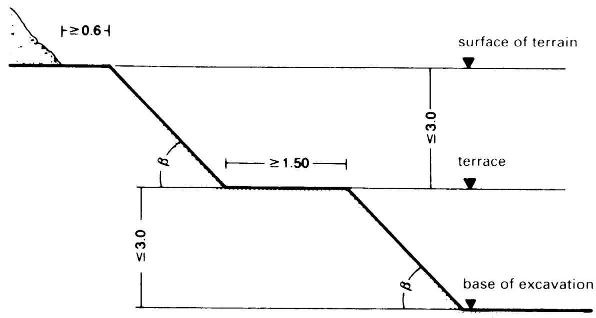
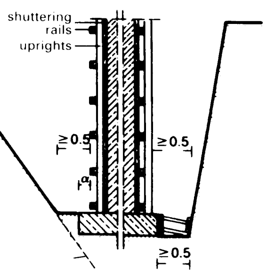
THE BUILDING SITE

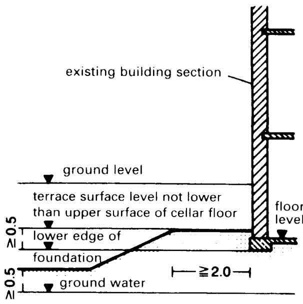
Foundations, Excavation, Trenches



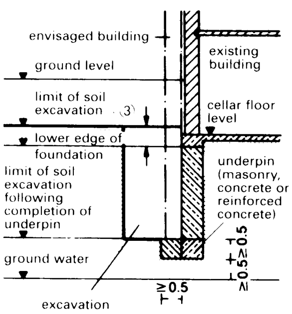
(1) **Banked excavation with terrace for the collection of precipitating material**



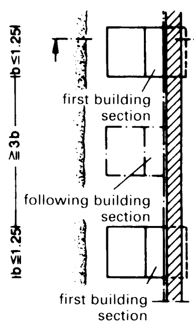
(2) **Formwork**



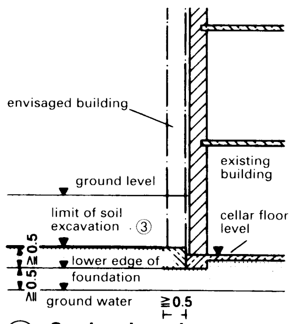
(3) **Securing existing neighbouring buildings**



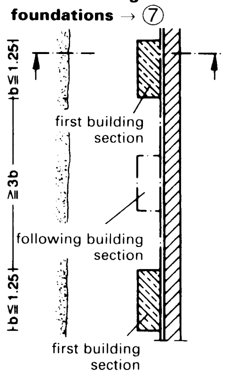
(4) **Section through underpinning** → (5)



(5) **Plan view** → (4)



(6) **Section through foundations** → (7)



(7) **Plan view** → (6)

Surveying, site investigation, appraisal

Failure to accurately assess the building site and water table conditions and to specify the correct foundations generally leads to irreparable structural damage and serious cost overruns.

Lateral ground displacement due to the load on the foundations causes the foundations to sink into the ground or become laterally displaced. This leads to total failure of the foundations.

Settlement due to compression of the building site under the foundations due to the load on the foundations and/or loads caused by neighbouring structures leads to deformations and damage (cracks) in the superstructure.

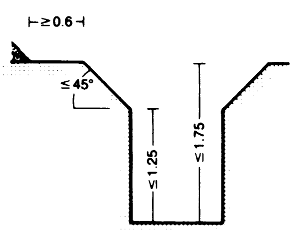
Where there is adequate local knowledge of the nature, mechanical properties, stratification and bearing strength of the sub-soil layers, calculations can be made which determine the dimensions of shallow foundations (individual and strip foundations; foundation pads and rafts) and deep foundations (pile foundations). If such knowledge is not available, timely investigation of the ground is required, if possible in consultation with an appropriate expert. This involves examination of the strata by excavation (manual or mechanical excavator), borings (auger/rotary bit or core drilling) with the extraction of samples and probes. The number and depth of inspections required depends on the topography, type of building and information available.

The depth of the ground water table can be investigated by inserting measuring pipes into boreholes and taking regular measurements (water table fluctuations). The ground water samples should also be tested to assess whether it is aggressive towards concrete (i.e. presence of sulphates, etc.).

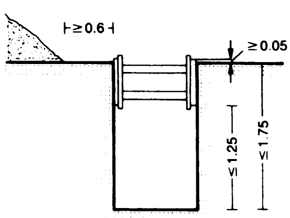
Ground probes (and sample cores) are used to investigate granular composition, water content, consistency, density, compressibility, shear strength and permeability. Probes provide continuous information on soil strength and density as they penetrate the various sub-soil layers.

All test results and the opinion of an expert site investigator should be brought to the attention of the building supervisors.

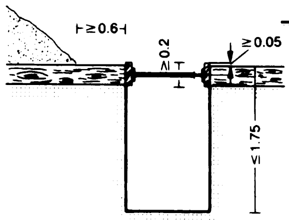
Consult local and national standards for ground (rock) descriptions, classification of earthworks, sub-soil characteristics, stratification, ground water conditions, necessary foundation/excavation depths, calculation of excavation material quantities, and construction and safety of excavations.



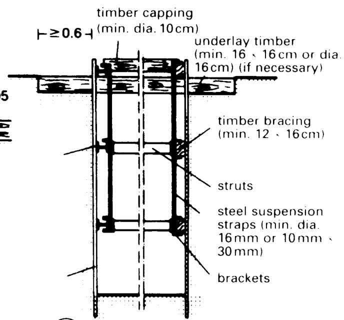
(8) **Excavation with banked edges**



(9) **Partly secured excavation**



(10) **Excavation with prop support**



(11) **Vertical sheet iron piles**

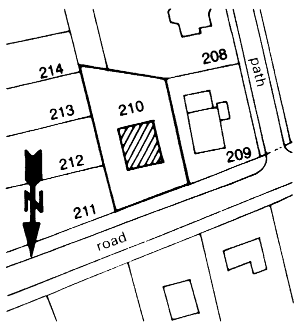
EXCAVATIONS

Site and Building Measurements

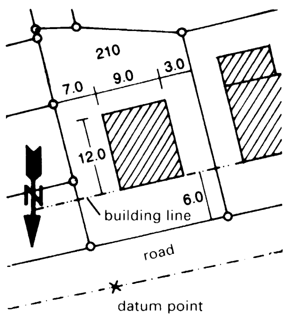
The building site must be surveyed and the plan of the proposed house entered on the official site plan → ① – ②. When the requirements of the planning and building regulations have been met and planning permission granted, the foundations are pegged out as shown by wooden pegs and horizontal site boards → ④ – ⑧. The excavation must exceed the cross-sectional area of the house to provide adequate working space ≥500 mm → ④ – ⑤. The slope of the sides of the excavation depends on the ground type; the sandier the soil, the flatter the slope → ④.

After excavation, string lines are tightly stretched between the site boards → ⑧ to mark out the external dimensions of the building. The outside corners of the house are given at the crossing points of the lines by plumb bobs. The correct level must be measured → ⑦. Dimensions are orientated by fixed points in the surroundings. Setting boards → ⑩, of wood or aluminium, 3 m long, with a level built-in or fixed on top, are installed horizontally with the ends supported on posts. Intermediate contour heights are measured with a scaled rod.

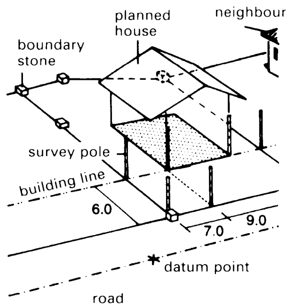
A water-filled, transparent, flexible hose 20–30 m long, with glass tube sections at each end marked out in mm, when held vertically, is used to read water levels. After calibrating by holding both glass tubes together, levels between points on the site can be compared accurately to the mm, without the need for visual contact (e.g. in different rooms).



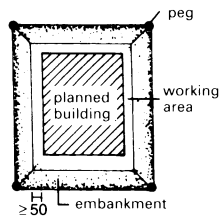
① **Official site plan**



② **Site plan with the building dimensions drawn in**

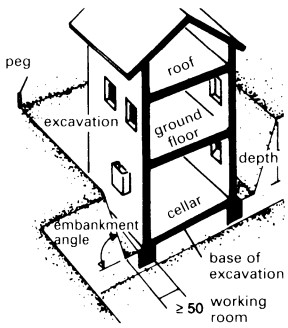


③ **The planned house in relation to the site**

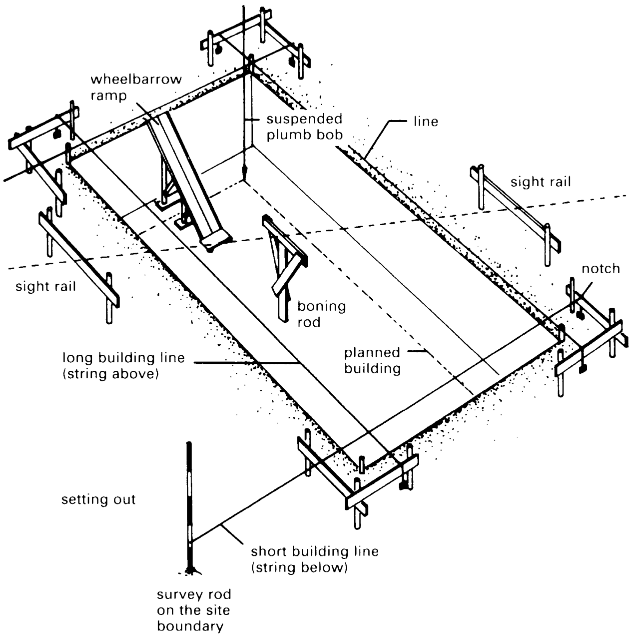


type of ground	embankment angle
loose soil	40°
medium loose soil	40°
firm soil	60°
loose and firm rock	80°

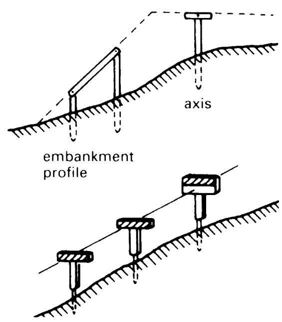
④ **Excavation**



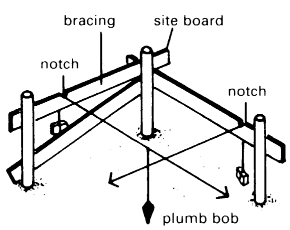
⑤ **The house in the excavation**



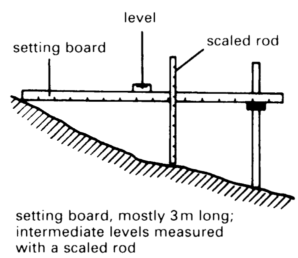
⑧ **Setting out: how the building is measured into place → ⑨**



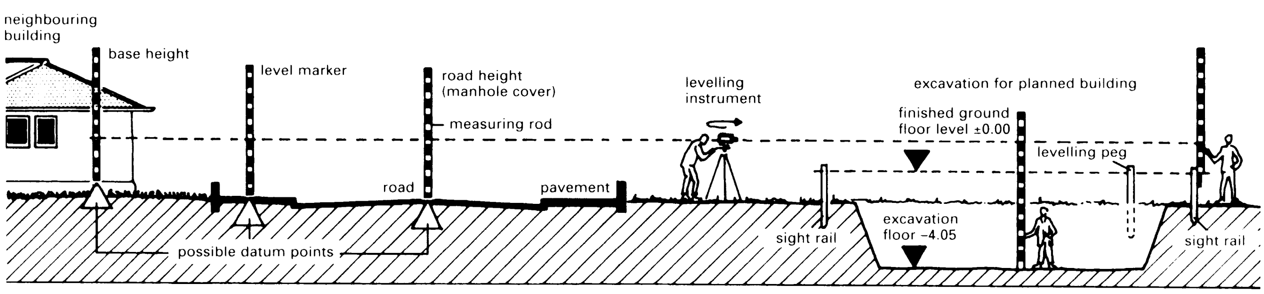
⑥ **Boning rods**



⑨ **Corner site boards**

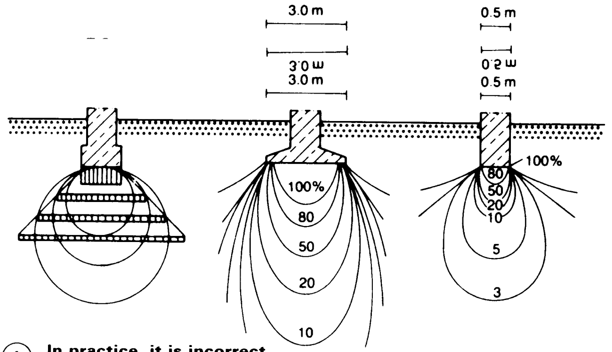


⑩ **Setting board**



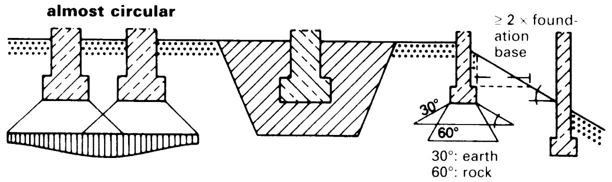
⑦ **Measuring levels for the building**

EARTHWORKS AND FOUNDATION STRUCTURES



① In practice, it is incorrect to assume that pressure is distributed at an angle of 45° or less; lines of equal pressure (isobars) are almost circular

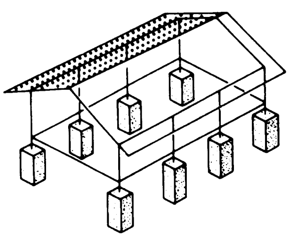
②-③ Wide foundations result in higher stresses than thinner ones with the same base pressure



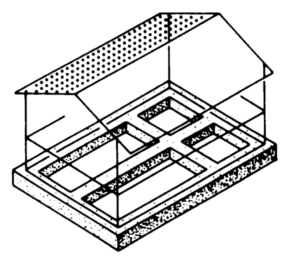
④ Intersection of foundation influence lines causes danger of settlement and crack formation (important when new building is adjacent to old building)

⑤ Foundations on a sand filling of 0.8–1.20 m high, applied in layers of 15 cm in a slurry; the load is distributed over a larger area of the site

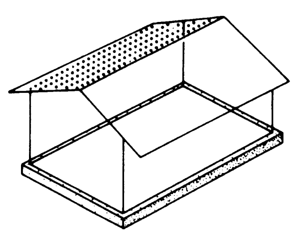
⑥ Foundations on a hillside: lines of pressure distribution = angle of slope of the ground



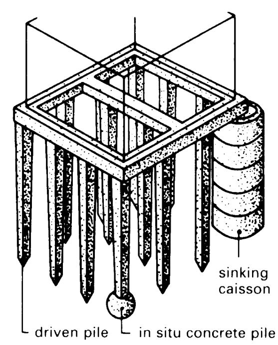
⑦ Individual foundations for light buildings without cellars



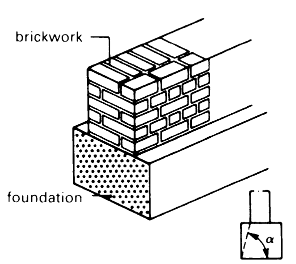
⑧ Strip foundations are most frequently used for building



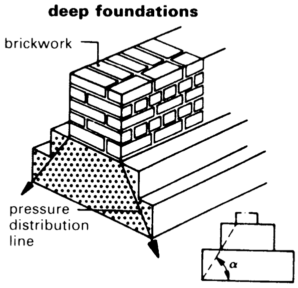
⑨ Raft foundation reinforced with structural steel



⑩ Grid pile and sinking caisson arrangement for deep foundations



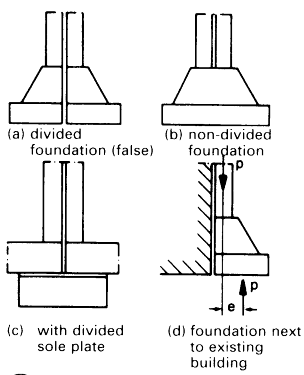
⑪ Simple strip foundation on lean concrete



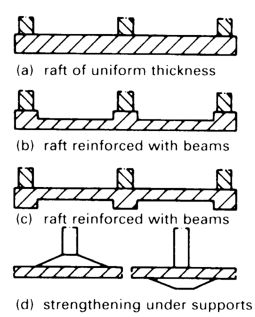
⑫ Widened, stepped foundation in unreinforced concrete

Technical investigations of the ground should provide sufficient data for efficient construction planning and execution of the building work. Depending on the construction type, the ground is evaluated either as building (for foundations), or as building material (for earth works). Building structures are planned (if legally possible and with local approval), according to expert assessment (i.e. avoiding marshy areas, landfill, etc.). The building construction type and the prevailing ground conditions affect the design of the foundations, e.g. individual footings → ⑦, strip foundations → ⑧, raft foundations → ⑨, or if the ground strata are only able to carry the load structure at greater depth, pile foundations → ⑩. Pressure distribution must not extend over 45° in masonry, or 60° in concrete. Masonry foundations are seldom used, due to high cost. Unreinforced concrete foundations are used when the load spreading area is relatively small, e.g. for smaller building structures. Steel reinforced concrete foundations are used for larger spans and at higher ground compression; they contain reinforcement to withstand the tensile loads → ⑪ + ⑫. Reinforced, instead of mass, concrete is used to reduce foundation height, weight and excavation depth. For flexible joints and near to existing structures or boundaries → ⑬. For cross-sections of raft foundations → ⑭ – used when load-bearing capacity is lower, or if individual footings or strip foundations are inadequate for the imposed load. Frost-free depth for base ≥ 0.80 m, for engineering structures 1.0–1.5 m deep.

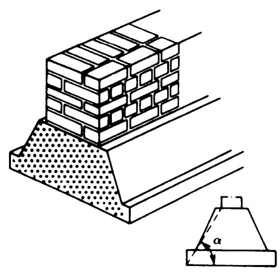
Methods to improve the load-bearing capacity of the site
Vibratory pressure process, with vibrator, compact in a radius of 2.3–3 m; separation of the vibration cores approx. 1.5 m; the area is thus filled; improvement depends on the granulation and original strata. Ground compression piles: core is filled up with aggregate of varied grain size without bonding agent. Solidification and compression of the ground: pressure injection of cement grout; not applicable to cohesive ground and ground which is aggressive to cement; only applicable in quartzous ground (gravel, sand and loose stone); injection of chemicals (silicic acid solution, calcium chloride); immediate and lasting petrifaction.



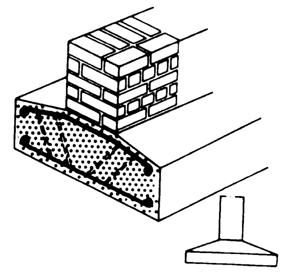
⑬ Application of foundations on dividing lines and movement joints



⑭ Cross-sections of raft foundations

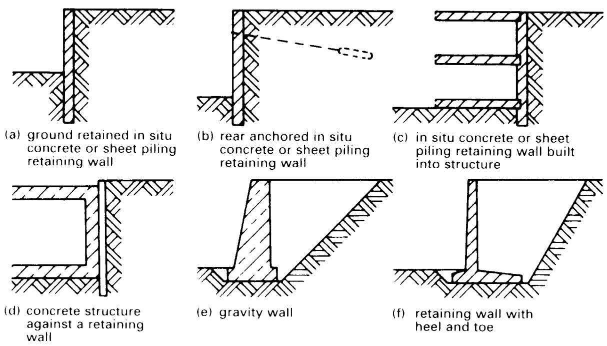


⑮ Chamfered foundation in unreinforced concrete

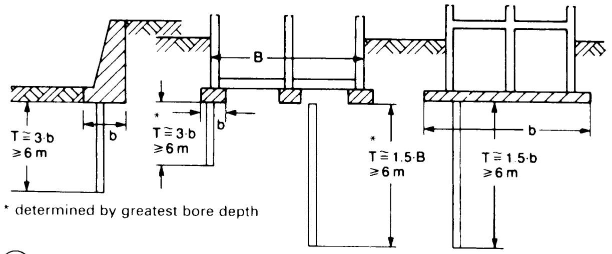


⑯ Yet wider foundation in the form of a steel reinforced concrete plate

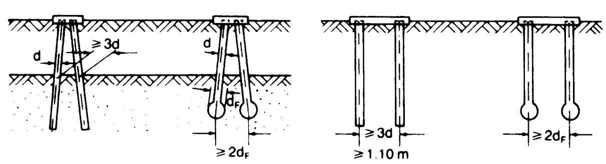
EARTHWORKS AND FOUNDATION STRUCTURES



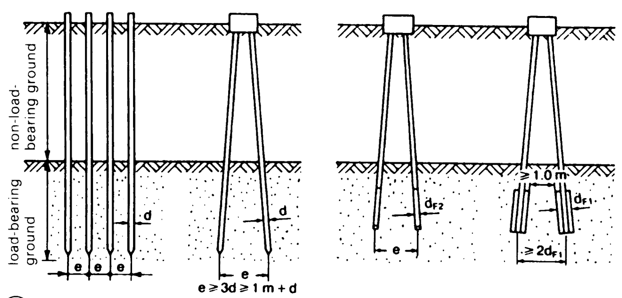
① **Building structures rated for the retention of soil pressure**



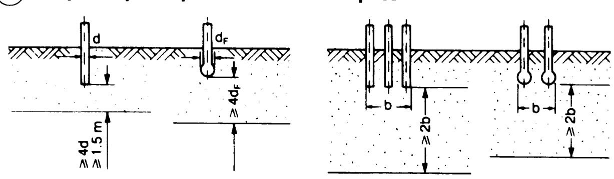
② **Minimum depths for trial bores**



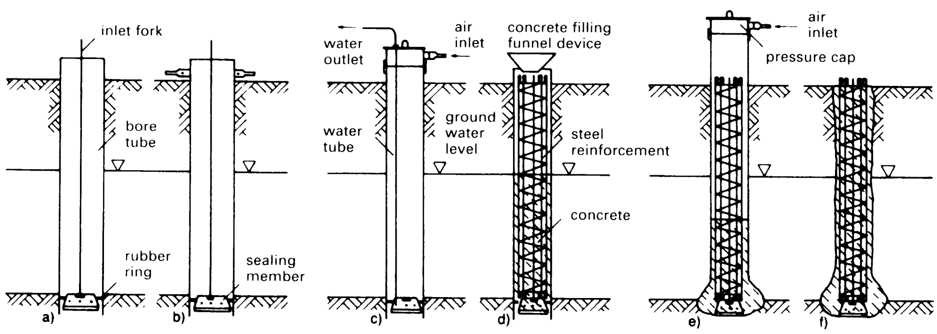
③ **Requisite pile separations for bored piles**



④ **Requisite pile separations for driven piles**



⑤ **Requisite depth of load supporting ground under bored piles**



⑥ **Compressed concrete bore pile (Brechtel System)**

To calculate the active soil pressure on retaining walls → ① and the permissible loading sub-soil, the type, composition, extent, stratification and strength of the ground strata must be known. Where local knowledge is inadequate, trial excavation and boreholes are necessary (separation of the bore holes ≤ 25 m). For pile foundations, the bore depths should extend to the foot of the piles → ②. According to the method of measurement, these depths can be reduced by a third (T = 1.0B or 2 × pile diameter, but ≥6.0 m). For the required pile separations for bored piles → ③; for driven piles → ④. The stated values do not apply to load-bearing plugged and bored pile walls. For the requisite depth of the load-bearing ground under bored piles → ⑤; for compressed concrete bored piles, Brechtel System → ⑥.

Pile foundations: Loads can be transmitted by the piles to the load-bearing ground by surface friction, end bearing or both bearings; the type of load transfer depends on the building site and the nature of the piling. Bearing pile foundations: load transmission takes place at ends of the piles onto the load-bearing ground and/or through skin friction. Suspended pile foundations: the piles do not extend downwards until the ends are on the load-bearing region. Weak load-bearing layers are compacted by pile driving.

Type of load transfer: Friction piles essentially transfer the load through surface friction via the load bearing region around the circumference of the pile. End bearing piles: the load is principally transmitted by the pile end on to the bearing stratum; in this case, surface friction is not significant. The permissible end pressure is significantly increased in some types of pile by widening the bases of the piles.

Position of the piles in the ground: Foundation piles are in the ground over their whole length. Retaining and projecting piles are free standing piles, whose lower portions only are below ground; the tops of these piles are exposed and therefore subject to buckling stresses.

Materials: wood, steel, concrete, reinforced concrete and prestressed concrete piles.

Method of insertion in the ground: Driven piles are rammed into the ground by pile driving hammers. Jacked piles are inserted by pressure. Bored piles are inserted by way of a bore hole. Screwed piles are inserted by rotation. With driven tube piles, a steel tube former is driven into the ground and withdrawn as the concrete pile is cast in situ. A distinction is made between piles which compact the ground, pierce it, or pass through a hole in it.

Type of loading: Axially loaded piles. Bearing piles are subject to compressive stresses – the load being transmitted through point pressure and surface friction. Tensile piles are subjected to tensile stress with loads transmitted through surface friction. Horizontally loaded piles. Retaining or projecting piles are subject to bending stresses, e.g., horizontally loaded large bore piles, sheet piles.

Manufacture and installation: Prefabricated piles are made in finished sections and delivered to the point of use, and driven into the ground by hammering, pressing, vibrating, screwing or by inserting in ready-prepared bore holes. In situ piles are created in a hollowed-out chamber in the ground, such as bored piles, tube piles, auger piles and cylinder piles. Mixed foundation piles are assembled from in situ and prefabricated parts. In situ piles provide the advantage that their length is not critical pre construction, and can be designed on the basis of compaction results, and examination of cores of the ground strata obtained during the boring process.

BUILDING AND SITE DRAINAGE

material	internal connecting drains	stacks	internal collection drains	u/ground drains: inaccessible: in building	u/ground drains: in earth	vent pipes	rainwater drains: within buildings	rainwater drains: in the open	condensation pipes from boilers	fire resistance
clay pipes with sleeves	–	–	+	+	+	–	+	–	+	A1 non-combustible
clay pipes with straight ends	–	+	+	+	+	–	+	–	+	A1
thin walled clay pipes with straight ends	+	+	+	+	+	+	+	–	+	A1
concrete pipes with rebate	–	–	–	–	+	–	–	–	–	A1
concrete pipe with sleeve	–	–	+	+	+	–	–	–	–	A1
reinforced concrete pipe	–	–	+	+	+	–	–	–	–	A1
glass pipe	+	+	+	–	–	+	+	–	+	A1
cement fibre pipe	+	+	+	+	+	+	+	+	–	A1 non-combustible
cement fibre pipe	–	–	+	+	+	–	–	–	–	A2
metal pipe (zinc, copper, aluminium, steels)	–	–	–	–	–	–	–	+	–	A1
cast iron pipe without sleeve	+	+	+	+	+	+	+	+	–	A1
steel pipe	+	+	+	+	+	+	+	+	–	A1
stainless steel pipe	+	+	+	+	+	+	+	+	+	A1
PVC-U pipe	–	–	–	+	+	–	–	–	+	B1 low combustibility
PVC-U pipe, corrugated outer surface	–	–	–	+	+	–	–	–	+	–
PVC-U pipe, profiled	–	–	–	+	+	–	–	–	+	–
PVC-U foam-core pipe	–	–	–	+	+	–	–	–	+	–
PVC-C pipe	+	+	+	+	–	+	+	+	+	B1
PE-HD pipe	+	+	+	+	–	+	+	+	+	B2 combustible
	–	–	–	+	+	–	–	–	+	–
PE-HD pipe, with profiled walling	–	–	–	–	+	–	–	–	+	–
PP pipe	+	+	+	+	–	+	+	–	+	B1
PP pipe, mineral reinforced	+	+	+	+	–	+	+	–	+	B2
ABS/ASA/PVC pipe	+	+	+	+	–	+	+	–	+	B2
ABS/ASA/PVC pipe, mineral reinforced outer layer	+	+	+	+	–	+	+	–	+	B2
UP/GF pipe	–	–	–	+	+	–	–	–	+	–

UP/GF pipe	–	–	–	+	+	–	–	–	+	
ABS/ASA/PVC pipe, mineral reinforced outer layer	+	+	+	+	–	+	+	–	+	B2
ABS/ASA/PVC pipe	+	+	+	+	–	+	+	–	+	B2
mineral reinforced	+	+	+	+	–	+	+	–	+	B2

External underground drains are understood to be those which are laid outside the plan area of the building. Drains underneath cellar areas are taken as interior drains. Depending on topography, the depths required are 0.80 m, 1.00 m and 1.20 m. In severe climates, measures must be taken to protect against frost.

Changes in direction of main drains must be constructed only with prefabricated bend fittings and no individual bend should be greater than 45°. If a junction of drains cannot be formed with prefabricated fittings, then a manhole must be constructed. Inaccessible double junctions are not permitted and a drain must not be reduced by connection into a narrower pipe in the direction of flow (with the exception of rainwater drainage outside buildings).

nominal dimensions, DN (mm)	minimum falls for: foul water drains within buildings	rainwater drains within buildings	combined drains within buildings	foul water drains outside buildings	rainwater and combined drains outside buildings
up to 100	1:50	1:100	1:50	1:DN	1:DN
125	1:66.7	1:100	1:66.7	1:DN	1:DN
150	1:66.7	1:100	1:66.7	1:DN	1:DN
from 200	1:DN/2	1:DN/2	1:DN/2	1:DN	1:DN
fill level *h/d*	0.5	0.7	0.7	0.5*	0.7**

* for ground drains greater than 150 mm dia.; also 0.7
** for ground drains greater than 150 mm dia. connected to a manhole with open throughflow; also 1.0

(2) **Minimum falls for drains**

BUILDING AND SITE DRAINAGE

term	symbol	unit	explanation
rainfall value	$r_{T(n)}$	l/(s·ha)	rainfall value, calculated according to the building section of the drainage system, with accompanying rain duration (T) and rain frequency (n)
rainfall area	A	m²	the area subjected to rainfall measured in horizonal plane (A) from which the rain water flows to the drainage system
discharge coefficient	ψ	1	in the meaning of this standard, the relationship between the rainwater flowing into the drainage system and the total amount of rainwater in the relevant rainfall area
water flow	$\dot V_e$	l/s	effective volume of water flow, not taking into account simultaneity
rainwater discharge	$\dot V_r$	l/s	discharge of rainwater from a connected rainfall area by a given rainfall value
foul water discharge	$\dot V_s$	l/s	discharge in the drainage pipe, resulting from the number of connected sanitary units taking into account simultaneity
combined water discharge	$\dot V_m$	l/s	sum of the foul water discharge and rainwater discharge $\dot V_m = \dot V_s + \dot V_r$
pumping flow	$\dot V_p$	l/s	calculated volume flow of a pump etc.
connection value	AW_s	1	the value given to a sanitary fitting to calculate the following drainage pipe ($1\,AW_s \hat{=} 1$ l/s)
drainage discharge factor	K	l/s	amount depending on the type of building; results from the characteristics of the discharge
discharge capacity	$\dot V_v$	l/s	calculated discharge through a drainage pipe when full, without positive or negative static pressure
partial fill discharge	$\dot V_T$	l/s	discharge through a drainage pipe while partly full
degree of fill	h/d_i	1	relationship between the filling height h and the diameter d_i of a horizontal drainage pipe
fall	I	cm/m	difference in level (in cm) of the base of a pipe over 1 m of its length or its relative proportion (e.g. 1:50 = 2 cm/m)
functional roughness	k_b	mm	roughness value, which takes into account all the loss in flow in drainage pipes
nominal bore	DN	–	this is the nominal size, which is used for all compatible fittings (e.g. pipes, pipe connectors and bends); it should be similar to the actual bore; it may only be used instead of the actual bore in hydraulic calculations when the cross-sectional area calculated from the smallest actual bore is not more than 5% less than that calculated from the nominal bore (in relation to a circular cross-section this represents about 2.5%)
actual bore	DS	mm	internal dimension (diameter) of pipes, fittings, manhole covers etc., with specified permitted tolerances* (used as production specification to maintain the necessary cross-sectional properties (area, circumference etc.)
minimum bore	DS_{min}	mm	according to the regulations the smallest permissible bore, given by the smallest tolerated actual bore dimension
minimum inner diameter	$d_{i\,min}$	mm	the minimum inner diameter of drainage pipes, related to the 5% tolerance allowed from the dimension of the nominal bore
flooding	–	–	the situation when foul and/or rainwater escapes from a drainage system or cannot enter into it, irrespective of whether this happens in the open or inside a building
overloading	–	–	the situation when foul and/or rainwater runs under pressure in a drainage system, but does not leak to the surface and therefore causes no flooding
drainage section	T_S	m	a section of the drainage system in which the volume of effluent, the diameter d_i, and/or the fall I of the drainage pipe does not alter

*now: lower dimensional limit

(1) Terminology for building and site drainage

(1) **Terminology for building and site drainage**

Calculation of foul water flow

The deciding factor in calculating the size of the nominal bore is the maximum expected foul water discharge $\dot V_s$, which is given by the sum of the connection values and/or, if appropriate, the effective water consumption, while taking into account the simultaneous use of the various sanitary fittings.

$$\dot V_s = K \cdot \sqrt{\Sigma AW_s} + \dot V_e$$

Guide values for the drainage discharge factor K are shown in (2) and example connection values AW_s are given in (3).

If the foul water discharge $\dot V_s$ is smaller than the largest connection value of an individual sanitary fitting, then the latter value is to be taken. For drainage systems that do not fit into the categories of building listed in (2), K values should be calculated according to individual specific uses.

type of building, drainage system	K (l/s)
apartment buildings, pubs/restaurants, guest houses, hostels, office buildings, schools	0.5
hospitals (wards), large pubs/restaurants, hotels	0.7
launderettes, rows of showers	1.0*
laboratory installations in industrial organisations	1.2*

*in the cases when the total water flow $\dot V_e$ is not relevant

(2) **Factors for drainage discharge**

sanitary fitting or type of drainage pipe	connection value AW_s	DN of the single connecting drain
hand basins, vanity units, bidets, row of wash basins	0.5	50
kitchen waste run-off (single/double sink), including dishwasher for up to 12 covers, floor gully, washing machine (with trapped drain) for up to 6 kg dry laundry	1	50
washing machines for 6–12 kg dry laundry	1.5*	70*
commercial dishwashers	2*	100*
floor gullies: nominal bore 50	1	50
nominal bore 70	1.5	70
nominal bore 100	2	100
WC, basin type dishwasher	2.5	100
shower tray/unit, foot bath	1	50
bath tub with direct connection	1	50
bath tub with direct connection, (up to 1 m length) above floor level, connected to a drain DN ≥70	1	40
bath tub or shower tray with an indirect connection, connection from the bath outlet less than 2 m length	1	50
bath tub or shower tray with an indirect connection, connection from the bath outlet longer than 2 m length	1	70
connecting pipe between bath overflow and bath outlet	–	·40
laboratory sink	1	50
outlet from dentists' treatment equipment (with amalgam trap)	0.5*	40*
urinal (bowl)*	0.5	50
		nominal bore of internal collecting drain
number of urinals: up to 2	0.5	70
up to 4	1	70
up to 6	1.5	70
over 6	2	100

* using these given estimated values, the actual values should be calculated

(3) Connection values of sanitary fittings and basic values for

(3) **Connection values of sanitary fittings and basic values for nominal bores of individual drainage connections (branch drains)**

type of unit		ΣAW_s
(a)	**multi-room flat** for drainage from all sanitary rooms and kitchen	5
(b)	**multi-room flat** for drainage from all sanitary rooms, but without the kitchen	4
studio flat for drainage from all sanitary fittings		4
hotel rooms and similar for drainage from all sanitary fittings		4

(1) **Connection values for specific units (for stacks, above- and underground drainage)**

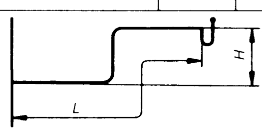
In the calculation of water flows for load types listed in (2), no conversion of the connection value AW_s needs to be carried out.

type of load	flow measurement
launderettes, rows of showers	water flow $\dot{V}_e$
laboratory installations	water flow $\dot{V}_e$
sundry separators (e.g. oil)	water flow $\dot{V}_e$
drainage pumps, sewage pumps and large washing and dishwashing machines, connected to the mains water and to the drains	pumped flow $\dot{V}_p$
rainwater share in a combined drainage system	rainwater discharge $\dot{V}_r$

(2) **Load types**

individual connecting drain pipe					DN with regard to the layout criteria	
sanitary units	nominal bore (DN) basis	layout criteria			unventilated	ventilated
		length L (m[1])	height H (m[1])	number of bends[2]	DN	DN
sink unit, washbasin, bidet	40	up to 3	up to 1	up to 3	40	40
				over 3	50	40
	40	over 3 or	over 1 up to 3	over 3	70	50
bath tubs – connection to a stack above floor level DN of the stack >70	40	up to 1	up to 0.25	without limit	40	40
bath tub with direct connection	50	up to 3	up to 0.25	without limit	50	50
		over 3 or	over 1 up to 3		70	50
bath tub with connection to floor gulley	>40	up to 3	up to 0.25	without limit	40	40
floor gully (bath drain) with connection to bath tub or shower tray	70	up to 5	up to 1	without limit	70	70
		over 5 or up to 10	over 1 up to 3		100	70
single connection pipes	50	over 3	over 1 up to 3	without limit	70	50
single connection pipes	70	over 5 or	over 1 up to 3	without limit	100	70
single connection pipe without WC	100	up to 10	up to 1		100	100
		over 10 or	over 1 up to 3		125	100
WC	100	up to 5	up to 1	without limit	100	100
WC max. 1m horizontal distance to stack	100	up to 5	over 1 up to 4		100	100
single connection pipes	all		over 3		ventilation essential	

1)



H difference in height between the connection to a ventilated pipe and the trap of a sanitary unit
L straightened out length of pipe up to the trap

(maximum permitted lengths and height differences of single connection pipes)

2) number of bends including exit bend of trap

(3) **Nominal bores of above-ground drainage in connection with the layout criteria of the pipe runs**

Dimensioning of drainage systems following the connection of a pump installation

Non-pressurised drainage following a pump installation is to be calculated as follows.

