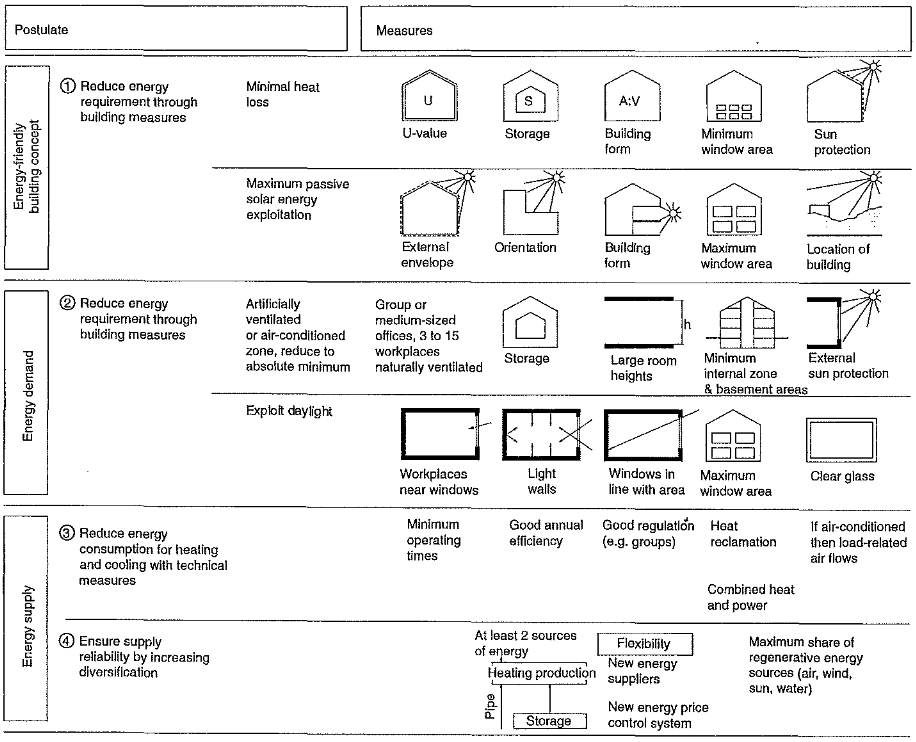
Energy source	Primary energy	Natural energy conversion	Technical energy conversion	Secondary energy: heat	Secondary energy: electricity	Secondary energy: fuels
sun	water power	evaporation, precipitation, thawing	hydropower station		x	
	wind power	atmospheric movement (wind)	wind energy converter		x	
		wave movement	wave power station		x	
	solar radiation	ocean currents	ocean current power station		x	
		warming of earth's surface and atmosphere	ocean warmth power station		x	
		solar radiation	collector, solar thermal power station	x		
			solar cell, photovoltaic power station		x	
			photolysis			x
	biomass	biomass production	conversion plant			x
			thermal power station	x	x	
earth	isotopic decay	geothermic	geothermal power station	x	x	
moon	gravitation	tides	tidal power station		x	

1 Renewable energies and their uses

Passive measures	Active measures	Hybrid measures
– town planning ecology – building form and alignment – thermal inertia – thermal insulation – special types of glass – double façades, buffer zones – atriums	– combined heat and power – total energy plants – solar thermal energy – photovoltaic – building element heating and cooling – heat pump technology – geothermal energy – fuel cells – condensing boilers – cooling systems (e.g. cool storage)	– storage of warmth and cold in connection with active systems – air conditioning through building elements/ground

2 Measures in ecological building technology



3 Objectives and measures for the design of energy and building technology (Economic Affairs → refs)

RENEWABLE ENERGY

Overview

Scarcer resources and increasing energy prices are resulting in more interest in renewable energy sources. The limited supply and increasing consumption of energy reserves is leading to the necessity of developing alternatives. The construction and operation of buildings represents a large proportion of overall energy consumption.

In addition to saving energy through ever improved thermal insulation and more effective methods of energy processing with higher efficiencies, the use of renewable energies is becoming increasingly significant. The development and diffusion of new and optimised processes and equipment is supported by grant programmes.

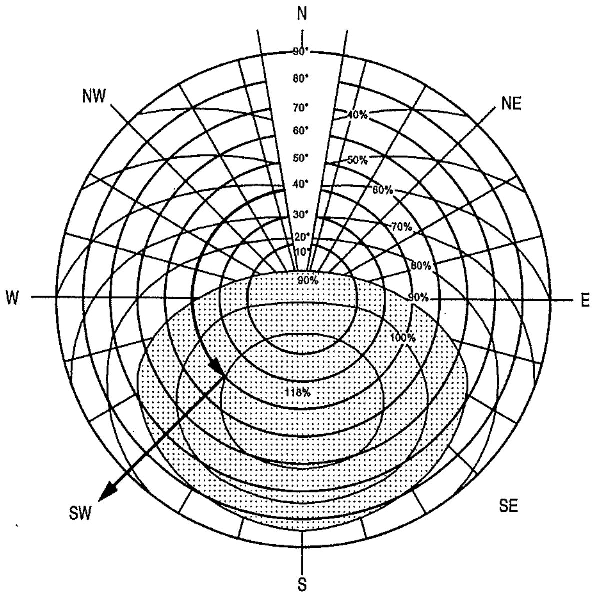
The optimal design of each building project has an essential role to play. The forecast demand for electrical and heat energy for a particular building should be compared with the opportunities available at the location and the most efficient process selected. As new processes and devices are developed or made effective, existing buildings and systems should be checked often for efficiency and may need to be upgraded.

The methods of exploiting renewable energies are multifarious and are being extended constantly. The type and extent of this use depends on the possibilities at the location, the type and size of the building project and the budget.

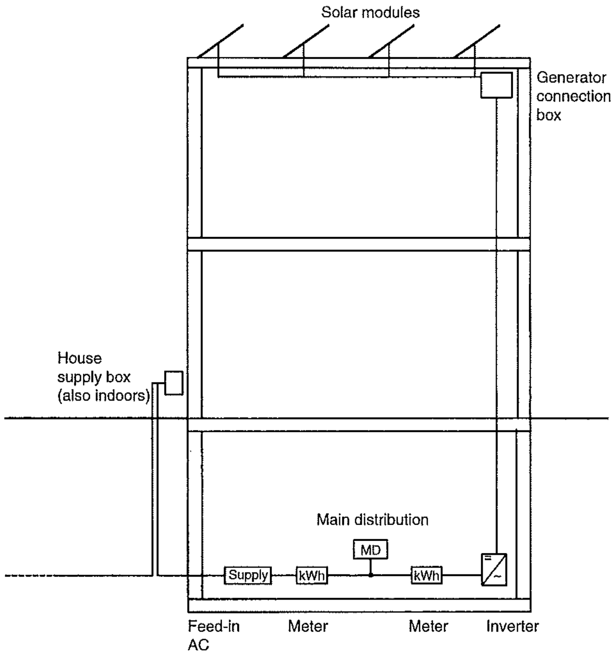
The application of a particular process can be supported by public grant programmes and the energy industry. What can be grant-aided and to what level varies according to region and is regularly adapted to altered conditions (regulated in the Renewable Energy Law – EEG).

RENEWABLE ENERGY
Overview
Solar energy
Bioenergy
Geothermal energy, heat pumps
CHP, block heating and power, fuel cells

Building services



❶ Performance of photovoltaic elements according to tilt and alignment (Shell → refs)



❷ Principle of a grid-connected photovoltaic system (Bohne → refs)

Photovoltaics

Sunlight is converted into electricity in solar cells. This is an important element of the ecological design of buildings, because renewable electrical energy is generated. Solar cells can use direct and diffused solar radiation. Shadowing of their surface is to be avoided, with partial shadows having a more serious effect than temporary shadows (i.e. trees are worse than clouds).

The solar yield depends on the climate and the alignment of the panels → ❶. The optimum alignment in northern latitudes is facing due south, with a tilt angle from the horizontal dependent on latitude. At good locations, in Germany for example, an average annual yield of 800–900 kWh/m^2 can be expected, or under optimum conditions approx. 1100 kWh/m^2. A rule of thumb is to expect to require 7.5 m^2 of panels for each kW of installed capacity.

Solar cells are connected together into larger units called modules. Various types of module (mono-crystalline, multi-crystalline, amorphous) differ in performance, efficiency and appearance. Mono-crystalline cells have uniformly dark grey to black surfaces, multi-crystalline grey to blue and variable; semi-transparent modules are also possible.

The conversion of the direct current coming from the solar cells into alternating current in the inverter causes little conversion loss. Most systems are connected to the grid for more cost-effective operation: the electricity coming from the solar modules is fed into the grid, which requires a separate feed-in meter.

