of the elevation angle of 20°. The point of intersection with the direction of the shadow gives the length of the shadow.

Panorama mask. In many countries, a representation of the path of the sun is available for various geographical areas. These representations are printed on clear film, and include data on azimuth and elevation angles, as well as time of year and time of day. In use, a copy of the relevant sheet is bent in a curve and positioned in the direction of the sun → (11). By looking through the panorama mask, any encroachment of shadows from the surroundings and from overhead shadows is transferred to the printed path of the sun, on a scale of 1:1 → (12). The film can then be used to analyse the occurrence of shadows and sunshine on façades and on sections of buildings to the correct scale.

Horizontoscope. The horizontoscope is an aid to determining the true conditions of sunshine and shadow on building sites and on and in buildings. The horizontoscope consists of a transparent dome, a compass, the base and exchangeable curved sheets which are placed on the base, according to the task in hand, to investigate light, radiation or heat, etc.

The purpose of the horizontoscope is to construct the light and shade conditions which exist in a room, e.g. → (13). At a particular point in the room, the opening for incident light can be assessed by means of a window cut-out projected on the dome and at the same time on the curved sheet underneath. It is therefore possible to determine both the radiation conditions and light effects in the room for each point in the room, and for any time of day and time of year, depending on the alignment of the building → (13).

Model simulation. In order to simulate and establish accurate annual shadow and solar radiation effects in and on a building, it is possible to construct a true-to-scale model and to test it under an artificial sun (parallel light) → (14).



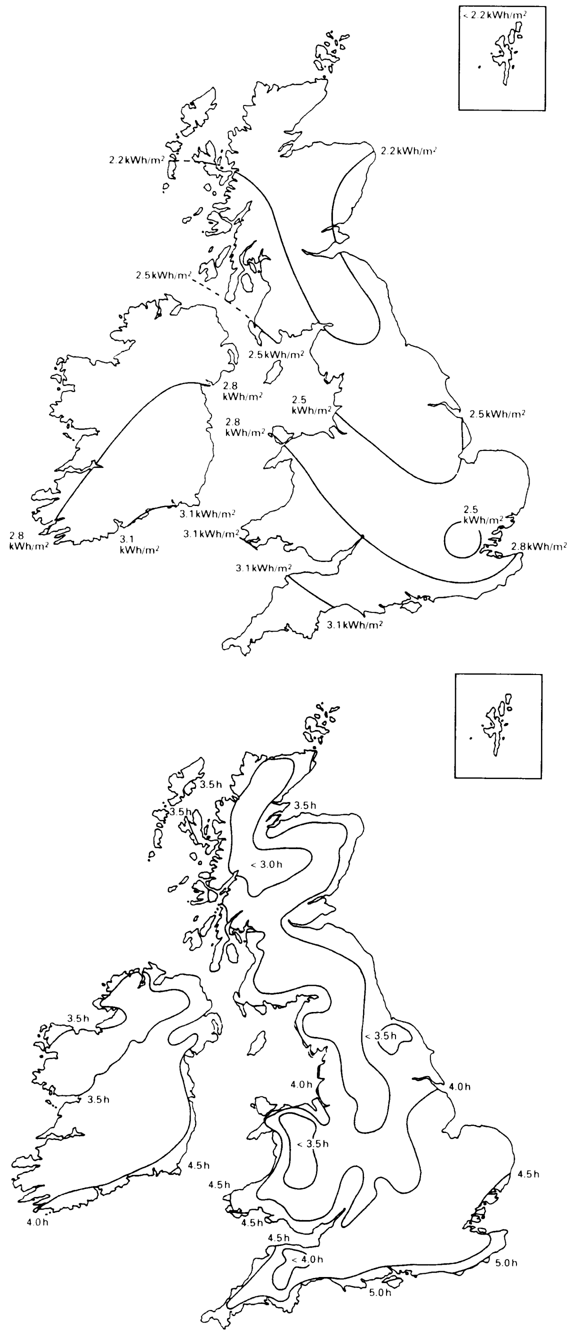
1 artificial sun with parabolic reflector or similar

2 model: e.g. for city buildings, architecture

3 simulator to represent variations in time of day, time of year and latitude

(14) **Artificial sun model**

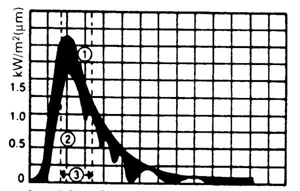
DAYLIGHT



(15) **Mean daily solar radiation and hours of sunshine in the UK**

condition of sky, e.g. latitude 51°N			
weather	clear, cloudless blue sky	misty, cloudy; sun visible as white disk	cloud-covered sky, dull day
horizontal irradiance (W/m²)	600–800	200–400	50–150
horizontal illuminance (lx)	60000–100000	19000–40000	5000–20000
diffusion component, sky	10–20%	20–30%	80–100%

(16) **Different intensities of radiation and varying quality of daylight in various weather conditions**



(1) intensity J of solar radiation at the limit of the Earth's atmosphere as a function of the wavelength ($\gamma_s = 90°$)
the shaded region shows the losses from reflection, scatter and absorption of radiation due to the water vapour, carbon dioxide and ozone in the air, as well as dust particles
(2) intensity J of the solar radiation that reaches the Earth
(3) range of visible light

(17)

Meteorological features

The radiation of heat and the intensity of the sunlight on the surface of the Earth over the course of the year are determined by the geographical latitude, the weather and the varying conditions of the sky (clear, clouded, dull, partly clouded, etc.).

The facts given below are important with regard to our typical patterns of daylight and sunshine duration.

There are 8760h in a year. The duration of 'bright daylight' during the course of a year amounts to around 4300h on average.

The number of hours of sunshine per year varies from one country to another. Even within the same country it may vary from one location to another. The majority of these hours of sunshine usually occur during summer.

Over most of the year, that is, during 2/3 of the daylight hours, the sunlight that reaches the Earth is scattered to a greater or lesser degree owing to the local weather conditions.

The direct and indirect solar radiation (global radiation) which reaches the surface of the Earth produces a locally varying climate on the surface and in its near vicinity (see → (15)). The periods of sunshine are considered in units of tenths of hours. The data represent only the macro-climate; local variations in the micro-climate are not accounted for. Climatic data relating to a specific location (temperature, sunshine duration, sky conditions etc.) can be obtained, for example, from the Meteorological Office in Bracknell, UK.

During 'bright daylight hours', varying intensities of solar radiation are received on the surface, depending on the geographical latitude and the weather conditions, as are varying qualities of daylight → (16).

Physical basis of radiation

Solar radiation is a very inconstant source of heat. Only a small proportion of the solar energy radiated toward the Earth is transferred to the surface of the Earth as heat energy. This is because the Earth's atmosphere diminishes the solar radiation and does not permit a uniform intensity to penetrate to the surface.

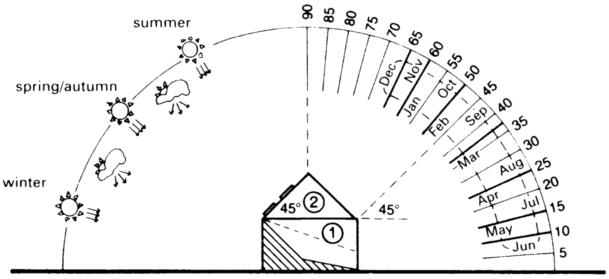
This reduction essentially occurs because of various turbidity factors, such as scatter, reflection and absorption of the radiation by dust and haze (the cause of diffuse daylight), and also because of the water vapour, carbon dioxide and ozone in the air.

The total energy of solar radiation reaching the Earth is transmitted in the wavelength range 0.2–3.0μm. Distribution of the total energy on the Earth's surface is as follows: approximately 3% ultra-violet radiation in the wavelength range 0.2–0.38μm; approximately 44% visible radiation in the wavelength range 0.38–0.78μm (the maximum lies at 0.5μm in the visible light range); approximately 53% infra-red radiation in the wavelength range 0.78–3.0μm.

The chart shown in → (17) represents the solar radiation which reaches the Earth. This is the solar constant, and has a value in our region of approximately $1000 W/m^2$ on an illuminated vertical surface.

The radiation power is reduced by very thick cloud to approximately $200 W/m^2$, and in the case of only diffuse radiation (a cloudy sky with the sun completely obscured) to approx. $50–200 W/m^2$ (see → (16)).

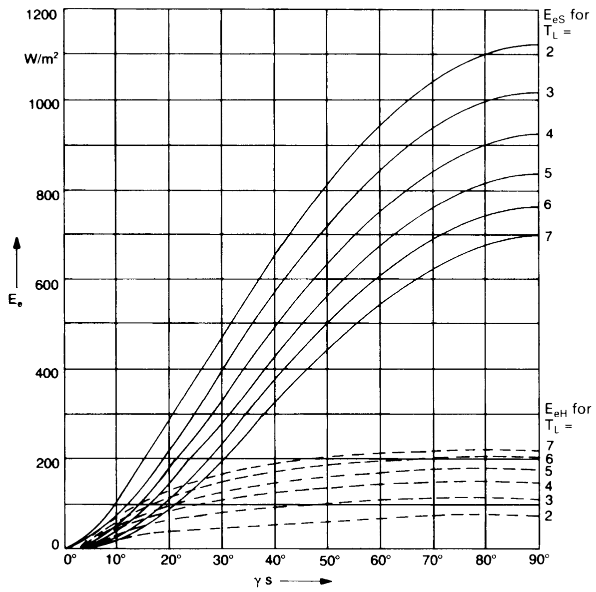
Global Radiation



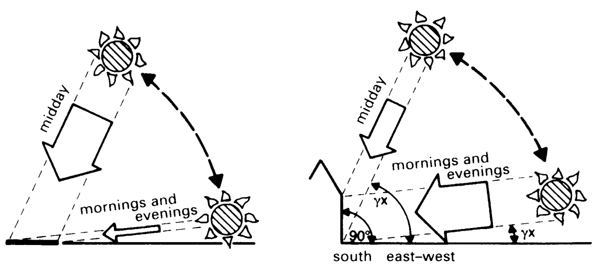
① internal building surfaces which can receive direct incident solar radiation from winter to summer

② optimum inclination of solar cells for global radiation used throughout the year → ㉒ – ㉔

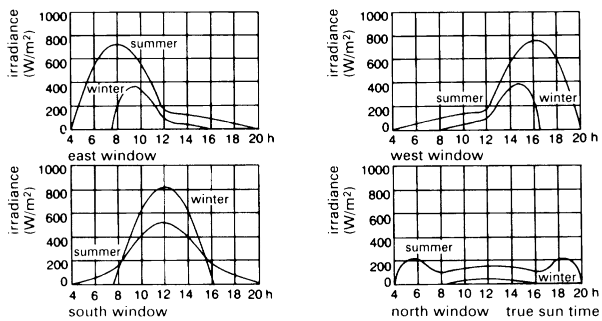
⑱ **Optimum angles of inclination for south-facing surfaces**



⑲ **Horizontal irradiances due to the sun E_{eS} and the (cloudless) sky E_{sH}, with various turbidities T_L, as a function of the elevation of the sun γ_s**



⑳ **Comparisons of the direct radiation on horizontal and vertical surfaces at various positions of the sun during the day. The level of incident radiation on a surface depends on the angle of that radiation (γx).**



㉑ **Examples of radiation intensity on vertical surfaces facing in various directions on cloudless days in winter (Dec.) and summer (June)**

The effective solar radiation on a building (on the surfaces which are aligned with the direction of radiation at the time) is referred to as the global radiation E_{eg}. This is the sum of the 'direct' and 'diffuse' solar radiation (conditioned by the Earth's atmosphere and due to the scattered radiation caused by the varying conditions of the sky), given in W/m^2 or in Wh/m^2 per month or per day or per year. In the case of diffuse and direct radiation, the component of the radiation which is reflected from neighbouring buildings, roads and bordering surfaces, for example, must be taken into account (particularly when such reflections are strong).

Global radiation can be employed as a source of heat, directly for 'passive use' through structural measures (e.g. glass surfaces to utilise the greenhouse effect or internal heat storage walls) → ⑱, or indirectly by 'active use' (e.g. using collectors, solar cells) → ⑱ for the energy requirements of a building. Also, the proportion of global radiation received directly determines the effective heating influence of the sun on the cooling load, which has to be calculated in the layout of heating and ventilation systems for each type of building.

The necessary global radiation on buildings and collector surfaces for the utilisation of solar energy must be determined. This is related to the location of the building, and can be obtained as an energy parameter.

→ ⑲ shows the horizontal irradiance in W/m^2 due to the sun E_{eS} and the sky E_{eH} as a function of the elevation of the sun for clear skies. The horizontal global irradiance E_{eg} is the sum of the components generated by the sun E_{eS} and the sky E_{eH}.

Application: In order to be able to determine the actual amount of solar energy to be used, the contributions must be presented as functions of the inclination and, if necessary, the orientation of the surfaces of the building, corresponding to → ⑪. The horizontal irradiance can be obtained from → ⑲.

→ ⑳ shows the reduction of the incident level of solar radiation as a consequence of the different inclinations (0–90°) and orientations.

In the case of a vertical surface, only about 50% of the annual horizontal global irradiance can be utilised.

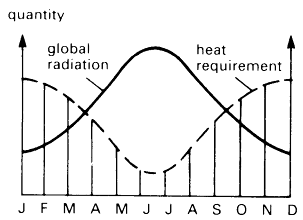
The quantity of radiation incident on a vertical, but differently orientated, surface under a cloudless sky can be read off the graphs in → ㉑, at least for the highest and lowest positions of the sun.

Passive and active solar systems

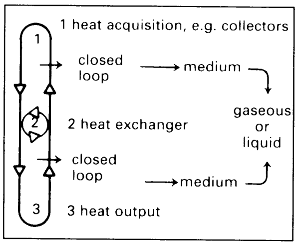
The energy requirement for a building in northern Europe during the 8-month period of heating in winter is relatively high in comparison to that required during the months from May to August. During the months of September and April, although the global radiation component is not very intensive (see → ㉒), part of the energy requirement of a building (heating, domestic water, ventilation etc.) can be covered by the use of the thermal energy of the surroundings, which again places emphasis on the problem of long-term storage.

In the application of solar energy, a distinction is made between two main systems according to their principle of operation: active or passive.

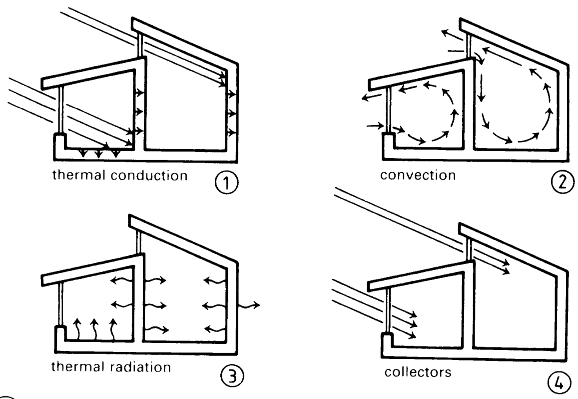
DAYLIGHT



(22) **Heating requirement and sunshine duration**



(23) **Heat cascade, active system**



(24) **Passive system (principles)**

glazing	g
double glazing in clear glass	0.8
triple glazing in clear glass	0.7
glass blocks	0.6
multiple glazing with special glass (thermal insulating glass/solar control glass)	0.2–0.8

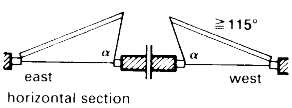
(25) **Total energy transmission factor g of various glazing types**

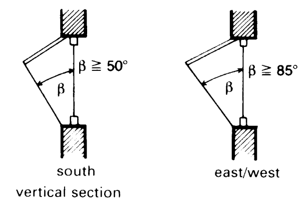
slot	1	2	3
item	internal construction type	recommended maximum value (gf × f) increased natural ventilation not available	recommended maximum value (gf × f) increased natural ventilation available
1	light	0.12	0.17
2	robust	0.14	0.25

(26) **Recommended maximum values (gf × f) as a function of natural ventilation alternatives**

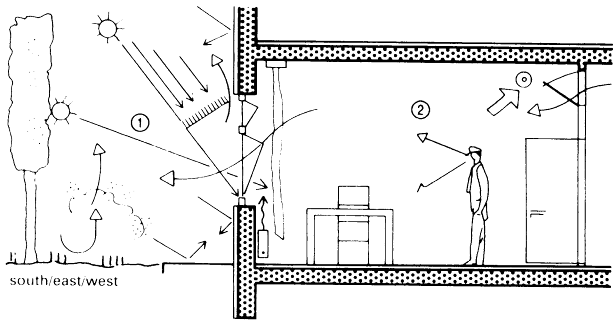
solar protection device	g
no solar protection device	1.0
inside and between the panes	
fabrics or films	0.4–0.7
Venetian blinds	0.5
outside	
Venetian blinds, rotatable slats, rear ventilated	0.25
Venetian blinds, roller shutters, shutters, fixed or rotatable slats	0.3
roof panels, loggia	0.3
window blinds, ventilated from above and from sides	0.4
window blinds, general	0.5

(27) **Reduction factor z of solar protection devices in association with glazing types**





(28) **Arrangement for sunshields, loggias, window blinds or similar**



(29) **Heat reduction through solar protection with simultaneous cooling by means of passive precautions (e.g. office buildings without air conditioning)**

Active systems are those in which the heat gain and heat output processes are driven by equipment installed in the building. They are also referred to as indirect systems, since the heat output occurs after the conversion processes. The operating principle of an active system is represented in → (23) as a heat cascade. The heat gain can be achieved by means of solar collectors or something similar.