(a) With rainwater drainage, the pumped flow from the pump $\dot{V}_p$ is to be added to the rainwater discharge $\dot{V}_r$.

(b) With foul water and combined drainage, the relevant highest value (pumped flow or the remaining effluent flow) is to be taken, under the condition that the addition of $\dot{V}_p$ and $\dot{V}_m$ or $\dot{V}_s$ does not result in a complete filling of the underground or above-ground drainage pipework. The calculated testing of the complete filling of pipes is only to be carried out on pipes for which there is a filling level of $h/d_i = 0.7$. If there are several foul water pump installations in a combined underground/above-ground drainage system, then the total pumped flow of the pumps can be reduced (e.g. for every additional pump add 0.4 $\dot{V}_p$).

Dimensioning of foul drain pipes: connecting pipes → (3)

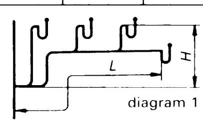
Single connecting pipes from hand basins, sink units and bidets, which do not have more than three changes of direction (including the exit bend of the trap) can be constructed from nominal bore 40 pipes. If there are more than three changes of direction, then a nominal bore 50 pipe is necessary.

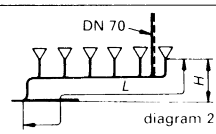
Internal collecting drainage

With unventilated internal collection drains, the drain length *L*, including the individual connection furthest away, should not exceed 3m for nominal bore 50 pipe, 5m for nominal bore 70, and 10m for pipes with a nominal bore of 100 (without WC connection). Where greater lengths are required, wider bores or the use of ventilated pipework should be considered. Internal collection drain pipes over 5m in length with a nominal bore of 100, WC connections and falls *H* of 1m or more must be ventilated.

above-ground collecting drain pipes					DN with regard to the layout criteria	
highest permitted ΣAW_S		DN	layout criteria			
unventilated	ventilated		length L m[1]	height H m[1]	unventilated DN	ventilated DN
1	–	50	up to 3	up to 1	50	–
1	1.5	50	up to 6	over 1 up to 3	70 from stack	50
3	–	70	up to 5	up to 1	70	–
3	4.5	70	up to 10	over 1 up to 3	100 from stack	70
16	–	100 without WC	up to 10	up to 1	100	–
				over 1 up to 3	–	100
	1.5	50	over 6 or	over 3	ventilation essential	
–	4.5	70	over 10 or	over 3		
–	25	100 without WC	over 10 or	over 3		
16	–	100 with WC	up to 5	up to 1	100	–
–	25	100 with WC	over 5	over 1	ventilation essential	
–	>16	all	ventilation essential			
3	–	100	WC with 1 sink unit on the ground floor – *H* at least 4m above the horiz. drain pipe – distance of WC from stack max. 1m			

1)





H difference in height from the connection to a ventilated pipe (stack, above-ground, underground) to the highest situated trap
L straightened out pipe length to the furthest situated trap

(4) **Nominal bores of above-ground drainage in connection with the layout criteria of the pipe runs**

BUILDING AND SITE DRAINAGE

DN	*) $d_{i\,min}$ (mm)	upper limit $\dot{V}_s$ (l/s)	K = 0.5 l/s		K = 0.7 l/s		K = 1.0 l/s	
			ΣAW_s	max number of WCs	ΣAW_s	max number of WCs	ΣAW_s	max number of WCs
70**)	68.2	1.5	9	–	5	–	2	–
100	97.5	4.0	64	13	33	8	16	4
125	115.0	5.3	112	22	57	14	28	7
	121.9	6.2	154	31	78	20	38	10
150	146.3	10.1	408	82	208	52	102	25

*) see explanations → p. 56
**) it is not permitted to connect more than four kitchen sanitary units to one separate stack (kitchen stack)

(1) **Foul water stack drains with top ventilation**

DN	*) $d_{i\,min}$ (mm)	upper limit $\dot{V}_s$ (l/s)	K = 0.5 l/s		K = 0.7 l/s		K = 1.0 l/s	
			ΣAW_s	max number of WCs	ΣAW_s	max number of WCs	ΣAW_s	max number of WCs
70**)	68.2	2.1	18	–	9	–	4	–
100	97.5	5.6	125	25	64	16	31	8
125	115.0	7.4	219	44	112	28	55	14
	121.9	8.7	303	61	154	39	76	20
150	146.3	14.1	795	159	406	102	199	50

*) see explanations → p. 56
**) it is not permitted to connect more than four kitchen sanitary units to one separate stack (kitchen stack)

(2) **Foul water stack drains with direct or indirect additional ventilation**

DN	*) $d_{i\,min}$ (mm)	upper limit $\dot{V}_s$ (l/s)	K = 0.5 l/s		K = 0.7 l/s		K = 1.0 l/s	
			ΣAW_s	max number of WCs	ΣAW_s	max number of WCs	ΣAW_s	max number of WCs
70**)	68.2	2.6	27	–	14	–	7	–
100	97.5	6.8	185	37	94	24	46	12
125	115.0	9.0	324	65	165	41	81	20
	121.9	10.5	441	88	225	56	101	28
150	146.3	17.2	1183	237	604	151	296	74

*) see explanations → p. 56
**) it is not permitted to connect more than four kitchen sanitary units to one separate stack (kitchen stack)

(3) **Foul water stack drains with secondary ventilation**

type of surface	coefficient
waterproof surfaces, e.g.	
– roof areas >3° falls – concrete surfaces, ramps – stabilised areas with sealed joints – asphalt roofs – paving with sealed joints	1.0
– roof area ≤3° falls	0.8
– grassed roof areas [1)	
– intensive planting	0.3
– extensive planting above 100mm built-up thickness	0.3
– extensive planting less than 100mm built-up thickness	0.5
partially permeable and surfaces with slight run-off, e.g.	
– concrete paving laid on sand or slag, areas with paving	0.7
– areas with paving, with joint proportion >15% (e.g. 100 × 100mm and smaller)	0.6
– water consolidated areas	0.5
– children's play area, partly stabilised	0.3
– sports areas with land drainage	
– artificial surfaces	0.6
– gravelled areas	0.4
– grassed areas	0.3
water permeable surfaces with insignificant or no water run-off, e.g. – park and planted areas – hardcore, slag and coarse gravelled areas, even with partly consolidated areas such as: – garden paths with water consolidated surface or – drives and parking areas with grassed concrete grid	0.0

1) according to guidelines for the planning, construction and maintenance of roof planting

(4) **Discharge coefficient (ψ) to calculate the rainwater discharge ($\dot{V}_r$)**

Foul water stacks

The nominal bore of all foul water stacks must be at least DN 70. For foul water stacks with top ventilation the figures given in (1) should be used for design calculations. The nominal bores shown for the stacks considered are associated with the maximum sum of the connection values with which the stack can be loaded. It should be noted that to avoid functional disruptions a limit is put upon the number of WCs (i.e. sanitary units that introduce quantities of large solid objects and surges of water) that may be connected to the various stacks. In addition to foul water flows, tables (1) – (3) also show examples of sums of connection values (see p. 56).

Foul water stacks with secondary ventilation can be loaded with 70% more foul water flow than stacks with top ventilation. They can be estimated in accordance with → (3).

Calculations governing underground and above-ground collection pipes (horizontal foul water drains) should be made based on the ratio h/d_i = 0.5 although for under-ground pipes outside the building over DN 150 can use h/d_i = 0.7. The values for the partial fill discharge flow of the pipes with minimum falls I_{min} are identified in relation to whether the pipes are laid inside or outside the building. Values below the given size steps are allowed for pipe calculations only in individually justified cases.

Calculations for rainwater pipes: rainwater discharge and rainfall value

The discharge from a rainfall area is calculated using the following relationship:

(5) $$\dot{V}_r = \psi \cdot A \cdot \frac{r_{T(n)}}{10000} \text{ in l/s}$$

where $\dot{V}_r$ = rainwater discharge in l/s
A = connected rainfall area in m^2
$r_{T(n)}$ = rainfall value in l/(s·ha)
ψ = discharge coefficient according to → (4)

Rainwater drainage pipes inside and outside buildings are fundamentally to be calculated with a minimum rainfall value of at least 300 l/(s·ha). It is also important to ensure that there are enough emergency overflows for large internal rainwater drainage systems. The requirements can be checked using the following standard figures for the location:

- $r_{15(1)}$ Fifteen minute rainfall value, statistically exceeded once per year. This rainfall value should only be used in exceptionally well reasoned cases for the calculation of rainwater drainage pipe sizes.
- $r_{5(0.5)}$ Five minute rainfall value, statistically exceeded once every two years.
- $r_{5(0.05)}$ Five minute rainfall value, statistically seen is exceeded once every twenty years.

For above- and underground drains within a building, subject to agreement with local guidelines, a rainfall value of less than 300 can be employed, though it must be at least as great as the five minute rainfall value in two years ($r_{5(0.5)}$). Across Germany, $r_{5(0.5)}$ varies from around 165 up to as much as 445 l/(s·ha) so it is important to check the figures with the local authority.

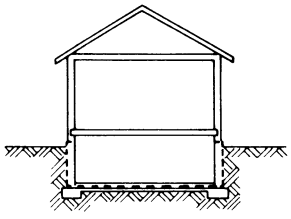
If smaller rainfall values are proposed and there are large roof drainage areas (e.g. above 5000 m^2), it is necessary to carry out an overloading calculation on the basis of what can be expected in the case of rainfall equivalent at least to a five minute rainfall value in 20 years ($r_{5(0.05)}$). These rainfall values can be as high as 950 l/(s·ha). Within the overload sector, take into account the resistances due to the layout of the pipes. If a special roof form is proposed (e.g. those with areas of planned flooding) they must be waterproofed to above the flood level and the additional loads must be taken into consideration.

Underground rainwater drainage pipes should have a nominal bore of DN 100 or more. If the pipe is outside the building and for mixed drainage (i.e. will also carry foul water), and connects to a manhole with open access, the nominal bore should be DN 150 or above.

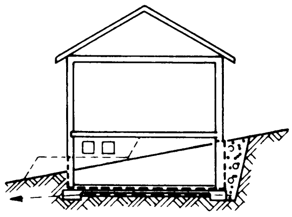
DAMP-PROOFING AND TANKING

Cellars are used less these days as storage rooms and more as places for leisure or as additional rooms for accommodation and domestic purposes. So, people want greater comfort and a better internal climate in the cellar. A prerequisite for this is proofing against dampness from outside. For buildings without cellars, the external and internal walls have to be protected from rising damp by the provision of horizontal damp-proof courses → (3) - (6). On external walls, the damp-proofing is 150–300 mm above ground level → (3) - (6). For buildings with brick cellar walls, a minimum of 2 horizontal damp-proof courses should be provided in the external walls → (7) - (8). The upper layer may be omitted on internal walls. Bituminous damp-proof membranes, asphalt, or specifically designed high-grade plastic sheet should be used for the vertical tanking in walls. Depending on the type of back filling used in the working area and the type of tanking used, protective layers should be provided for the wall surfaces → (12) - (14). Rubble, gravel chippings or loose stones should not be deposited directly against the tanking membrane.

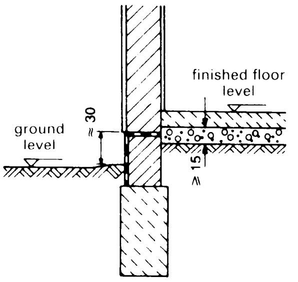
water occurs as	proofing required against	type of proofing
rising damp	capillary effect on vertical building elements	protective layers against ground dampness (damp proofing)
precipitation, running water	seepage of water not under pressure on sloping surfaces of building elements	proofing against seepage (tanking)
ground water	hydrostatic pressure	pressure retaining proofing (tanking)



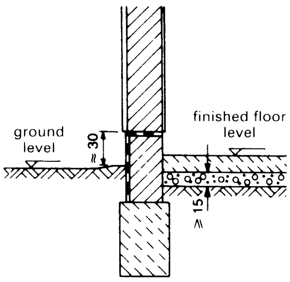
(1) **Cellar level protected horizontally and vertically against rising damp** → (7) - (14)



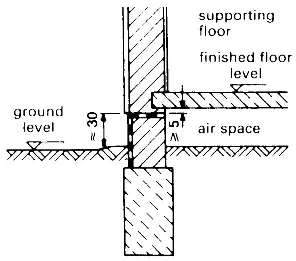
(2) **Good protection required on hill side of building; hillside water conducted away by drainage** → (5) - (6)



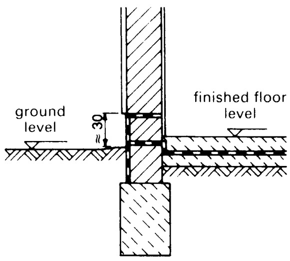
(3) **Damp-proofing of building with no cellar and with non-habitable room use; hardcore at the level of the damp-proof course**



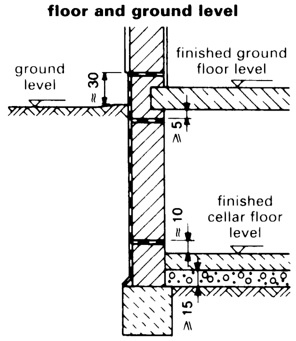
(4) **Damp-proofing of building with no cellar and with non-habitable room use; floor at ground level**



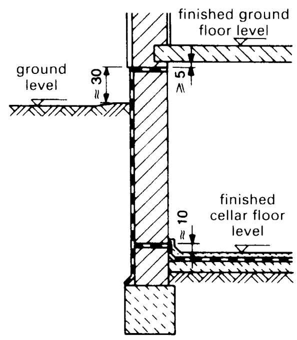
(5) **Damp-proofing of building with no cellar; floor with ventilated air gap between floor and ground level**



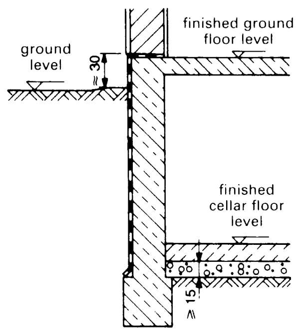
(6) **Damp-proofing of building with no cellar; low lying floor at ground level**



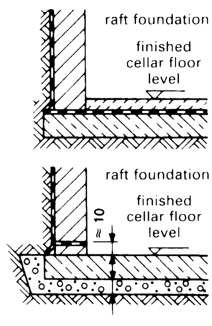
(7) **Damp-proofing of building with cellar with non-habitable room use (masonry walls on strip foundation)**



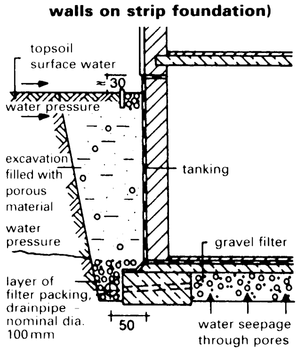
(8) **Damp-proofing of building with cellar; masonry walls on strip foundations**



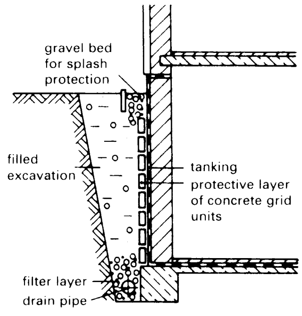
(9) **Damp-proofing and tanking of building with cellar; walls of concrete**



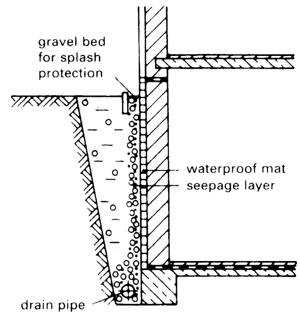
(10) **Damp-proofing and tanking of building with cellar; masonry walls on a raft foundation**



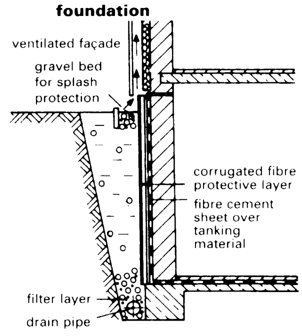
(11) **Drainage and tanking**



(12) **Protective wall of concrete grid units**



(13) **Waterproof mat**

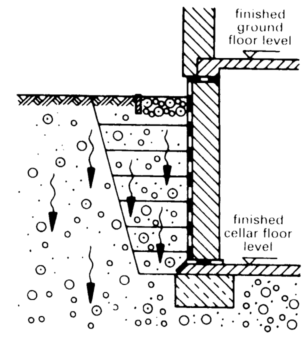


(14) **Protective layer of fibre cement boards**

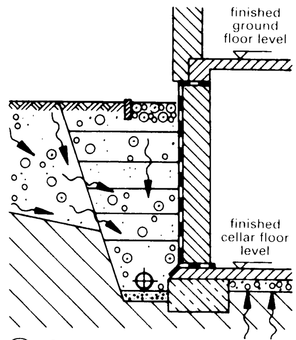
DAMP-PROOFING AND TANKING

Ground Water Drainage

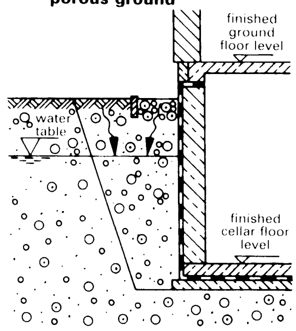
Ground water drainage involves the removal of water from the building site area through drainage layers and drainpipes to prevent the build-up of water pressure. This process should prevent blocking by soil particles (fixed filter drainage). A drainage facility consists of perforated drains, inspection and cleaning devices, and drainage pipes for water disposal. Drainage is the collective term for drain pipes and drainage layers. If drainage at the wall is necessary, reference should be made to the cases → ① – ③. → ① is relevant if ground dampness only occurs in very porous ground. → ② is relevant if the accumulation of water can be avoided by means of a drain, so that water under pressure does not occur. → ③ is relevant if water is present under pressure, as a rule in the form of ground water, or when removal of the water via a drain is not possible.



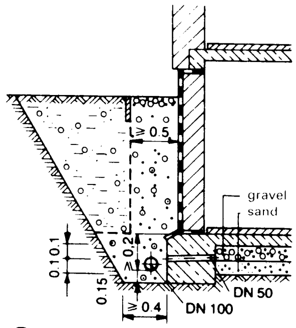
(1) **Ground dampness in very porous ground**



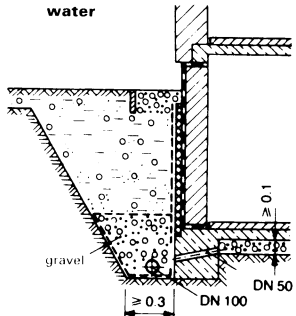
(2) **Non-pressurised water in slightly porous ground**



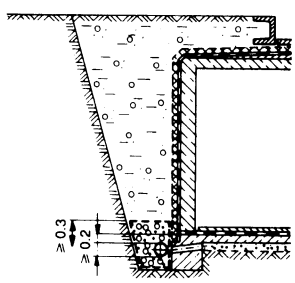
(3) **Water under pressure in ground containing ground water**



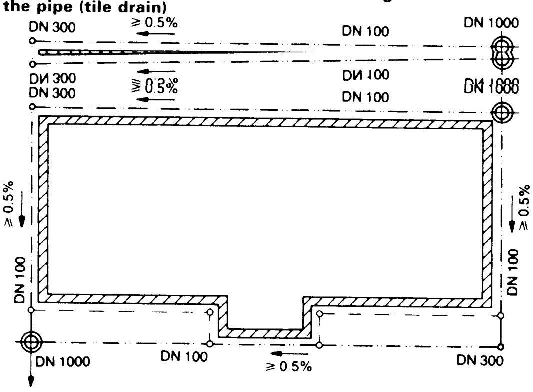
(4) **Drainage system with rubble trench fill (French drain)**



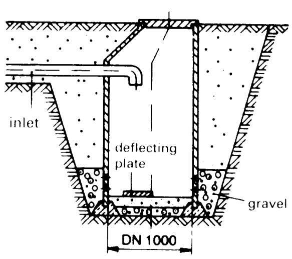
(5) **Drainage system with granular material around the pipe (tile drain)**



(6) **Drainage system for deep building work**



(7) **Example of an arrangement of drainpipes, inspection and cleaning access in a ring drainage system**



(8) **Soakaway for low drainage requirement**

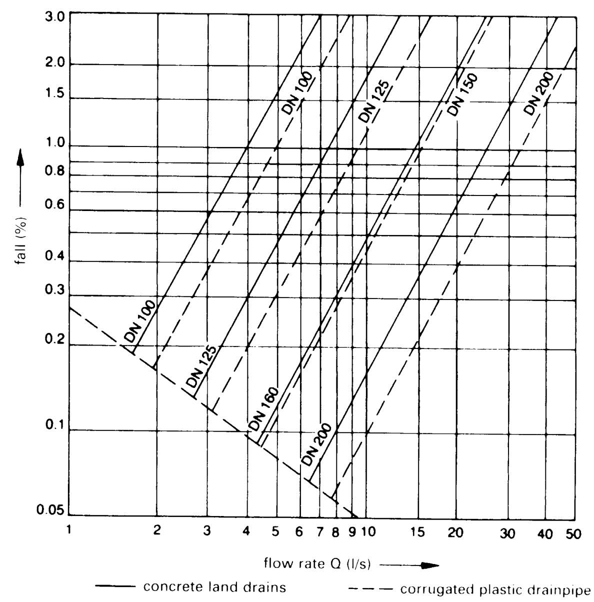
representation	component	material
	filter layer	sand geotextile (filter fleece)
	drainage layer	gravel individual/composite elements (drainage units, boards) (drainage mat)
	protective, separating	membrane, render
	d/proofing	
	drainpipe washout/inspection pipe washout/inspection/collecting shaft	

(9) **Key to diagrammatic representation**

position	material	thickness (m)
in front of walls	sand/gravel	≥0.50
	filter layer coarseness 0–4 mm	≥0.10
	seepage layer coarseness 4–32 mm	≥0.20
	gravel coarseness 4–32 mm and geotextile	≥0.20
on roof slabs	gravel coarseness 4–32 mm and geotextile	≥0.50
under floor slabs	filter layer coarseness 0.4 mm seepage layer coarseness 4–32 mm gravel coarseness 4–32 mm and geotextile	≥0.10
around land drains	sand/gravel	≥0.15
	seepage layer coarseness 4–32 mm and filter layer coarseness 0–4 mm	≥0.10
	gravel coarseness 4–32 mm and geotextile	≥0.10

drainpipe: nominal diameter 100 mm, 0.5% fall
washout and inspection pipe: nominal diameter 300 mm
washout, inspection and collecting shaft: nominal diameter 1000 mm

(10) **Specifications and depths of granular materials for drainage layers**



(11) **Measurement nomogram for drainage pipework**

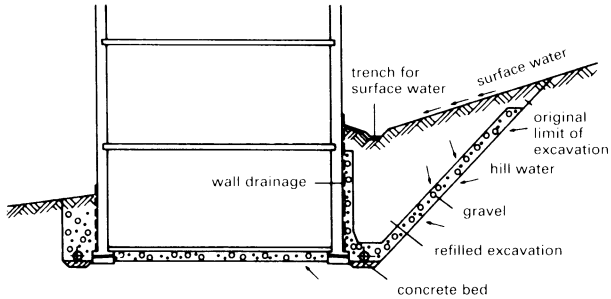
DAMP-PROOFING AND TANKING

If the precipitation on the site is not absorbed quickly, a build-up of water pressure can occur and tanking against the water pressure is needed, with drainage to conduct water away. For these measures → ① – ③; for tanking methods → ④ – ⑬.

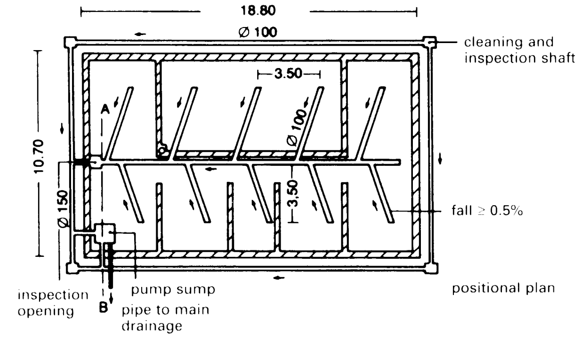
Water pressure

If parts of buildings are immersed in ground water, a water pressure retaining barrier layer (tanking) must be positioned over the base and side walls. To plan this design, the type of subsoil, the maximum ground water level and the chemical content of the water must be known. The tanking should extend to 300mm above the maximum ground water level. The materials can be 3-layer asphalt or specially designed plastic membranes, with metal fittings if necessary.

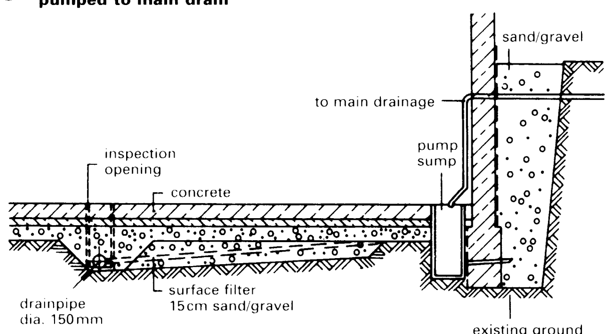
When the water level has sunk below the cellar floor level, the protective walls are constructed on the concrete base layer and rendered ready to receive the tanking. After the tanking is applied, the reinforced floor slab and structural cellar walls are completed hard against the tanking. NB the rounding of the corners → ⑥ – ⑦. The tanking must be in the form of a complete vessel or enclose the building structure on all sides. Normally, it lies on the water side of the building structure → ⑥ – ⑦. For internal tanking, the cladding construction must be able to withstand the full water pressure → ⑫.



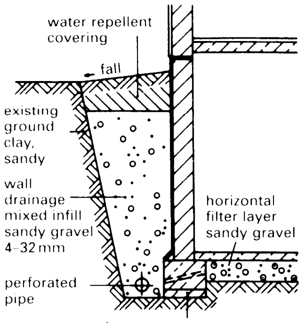
① **Building walls on hillside must be well drained**



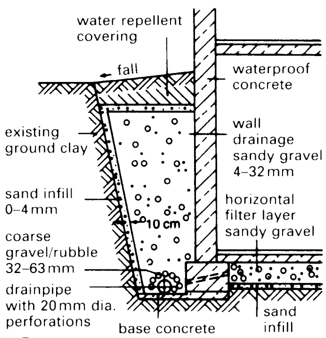
② **Surface drainage with perforated land drains and ring drainage pumped to main drain**



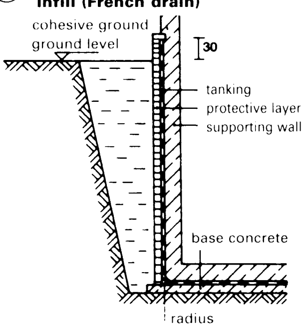
③ **Cross-section A–B** → ②



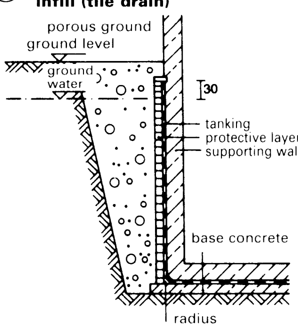
④ **Pipe drainage with mixed infill (French drain)**



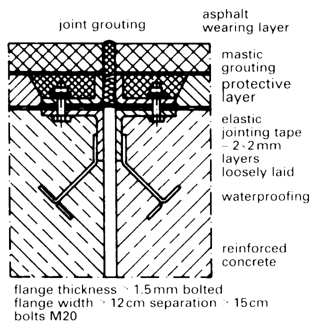
⑤ **Pipe drainage with layered infill (tile drain)**



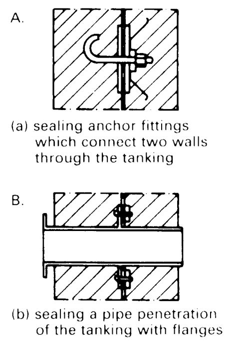
⑥ **Continuous water pressure resistant tanking**



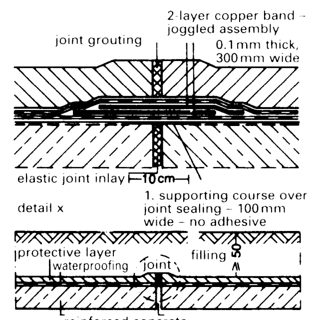
⑦ **Continuous water pressure resistant tanking**



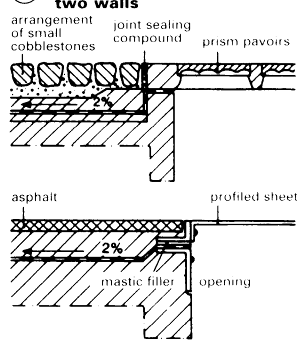
⑧ **Tanking over a flexible joint in reinforced concrete slab**



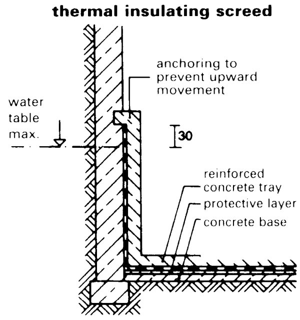
⑨ **Details: tanking between two walls**



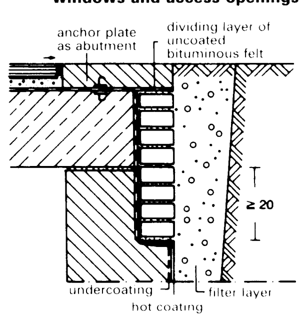
⑩ **Tanking over expansion joint in reinforced concrete slab; thermal insulating screed**



⑪ **Tanking at connections to windows and access openings**



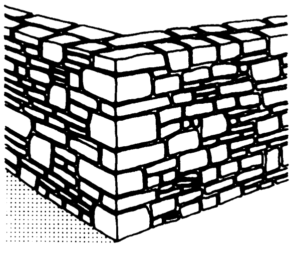
⑫ **Subsequently constructed tanking**



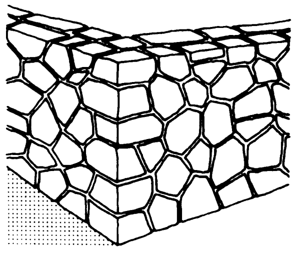
⑬ **Tanking at junctions of slab bearing on retaining wall**

MASONRY

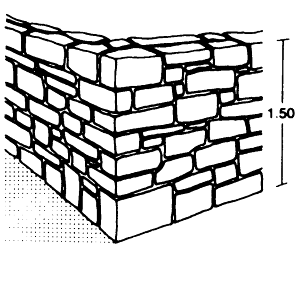
Natural Stone



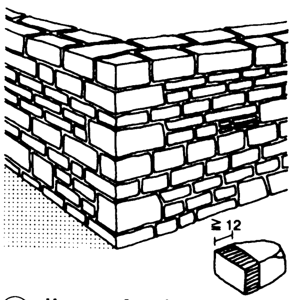
① Dry stone walling



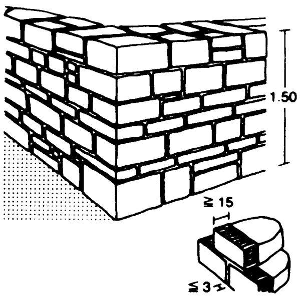
② Rough hewn uncoursed random rubble walling



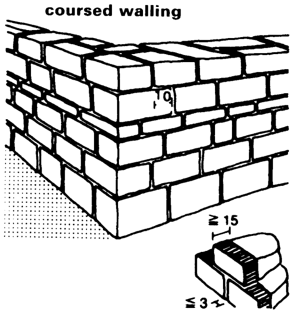
③ Squared random rubble uncoursed walling



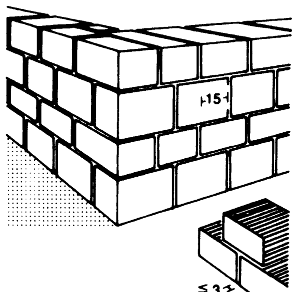
④ Hammer-faced squared random rubble irregularly coursed walling



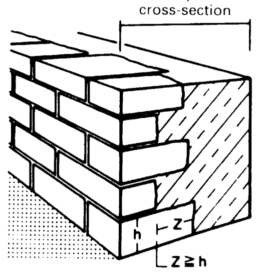
⑤ Irregular masonry courses



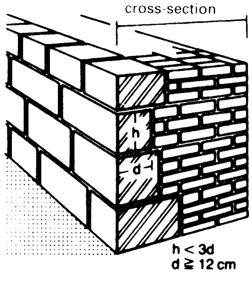
⑥ Regular masonry courses



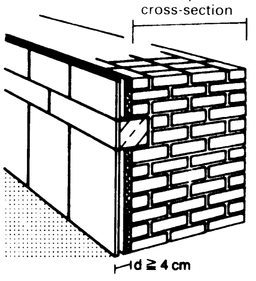
⑦ Ashlar walling



⑧ Ashlar faced mixed masonry walling



⑨ Mixed masonry with structurally effective cross-section



⑩ Stone cladding: structurally ineffective

Masonry in natural stone is referred to as random rubble, squared, dressed, ashlar, uncoursed, coursed, etc. → ① – ⑩. Stone quarried from natural deposits should be laid in the orientation as found in the quarry → ①, ③, ④, to give an attractive and natural appearance; this is also better from a structural viewpoint, as the loading is mainly vertical in pressure between the courses. Igneous stone is suitable for random, uncoursed masonry → ②. The length of the stones should be four or five times their height, no more, and certainly no less than the stone height. The stones' size is of great significance to the scaling of a building. Attention must be paid to good bonding on both sides. In natural masonry, the bonding should show good craftsmanship across the whole cross-section.

The following guidelines should be observed:

(a) Nowhere on the front and rear faces should more than three joints run into each other.
(b) No butt joint should run through more than two courses.
(c) There must be a minimum of one header on two-stretcher courses, or the header and stretcher courses should alternate with one other.
(d) The depth of the header must be approx. 1.5 times the height of a course and not less than 300 mm.
(e) The stretcher depth must be approx. equal to the course height.
(f) The overlap of the butt joints must be ≥ 100 mm (masonry courses) and 150 mm on ashlar walling → ⑤ – ⑦.
(g) The largest stones should be built in at the corners → ① – ⑥. The visible surfaces should be subsequently pointed.