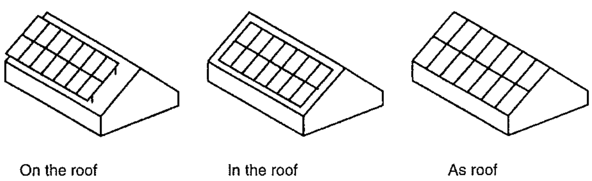
Large photovoltaic installations should be operated with changing tilt and alignment (tracking), with separate solar generators and grid feed-in equipment to achieve the optimum yield. Grid-connected systems work completely automatically without maintenance and have a lifetime of at least 20 years. Solar-generated electricity fed into the public grid is paid for over a guaranteed period as regulated in the Renewable Energy Law (EEG).

Photovoltaic elements can be integrated into the building envelope in various ways or mounted subsequently. They are designed for use in the open air and can be used as an independent part of a façade or roof. Solar cells are UV-resistant and weatherproof.

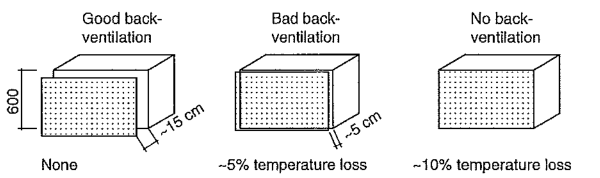
They can play an important architectural role and also fulfil other functions: sound, visual, sun and weather protection. Solar cells are mostly built on roofs, for which there are various possibilities: mounted on the roof (independently, mostly for later installation), integrated into the roof covering or forming the roof itself. The installation of photovoltaic modules in façades is also possible, in which case they should be back-ventilated in order to avoid reduction of yield → ❸ + ❹.

RENEWABLE ENERGY
Overview
Solar energy
Bioenergy
Geothermal energy
Heat pumps
CHP, block heating and power, fuel cells

Building services



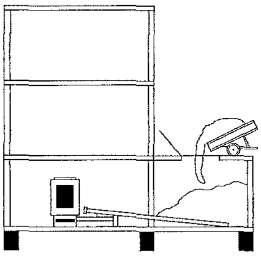
❸ Possible roof-related arrangements of photovoltaic elements



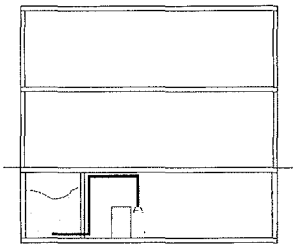
❹ Photovoltaic elements on a façade with possible yield reductions (Bohne → refs)

Wood type	kWh/m³	kWh/kg	Wood type	kWh/m³	kWh/kg
maple	1,900	4.1	spruce	1,700	4.4
birch	1,900	4.3	larch	1,700	4.4
beech	2,100	4.0	poplar	1,200	4.1
oak	2,100	4.2	robinia	2,100	4.1
alder	1,500	4.1	fir	1,400	4.5
ash	2,100	4.2	willow	1,400	4.1

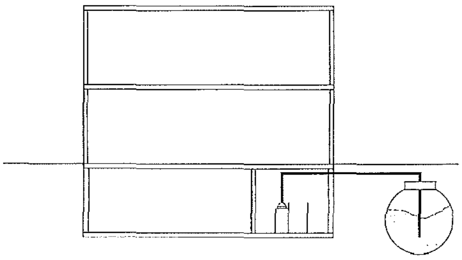
❶ Calorific value of various types of wood (Bohne → refs)



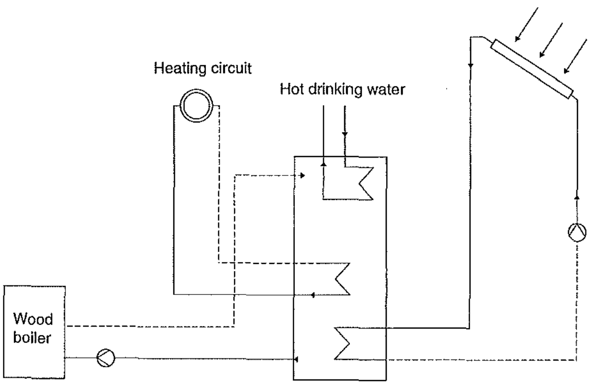
❷ Wood chip heating system with automatic feed (Bohne → refs)



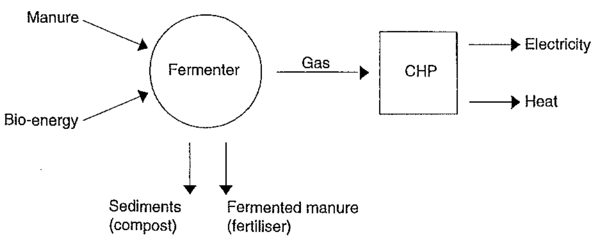
❸ Pellet heating boiler with fuel storage in a cellar room (Bohne → refs)



❹ Pellet heating boiler with fuel storage in an underground container (Bohne → refs)



❺ Heating plant with thermal solar system, wood-burning boiler and buffer cylinder for heating water (Bohne → refs)



❻ Principle of biogas use in agriculture

Biomass energy

Biomass is exploited for energy through thermo-chemical or biological processes (burning, gasification or liquefaction). The most significant sources are biodiesel, wood and agricultural waste products. Biodiesel is made by liquefying renewable raw materials which contain oil. It can replace heating oil or conventional oil and be used in appropriate boilers or block heating and power plants.

Wood as an energy source

Wood is available in great quantities and can be used in various forms. The water content of newly felled wood is 40–50%. Air-dried wood contains 15–20% water and produces twice the calorific value. There are various types of wood with different moisture contents, density, calorific value and also size, form and processing. Wood for burning is available as logs, wood chips and pellets.

For smaller installations up to 15 kW nominal heat output, natural logs can be used, which can be hardwood or softwood from forestry or waste products from timber processing. Demolition timber should be avoided. In larger installations, it is also possible to use sawdust, straw and further sources.

Centralised boilers are preferable to single stoves on account of better possibilities for controlling emissions. Automatically fed boilers show better emissions values than hand-fed.

In wood chip or pellet systems, the fuel is fed into the combustion chamber from an adjacent room or from a container using a spiral auger conveyor or pressure system. The continuous supply of fuel ensures a good degree of efficiency and enables the output to be adapted according to demand.

Pellets (pressed waste products of wood-processing industries with a very high energy value of 4.3–5.0 kWh/kg, about ⅓ that of heating oil) are delivered in trucks and blown into the storage container. The technology and the space required for the installation is comparable to an oil heating system.

The size of the boiler also corresponds to a boiler for oil or gas. The safety standards are, however, lower than for heating oil. Containers for wood chips are filled by tipping from a truck.

In order to extend the burning time in the boiler, heating water buffer cylinders are a sensible addition to a pellet or wood chip heating system, and are necessary for log heating systems; 40 litres per kW of nominal output should be assumed. Boilers for solid fuel up to 1 MW thermal output do not require a permit.

A further technological possibility is gasification of wood (e.g. of wood chips) for use in a block heating and power plant, for which some heating oil is required to start the motor. The combination of a wood-fired boiler with a thermal solar system is sensible because the water can be pre-warmed by solar energy and heated to feed temperature by the boiler → ❺.

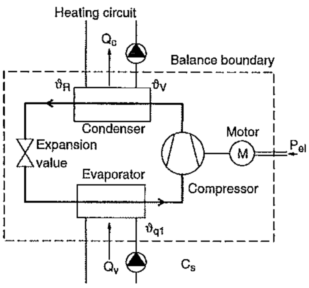
Biogas

The agricultural production of biogas on farms from slurry or harvested materials has great potential and is of increasing importance. The biomass is gasified in a digester, which then feeds a gas engine for combined heat and power. The digested slurry is spread on the fields as fertiliser and the residual sludge can be used as compost. Biomass gasification is a continuous and sensitive process and requires constant monitoring. A biogas plant requires a permit under the Federal Emissions Control Law.

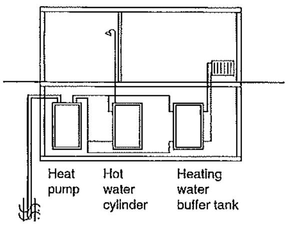
Gas from landfill sites (fermentation of solid matter) can also be employed to produce heat and power using gas probes or gas collecting drains for the operation of heat and power systems or simply as heating gas.