In passive systems, the solar energy is used 'directly'. This means that where the form of the building, the material, the type of construction and the individual components are suitable, the incident solar radiation is converted into heat energy, stored and then given out directly to the building.

Four physical processes which are important to the heat gain, conversion and output are described below.

(1) Thermal conduction → (24), (1)

When a material absorbs solar radiation, this energy is converted into heat. Heat flow is caused by a temperature difference, and is also dependent on the specific thermal capacity of the material concerned. For example, if the temperature of the surroundings is lower than that of a heated wall, then the 'stored' heat energy is transferred to the surroundings.

(2) Convection → (24), (2)

A wall or other material heated by solar radiation gives back the available energy to the surroundings, according to the temperature difference. The greater the temperature difference between wall and surroundings, the greater the amount of heat given up. Air that is heated in this process will rise.

(3) Thermal radiation → (24), (3)

Short-wave solar radiation is converted into long-wave (infra-red) radiation on the surface of the material. The radiation is emitted in all directions, and is dependent on the surface temperature of the materials.

(4) Collectors → (24), (4)

Sunlight penetrates glass surfaces which are orientated towards the south. Solar radiation converted inside the room (long-wave radiation) cannot pass back through the glass, and thus the inside of the room is heated (greenhouse effect) → (24), (4).

In any application of the systems described above, account must be taken of storage, controllability and distribution within the building.

Summertime thermal insulation

Summertime thermal insulation is recommended for transparent façades in buildings with natural ventilation in order to avoid the possibility of overheating. The recommendations are as follows: The product of the total energy transmission factor (g) (→ (25)) × the solar protection factor (z) (→ (27)) × the window surface component (f) on the façade, i.e. g × z × f, should have a value of 0.14–0.25 for strongly constructed buildings, and a value of 0.12–0.17 for those of lighter structure (see → (26)).

Extensive solar shading precautions → (28) should be critically evaluated, since wide-ranging visual effects may result and the view may be permanently impaired → (28).

The interplay of natural surroundings, physical laws and the development of constructional styles in specific materials means that each case requires accurate, individual analysis → (29).

Explanation of Figure (29)

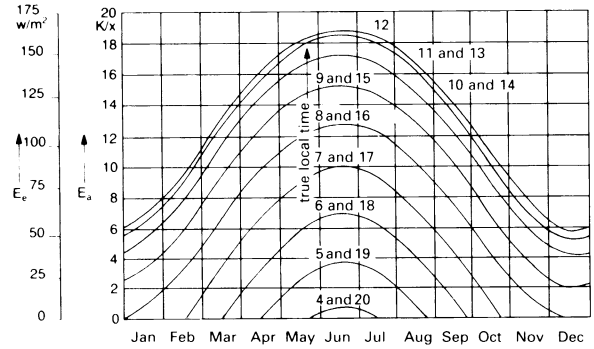
Outside and façade → (1)

- Shadows and cooling due to vegetation (trees, shrubbery, etc.)
- Light-coloured pathway (width approx. 1 m), e.g. pebbles, in front of the house
- Sun or anti-glare protection (b = 35°) installed, extent approx. 900 mm
- Façade in bright reflecting materials (pastel colours)
- Adequate window size (with insulating glass) for incident light and heat, with white internal frames

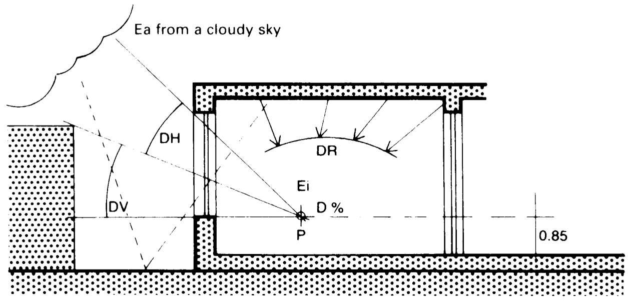
Inside → (2)

- Consideration for house plants, if present
- Light- or medium-coloured floor covering
- Flexible heating system (a combination of air and hot water)
- Light-coloured curtains as anti-glare protection to diffuse direct solar radiation (particularly during transition periods)
- Light matt colours (pastel and natural colours for furniture) on surrounding areas, particularly the ceiling
- Cross-ventilation via tilting flaps
- Simple mechanical ventilation, if required

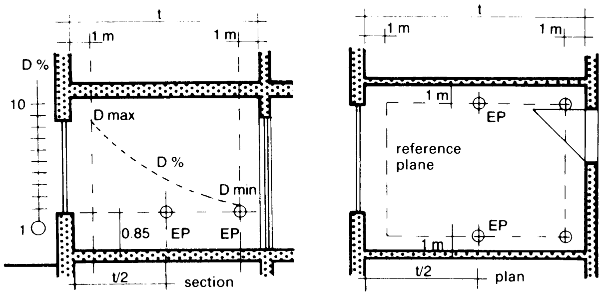
DAYLIGHT



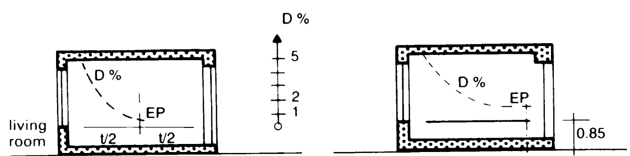
(30) **Horizontal illuminance Ea for a clouded sky at latitude 51°N, as a function of time of year and time of day; E_e = horizontal irradiance**



(31) **Daylight and internal area illuminance at point P**



(32) **Daylight ratio with side lighting, showing the reference plane and the variation in daylight in the internal area**



daylight ratios required in living rooms and workrooms

(33) **Required daylight ratios in living and work rooms**

internal illuminance Ei (lx)	external illuminance Ea (lx) 5000	10000
200	4.0%	2.0%
500	10.0%	5.0%
700	14%	7.0%

1 Required daylight ratios for satisfactory internal area illuminance at various levels of illuminance from a clouded sky (D = Ei/Ea × 100%)

external illuminance Ea (lx)	internal illuminance Ei (lx)
5000	50
10000	100

2 Anticipated internal area illuminance at EP, at various levels of illuminance from a clouded sky, with D = 1% (Ei = D × Ea/100%)

(34) **Internal area illuminance**

The measurement and evaluation of daylight in internal areas with light admission from the sides and above.

The daylight in internal areas can be evaluated according to the following quality criteria: illuminance and brightness; uniformity; glare; shadow.

Basis: In evaluating daylight in internal areas, the illuminance of a clouded sky (i.e. diffuse radiation) is taken as the basis. Daylight admitted to an internal area through a side window is measured by the daylight factor D. This is the ratio of the illuminance of the internal area (Ei) to the prevailing external illuminance (Ea), where D = Ei/(Ea × 100)%. Daylight in internal areas is always given as a percentage. For example, when the illuminance of the internal area is 500 lx and the external illuminance is 5000 lx, then D = 10%.

The daylight factor always remains constant. The illuminance of an internal area varies only in proportion to the external illuminance prevailing at the time. The external illuminance of a clouded sky varies from 5000 lx in winter to 20000 lx in summer → (30), and depends on the time of year and the time of day.

The daylight factor at a point P → (31) is influenced by many factors. D = (DH + DV + DR) × t × k1 × k2 × k3, where DH is the component of light from the sky, DV is the effect due to neighbouring buildings, DR is the contribution from internal reflections, and the following reduction factors are taken into consideration: t, the light transmission factor for the glass; k1, the scatter effects due to the construction of the window; k2, the scatter effects due to the type of glazing; k3, the effects of the angle of incidence of the daylight.

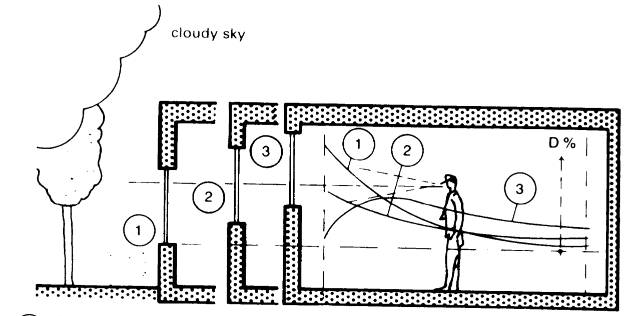
The reference plane for the horizontal illuminance of daylight in an internal area is as shown in → (32). It can be taken as 0.85 m above floor level, and is separated from the walls of the room by 1 m. The points EP used for the horizontal illuminance are fixed on this reference plane. The corresponding (to be determined) daylight factors can then be represented in the form of a daylight factor curve → (32). The shape of the curve on the section provides information about the horizontal illuminance on the reference plane (at the corresponding points), and then Dmin and Dmax can be established (see also uniformity). The curve of the daylight factor also provides information on the variation of daylight in the room.

Required daylight factors D%. The relevant, currently valid requirements are laid down in regulations relating to daylight in internal areas and in the guidelines for work areas. Since no other relevant data are available at present, the required variation in daylight can be determined and checked from the uniformity (see later).

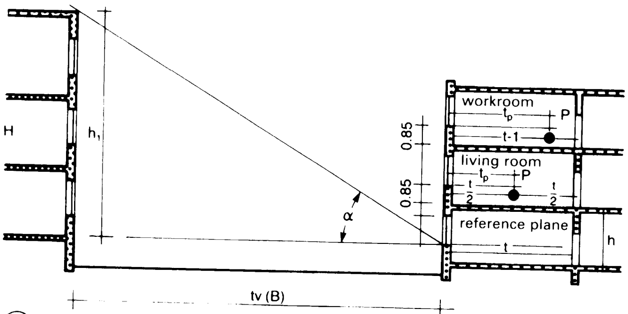
On the assumption that living rooms are comparable in terms of their dimensions with work rooms, the following values for the required daylight factors should be adhered to:

Dmin ≥ 1% in living rooms, reference point the centre of the room → (33);
Dmin ≥ 1% in workrooms, reference point the lowest position in the room → (33);
Dmin ≥ 2% in workrooms with windows on two sides;
Dmin ≥ 2% in workrooms with light coming from above, with the minimum mean daylight factor (Dm) ≥ 4%.

Note: With side windows, the associated maximum daylight factor should be at least six times greater than the minimum requirement, and in the case of light from above in workrooms, Dm should be twice as large as Dmin. Several examples for different internal area illuminance requirements as a function of external illuminance are shown in → (34).



(35) **Various daylight patterns in an internal area with different vertical window positions**

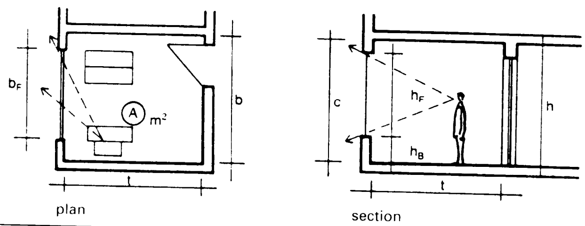


(36) **Diagram to determine the window widths required**

window width (ww) (m)

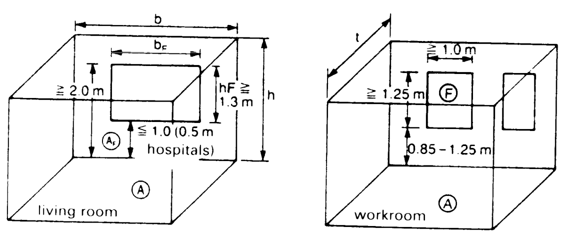
room height h		2.50 m			3.00 m	
window height hF		1.35 m			1.85 m	
room depth t		5 m	7 m		5 m	7 m
room width b / influence of adjacent building $\alpha = 0°$	5	2.75	2.75	5	2.75	2.75
	7	3.85	3.85	7	3.85	3.85
$\alpha = 20°$	5	2.75	4.46	5	2.75	2.75
	7	3.85	6.07	7	3.85	3.85
$\alpha = 30°$	5	3.69	–	5	2.75	3.85
	7	5.07	–	7	3.85	5.18

(37) **Determination of the required window widths (ww) with different room dimensions and interference from various adjacent building (extract)**



living rooms	workrooms		
$c \geq 2.20$ m $h_B \leq 0.90$ m $b_F \geq 0.55 \cdot b$ minimum requirement	as for living rooms, if: $h \leq 2.50$ m $t \leq 6.0$ m $A \leq 50$ m²	with $h < 3.50$ m window area > 30% of $b \times h$	with $h > 3.50$ m $c - h_B \geq 1.30$ m $h_B \leq 0.90$ m $b_F \geq 0.55 \cdot b$

(38) **Recommended visual links with outside**



$b_F \geq 0.55 \cdot b$
$b_F/m \geq 0.1 \cdot A/m^2$
$b_F \cdot h_F \geq 0.3 \cdot A_F$
$\geq 0.16 \cdot A$
$b_F \cdot h_F/m^2 \geq 0.07 \cdot A \cdot h/m^3$

window requirements in living rooms

for $t < 5$ m $F \geq 1.25$ m²
for $t > 5$ m $F \geq 1.5$ m²
$\Sigma F = 0.1 \cdot A$ for $A < 600$ m²
$\Sigma F = 60 + 0.01\,A$ for $A > 600$ m²

required window sizes in workrooms

(39) **Summary of visual links with outside and window sizes**

Brightness, window sizes and visual links

The position, size and type of windows essentially determine the pattern of daylight in an internal area → (35). The appropriate window sizes for living and work rooms of various dimensions are defined in → (38). The following conditions provide the basis for these calculations for living rooms:

- D% = 0.9 at the centre of a living room and at the lowest point in a workroom,
- width of window = 0.55 × room width,
- clouded sky,
- reflection from the wall = 0.6,
- reflection from the ceiling = 0.7,
- reflection from the floor = 0.2,
- light losses from the glass = 0.75,
- light losses from window-frame scatter k1 = 0.75,
- light losses from contamination k2 = 0.95,
- reflected light from neighbouring buildings Dv = 0.2,
- angle of light reflected from neighbouring buildings a = 0–50° (see → (36) + (37)).

Note: This applies by analogy to workrooms when their dimensions correspond to those of living rooms:

- room height (h) ≤ 3.50 m,
- room depth (t) ≤ 6 m,
- room area (A) ≤ 50 m².

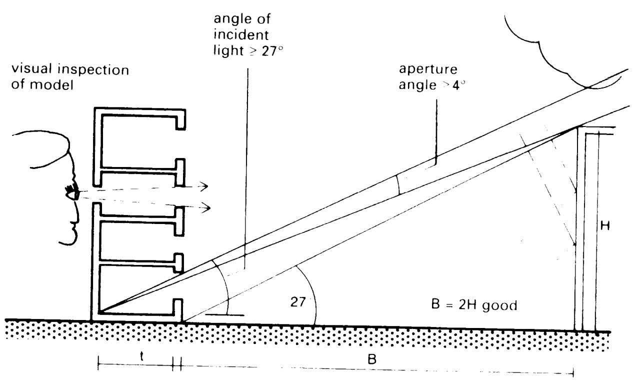
Visual links with the outside also demand the requisite window dimensions for living rooms and workrooms. Minimum recommended requirements are summarised in → (38) and → (39). These recommendations contain the following points:

- limiting clearances and clearance areas for the relevant building heights must be maintained,
- visual link with the outside is a requirement for all accommodation;
- as a rule, a window size of approx. 1/8–1/10 of the usable room area must be provided for living rooms.

Among other factors in the town planning interpretation of building instructions and standards, incident light, building separation, the external aspects of neighbouring buildings and window design all have to be taken into account → (40). For example, a building separation of B = 2H (≥ 27°) is the desired value. This results in an aperture angle of ≥ 4° (limited by building geometry and neighbouring buildings) to achieve the minimum level of daylight in rooms.

Newly developed town planning schemes should be carefully checked for the quality of light in internal areas since, in general, the building regulations and standards only set minimum requirements.

It is advisable to carry out a visual inspection of the designs to check the expected appearance of internal and external areas, either in model form, under an artificial sun and artificial sky, or using an endoscope device.