The masonry should be levelled and trued for structural bearing every 1.5–2.0 m (scaffold height). The mortar joints should be ≤ 30 mm thick, depending on coarseness and finish. Lime or lime cement mortar should be used, since pure cement mortar discolours certain types of stone. In the case of mixed masonry, the facing layer can be included in the load-bearing cross-section if the thickness ≥ 120 mm → ⑨. Front facing (cladding) of 25–50 mm thickness (Travertine, limestone, granite, etc.) is not included in the cross-section and the facing is anchored to the masonry with non-corroding tie-rods, with a 2 mm separation from it → ⑩.

group	type of stone	min. compressive strength in kp/cm² (MN/m²)
A	limestone, travertine, volcanic tufa	200 (20)
B	soft sandstone (with argillaceous binding agent)	300 (30)
C	dense (solid) limestone and dolomite (inc. marble) basalt lava and similar	500 (50)
D	quartzitic sandstone (with silica binding agent), greywacke and similar	800 (80)
E	granite, synite, diorite, quartz porphyry, melaphyre, diabase and similar	1200 (120)

⑪ **Minimum compressive strengths of types of stone**

	masonry type	mortar group	group as in 11				
			A	B	C	D	E
1	quarry stone	I	2 (0.2)	2 (0.2)	3 (0.3)	4 (0.4)	6 (0.6)
2		II/IIa	2 (0.2)	3 (0.3)	5 (0.5)	7 (0.7)	9 (0.9)
3		III	3 (0.3)	5 (0.5)	6 (0.6)	10 (1.0)	12 (1.2)
4	hammer finished masonry courses	I	3 (0.3)	5 (0.5)	6 (0.6)	8 (0.8)	10 (1.0)
5		II/IIa	5 (0.5)	7 (0.7)	9 (0.9)	12 (1.2)	16 (1.6)
6		III	6 (0.6)	10 (1.0)	12 (1.2)	16 (1.6)	22 (2.2)
7	irregular and regular masonry courses	I	4 (0.4)	6 (0.6)	8 (0.8)	10 (1.0)	16 (1.6)
8		II/IIa	7 (0.7)	9 (0.9)	12 (1.2)	16 (1.6)	22 (2.2)
9		III	10 (1.0)	12 (1.2)	16 (1.6)	22 (2.2)	30 (3.0)
10	ashlar walling	I	8 (0.8)	10 (1.0)	16 (1.6)	22 (2.2)	30 (3.0)
11		II/IIa	12 (1.2)	16 (1.6)	22 (2.2)	30 (3.0)	40 (0.4)
12		III	16 (1.6)	22 (2.2)	30 (3.0)	40 (4.0)	50 (5.0)

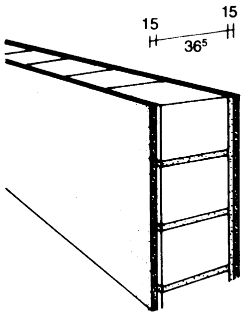
⑫ **Basic values – permissible compressive stress on natural stone masonry in kp/cm² (MN/m²)**

	slenderness ratio or eff. sl. ratio	8 (0.8)	10 (1.0)	12 (1.2)	16 (1.6)	22 (2.2)	30 (3.0)	40 (4.0)	50 (5.0)
1	10	8 (0.8)	10 (1.0)	12 (1.2)	16 (1.6)	22 (2.2)	30 (3.0)	40 (4.0)	50 (5.0)
2	12	6 (0.6)	7 (0.7)	8 (0.8)	11 (1.1)	15 (1.5)	22 (2.2)	30 (3.0)	40 (4.0)
3	14	4 (0.4)	5 (0.5)	6 (0.6)	8 (0.8)	10 (1.0)	14 (1.4)	22 (2.2)	30 (3.0)
4	16	3 (0.3)	3 (0.3)	4 (0.4)	6 (0.6)	7 (0.7)	10 (1.0)	14 (1.4)	22 (2.2)
5	18			3 (0.3)	4 (0.4)	5 (0.5)	7 (0.7)	10 (1.0)	14 (1.4)
6	20					3 (0.3)	5 (0.5)	7 (0.7)	10 (1.0)

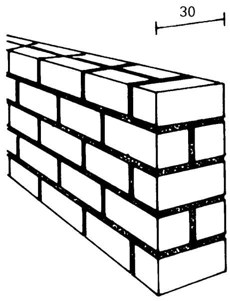
⑬ **Permissible compressive stresses on natural stone masonry in kp/cm² (MN/m²)**

MASONRY

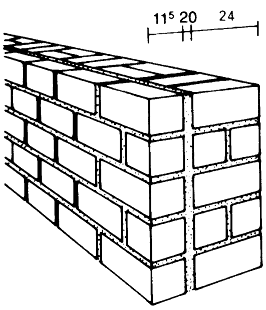
Bricks and Blocks



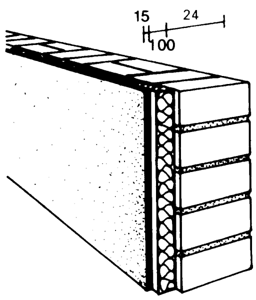
(1) **Single leaf plastered**



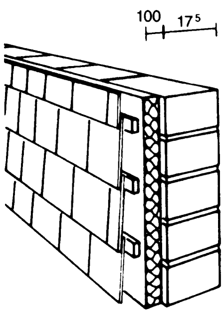
(2) **Single leaf fairfaced**



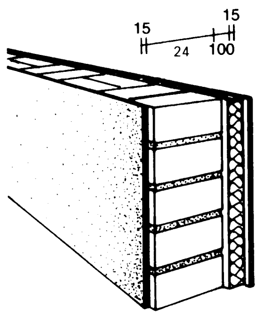
(3) **Double leaf with brick facing**



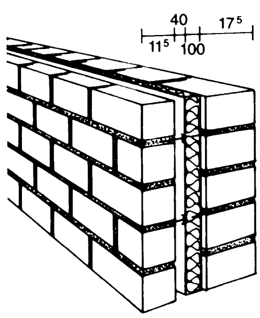
(4) **Single leaf with thermal insulated facing**



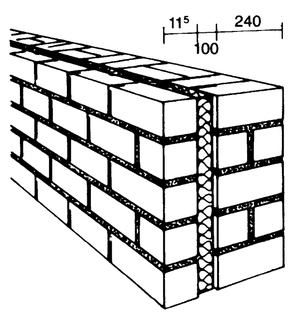
(5) **Single leaf with tile hanging**



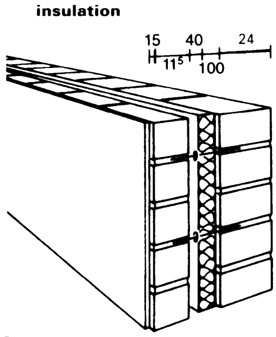
(6) **Single leaf with internal insulation**



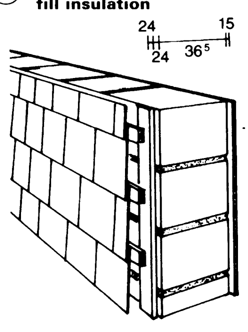
(7) **Double leaf cavity wall with partial fill cavity insulation**



(8) **Double cavity wall with full fill insulation**



(9) **Rendered facing with/without air cavity**

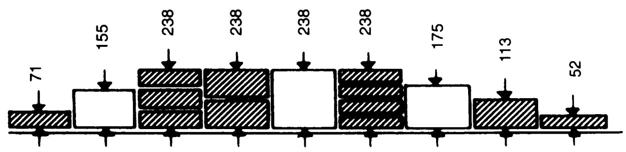


(10) **Tile hanging on insulating blockwork**

As per BS 6100: Section 5.3: 1984, masonry units include several terms: unit (special, shaped, standard shaped, cant, plinth, bullnose, squint, solid, cellular, hollow, perforated, common, facing, split-faced, lintel, fixing, concrete, calcium silicate, sandlime, flintlime, fired-clay, terracotta, faience), header, stretcher, closer (king, queen) and air brick. Brick: a masonry unit not over 338mm in length, 225mm in width or 113mm in height. The term 'brick' includes engineering, frogged, hand-made, stock, wire-cut, rusticated, rubber, tile and damp proof course bricks. Block: a masonry unit exceeding the size of any dimension of brick, including dense concrete, lightweight concrete, lightweight aggregate concrete, aerated concrete, autoclaved aerated concrete, thermal insulation, foam-filled concrete, clinker, dry walling, cavity closer and quoin blocks. All masonry work must be horizontally and vertically true, and properly aligned in accordance with regulations. On double leafed masonry → (7) + (9), floors and roof must be supported only by the inner leaf. Masonry leafs should be joined with a min. of 5 stainless steel wire ties, 3mm in diameter, per sq. m. The ties are separated 250mm vertically and 750mm horizontally.

designation		length (cm)	breadth (cm)	height (cm)
thin format	TF	24	11.5	5.2
standard format	SF	24	11.5	7.1
1½ standard format	1½ SF	24	11.5	11.3
2½ standard format	2½ SF	24	17.5	11.3

(11) **Masonry formats**



(12) **Interrelationship between brick/block height dimensions** → (11)

cellar wall thickness, d (cm)	height h (m) of ground above cellar floor with vertical wall loading (dead load) of ≥ 50 kN/m	< 50 kN/m
36.5	2.50	2.00
30	1.75	1.40
24	1.35	1.00

(13) **Minimum thickness of cellar walls**

thickness of the supporting wall to be braced	height of storey (m)	bracing wall in the 1st to 4th and 5th and 6th full storey levels from top: thickness (cm)		spacing (m)	length
11.5 ≤ d < 17.5 17.5 ≤ d < 24	≤ 3.25	≥ 11.5	≥ 17.5	≤ 4.50 ≤ 6.00	≥ 1/5 of the height
24 ≤ d < 30 30 ≤ d	≤ 3.50 ≤ 5.00			≤ 8.00	

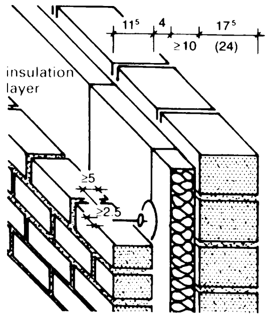
(14) **Thickness, spacing and length of bracing walls**

dimensions (cm)		thickness of wall (cm) 11.5	17.5	24	30	≥ 36.5
recesses in masonry bonding	breadth	–	≤ 51		≤ 63.5	≤ 76
	residual wall thickness	–	≥ 11.5		≥ 17.5	≥ 24
sawn out slots	breadth	≤ wall thickness				
	depth	≤ 2	≤ 3	≤ 4	≤ 5	≤ 6
min. spacing between recesses and slots		199				
distance from openings		≥ 36.5				
distance from wall junctions		≥ 24				

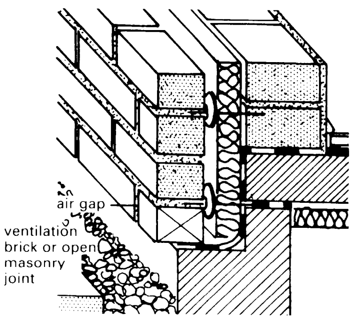
(15) **Permissible vertical recesses and slots in braced and bracing walls**

MASONRY

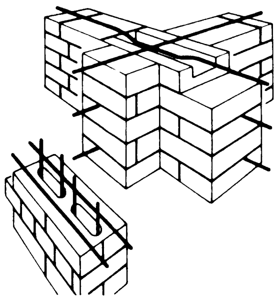
Bricks and Blocks



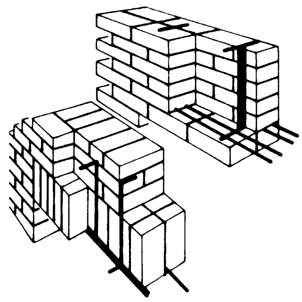
(1) **Double leaf masonry with full fill cavity insulation**



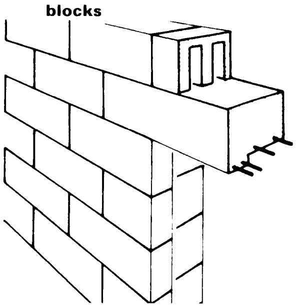
(2) **Detail at base**



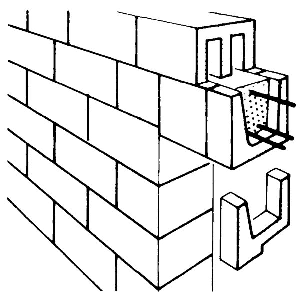
(3) **Crossover with reinforced light concrete masonry blocks**



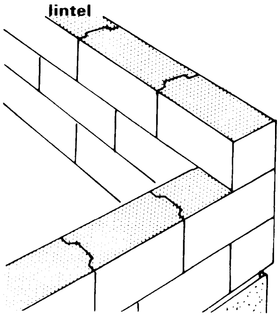
(4) **Reinforced masonry for door or window lintel**



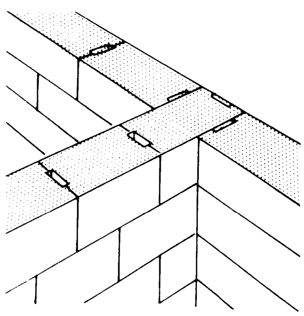
(5) **Masonry of light concrete blocks (hollow blocks) with reinforced pumice concrete lintel**



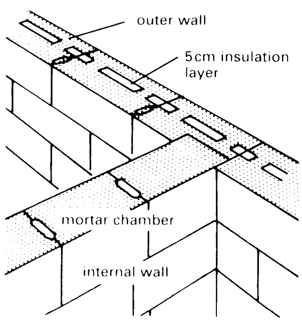
(6) **Masonry in hollow blocks with in situ reinforced trough lintel**



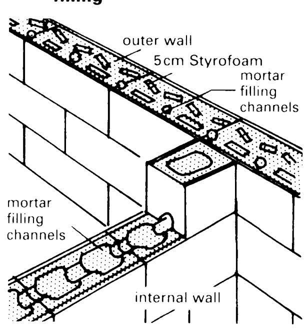
(7) **Aerated concrete blocks with cemented joints: 1 mm**



(8) **Poroton blocks with mortar filling**



(9) **Building blocks with 5 cm insulation layer and mortar filled cavities**



(10) **Special wall blocks with insulation and mortar filling channels**

Masonry walling has to be braced with lateral walls and the tops restrained by upper floors (cellular principle). Bracing walls are plate-like components which stiffen the structure against buckling → p. 63 ⑭. They are rated as supporting walls if they carry more than their own weight from one storey. Non-supporting walls are plate-like components which are stressed only by their own weight and do not provide buckling support. Recesses and slots have to be cut out or positioned in the masonry bonds. Horizontal and slanting recesses are permitted, but with a slenderness ratio of ≤ 140mm and thickness ≥ 240mm under special requirements → p. 63 ⑮. Ties should be provided for connection between external walls and partition walls acting as bracing walls that transmit horizontal loads. Horizontal reinforcement is required in structures of more than two complete storeys or which are more than 18[t]m long, if the site conditions demand it, or where there are walls with many or large openings (if the sum of the opening widths is more than 60% of the wall length, or where the window width is over 2/3 of the storey height or more than 40% of the wall length).

heading number	lengthwise dimension* (m) OD	OS	OL	number of courses	height dimension (m), with block thickness (mm) 52	71	113	155	175	238
1	0.115	0.135	0.125	1	0.0625	0.0833	0.125	0.1666	0.1875	0.25
2	0.240	0.260	0.250	2	0.1250	0.1667	0.250	0.3334	0.3750	0.50
3	0.365	0.385	0.375	3	0.1875	0.2500	0.375	0.5000	0.5625	0.75
4	0.490	0.510	0.500	4	0.2500	0.3333	0.500	0.6666	0.7500	1.00
5	0.615	0.635	0.625	5	0.3125	0.4167	0.625	0.8334	0.9375	1.25
6	0.740	0.760	0.750	6	0.3750	0.5000	0.750	1.0000	1.1250	1.50
7	0.865	0.885	0.875	7	0.4375	0.5833	0.875	1.1666	1.3125	1.75
8	0.990	1.010	1.000	8	0.5000	0.6667	1.000	1.3334	1.5000	2.00
9	1.115	1.135	1.125	9	0.5625	0.7500	1.125	1.5000	1.6875	2.25
10	1.240	1.260	1.250	10	0.6240	0.8333	1.250	1.6666	1.8750	2.50
11	1.365	1.385	1.375	11	0.6875	0.9175	1.375	1.8334	2.0625	2.75
12	1.490	1.510	1.50	12	0.7500	1.0000	1.500	2.0000	2.2500	3.00
13	1.615	1.635	1.625	13	0.8125	1.0833	1.625	2.1666	2.4375	3.25
14	1.740	1.760	1.750	14	0.8750	1.1667	1.750	2.3334	2.6250	3.50
15	1.865	1.885	1.875	15	0.9375	1.2500	1.875	2.5000	2.8125	3.75
16	1.990	2.010	2.000	16	1.0000	1.3333	2.000	2.6666	3.0000	4.00
17	2.115	2.135	2.125	17	1.0625	1.4167	2.125	2.8334	3.1875	4.25
18	2.240	2.260	2.250	18	1.1250	1.5000	2.250	3.0000	3.3750	4.50
19	2.365	2.385	2.375	19	1.1875	1.5833	2.375	3.1666	3.5625	4.75
20	2.490	2.510	2.500	20	1.2500	1.6667	2.500	3.3334	3.7500	5.00

* OD = outer dimension, OS = opening size, OL = overlap

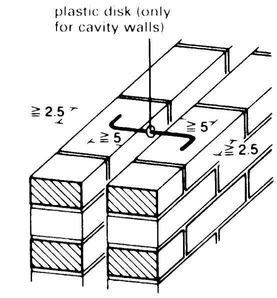
(11) **Setting out dimensions for masonry work**

block format	block format	dimension (cm)	number of courses per 1 m height	wall thickness (cm)	per m² of wall: no. of blocks	per m² of wall: mortar (litre)	per m³ of masonry: no. of blocks	per m³ of masonry: mortar (litre)
perforated blocks (up to 10% less mortar for solid blocks)	DF	24 × 11.5 × 5.2	16	11.5 36.5	66 132 198	29 68 109	573 550 541	242 284 300
	NF	24 × 11.5 × 7.1	12	11.5 24 36.5	50 99 148	26 64 101	428 412 406	225 265 276
	2 DF	24 × 11.5 × 11.3	8	11.5 24 36.5	33 66 99	19 49 80	286 275 271	163 204 220
	3 DF	24 × 17.5 × 11.3	8	17.5 24	33 45	28 42	188 185	160 175
	4 DF	24 × 24 × 11.3	8	24	33	39	137	164
	8 DF	24 × 24 × 23.8	4	24	16	20	69	99
blocks and hollow blocks	blocks and hollow blocks	49.5 × 17.5 × 23.8 49.5 × 24 × 23.8 49.5 × 30 × 23.8 37 × 24 × 23.8 37 × 30 × 23.8 24.5 × 36.5 × 23.8	4 4 4 4 4 4	17.5 24 30 24 30 36.5	8 8 8 12 12 16	16 22 26 26 32 36	46 33 27 50 42 45	84 86 88 110 105 100

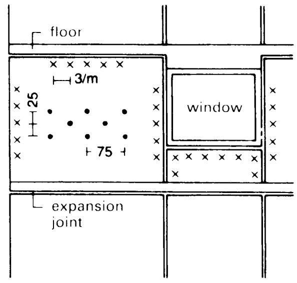
(12) **Building material requirements for masonry work**

MASONRY

Bricks and Blocks



(1) **Wire ties for external double leaf cavity walls**



(2) **Anchoring of the outer leaf → pp. 63–4**

wall thickness (cm)	17.5	11.5
storey height (m)	≤ 3.25	
live load (kN/m²) including addition for light dividing walls	≤ 2.75	
number of complete storeys above	4 1)2)	2 2)

Only permissible as intermediate support for one way spanning floors of span ≤ 4.5 m; while for two way spanning floors, the smaller span is to be taken 3).
Between the bracing walls, only one opening is permitted with a width of ≤ 1.25 m.
1) Including any storeys with walls 11.5 cm thick
2) If the floors continuously span in both directions, then the values for the direction which results in the lower loading of the walls from the floor should be multiplied by 2.
3) Individual loads from the roof construction imposed centrally are permissible if the transference of the loads on to the walls can be proved. These individual loads must be ≤ 30 kN for 11.5 cm thick walls and ≤ 50 kN for walls which are 17.5 cm thick.

(3) **Supporting internal walls with d < 24 cm; conditions of use**

wall thickness (cm)	permissible maximum value for openings (m²) at a height above ground level of 0–8 m		8–20 m		20–100 m	
	ε = 1.0	ε ≥ 2.0	ε = 1.0	ε ≥ 2.0	ε = 1.0	ε > 2.0
11.5	12	8	5	5	6	4
17.5	20	14	13	9	9	6
≥ 24	36	25	23	16	16	12

(4) **Areas of openings in non-supporting walls (only mortar IIa or III)**

description	gross density (kg/m³)	outer walls	party and staircase walls
light hollow concrete blocks two and three chambers	1000 1200 1400	300 365 490	300 240 240
light solid concrete blocks	800 1000 1200 1400 1600	240 300 300 365 490	300 300 240 240 240
aerated concrete blocks	600 800	240 240	365 365
autoclaved aerated concrete	800	175	312.5
large format components with expanded clay, expanded shale, natural pumice, lava crust without quartz sand	800 1000 1200 1400	175 200 275 350	312.5 312.5 250 250
light concrete with porous debris structure with non-porous additions such as gravel	1600 1800 2000	450 625 775	250 250 250
as above, but with porous additions	1200 1400 1600	275 325 425	250 250 250

(5) **Minimum thicknesses of external party and staircase walls plastered on both sides**

Solid masonry walling comprises a single leaf, where the facing work is attached to the background masonry by a masonry bond. Each course must be at least two bricks/blocks in depth, between which there is a continuous, cavity-free longitudinal mortar joint of 20 mm thickness. The facing leaf is included in the load-bearing cross-section → p. 63.

In double leaf walling without cavity, for load considerations, only the thickness of the inner leaf is taken into account. For calculating the slenderness ratio and spacing of the bracing components, the thickness of the inner shell plus half the thickness of the outer is used. If regulations allow it the cavity can be completely filled (double leaf cavity walling with insulating cavity fill).

Double leaf cavity walling without cavity fill: min. thickness of inner leaf → (6); outer leaf ≥ 115 mm; the air gap should be 60 mm wide; the leafs are connected by ties → (1) – (2). The outer leaf must be supported over the whole area and attached at least every 12 m. The air gap is to extend from 100 mm above the ground to the roof, without interruption. The outer leafs are to be provided with ventilation openings top and bottom, on every 1500 mm² wall area (including openings). Vertical movement joints are to be provided in the outer leaf, at least at the corners of the building, and horizontal movement joints should be provided at the foundation level → (2).

Reinforced masonry: wall thickness ≥ 115 mm; block/brick strength classification ≥ 12, mortar III; joints with ≤ 20 mm reinforcement; steel diameter ≤ 8 mm, ≤ 5 mm at crossover points.

Wall types, wall thicknesses: Evidence must be provided of required structural wall thicknesses. This is not necessary where the selected wall thickness is clearly adequate. When selecting the wall thickness, particular attention should be paid to the function of the walls with regard to thermal and sound insulation, fire protection and damp-proofing. Where external walls are not built of frost resistant brick or stone, an outer rendering, or other weather protection should be provided.

Supporting walls are predominantly subjected to compressive stresses. These panel type structural elements are provided for the acceptance of vertical loads (e.g. floor and roof loads) and horizontal loads (e.g. wind loads).

number of permissible full storeys including the finished roof structure	2	≥ 3
for ceilings that only load single leaf transverse walls (partitioned type of construction) and on heavy ceilings with adequate lateral distribution of the loads	11.5 1)	17.5
for all other ceilings	24	24
1) highest permissible vertical live load including addition for light dividing walls	p = 2.75 kN/m²	

(6) **Minimum thickness (in cm) of the internal leaf in double leaf masonry external walls**

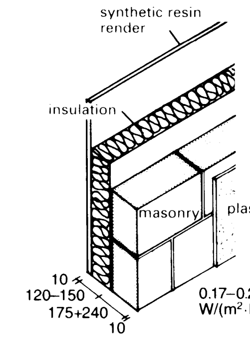
thickness of the supporting wall to be braced (cm)	storey height (m)	bracing wall: 1st and 4th storeys from the top, thickness (cm)	5th and 6th storeys from the top, thickness (cm)	spacing (m)
≥ 11.5 < 17.5	≤ 3.25	≥ 11.5	≥ 17.5	≤ 4.50
≥ 17.5 < 24				≤ 6.00
≥ 24 < 30	≥ 3.50			≤ 8.00
≥ 30	≤ 5.00			

(7) **Thickness and spacing of bracing walls**

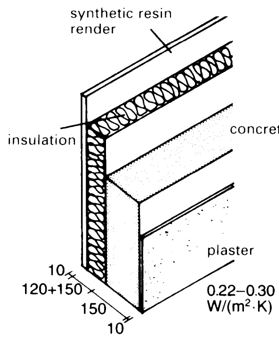
EXTERNAL WALLS

Low-energy Building Construction

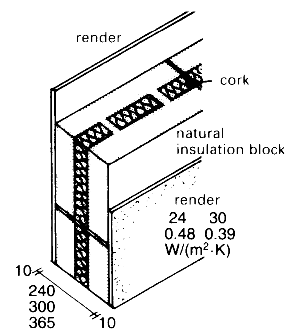
The thermal insulation characteristics of external walls is an important element in the saving of thermal energy. The insulation provided by low energy building construction is greatly affected by the connections between the various building components. Significant heat losses can occur in these locations. Standard cross-sections depicting various types of building materials indicate the insulation values which can be achieved. A large range of building materials are available, such as concrete, masonry, timber, insulation materials, plaster, cork, reeds and clay. Clay has proved itself as a building material for thousands of years. It is the most common and most tested material in the world and, biologically and ecologically, is an exemplary material. Finished clay insulation products are now available and are well suited to today's level of technology → ⑩ – ⑪.



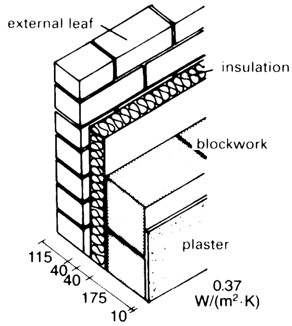
① **Masonry with bonded insulation panels**



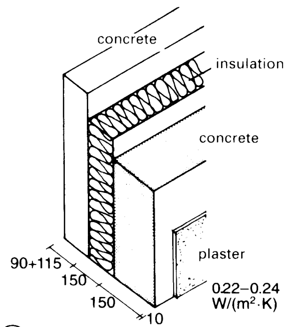
② **Concrete with bonded insulation panels**



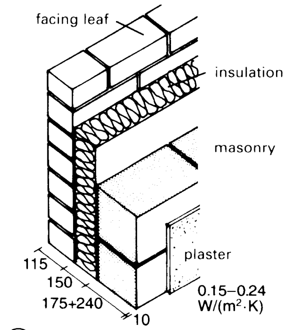
③ **Natural clay insulation blocks (Bioton)**



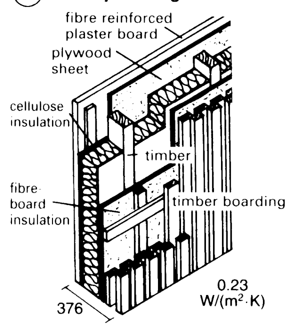
④ **Cavity walling**



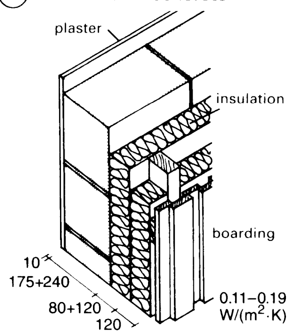
⑤ **Double skin concrete**



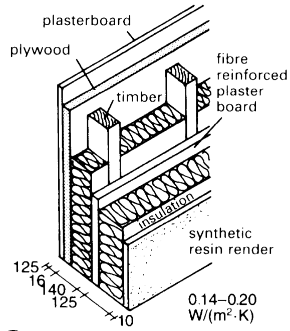
⑥ **Aerated concrete cavity wall**



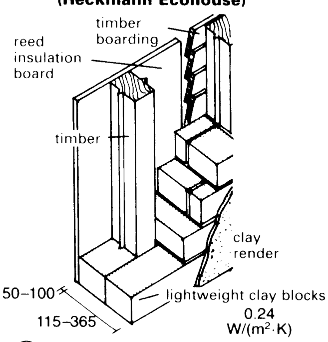
⑦ **Low energy wall (Heckmann Ecohouse)**



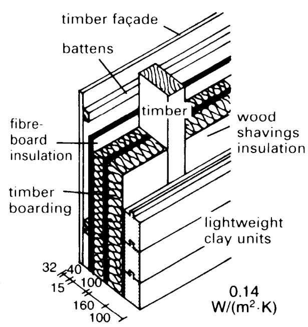
⑧ **Walling with applied sheathing**



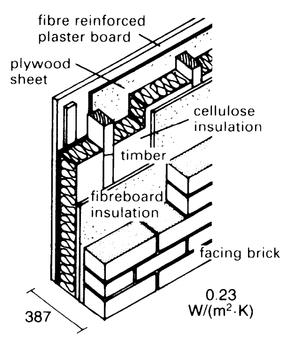
⑨ **Timber panel construction**



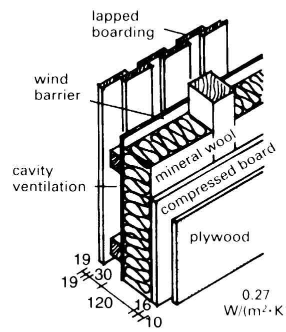
⑩ **Balloon frame with lightweight clay blocks**



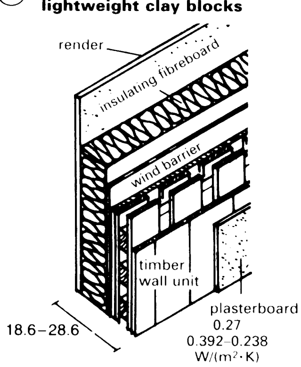
⑪ **Timber frame with lightweight clay elements**



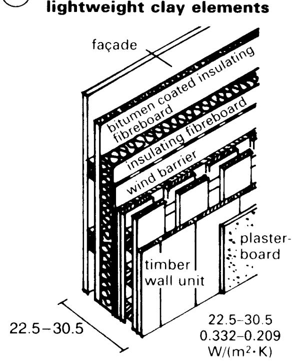
⑫ **Low energy wall with facing brick**



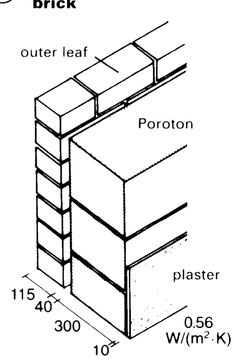
⑬ **Timber frame (insulation between the posts)**



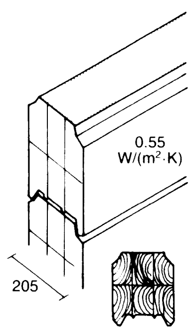
⑭ **Timber unit wall (Lignotrend)**



⑮ **Variation of** → 14

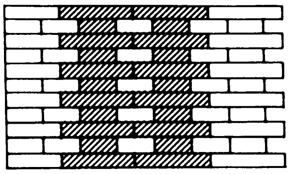


⑫ **Poroton (clay insulating block) cavity wall**

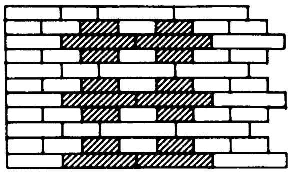


⑬ **Profiled laminated timber log construction**

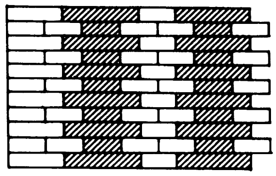
MASONRY BONDS



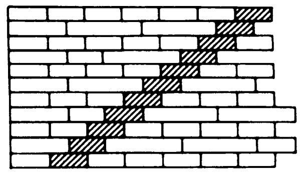
(1) English bond



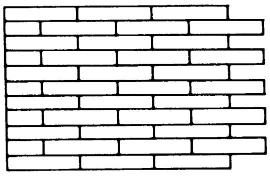
(2) Variation on English bond



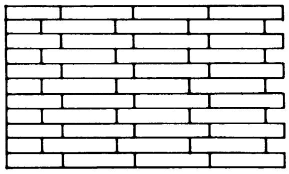
(3) One stretcher, one header; alternating with course of headers



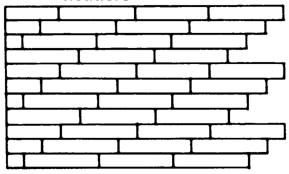
(4) Two stretchers, one header; alternating with course of headers



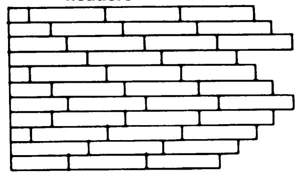
(5) Half-lap stretcher bond



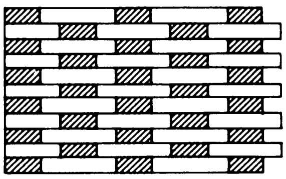
(6) Quarter-lap stretcher bond



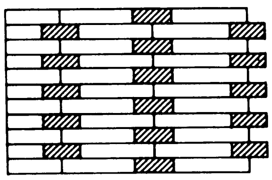
(7) Stretcher bond with 1/4 lap rising right



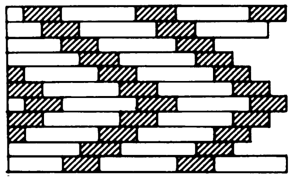
(8) Stretcher bond with 1/4 lap rising right and left



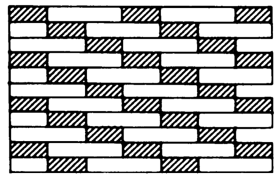
(9) Flemish bond: 1 header, 1 stretcher; alternated each course



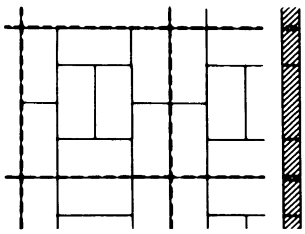
(10) 1 header; 2 stretchers alternating coursewise



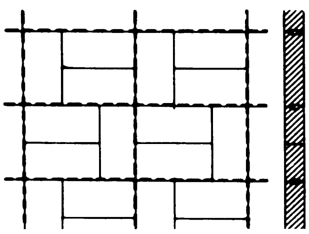
(11) 1 header; 1 stretcher alternating coursewise with 1/4 bond rising right and left



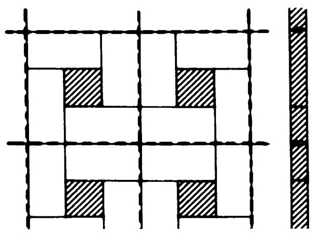
(12) 1 header; 1 stretcher alternating coursewise with 1/2 bond rising left



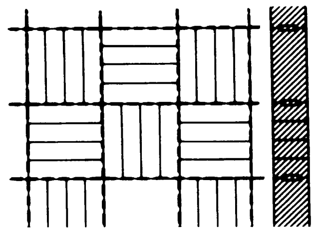
(13) 1/4 brick thick (brick on edge) reinforced wall with 8 brick panel



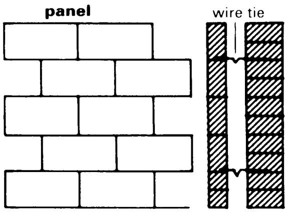
(14) As (13), with 3 brick panel



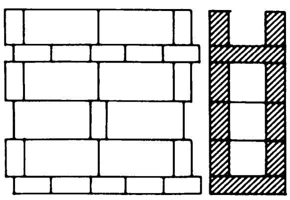
(15) As (13), with 4 1/2 brick panel



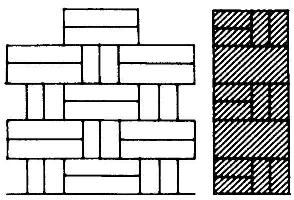
(16) Reinforced brick wall, 1/2 brick thick with 4 brick panel



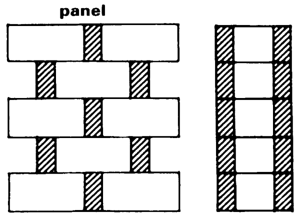
(17) Brick on edge external leaf linked by ties to internal leaf



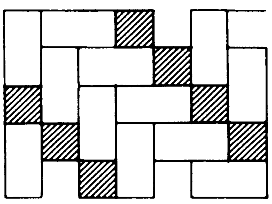
(18) Cavity wall with 2×1/4 brick leafs, tied by a connecting header course, and alternate header bricks on edge



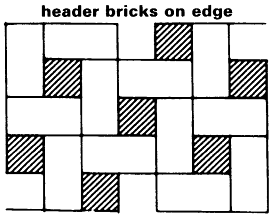
(19) Ornamental brick wall



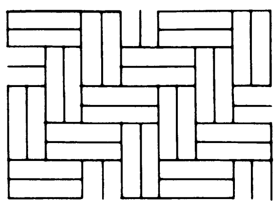
(20) Cavity wall of 2×1/4 brick leafs bonded by header bricks on edge



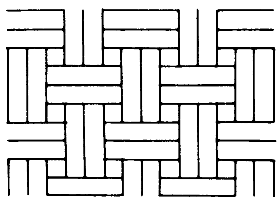
(21) Floor finish of whole and half bricks