Water	Surface water	river, lake, seawater
	Underground water	groundwater, spring water, well water, deep/thermal water
	Waste heat	cooling water, municipal drain water, domestic drain water, industrial service water outflow, lighting heat
	Circulating water	district heating network, water supply main, process water
Air	outdoor air, escaping air, industrial extract air, lighting heat, heat from people, process heat	
Ground		
Solar energy		

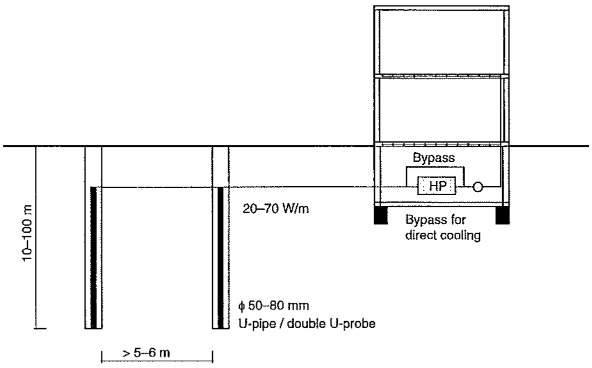
1 Heat sources for the running of a heat pump



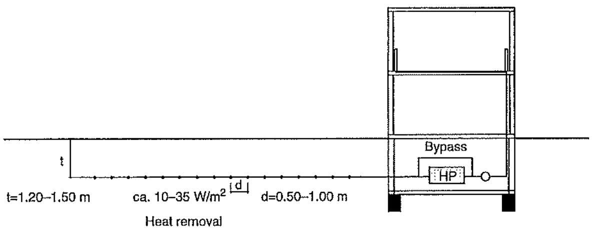
2 Functional principle of a heat pump (Schmid → refs)



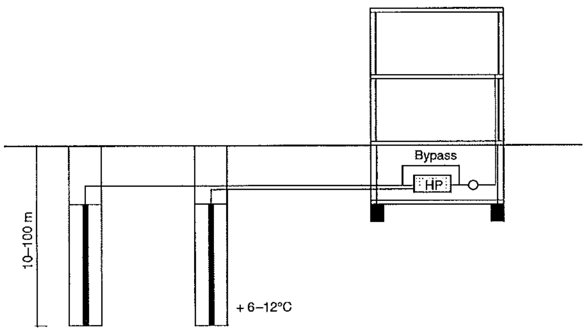
3 Heat pump system



4 Downhole heat exchanger as heat source for a heat pump (in combination with the activation of a building element for air conditioning) (Bohne → refs)



5 Ground source heat collectors as heat source for a heat pump (Bohne → refs)



6 Groundwater as heat source for a heat pump (in combination with underfloor heating) (Bohne → refs)

Ground source energy

This describes the exploitation of geothermal energy at a depth to approx. 400 m. The temperature gradient is about 3 K/100 m of depth and temperatures of approx. 7–11°C can be expected at a depth of 10–20 metres; the flow of warmth is influenced only by weather and air temperature near the surface. The relatively constant temperatures can be exploited for heating and cooling. Many processes are available for energy use:

Ground source heat collectors

These are metal or plastic pipes laid horizontally under the ground. The spacing and depth are dependent on the properties of the soil. The heat extraction is 10–40 W/m². Geothermal heat collectors should not be built over and the surface should not be impermeably paved.

Downhole heat exchangers

These require less space and have better thermal performance than ground source heat collectors. They can be installed as indirect or, less often, as direct systems in a closed circuit. An indirect system would, for example, connect a brine circuit with the heat pump through an intermediate heat exchanger. There are various construction types: U-pipe or double-pipe probes and coaxial probes, where the borehole is grouted with a cement-bentonite suspension for better heat transfer. The extraction output is 20–70 W/m.

Groundwater wells as a heat source

Heat can be extracted directly from an aquifer: heat exchangers shaped like an immersion heater are lowered down boreholes into the aquifer and connected to a heat pump with a brine circuit. The usual process is the extraction and refilling of the groundwater with pumping or suction wells. Such systems (and also downhole heat exchangers) generally require a permit, and the required drilling work must always be performed by approved firms. Then extracted energy can be used directly to heat or cool building elements or indirectly with heat pumps.

The suitability of using air or surface water as a heat source should be investigated for each specific project, because the annual variation of temperature is directly opposite to the heating demand.

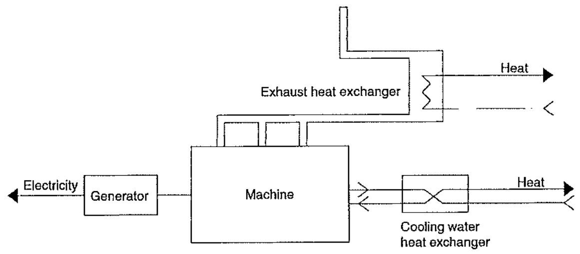
Heat pump

Environmental or geothermal energy is exploited in a thermodynamic process through the introduction of mechanical energy: ¾ of the energy required for heating is gained from the environment and the remainder is consumed as electricity to power the compressor. Heat pumps are of particular interest for integrated energy supply concepts, because they can be used for heating and also cooling.

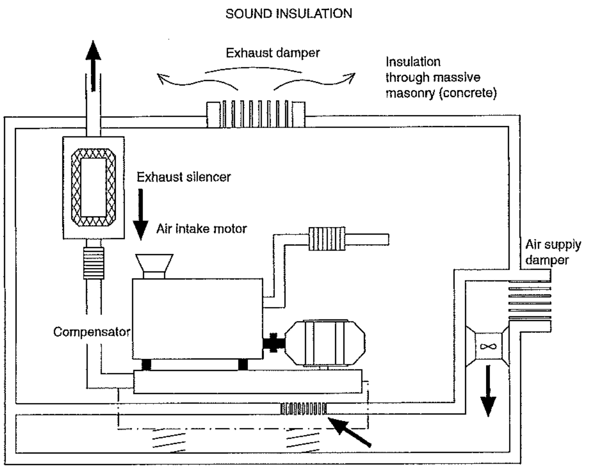
A heat pump essentially consists of evaporator, compressor, condenser and expansion valve. These parts are connected with pipes in a closed medium circuit. The effect is to extract heat from the surroundings by evaporation. The now gaseous medium is compressed in an electrically driven compressor, increasing the temperature and pressure. A further heat exchanger then transfers this heat to the heating system, causing the medium to condense again. The control valve serves to reduce the pressure in the medium to the low initial pressure.

Heat pumps can be used with low-temperature heating systems (optimal for relatively low feed temperature such as in underfloor heating) and central water heating. The heat delivered by the compressor of the heat pump must always be dissipated, thus the installation of a buffer cylinder (not necessary for underfloor heating).

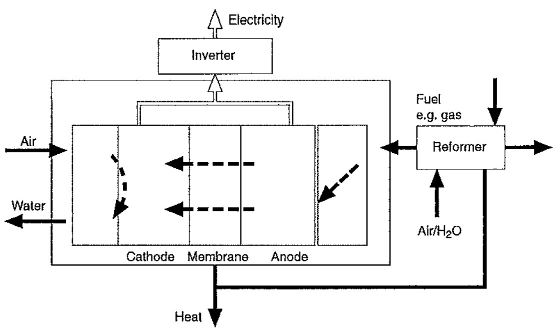
The heat pump works independent of the time of day or season and is considered to be an environmentally beneficial heating system. The electricity for the operation of a heat pump is sometimes grant-aided through lower electricity prices and requires a separate meter.



❶ Functional principle of combined heat and power (Schmid → refs)



❷ Block heating and power system and constructional ancillaries (Bohne → refs)



❸ Principle of a fuel cell (Bohne → refs)

Description	Abbreviation	Operating temperature	Electrolyte	Fuel	Oxidant	Application
alkaline FC	AFC	80 °C	caustic potash	hydrogen	oxygen	space
polymer-electrolyte-membrane FC	PEMFC	80 °C	solid polymer	hydrogen, methanol	oxygen/ air	transport, small power station
phosphoric acid FC	PAFC	200 °C	phosphoric acid	natural gas	air	thermal power station
molten carbonate FC	MCFC	650 °C	lithium and potassium carbonate	natural, town and biogas	air	power station, thermal power station
oxide ceramic FC	SOFC	1000 °C	zirconium oxide	natural, town and biogas	air	power station, thermal power station

❹ Overview of fuel cell types

Combined heat and power (CHP) is the combined production of heating and mechanical energy, which is converted into electricity in a generator. The basic idea is the generation of electrical energy and the exploitation of the heat, which is always produced at the same time. Smaller installations (for one or more buildings) use combustion motors or gas turbines instead of the water/steam circuit normally found in a power station.

A **block heating and power system** is a small power station, which produces electricity and space heating at the same time, working as a mini- or micro-CHP system. The size of a block heating and power system has a decisive influence on its cost-effectiveness, because the energy produced by a CHP system consists of about ⅓ electricity and ⅔ heat. The variable energy demand for buildings according to time of day and season necessitates the sizing of the block heating and power system according to electricity or heating demand. If the block heating and power system is designed to meet heating demand, then excess electricity is fed into the grid and electricity is consumed from the grid when the output is insufficient. If the block heating and power system is designed to meet electricity demand, then excess heat is stored in a buffer cylinder and an external boiler is required when the heat produced is insufficient.

Block heating and power systems are mostly designed to meet the heating demand. The precondition is that the curve of heat and electricity demand against time is known for the building or consumer group. For the design of new residential buildings, the demand can be estimated fairly accurately using characteristic curves. A block heating and power system will normally produce enough heat to meet basic requirements and excess electricity is fed into the grid though an additional meter. The heating demand at peak times is then met by an additional source of heating.