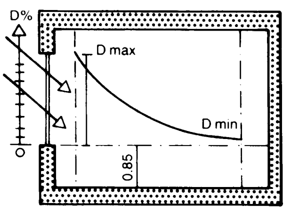
(40) **Incident light and building separation**

type of work	daylight, D%
coarse	1.33
moderately fine	2.66
very fine	5.00
fine	10.00
note: 10% is too high for the south side, but good on the north	

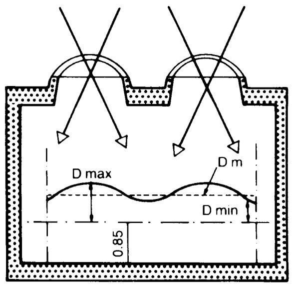
(41) **Illuminance, D%**

colour brightness		non-colour-treated materials		floor coverings, rolls and sheets	
(dark to bright)		(dark to bright)		(dark to bright)	
red	0.1 to 0.5	smooth concrete	0.25–0.5	dark	0.1–0.15
yellow	0.25–0.65	faced masonry		medium	0.15–0.25
green	0.15–0.55	red brick	0.15–0.3	bright	0.25–0.4
blue	0.1–0.3	yellow brick	0.3–0.45		
brown	0.1–0.4	lime sandstone	0.5–0.6		
white (medium)	0.7–0.75	wood			
grey	0.15–0.6	dark	0.1–0.2		
black	0.05–0.1	medium	0.2–0.4		
		bright	0.4–0.5		

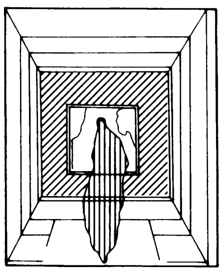
(42) **Reflection level (material colours, untreated)**



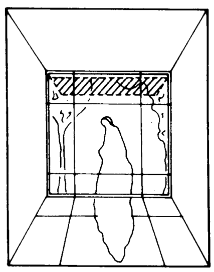
(43) **Uniformity; light from the side**



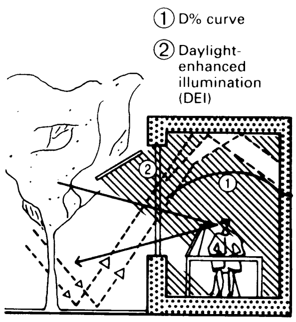
(44) **Uniformity; light from above**



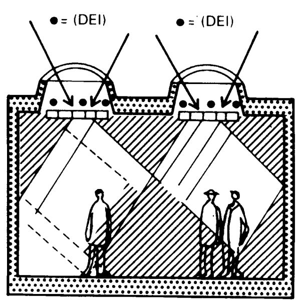
(45) **Glare**



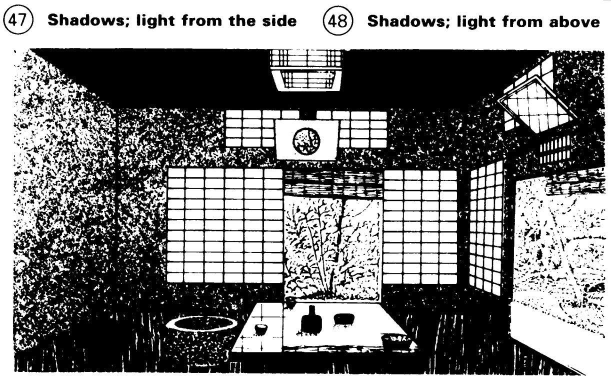
(46) **Low glare**



(47) **Shadows; light from the side**



(48) **Shadows; light from above**



(49) **Light conditions in a Japanese house**

Illuminance, level of reflection, colour rendering and glare
The interplay of these characteristics of daylight has a great influence on the brightness in internal areas. To fulfil specific visual tasks, specific daylight illuminance levels are required, depending on the type of activity → (41). Therefore, the choice of reflection levels for the walls has to be coordinated with the requirements of the visual tasks which are to be performed. The varied structuring of the brightness in a room is dependent on the reflection levels of the surfaces and the choice of arrangement of the windows in the façade → (42) (and see also → (35)).

The uniformity G of the daylight illumination (defined as Dmin/Dmax) should be ≥ 1:6 in the case of light from the side → (43). In the case of light from above, G ≥ Dmin/Dmax 1:2 → (44). This, in principle, characterises the variation of daylight in internal areas. The uniformity is better in the case of overhead illumination, since the zenith luminance is three times greater than the luminance on the horizon.

Measures used to vary the uniformity can be influenced by:

- the level of reflection (if very high),
- the direction of any glare,
- the arrangement of the windows.

Glare is caused by direct and indirect reflection from the surfaces and by unfavourable luminance contrasts → (45), (46). Measures for the avoidance of glare include:

- solar shading outside,
- glare protection, inside and outside, in association with solar shading,
- matt surfaces,
- correct positioning of daylight-enhancing illumination.

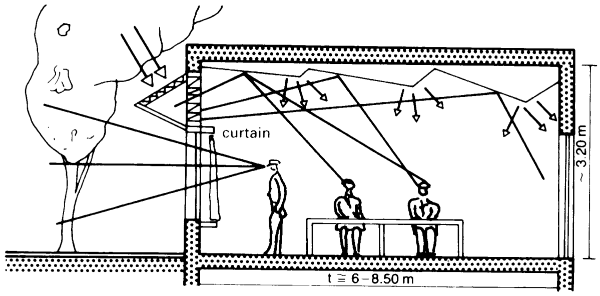
Shadow is desirable to a certain degree, in order to be able to distinguish objects or other aspects of the room (→ (47), schematic). Measures required for a more three-dimensional shadow effect in the case of side lighting include:

- solar shading,
- glare protection (even in the north),
- balanced distribution of daylight,
- no direct glare,
- multi-layered or staggered façade.

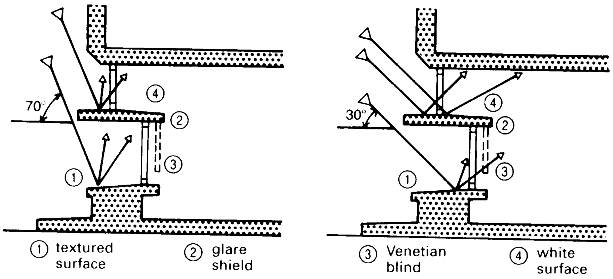
Measures for appropriate shading with light from above include:

- incident daylight on the lower edge of the light opening, through translucent materials, light gratings or similar filters (→ (48), schematic),
- daylight-enhancing illumination,
- bright matt surfaces combined with coloured differentiation (e.g. a supporting structure).

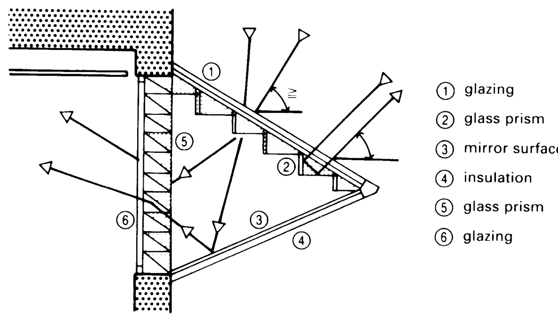
Summary: Quality criteria, daylight coming from the side. In essence, the named quality criteria for daylight must be interpreted in such a way that spatial identity results. The variation of daylight in the internal area, combined with a good external view, are largely the result of the design of the façade, that is, the transition from inside to outside. A staggered, multi-layered and simultaneously transparent transition from inside to outside can satisfy the various requirements relating to daylight throughout the seasons of the year → (49).



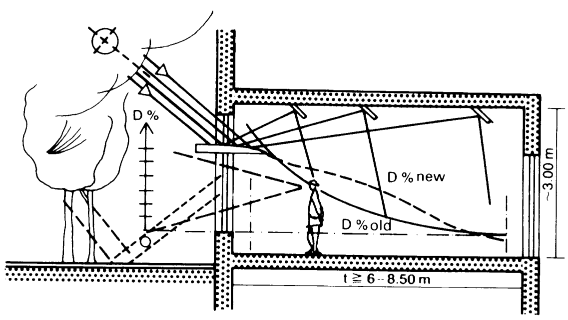
(50) **Principle of light redirection**



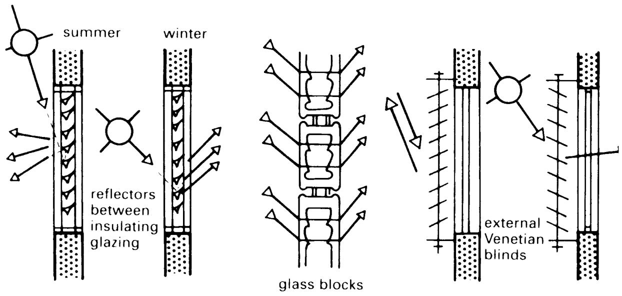
(51) **Mount Airy Public Library, NC, USA**



(52) **Prismatic redirection of light**



(53) **Ceiling design for light redirection**



(54) **Redirection of light**

Light redirection (light from the side)

As the depth of a room increases (normally 5–7 m), the intensity of the daylight in the room diminishes (see daylight factor curve). Redirecting the light allows rooms to be completely illuminated with daylight, even rooms of considerable depth.

The redirection of the light is based on the principle that the angle of incidence equals the angle of reflection. The aim of this redirection is (→ (50)):

- to obtain a more uniform distribution of daylight;
- to obtain better daylight illumination in the depths of the room;
- to avoid glare when the sun is high, and to make use of winter sun;
- to mask out zenith luminance, or to make indirect use of it;
- to redirect particularly diffuse radiation;
- to eliminate the need for additional solar protection (possibly trees) by achieving glare protection on the inside.

Light shelves (reflectors). These can be placed inside or outside the window in the area of the abutment. Mirrored, polished or white surfaces can be used as the reflection plane. They improve the uniformity of the illumination, particularly if the ceiling is shaped to correspond with the redirected light. If necessary, glare protection can be provided in the region between the abutment and the ceiling → (51).

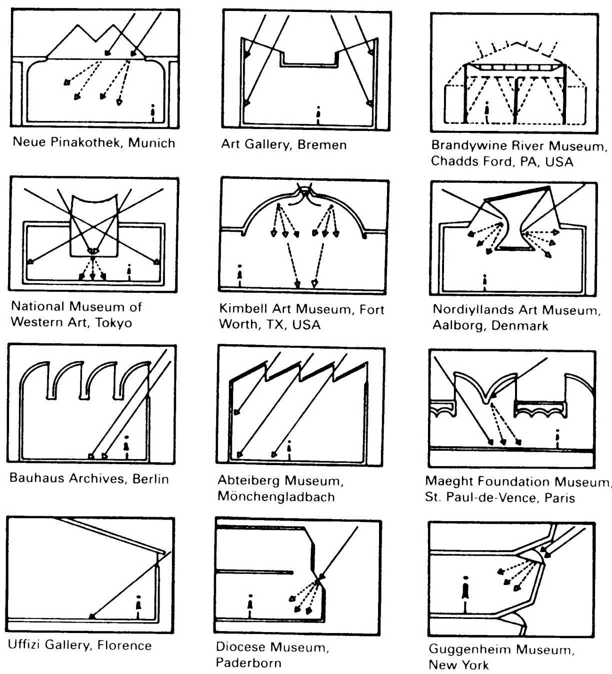
Prisms. Optical prisms can be used to achieve a desired selection of radiation and redirection → (52). Prism plates reflect the sunlight with less deviation, and only allow diffuse light from the sky to pass through. In order to prevent penetration of the sun's rays, the prism plates are mirrored. The prism plates guarantee adequate daylight illumination up to a room depth of approximately 8 m.

Outlook, light deflection and glare protection. The illumination in the depths of a room can be improved by redirecting the light and by providing reflecting surfaces on the ceiling → (53). The outlook remains the same, but the zenith illuminance is masked out. Glare protection is only required in winter, but if necessary, a means of enhancing daylight illumination may be provided on the abutment.

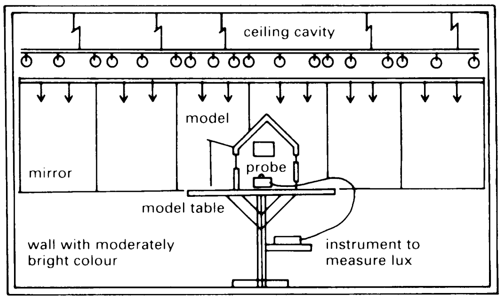
Solar control glass, glass bricks and Venetian blinds are used for radiation selection and redirection, and include the following systems (→ (54)):

- solar control glass, i.e. mirror reflectors (rigid) between the glass panes cause the light to be reflected in summer and transmitted in winter;
- glass blocks, i.e. polished prisms to increase the uniformity of the light;
- Venetian blinds, i.e. adjustable bright outer blinds to deflect the daylight.

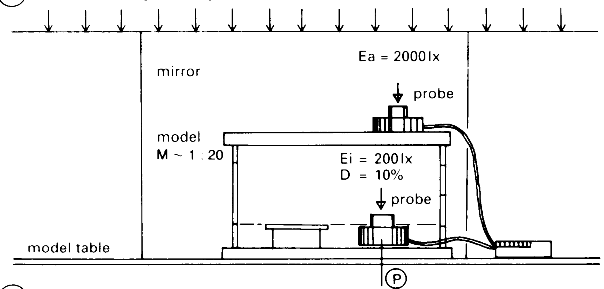
Examples of light redirection in ceiling areas in museums are shown in → (55).



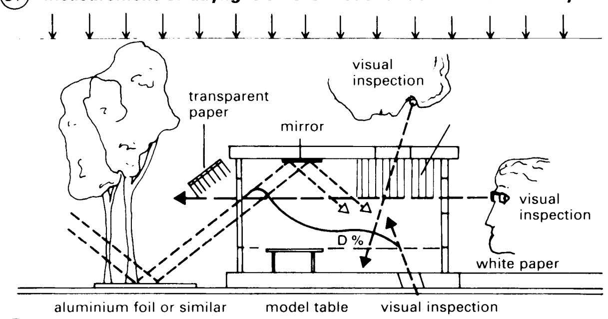
(55) **Redirection of light; light from above (the examples shown here are museums)**



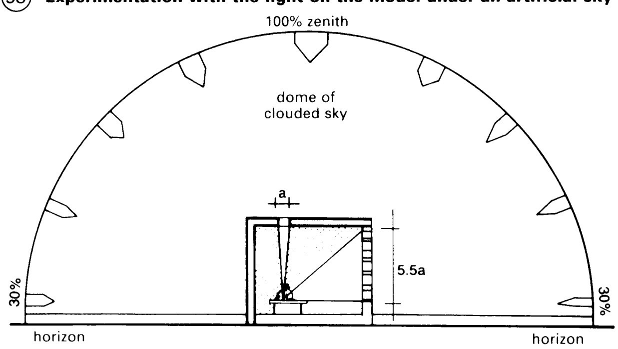
(56) **Artificial sky, example**



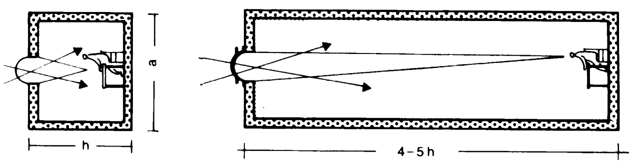
(57) **Measurement of daylight on the model under an artificial sky**



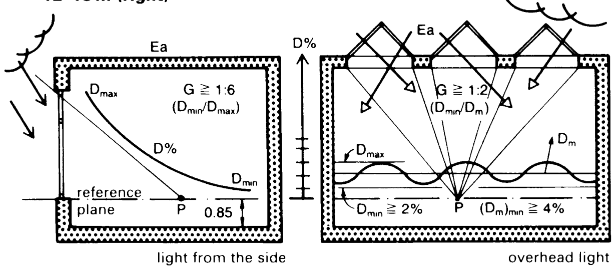
(58) **Experimentation with the light on the model under an artificial sky**



(59) **Room with roof aperture and side window, showing the distribution of zenith luminance**



(60) **Square room with a roof aperture and a height of 3 m (left) and 12–15 m (right)**



(61) **Daylight (D% and Dm%) and uniformity (G) with side and overhead light**

DAYLIGHT

Methods and procedures for determining the level of daylight (D%) in internal areas (side and overhead light) with a clouded sky

A number of methods are available to determine the level of daylight, for example calculation, graphical methods, computer-supported methods and measurement techniques.

In order to arrive at a basis for a decision on the 'room to be built' or the 'building to be erected', an approximate simulation of the daylight levels is recommended. This can be accomplished using drawing methods or with a model.

However, the distribution of the daylight can only be determined and evaluated in three dimensions. Therefore a model of the room or building should be tested under simulated conditions so that the various effects of daylight can be examined.

Experimental method. A model room was built with a suspended bright, matt, translucent ceiling, artificial illumination above the ceiling and a mirrored surface rotating in a horizontal plane which mirrored the surrounding walls. This simulated the actual effect of a uniformly clouded sky → (56).

An illuminance of approx. 2000–3000 lx was adequate. The external illuminance of the artificial sky was measured (Ea = 2000 lx), using a special purpose-made device, on a 1:20 scale architectural model. The illuminance in the inner area of the model was measured by means of a probe (Ei = 200 lx). Thus the daylight factor in the internal area had a value of 10% at point P. The variation of daylight in the model was determined using this method → (57).

Different materials can be used to influence the variation in daylight, illuminance, colours effects, room dimensions, etc., but care should be taken that the quality criteria for daylight are maintained. The following materials can be used to experiment with the effects of light on the model: cardboard or paper of various colours, preferably pastels; transparent paper to prevent glare and to generate diffuse radiation; aluminium foil or glossy materials as reflective surfaces → (58).

Daylight in internal areas with light from above

The illumination of internal areas with daylight from 'above' is subject to the same prerequisites and conditions that apply to rooms with windows at the side, i.e. daylight illumination with a clouded sky. Whilst light from the side produces relatively poor uniformity of light distribution (and hence increased demand for D%), this is not the case with lighting from above. The quality of daylight in the latter case is significantly influenced by zenith luminance, room proportions, quality criteria, daylight from above and diminution factors.

The best place to work in the room shown (→ (59)) is at a distance from the side window which is equal to the height above the working position of the overhead light source. If the same level of illuminance that is produced by the overhead light on the reference plane (0.85 m above floor level) is to be generated by light from the side window, then the window must be 5.5 times larger in area than the roof light aperture. The reason for this is that the light from above is brighter, since the zenith luminance is roughly three times the horizontal luminance. This means the light from above represents 100% of the light from the sky, whereas only 50% of the light from the sky is admitted through a side window.

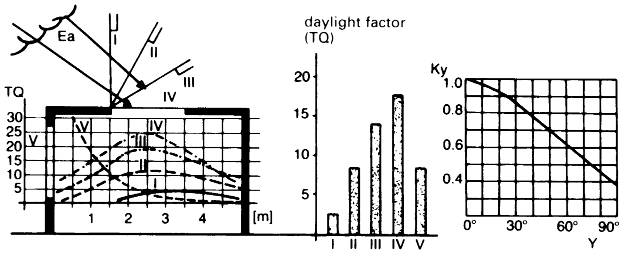
The illumination of a room from above is dependent on the proportions of the room, i.e. length, width and height (see → (60)). However, the possible occurrence of the 'dungeon effect' should be avoided.