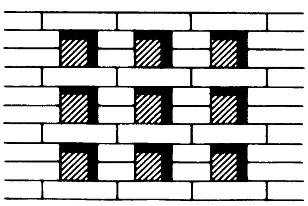
(22) As (21) with different pattern (other versions possible)



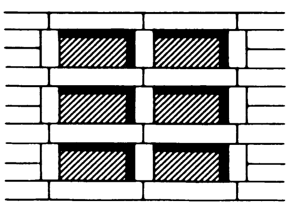
(23) Heavily loaded floor finish with bricks on edge (herring-bone pattern as in parquet)



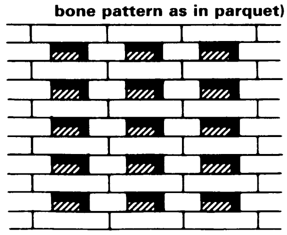
(24) As (23) with quarter pieces (weave pattern)



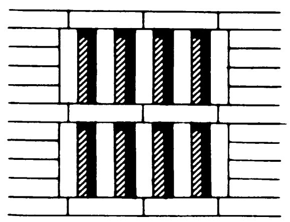
(25) Brickwork with gaps (honeycomb) for light or air admission (holes 1/2 × 1/2 brick)



(26) As (25) (holes 1/2 × 3/4 brick)

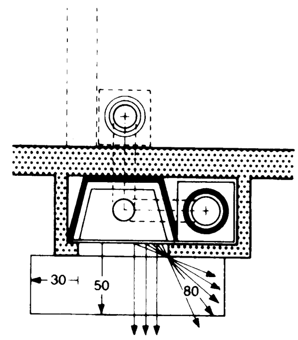


(27) As (25) (holes 1/4 × 1/2 brick)

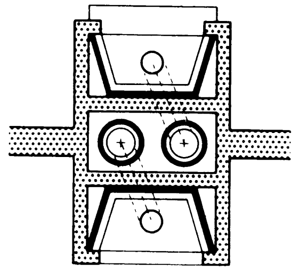


(28) As (25) (holes 1 × 1/4 brick)

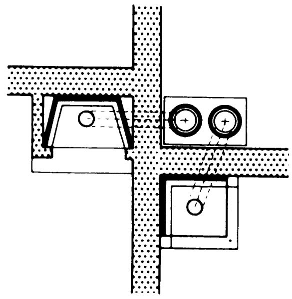
FIREPLACES



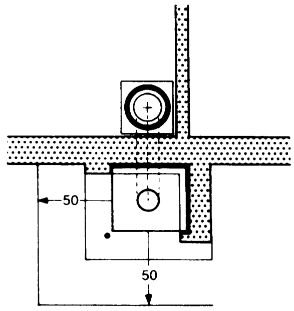
(1) **Fireplace open on one side with safety area**



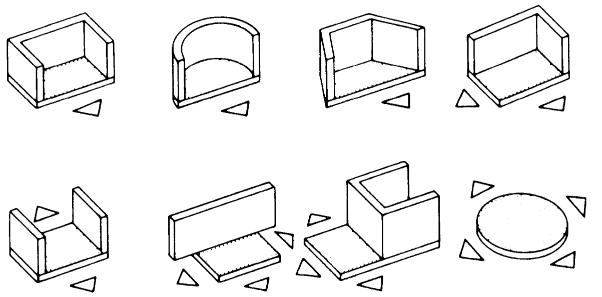
(2) **Fireplaces open on one side in separate rooms**



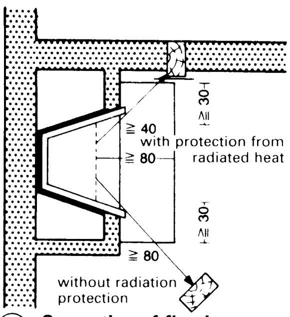
(3) **Fireplaces open on one/two sides in separate rooms**



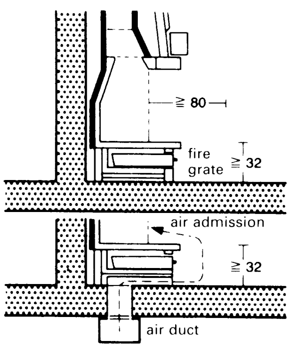
(4) **Fireplace open on two sides with safety area**



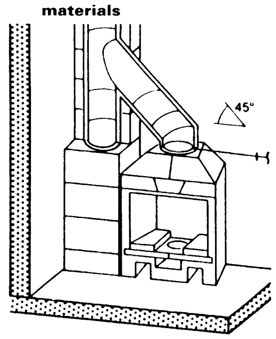
(5) **Heat radiation surfaces and directions**



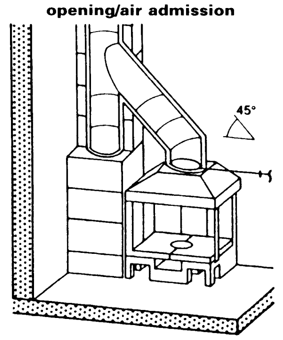
(6) **Separation of fireplace opening from combustible materials**



(7) **Protection of combustible floor from the fireplace opening/air admission**



(9) **Fireplace open on one side**

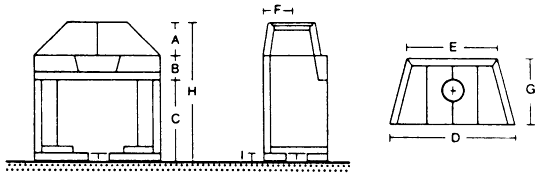


(10) **Fireplace open on two sides**

Every open fire must be connected to its own separate flue and should be immediately adjacent to the next → (1) – (4). Flue cross-sections must be matched to the size of the open fire → (8). The effective height of the flue from the smoke hood to the chimney mouth should be ≥ 4.5 m. The angle of a connecting flue to the main flue should be 45° → (9) – (10). Open fires must not be sited in rooms with less than 12 m² floor area. Only wood with a low resin content, and beech, oak, birch or fruit tree timber with few knots, should be used for burning. In the case of the use of gas appliances, reference should be made to the relevant regulations.

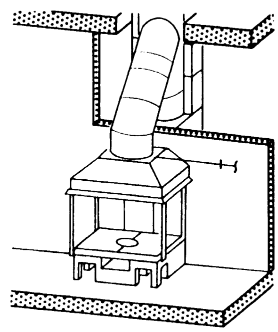
Air for combustion must come from outside and needs to be able to enter even if the doors and windows are airtight. Air admission openings can usefully be sited in the base of the fire, or at the front, and ducts that introduce air to a position close to the fireplace opening should be provided → (7).

The fireplace opening must be separated from combustible materials and built-in furniture by at least 800[t]mm to the front, above and to the sides → (6) – (7). Open fires must be constructed from non-combustible materials that satisfy local regulations and must be of stable construction. The floor, walls and grate and the smoke hood should be made from fire clay bricks/slabs, fire resistant concrete or cast iron (although the grate and hood are often metal). Any bricks or stones used must be of suitable type for chimney construction. Smoke hoods can be made from 2 mm steel brass, or copper sheet.

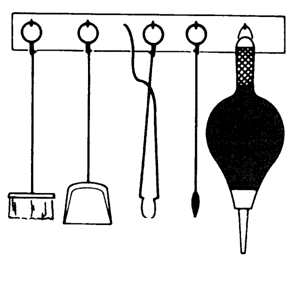


type		open on 1 side					open on 2 sides			open on 3 sides		
		1	2	3	4	5	6	7	8	9	10	11
room area (m²)		small rooms	16–22	22–30	30–35	33–40	25–35	35–45	over 48	35–45	45–55	over 55
room volume (m³)		small rooms	40–60	60–90	90–105	105–120	90–105	105–150	over 150	35–150	45–150	over 200
size of fire opening (cm²)		2750	3650	4550	5750	7100	5000	6900	9500	7200	9800	13500
dimension fire opening (cm)		60/46	70/52	80/58	90/64	100/71						
diameter (cm) of associated flue		20	22	25	30	30	25	30	35	25	30	35
all dimensions (cm)	A	22.5	24	25.5	28	30	30	30	30	30	30	30
	B	13.5	15	15	21	21	–	–	–	–	–	–
	C	52	58	64	71	78	50	58	65	50	58	65
	D	72	84	94	105	115	77		108	77	90	114
	E	50	60	65	76	93	77	90	108	77	90	114
	F	19.5	19.5	22.5	26	26	27.5	30	32.5	27.5	30	32.5
	G	42	47	51	55	59	64	71	82	64	71	82
	H	88	97	104.5	120	129	80	88	95	80	88	95
	I	6	6	6	7	7	6.4	6.4	6.4	6.4	6.4	
weight		165	80	310	385	470	225	300	405	190	255	360

(8) **Dimensions and sizes of open fires**

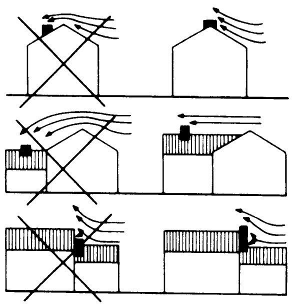


(11) **Fireplace open on three sides**

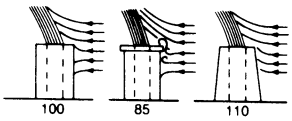


(12) **Fireplace tools**

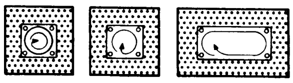
CHIMNEYS AND FLUES



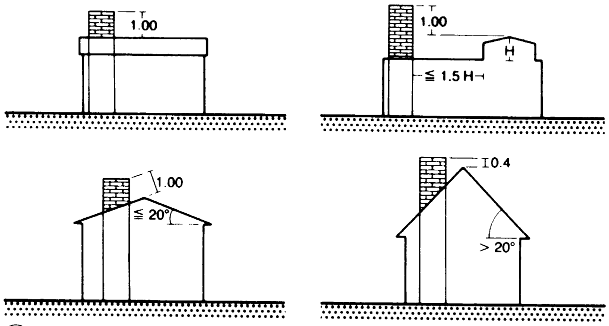
① Wind effect on chimney efficiency



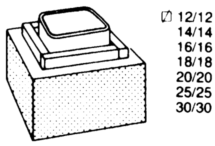
② ③ ④ **Comparative values of efficiency**



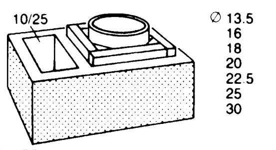
⑤ **Effect of chimney top and cross-section on efficiency**



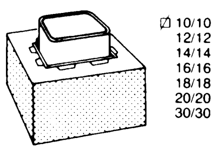
⑥ **Chimney heights above the roof and roof structures**



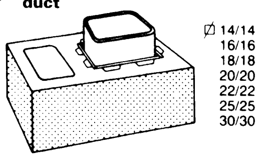
⑦ **Modular flue**



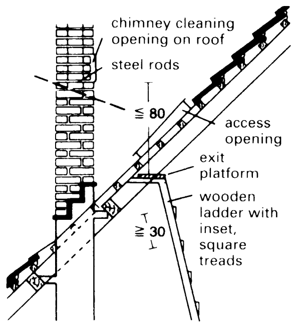
⑧ **Modular flue with ventilation duct**



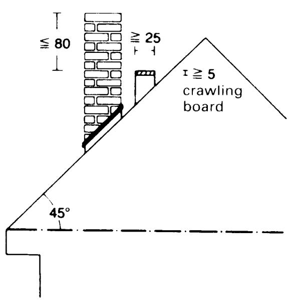
⑨ **Modular flue (rear ventilated)**



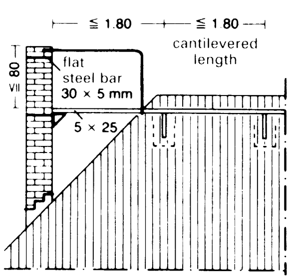
⑩ **Modular flue (rear ventilated) with ventilation duct**



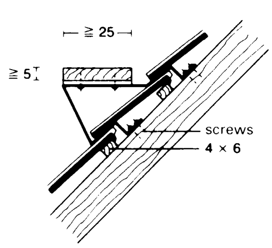
⑪ **Access opening with ladder and platform**



⑫ **A crawling board is necessary for roof slopes above 15°**



⑬ **Length and attachment of the crawling board**

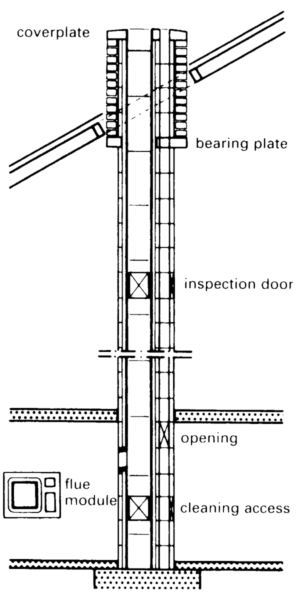


⑭ **Crawling boards are fixed more firmly to rafters than to the tile battens**

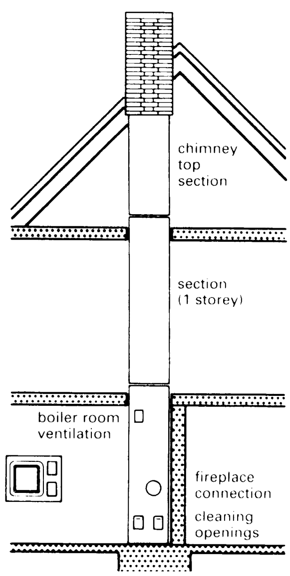
Flues and chimneys are ducts in and on buildings, which are intended exclusively to convey the gases from fireplaces to the outside over the roof. The following should be connected to a flue: fireplaces with a nominal heat output of more than 20 kW; gas fire places with more than 30 kW; every fireplace in buildings with more than five full storeys; every open fire and forge fire; fireplaces with a means of opening and every fireplace with a burner and fan.

Provision should be made in the foundation plans to support the weight of the fireplace, flue and chimney. Flues must have circular or rectangular internal cross-sections. The cross-section must be ≥ 100 cm², with a shortest side of 100 mm. Brick flues must have a shortest internal side of length ≥ 135 mm, the longer side must not exceed 1.5 times the length of the shorter. The shortest effective flue height ≥ 4 m; for gaseous fuels ≥ 4 m. The mouth of the chimney should be ≥ 400 mm above the apex of the roof, where the roof slope is greater than 20° and for roof slopes less than 20° this dimension is ≥ 1 m → ⑥. Where chimneys are closer to structures on the roof than between 1.5 and 3 times the height of the structure, it must be ensured that they clear the structure by at least 1 m. Where the mouth of a chimney is above a roof which has a parapet which is not closed on all four sides, it must be at least 1 m above the parapet. Every flue must have a ≥ 100 mm wide by ≥ 180 mm high cleaning opening which is at least 200 mm lower than the lowest fireplace connection. Chimneys which cannot be cleaned from the mouth opening, must have an additional cleaning opening in the flue in the roof space or in the chimney above the roof. The following materials may be used for single skin flues: light concrete blocks, clay bricks, lime sandstone -solid bricks, foundry bricks.

Materials for treble-skinned chimneys, with outer casing, insulation layer and moveable inner lining can be formed components in light concrete or fireclay for the inner lining; for the outer casing, formed components in light concrete, masonry stone, bricks with vertical perforations, lime sandstone, foundry bricks, or aerated concrete blocks. For the insulating layer, non-combustible insulating material must be used. Exposed outer surfaces of the chimney in the roof space should be provided with a rough cast finish of at least 5–10 mm thickness. Flue walls must not be loadbearing. The chimney can be clad with slates, shingle slates or cement fibre sheets. Zinc or copper sheet can be fixed to the chimney on to the sub-structure using dowels (not wooden dowels). Prefabricated claddings are recommended.

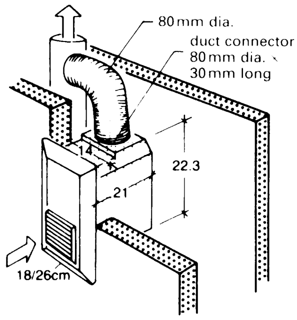


⑮ **Modular flue installation**

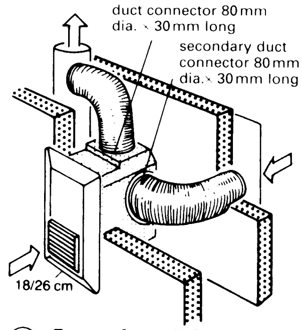


⑯ **Prefabricated flue (in storey height lengths)**

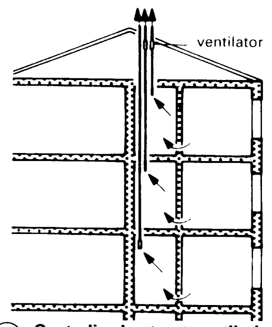
VENTILATION DUCTING



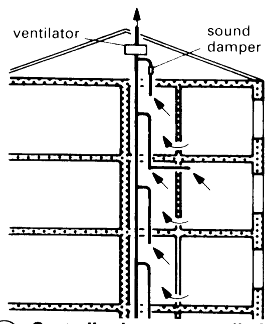
① **Single-room extract fan unit for concealed installation**



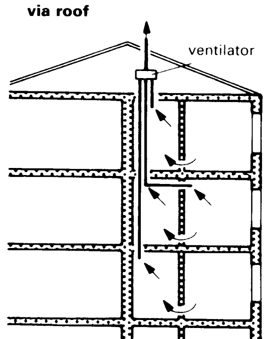
② **Extract fan unit for two rooms: concealed installation**



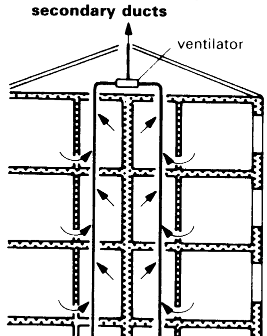
③ **Centralised extract ventilation system with exhaust ducted via roof**



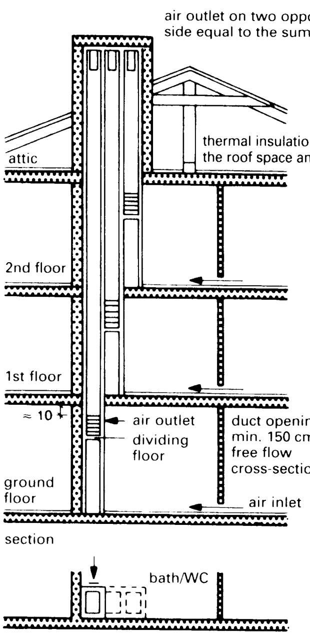
④ **Centralised extract ventilation system with primary and secondary ducts**



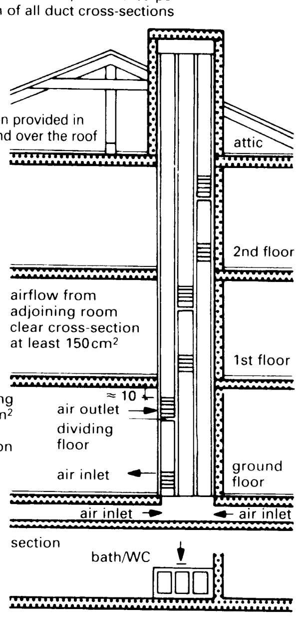
⑤ **Centralised ventilation system with separate primary ducts**



⑥ **Centralised ventilation system with a number of primary ducts without secondary ducts**



⑦ **Single duct convection ventilation system**



⑧ **Supply and extract convection ventilation system**

Extract fan units should meet the ventilation requirements of bathrooms and lavatories in residential and non-residential buildings (such as schools, hotels and guest houses) and extract air from one or several rooms into an extract duct → ① – ②. Ventilation systems should be sized for a minimum of 4 complete changes of air in the rooms which need to be ventilated. A flow of 60 m³/h is adequate for bathrooms with a toilet and a flow of 30 m³/h is adequate for one toilet. Every internally sited room to be ventilated must have a non-closable ventilation opening. The size of the area through which air flows must be 100 mm² for every m³ of room volume. Gaps around the door may be taken as equivalent to 250 mm². In bathrooms, the temperature must not fall below 22°C, due to the flow of air.

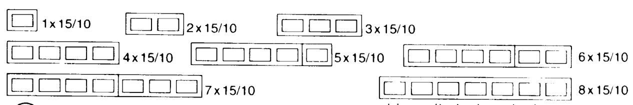
The velocity of flow in the living area should be ≥ 0.2 m/s. The exhausted air must be led outside. Each individual ventilation system must have its own main duct → ③ – ⑤.

Central ventilation systems have common main ducting for a number of living areas → ④ – ⑥.

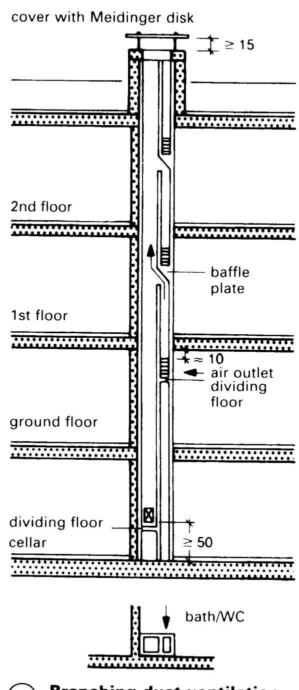
The effective functioning of branching duct convection ventilation systems depends essentially on the available cross-section area of duct available per connection → ⑨. The cross-section of the ventilation shaft for single-duct systems without mechanical extract → ⑦ in bathrooms and WCs without open windows (up to 8 storeys) should be 1500 mm² per room.

clear cross-section of the main duct cm²	permissible no. of adjacent duct connections with average effective total height up to 10 m	10–15 m	over 15 m	internal dimensions main duct (cm)	auxiliary duct (cm)
340	5	6	7	20 × 17	9 × 17
400	6	7	8	20 × 20	12 × 20
500	8	9	10	25 × 20	12 × 20
340	5	6	7	20 × 17	2 × 9/17
400	6	7	8	20 × 20	2 × 12/20
500	8	9	10	25 × 20	2 × 12 × 20
340	5	6	7	2 × 12/17	9 × 17
400	6	7	8	2 × 20/20	12 × 20
500	8	9	10	2 × 25/20	12 × 20

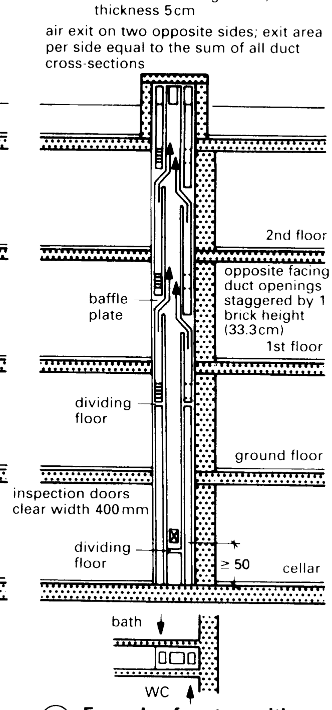
⑨ **Table of dimensions for branching duct convection systems**



⑩ **Single duct ventilation**

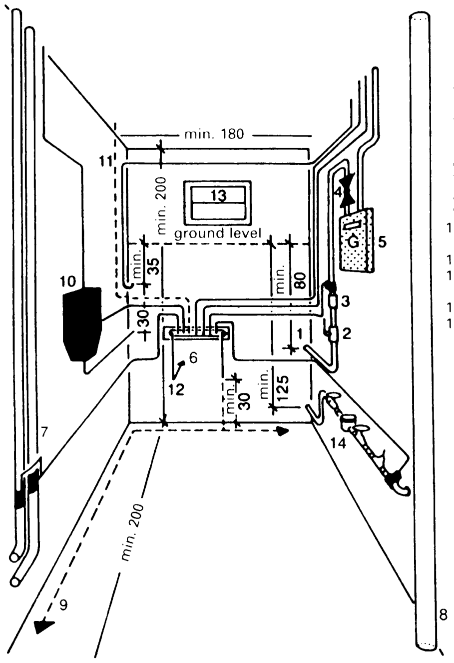


⑪ **Branching duct ventilation system with one main and one auxiliary duct**



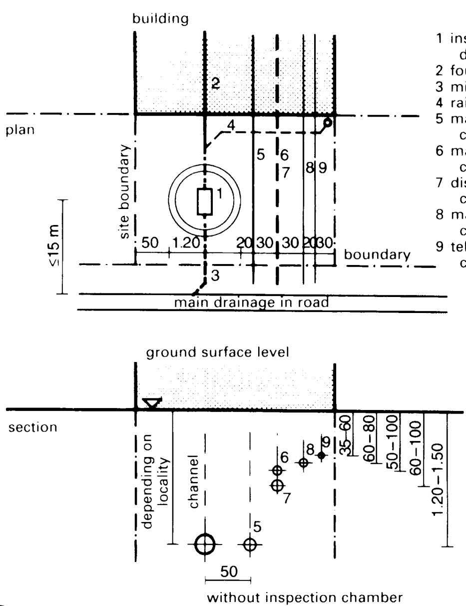
⑫ **Example of system with one main duct and two auxiliary ducts**

SERVICES: CONNECTIONS



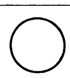
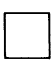
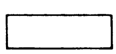
1 gas connection
2 main gas cut-off valve
3 isolator
4 cut-off valve
5 gas meter
6 earthing
7 heating pipe
8 drainage pipe
9 foundation earth
10 electrical mains board
11 telephone cable
12 lightning conductor
13 ventilation
14 water main connection

(1) **Mains connection room**



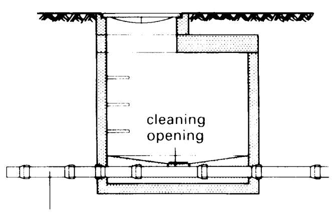
1 inspection chamber dia. 1.0
2 foul water drain
3 mixed water drain
4 rainwater drain
5 mains water connection
6 mains gas connection
7 district heating connection
8 mains electricity connection
9 telephone connection

(2) **Mains connections**

section through manhole	clear width of manholes in m for a manhole depth of > 0.4 to ≤ 0.8 (min.)	> 0.8 (min.)
	0.8	1*)
		0.9 × 0.9
	0.6 × 0.8	0.8 × 1
	no rungs	with rungs

*) shafts above a working height of 2 m calculated from the invert level can be reduced to a diameter of 0.8 m

(3) **Sizes of manholes**

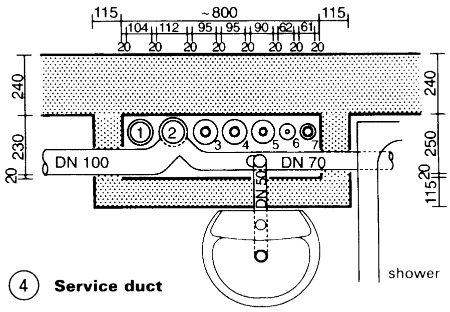


Inspection and cleaning manhole

In houses for one and two families there is no necessity for a mains connection room.

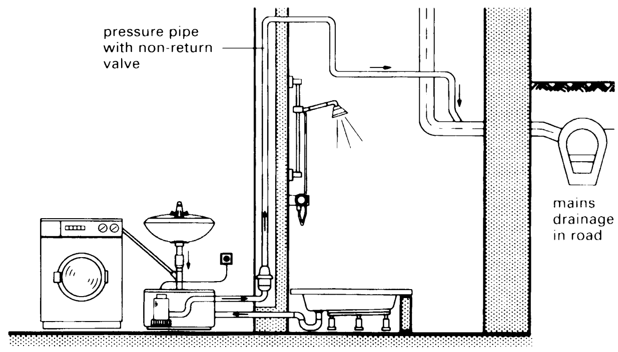
Mains connections rooms should be planned in collaboration with the mains service providers. They must be in locations which can be accessed easily by all (e.g. off the staircase or cellar corridor, or reached directly from outside) and they must not be used for through passage. They have to be on an outside wall, through which the connections can be routed → (1)–(2). Walls should have a fire resistance of at least F30 (minutes). Doors should be at least 650/1950 mm. With district heating schemes, the door must be lockable. A floor gully must be provided where there is connection to water or district heating mains. Mains connections rooms must be ventilated to the open air. The room temperature must not exceed 30°C, the temperature of the drinking water should not exceed 25°C, and the room must not be susceptible to frost.

For up to 30 dwellings, or with district heating for about ten dwellings, allow the following room size: clear width >1.80 m, length 2.00 m, height 2.00 m → (1). For up to approximately 60 dwellings or where there is district heating for 30 dwellings: 1.80 m wide, 3.5 m long, 2.0 m high.

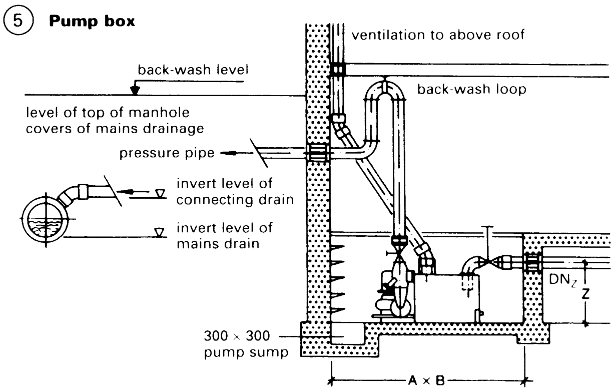


1 mechanical ventilation bath/WC dia. 100
2 foul water dia. 100
3 heating flow DN25
4 heating return DN25
5 hot water supply DN20
6 hot water return DN15
7 cold water supply DN25
(DN = nominal bore)

(4) **Service duct**



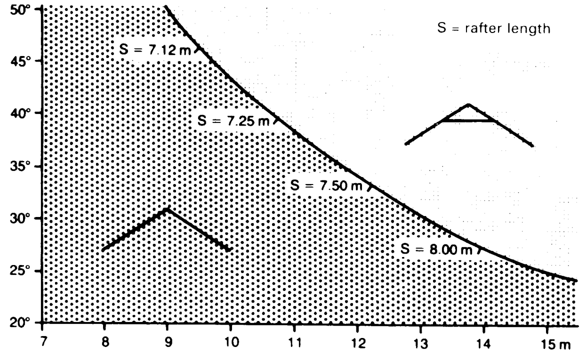
(5) **Pump box**



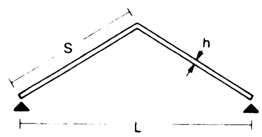
	capacity	lift (m) 3	7	14	dimensions (mm) A	B	Z	DN_Z (mm)
family house	m³/h	47	12	–	1000	1000	450–500	100
multi-family home	m³/h	64	22	–	1800	1300	700–850	125
large complex	m³/h	144	100	18	2600	1950	800–900	150

(6) **Pump installation**

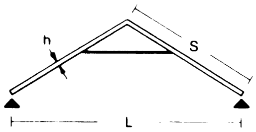
ROOF STRUCTURES



(1) **Economic limits, slope v. span: couple/collar roofs**



(2) **Couple roof**



(3) **Collar roof**

roof slope (degrees)	span L (m)	height of structural component h
15–40	10–20	$h \sim \frac{1}{25} \cdot S$
30–60	10–20	$h \sim \frac{1}{30} \cdot S$


Couple roofs represent the most economical solution for low building widths.

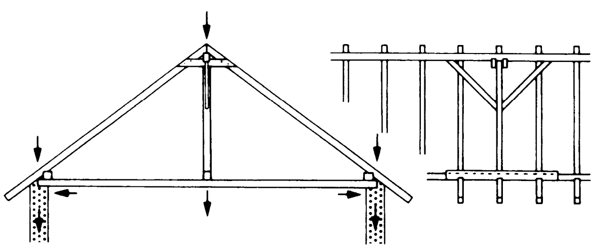

Collar roofs are never the cheapest for slopes under 45°, but are suitable for large free span roofs.


Simply supported roofs are always more expensive than couple roofs and are only used in exceptional cases.

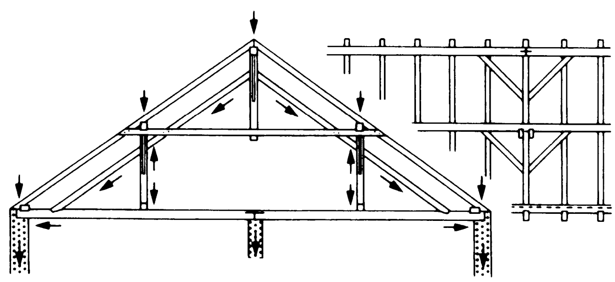

Roofs with two hangers (vertical posts) almost always are the most economical construction.


Purlin roofs with three hangers are only considered for very wide buildings.

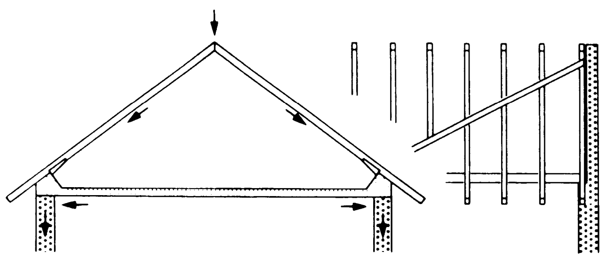
Roofs form the upper enclosure of buildings, protecting them from precipitation and atmospheric effects (wind, cold, heat). They comprise a supporting structure and a roof cover. The supporting components depend on the materials used (wood, steel, reinforced concrete), roof slope, type and weight of roof covering, loading, etc. Loading assumptions must comply with current regulations (dead-weight, live loads, wind and snow loadings). A distinction is made between roofs with and without purlins, because of their different structural system, and of the different functions of the supporting components. However, these two types of construction may be combined. The different types of load transfer also have consequences for the internal planning of the building.



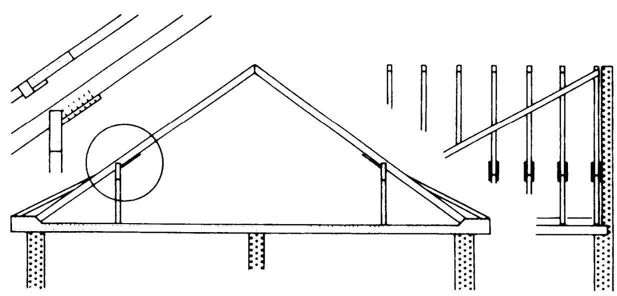
(4) **Strutless purlin roof with centre hanger**



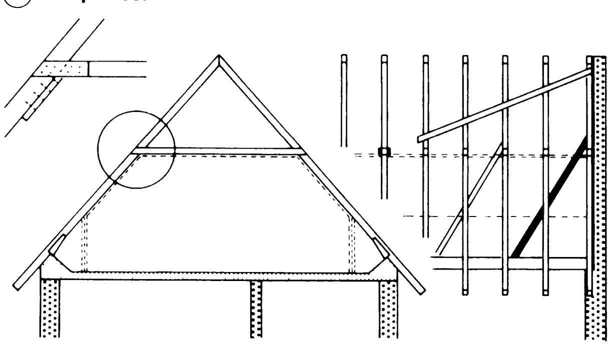
(5) **Strutted purlin roof**



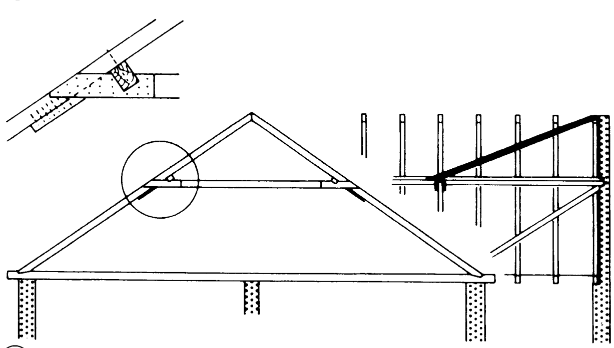
(6) **Couple roof**



(7) **Couple roof with hangers**



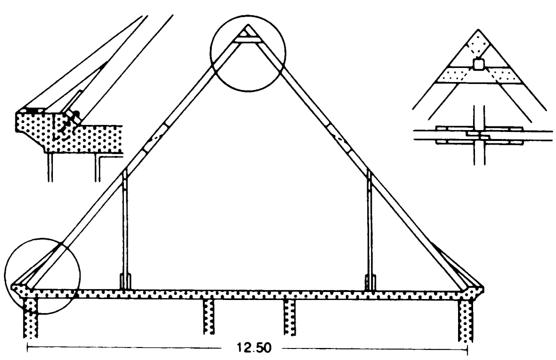
(8) **Collar roof with loft room**



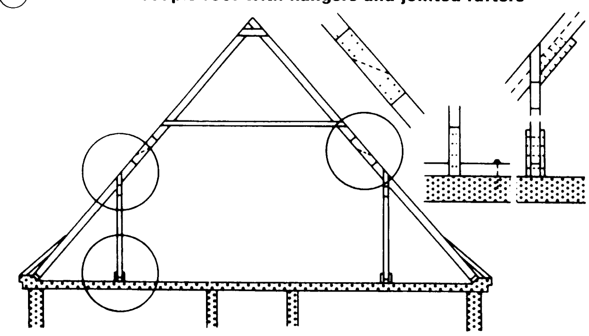
(9) **Close couple roof with collar and purlins**

ROOF STRUCTURES

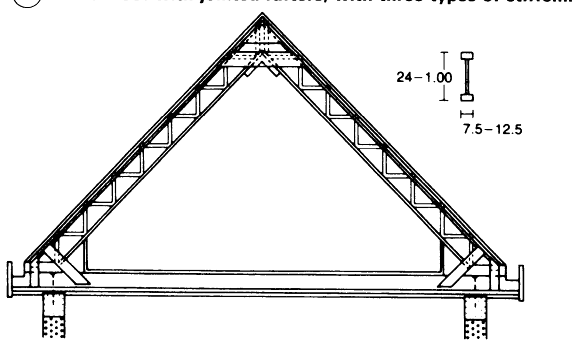
In a purlin roof, rafters have a subordinate function (round section timber spars also possible for small spans). Purlins are load-bearing beams, conducting loads away from the rafters to the supports. Regular supports are required for the purlins (trusses or cross-walls). Early type: ridge purlin with hanger. Double pitch purlin roofs have at least one hanger, situated in the centre of the roof. Suitable when the length of the rafters ≤ 4.5 m; on wider house structures, with rafter length > 4.5 m, then two or more purlins with suitable vertical hangers are required. A rafter roof (rigid triangle principle) is possible in simple form, with short rafters up to 4.5 m. If the rafters' length exceeds 4.5 m, intermediate support is required in the form of collars. This regular, strong system of construction provides a support-free internal roof space. Couple close roofs require a strong tensile connection between the feet of the rafters and the ceiling beams. Sprocketed eaves are a common feature, giving a change of angle in the roof slope. Simple couple and collar roof construction is unsuitable for large roofs. Collar roofs are suitable for building widths to approx. 12.0 m, rafter lengths up to 7.5 m, collar lengths up to 4 m. The collar roof is a three-link frame with a tension member. Prefabricated roof trusses are a very common form of structure for pitched roofs. While economical in the use of timber and light and easy to erect, they have the disadvantage of totally obstructing the roof space.