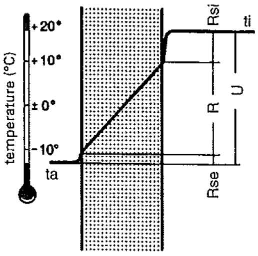
Block heating and power systems are available in various sizes: the smallest models for single houses from approx. 2 kW of electrical power and powered by a four-stroke or Stirling motor (micro-CHP), small plants up to 30 kW can be used for blocks of up to six flats (mini-CHP). Compact block heating and power systems cover the range up to 400 kW, above that large systems are needed. The space required for a mini-CHP system from 5.5 kW electricity output is 4 m^2, for 15 kW 6.5 m^2, and any areas for additional heating boilers should be added.

For installation in buildings, sufficient air supply and extract openings should be specified and the exhaust pipe continued to above the roof. The system should either be encapsulated as a module or sufficiently sound insulated between itself and occupied rooms.

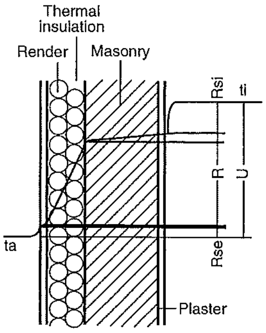
Fuel cells produce electricity and heat out of water and hydrogen in a reverse-electrolysis process. They consist of electrodes (anode and cathode) and an electrolyte. This separates the electrodes and the reaction partner supplied. Fuel cells generate DC, which is concerted into AC in an inverter. The waste heat can be used for space heating through a cooling circuit. Hydrogen is produced from natural gas or methane/methanol in a reformer. Like CHP systems, fuel cells produce electricity and heat simultaneously, but without mechanical parts or noise.

As with a CHP system, the selection of the correct fuel cell can be based either on electricity or heating demand, and in the same way design to cover base load with an alternative source for the production for peak loads is sensible. The excess heat in the summer months can be used to drive an absorption refrigeration machine.

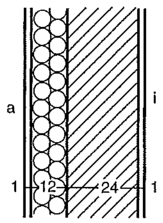
Fuel cells are differentiated according to operating temperatures (high-temperature, low-temperature fuel cells) and electrolyte used. Low-temperature fuel cells are already available for smaller building applications like blocks of flats or small commercial use, but high-temperature fuel cells are practical only in large applications because they produce electricity and heat in large quantities and the high temperatures have to be dispersed through multiple use in an energy cascade. Fuel cells are suitable for upgrading and new installations.



❶ Temperature curve in a single-layer building element



❷ Temperature curve in a multi-layer building element



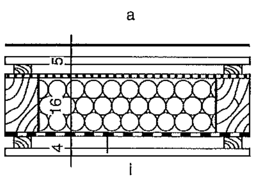
External wall with external wall insulation system

U req 0.35 W/m²K
R req 1.2 m²K/W

Thermal transmittance
U exstg = 0.29 W/m²K

	Building material layer	Density kg/m³	Thickness d (m)	Weight/area kg/m²	λ W/mK	d/λ m²K/W
	Rsi					0.040
1	Render		0.01			
2	Insulation	30	0.12	32.6	0.040	3.000
3	Sand-lime masonry	1800	0.24	432.0	0.990	0.242
4	Plaster	1400	0.01	14.0	0.700	0.014
	Rsi					0.130
Σ						RT = 3.427

❸ Calculation of thermal transmittance (U-value) for an external wall with an external wall insulation system



Pitched roof

U req 0.30 W/m²K
R req 1.75 m²K/W
according to DIN 4108-2

Insulation proportion fa 85%
Rafter proportion fb 15%

Thermal transmittance
U exstg = 0.29 W/m²K

	Building material layer	Density kg/m³	Thickness d (m)	Weight/area kg/m²	λ W/mK	d/λ m²K/W
	Rse					0.040
1	Roof covering					
2	Battens					
3	Underlay					
4	Insulation	30	0.16	4.8	0.040	4.000
5	Rafters	600	0.16	96.0	0.130	1.231
6	Battens, enclosed air layer		0.025			0.16
7	Plasterboard	900	0.0125	11.3	0.250	0.050
	Rsi					0.100
Σ	Upper limit value **R'T** = 1/(fa/RT, insulation + fb/RT, rafters) = 3.445					
	Lower limit value R"T = Rse + R1 + R2 + R3 + R4 + R5 + R6 + R7 + Rsi = 3.341					
	R'T = (R'T + R"T)/2 = 3.393					

❹ Calculation of thermal transmittance (U-value) for a pitched roof construction

Thermal insulation measures are necessary in buildings to limit heat loss and to protect against condensation; verifications that these have been carried out are required, as stated in various standards and regulations:

The **Energy Saving Regulation (EnEV 2007)** contains limiting values for the **primary energy demand** and the **transmitted heat demand** of residential and non-residential buildings → p. 474. The determination of the coefficients of thermal conductivity (U-values), the energetic design values (heat transmission resistance, thermal conductivity) and the essential basic terms are described below.

Heat quantity, unit Wh [= 1.16 kcal]; temperature °C; temperature difference K (Kelvin). 1.16 Wh (= 1 kcal) increases the temperature of 1000 g of water by 1 K (= **thermal capacity**)

Heat transfer can be by convection (carrying), conduction, radiation or water vapour diffusion; heat transfer can be slowed by thermal insulation, but never prevented.

Thermal conductivity λ, unit W/mK [kcal/mhK], is a property of a material; the smaller this value, the less the thermal conductivity. The design values include, in contrast to the nominal values, a supplement for practical application (temperature, moisture, ageing).

Thermal resistance R, unit m²K/W [m²hK/kcal] is a property of a layer: **R** = d/λ (d = layer thickness in m). The calculation of the thermal resistance is important for the determination of the heat transfer coefficient U → ❸ – ❹.

Surface resistance is the thermal insulation value of the air film adhering to the building element. The external surface resistance ($\mathbf{R}_{se}$) and the internal surface resistance ($\mathbf{R}_{si}$) are differentiated.

Overall resistance 1/U, unit m²K/W [m²hK/kcal], is the sum of the resistances of a building element to the transmission of heat (thermal resistances and surface resistances): $\mathbf{1/U} = \mathbf{R}_{si} + \mathbf{R} + \mathbf{R}_{se}$

Thermal transmittance U, unit W/m²K [kcal/m²hK], is the reciprocal of the overall resistance 1/U and the most important parameter for the calculation of thermal insulation.

Maximum values are prescribed for various cases.

Energetic values (design values) for individual building products (thermal conductivity λ, thermal resistance **R**) are required for the calculation of the U-values. → ❸ – ❹ show the calculation of thermal transmittance **U** through the example of an external wall with an external wall insulation system and also a pitched roof.

(This building element consists of a rafter component (15%) and an insulated area between the rafters (85%). Thermal resistance **R** in this case is composed of the average of the upper limit value **R'**T and the lower limit value **R"**T. For the determination of **R'**T, the rafter component and the insulation component are added according to area. For the determination of **R"**T, the individual thermal resistances and surface resistances are added.)

BS EN ISO 9229
BS EN ISO 13370
BS EN ISO 13790
DIN 4108
DIN EN ISO 6946
DIN EN 12524

EnEV 2007

Air temperature	Dew point temperature at a relative humidity of:										
	35%	40%	45%	50%	55%	**60%**	65%	70%	75%	80%	85%
30°C	12.9	14.9	16.8	18.4	20.0	21.4	22.7	23.9	25.1	26.2	27.2
25°C	8.5	10.5	12.2	13.9	15.3	16.7	18.0	19.1	20.3	21.3	22.3
24°C	7.6	9.6	11.3	12.9	14.4	15.8	17.0	18.2	19.3	20.3	21.3
23°C	6.7	8.7	10.4	12.0	13.5	14.8	16.1	17.2	18.3	19.4	20.3
22°C	5.9	7.8	9.5	11.1	12.5	13.9	15.1	16.3	17.4	18.4	19.4
21°C	5.0	6.9	8.6	10.2	11.6	12.9	14.2	15.3	16.4	17.4	18.4
20°C	4.1	6.0	7.7	9.3	10.7	**12.0**	13.2	14.3	15.4	16.4	17.4
19°C	3.2	5.1	6.8	8.3	9.8	11.1	12.3	13.4	14.5	15.5	16.4
18°C	2.3	4.2	5.9	7.4	8.8	10.1	11.3	12.5	13.5	14.5	15.4
17°C	1.4	3.3	5.0	6.5	7.9	9.2	10.4	11.5	12.5	13.5	14.5
16°C	0.5	2.4	4.1	5.6	7.0	8.2	9.4	10.5	11.6	12.6	13.5
15°C	−0.3	1.5	3.2	4.7	6.1	7.3	8.5	9.6	10.6	11.6	12.5

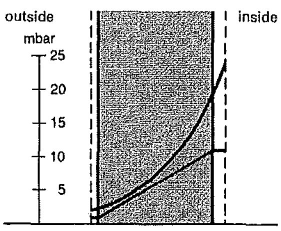
❶ Dew point temperatures of air, depending on air temperature and relative humidity

Temp. °C	Max. partial vapour pressure of air (kp/m^2)
−10	26.9
−5	40.9
±0	62.3
+5	88.9
+10	125.2
+15	173.9
+20	238.1
+25	323.0