Quality criteria for overhead light. The variation of daylight (D%) in an internal area with side windows is characterised by Dmin and Dmax → (61). A uniformity of G ≥ 1:2 (Dmin/Dm) and a Dmin of ≥ 2% is required for daylight illumination with overhead light in workrooms (Dm)min ≥ 4% → (61).

ratio Dmin:Dmax	recommendation	ke value = O/h: 90°	60°	45°	O = h·ke
approx. 1:1	target values	< 1 . . . 1.1			
1:1.5		1.2	1.3	1.4	
1:2	tolerable	1.4	1.5	1.7	
1:2.5	critical	1.6	1.8	2.0	
1:3	avoid	1.7	2.0	2.2	

height of overhead illumination, room height and the uniformity of lighting which is sought, showing the corresponding overhead light arrangements in the roof area (ke factor)

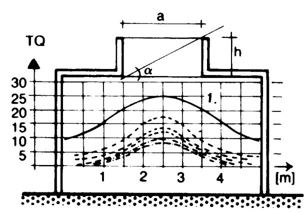
(62) **Recommended values for the ratio Dmin/Dmax**



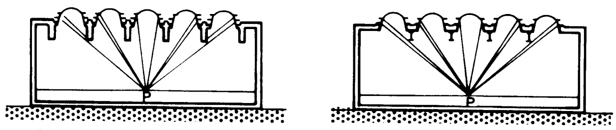
(a) Comparative variations in the daylight factor for side and overhead illumination with various inclinations of the rooflights

(b) Diminution factor ky as a function of the inclination y of the glazing in shed roofs

(63)



(64)
—— 1 **with horizontal rooflight; no shaft, i.e. h = 0**
---- 2 **with a light shaft; h = a**
– – – 3 **with a light shaft; h = 2a**

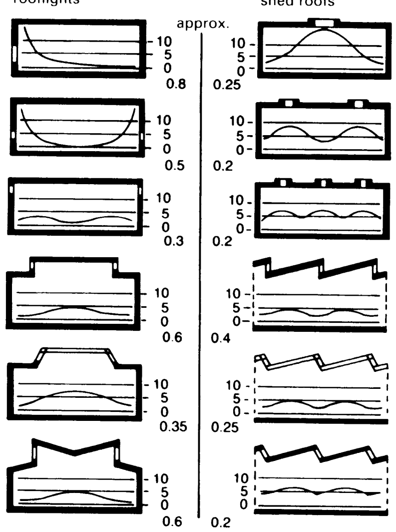


(a) Reduction in the quantity of daylight with overhead lighting with deep aperture shafts and bulky lower structures

(b) Uniform illumination in the internal area and hence better daylight conditions from rooflights with a lighter, filigree lower structure, with good reflection characteristics

(65)

side windows and opposite-facing rooflights | D% kF for D = 5% | D% | rooflights + shed roofs + inclined shed roofs



kF = window area/floor area = 1.6
values required for Dmin = 5% are shown for comparison

(66) **Effects of different windows and rooflights on the variation in the daylight factor in a room with fixed principal dimensions**

DAYLIGHT

Rooflighting

Rooflights arranged at points on the ceiling area generate typical minimum and maximum brightnesses in the region where the light is required, the work plane. The mean value between these 'bright' and 'dark' areas is calculated, and this is termed the mean daylight factor Dm.

Thus, Dm is the arithmetic mean between Dmin and Dmax with respect to the reference or work plane (0.85 m above floor level). The required G ≥ 1:2 is not based on Dmax, but on Dmin, since unevenness in the daylight from above is sensed physiologically as 'stronger than contrast'. At this uniformity (Dmin = 1 and Dm = 2), Dmin must be ≥ 2% (compare → (61)).

Furthermore, the quality criteria striven for in controlling the overhead daylight in the room are limited by the room height and the shape of the rooflight (ke factor).

An ideal uniformity is achieved when the spacing between the rooflights (O) is equivalent to the room height (h), i.e. a ratio of approximately 1:1.

In practice the rule is that the ratio of rooflight spacing to room height should be 1:1.5–1:2 (see → (62)). This figure contains a table from which these ratios and their effects can be obtained. The figure also provides a recommendation for the light shafts which should be let into the roof.

Type of rooflight and construction

The inclination of the rooflights determines the percentage of the light component from the sky which is available. In → (63)a, the quantity of incident light admitted through a side window is compared with the quantity of light provided by rooflights at various inclinations. The greatest quantity of light is received through a horizontal rooflight.

On the other hand, the maximum illuminance from a side window is achieved only in the vicinity of the window; for glazing which is vertically overhead, the lowest illuminance is on the reference plane.

Thus there is a diminution factor (ky) for the quantity of incident light which depends on the angle of inclination of the rooflight. The diminution factors corresponding to shed roofs of various inclinations are shown in → (63)b.

The diffuse incident light which falls on the rooflight is affected by the construction and depth of the installation before it supplies the room with daylight. The various levels of incident light for shafts of different proportions beneath rooflights the are shown in → (64). Excessively high and massive shafts and built-in depths should be avoided → (65)a, while a filigree, highly reflective construction is to be recommended → (65)b.

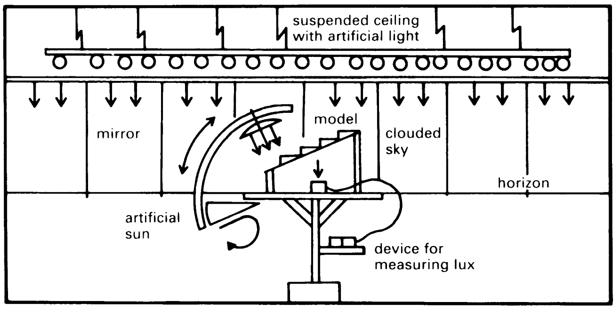
The quality of daylight in an internal area with rooflights is not only dependent on the factors discussed above. Another significant factor is the ratio of the total area of the overhead lights to the floor area of the room (kF factor).

The diagrams in → (66) show the levels of daylight from side windows with various geometrical features and overhead illumination.

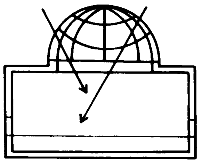
In order to increase the daylight factor Dmin by 5% for side windows or opposite-facing rooflights, the proportions of the windows must be increased significantly, typically up to a ratio of 1:1.5. By contrast, for the same demands from overhead lighting, particularly with shed roof-type lights, the area need only be increased by a relatively small amount. A ratio of rooflight area to floor area of from 1:4 to 1:5 is adequate.

Additional diminution factors for rooflights are given below.

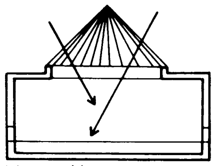
- transmittance of the glazing, t
- scatter and constructional features, k1
- soiling of the glazing, k2
- diffuse illumination, k3.



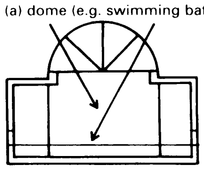
(67) **Artificial sky and artificial sun**



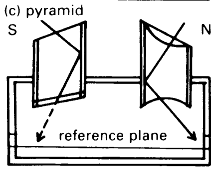
(a) dome (e.g. swimming bath)



(c) pyramid

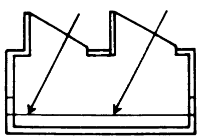


(b) barrel vault (e.g. arcades)

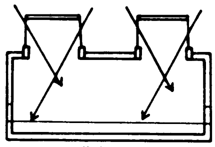


(d) light shafts for direct and indirect incident radiation

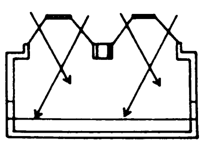
(68) **Large individual rooflights**



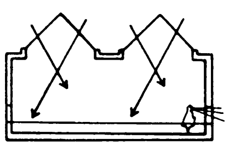
(a) monopitch rooflights



(c) lantern lights

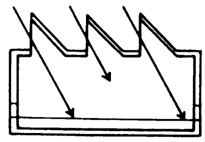


(b) inclined lantern lights

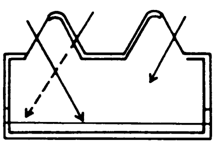


(d) ridgelights (also as individual pyramids)

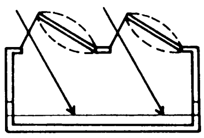
(69) **Continuous rooflights**



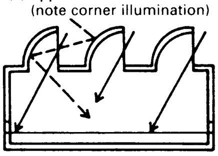
(a) 90° inclined



(c) opposed inclined surfaces (note corner illumination)

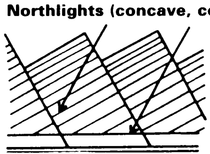


(b) 60° inclination (concave, convex)

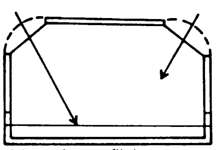


(d) rounded with white external surfaces

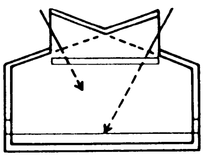
(70) **Northlights (concave, convex)**



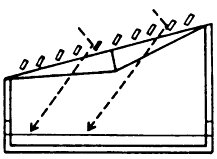
(a) intermeshed offset diagonal shells



(c) cornice rooflights



(b) butterfly rooflight with translucent ceiling



(d) glass roof with slats for diffuse and direct light

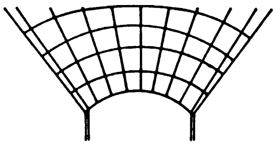
(71) **Special shapes**

Empirical evaluation of the quality of daylight from overhead illumination

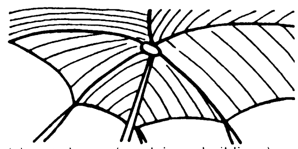
The definitive evaluation of daylight conditions should be performed against the background of a clouded sky. However, rooflights are not only recipients of diffuse radiation, they are also subject to direct solar radiation. These varying lighting conditions should be simulated, not only under an artificial sky, but also under an artificial sun. In this process, the quality criteria for the daylight on the model should be assessed by eye → (67).

Design parameters for overhead illumination are listed below (→ (68) – (72); see also → (55)).

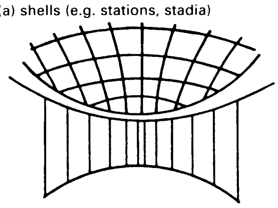
- Rooflights should not be orientated toward the south.
- Convert solar radiation into diffuse light radiation.
- Maintain quality criteria for daylight.
- Avoid excessive contrasts in luminance levels.
- Pay attention to variation in Dm.
- Ensure illumination of all room corners and enclosing surfaces.
- Avoid glare by artificial shading.
- Treat room-enclosing surfaces according to their separate technical requirements.
- Ensure that it is possible to see outside.



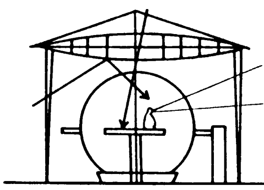
(a) shells (e.g. stations, stadia)



(c) tent shapes (e.g. leisure buildings)



(b) membranes (e.g. for sports halls)

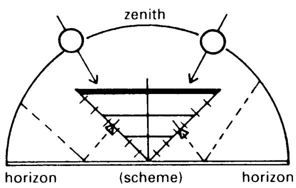


(d) transparent room under a freestanding roof with directed outward vision and passage of light

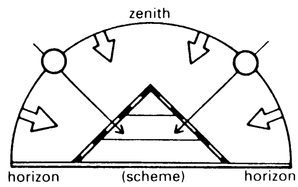
(72) **Large rooflights with distinctive shapes**

Side and overhead lighting

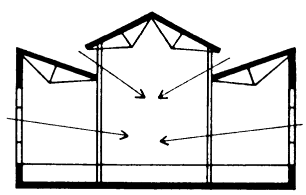
The choice between side and overhead illumination depends on the use to which the building is to be put and also on the available external light sources, i.e. the geographical location. For example, where there are extreme light and climatic conditions, appropriate forms of construction must be developed and the shapes of buildings must be designed to match the prevailing light conditions at that latitude (i.e. to make optimum use of the diffuse and direct sunlight → (73) – (76).



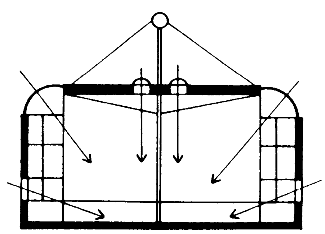
(73) **Constructional style suitable for southern regions (high direct solar radiation), side illumination**



(74) **Constructional style suitable for northern regions (high proportion of diffuse light), side and overhead illumination**



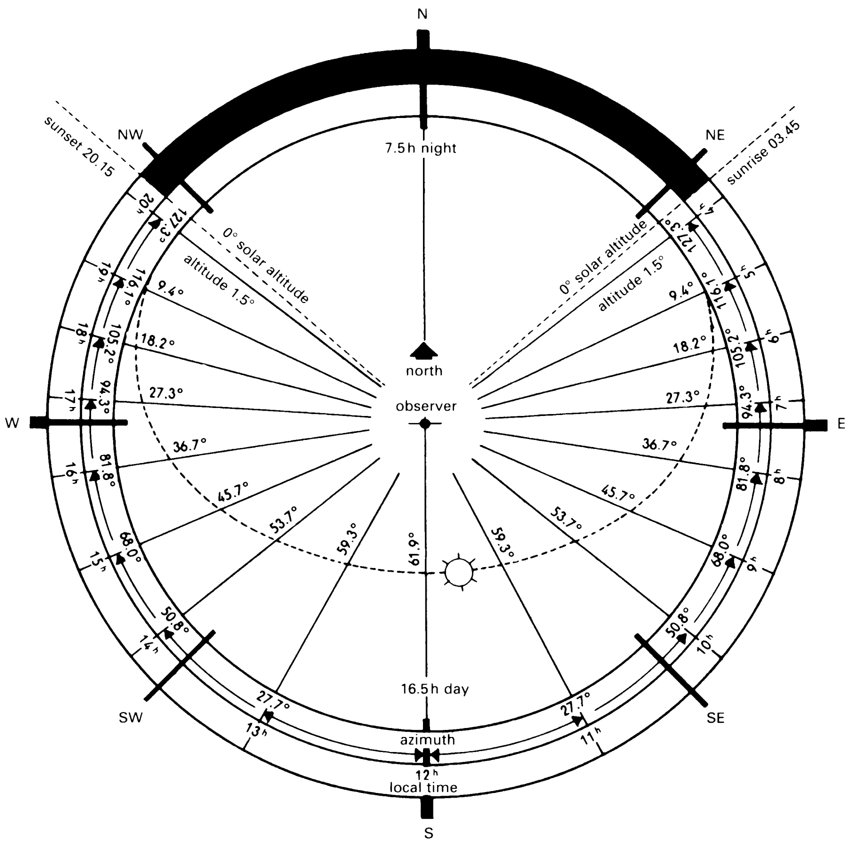
(75) **Style with potential for illumination from the side and overhead**



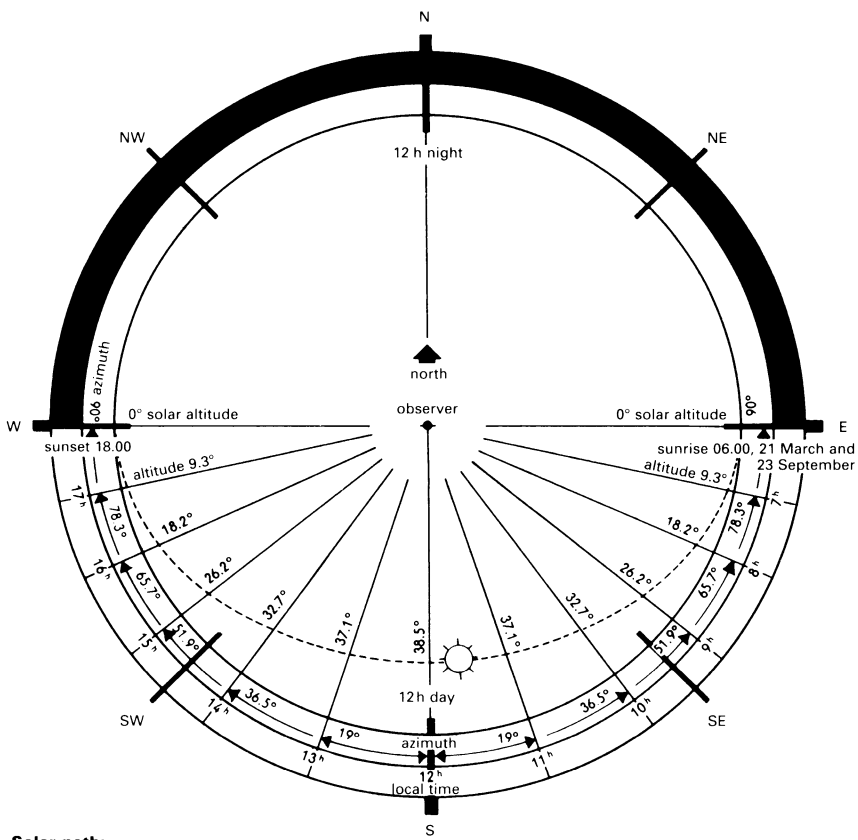
(76) **Side and overhead illumination, room-enclosing surfaces recessed**

DAYLIGHT: INSOLATION

Determination of the sunshine on structures



① **Solar path at the summer solstice (21 June) longest day of the year 51.5°N (London, Cardiff)**



② **Solar path: spring equinox (21 March) autumn equinox (23 September)**

Application

The path of sunshine on a planned structure can be obtained directly from the following procedure if a plan of the structure, drawn on transparent paper, is laid in its correct celestial orientation over the appropriate solar path diagram. The following solar path data relate to the latitude region 51.5°N (London, Cardiff).