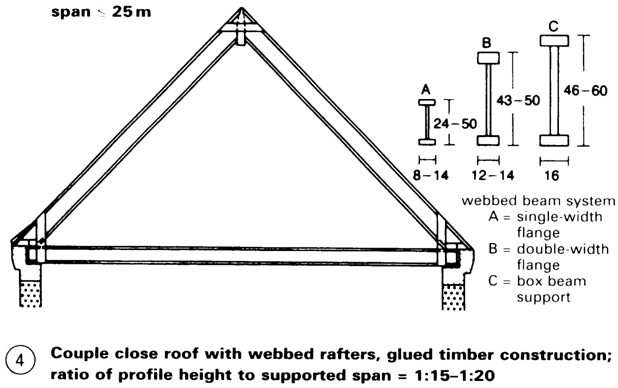
(1) **Restrained couple roof with hangers and jointed rafters**



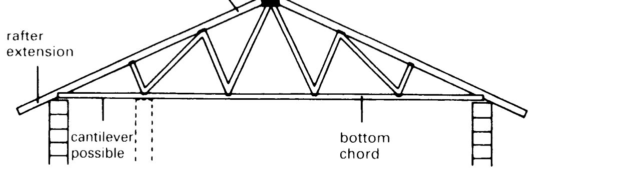
(2) **Collar roof with jointed rafters, with three types of stiffening**



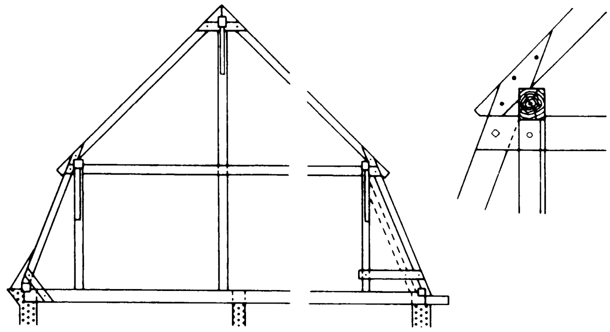
(3) **Couple close roof in timber framing with lifetime guaranteed glued joints with 45° inclined struts as twinned supports over span ≤ 25 m**



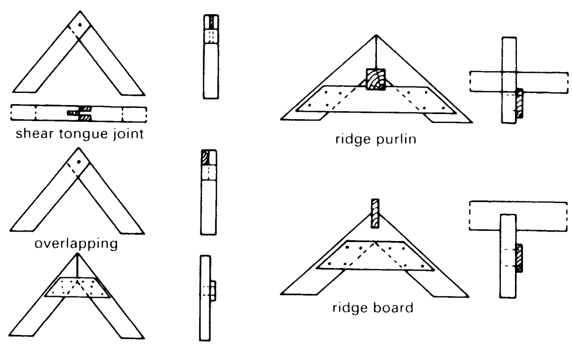
(4) **Couple close roof with webbed rafters, glued timber construction; ratio of profile height to supported span = 1:15–1:20**



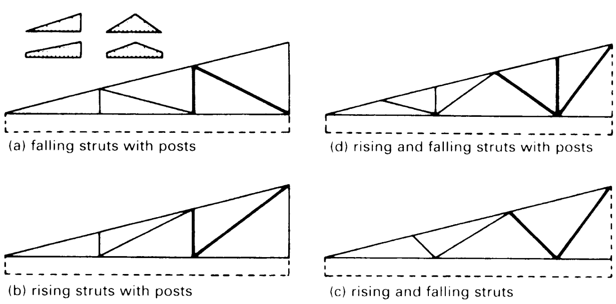
(5) **Trussed rafter with 'gang nail' system for flat roof, lean-to roof and ridge roof**



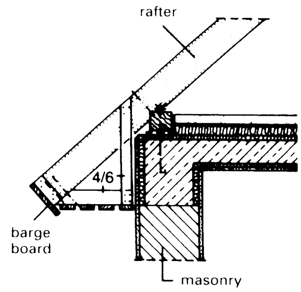
(6) **Mansard roof**



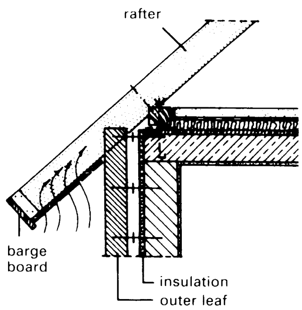
(7) **Butt joint with butt strap**



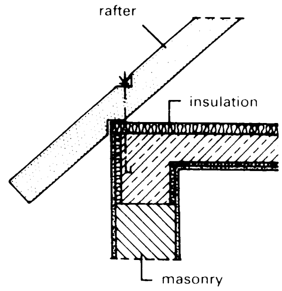
(8) **Timber construction forms and reinforcings**



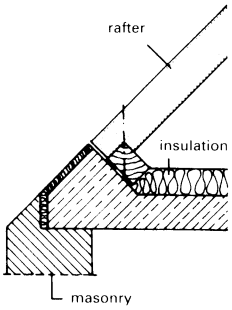
(1) **Eaves detail, purlin roof**



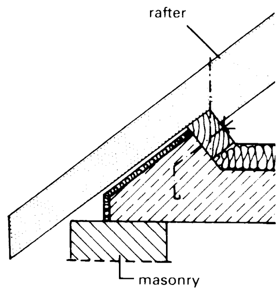
(2) **Eaves detail with cavity walling**



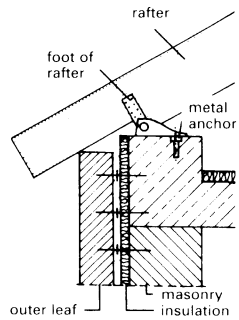
(3) **Rafter ends fixed with bolts into downstand beam**



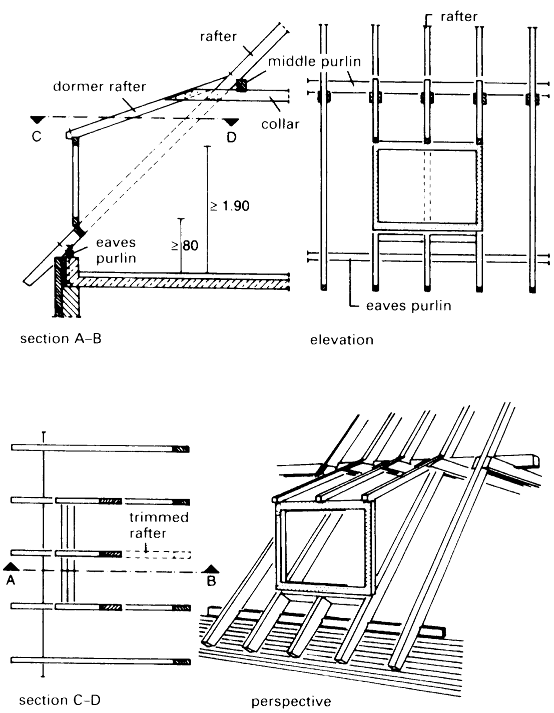
(4) **Curb support, sole plate, rafter nailing**



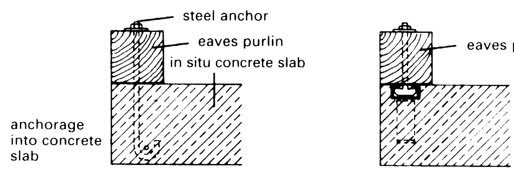
(5) **Rafter continued to the eaves**



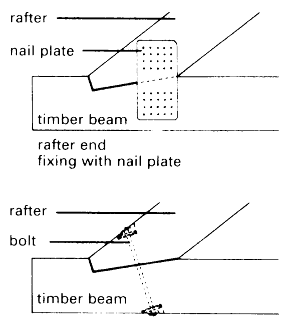
(6) **Steel rafter connection**



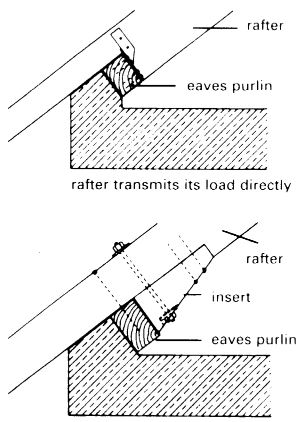
(7) **Dormer window in a purlin roof**



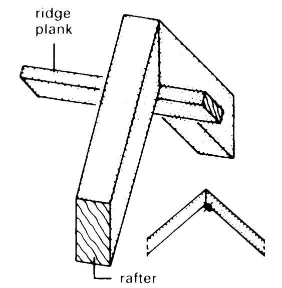
(8) **Anchorage to solid slab**



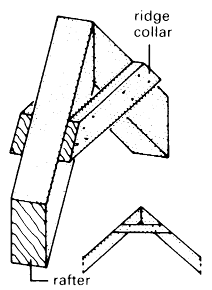
(9) **Rafter end fixing with bolts**



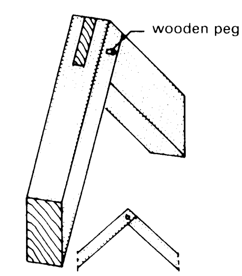
(10) **Detail at foot of roof allowing rafters to overhang**



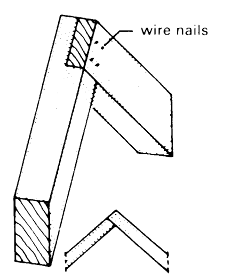
(11) **Ridge details of purlin roof; ridge plank to align the ridge**



(12) **Ridge collar connecting two rafters**

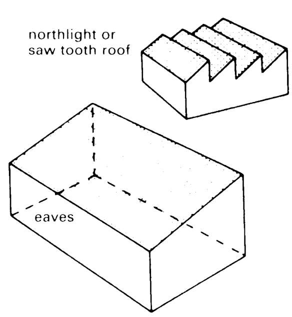


(13) **Simple tenon joint connecting two rafters**

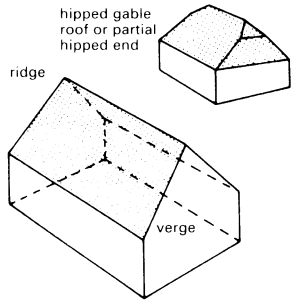


(14) **Scarf joint connecting two rafters**

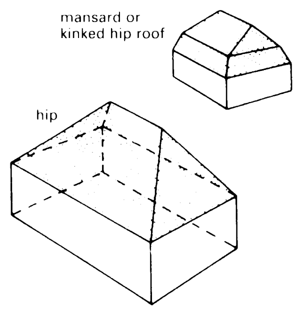
ROOF FORMS



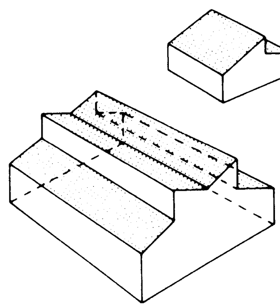
(1) **Mono-pitch roof**



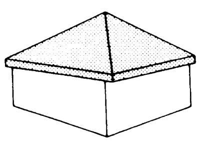
(2) **Ridge roof**



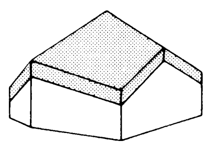
(3) **Hipped roof**



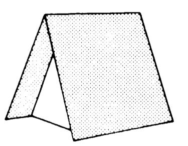
(4) **Combination roof**



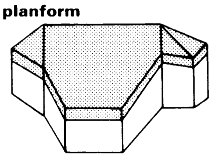
(5) **Pyramid roof**



(6) **Pyramid roof, polygonal planform**



(7) **Roof house**

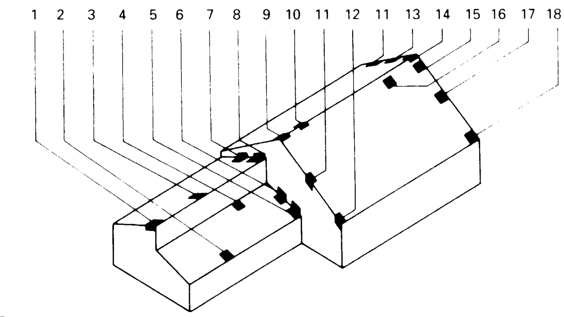


(8) **Mansard roof, polygonal planform**

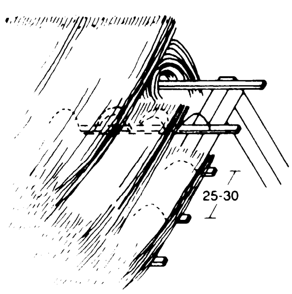
ROOF COVERINGS

Thatched roofs are of rye straw or reeds, hand-threshed 1.2–1.4 m long on battens, 300 mm apart with the thatching material laid butt-end upwards and built up to a thickness of 180–200 mm. The life of such a roof is 60–70 years in a sunny climate, but barely half that in damp conditions. Shingle roofs use oak, pine, larch, and, rarely, spruce. Slate roofs are laid on ≥ 25 mm thick sheathing of ≥ 160 mm wide planks, protected by 200 gauge felt against dust and wind. Overlap is 80 mm, preferably 100 mm. The most natural effect is given by 'German slating' → (12). Rectangular patterns are more suitable for artificial slates (cement fibre tiles) → (13). Tiles: choice of plain tiled, interlocking tiled, or pantiled roof → (14), (16)–(17) or concrete roof tiles with ridge capping → (15). Special shaped tiles are available to match standard roof tiles → (9):

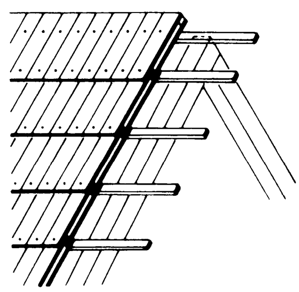
1 mono-pitch: edge tile, corner tile right
2 eaves tile
3 mono-pitch roof tile
4 wall connecting tile
5 eaves: wall connecting, corner tile right
6 wall connecting tile right
7 wall connecting tile left
8 lean-to roof: wall connecting, corner tile left
9 ridge end tile left
10 ridge and hip tile
11 edge tile left
12 eaves edge tile left
13 ridge connecting edge tile, corner tile left
14 ridge starting tile right
15 ridge edge connecting tile corner tile right
16 ridge connecting tile
17 edge tile right
18 eaves edge corner tile right



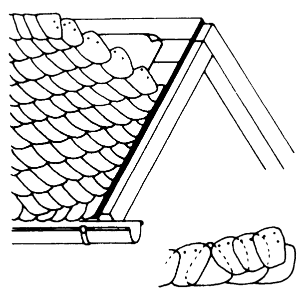
(9) **Shaped tiles**



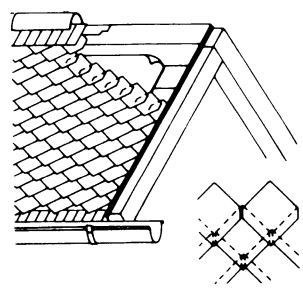
(10) **Thatched roof of rye straw or reed, 0.7 kN/m²**



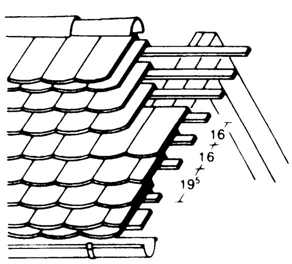
(11) **Shingle roof, 0.25 kN/m²**



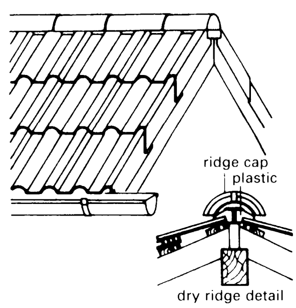
(12) **German slate roof, 0.45–0.6 kN/m²**



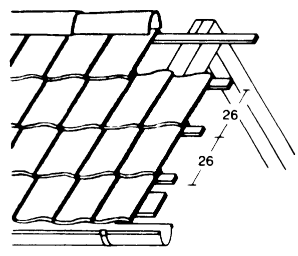
(13) **English slate roof with cement fibre boards, 0.45–0.55 kN/m²**



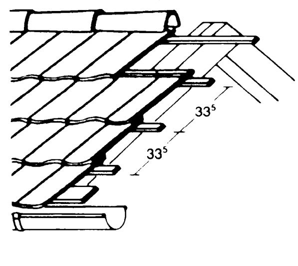
(14) **Double roof (plain tiles) heavy roofing, 0.6 kN/m², 34–44 tiles/m²**



(15) **Concrete roof tiles, 0.6–0.8 > slope 18° kN/m²**

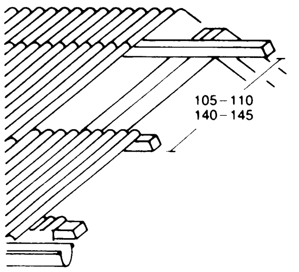


(16) **Pantile roof, lighter, 0.5 kN/m²**

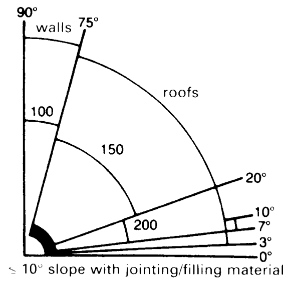


(17) **Interlocking tile roof, 0.55 kN/m²**

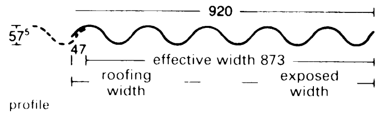
ROOF COVERINGS



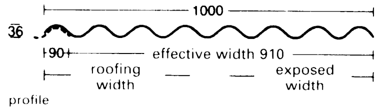
① **Corrugated cement fibre board with ridge and eaves components 0.2 kN/m²**



② **Min. roof slope and sheet overlap → ①**

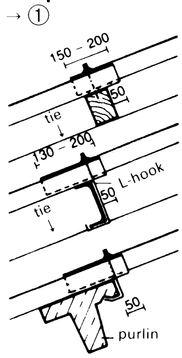


length (mm)	2500	2000	1600	1250	thickness 6.5
width (mm)	920	920	920	920	weight 16–32 kg

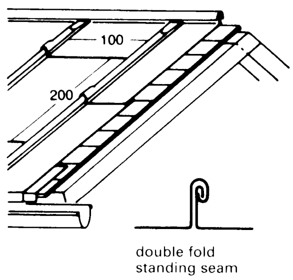


length (mm)	2500	2000	1600	1250	thickness 6.0
width (mm)	1000	1000	1000	1000	weight 15.8–31.5

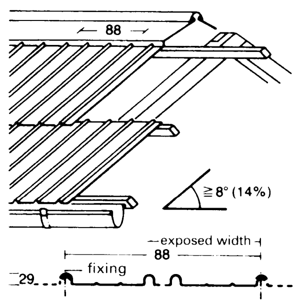
③ **Corrugated fibre cement sheets**



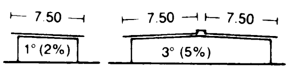
④ **Fixing arrangements**



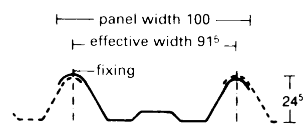
⑤ **Sheet roofing; welted joint construction 0.25 kN/m²**



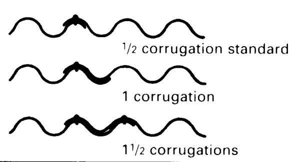
⑥ **Steel pantile roofing 0.15 kN/m²**



length (mm)	9000	7500	4000	thickness 8.0
width (mm)	1000	1000	1000	weight 19 kg/m



⑦ **Large elements for roof and wall (Canaleta)**

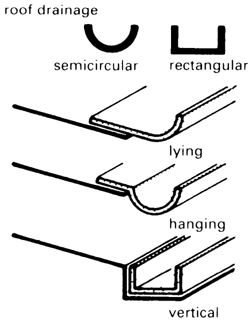


roof depth eaves/ridge	profile ht 18–25 mm	26–50 mm
up to 6 m	10° (17.4%)	5° (8.7%)
6–10 m	13° (22.5%)	8° (13.9%)
10–15 m	15° (25.9%)	10° (17.4%)
over 15 m	17° (29.2%)	12° (20.8%)

8–10°	200 mm with sealing of overlap
10–15°	150 mm without sealing of overlap
over 15°	100 mm without sealing of overlap

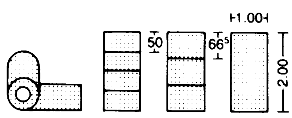
⑧ **Min. slope: corrugated sheet roof, side overlap**

roof drainage



⑨ **Shape and position of the guttering**

supplied form	rolls	panels
length (m)	30–40	2.0
max. width (m)	0.6 (0.66)	1.0
thickness (mm)	0.1–2.0	0.2–2.0
specific wt (kg/dm³)	8.93	8.93



⑩ **Form and dimensions of rolled copper for strip and sheet roofing**

Cement fibre sheet roofs have corrugated sheets with purlins 700–1450 mm apart with 1.6 m long sheets, or 1150–1175 mm with 2.50 m long sheets. Overlap: 150–200 mm → ①–②. Metal sheet roofs are covered in zinc, titanium-coated zinc, copper, aluminium, galvanised steel sheet, etc. → ⑤ + ⑥. Many shapes are available for ridge, eaves, edge, etc. Copper sheet comes in commercially produced sizes → ⑩. Copper has the highest ductility of all metal roofings, so it is suitable for metal forming operations, pressing, stretching and rolling. The characteristic patina of copper is popular. Combinations involving aluminium, titanium-coated zinc and galvanised steel should be avoided, combinations with lead and high grade steel are quite safe. Copper roofs are impervious to water vapour and are therefore particularly suitable for cold roofs → p. 81.

Roof load: calculation in kN per m² of roof surface. Roof coverings are per 1 m² of inclined roof surface without rafters, purlins and ties. Roofing of roof tiles and concrete roof tiles: the loadings do not include mortar jointings – add 0.1 kN/m² for the joints.

Plain tiles and plain concrete tiles	
for split tiled roof including slips	0.60
for plain tiled roof or double roof	0.80
Continuous interlocking tiles	0.60
Interlocking tiles, reformed pantiles, interlocking pantiles, flat roof tiles	0.55
Interlocking tiles	0.55
Flanged tiles, hollowed tiles	0.50
Pantiles	0.50
Large format pantiles (up to 10 per m²)	0.50
Roman tiles without mortar jointing	0.70
with mortar jointing	0.90
Metal roofing aluminium roofing (aluminium 0.7 mm thick) including roof boards	0.25
Copper roof with double folded joints (copper sheet 0.6 mm thick) including roof boards	0.30
Double interlocking roofing of galvanised sheets (0.63 mm thick) including roofing felt and roof boards	0.30
Slate roofing – German slate roof on roof boards including roof felting and roof boards with large panels (360 mm × 280 mm)	0.50
with small panels approx. (200 mm × 150 mm)	0.45
English slate roof including battens on battens in double planking	0.45
on roof boards and roofing felt, including roof boards	0.55
Old German slate roof on roof boards and roofing felt	0.50
double planking	0.60
Steel pantile roof (galvanised steel sheet)	
on battens – including battens	0.15
on roof boards, including roofing felt and roof boards	0.30
Corrugated sheet roof (galvanised steel sheet) including fixing materials	0.25
Zinc roof with batten boards – in zinc sheet no. 13, including roof boards	0.30

roof area to be drained: semicircular guttering (m²)	guttering diameter (mm)	drain channel section width (mm)
up to 25	70	200
25–40	80	200 (10 parts)
40–60	80	250 (8 parts)
60–90	125	285 (7 parts)
90–125	180	333 (6 parts)
125–175	180	400 (5 parts)
175–275	200	500 (4 parts)

General rule: guttering should be provided with a fall to achieve greater flow velocities to combat blockages, corrosion and icing. Guttering supports are usually of flat galvanised steel in widths from 20 to 50 mm and 4–6 mm thick.

⑪ **Standard sizes: guttering v. surface area to be drained**

roof area to be drained: round drain pipe (m²)	diameter of drainpipe (mm)	section width of sheet metal pipes (mm)
up to 20	50	167 (12 parts)
20–50	60	200 (10 parts)
50–90	70	250 (8 parts)
60–100	80	285 (7 parts)
90–120	100	333 (6 parts)
100–180	125	400 (5 parts)
180–250	150	500 (4 parts)
250–375	175	
325–500	200	

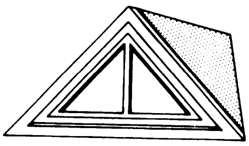
Fixing by means of pipe brackets (corrosion protected) whose internal diameter corresponds to that of the drain pipe; minimum distance of drain pipe from wall = 20 mm; pipe brackets separated by 2.0 m

⑫ **Standard sizes: drain pipes v. surface area to be drained**

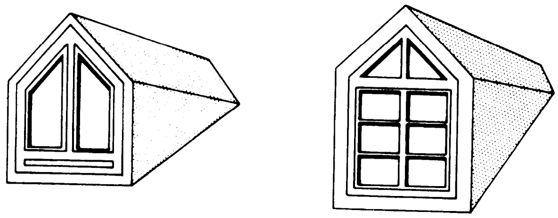
DORMERS

When gable windows do not allow sufficient light into the attic then roof windows or dormer windows are required. The size, form and arrangement of dormers depend on the type of roof, its size and the light requirement.

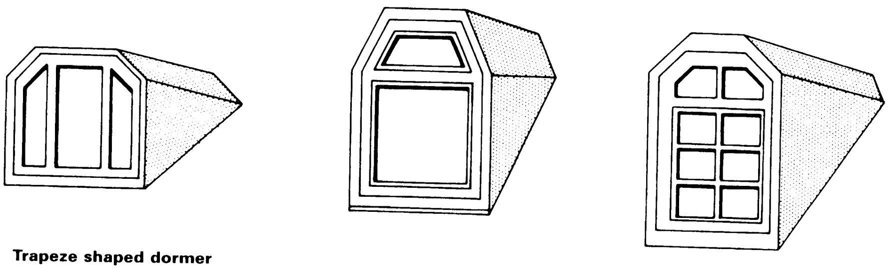
Dormers should all be of the same size and shape if possible. The shape, materials used and the consistent use of details ensure harmonious integration into the roof slope. Normally, to avoid expensive trimming of rafters, the width of the dormers should conform to the rafter spacing.



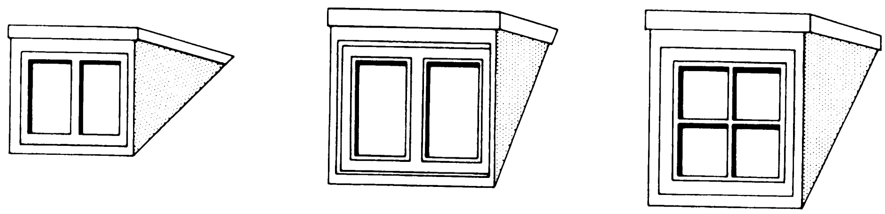
(1) **Triangular dormer 45°**



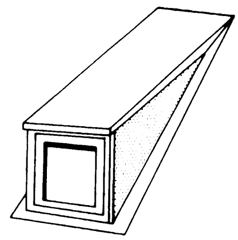
(2) **Gabled dormer 45°**



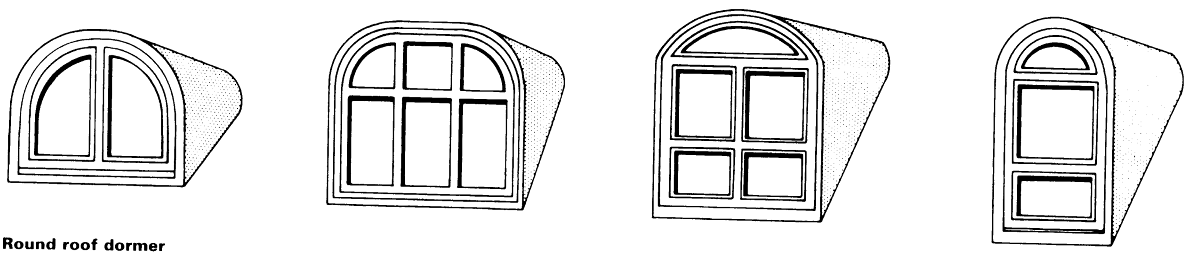
(3) **Trapeze shaped dormer**



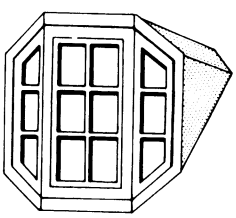
(4) **Flat roofed dormer**



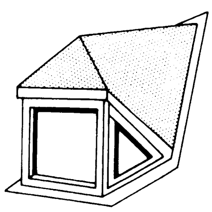
(5) **Sloped dormer**



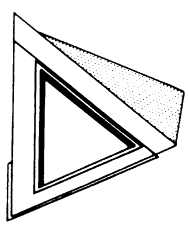
(6) **Round roof dormer**



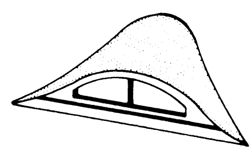
(7) **Bay dormer**



(8) **Hip roofed bay dormer**

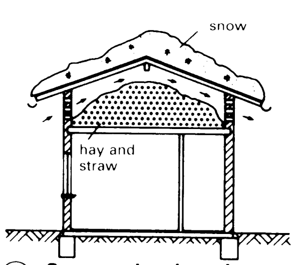


(9) **Triangular dormer**

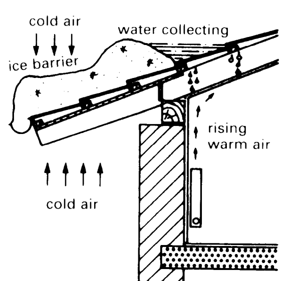


(10) **Ox-eye dormer**

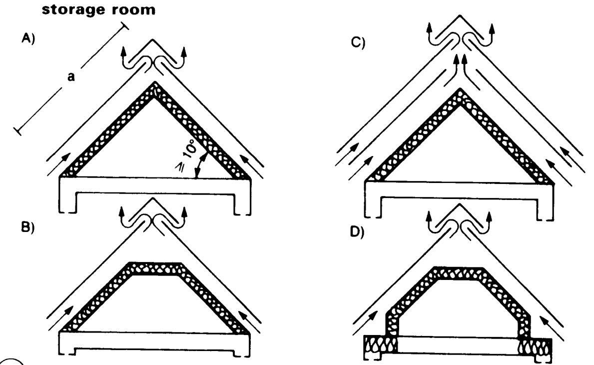
LOFT SPACE



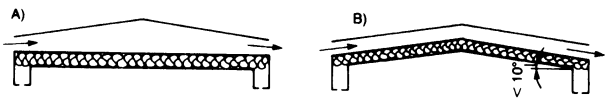
(1) **Cross-section through an alpine farmhouse with a storage room**



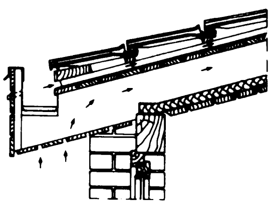
(2) **Ice blockage sequence**



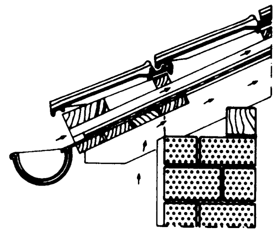
(3) **Examples of ventilated roofs: roof sloping at ≥ 10° (schematic)**



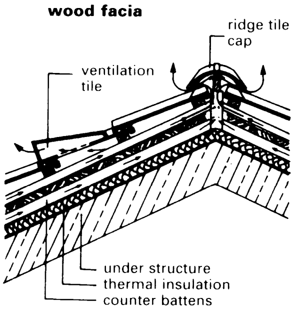
(4) **Examples of ventilated roofs – roof sloping at < 10° (schematic)**



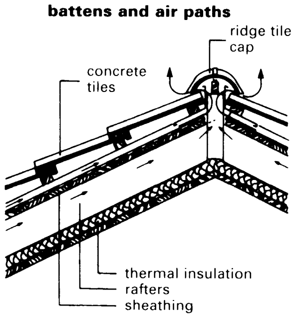
(5) **Ventilation of the roof space through joints in the wood facia**



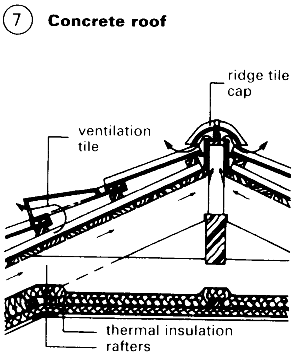
(6) **Eave design: double layer cold roof with counter battens and air paths**



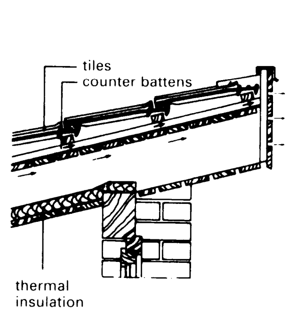
(7) **Concrete roof**



(8) **Wooden roof construction**

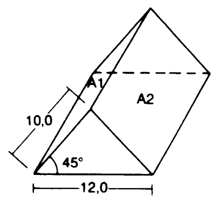


(9) **Wooden roof with suspended ceiling**



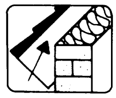
(10) **Double layer cold roof: exhaust of both air flows through slots in the facia board**

Unoccupied roof space in old Alpine farmhouses served as 'stores' for the preservation of harvested crops (hay, straw, etc.). They were open at the eaves, so that cold external air circulated around the roof area, the temperature being little different from the outside → (1), so that snow would lie uniformly distributed on the roof. The living rooms below were protected from the cold by the goods stored in the roof space. If the roof space was heated, without adequate thermal insulation, the snow would melt and ice would build up on the roof → (2). The installation of thermal insulation material under the ventilated roof alleviates the situation. Openings are arranged on two opposite sides of the ventilated roof space, each equivalent to at least 2% of the roof area which is to be ventilated. So that dampness can be removed, this corresponds on average to a slot height of 20mm/m → (5) – (10).



(11) **Dimensions of double pitch roof**

calculation



Example:

eaves

Condition:

≥ 2‰ of the associated inclined roof surface A1 or A2
However, at least 200cm²/m
A_L = ventilation cross-section
A_L eaves ≥ 2/1000 × 9.0 = 0.018m²/m
= 180cm²/m
Since, however, 180cm²/m is less than the required minimum cross-section of 200cm²/m, the minimum value must be taken.