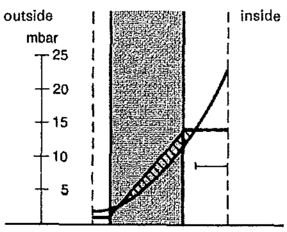
❷ Partial vapour pressure of air

Outside temperature (°C)	Relative humidity		
	50	60	70
−12	33.5%	25%	17.8%
−15	30.8%	23%	16.2%
−18	28.4%	21%	15.0%

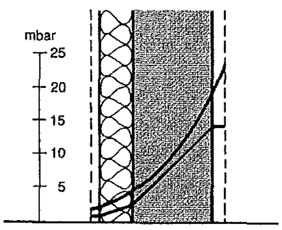
❸ Max. proportion of the surface air film or up to the vapour limit ('X')



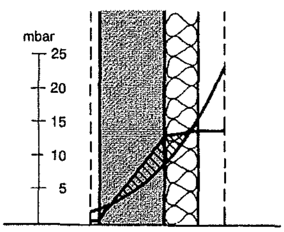
❹ Partial water vapour pressure remains under the maximum possible; no condensation



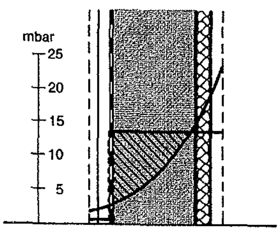
❺ Too great a proportion of surface air film due to too little insulation; condensation at and in building element; X = max. permissible proportion of the surface air film



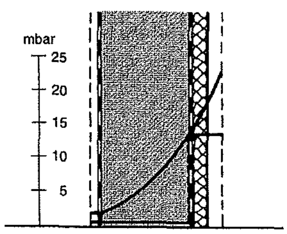
❻ The layer factor = gradient of the curve, falling to the outside: good



❼ Incorrect sequence of layers: the layer factor = gradient of the curve, uphill to the outside: condensation inside the building element



❽ Vapour barrier on cold side: condensation in building element



❾ Vapour barrier on warm side prevents formation of condensation

Water vapour diffusion

The air in a room, and also the air in general, contain water in the form of water vapour. The quantity of water in the air, depending on temperature, is called the **relative humidity**. It is important to note that warm air can absorb much more water vapour than cold air. The relative humidity can therefore fluctuate greatly according to the temperature conditions, although the absolute quantity of water remains constant. For the formation of condensation, an important factor is that **the relative air humidity increases with falling temperatures.** In extreme cases, this can be so pronounced that the air is no longer capable of holding the water in the form of vapour and it is then deposited as condensation.

The atmospheric air pressure is 1 bar or 1000 mbar (also called hecto-pascal). In a water vapour–air mixture, part of this pressure (called the **partial water vapour pressure** or partial vapour pressure) is created by water vapour. It is also advantageous to use this value to describe the water vapour content of the air (→ ❷) because this enables considerations about diffusion to be illustrated more clearly (0.6 mbar = 1 g water/kg air). Differences of partial vapour pressure are then only different contents of water vapour molecules at the same overall (air) pressure.
Different partial vapour pressures attempt to equalise through diffusion (by wandering through the building elements and their layers). The layers of the building element oppose this with their **diffusion resistance;** this gives the thickness of the air layer, which would have the same diffusion resistance as the building element; it is calculated as the product of the layer thickness **d** (cm, m) and the material-specific vapour resistivity **m.** Under diffusion, a partial vapour pressure gradient is set up inside the building element; as with the temperature distribution in the building element, this gradient is distributed among the individual layers of the building element according to their proportion of its overall diffusion resistance. The surface air film layers in this case can be neglected on account of their lack of thickness (outside 0.5, inside 2 cm). (Example: inside 20°/50% C = 11.7 mbar, outside −15°/18% = 1.3 mbar, difference 10.4 mbar. **Wall** (24 cm extruded clay block): m × d = 4.5 × 24 = 108 cm. **Internal plaster** (1.0 cm): m × d = 6 × 1.0 = 6 cm. 108 + 6 = 114 cm (100%) (108 cm = 94.7% = 9.8 mbar, 6 cm = 5.3% = 0.6 mbar)

❿ Calculation of partial vapour pressure

Diffusion examples

In order to avoid damage to buildings, condensation in building elements should be avoided.

Condensation occurs where the actual water vapour content threatens to become more than that possible for the temperature. In the examples → ❹ – ❾ the building element including its surface air films is shown to a scale according to its insulation; the curved line is the curve of the maximum possible partial vapour pressure, which is determined by the straight temperature curve.

The following are important to avoid damage:

Sufficient thermal insulation

Example → ❹ shows a single-layer building element without condensation.

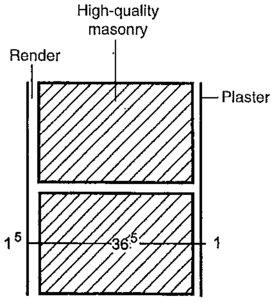
But in example → ❺ condensation is formed on the inner face of the building element, because the proportion of the surface air film is too large. The surface air film cannot exceed a certain proportion X of the overall resistance 1/U → ❸.

Correct sequence of layers

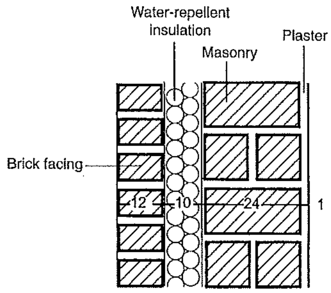
The gradient of the diffusion curve should be as steep as possible on the inside and flat on the outside → ❻; otherwise, condensation occurs → ❼. This gradient is given by the layer factor $\mu\lambda$: inside, high water vapour resistance factor, good thermal conductivity = high layer factor $\mu\lambda$: outside, low water vapour resistance factor, low thermal conductivity = low layer factor $\mu\lambda$.

Vapour barrier at the correct location

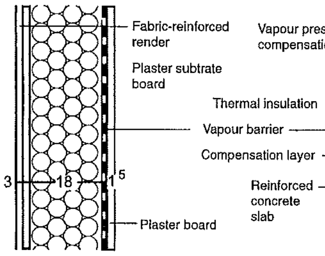
If there is a vapour barrier on the outside, then the entire vapour pressure gradient occurs there and the result is condensation → ❽; if this is to be avoided, then a vapour barrier must be installed on the warm side with an equivalent diffusion resistance suitable for the location, in which case the layers in front of the vapour barrier must not exceed a certain proportion of the overall thermal resistance **1/U** → ❾.



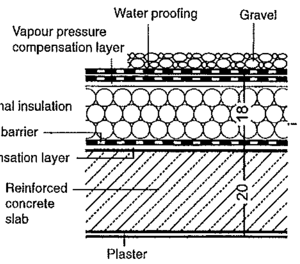
❶ Single-skin solid wall



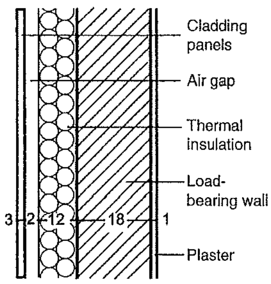
❷ Double-skin solid wall with cavity insulation



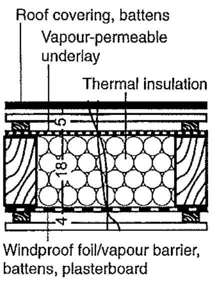
❸ Warm façade as prefabricated construction



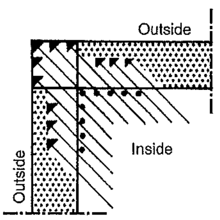
❹ Flat roof as warm roof construction → p. 92



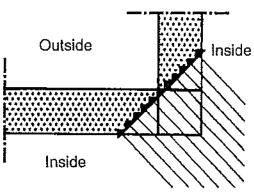
❺ Solid wall with rear-ventilated external skin



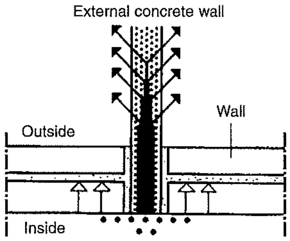
❻ Pitched roof as rear-ventilated construction (cold roof)



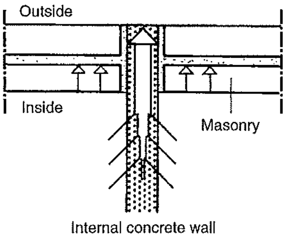
❼ Condensation forms at the internal surface of the external corner



❽ No condensation forms at the internal corner



❾ When the external surface area of the thermal bridge is large, condensation is formed (high heat loss per unit of area)



❿ When the internal surface area of the thermal bridge is large, the heat loss per unit area is considerably less

Construction without vapour barrier → ❶ – ❷

The traditional way of building does not use vapour-retarding barriers. The layers are arranged so that no condensation is formed → p. 472. In very damp rooms, the vapour pressure distribution should be checked by calculation. Multi-layered walls are constructed as two layers with cavity insulation or as an external wall insulation system.