For more northern areas, e.g. at 55°N (Newcastle), 3.5° should be subtracted. The values in degrees given inside the outer ring relate to the 'azimuth', i.e. the angle by which the apparent east–west movement of the sun is measured in its projection on the horizontal plane. The local times given in the outer ring correspond to the standard time for longitude 0° (Greenwich, i.e. the meridian of Greenwich Mean Time).

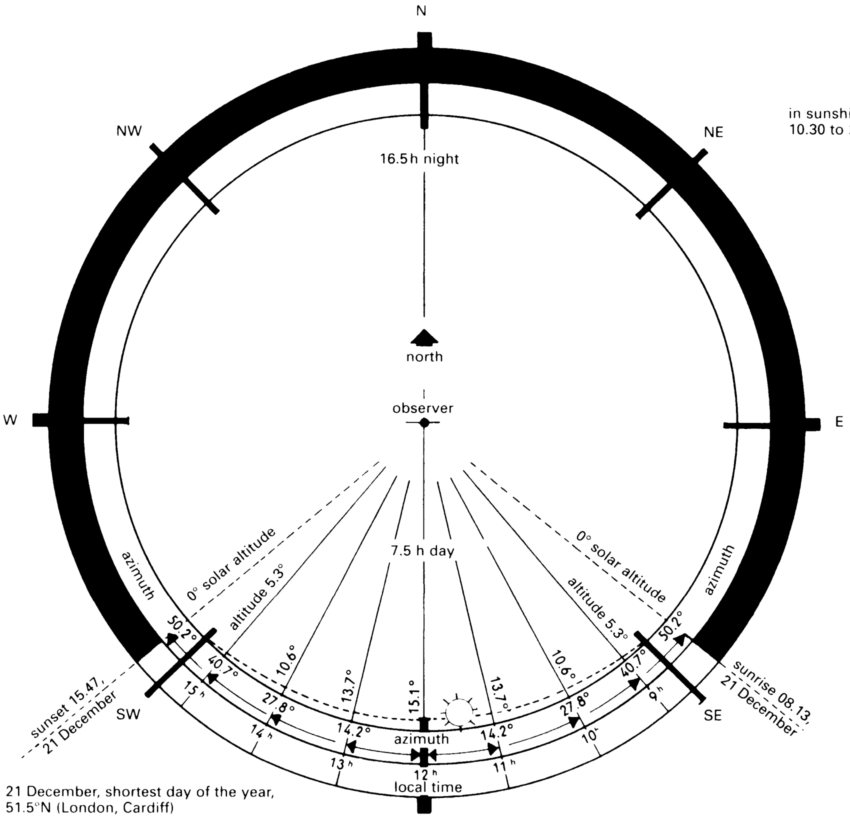
At locations on degrees of longitude east of this, the local time is 4 min earlier, per degree of longitude, than the standard time. For every degree of longitude to the west of 0°, the local time is 4 min later than the standard time.

Duration of sunshine

The potential duration of sunshine per day is almost the same from 21 May to 21 July, i.e. 16–16¾h, and from 21 November to 21 January, i.e. 8¼–7½h. In the months outside these dates, the duration of sunshine varies monthly by almost 2h. The effective duration of sunshine is barely 40% of the figures given above, owing to mist and cloud formation. This degree of efficacy varies considerably depending on the location. Exact information is available from the regional observation centres of the areas in question.

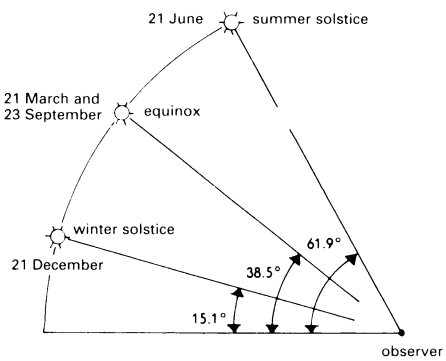
Sun and heat

The natural heat in the open air depends on the position of the sun and the ability of the surface of the Earth to give out heat. For this reason, the heat curve lags approximately 1 month behind the curve of solar altitude, i.e. the warmest day is not 21 June, but in the last days of July, and the coldest day is not 21 December, but in the last days of January. Again, this phenomenon is such that local conditions are extraordinarily varied.

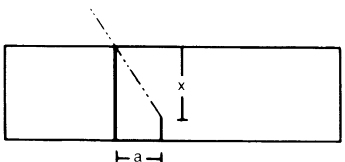


21 December, shortest day of the year, 51.5°N (London, Cardiff)

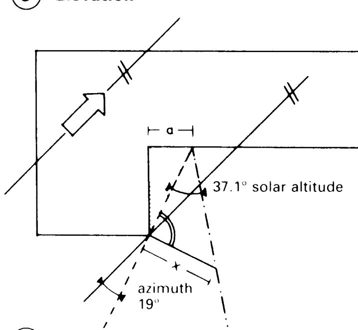
(1) **Solar path, winter solstice**

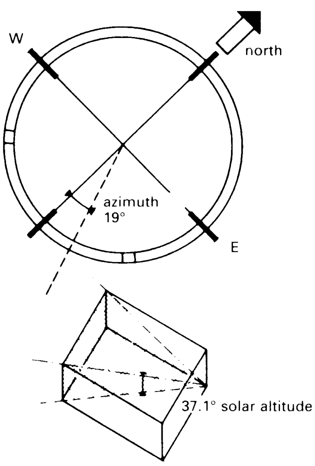


(2) **Solar positions at midday on the equinoxes and solstices**



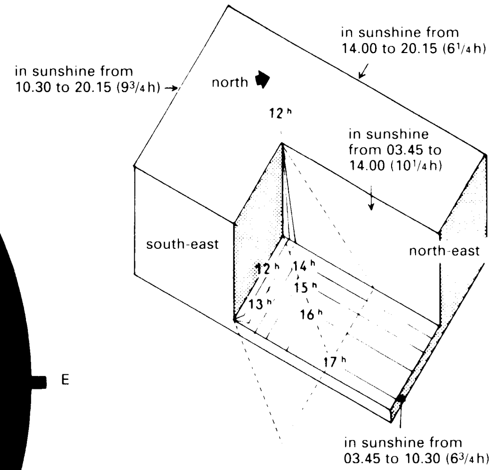
(3) **Elevation**





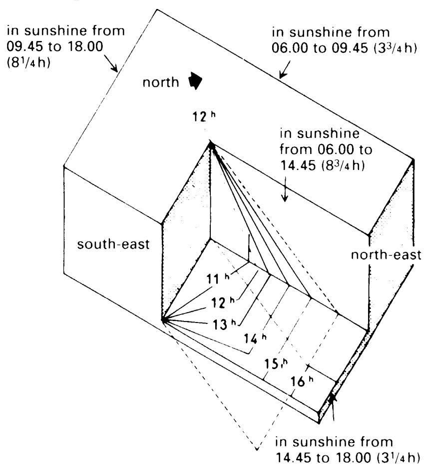
(4) **Plan**

to establish the duration of sunshine or shadow on a building at a particular time of year and time of day (e.g. 11.00 on the equinox), the azimuth in the plan view is constructed on the corner of the building in question. This determines the boundary of the shadow in the plan view upon which the solar altitude (effective light beam) is constructed by rotation about the azimuth line. The intersection x at right angles to the plan view shadow, translated to the elevation, provides the boundary of the shadow on the front of the building as a distance below the upper edge of the building.



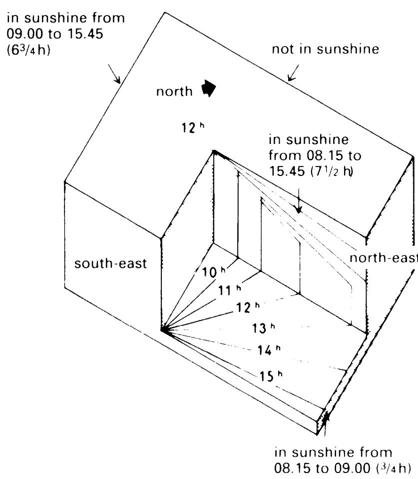
shortly after 11.00 shadow begins to form on the north-east side; shortly after 13.00 the south-east side is also in shadow, whilst the other sides are in sunlight at the corresponding times

(5) **Summer solstice**



the north-east side is in shadow shortly after 10.00, the south-east side shortly before 15.00

(6) **Equinox**



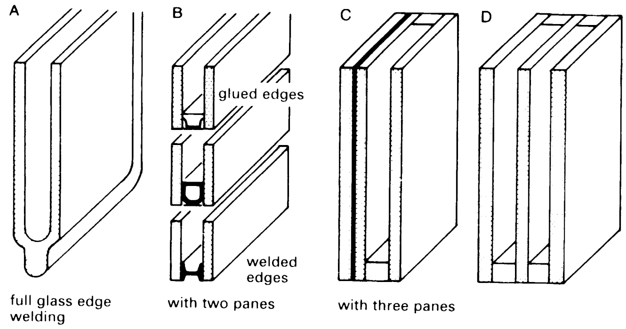
the north-east side is in the sun for barely 1h, the south-east receives shadows shortly after 15.00

(7) **Winter solstice**

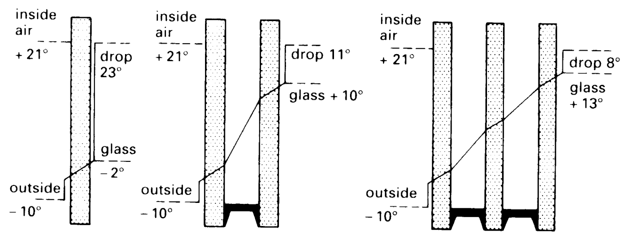
GLASS

Double/Triple Glazing

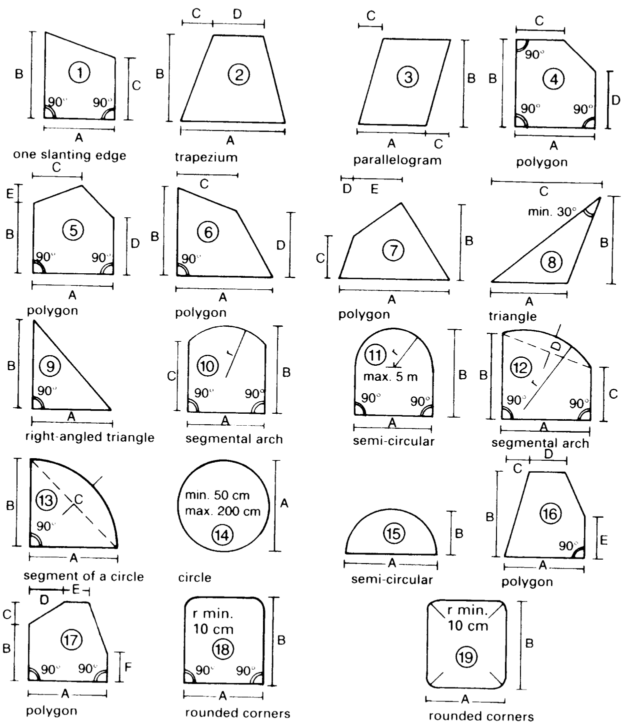
Multi-layered, insulating glazing units are manufactured out of two or more sheets of glass → ① (clear float glass, tinted and coated glass, rough cast and patterned glass) separated by one or more air- or gas-filled cavities. Multi-layered glazing units can, depending on the assembly, provide high thermal and/or sound insulation (e.g. sound-reducing units, solar protection units, heat-absorbing units, laminated glass with intermediate layers). There is dried air or a special gas in the spaces between the glass sheets. Different edge treatments define three types of units: full glass edge welding → ①A; edges welded together with inserts → ①B; glued organic edge sealing → ①C.



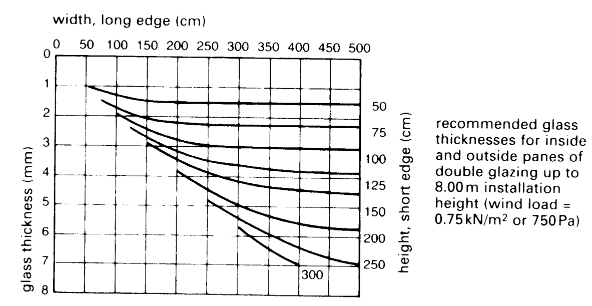
① **Multi-pane glazing units**



② **Heat transfer with single, double and triple glazing**



③ **Manufactured glazing units, possible shapes**



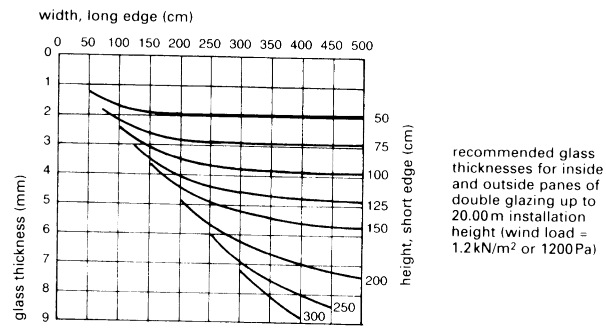
④ **Recommended thicknesses, 8 m high glass**

cavity width		double glazing with 2 × OPTIFLOAT float glass 4mm	5mm	6mm	8mm	10mm	12mm	k (W/m²K)
8	width (cm)	141	185	185	300	300	300	3.2
	height (cm)	240	300	500	500	500	500	
	surface area (m²)	3.4	5.5	9.2	15.0	15.0	15.0	
	aspect ratio	1:6	1:10	1:10	1:10	1:10	1:10	
	overall thickness (mm)	16	18	20	24	28	32	
10	width (cm)	141	245	280	300	300	300	3.1
	height (cm)	240	300	500	500	500	500	
	surface area (m²)	3.4	7.3	14.0	15.0	15.0	15.0	
	aspect ratio	1:6	1:10	1:10	1:10	1:10	1:10	
	overall thickness (mm)	18	20	22	26	30	34	
12	width (cm)	141	245	280	300	300	300	3.0
	height (cm)	141	245	280	300	300	300	
	surface area (m²)	3.4	7.3	14.0	15.0	15.0	15.0	
	aspect ratio	1:6	1:10	1:10	1:10	1:10	1:10	
	overall thickness (mm)	20	22	24	28	32	36	
thickness tolerance (mm)		± 1.0	± 1.0	± 1.0	± 1.0	± 1.0	± 1.0	
size tolerance (mm)		± 1.5	± 2.0	± 2.0	± 2.0	± 2.0	± 2.0	
weight (kg/m²)		20	25	30	40	50	60	

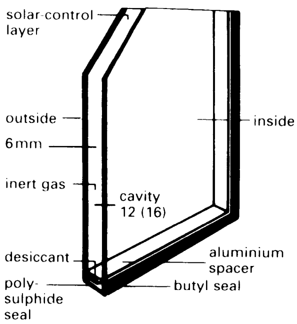
⑤ **Double glazing**

build-up OPTIFLOAT (mm) cavity width (mm)	4 4 4 (8.5) (8.5)	5 5 5 (8.5) (8.5)	4 4 4 (6) (6)	5 5 5 (6) (6)
k value (W/m²K)	1.9	1.9	2.0	2.0
light transmittance (%)	74	72	74	72
unit thickness (mm)	29	32	24	27
max. edge length (cm)	141 × 240	180 × 240	141 × 240	180 × 240
min. size (cm²)	24 × 24	24 × 24	24 × 24	24 × 24
aspect ratio	1:6	1:6	1:6	1:6
max. area (m²)	3.4	3.4	3.4	3.4
weight (kg/m²)	ca. 30	ca. 38	ca. 30	ca. 38
thickness tolerance: −1mm +2mm		size tolerance: ± 2.0 mm		

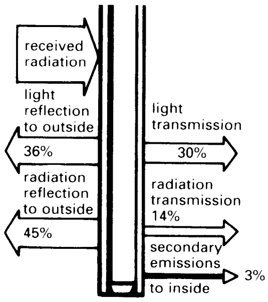
⑥ **Triple glazing**



⑦ **Recommended thicknesses, 20 m high glass**



(1) **Solar control double glazing**



(2) **Solar control double glazing (gold 30/17)**

type	light transmittance, T_L (%)	light reflection outside/inside, R_L (%)		UV transmittance, T_{UV} (%)	k value (W/m²K)	total energy transmittance, g (%)	mean transmittance value, b	selectivity code, S	max. dimensions (cm × cm)
titanium									
66/43	66	21	18	17	1.4	43	0.49	1.53	260×500
auresin									
66/44	66	15	11	7	1.4	44	0.50	1.50	240×340
50/32	50	19	16	9	1.5	32	0.37	1.56	240×340
49/32	49	38	36	10	1.4	32	0.37	1.53	260×500
45/39	45	30	17	11	1.5	39	0.45	1.15	240×340
40/26	40	32	22	8	1.3	26	0.30	1.54	240×340
39/28	39	26	11	9	1.4	28	0.32	1.40	240×340
gold									
40/26	40	25	36	11	1.4	26	0.30	1.54	240×340
30/23	30	18	40	11	1.4	23	0.26	1.30	240×340
silver									
50/35	50	40	35	14	1.4	35	0.40	1.43	240×340
50/30	50	37	34	18	1.3	30	0.34	1.67	260×500
49/43	49	36	22	14	1.5	43	0.49	1.14	240×340
48/48	48	39	21	13	1.5	48	0.55	1.00	240×340
37/32	37	40	14	8	1.5	32	0.37	0.16	240×340
36/33	36	46	26	8	1.4	33	0.38	1.09	240×340
36/22	36	48	45	9	1.2	22	0.25	0.68	240×340
15/22	15	26	42	8	2.6	22	0.25	0.68	200×340
bronze									
49/23	49	16	35	12	1.4	33	0.38	1.48	240×340
36/26	36	26	46	8	1.4	26	0.30	1.38	240×340
neutral									
51/39	51	11	30	15	1.6	39	0.45	1.31	240×340
51/38	51	16	10	18	1.6	38	0.44	1.34	300×500
green									
37/20	37	25	36	3	1.4	20	0.23	1.85	260×500
38/28	38	34	17	8	1.4	28	0.32	1.36	240×340
grey									
47/51	47	6	22	27	2.9	51	0.59	0.92	240×340
43/39	43	7	17	18	1.5	39	0.45	1.09	240×340
clear glass (for comparison)	78	15	15	98	3.0	72	0.83	1.08	

(3) **Solar control double glazing**

Solar Control Double Glazing

Solar control double glazing is characterised by a high light transmittance and an energy transmittance which is as low as possible. This is achieved by a very thin layer of precious metal deposited on the protected inside layer of one of the panes. Apart from its solar control qualities, solar control double glazing fulfils all the requirements of highly insulating double glazing, with k values up to 1.2 W/m²K. The choice of a wide range of colours and colourless tones, augmented by the availability of colour-matched single- and double-glazed façade panels, presents many design opportunities. Solar control glass can be combined with sound-reduction glass, armoured glass, laminated glass, safety glass or ornamental/cast glass as either internal or external sheets. A combination with wired glass is not possible.