Measurement:

A_L eaves ≥ 200cm²/m

Application:

Determination of the height of the ventilation slot of the unrestricted air space to be ventilated, allowing for the 8cm wide rafters, with A_L – 200cm²/m:

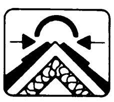
Height:

Ventilation slot $H_L = \frac{\text{required } A_L}{100 - (8+8)}$

$H_L = \frac{200}{100 - 16}$

$H_L \geq 2.4$cm

On a double pitch roof with a rafter length < 10m, the value of ≥ 200cm²/m applies, for the eaves (A_L eaves)
On double pitch roofs with rafter length ≥ 10m
A_L eaves ≥ 2/1000 × A1 or A2cm²/m



Example:
ridge

Condition:

≥ 0.5‰ of the associated sloping roof surface A1+ A2

Calculation:

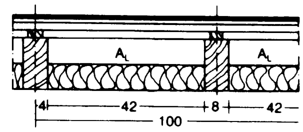
A_L ridge = 0.5/1000 × (9.0+9.0) = 0.0009m²/m = 9cm²/m

Measurement:

A_L ridge = 9cm²/m

Application:

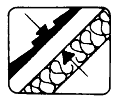
Ridge elements with ventilation cross-section and/or vent tiles according to manufacturer's data.



dimension to be considered is the ventilation cross-section between the thermal insulation and the underside of the roof assembly

(12) **Roof construction: insulation between the rafters**

calculation



Example:

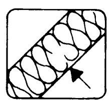
remaining roof surface

Free ventilation cross-section A_L ≥ 200cm²
Free height ≥ 2cm

Calculation:

Height of the ventilation area $= \frac{\text{required } A_L}{100 - (8 + 8)} = \frac{200}{100 - 16} = 2.4$cm

The space under the sarking felt must be taken into account, i.e. with a 2cm height, the distance from the upper edge of the thermal insulation to the upper edge of the rafter must be at least 4.4cm.



Example:
equivalent air layer diffusion thickness

Condition:

a = length of rafters
s_d = equivalent air layer diffusion thickness
a ≤ 10m: s_d ≥ 2m
a ≤ 15m: s_d ≥ 5m
a > 15m: s_d ≥ 10m
with s_d = μm•s (m)
μ = water vapour
Coefficient of diffusion resistance
s = material thickness (m)

Application:

(a) Rigid polyurethane foam (8cm thick)
s = 8cm = 0.08m
μ = 30/100
s_d = 30 × 0.08 = 2.4m
s_d required = 2m

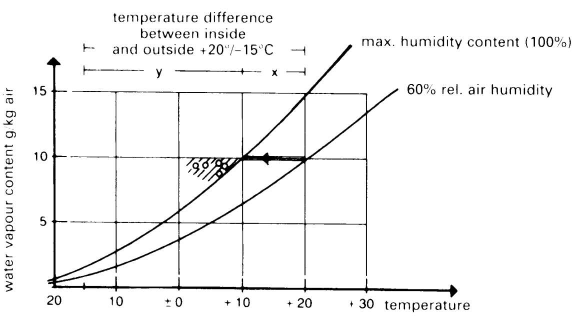
(b) Mineral fibre insulating mat with laminated aluminium foil (by enquiry to manufacturer)
s = 8cm
s_d = 100m > s_d required = 2m

By using a suitable insulation, the requirement s_d = 2m can be easily met. The equivalent thickness s_d of the insulation system is best obtained by enquiry to the manufacturer.

(13) **Example: calculation of the ventilation cross-section of a ridge roof**

paved roof for walking on	2° – 4°	usually	3° – 4°
wood cement roof	2.5° – 4°	usually	3° – 4°
roof with roof felting, gravelled	3° – 30°	usually	4° – 10°
roof with roof felting, double	4° – 50°	usually	6° – 12°
zinc, double upright folded joints (standing seams)	3° – 90°	usually	5° – 30°
felted roof, single	8° – 15°	usually	10° – 12°
plain steel sheeted roof	12° – 18°	usually	15°
interlocking tiled roof, 4 segment	18° – 50°	usually	22° – 45°
shingle roof (shingle canopy 90°)	18° – 21°	usually	19° – 20°
interlocking tiled roof, standard	20° – 33°	usually	22°
zinc and steel corrugated sheet roof	18° – 35°	usually	25°
corrugated fibre cement sheet roof	5° – 90°	usually	30°
artificial slate roof	20° – 90°	usually	25° – 45°
slate roof, double decked	25° – 90°	usually	30° – 50°
slate roof, standard	30° – 90°	usually	45°
glass roof	30° – 45°	usually	33°
tiled roof, double	30° – 60°	usually	45°
tiled roof, plain tiled	35° – 60°	usually	45°
tiled roof, pantiled roof	40° – 60°	usually	45°
split stone tiled roof	45° – 50°	usually	45°
roofs thatched with reed or straw	45° – 80°	usually	60° – 70°

(1) **Roof slopes**



(2) (1) water precipitates out from air if the air is cooled below the dew point; the temperature difference between the room air and the dew point (dependent on the water vapour content of the room air) can be expressed as a percentage 'x' of the temperature difference between inside and outside 3

(2) the temperature difference between inside and outside depends on the structural layers and air, in accordance with their contribution to the thermal insulation

(3) if the fraction by which the layers on the inside of the condensation barrier contribute to the thermal insulation 'x and y' remains less than the percentage 'x', then the temperature of the condensation barrier remains above the dew point and no condensation can occur.

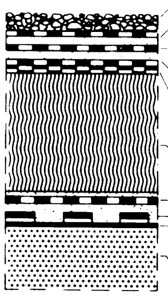
	living rooms 20°C, 60% rel. humidity			swimming bath 30°C, 70% rel. humidity		
outside temperature	–12	–15	–18	–12	–15	–18
(%)	25	23	21	15	14	13

(3) **Maximum contribution 'x' to the thermal insulation of a building component, which the layers on the inside of the condensation barrier, including the air boundary layer, can have so as to avoid condensation.**

example:

living room 20°/60% rel. humidity	
outside temperature	–15°C, x = 23%
concrete layer 20 cm 1/C	= 0.095 m²K/W
air boundary layer inside 1/α	= 0.120 m²K/W
layers up to the vapour barrier	= 0.215 m²K/W
0.215 23%; 100%	= 0.94 m²K/W

outer insulation of > 0.94–0.215 > 0.725 > 3cm Styrofoam on the vapour barrier = no condensation



(4) **Ideal layout of a warm roof**

roof weight	required thermal resistance
100 kg/m²	0.80 m² · K/W
50 kg/m²	1.10 m² · K/W
20 kg/m²	1.40 m² · K/W

(5) **Insulation values for flat roofs**

ROOF SLOPES AND FLAT ROOFS

Cold roof → p. 81: constructed with ventilation under roof covering; critical in respect of through flow of air if the slope is less than 10%, therefore, now only used with vapour barrier. Warm roof in conventional form → (4): (construction including a vapour barrier) from beneath is roof structure – vapour barrier – insulation – weatherproofing – protective layer. Warm roof in upside-down format → p. 81: construction from beneath is roof structure – weatherproofing – insulation using proven material – protective layer as applied load. Warm roof with concrete weatherproofing → p. 81: built from underneath: insulation – concrete panels as roof structure and waterproofing (risky). Solid slab structure – must be arranged to provide room for expansion due to heat; consequently, flexible joints arrangement over supporting walls → p. 80 (5) – (8) and separation of internal walls and roof slab (Styrofoam strips are first attached by adhesive to the underside of the slab). Prerequisites for correct functioning: built-in slope ≥ 1.5%, and preferably 3% (or a build-up of surface water can result).

Vapour barrier: if possible, as a 2 mm roof felt incorporating aluminium foil on a loosely laid slip layer of perforated glass fibre mat on top of the concrete roof slab, treated with an application of bitumen solution as a dust seal. The vapour barrier is laid as far beneath the roof build-up as required to exclude condensation → (2) + (3).

Insulation of non-rotting material (foam); see dimensions in → (4); two-layer arrangement or single layer with rebated joints: ideally, interlocking rebates all round.

Roof membrane on vapour permeable membrane (corrugated felting or insulating layer to combat bubble formation), triple layer using the pouring and rolling technique with two layers of glass fibre based roofing felt with a layer of glass fibre mat in between, or two layers of felt using the welding method with thick bitumen course (d ≥ 5 mm). A single layer of sheeting is permissible, but due to risk of mechanical damage caused by the thinness of the layer and possible faulty seams, two layers offer additional safety.

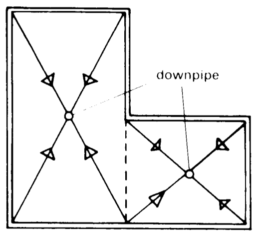
Protective layer should consist, if possible, of a 50 mm ballast layer with 15–30 mm grain size on a doubled hot brush applied layer on a separating membrane; prevents bubble formation, temperature shocks, mechanical stresses, and damage from UV radiation. Additional protection with 8-mm layer of rubber shred sheeting under the ballast layer. The joints should be hot sealed (a basic prerequisite for terraces and roof gardens).

Essential detail points

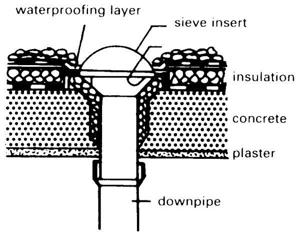
Outlets → p. 80 → (1) – (4) always thermally insulated, two draining levels, with connection also at the vapour barrier, to form an outlet then sealed against the drain pipe. For thermally insulated discharge pipe with condensation layer → p. 80 (4) for prevention of damage due to condensation. The surface slope to the intakes should exceed 3%. A 'ventilator' for the expansion layer is not required. The flexible joint should be continued to the edge of the roof → p. 80 → (5) – (8). The edge details must be flexible, using aluminium or concrete profiles → p. 80 → (5) – (8); zinc connections are contrary to technical regulations (cracking of roof covering). Wall connection should be ≥ 150 mm above the drainage level and fixed mechanically, not by adhesive only. If steel roof decking is used as a load-bearing surface, the roof skin may crack due to vibration; precautions are required to increase the stiffness by using a thicker sheet or a covering of 15 mm woodwool building board (mechanically fixed), to reduce the vibrations (gravel ballast layer) and crack resistant roof sheeting! The vapour barrier on the decking should always be hot fused (due to thermal conduction).

FLAT ROOFS

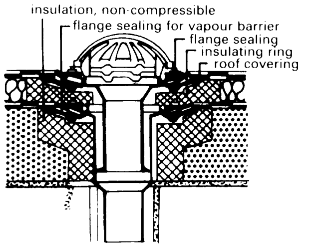
Warm Roof Construction



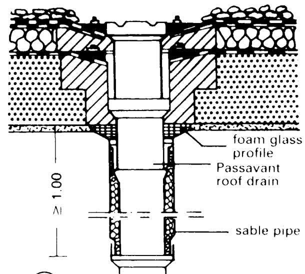
(1) **Roof drainage – at least 2 outlets – slope 3%**



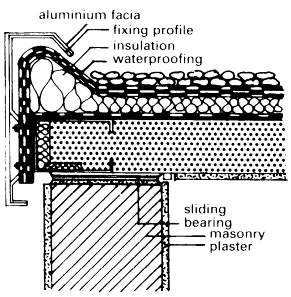
(2) **Flat roof outlet in glass-fibre reinforced polyester with prefabricated insulation; better: two stage → (3)**



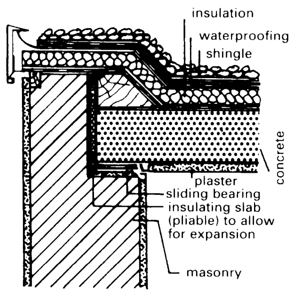
(3) **Two-stage outlet with flange sealing and foam glass insulation material, underside embedded in concrete ('Passavant') scale 1:10**



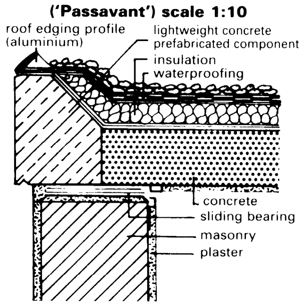
(4) **With insulated down pipe**



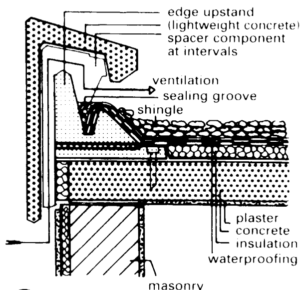
(5) **Flat roof edge with open sliding joint**



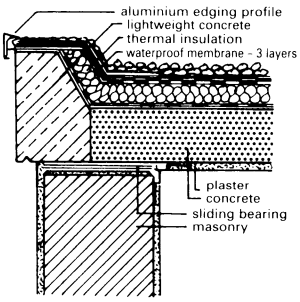
(6) **Flat roof edge with concealed sliding joint (slide track)**



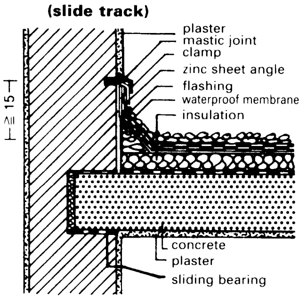
(7) **Concealed roof edge**



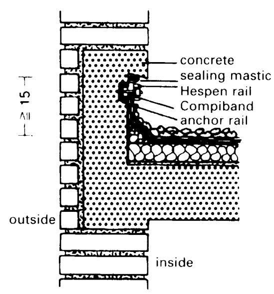
(8) **Concrete edge profile**



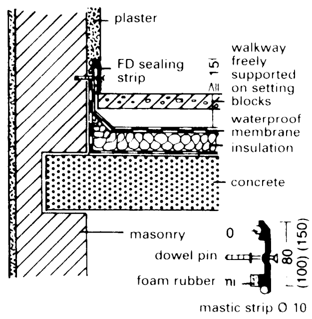
(9) **Protective layer – double layer gravel bedding; better: ballasting**



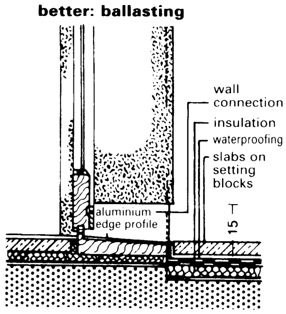
(10) **Wall connection zinc sheet angle and flashing**



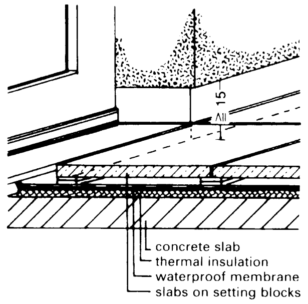
(11) **Wall connection: flanged connection with anchorage and Hespen rail**



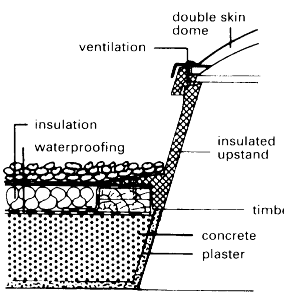
(12) **Wall connection with FD sealing strip (walkway)**



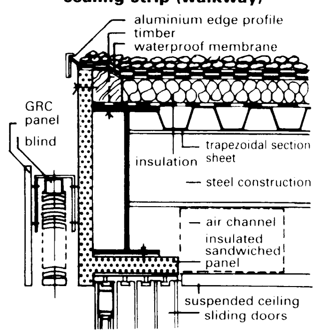
(13) **Wall connection in the vicinity of a terrace door**



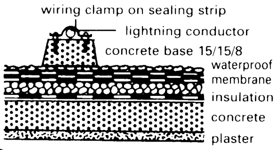
(14) **Wall connection, better with door threshold at the level of the upstand**



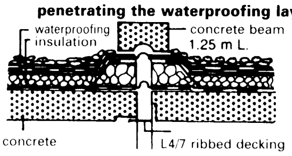
(15) **Double skin dome with ventilation gap** → p. 159



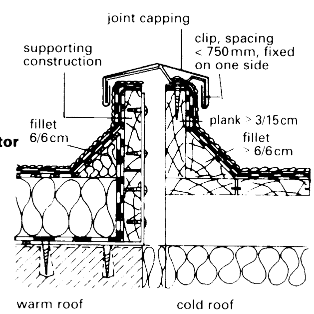
(16) **Indoor swimming pool with insulated sandwiched panel fascia**



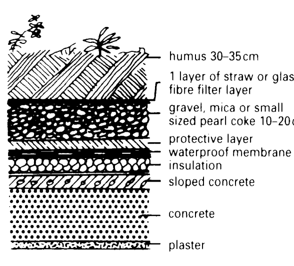
(17) **Installation of the lightning conductor on concrete blocks without penetrating the waterproofing layer**



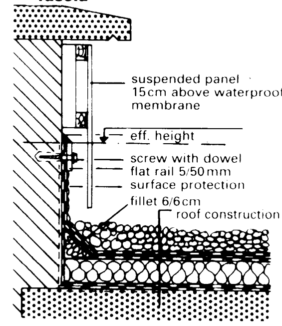
(18) **Raised expansion joint with additional protection**



(19) **Movement joint with supporting construction and capping**



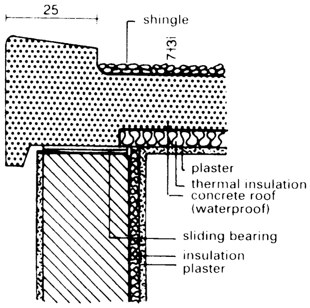
(20) **Roof garden on a warm roof – protective layer could be replaced by shredded rubber sheet**



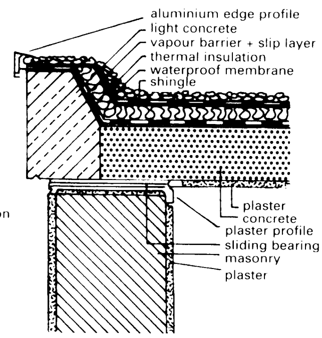
(21) **Chimney connection with suspended facia panel**

FLAT ROOFS

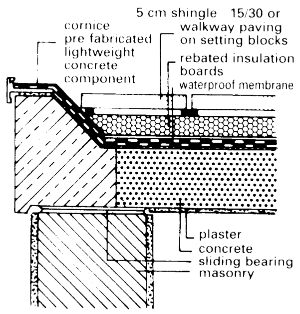
Cold Roof Construction



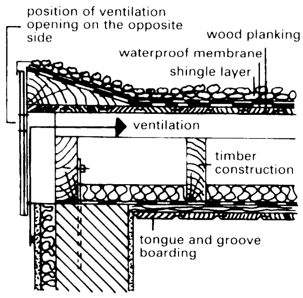
(1) **Waterproof concrete roof (Woermann roof)**



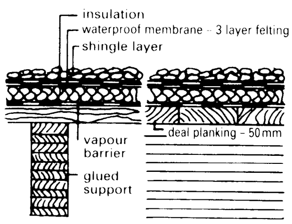
(2) **Flat roof with membrane waterproofing**



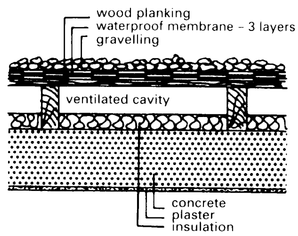
(3) **Flat roof construction**



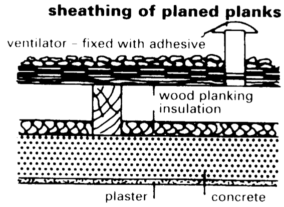
(4) **Cold roof in timber construction**



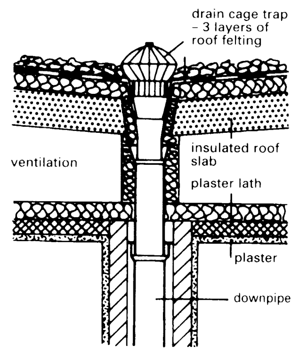
(5) **Warm roof with glue-laminated beams and sheathing of planed planks**



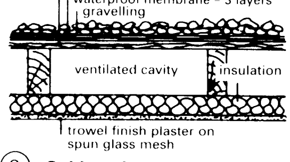
(6) **Cold roof – heavy construction**



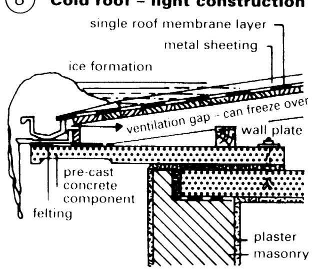
(7) **Additional ventilator in a cold roof for oversized roof areas and for ventilation at the connection to taller structural components**



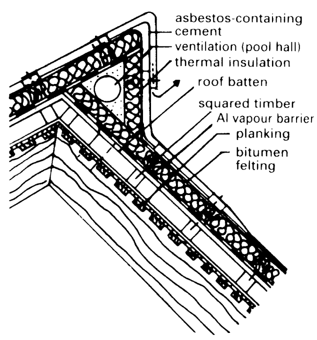
(9) **Cold roof – flat roof outlet, insulated in void**



(8) **Cold roof – light construction**



(10) **Cornice of pre-fabricated components; if the ventilation opening is too large a projection, it may freeze over**



(11) **Ridge ventilation on a sloping cold roof (indoor swimming pool)**

Roof terrace surfaces are loose laid in a bed of shingle or on block supports. Advantage: water level is below surface; no severe freezing. Roof garden has surface drainage through drainage layers, ballasting of shingle or similar, with a filter layer on top → p. 80 (20).

Roofs over swimming pools, etc. are suspended ceilings with ventilated or heated void; see Table (3) → p. 79. Usually, the contribution of all layers up to the vapour barrier, including the air boundary layer, gives a max. 13.5% of the resistance to heat 1/k.

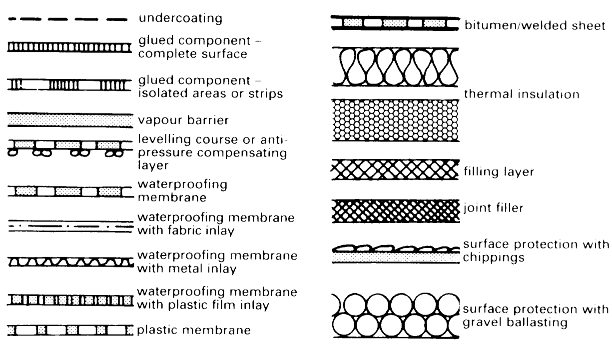
On wood → (5) is a simple solution, and good value for money. NB: insulation above the vapour barrier should be thicker than with a concrete roof, not only due to the low surface weight, but also because the contribution of the layers up to the vapour barrier (air boundary layer + wood thickness) would otherwise be too high.

An inverted roof → (2) is an unusual solution with long-term durability (up to now, however, only achievable with various polystyrene foam materials). Shingle alone as the upper roof layering is insufficient in certain cases; it is better to have a paved surface. Advantage: quickly waterproof, examination for defects is easy, no limit to use. Insulation 10–20% thicker than for a normal warm roof.

With a concrete roof → (1), due to the position of the insulation, condensation occurs in certain conditions, which always dry out in the summer; unsuitable for humid rooms. The risk is dependent on the care taken by the manufacturer to avoid cracks due to the geometry (shrinkage) and solving the problem of connections to, and penetrations of, the concrete.

A completely flat cold roof → (6) – (8) is only allowable with vapour barrier: diffusion resistance → pp. 111–14 of the inner skin ≥ 10m; the air layer here is only for vapour pressure balance, analogous to the warm roof, as it does not function properly as a ventilation system unless the slope is at least 10%. Layer sequence → (6) and (8). NB: inner skin must be airtight; tongue and groove panelling is not. Insulation → p. 79. Waterproofing as for warm roof → p. 80. Slope ≥ 1.5%, preferably 3% – important for drainage. Inlets should be insulated in the air cavity region; use insulated inlet pipes → (9). It is necessary for the vapour barrier to be unbroken (tight overlapping and wall connections, particularly for swimming pools; unavoidable through-nailing is permissible).

On light constructions, the internal temperature range should be improved by additional heavy layers (heat storage) under the insulation. Unfavourable internal temperature range: temperature fluctuations almost the same as those outside implies an internal climate similar to that of an unheated army hut; this cannot be improved by thermal insulation alone. A quick response heating system and/or additional thermal mass is required. For the artificial ventilation of rooms under cold roofs, always maintain a negative pressure; otherwise, room air will be forced into the roof cavity.



(12) **Key to representation of roof covering components**

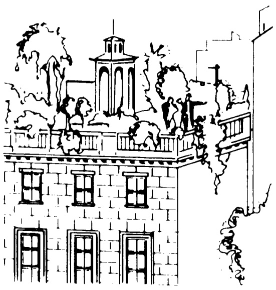
ROOF GARDENS

History

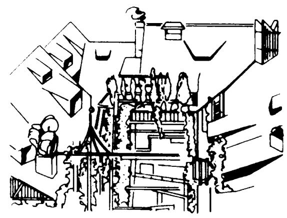
The concept of roof gardens and roof cultivation had already been exploited by the Babylonians in biblical times by 600 BC. In Berlin, in 1890, farm house roofs were covered with a layer of soil as a means of fire protection, in which vegetation seeded itself. Le Corbusier was the first in our century to rediscover the almost forgotten green roof.

The characteristics of roof cultivation

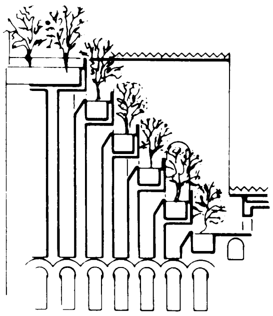
1 Insulation by virtue of the layer of air between blades of grass and through the layer of soil, with its root mass containing microbial life processes (process heat).
2 Sound insulation and heat storage potential.
3 Improvement of air quality in densely populated areas
4 Improvements in microclimate
5 Improves town drainage and the water balance of the countryside
6 Advantageous effects for building structures: UV radiation and strong temperature fluctuations are prevented due to the insulating grass and soil layers
7 Binds dust
8 Part of building design and improves quality of life
9 Reclamation of green areas



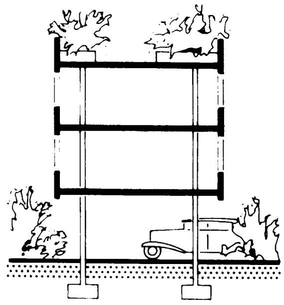
(1) **Roof garden on rented housing: 'Pointer towards a new form of architecture'**



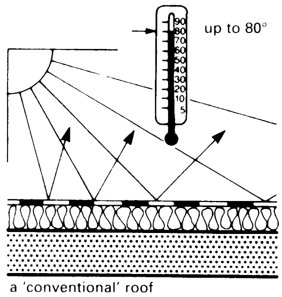
(2) **Roof garden in the form of a collection of plant containers on balconies and roof terraces**



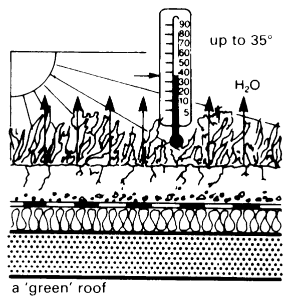
(3) **The hanging gardens of Semiramis in Babylon (600 BC)**



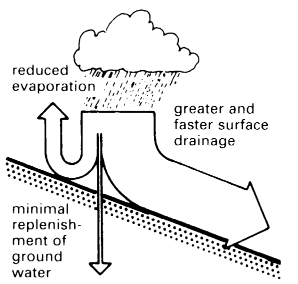
(4) **'Lost' areas of greenery are reclaimed by roof planting**



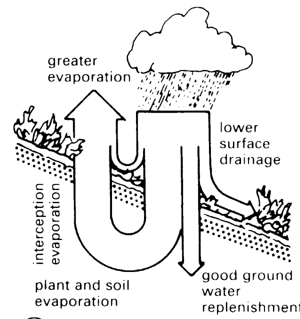
(5) **Overheated, dry town air → (6)**



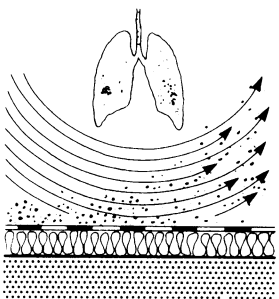
(6) **Cooler and moister air due to energy consuming plant transpiration**



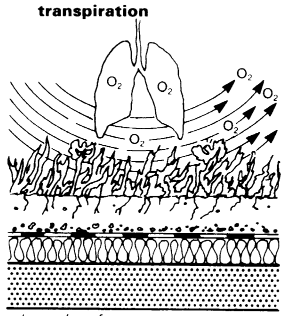
(11) **Distribution of precipitation – consolidated surfaces → (12)**



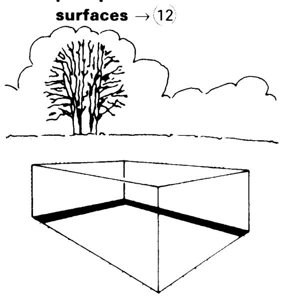
(12) **Distribution of precipitation – natural surfaces**



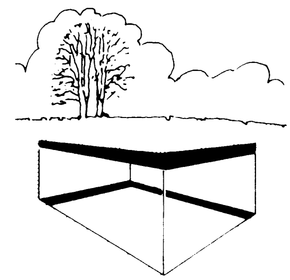
(7) **Production of dust and dust swirling → (8)**



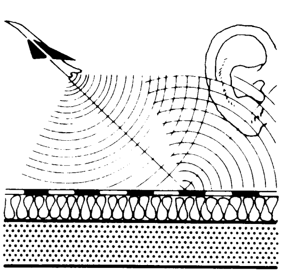
(8) **Improvement of city air due to filtering out and absorption of dust and due to oxygen production by plants**



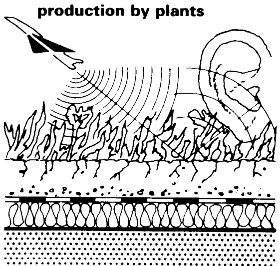
(13) **With the construction of every house, a part of the countryside is lost → (14)**



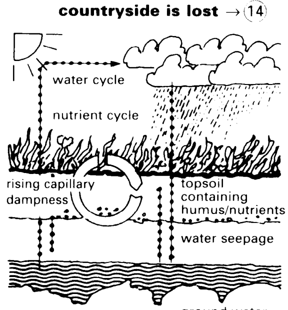
(14) **A major proportion of the lost ground area can be regained by cultivating the roof**



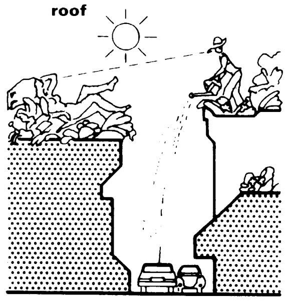
(9) **Sound reflection on 'hard surfaces' → (10)**



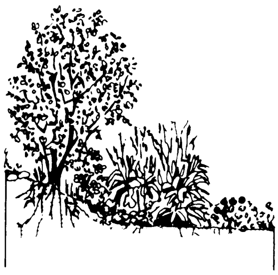
(10) **Sound absorption due to the soft planted surface**



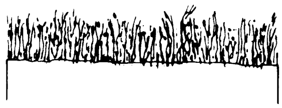
(15) **Natural cycle of water and nutrients**



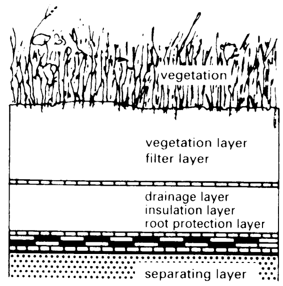
(16) **Psycho-physiological value of cultivated areas (the feeling of well being is positively influenced by the areas of greenery)**



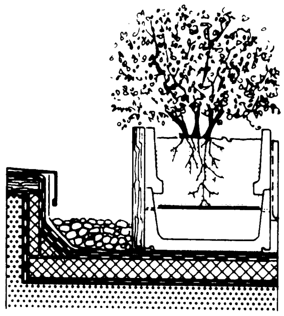
① Intensive cultivation



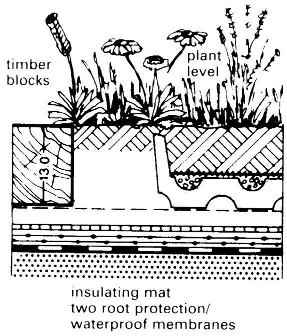
② Extensive cultivation



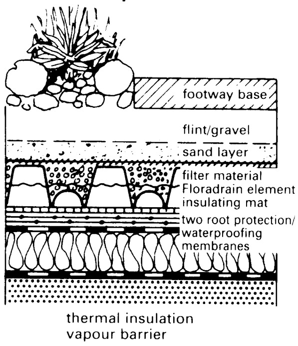
③ Layer construction of a cultivated roof



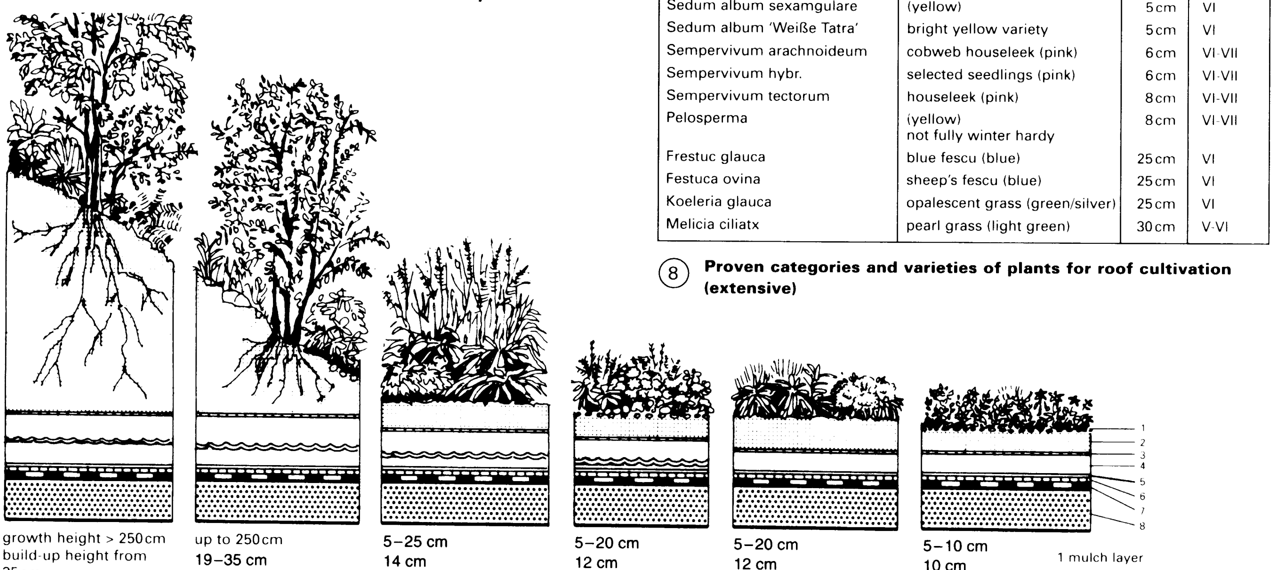
④ Plant containers forming the boundary of a cultivated area



⑤ Zinco Floraterra roof cultivation system



⑥ Zinco Floradrain roof cultivation system



⑦ Various types of roof cultivation

Roof slope

The slope of a double pitch roof should not be greater than 25°. Flat roofs should have a minimum slope of 2–3%.

Types of roof cultivation

Intensive cultivation: the roof is fitted out as a domestic garden, with equipment such as pergolas and loggias; continual attention and upkeep are necessary; planting – grass, shrubs and trees. Extensive cultivation: the cultivation requires a thin layer of soil and requires a minimum of attention; planting – moss, grass, herbs, herbaceous plants and shrubs. Mobile cultivation: plants in tubs, and other plant containers serve for the cultivation of roof terraces, balustrades and balconies.

Watering

Natural watering by rain water: water is trapped in the drainage layer and in the vegetation layer. Accumulated water: rain water is trapped in the drainage layer and is mechanically replenished if natural watering is inadequate. Drip watering: a water drip pipe is placed in the vegetation or drainage layer to water the plants during dry periods. Sprinkling system: sprinkling system over the vegetation layer.

Fertiliser

Fertiliser can be spread on the vegetation layer or mixed with the water during artificial watering.