On the external side of the insulating layers, there is a risk of cracking due to heat build-up and substrate with poor shear strength, so mineral render reinforced with mesh is used here (or plastic modified render).

Construction with vapour barrier → ❸ – ❹

More recent building ('warm roof', 'warm façade') features an external vapour barrier layer (e.g. waterproofing) and, on account of this, an additional **internal vapour barrier**. In order to prevent condensation on the inside face of the building element, the layers in front of the vapour barrier cannot exceed a certain proportion of the overall thermal resistance → p. 472. Warm façades require careful construction and have therefore mostly become established as prefabricated systems (sandwich construction). In a warm roof, a water vapour pressure equalisation layer is arranged under the waterproofing, and only an **equalisation layer for the damping of stresses** is provided under the vapour barrier.

Construction with rear-ventilated outer skin → ❺ – ❻

The rear ventilation of the skin removes the vapour barrier effect of the relatively vapour-sealed outer layers. The width of the air gap with panel-like external skin amounts to min. 20 mm, or for brickwork outer skin min. 40 mm.

Functional ventilation requires a height difference (minimum fall 10%) between air inlet and outlet.

If there is less fall, then a vapour-retarding/vapour barrier layer is required (arranged as → Construction with vapour barrier, above), because there would otherwise be condensation on the outer skin resulting from excessive vapour transmission. The layers of the inner skin are to be formed as with the construction without vapour barrier and with falling layer factor. The inner skin must nonetheless always be airtight.

Thermal bridge

Thermal bridges are parts of building elements with low thermal insulation compared with surrounding areas. This results in the proportion of the surface air film in the overall resistance increasing so that the surface temperature of the inner side of the thermal bridge sinks and condensation forms.

The **increased heating cost** due to the thermal bridge are often insignificant, as long as it is relatively small, but in order to avoid **condensation** on the inner surface of the building element, with unpleasant results like mould etc., the temperature of the inner surface of the thermal bridge must be improved (e.g. by reducing the cooling effect of the thermal bridge with an insulation layer against the 'external cold', increasing the heat transfer to the thermal bridge by increasing its surface area, high-conducting surroundings for the thermal bridge and/or blowing with warm air).

This means that thermal resistance $\mathbf{R_{si}}$ is reduced in relation to the thermal bridge and thus also the proportion of the surface air film in the overall resistance **1/U** → p. 471.

Typical examples of thermal bridges are shown in → ❾ – ❿. However, even a normal external corner in a building → ❼ forms a thermal bridge, because a smaller internal surface introduces heat opposite a larger external surface, which loses heat. In addition, the surface resistance of the surface air film in the corners is considerably higher than between the corners.

BS EN ISO 9229
BS EN ISO 13370
BS EN ISO 13790
DIN 1053
DIN 4108
DIN EN ISO 6946
DIN EN 12524

EnEV 20077

Energy Saving Regulation

The Energy Saving Regulation 2007 (**EnEV 2007**) replaces the formerly applicable energy saving regulations 2002/2004. The limit values for residential buildings have not been altered. For non-residential buildings, however, a new verification process is now required. In addition to thermal insulation regulations, subsidiary measures like, for example, those concerning condensing boilers, are required, as already in EnEV 2002/2004.

Under EnEV 2007, a new overall consideration of the energy required for heating, hot water, ventilation, cooling and lighting (only for non-residential buildings) is to be produced.

The energy consumption necessary to heat rooms will no longer be the regulated parameter, but the quantity of primary energy to be used for heating, hot water etc. under standard conditions.

Excerpts from the Energy Saving Regulation, using the example of a new residential building:

Normally heated houses are to be evaluated according to whether they adequately limit the annual primary energy demand and the transmitted heat requirement in accordance with the new EnEV 2007.

Depending on the ratio of **heat-transmitting area A to heated building volumes V_e (A/V_e ratio)**, the maximum permissible annual primary energy demand will be determined according to EnEV 2007, according to the **envelope area process.** The basis for this is the monthly balance procedure (DIN EN 832) with the conditions given in DIN 4108.

For the **thermal insulation design of stairwells,** a temperature of ≧15°C can be assumed in accordance with the design. This temperature may have to be ensured by the provision of radiators in the lower stairwell.

BS EN ISO 9229
BS EN ISO 13370
BS EN ISO 13790
DIN EN 832
DIN 4108
DIN EN 12524
DIN V 18599

EnEV 2007

Design values of building products

For the determination of U-values in the verification of thermal insulation, the **energetic characteristics** are required for each building product. These are called the **design values** of the thermal conductivity and the thermal resistance of the materials and components, and also the design values of the thermal transmittance coefficients of glazing, windows and French windows, including frames. The design values can be taken from the tables in DIN EN 12524.

Some important building products, like thermal insulation and masonry components, are, however, not included in this standard. For these items, the design values are to be determined from the **nominal value** in DIN V 4108-4 or from **type approvals** under building regulations or other guidelines.

The nominal value for a product is multiplied by conversion values for temperature, moisture and ageing to give the design values. The nominal values for the thermal conductivity of thermal insulation materials are also to be subjected to a partial safety factor of $\gamma = 1.2$, which has been laid down by the responsible standards committee. According to harmonised European standards, this should apply to all insulation materials, which carry a CE mark. DIN V 4108-4 deals, in tabular form, with the conversion into the design value for all common building products.

In a similar way, the above two standards are to be used for the determination of the required energetic characteristics for the calculation of thermal insulation according to EnEV 2007.

Heating system and drinking water heating

The heating system and drinking water heating are to be constructed in accordance with the requirements of EnEV 2007.

Sun protection

According to EnEV 2007, protection from summer heat is to be verified independent of the proportion of the building's surface taken by the window area following DIN 4102-2. This states that summer heat protection depends on the **climatic region** and **sun input factor S** of the transparent external building elements.

The verification of thermal protection in summer depends on the following factors, among others: Overall degree of energy transmission of the glazing, window inclination and orientation, frame as proportion of the windows, effectiveness of the sun protection apparatus, proportion of window area in the façade (related to rooms), climatic region (building location), light or heavy construction (effective thermal capacity). These factors are collected into a maximum permissible sun input factor S_{max}, which may not be exceeded by the room-related sun input factor S.

Wind and airtightness

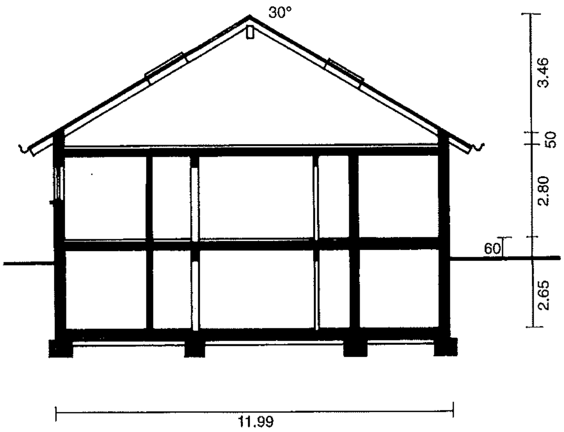
EnEV 2007 states that new buildings are to be constructed so that the heat-transmitting surface envelope, including joints, is sealed **permanently airtight** in accord with the state of the technology.

This means that air infiltration at the joints of the external windows, French windows and roof windows must be compliant. As part of the EnEV 2007 stipulations, when using **mechanical ventilation systems** the inclusion in calculations of **heat recovery** or a controlled **reduced rate of air changes** is permissible only if the airtightness of the building is verified. Ventilation systems must also be equipped with means for the user to influence the airflow volume per unit of use. It must be ensured that the heat recovered from the extract air is used before the heat provided by the heating system. In closed condition, there must be compliance with EnEV requirements. A test of airtightness (blower door test) can be taken into account in the calculation of the annual primary energy demand for the verification of thermal insulation.