Each glass type is identified by colour (as seen from the outside) as well as by a pair of values: the first is the light transmittance and the second the total energy transmittance, and both are given as percentages. Example: auresin (= blue) 40/26.

Light transmittance T_L in the 380–780 nm (nanometres) wavelength band, based on the light sensitivity of the human eye (%).

Light reflection R_L from outside and inside (%).

Colour rendering index R_a:

$R_a > 90$ = very good colour rendering;

$R_a > 80$ = good colour rendering.

UV transmittance T_{UV} in the 320–2500 nm wavelength band is the sum of the direct energy transmission and the secondary heat emission (= radiation and convection) towards the inside.

The b value is the mean transmittance factor of the sun's energy based on an energy transmission of a 3 mm thick single pane of glass of 87%. Accordingly:

$$b = \frac{g\,(\%)}{87\%}$$

where g is the total energy transmittance.

Selectivity code S. $S = T_L/g$. A higher value for the selectivity code S shows a favourable relationship between light transmittance (T_L) and the total energy transmittance (g).

The thermal transmittance k of a glazing unit indicates how much energy is lost through the glass. The lower this value, the lower the heat loss. The k value of conventional double-glazing units is greatly dependent on the distance between the two sheets of glass and the contents of the cavity (air or inert gas). With solar-control glass, an improved k value is achieved because of the precious metal layer. Standard k values are based on a glass spacing of 12 mm.

Generally, colour rendering seems unaltered when looking through a glass window from inside a room. However, if a direct comparison is made between looking through the glass and through an open window, the slight toning produced by most glass is perceptible. Depending on the type of glass, this is usually grey or brown. This difference can also be seen when looking from outside a room through two panes set at a corner. The interior colour climate is only marginally effected by solar-control glazing since the spectral qualities of the daylight barely change. Colour rendering is expressed by the R index.

Multifunctional Double-Glazing Units

Owing to the increasing demands being placed on façade elements, glazing is required to provide a wide range of functions: thermal insulation, sound reduction, solar control, personal security, fire protection, aesthetic and design aspects, environmental protection and sustainability. These functions demand an increased protection element which cannot be provided by conventional double glazing.

Multifunctional double-glazing units can combine several protection properties, and it is technically possible to fulfil almost all of those listed above. However, a standard multifunctional double-glazing unit is not yet commercially available → (4).

build-up: glass/cavity/glass	unit thickness	thermal insulation, k_V value	sun control, g value	energy balance, k value	sound reduction, R_W	colour rendering, R_{aD}	security	aesthetics	environmental protection
mm	mm	W/m²K	%	W/m²K	dB	–	–	–	–
TG* 6/16/4	26	1.2	43	0.68	36	98	yes	yes	yes

*TG = toughened glass

(4) **Examples of multifunctional glass**

TG combinations		float 4	float 5	float 6	float 8	float 10	TG 4	TG 5	TG 6	TG 8	TG 10	LG 6	LG 8	LG 10	LG 12
glass thickness (mm)	4	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200	100× 200
	5	120× 240	120× 300	120× 300	120× 300	120× 300	100× 300	120× 300	120× 300	120× 300	120× 300	120× 300	120× 300	120× 300	120× 300
	6	141× 240	210× 300	210× 360	210× 360	210× 360	100× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360
	8	141× 240	210× 300	210× 360	210× 360	210× 360	100× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360
	10	141× 240	210× 300	210× 360	210× 360	210× 360	100× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360	210× 360

TG = toughened glass, LG = laminated glass

① **Normal maximum sizes of glazing units using toughened glass (cm)**

LG combinations		float 4	float 5	float 6	float 8	float 10	TG 4	TG 5	TG 6	TG 8	TG 10	LG 6	LG 8	LG 10	LG 12
glass thickness (mm)	6	141× 240	225× 300	225× 321	225× 321	225× 321	100× 200	120× 300	210× 321	210× 321	210× 321	225× 321	225× 321	225× 321	225× 321
	8	141× 240	225× 300	225× 400	225× 400	225× 400	100× 200	120× 300	210× 360	210× 360	210× 360	225× 321	225× 400	225× 400	225× 400
	10	141× 240	225× 300	225× 400	225× 400	225× 400	100× 200	120× 300	210× 360	210× 360	210× 360	225× 321	225× 400	225× 400	225× 400
	12	141× 240	225× 300	225× 400	225× 400	225× 400	100× 200	120× 300	210× 360	210× 360	210× 360	225× 321	225× 400	225× 400	225× 400

TG = toughened glass, LG = laminated glass

② **Normal maximum sizes of glazing units using laminated glass (cm)**

Toughened (tempered) glass

Toughened safety glass is a pre-stressed glass. Pre-stressing is achieved by thermal treatment. The production method consists of rapid heating followed by rapid cooling with a blast of cold air. In comparison to float glass, which produces sharp, dagger-like glass splinters when broken, this glass breaks into small, mostly round-edged glass crumbs. The danger of injury is thus greatly reduced. Toughened glass has the further advantages of increased bending and impact-resistant qualities and tolerance to temperature change (150 K temperature difference, and up to 300°C compared with 40°C for annealed material. It is also unaffected by sub-zero temperatures). Toughened glass also has enhanced mechanical strength (up to five times stronger than ordinary glass), so it can be used in structural glazing systems. Alterations to, and work on, toughened glass is not possible after production. Even slight damage to the surface results in destruction. However, tempered safety glass can be used in conventional double-glazing units → ①.

Areas of use: sports buildings (ball impact resistant); school and playschool buildings because of safety considerations; living and administration buildings for stairways, doors and partitions; near radiators to avoid thermal cracking; for fully glazed façades, and elements such as glazed parapets and balustrades on balconies and staircases to prevent falls.

Laminated glass

During the manufacture of laminated glass, two or more panes of float glass are firmly bonded together with one or more highly elastic polyvinylbutyral (PVB) films. Alternatively, resin can be poured between two sheets of glass which are separated by spacers, and the resin is then cured. This process is called cast-in-place (CIP). The normal transparency of the glass may be slightly reduced depending on the thickness of the glass. Laminated glass is a non-splintering glass as the plastic film(s) hold the fragments of glass in place when the glass is broken, thus reducing the possibility of personal injury to a minimum.

There are several categories of laminated glass: safety glass, anti-bandit glass, bullet-resistant glass, fire-resistant glass and sound-control glass. The thickness and the number of layers of glass, and the types of interlayer, are designed to produce the required properties.

Laminated safety glass

Laminated safety glass normally consists of two layers of glass bonded with polyvinylbutyral (PVB) foil. This is a standard product which is used to promote safety in areas where human contact and potential breakage are likely. The tear-resistant foil makes it difficult to penetrate the glass, thus giving enhanced security against breakage and break-in. Even when safety glass is broken, the security of the room is maintained. Laminated safety glass is always used for overhead glazing for safety and security reasons → ②. Building regulations insist on its use in certain situations.

Areas of use: glazed doors and patio doors; door side-lights; shops; all low-level glazing; balustrades; bathing and shower screens; anywhere that children play and may fall against the glass, or where there is a high traffic volume, e.g. entrance areas in community buildings, schools and playschools.

Laminated anti-bandit glass

Laminated anti-bandit glass is the most suitable material for providing complete security in protective glazing systems. Anti-bandit glass can be made with two glass layers of different thicknesses bonded with PVB foil, or with three or more glass layers of different glass thicknesses bonded with standard or reinforced PVB foil. Additional security can be provided by incorporating alarm bands, or wires connected to an alarm system.

One side of this glass will withstand repeated blows from heavy implements such as bricks, hammers, crowbars, pickaxes etc. There may be crazing in the area of impact, but the tough, resilient PVB interlayers absorb the shock waves, stop any collapse of the pane and prevent loose, flying fragments of glass. Even after a sustained attack, the glass continues to provide visibility and reassurance, as well as protection from the elements. Additional security can be achieved by bonding the glass to the framing members so that the frame and the glass cannot be separated during an attack. Normally, the side of the expected attack is the external side. Only in law courts should the side of the expected attack be on the inside. It is not permissible to change the orientation of the glazing without good reason.

Areas of use: shops; display cases; museums; kiosks and ticket offices; banks; post offices; building societies; wages and rent offices; etc.

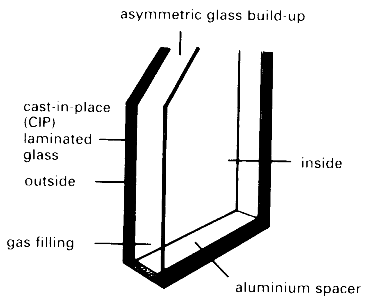
Blast-resistant glass

Safety and anti-bandit glass can also be used to provide protection against bomb attack and blast. The glass performs in two ways. First, it repels any bomb which is thrown at it, causing it to bounce back at the attacker, and second, under the effects of a blast it will deform and crack, but the glass pieces remain attached, reducing the likelihood of flying splinters.

Bullet-resistant glass

For protection against gunshots, a build-up of multiple layers is required, the overall thickness (20–50 mm) depending on the classification required. This glass incorporates up to four layers of glass, some of different thicknesses, interlayered with PVB. When attacked, the outer layers on the side of the attack are broken by the bullet and absorb energy by becoming finely granulated. The inner layers absorb the shock waves. A special reduced-spalling grade of glass can be used to minimise the danger of glass fragments flying off from the rear face of the glass. Even after an attack, barrier protection is maintained and visibility (apart from the impact area) is unaffected. Bullet-resistant classifications are based on the type of weapon and calibre used, e.g. handgun, rifle or shotgun.

Areas of use: banks; post offices; building societies; betting offices; wages and rent offices; cash desks; security vehicles; embassies; royal households; political and government buildings; airports; etc.



- weight of glass: the heavier the glass pane, normally the higher the acoustic insulation
- the more elastic the pane (e.g. resin-filled cast-in-place), normally the higher the acoustic insulation
- the thicknesses of the inner and outer panes must be different; the greater the difference, normally the higher the acoustic insulation

(1) **Sound-control double-glazing unit**

type	build-up outside, cavity inside	thickness	weight	k value, gas-filled	light transmittance	gen. colour rendering index	g value	sound reduction, R_w	max. edge length	max. area	max. side prop.	shading coeff.
	mm	mm	kg/m²	W/m²K	%	–	%	dB	cm	m²	–	–
37/22	6/12/4	22	25	2.9	82	97	75	37	300	4.0	1:6	0.86
39/24	6/14/4	24	25	2.9	82	97	75	39	300	4.0	1:6	0.86
40/26	8/14/4	26	30	2.9	81	97	72	40	300	4.0	1:6	0.83
43/34	10/20/4	34	35	3.0	80	96	69	43	300	4.0	1:6	0.79
44/38	10/24/4	38	35	3.0	80	96	69	44	300	4.0	1:6	0.79

(2) **Sound-control double-glazing units**

type	build-up outside, cavity inside	thickness	weight	k value, gas-filled	light transmittance	gen. colour rendering index	g value	sound reduction, R_w	max. edge length	max. area	max. side prop.	shading coeff.
	mm	mm	kg/m²	W/m²K	%	–	%	dB	cm	m²	–	–
45/30 CIP	CIP 9.5/ 15/6	30	40	3.0	78	97	64	45	200× 300	6.0	1:10	0.74
47/36 CIP	CIP 10/ 20/6	36	40	3.0	78	97	64	47	200× 300	6.0	1:10	0.74
50/40 CIP	CIP 10/ 20/10	40	50	3.0	77	95	62	50	200× 300	6.0	1:10	0.71
53/42 CIP	CIP 12/ 20/10	42	55	3.0	75	95	60	53	200× 300	6.0	1:10	0.69
55/50 CIP	CIP 20/ 20/10	50	75	3.0	72	93	54	55	200× 300	6.0	1:10	0.62

(3) **Super sound-control double-glazing units**

Fire-resistant glass

Fire resistance can be built up in two ways. One is a laminated combination of Georgian wired glass and float glass (or safety or security glass) with a PVB interlayer. The other way is to incorporate a transparent intumescent layer between the pre-stressed borsilicate glass sheets which, when heated, swells to form an opaque, fire-resistant barrier. Fire resistance of up to 2 h can be achieved. It must be remembered that in any given situation, the performance of the glazing depends on adequate support during the 'period of stability' prior to collapse.

Areas of use: fire doors; partitions; staircase enclosures; rooflights and windows in hospitals; public buildings; schools; banks; computer centres; etc. (→ pp. 130–31.)

Structural glazing

There is an increasing demand for large, uninterrupted areas of glass on façades and roofs, and it is now possible to use the structural properties of glass to support, suspend and stiffen large planar surfaces. Calculation of the required glass strengths, thicknesses, support systems and fittings to combat structural and wind stresses has become a very specialised area (consult the glass manufacturer). A wide variety of glass types may be used, e.g. toughened and laminated, single and double glazed, with solar control or with thermal recovery twin glass walls. Panels as large as 2 m × 4.2 m are possible. These are attached at only four, six or eight points and can be glazed in any plane, enabling flush glazing to sweep up walls and slopes and over roofs in one continuous surface. Various systems have been used to create stunning architectural effects on prestigious buildings throughout the world, even in areas which are prone to earthquakes, typhoons and hurricanes. Dimensional tolerances tend to be very small. For example, in a project for an art gallery in Bristol, UK, a tolerance of ±2 mm across an entire frameless glass façade 90 m long and 9 m high has been achieved. The 2.7 m × 1.7 m glass façade panels are entirely supported on 600 mm wide structural glass fins.

Sound-control glass → (1) – (3)

Compared with monolithic glass of the same total thickness, all laminated glass specifications provide an increased degree of sound control and a more consistent acoustic performance. The multiple construction dampens the coincident effect found in window glass, thus offering better sound reduction at higher frequencies, where the human ear is particularly sensitive. The cast-in-place type of lamination is particularly effective in reducing sound transmittance.

Sealed multiple-glazed insulating units and double windows, particularly when combining thick float glass (up to a maximum of 25 mm) and thinner glass, effectively help to dampen sound.

Areas of use: windows and partitions in offices; public buildings; concert halls; etc.

Other types of glass

There are other types of glass which have been developed especially for certain situations. Shielding glass has a special coating to provide electronic shielding. Ultra-violet light-control glass has a special interlayer which reflects up to 98% of UV rays in sunlight. Various mirror-type glasses are used in surveillance situations, e.g. one-way glass (which requires specific lighting conditions) or Venetian striped mirrors with strips of silvering (any lighting conditions).