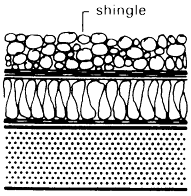
botanical name	English name (colour of the flower)	height	flowering season
Saxifraga aizoon	encrusted saxifrage (white-pink)	5cm	VI
Sedum acre	biting stonecrop (yellow)	8cm	VI–VII
Sedum album	white stonecrop (white)	8cm	VI-VII
Sedum album 'Coral Carpet'	white variety	5cm	VI
Sedum album 'Laconicum'	white variety	10cm	VI
Sedum album 'Micranthum'	white variety	5cm	VI-VII
Sedum album 'Murale'	white variety	8cm	VI-VII
Sedum album 'Cloroticum'	(light green)	5cm	VI-VII
Sedum hybr.	(yellow)	8cm	VI-VII
Sedum floriferum	(gold)	10cm	VIII-IX
Sedum albumreflexum 'Elegant'	rock stonecrop (yellow)	12cm	VI-VII
Sedum album sexamgulare	(yellow)	5cm	VI
Sedum album 'Weiße Tatra'	bright yellow variety	5cm	VI
Sempervivum arachnoideum	cobweb houseleek (pink)	6cm	VI-VII
Sempervivum hybr.	selected seedlings (pink)	6cm	VI-VII
Sempervivum tectorum	houseleek (pink)	8cm	VI-VII
Pelosperma	(yellow) not fully winter hardy	8cm	VI-VII
Frestuc glauca	blue fescu (blue)	25cm	VI
Festuca ovina	sheep's fescu (blue)	25cm	VI
Koeleria glauca	opalescent grass (green/silver)	25cm	VI
Melicia ciliatx	pearl grass (light green)	30cm	V-VI

⑧ **Proven categories and varieties of plants for roof cultivation (extensive)**

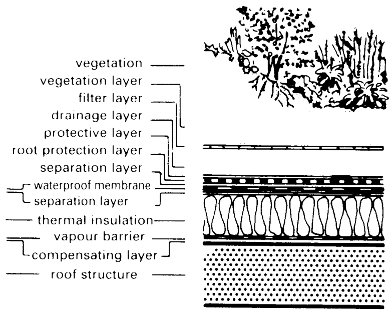
ROOF GARDENS

Roof Construction

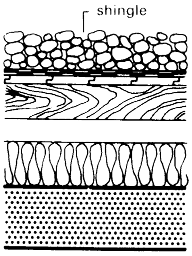
For the vegetation layer, expanded clay and expanded slate are used, these materials offering structural stability, soil aeration, water storage potential and lending themselves to landscaping. Problems to be solved: storage of nutrients, soil reaction (pH value), through-ventilation, water storage. The filter layer, comprising filter material, prevents clogging of the drainage layer. The drainage layer prevents excessive watering of the plants and consists of: mesh fibre mats, foam drainage courses, plastic panels and protective structural materials. The protective layer provides protection during the construction phase and against point loading. The root protection layer of plants, etc., are retained by PVC/ECB and EPDM sheeting. The separating layer separates supporting structure from the roof cultivation. Examples → ① – ⑧ illustrate a range of customary flat roof structures and variations incorporating roof cultivation. Before roof cultivation is applied, the integrity of the roof and of the individual layers must be established. The technical condition of the roof surface must be carefully checked. Attention should be paid to: construction of the layers (condition); correct roof slope; no unevenness; no roof sagging; no waterproofing membrane faults (bubbles, cracking); expansion joints; edge attachments; penetrating elements (light shafts, roof lights, ventilating pipes); and drainage. Double pitch roofs can also be cultivated, but much preparatory construction work is needed when inclined roofs are cultivated (danger of slippage, soil drying out) → ⑨ – ⑫.



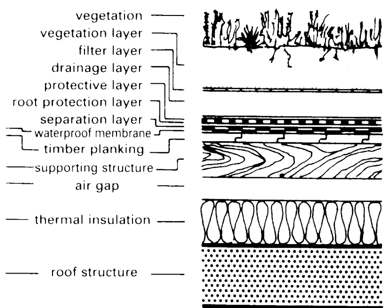
(1) **Warm roof** → ②



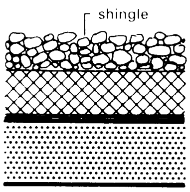
(2) **Warm roof with cultivation**



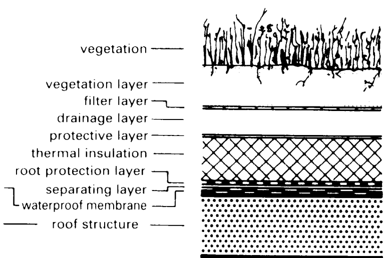
(3) **Cold roof** → ④



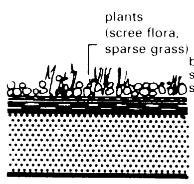
(4) **Cold roof with cultivation**



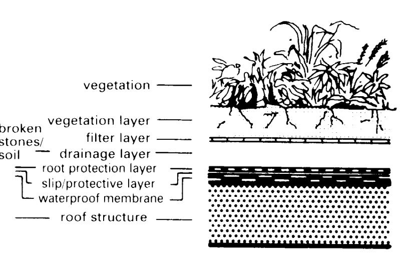
(5) **Inverted roof** → ⑥



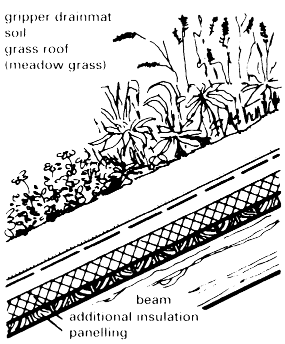
(6) **Inverted roof with cultivation**



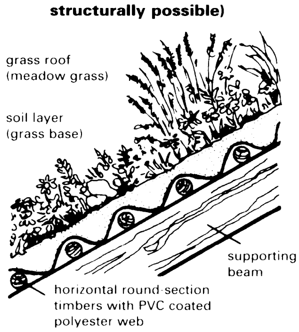
(7) **Retrospective roof cultivation at low expense**



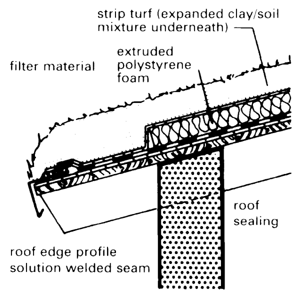
(8) **Retrospective roof cultivation (if constructionally and structurally possible)**



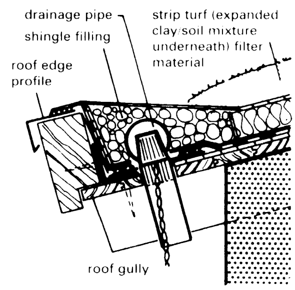
(9) **Roof cultivation on sloping roof**



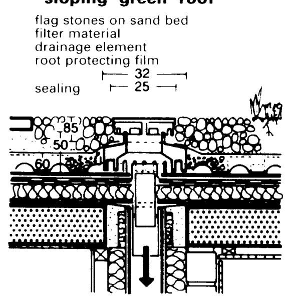
(10) **Roof cultivation on a steep roof**



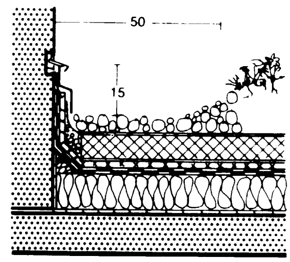
(11) **Detail of the eaves on a sloping 'green' roof**



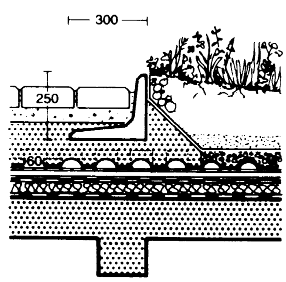
(12) **Eaves detail** → 11



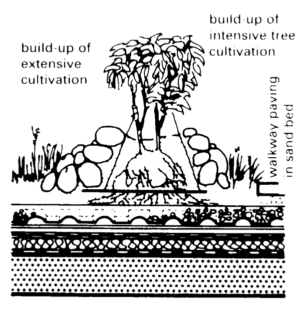
(13) **Drainage inspection shaft**



(14) **Wall connection with shingle edging strip**



(15) **Transition from road surface to intensive roof cultivation**



(16) **Transition from footpath to intensive or extensive cultivation**

ROOF CULTIVATION

Extract from Guidelines of the Roof Garden Association

Definitions

(1) Extensive roof cultivation implies a protective covering that needs upkeep, replacing the customary gravel covering.

(2) To a large extent, the planted level is self-replenishing and the upkeep, i.e., maintenance, is reduced to a minimum.

Scope

These guidelines apply to areas of vegetation without natural connection to the ground, particularly on building roofs, and roofs of underground garages, shelters, or similar structures.

Principles of constructive planning and execution

(1) In extensive roof cultivation, the cultivated area acts as a protective covering – see the recommendations for flat roofs.

(2) Roof construction and structure: the relevant structural and constructional principles of the building and its roof must be carefully interrelated with the technical requirements imposed by the vegetation and its supporting elements.

(3) The surface loading required to secure the waterproof membrane is the minimum weight per unit area of the operative layers in accordance with the table below, taken from the Roof Garden Association recommendations for planting on the flat roofs.

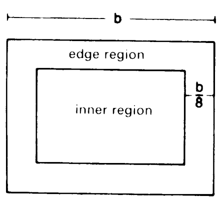
(4)

Height of the eaves above ground level (m)		Load on the edge region (kg/m^2)	Inner region (kg/m^2)
up to 8	at least	80	40
8–20	at least	130	65
over 20	at least	160	60

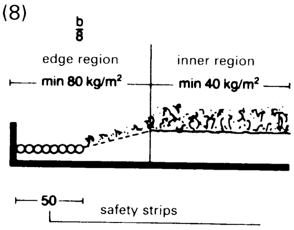
(5) The type of construction employed in the roof and the degree of surface loading are dependent on the wind loading, the height of the building and the surface area of the roof.

(6) High suction loads can occur around the edges and corners of the roof over a width $b/8 \geq 1\,m \leq 2\,m$.

(7)



(8)



(9) Cultivated roofs should be designed to be easily maintained, i.e. areas which need regular attention (such as roof drainage inlets, structures which protrude from the cultivated area, expansion joints and wall junctions) should be easily accessible.

(10) In these areas, the protective layer should comprise of inorganic materials such as shingle or loose stones.

(11) These areas should be linked with the roof drainage inlets, so that any overflow from the planted areas can drain away.

(12) Large surface areas should be subdivided into separate drainage zones.

Requirements, functions, constructive precautions

(1) The waterproofing membrane should be designed in accordance with the recommended specifications for flat roofs.

(2) The development of the cultivated area should not impair the function of the roof waterproofing membrane.

(3) It should be possible to separate the waterproofing layers from the cultivation layers, i.e. it must be possible to inspect the waterproof membrane of the roof.

(4) The root protection layer must provide durable protection to the roof waterproofing layers.

(5) High polymer waterproofing membranes should, because of their physical and chemical makeup, be able to satisfy the demands of the root protection layer.

(6) If a bituminous roof waterproofing system is applied, then bitumen-compatible root protection layers should be employed.

(7) The root protection layer should be protected from mechanical damage by a covering; non-rotting fibre mats should be used since these can store nutrients and additional water.

(8) The vegetation layer must have a high structural stability and must exhibit good cushioning capability and resistance to rotting.

(9) The pH value should not exceed 6.0 in the acidic range.

(10) The construction of the layers must be capable of accepting a daily precipitation level of at least $30/m^2$.

(11) There should be a volume of air of at least 20% in the layer structure in the water saturated condition.

Maintenance at the plant level

(1) Wild herbaceous plants and grasses from the dry grassland, steppe and rock crevice species should be used in the planted areas. All plants used should be perennial.

(2) The plants used should be young plants, sown as seed or propagated by cuttings.

(3) Maintenance: at least one routine per year, when the roof inlets, security strips, roof connections and terminations are inspected and cleaned as necessary.

(4) Plants, mosses and lichen which settle are not considered as weeds.

(5) All undesirable weeds should be removed.

(6) Woody plants, in particular willow, birch, poplar, maple and the like, are considered to be weeds.

(7) Regular mowing and fertilising should be carried out.

(8) Changes at the plant level may occur through environmental effects.

Fire prevention

(1) All fire precaution recommendations should be observed.

(2) The requirements are fulfilled if the flammability of the structure is classed as flame resistant (material classification B1).

Characteristics of a satisfactory roof cultivation

An extensive planted area has planting out, sowing, setting of cuttings, pre-cultivated plants (plant containers, mats and panels). The vegetation layer provides stability for the plants, contains water and nutrients and allows material and gas exchange and water retention. The vegetation layer must have a large pore volume for gas exchange and water retention. The filter layer prevents the flushing out of nutrients and small components of the vegetation layer and silting up of the drainage layer. It also ensures that water drains away gradually. The drainage layer provides safe removal of overflow water, aeration of the vegetation layer, the storage and, if necessary, a water supply. Root protection protects the roof waterproofing membrane from chemical and mechanical contact with the roots of the plants which, in searching for water and nutrients, can be destructive. Roof construction must be durably waterproof, both on the surface and in all connections with other components. The formation of condensation water in the roof structure must be effectively and permanently prevented.

TENSILE AND INFLATABLE STRUCTURES

The construction of awnings and tensile roofs is becoming more widespread. These constructions vary from simple awnings and roofs, to technically very complicated tensile structures of the most diverse types.

Materials: artificial fibre material (polyester) is used as the base fabric, with corrosion resistant and weather proof protective layers of PVC on both sides.

Characteristics: high strength (can resist snow and wind loads); non-rotting; resistant to aggressive substances; water and dirt repellent, and fire resistant.

Weight: 800–1200 g/m^2.

Permeability to light: from 'impermeable' up to 50% permeability.

Life: 15–20 years; all popular colour shades; good colour fastness

Workability: manufactured in rolls; widths 1–3 m, usually 1.5 m; length up to 2000 running metres; cut to shape to suit structure; can be joined by stitching, welding, with adhesives, combinations of these, or by clamp connectors.

Add-on standard systems ①

Standard units allow the structure to be extended indefinitely, often on all sides. They embrace most planforms: square, rectangular, triangular, circular, polyhedra. *Application:* connecting passageways, rest area pavilions, shade awnings, etc.

Framed structures

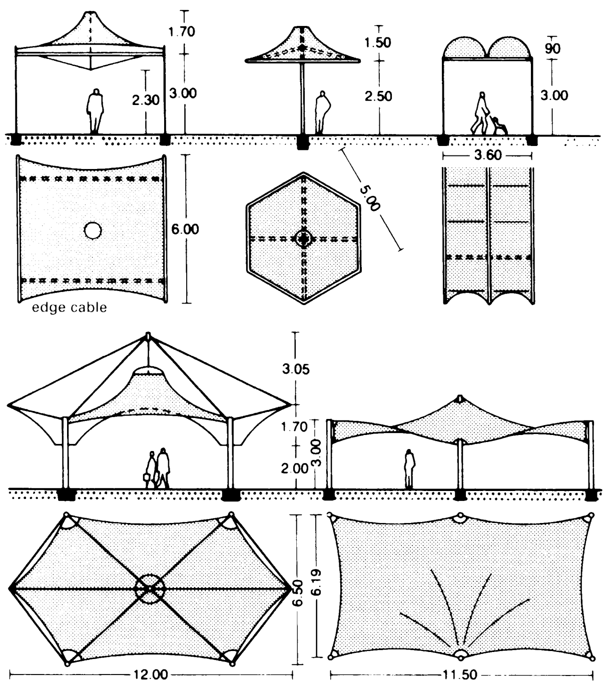
A supporting frame is made from wood, steel or aluminium, over which the membrane is stretched as a protective covering. *Application:* exhibition halls, storage and industrial areas.

Air supported structures → ④

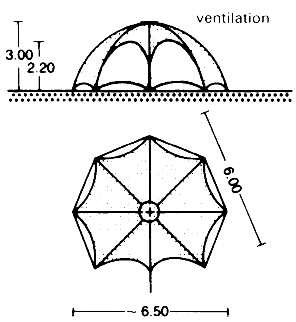
The structural membrane is supported by compressed air at low pressure, and air locks prevent the rapid release of the supporting air. The system can be combined with heating, and additional insulation can be provided by an inner shell (air mattress). Maximum width is 45 m, with length unlimited. *Application:* exhibition, storage, industrial and sport halls; also as roofing over swimming pools and construction sites in winter.

Tensioned structures → ⑤

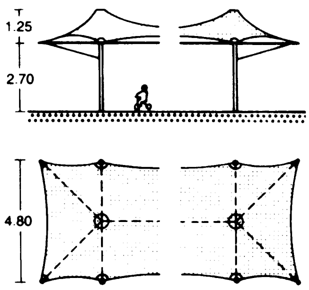
The membrane is supported at selected points by means of cables and masts, and tensioned around the edges. To improve thermal insulation, the structure may be provided with additional membranes. Span can be up to more than 100 m. *Application:* exhibition, industrial and sports halls, meeting and sports areas, phantom roofs.



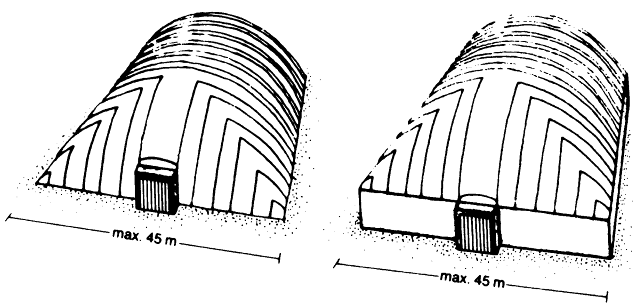
① **Standard add-on systems**



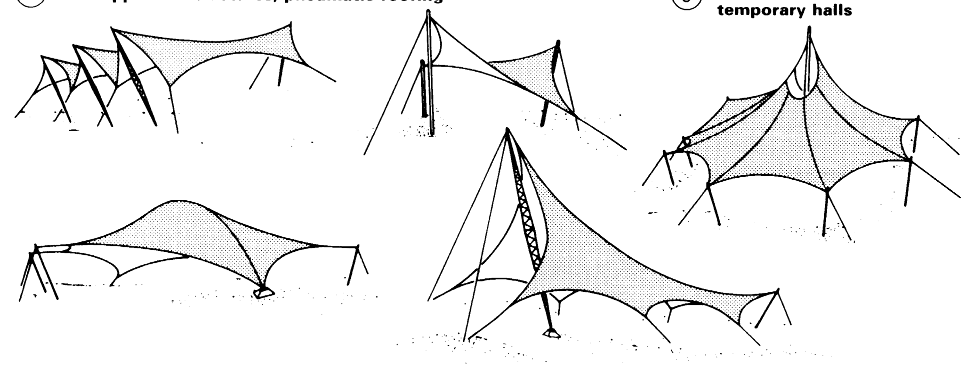
② **Domed construction**



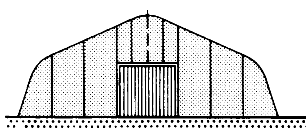
③ **Canopies**



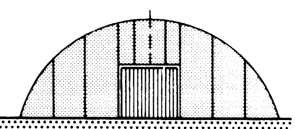
④ **Air supported structures, pneumatic roofing**



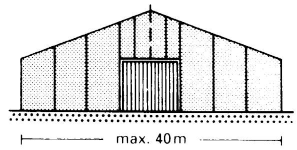
⑤ **Tensioned structures, special textile constructions**



⑥ **Framed structures, temporary halls**



⑦



⑧

⑥ - ⑧

Temporary buildings with supporting structures of wood, steel or aluminium; maximum span 40 m; prefabrication for rapid assembly and low cost

CABLE NET STRUCTURES

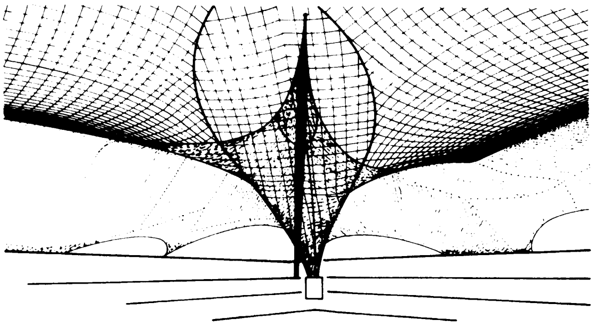
Cable net structures offer the possibility of covering large unsupported spans with considerable ease. The German pavilion at the World Exhibition in Montreal in 1976 was constructed in this fashion → ① + ②, the Olympic Stadium in Munich, 1972 → ③–⑧ and the ice rink in the Olympic Park in Munich → ⑩–⑬. An interesting example is also provided by the design for the students club for the University and College of Technology in Dortmund → ⑨.

As a rule, the constructional elements are steel pylons, steel cable networks, steel or wooden grids, and roof coverings of acrylic glass or translucent, plastic-reinforced sheeting.

Cables are fastened into the edges of the steel network, the eaves, etc., and are laid over pin-jointed and usually obliquely positioned steel supports, and then anchored.

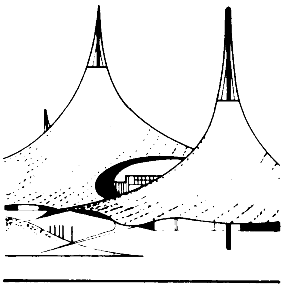
'Aerial supports', cable supporting elements which are stayed from beneath, divide up the load of the main supporting cable to reduce the cable cross-sections.

The transfer of load of the tension cables usually takes place via cast components – bolt fixings, housings, cable fixings, etc. The cable fixings can be secured by self-locking nuts or by the use of pressure clamps.

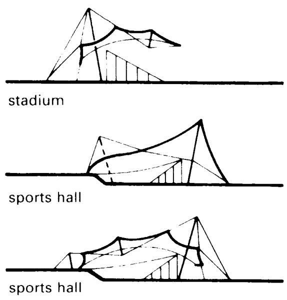


Architects: R. Gutbrod, F. Otto

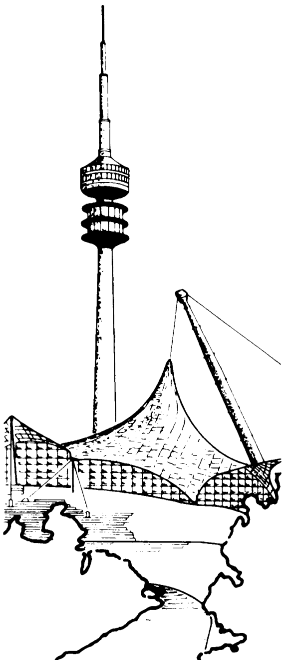
① **German Pavilion, Expo Montreal 1967**



② **Montreal 1967**

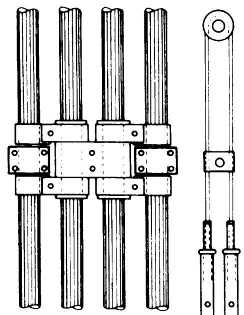


③ **Olympic park, Munich 1972**

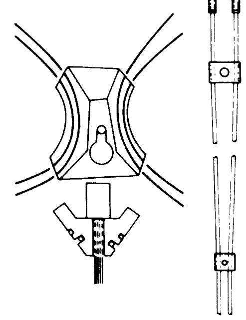


Architects: Behnisch & Partner

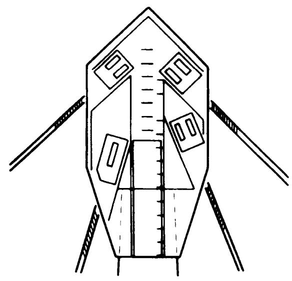
④ **Olympic stadium, Munich 1972**



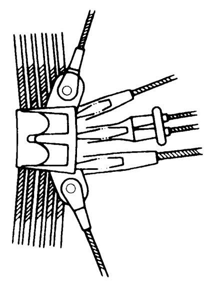
⑤ **Cable network attachment**



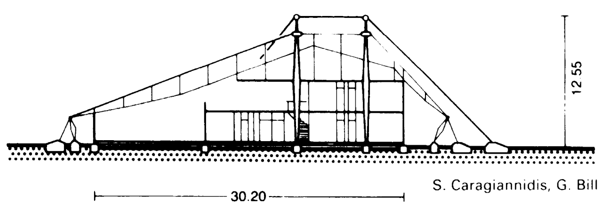
⑧ **Cable attachment saddle at a high suspension point**



⑥ **Transfer of loads from the cables to the cross-beams on a mast head**

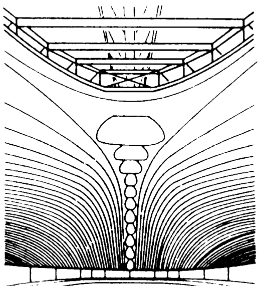


⑦ **Support cable attachment point to the edge cables**



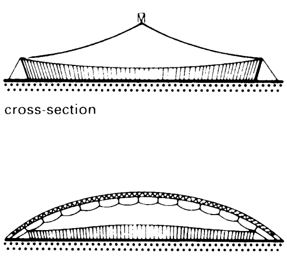
S. Caragiannidis, G. Bill

⑨ **Student design**

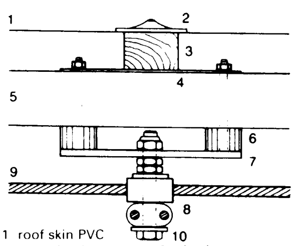


Architects: Kurt Ackermann and Partner, 1983

⑩ **Ice rink, Olympic park, Munich**

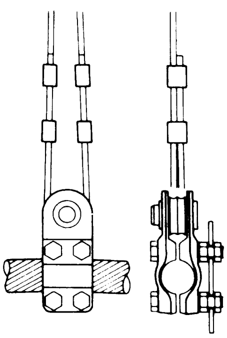


⑪ **Canopies → ⑩**



1 roof skin PVC coated polyester fabric
2 BST disks
3 batten: 40 × 60mm
4 connecting beam
5 batten: 60 × 60mm
6 plastic spacer h = 25mm
7 flat steel plate 300/60 × 8
8 pressure clamp
9 wire netting (11.5mm)
10 bolt

⑫ **Cable clamp, showing roof construction**



⑬ **Cable network; edge cable clamp**

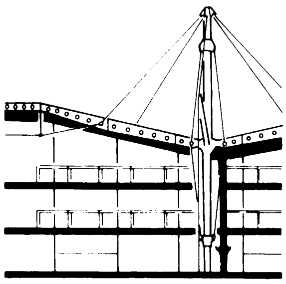
SUSPENDED AND TENSIONED STRUCTURES

The suspension or support of load-bearing structures provides a means of reducing the cross-sections of the structural members, thus enabling delicate and filigree designs to be developed. As a rule, this is only possible in steel and timber skeletal structures. The tensioning cables are of steel and can usually be tensioned on completion of the structure. The cables support tensile forces only.

Suspended structures have the purpose of reducing the span of supporting beams or eliminating cantilevered structures. Tensioned structures, likewise, reduce the span of beams and, hence, also the section modulus which has to be considered in determining their cross-section → ⑫. In similar fashion to cable network structures, aerial supports are required on trussed structures. They have to accept buckling (compressive) stresses.

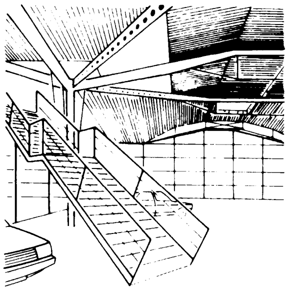
Significant contributions to the architecture of suspended structures have been made by Günter Behnisch → ⑤, Norman Foster → ①-④, Richard Rogers → ⑥-⑦ and Michael Hopkins → ⑧-⑨. The Renault building in Swindon, by Norman Foster, consists of arched steel supports, which are suspended from round, pre-stressed hollow steel masts from a point in the upper quarter of the gable → ①-④. The design enabled the ground area to be extended by approximately 67%. The suspended construction offers connection points which make it possible to execute the construction work without interfering with other work.

The new Fleetguard factory in Quimper, for an automobile concern in the USA, had to be designed for changing requirements and operations. For this, Richard Rogers chose a suspended construction so to keep the inside free of any supporting structure → ⑥-⑦. The same design ideas form the basis of the sports halls of Günter Behnisch → ⑤ and the Schlumberger Research Centre in Cambridge, by Michael Hopkins → ⑧-⑨. An airport administration building (proposed design for Paderborn/Lippstadt) → ⑩ and a concert hall (proposed design for the Dortmund Fair) → ⑪ may also be built in this fashion.

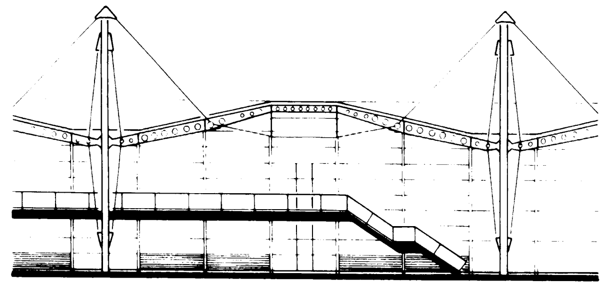


Architects: Norman Foster Associates, London

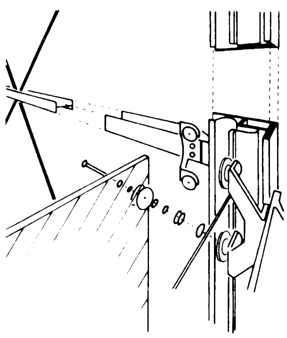
① **Renault sales centre, Swindon**



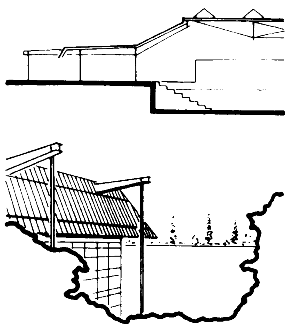
② **Internal view of the showroom**



③ **External view showing the gallery**

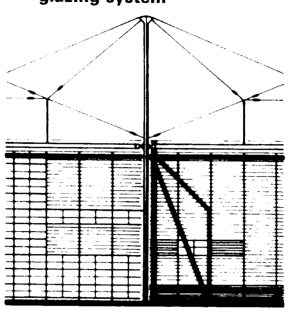


④ **Detail of the 'planar' glazing system**



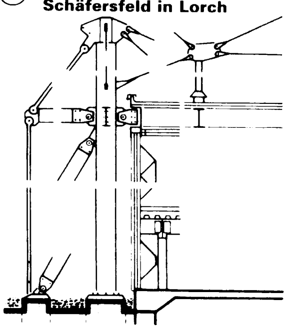
Architects: Behnisch & Partners; Stuttgart

⑤ **Sports hall on the Schäfersfeld in Lorch**

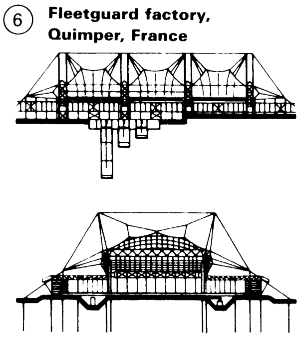


Architects: Richard Rogers & Partners, London

⑥ **Fleetguard factory, Quimper, France**

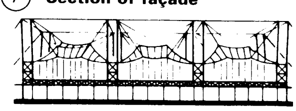


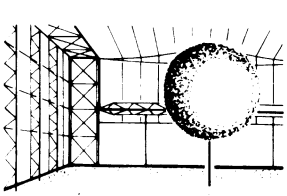
⑦ **Section of façade**



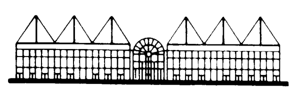
Architects: Michael Hopkins & Partners; London

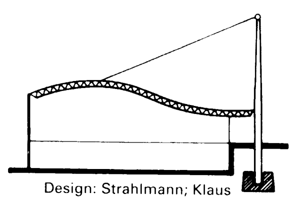
⑧ **Schlumberger Research Centre, Cambridge/GB**





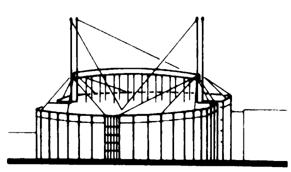
⑨ **Winter garden: internal perspective**





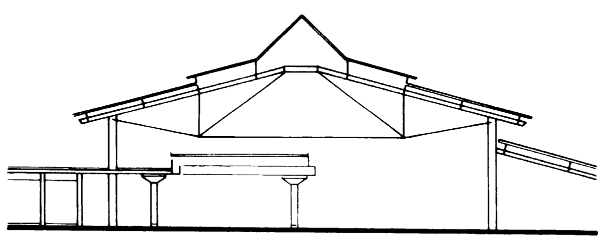
Design: Strahlmann; Klaus

⑩ **Departure hall, Paderborn/Lippstadt Airport**



Competitive design: Portmann; Echterhoff; Hugo; Panzer

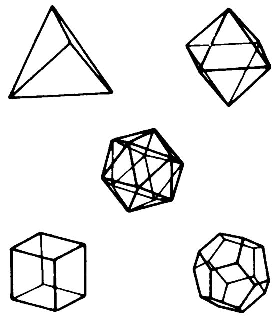
⑪ **Concert hall, exhibition park, Dortmund**



Architects: Gerber & Partners, Dortmund

⑫ **Underground station, Stadtgarten, Dortmund**

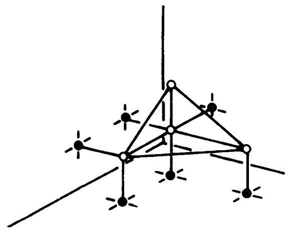
SPACE FRAMES: PRINCIPLES



tetrahedron	(4 faces)
cube	(6 faces)
octahedron	(8 faces)
dodecahedron	(12 faces)
icosahedron	(20 faces)

→ spherical network

(1) **Five platonic bodies**



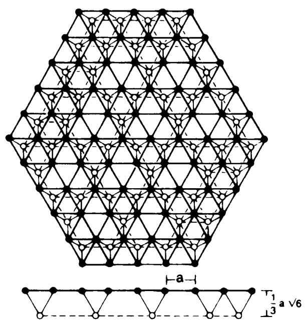
each joint in the three-dimensional space must be fixed by three members to make the three-dimensional frame rigid so, to achieve kinematic stability: no. of members = 3 × number of joints − (1 + 2 + 3)

(2) **Föppl framework formula**

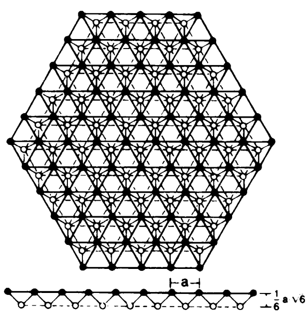
Ideally, space frames should be constructed from equal sided and/or isosceles right-angled triangles, so that regular polyhedrons are formed. In plane infinite networks, there are exactly three geometric structures; in spherical finite structures, there are exactly five regular polyhedron networks, which are comprised of only one type of joint, member, and hence also, surface. Regular plane networks are triangular, square and hexagonal.

Of the five platonic bodies used, the space frame formula decrees that only those three-dimensional joint-member space frames whose members form a closed triangular network are kinematically stable, i.e. the tetrahedron, the octahedron and the icosahedron. The cube requires an additional 6, and the dodecahedron, an additional 24 members, to become stable. If a spherical, triangular network is not closed over the whole surface, the basic polygon must be prevented from moving by an appropriate alternative method.

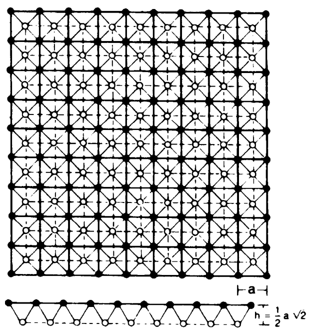
The lengths of the members of a body for a space frame form a geometric series with the factor 2. One joint with a maximum of 18 connections at angles of 45°, 60° and 90° is sufficient for the construction of a regular framework. As with plane structures, it must be accepted that the members are connected with flexible joints.