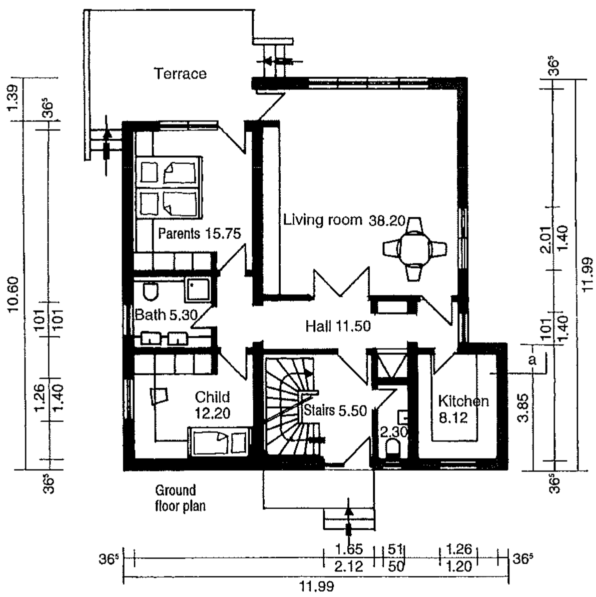
Thermal bridges

Good thermal insulation includes not only highly insulated building components, but also the appropriate connections between the building elements. There is a danger of additional heat loss at these joints and low surface temperature in the building elements during the heating period. **Additional consumption of energy** for heating and the possibility of condensation and mould formation are the result. Thus it should be borne in mind that this thermal bridging effect can have considerably worse consequences with highly insulated elements than with building elements with less thermal insulation. Thermal bridges can be considered, according to EnEV, for the determination of the annual heating energy demand by increasing the thermal transmission values (U-values) or in a separate verification.

heated volume	Va:	**535.86 m³**						
usable building area	AN = 0.32*Va:	**171 m²**						
Building element	**Description**	**Area**	**Thermal transmittance U**	**Temperature correction factor**			**Heat loss**	**Unit**
		m²			FX			
external wall		147.35	0.24		1.00		35.364	W/K
dormer wall	east/west	0.00	0.17		1.00		0.000	W/K
windows	north	9.41	0.80		1.00		7.528	W/K
	east/west	7.01	0.80		1.00		5.608	W/K
	south	8.50	0.80		1.00		6.800	W/K
	roof	3.28	0.80		1.00		2.624	W/K
front door	north	3.50	1.40		1.00		4.900	W/K
roof pitch	to outside air	159.78	0.13		1.00		20.771	W/K
floors	to insulated roof space	0.00	0.19		0.50		0.000	W/K
floor slab	to ground	154.95	0.19		0.50		14.720	W/K
	sum :	**493.78**		**sum A*U*F**			98.316	W/K
thermal bridge supplement				H_{WB}				W/K
transmission heat loss H_T				sum A*U*F+H_{WB}			98.316	W/K
air volume V	building up to 3 full storeys			0.76 V_e			407.253	m³
	building over 3 full storeys			0.80*V_e				m³
ventilation heat loss Hv		airtightness $n_{50} > 3.0\ h^{-1}$		0.70*0.34*V_e				W/K
		airtightness $n_{50} < 3.0\ h^{-1}$		0.60*0.34*V_e			109.314	W/K
envelope area factor				A/V_e			0.922	m^{-1}
solar heat gain of transparent building elements	element	area	overall degree of energy transmittance g	F_F	F_S	F_C	specific gain A*g*0.9*F_F*F_S*F_C	
	windows north	9.41	0.53	0.70	0.90	1.00	2.83	
	windows east/west	7.01	0.53	0.70	0.90	1.00	2.11	
	windows south	8.50	0.53	0.70	0.90	1.00	2.55	
	front door	3.50	0.80	0.70	0.90	1.00	1.59	
solar gain of opaque building elements			degree of absorption a	form factor F_t				
	external walls		0.50	0.50				
	roof pitch		0.80	1.00				
internal heat gain specific thermal mass Cwirk*Ve	surface-specific solid construction			5 W/m² 50 Wh/m³K*V_e			855.00 26793.00	W Wh
	light construction			15 Wh/m³K*V_e				
annual heating energy demand	absolute			Qh = Q_t+Q_v−Q_g			5597.00	kWh/a
	specific			Q'$_h$			33.11	kWh/m²a
plant input number eP				e_P			1.29	
primary energy demand Q'P		existing	Q_P exstg. = ep*(Q"h + 12.5)				58.94	kWh/m²a
		permissible	Q"p perm. = 50.94 + 75.29*A/V_e + 2600/(100 + AN)				116.52	kWh/m²a
specific transmission heat loss related to envelope area H'T		existing	H/T exstg. = HT/A				0.24	W/m²K
		permissible	H'T perm. = 0.3 + 0.15/(A/V_e)				0.77	W/m²K
final energy demand		heating	gas/oil/electricity	q WE,E			51.80	kWh/m²a
		operating energy	electricity	q HE,E			2.30	kWh/m²a



Cross-section a-a



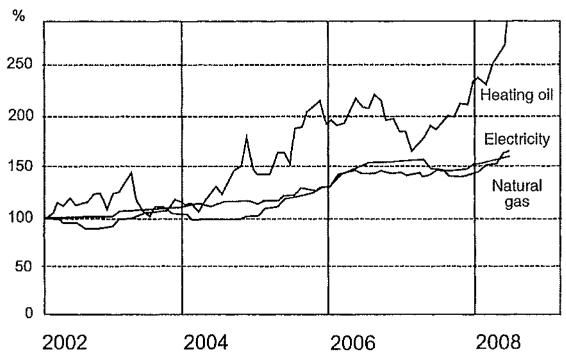
❶ Calculation example: determination of the annual primary energy demand of a property, EnEV 2007

BUILDING PHYSICS
Thermal insulation
Sound insulation
Room acoustics
Lightning protection

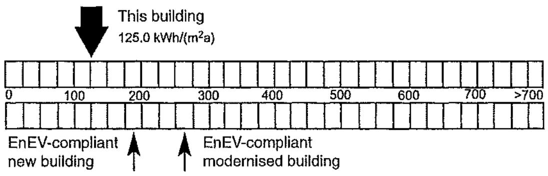
BS EN ISO 9229
BS EN ISO 13370
BS EN ISO 13790
DIN EN 832
DIN 4108
DIN EN 12524
DIN V 18599

EnEV 2007

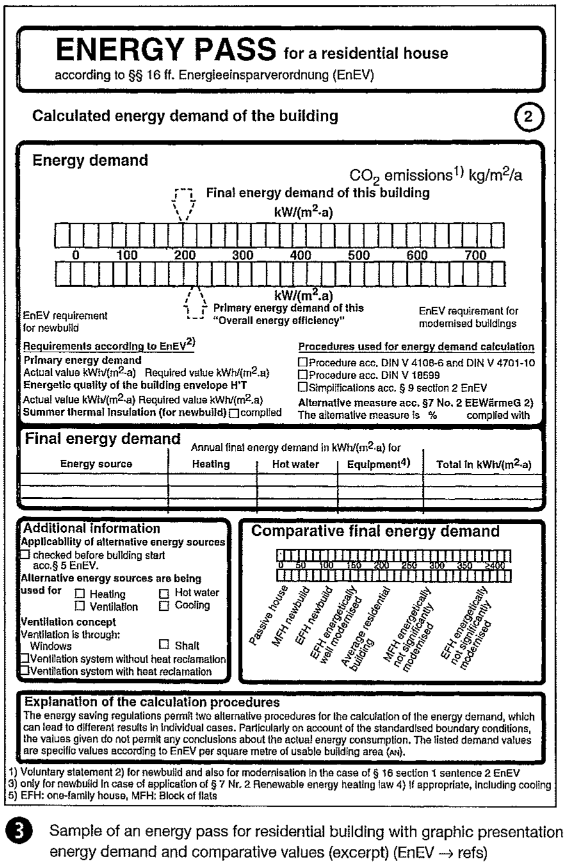
Building services



❶ Average development of producer energy prices (Federal Statistics Office → refs)



❷ Graphic comparison of annual energy demand of building with average similar building (example)



ENERGY PASS for a residential house

according to §§ 16 ff. Energieeinsparverordnung (EnEV)

Calculated energy demand of the building ②

Energy demand

CO_2 emissions1) $kg/m^2/a$

Final energy demand of this building

$kW/(m^2 \cdot a)$

0 100 200 300 400 500 600 700

$kW/(m^2.a)$

EnEV requirement for newbuild

Primary energy demand of this "Overall energy efficiency"

EnEV requirement for modernised buildings

Requirements according to EnEV2)

Primary energy demand

Actual value $kWh/(m^2 \cdot a)$ Required value $kWh/(m^2.a)$

Energetic quality of the building envelope H'T

Actual value $kWh/(m^2 \cdot a)$ Required value $kWh/(m^2.a)$

Summer thermal insulation (for newbuild) ☐ complied

Procedures used for energy demand calculation

☐ Procedure acc. DIN V 4108-6 and DIN V 4701-10

☐ Procedure acc. DIN V 18599

☐ Simplifications acc. § 9 section 2 EnEV

Alternative measure acc. §7 No. 2 EEWärmeG 2)

The alternative measure is % complied with

Final energy demand

Energy source	Heating	Hot water	Equipment4)	Total in $kWh/(m^2 \cdot a)$
	Annual final energy demand in $kWh/(m^2 \cdot a)$ for			

Additional information

Applicability of alternative energy sources

☐ checked before building start acc.§ 5 EnEV.

Alternative energy sources are being used for ☐ Heating ☐ Hot water ☐ Ventilation ☐ Cooling

Ventilation concept

Ventilation is through:

Windows ☐ Shaft

☐ Ventilation system without heat reclamation

☐ Ventilation system with heat reclamation

Comparative final energy demand

0 50 100 150 200 250 300 350 ≥400

Passive house
MFH newbuild
EFH newbuild
EFH energetically well modernised
Average residential building
MFH energetically not significantly modernised
EFH energetically not significantly modernised

Explanation of the calculation procedures

The energy saving regulations permit two alternative procedures for the calculation of the energy demand, which can lead to different results in individual cases. Particularly on account of the standardised boundary conditions, the values given do not permit any conclusions about the actual energy consumption. The listed demand values are specific values according to EnEV per square metre of usable building area (A_N).