GLASS

glass pattern	colour	thickness (mm)	double-glazing unit structure: direction	double-glazing unit structure: side	max. aspect ratio with 12mm cavity	max. size (cm)
old German	yellow, clear	4	Λ	×	1:6	150 × 210
old German K, short side >250mm	clear, yellow, bronze, grey	4	×	×	1:6	150 × 210
ox-eye glass	yellow, clear	6	×	○	1:6	150 × 210
chinchilla	bronze, clear	4	Λ	×	1:6	156 × 213
Croco 129	clear	4	×	×	1:6	156 × 213
Delta	clear, bronze	4	×	×	1:6	156 × 213
Difulit 597	clear	4	×	×	1:6	150 × 210
wired Difulit 597	clear	7	×	×	1:10	150 × 245
wired glass[1]	clear	7	×	×	1:10	186 × 300
wired glass[1]	clear	9	×	×	1:10	150 × 245
wired optical	clear	9	×	○	1:10	150 × 300
wired ornamental 187 (Abstracto)	clear, bronze	7	□	○	1:10	180 × 245
wired ornamental 521, 523	clear	7	×	○	1:10	180 × 245
wired ornamental Flora 035 + Neolit	clear	7	Λ	×	1:10	180 × 245
Edelit 504, one or both sides	clear	4	Λ	×	1:6	150 × 210
Flora 035	bronze, clear	5	Λ	×	1:6	150 × 210
antique cast	yellow, grey, clear	4	×	×	1:6	150 × 210
antique cast 1074, 1082, 1086	grey	4	×	×	1:6	126 × 210
Karolit double-sided	clear	4	Λ	×	1:6	150 × 210
cathedral large and small hammered	clear	4	×	×	1:6	150 × 210
cathedral 102	yellow	4	×	×	1:6	150 × 200
cathedral 1074, 1082, 1086	grey	4	×	×	1:6	150 × 210
basket weave	clear, yellow	4	Λ	○	1:6	150 × 210
beaded 030	clear	5	Λ	×	1:6	150 × 210
Listral	clear	4	Λ	○	1:6	150 × 210
Maya	clear, bronze	5	×	○	1:6	156 × 213
Maya opaque	clear, bronze	5	×	○	1:6	156 × 213
Neolit	clear	4	Λ	○	1:6	150 × 210
Niagra	yellow, bronze, clear	5	Λ	○	1:10	156 × 213
Niagra opaque	clear	5	Λ	×	1:10	156 × 213
ornament 134 (Nucleo)	bronze, clear	4	Λ	×	1:6	150 × 210
ornament 178 (Silvit)	bronze, clear	4	Λ	×	1:6	150 × 210
ornament 187 (Abstracto)	yellow, bronze, clear	4	□	○	1:6	150 × 210
ornament 502, 504, 520	clear	4	×	×	1:6	150 × 210
ornament 521, 523	clear	4	×	○	1:6	150 × 210
ornament 523	yellow	4	×	×	1:6	150 × 210
ornament 528	clear	4	×	○	1:6	150 × 210
ornament 550, 552, 597	clear	4	×	×	1:6	150 × 210
patio	bronze, clear	5	Λ	○	1:10	156 × 213
hammered crude glass	clear	5	×	×	1:10	186 × 300
hammered crude glass	clear	7	×	×	1:10	186 × 450
Tigris 003	clear	5	Λ	×	1:6	150 × 210

□ = structured surface either way × = structured surface either side
Λ = structured surface vertical ○ = structured surface outside only
[1] wired glass in rooflights, max. aspect ratio 1:3

(1) **Cast glass combinations**

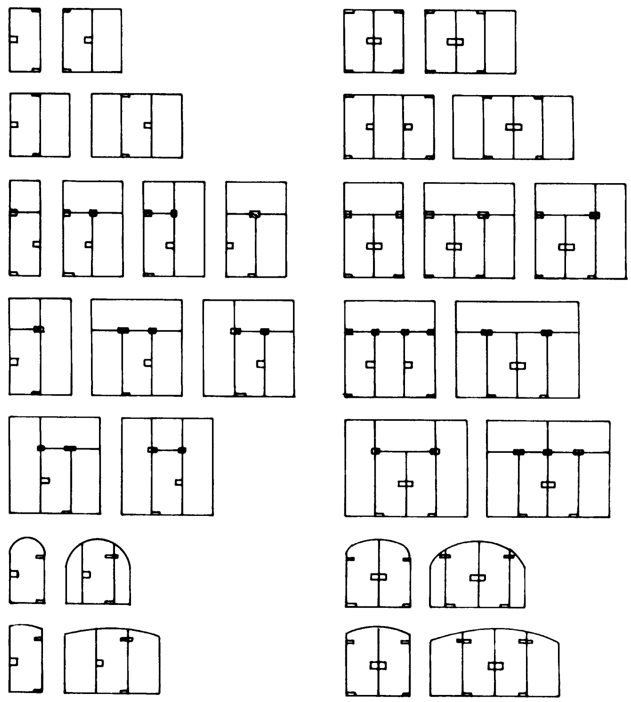
The term cast glass is given to machine-produced glass which has been given a surface texture by rolling. It is not clearly transparent → (1). Cast glass is used where clear transparency in not desired (bathroom, WC) and where a decorative effect is required. The ornamental aspects of cast glass are classified as clear and coloured ornamental glass, clear crude glass, clear and coloured wired glass, and clear and coloured ornamental wired glass. Almost all commercially available cast glass can be used in double-glazing units → (1).

Normally, the structured side is placed outside in order to ensure a perfect edge seal. So that double-glazing units may be cleaned easily, the structured side is placed towards the cavity. This is possible only with lightly structured glass. Do not combine coloured cast glass with other coloured glasses such as float, armoured or laminated glass, or with coated, heat-absorbing or reflective glass.

glass type	nominal thickness (mm)	tolerance (mm)	max. dimensions (cm × cm)	
agricultural glass (standard sizes)	3	±0.2	48 × 120 46 × 144	73 × 143 73 × 165
	4	±0.3	60 × 174	60 × 200

(2) **Agricultural glass**

Glass entrance screens consist of one or several glass doors, and the side and top panels. Other possibilities are sliding, folding, arched and half-round headed entrance screens. Various colours and glass structures are available. The dimensions of the doors are the same as those of the frame → (3) – (5). When violently smashed, the glass disintegrates into a network of small crumbs which loosely hang together. Normal glass thicknesses of 10 or 12mm are used, and stiffening ribs may be necessary, depending on the structural requirements.



(3) **Single-leaf doors** **Double-leaf doors**

	size I	size II	size III
standard door leaf, overall dimensions	709 × 1972 mm²	834 × 1972 mm²	959 × 1972 mm²
frame rebate dimensions	716 × 1983 mm²	841 × 1983 mm²	966 × 1983 mm²
structural opening sizes	750 × 2000 mm²	875 × 2000 mm²	1000 × 2000 mm²

special sizes are possible up to dimensions of:

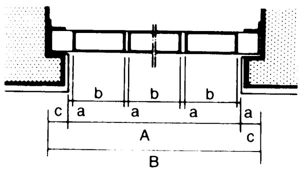
1000 × 2100 mm²
1150 × 2100 mm²

(4) **Glass doors, standard sizes**

glass type	glass thickness (mm)	maximum sizes (mm²)	thickness tolerances (mm)
clear, grey, bronze	10 12	2400 × 3430 2150 × 3500*	± 0.3
OPTIWHITE®	10 10	2400 × 3430 2150 × 3500*	± 0.3
structure 200	10 10	1860 × 3430 1860 × 3500*	± 0.5
bamboo, chinchilla clear/bronze	8 8	1700 × 2800 1700 × 3000*	± 0.5

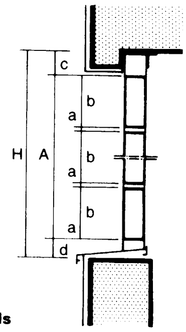
(5) **Glass entrance screens (side and top panels)**

Glass Blocks

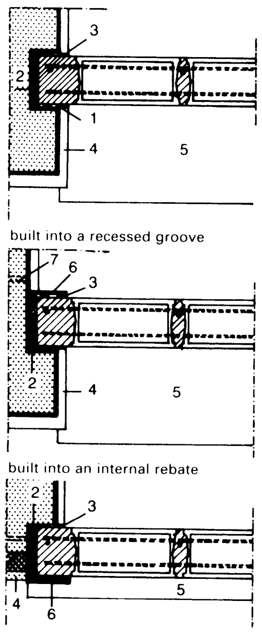


$A = n_1 \cdot b + n_2 \cdot a$ n_1 = number of blocks (a)
$B = A + 2 \cdot c$ n_2 = number of joints (b)
$H = A + c + d$ c = 8.5cm
d = 6.5cm

formula to calculate the minimum structural opening



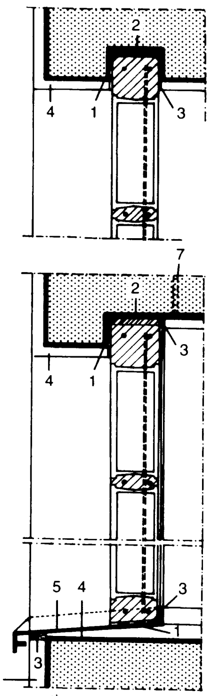
(1) **Standard dimensions for glass block walls**



built onto a façade with angle anchoring

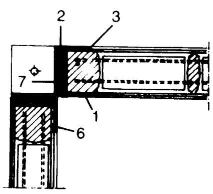
plan

1 slip joint
2 expansion joint, e.g. rigid foam
3 flexible sealing
4 plaster
5 aluminium window sill
6 L section
7 anchor or peg



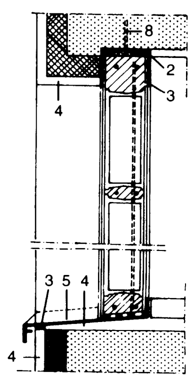
section

(2) **Constructional examples of glass block walls**



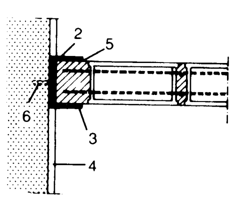
plan of corner detail

1 slip joint
2 expansion joint, e.g. rigid foam
3 flexible sealing
4 plaster
5 aluminium window sill
6 U section
7 L section
8 anchor or peg



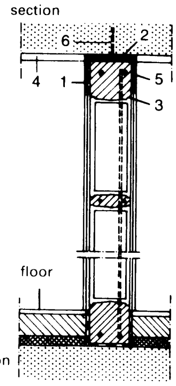
section

(3) **Installation with U sections and external thermal insulation**



plan

1 slip joint
2 expansion joint, e.g. rigid foam
3 flexible sealing
4 plaster
5 U section
6 anchor or peg

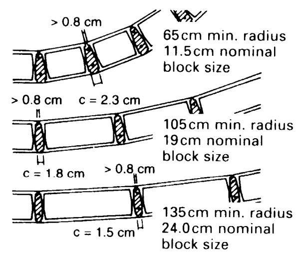


section

(4) **Internal wall junction using U sections**

Glass blocks are hollow units which consist of two sections melted and pressed together, thereby creating a sealed air cavity. Both surfaces can be made smooth and transparent, or very ornamental and almost opaque. Glass blocks can be obtained in different sizes, coated on the inside or outside, uncoated, or made of coloured glass. They can be used internally and externally, e.g. transparent screen walls and room dividers (also in gymnastic and sports halls), windows, lighting strips, balcony parapets and terrace walls. Glass blocks are fire-resistant up to G 60 or G 120 when used as a cavity wall with a maximum uninterrupted area of 3.5 m², and can be built either vertically or horizontally. Glass blocks cannot be used in a load-bearing capacity.

Properties: good sound and thermal insulation; high light transmittance (up to 82%), depending on the design; can have translucent, light scattering and low dazzle properties; can also have enhanced resistance to impact and breakage. A glass block wall has good insulation properties: with cement mortar, k = 3.2 W/m²K; with lightweight mortar, k = 2.9 W/m²K.



smallest radius R with glass thickness 8cm joints must be < 1.0cm wide			
glass block nominal size	11.5cm	19.0cm	24.0cm
joint width c = 1.5cm	200.0cm	295.0cm	370.0cm
joint width c = 1.8cm	95.0cm	180.0cm	215.0cm
joint width c = 2.3cm	65.0cm	105.0cm	135.0cm

(5) **Minimum radii of glass block walls**

	dimensions (mm)	weight (kg)	units (m²)	units, boxes	units, pallets
	115 × 115 × 80	1.0	64	10	1000
	146 × 146 × 98 6" × 6" × 4"	1.8	42	8	512
	190 × 190 × 50	2.0	25	14	504
	190 × 190 × 80	2.3	25	10	360
	190 × 190 × 100	2.8	25	8	288
	197 × 197 × 98 8" × 8" × 4"	3.0	25	8	288
	240 × 115 × 80	2.1	32	10	500
	240 × 240 × 80	3.9	16	5	250
	300 × 300 × 100	7.0	10	4	128

(6) **Dimensions of glass block walls**

arrangement of joints	thickness (mm)	wall dimensions shorter side (m)	longer side (m)	wind load (kN/m²)
vertical	≥80	≤1.5	>1.5	≤0.8
offset (bonded)			≤6.0	

(7) **Permissible limits for unreinforced glass block walls**

GLASS

Profiled glass is cast glass produced with a U-shaped profile. It is translucent, with an ornamentation on the outside surface of the profile, and conforms to the properties of cast glass.

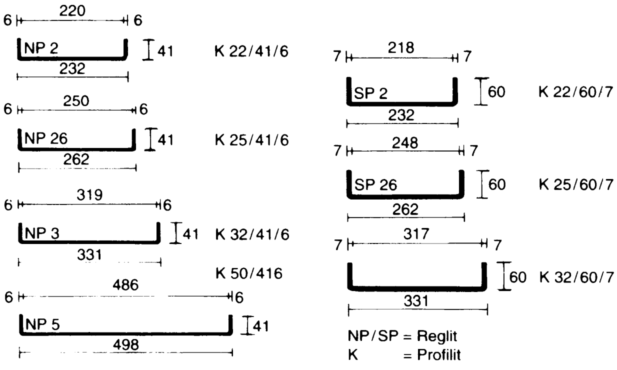
Low maintenance requirements. Suitable for lift shafts and roof glazing. Rooms using this glass for fenestration are rendered dazzle-free.

Special types: Profilit-bronze, Cascade, Topas, Amethyst. Heat-absorbing glass Reglit and Profilit 'Plus 1.7' attain a k value of 1.8 W/m²K.

Solar-control glass (Type R, 'Bernstein'; Type P, 'Antisol'), which reflects and/or absorbs ultra-violet and infra-red radiation, can be used to protect delicate goods which are sensitive to UV radiation. The transmission of radiant energy into the room is reduced, as is the convection from the glazing, whilst the light transmission is maintained.

For glazing subject to impacts, e.g. in sports halls, Regulit SP2 or Profilit K22/60/7 without wire reinforcement should be used.

Regulit and Profilit are allowed as fire-resistant glass A 30. Normal and special profiles are also available reinforced with longitudinal wires.



(1) **Profiled glass – sections**

height from ground level to top of glazed opening	up to 8 m	up to 20 m	up to 100 m	up to 8 m	up to 20 m	up to 100 m	up to 8 m	up to 20 m	up to 100 m
glass type → (1)	L*	L*	L*	L*	L*	L*	L*	L*	L*
NP2 K22/41/6	3.25	2.55	2.20	4.35	3.45	2.95	4.60	3.65	3.10
NP26 K25/41/6	3.05	2.40	2.05	4.10	3.25	2.75	4.35	3.45	2.90
NP3 K32/41/6	2.75	2.20	1.85	3.70	2.95	2.50	3.90	3.10	2.65
NP5 K50/41/6	2.30	1.80	1.55	3.05	2.40	2.00	3.25	2.55	2.15
SP2 K22/60/7	5.15	4.05	3.45	6.65	5.45	4.65	7.00	5.75	4.90
SP26 K25/60/7	4.85	3.85	3.25	6.55	5.15	4.40	6.90	5.45	4.65
K32/60/7	4.40	3.45	2.95	5.85	4.55	3.90	6.20	4.90	4.15

(2) **Sheltered buildings (0.8 – 1.25 g)**

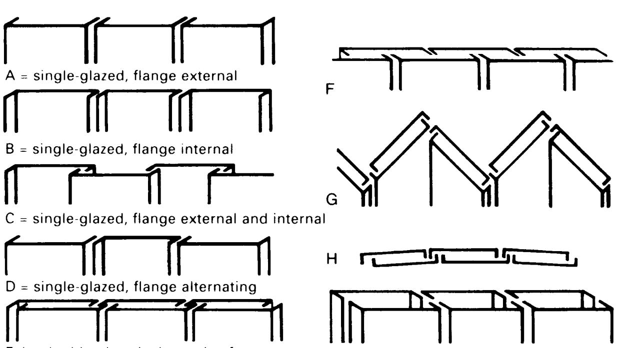
height from ground level to top of glazed opening	h/a = 0.25; –(1.5•q)						H/a = 0.5; –(1.7•q)					
	up to 8 m	up to 20 m	up to 100 m	up to 8 m	up to 20 m	up to 100 m	up to 8 m	up to 20 m	up to 100 m	up to 8 m	up to 20 m	up to 100 m
glass type → (1)	L*	L*	L*	L*	L*	L*	L*	L*	L*	L*	L*	L*
NP2 K22/41/6	2.60	2.10	1.75	3.75	2.95	2.50	2.45	1.95	1.65	3.50	2.75	2.35
NP26 K25/41/6	2.50	1.95	1.70	3.50	2.80	2.35	2.35	1.85	1.60	3.30	2.65	2.20
NP3 K32/41/6	2.20	1.75	1.50	3.15	2.50	2.15	2.10	1.65	1.45	2.95	2.35	2.00
NP5 K50/41/6	1.85	1.45	1.25	2.60	2.10	1.75	1.75	1.35	1.15	2.45	1.95	1.65
SP2 K22/60/7	4.20	3.30	2.80	5.95	4.65	3.95	3.95	3.10	2.65	5.55	4.40	3.70
SP26 K25/60/7	3.95	3.10	2.65	5.60	4.40	3.80	3.70	2.90	2.60	5.25	4.15	3.55
K32/60/7	3.60	2.80	2.40	5.00	4.00	3.40	3.35	2.65	2.25	4.75	3.75	3.20

L = length of glass units (m)