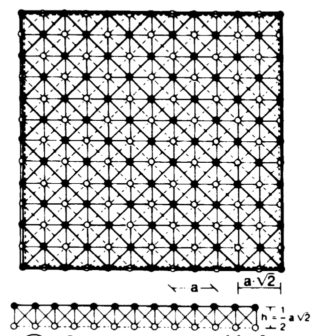
(3) **Space structure grid of octahedrons and tetrahedrons with regular cut-outs in the lower section**



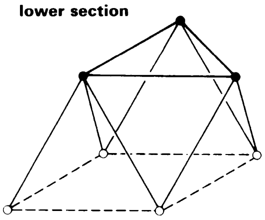
(4) **Space structure grid of octahedrons and tetrahedrons in compressed format**



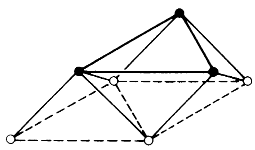
(5) **Space structure grid of semi-octahedrons and tetrahedrons parallel to the edges**



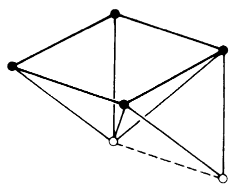
(6) **Space structure grid of semi-octahedrons and tetrahedrons in a rotated position (45°)**



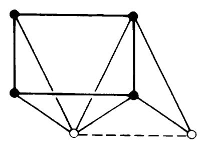
(7) **Space building blocks: octahedron and tetrahedron**



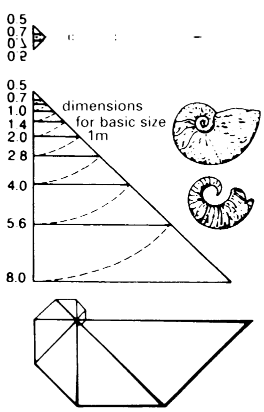
(8) **Space building blocks: octahedron and tetrahedron (large cube corners) in compressed format**



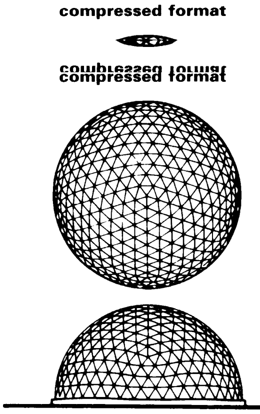
(9) **Space building blocks: semi-octahedron and tetrahedron**



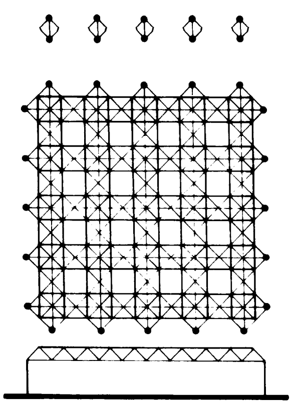
(10) **Space building blocks: semi-octahedron and tetrahedron**



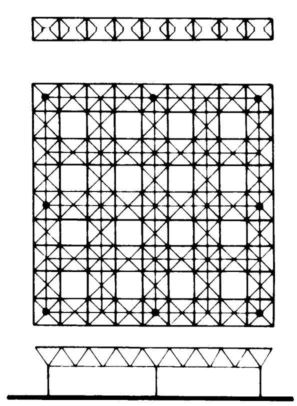
(11) **The geometric series for the length of members with the factor √2 and the natural pattern for the geometric series: shells of Ammonites**



(12) **Spherical dome featuring an icosahedron structure**

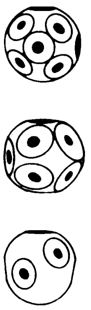


(13) **Space frame structure**

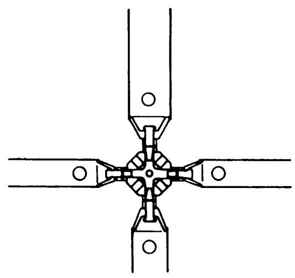


(14) **Space frame structure**

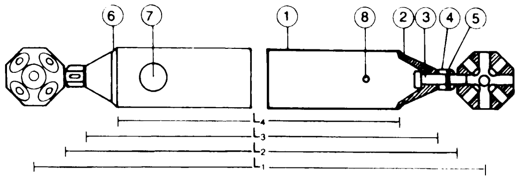
SPACE FRAMES: APPLICATION



(1) **MERO joint connections**



(2) **Arrangement of members at a joint**

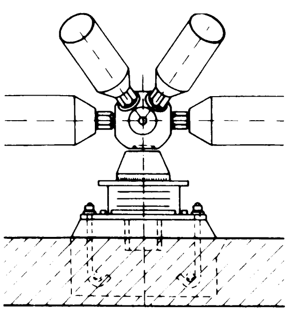


L_1 = system axial dimension
L_2 = nominal dimension of member
L_3 = finished dimension of member
L_4 = net length of tube

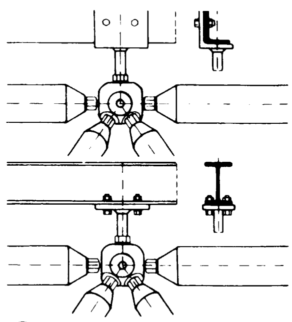
1 hollow section profile (tube)
2 cone
3 threaded bolts
4 keyed sleeve
5 slotted pin
6 weld seam
7 drainage hole
8 bolt insertion hole

(3) **Construction of a MERO frame member**

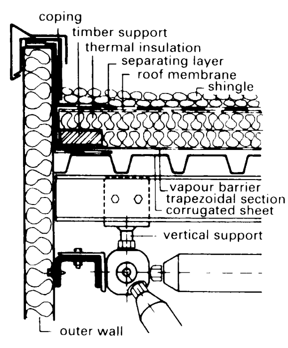
The MERO space frame developed by Mengeringhausen consists of joints and members → (1) – (3). The underlying principle is that joints and members are selected from the frame systems as are appropriate for the loads which are to be carried. In the MERO structural elements, the joint/member links do not act as 'ideal pin-joints', but are able to transmit flexural moments in addition to the normal forces in the members → (4) – (7). This three-dimensional format permits a free selection of a basic grid unit, then, with the factors √2 and √3 to size the lengths of the members, to develop a structure to provide the required load-bearing surfaces → (12) – (14) The unlimited flexibility is expressed in the fact that curved space frames are also possible. The Globe Arena in Stockholm → (13) is, at present, the largest hemispherical building in the world. The assembly methods involve elements of prefabrication, sectional installation or the slab-lift method. All the components are hot galvanised for corrosion protection. As a consequence of the high level of static redundancy of space frames, the failure of a single member as a result of fire will not lead to the collapse of the structure. Starting from spherical joints, that allow 18 different points of attachment for tubular members, a large variety of other joint systems between nodes and members have been developed so as to optimise the solution to load-bearing and spanning requirements → (8) – (11).



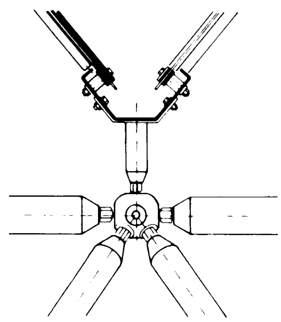
(4) **Frame support**



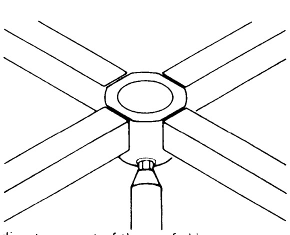
(5) **Purlin support**



(6) **Structural connections to wall and roof**

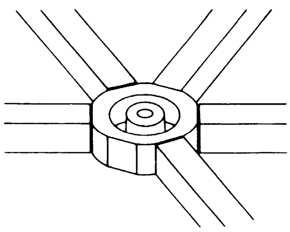


(7) **Structural connections – central channel**



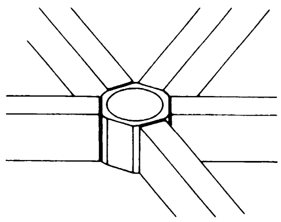
direct support of the roof skin on upper beam members, two layer supporting structure, screwed connections not resistant to bending, interlocked transition from frame member to joint in the upper beam, lower beam in the KK system

(8) **NK System (cup joint)**



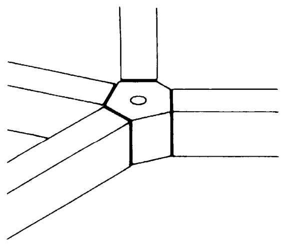
direct support of the roof skin, single-layered structure in triangular grid, screwed connections not resistant to bending, interlocked transition from structure member to joint

(9) **TK System (plate joint)**



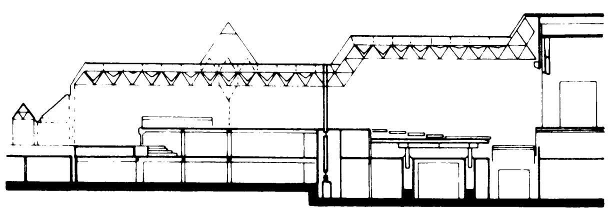
direct support of the roof skin, single layered structure, also in trapezoidal surface geometry, multi-screwed connections resistant to bending, interlocked transition from structure member to joint

(10) **ZK System (cylindrical joint)**



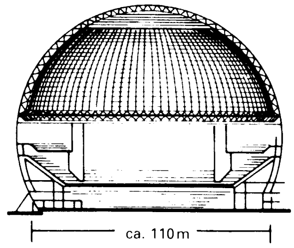
direct support of the roof skin, single and multi-layered structures, single and multi-screwed connections; member-integrated nodal optical points

(11) **BK System (block joint)**



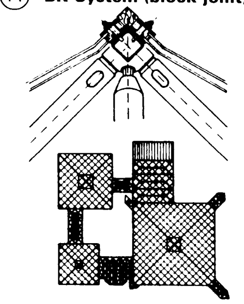
Architect: Strizewski

(12) **Partial section through the city hall in Hilden**



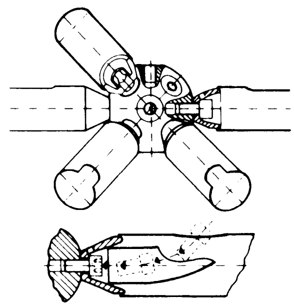
Architect: Berg

(13) **Section through the Globe Arena in Stockholm**

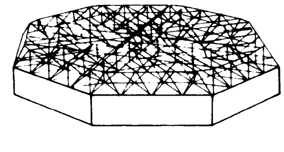


(14) **Detail of the roof ridge; roof plan of the plant exhibition hall, Gruga, Essen (NK System)**

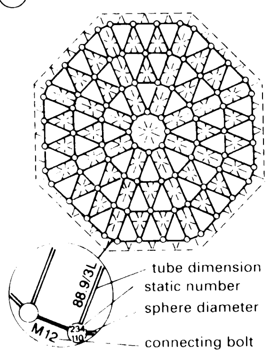
SPACE FRAMES: APPLICATION



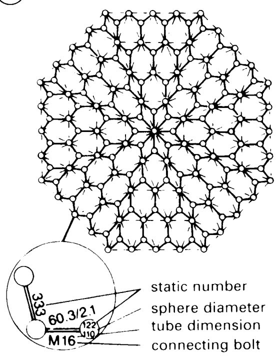
(1) **Joint**



(2) **Space frame system**



(3) **Upper beam members**



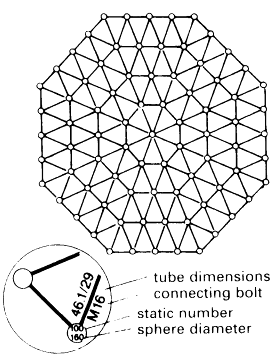
(4) **Diagonal members**

The Krupp–Montal® space frame was developed by E. Rüter, Dortmund-Hörde. The members are bolted to the forged steel sphere with bolts inside the tubes. The bolts have hexagonal recesses in their heads and are inserted into a guide tube through a hole in the tubing of the structural member. In general, all members are hot galvanised. A coloured coating may also be applied to them. On the Krupp–Montal® System, the bolts can be examined without being removed from the frame members; if required, it is possible to replace framework members without destroying the framework. The Krupp–Montal® System is illustrated in → (1) – (5), with points of detail in → (6) – (8).

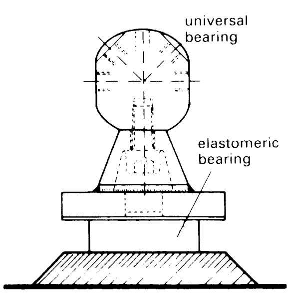
The KEBA tube and joint connection has been designed for the transmission of tensile and compressive forces. It does not require bolts and can be dismantled without problems → (9) – (13). The KEBA joint consists of the jaw fitting, the interlocking flange, the tapered wedge and the caging ring with locking pin.

The Scane space frame has been developed by Kaj Thomsen. Bolts provide the means of connection, which are inserted in the ends of the members using a special method and are then screwed into the threaded bores of the spherical joint fittings → (14) – (15).

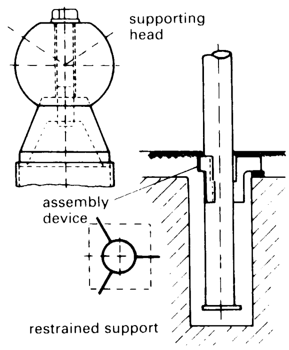
In the case of all space frames, an unsupported span of at least 80–100 m is possible.



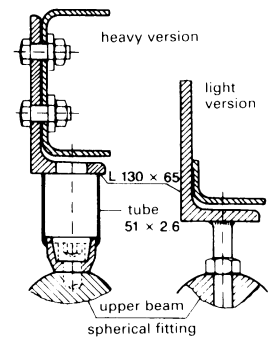
(5) **Lower beam members**



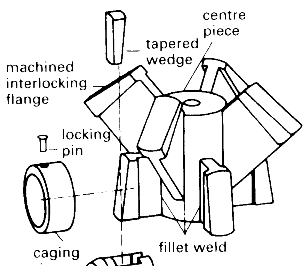
(6) **Universal bearing**



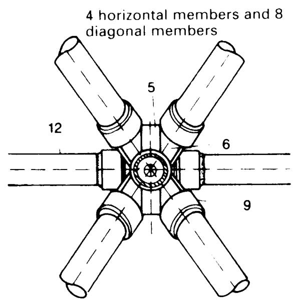
(7) **Supporting head fitting, restrained support**



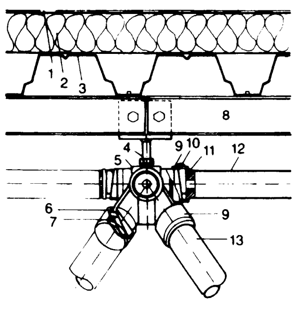
(8) **Purlin fixings**



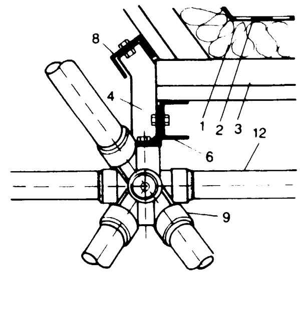
(9) **KEBA joints**



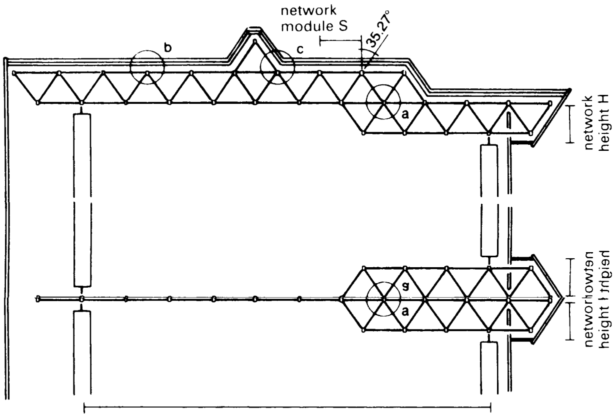
(10) **Common centre joint linking 12 members**



(11) **Standard upper joint**

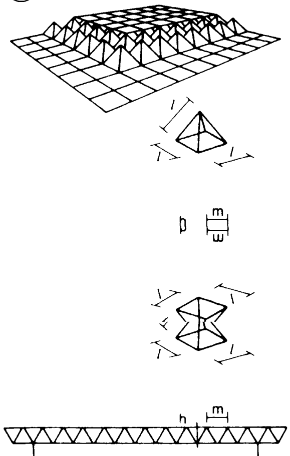


(12) **Common centre joint**

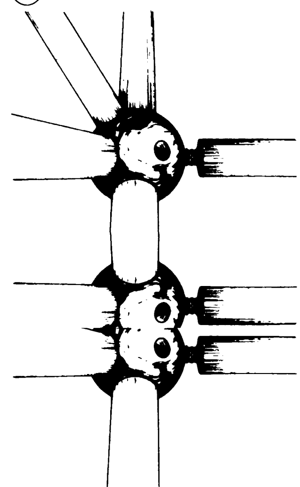


1 roof membrane
2 insulation
3 steel corrugated sheet
4 vertical distance piece
5 centre piece
6 interlocking flange
7 tapered wedge
8 purlin, tie beam
9 caging ring
10 locking pin
11 jaw fitting
12 horizontal tube
13 diagonal tube

(13) **Example of a possible roof form with joint details** (10) – (12)

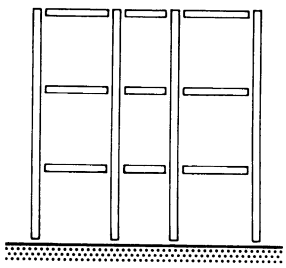


(14) **Space frame system**

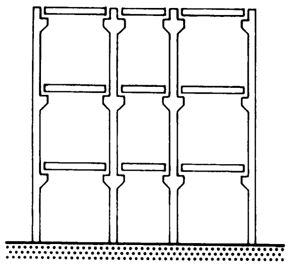


(15) **Joint (nodal point)**

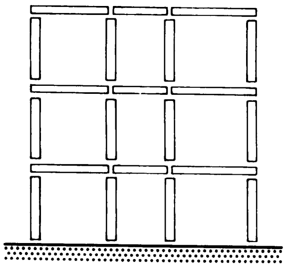
MULTISTOREY STRUCTURES



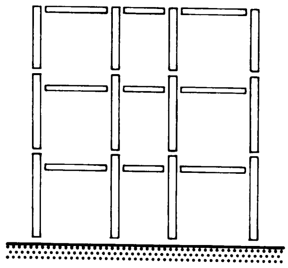
(1) **Continuous verticals, ties on concealed brackets**



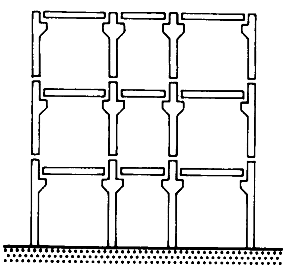
(2) **Continuous verticals, ties on brackets**



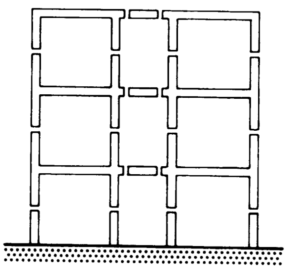
(3) **Sectional verticals, individual vertical supports with ties**



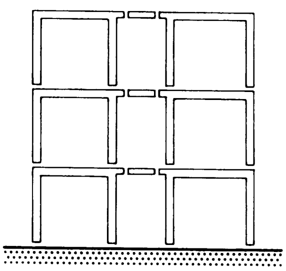
(4) **Sectional verticals, ties on brackets**



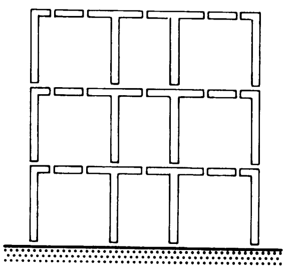
(5) **Sectional verticals, ties on brackets**



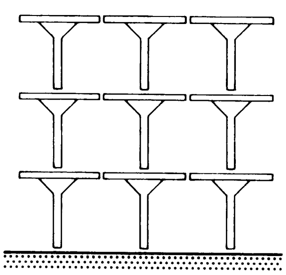
(6) **H-shaped rigid frame units**



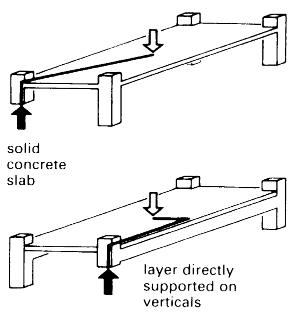
(7) **U-shaped linked frame units**



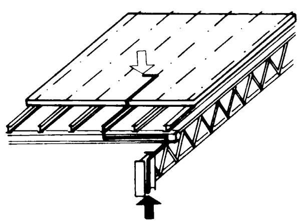
(8) **T- and L-shaped vertical supports**



(9) **Square headed mushroom frame unit**

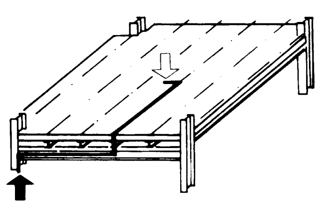


(10) **Floor support structure with a single load-bearing layer**



loads on the decking are transmitted via the beams to the points of vertical support

(11) **Floor support structure with two layers**



loads on the beams are taken to the main supports

(12) **Floor support structure with three layers (for very large supported spans)**

The main choice is of in situ or prefabricated manufacture in the form of slab or frame construction. The selection of the materials is according to type of construction and local conditions.

As in all areas of building construction, the number of storeys is limited by the load-bearing capacity and weight of the building materials. Construction consists of a vertical, space enclosing supporting structure made from structural materials with or without tensile strength. Vertical and lateral stiffening is necessary through connected transverse walls and ceiling structures. Frame construction, as a non-space enclosing supporting structure, permits an open planform and choice of outer wall formation (cantilevered or suspended construction). A large number of floor levels is possible with various types of prefabrication.

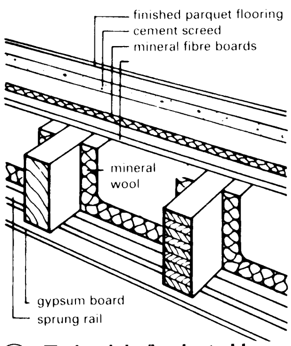
Structural frame materials: reinforced concrete – which provides a choice of in situ and prefabricated, steel, aluminium and timber.

Types of structure: frames with main beams on hinged joints, or rigid frame units in longitudinal and/or transverse directions. *Construction systems:* columns and main beams (uprights and ties) determine the frame structure with rigid or articulated joints (connecting points of columns and beams). *Fully stiffened frames:* columns and beams with rigid joints are connected to rigid frame units. *Articulated frame units* one above the other: columns and beams are rigidly connected into rigid frame units and arranged one above the other with articulated joints. *Pure articulated frames:* nodal points are designed to articulate, with diagonal bracing structures (struts and trusses) and solid diaphragms (intermediate walls, gable walls, stairwell walls); mixed systems are possible. *Rigid joints* are easily achieved with in situ and prefabricated reinforced concrete; however, prefabricated components are usually designed with articulated joints and braced by rigid building cores.

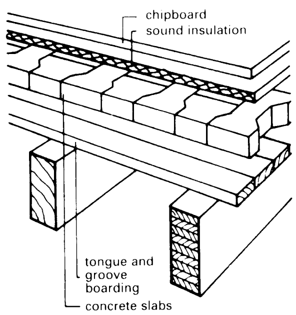
Construction

Framed structures with continuous vertical supports → (1) – (2); ties beams rest on visible brackets or conceal bearings. *Skeleton structures* with sectional vertical supports → (3) – (5); the height of the verticals can possibly extend over more than two storeys; the supporting brackets can be staggered from frame to frame; hinged supports with stiffened building cores. *Framed structures* with frame units → (6) – (8): *H-shaped frame units,* if required, with suspended ties at the centre connection (articulated storey height frames); *U-shaped frame units,* with separate ties in the centre, or with ties rigidly connected to frames (articulated storey height frames). *Flat head mushroom unit frame* construction → (9): columns with four-sided cantilevered slabs (slabs and columns rigidly connected together, articulated connection of the cantilevered slab edges). *Floor support structures* directly accept the vertical loads and transmits them horizontally onto the points of support; concrete floor slabs of solid, hollow, ribbed or coffered construction are very heavy if the span is large, and prove difficult in service installation; use of the lift-slab method is possible, suitable principally for rectangular planforms → (10) – (12).

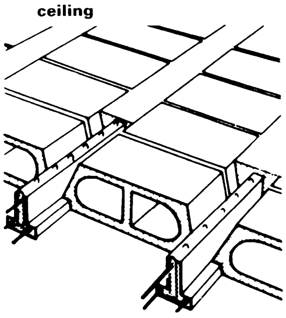
SUSPENDED FLOORS



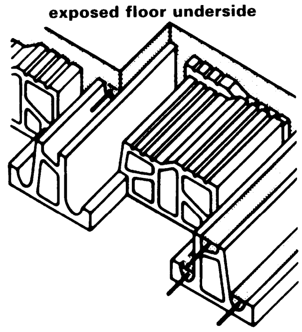
① **Timber joist/laminated beam floor construction with ceiling**



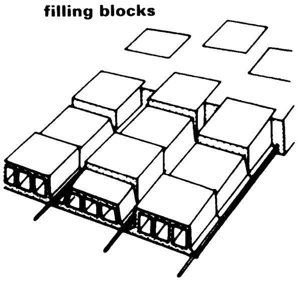
② **Timber joist/laminated beam floor construction with exposed floor underside**



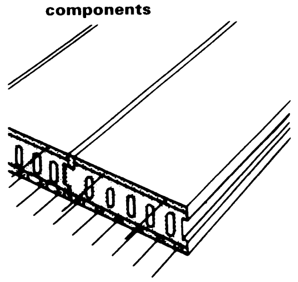
③ **Prefabricated reinforced concrete component floor with non-load-carrying filling blocks**



④ **Floor assembled from reinforced concrete ribs with cellular clay infill components**

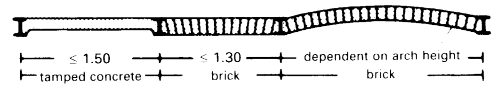


⑤ **In situ reinforced hollow pot concrete floor**

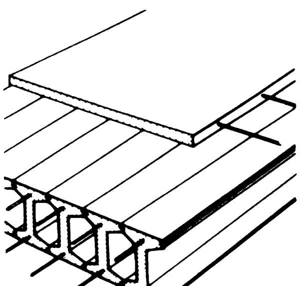


⑥ **Hollow core, pre-cast concrete flooring units with twisted, pre-stressed steel wires**

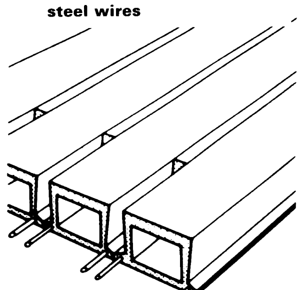
Wooden beam floors with solid timber joist or laminated beam supports → ① – ② in open or closed construction. Sound insulation is increased by laying additional 60 mm thick concrete paving slabs → ②. Part or full assembled floors are laid dry, for immediate use → ③ – ⑧. *Ribbed floors:* space the axes of the beams as follows: 250–375–500–625–750–1000–1250 mm. *Heavy floors* use in situ concrete on shuttering → ⑪. They can support only when cured and add moisture to the construction. *Reinforced concrete slab floors* span both ways; the span ratio 1:1.5 should not be exceeded. Thickness ≥ 70 mm – economic to approx. 150 mm. Pre-cast concrete reinforcing shuttering, of large format finished concrete slabs of a least 40 mm thickness which have integrated exposed steel reinforcing mesh, are completed with in situ concrete to form the structural slab → ⑫. The floor thickness is from 100–260 mm. This method combines the special features of pre-finished with those of conventional construction. Maximum slab width is 2.20 m. When the joints have been smoothed, the ceiling is ready for painting; finishing plaster is unnecessary. *Hollow pot floors* → ⑤ also as prefabricated floor panels. Floor thickness is 190–215 mm max., with supported spans of 6.48 m. *Prefabricated floor panels* are 1.00 m wide; concrete covering layer is not required. *Pre-stressed concrete – hollow slab floor* → ⑥, consists of self-supporting pre-stressed units with longitudinal cavities, so they have a low unit weight. They are joined together using jointing mastic. Slab width: 150 and 180 mm, 1.20 m wide. The elements can be max. 7.35 m long. *Composite steel floors* → ⑬. Trapezoidal and composite floor profiles, made of galvanised steel strip sheet, form the basic element for shuttering and ceilings.



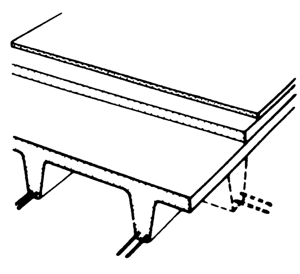
tamped concrete with axis spacing ≤ 150 cm
brick with axis spacing ≤ 130 cm
cambered (Prussian cap): axis spacing depending on structural calculations 3 m
steel supported floor with infills → ⑭



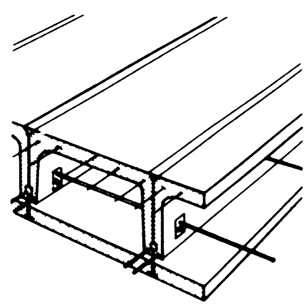
⑦ **Prefabricated reinforced concrete I-beam floor**



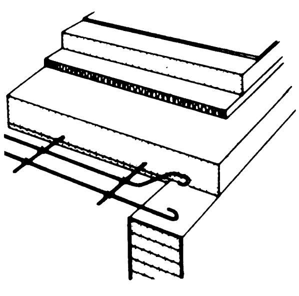
⑧ **Prefabricated reinforced concrete hollow beam floor**



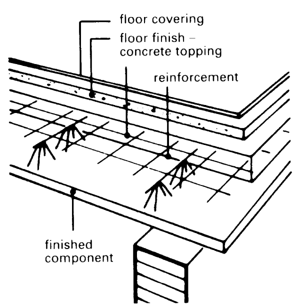
⑨ **In situ reinforced concrete ribbed floor, rib separation ≤ 70 cm, rib width ≥ 5 cm**



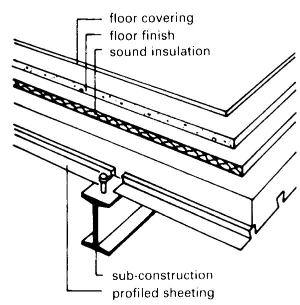
⑩ **U-section reinforced concrete beams bolted to provide lateral stiffness**



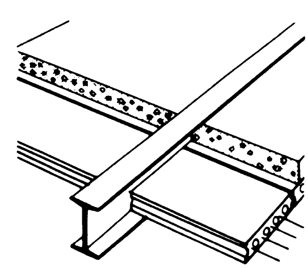
⑪ **Reinforced concrete slab floor, reinforced in one or two directions**



⑫ **Pre-cast concrete reinforcing shuttering for in situ floor**



⑬ **Composite steel/concrete floor**



⑭ **Steel supported floor with pre-cast reinforced pumice concrete infill units**

FLOORING

Flooring has a decisive effect on the overall impression created by rooms, the quality of accommodation and maintenance costs.

Natural stone floors: Limestone, slate or sandstone slabs can be laid rough hewn, in natural state, or with some or all edges cut smooth or polished → ①–②. The surfaces of sawn tiles, limestone (marble), sandstone and all igneous rocks can be finished in any manner desired. They can be laid in a bed of mortar or glued with adhesive to the floor sub-layer.

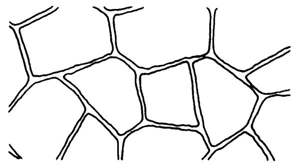
Mosaic floors: Various coloured stones: (glass, ceramics or natural stone) are laid in cement mortar or applied with adhesives → ③–⑧.

Ceramic floor tiles: Stoneware, floor, mosaic and sintered tiles are shapes of coloured clay which are sintered in the burning process, so that they absorb hardly any water. They are, therefore, resistant to frost, have some resistance to acids and high resistance to mechanical wear, though they are not always oil resistant.

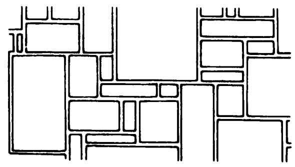
Parquet flooring is made from wood in the form of parquet strips, tiles, blocks or boards → ⑰–㉒. The upper layer of the finished parquet elements consists of oak or other parquet wood, in three different styles → ⑰–⑱.

Pine or spruce are used for floor boarding. Tongue and groove planks are made from Scandinavian pine/spruce, American red pine, pitch pine.

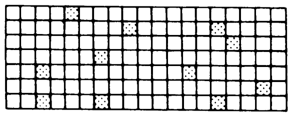
Wood block paving (end grained wood) is rectangular or round, and laid on concrete → ㉓–㉔.



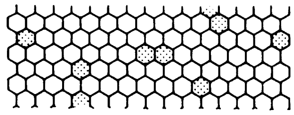
① **Natural, irregularly laid stone floor**



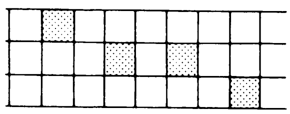
② **Natural stone floor in Roman style**



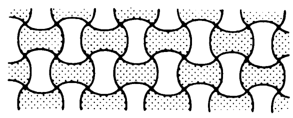
③ **Small mosaic squares 20/20; 33/33 mm**



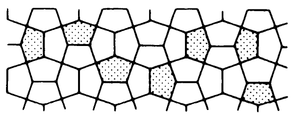
④ **Small mosaic: hexagonal 25/39; 50/60 mm**



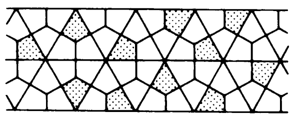
⑤ **Square mosaic: 50/50; 69/69; 75/75 mm**



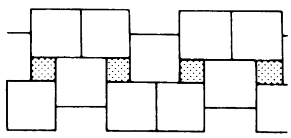
⑥ **Small mosaic: intersecting circle pattern 35/35; 48/48 mm**



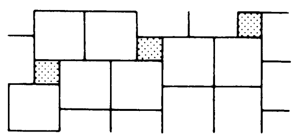
⑦ **Small mosaic: five-sided 45/32 mm**



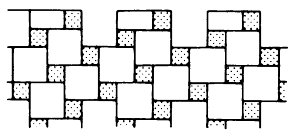
⑧ **Small mosaic in Essen pattern: 57/80 mm**



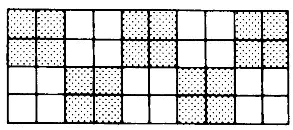
⑨ **Square, with an inlay of smaller tiles**



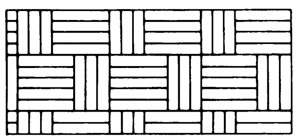
⑩ **Square, with inlay 100/100; 50/50 mm**



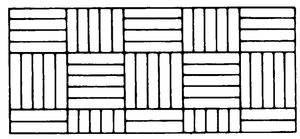
⑪ **Square, with displaced inlay of smaller tiles**



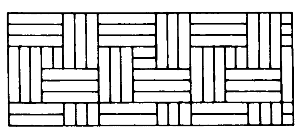
⑫ **Square, incorporating doubled chessboard pattern**



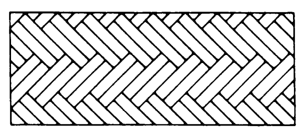
⑬ **Open basket**



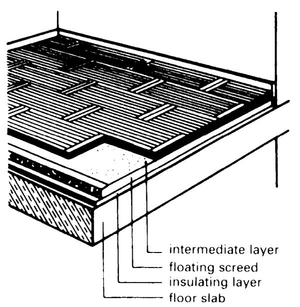
⑭ **Square basket**



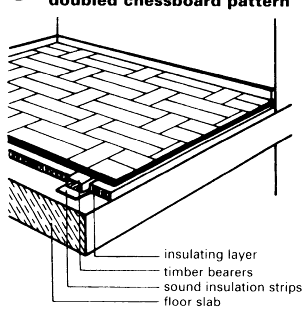
⑮ **Open basket**



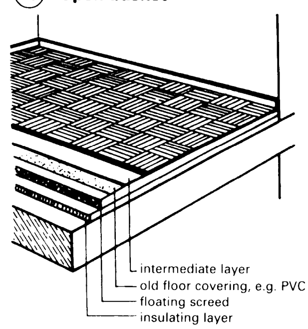
⑯ **Herring bone pattern**



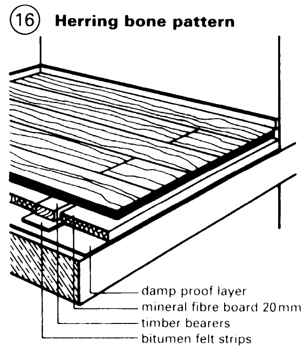
⑰ **Finished parquet elements on floor screed**



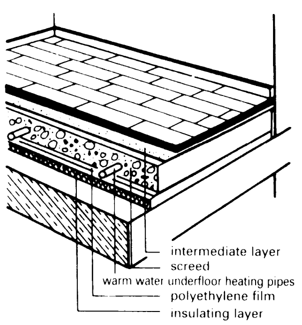
⑱ **Finished parquet elements on timber battens**



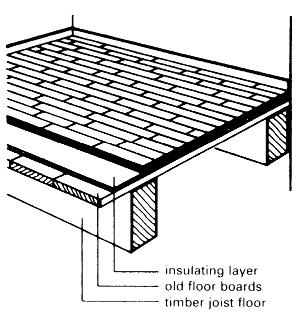
⑲ **Finished parquet elements on old floor covering**



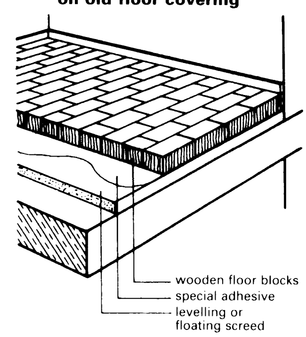
⑳ **Finished parquet elements on timber battens**



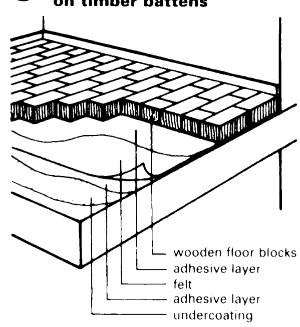
㉑ **Finished parquet flooring elements on underfloor heating**



㉒ **Finished parquet flooring elements on old wooden floor**



㉓ **Wooden floor blocks, glued down, with surface treatment (living area)**



㉔ **Wooden floor blocks, glued down on even, smoothed concrete underlayer (specialised finish)**