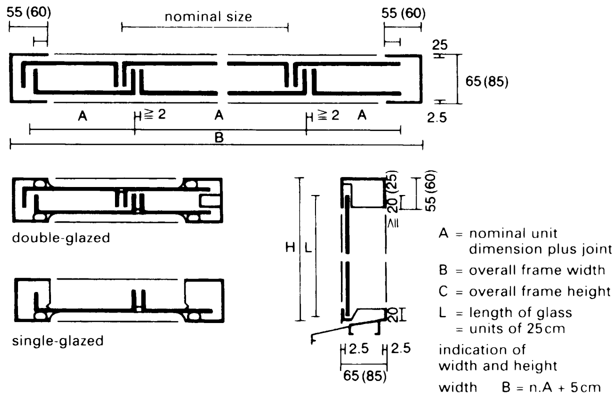
(3) **Exposed buildings**

light transmittance	single-glazed	up to 89%
	double-glazed	up to 81%
sound reduction	single-glazed	up to 29 dB
	double-glazed	up to 41 dB
	triple-glazed	up to 55 dB
thermal insulation	single-glazed	k = 5.6 W/m²K
	double-glazed	NP k = 2.8 W/m²K
		SP k = 2.7 W/m²K

(4) **Physical data**

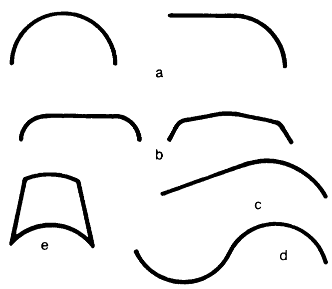


(5) **Possible combinations**



A = nominal unit dimension plus joint
B = overall frame width
C = overall frame height
L = length of glass = units of 25 cm
indication of width and height
width B = n.A + 5 cm
height H = L + 4 cm

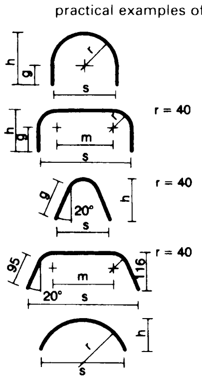
(6) **Building dimensions**



(a) single bends as sections of a circle with and without straight sections
(b) double or multiple bends with identical or different radii
(c) sine curve bends
(d) 'S' bends
(e) 'U' bends with or without straight sections

(7) **Bent forms**

practical examples of possible bent forms using ornamental glass



s	r	g	h	size*
80–300	40–150	0–100	40–190	126–501

s	m	g	h	size*
100–340	20–260	0–100	40–140	146–506

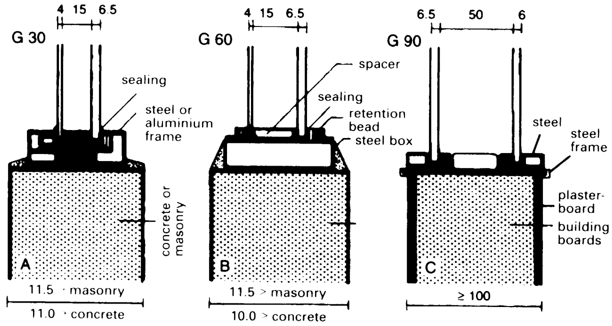
s	g	h		size*
80–200	7–183	33–200		112–464

s	m			size*
160–340	20–200			308–488

s	h	r		size*
140–300	60–100	71–163		202–382

* unfolded

(8) **Bent forms (mm)**



(1) **Glazing with fire-protection class G**

Fire-resistant glass

Normal glass is of only limited use for fire protection. In cases of fire, float glass cracks in a very short time due to the one-sided heating, and large pieces of glass fall out enabling the fire to spread. The increasing use of glass in multistorey buildings for façades, parapets and partitions has led to increased danger in the event of fire. In order to comply with building regulations, the fire resistance of potentially threatened glazing must be adequate. The level of fire resistance of a glass structure is classified by its resistance time: i.e. 30, 60, 90, 120 or 180min. The fire resistance time is the number of minutes that the structure prevents the fire and combustion gasses from passing through. The construction must be officially tested, approved and certificated → (1).

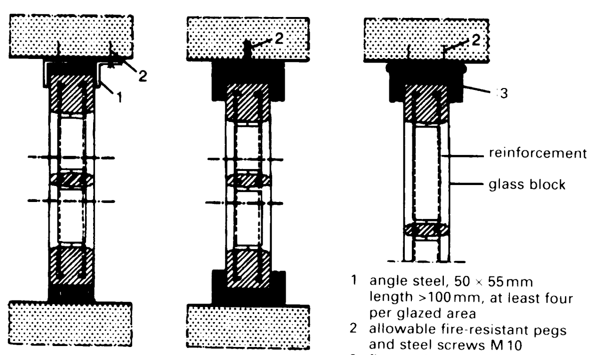
Fire-resistant glass comes in four forms: wired glass with point-welded mesh, maximum resistance 60–90min; special armoured glass in a laminated combination with double-glazing units; pre-stressed borosilicate glass, e.g. Pyran; multi-laminated panes of float glass with clear intumescent interlayers which turn opaque on exposure to fire, e.g. Pyrostop. (→ pp. 130–31)

Glass blocks with steel reinforcement

Fire-resistant, steel-reinforced glass blocks can, as with all other glass block walls, be fixed to the surrounds with or without U sections. All other types of fixing methods are also applicable. Because of the strongly linear spread of fire and the production of combustion gases, fire-resistant glass block walls should be lined all round with mineral fibre slabs (stonewool) → (3).

resistance class I	G 60	G 120	G 90	G 120	F 60
glazing size (m²)	3.5m²	2.5m²	9.0m²	4.4m²	4.4m²
max. element height	1	3.5m	3.5m	3.5m	3.5m 3.5m
max. element width	1	6.0m	6.0m	6.0m	6.0m 6.0m
sill height needed	1.8m	1.8m	none	none	none
type of glazing	single skin	double skin	single skin	double skin	double skin
glass block format	190×190×80	190×190×80	190×190×80	190×190×80	190×190×80

(2) **Fire-protection classes for glass blocks**



1 angle steel, 50 × 55mm length >100mm, at least four per glazed area
2 allowable fire-resistant pegs and steel screws M 10
3 flat steel strips to fix the glass block wall (welded)

(3) **Edge details, fire-protection glazing**

Sound reduction

Because of its weight, a glass block wall has particularly good sound insulation properties:

1.00kN/m² with 80mm glass blocks;
1.25kN/m² with 100mm glass blocks;
1.42kN/m² with special BSH glass blocks.

To be effective, the surrounding building elements must have at least the same sound reduction characteristics. Glass block construction is the ideal solution in all cases where good sound insulation is required. In areas where a high level of sound reduction is necessary, economical solutions can be achieved by using glass block walls to provide the daylight while keeping ventilation openings and windows. These can serve as secondary escape routes if they conform to the minimum allowable size.

Follow the relevant regulations with regard to sound reduction where the standards required for particular areas can be found. The sound reduction rating (R'w) can be calculated from the formula R'w = LSM + 52dB (where LSM is the reduction value of airborne sound) → (5). Single-skin glass block walls can meet the requirements of sound reduction level 5 → (6).

	type of room	permitted maximum sound levels in rooms from outside noise sources: mean levels*	mean max. levels
1	living rooms in apartments, bedrooms in hotels, wards in hospitals and sanatoriums	day 30–40dB(A) night 20–30dB(A)	day 40–50dB(A) night 30–40dB(A)
2	classrooms, quiet individual offices, scientific laboratories, libraries, conference and lecture rooms, doctors' practices and operating theatres, churches, assembly halls	30–40dB(A)	40–50dB(A)
3	offices for several people	35–45dB(A)	45–55dB(A)
4	open-plan offices, pubs/restaurants, shops, switchrooms	40–50dB(A)	50–60dB(A)
5	entrance halls, waiting rooms, check in/out halls	45–55dB(A)	55–65dB(A)
6	opera houses, theatres, cinemas	25dB(A)	35dB(A)
7	recording studios	take note of special requirements	

* equivalent maximum permitted constant level

(4) **Permitted maximum sound levels for different categories of room use**

noise source	distance from window to centre of road	recommended standard sound reduction levels for standard categories of room use: 1	2	3	4
motorways, average traffic	25m	4	3	2	1
	80m	3	2	1	0
	250m	1	0	0	0
motorways, intensive traffic	25m	5	4	3	2
	80m	4	3	2	1
	250m	2	1	0	0
main roads	8m	3	2	1	0
	25m	2	1	0	0
	80m	1	0	0	0
secondary roads	8m	2	1	0	0
	25m	1	0	0	0
	80m	0	0	0	0
main roads in city centres	small building intensive traffic	5	5	4	3
	large building average to intensive traffic	4	4	3	2

(5) **Recommended standard sound-reduction levels for standard categories of room use subjected to traffic noise**

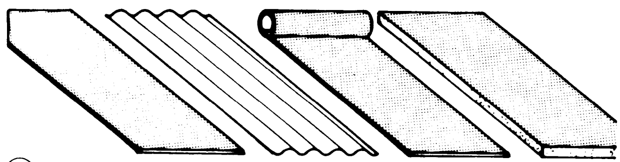
sound-reduction level	R_w	
6	≥ 50dB	for double-skinned glass block walls/windows
5	45–49dB	for single-skinned glass block areas
4	40–44dB	for single-skinned glass block areas
3	35–39dB	
2	30–34dB	
1	25–29dB	
0	≤ 25dB	

(6) **Standard sound-reduction levels for windows**

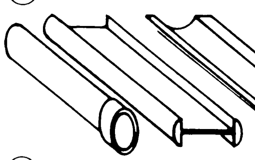
glass block format (mm)	airborne sound reduction value (LSM)	sound reduction rating (R'_w)
190 × 190 × 80	−12dB	40dB
240 × 240 × 80	−10dB	42dB
240 × 115 × 80	−7dB	45dB
300 × 300 × 100	−11dB	41dB
double-skinned wall with 240 × 240 × 80	−2dB	50dB

(7) **Glass block areas**

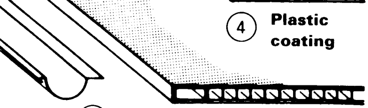
PLASTICS



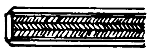
(1) **Available forms, sheet**



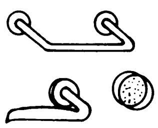
(2) **Sections**



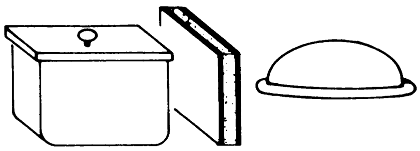
(3) **Webbed sandwich**



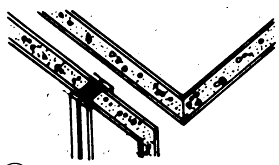
(4) **Plastic coating**



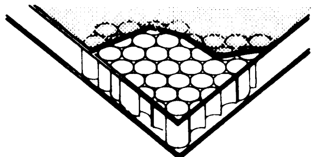
(5) **Pre-formed parts**



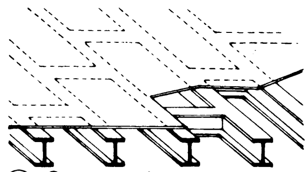
(6) **Finished parts**



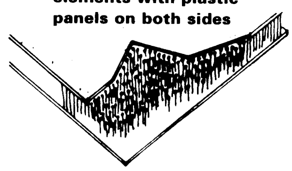
(7) **Sandwich panels**



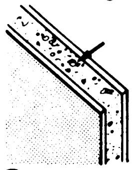
(8) **Honeycomb supporting elements with plastic panels on both sides**



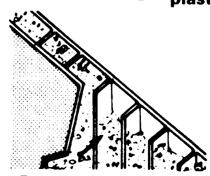
(9) **Supports with plastic sheeting**



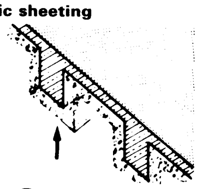
(10) **Supporting elements with plastic sheeting**



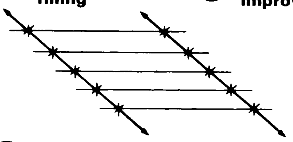
(11) **Sandwich filling**



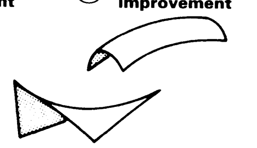
(12) **Wall improvement**



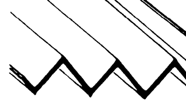
(13) **Ceiling improvement**



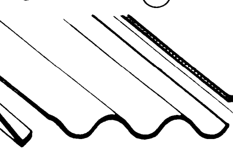
(14) **Skeletal supporting structure**



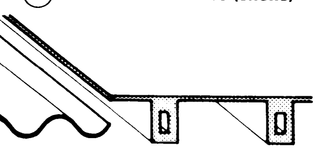
(15) **Surface structures (shells)**



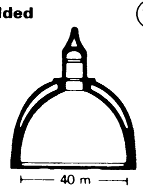
(16) **Folded**



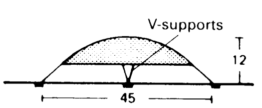
(17) **Corrugated**



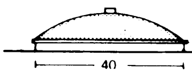
(18) **Ribbed**



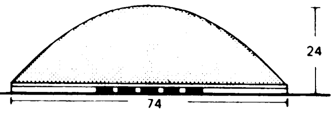
(19) **St Peter's, Rome (1585): 2600 kg/m²**



(20) **Sandwich dome, three-point support, Hanover (Jungbluth, 1970): 33 kg/m²**



(21) **Concrete shell (Schott Jena, 1925): 450 kg/m²**



(22) **Hall supported by air pressure, Forossa, Finland (1972): 1.65 kg/m²**

Plastics, as raw material (fluid, powdery or granular), are divided into three categories: (1) thermosetting plastics (which harden when heated); (2) thermoplastics (which become plastic when heated); (3) elastomers (which are permanently elastic). Plastics are processed industrially using chemical additives, fillers, glass fibres and colorants to produce semi-finished goods, building materials, finished products → (1) – (6).

The beneficial characteristics of plastics in construction include: water and corrosion resistance, low maintenance, low weight, colouring runs throughout the material, high resistance to light (depending on the type), applications providing a durable colour finish on other materials (e.g. as a film for covering steel and plywood → (4) etc.). They are also easy to work and process, can be formed almost without limits, and have low thermal conductivities.

Double-skinned webbed sections are available in a wide range of thicknesses, widths and lengths. Being translucent, these sections are suitable for roof or vertical glazing. These are permeable to light → (3).

The large number of trade names can be bewildering so designers must refer to the international chemical descriptions and symbols when selecting plastics, to ensure that their properties match those laid down in standards, test procedures and directives. The key plastics in construction, and their accepted abbreviations, are:

ABS	= acrylonitrile-butadiene-styrene	PC	= polycarbonate
CR	= chloroprene	PE	= polyethylene
EP	= epoxy resin	PIB	= polyisobutylene
EPS	= expanded polystyrene	PMMA	= polymethyl methacrylate (acrylic glass)
GRP	= glass fibre-reinforced plastic	PP	= polypropylene
GR-UP	= glass fibre-reinforced polyester	PS	= polystyrene
IIR	= butyl rubber	PVC	= polyvinyl chloride, hard or soft
MF	= melamine formaldehyde	UP	= unsaturated polyester resin
PA	= polyamide		

The plastics used to produce semi-finished materials and finished components contain, as a rule, up to 50% filling material, reinforcement and other additives. They are also significantly affected by temperature so an in-service temperature limit of between 80° and 120° should be observed. This in not a serious problem given that sustained heating to above 80° is found only in isolated spots in buildings (e.g., perhaps around hot water pipes and fires). Plastics, being organic materials, are flammable. Some are classed as a flame inhibiting structural material; most of them are normally flammable; however, a few are classed as readily flammable. The appropriate guidelines contained in the regional building regulations for the application of flammable structural materials in building structures must be followed.

Classification of plastic products for building construction

(1) Materials, semi-finished: 1.1 building boards and sheets; 1.2 rigid foam materials, core layers; 1.3 foam materials with mineral additions (rigid foam/light concrete); 1.4 films, rolls and flat sheets, fabrics, fleece materials; 1.5 floor coverings, artificial coverings for sports areas; 1.6 profiles (excluding windows); 1.7 pipes, tubes and accessories; 1.8 sealing materials, adhesives, bonding agents for mortar, etc.
(2) Structural components, applications: 2.1 external walls; 2.2 internal walls; 2.3 ceilings; 2.4 roofs and accessories; 2.5 windows, window shutters and accessories; 2.6 doors, gates and accessories; 2.7 supports.
(3) Auxiliary items, small parts, etc.: 3.1 casings and accessories; 3.2 sealing tapes, flexible foam rolls and sheets; 3.3 fixing devices; 3.4 fittings; 3.5 ventilation accessories (excluding pipes); 3.6 other small parts.
(4) Domestic engineering: 4.1 sanitary units; 4.2 sanitary objects; 4.3 valves and sanitary accessories; 4.4 electrical installation and accessories; 4.5 heating.
(5) Furniture and fittings: 5.1 furniture and accessories; 5.2 lighting systems and fittings.
(6) Structural applications; 6.1 roofs and supporting structures, illuminated ceilings; 6.2 pneumatic and tent structures; 6.3 heating oil tanks, vessels, silos; 6.4 swimming pools; 6.5 towers, chimneys, stairs; 6.6 room cells; 6.7 plastic houses.

Construction using plastics is best planned in the form of panel structures (shells). These have the advantage of very low weight, thus reducing loading on the substructure, and also offer the possibility of prefabricated construction → (14) – (17). Structures in plastics (without the use of other materials) at present only bear their own weight plus snow and wind loads, and possibly additional loads due to lighting. This allows large areas to be covered more easily → (19) – (22).