1) Voluntary statement 2) for newbuild and also for modernisation in the case of § 16 section 1 sentence 2 EnEV
3) only for newbuild in case of application of § 7 Nr. 2 Renewable energy heating law 4) If appropriate, including cooling
5) EFH: one-family house, MFH: Block of flats

❸ Sample of an energy pass for residential building with graphic presentation of energy demand and comparative values (excerpt) (EnEV → refs)

Energy pass

According to the Energy Saving Regulation (**EnEV**), an energy pass must be issued within a specified period (and with certain limitations), for new buildings and for structural alterations, in connection with which energetic calculations are carried out for the entire building. Normally this also applies to existing buildings that are for sale or a new let (there are exceptions, e.g. listed buildings!).

The energy pass documents the energy demand or consumption of a building and, with a graphic evaluation (see → ❷), provides a simple comparison with an average similar building

The procedure for the determination of the energy figures in the energy pass is laid down by EnEV : **energy demand** is presented as annual primary energy demand and final energy demand, and **energy consumption** as the energy consumption value.

Primary energy demand shows the overall energy efficiency of the building. It also takes into account, besides the final energy, the supply chain (e.g. investigation, extraction, distribution, conversion) of the energy source being exploited. Low values point to a low demand and thus to high energy efficiency and energy use which is light on resources and the environment.

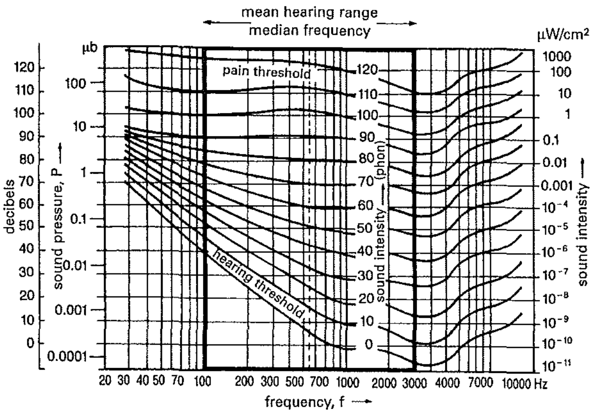
Final energy demand is the annual energy requirement for heating, ventilation and hot water (in non-residential buildings also for cooling and lighting) according to the technical rules and is a measure of the energy efficiency of the building and its facilities' technology. Low values signal a low demand and thus high energy efficiency.

These figures are calculated on the basis of construction and other building-related documents and assume standardised conditions (e.g. climatic data, user behaviour, indoor temperature). In this way, the energetic quality of a building should be documented independent of the user behaviour and weather situation, but the calculated values permit no forecast of the actual energy consumption on account of the standardised conditions.

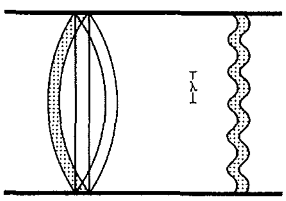
The **energy consumption value** is determined for the building based on the heating and hot water cost invoicing. Climatic factors are applied to the recorded energy consumption for heating to convert this to an average value for Germany. The energy consumption value does give an indication of the energetic quality of the building and its heating system, but there can be clear deviations on account of the differing heating and ventilation behaviours of the users.

EnEV 2007 contains in its annexes samples of energy passes for residential and non-residential buildings → ❸. Energy passes also have to be displayed for public buildings > 1000 m^2. They are issued by qualified neutral building experts and are valid for 10 years.

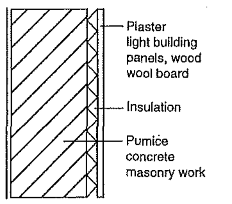
If measures are possible for the sensible improvement of a building's energetic properties, these are appended to the energy pass as a modernisation recommendation. The energy pass brings advantages when marketing a building, offers a spur to investment and provides additional certainty for decisions about buying or renting.



❶ Relationship between sound intensity (phon), sound pressure (µb), sound level (dB) and sound intensity (µW/cm²)



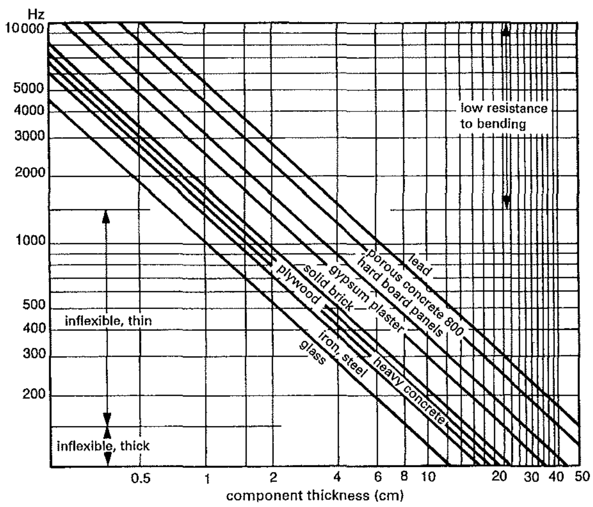
❷ Illustration of a bending wave on a wall at normal frequencies: the wall (left) does not vibrate as a whole, but (right) its parts vibrate against each other



❸ Improvement in sound insulation up to +7 dB with free-standing soft cladding and cavity filling

0–10	start of hearing perception
20	light rustling of leaves
30	lower limit of everyday residential noise
40	medium residential noise, quiet conversation, quiet residential street
50	normal conversation, radio music at room volume in closed rooms, city noise without individual noises
60	noise from a relatively quiet vacuum cleaner, normal street noise in commercial streets
70	single typewriter, telephone ringing at 1 m distance
80	street with heavy traffic, typing pool
90	loud factory interior
100	car horn at 7 m distance, motorcycle
100–130	very noisy industrial works (metalworking etc.)

❹ Scale of sound intensities, values in dB(A)



❺ Boundary frequency for panels of various materials

Sound

Sound propagates as mechanical vibrations and pressure waves, which cause very small increases or reductions of pressure, measurable in microbars (µb), compared to atmospheric pressure (= 1.0333 kg/cm²). For example, the pressure variation when speaking with a raised voice is about a millionth of an atmosphere.

Audible sound vibrations lie in a frequency range of **20–20000 Hz (hertz);** 1 Hz = 1 vibration/second (for **sound insulation in building,** the range between **100 and 3200 Hz** is of significance, as this is where the human ear is particularly sensitive). Sound pressures within the range of human hearing vary from the audibility threshold to the pain threshold → ❶. This range is divided into 12 parts = **12 B (bel)** (named after Alexander Graham Bell, inventor of the telephone). As 1/10 bel = **1 decibel (dB)** is just audible to the human ear as a pressure difference at the standard frequency of 1000 Hz, decibels are used as the physical measure of sound intensity related to an area unit → ❶. Sound levels are normally given in dB (A) or, above 60 dB, in dB (B), a measure roughly equivalent to the former phon.

Sound reduction

Sound reduction denotes all measures undertaken to reduce sound transmission from the source to the hearer; it is not possible to entirely prevent transmission. If the sound source and the hearer are in one room, this is done by sound absorption; if they are in different rooms, it is mainly achieved with **sound insulation.** Sound reduction measures are differentiated according to the source of the noise into **airborne sound** (if the sound source agitates the surrounding air), **structure-borne sound** (when the sound source agitates a building element) and **impact sound** (structure-borne sound typically caused by footsteps on a floor or stairs).

The measurement of airborne sound is normally given as the weighted sound reduction R'_w, i.e. the difference in sound level between the room containing the source (loud room) and the receiving room (quiet room), taking into account bypass transmission through flanking building elements. For impact sound, the analogous parameter to be determined is the weighted impact sound level $L'_{n,w}$.

The sound is transmitted through air as a longitudinal wave and in solid materials as a bending wave → ❷. The transmission speed of a longitudinal wave is 340 m/s, that of a bending wave varies according to material, layer thickness and frequency.

The **boundary frequency** is that at which the transmission speed of the bending wave in a building element is also 340 m/s; at this frequency, the transfer of sound out of the air into the building element and vice versa is particularly good and thus the sound insulation of the element particularly bad, worse than would be expected for the wall density. For heavy elements, which bend stiffly, the boundary frequency is above, and for thin, soft materials is below, the relevant frequency range → ❺.

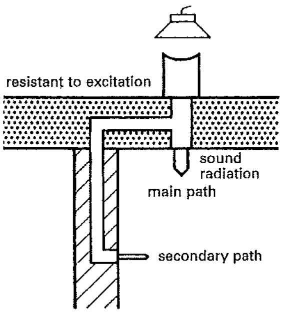
Generally **sound insulation is produced by mass**, and works better with heavy, thick building elements where the sound energy first has to transfer from air into the element, then excites the mass of the element and then repeatedly transfers from the material into the air, which all cause a reduction in sound. If, however, the building element is directly excited (impact sound), then the insulation is naturally less effective.

Sound-insulating lightweight construction in the form of cladding layers, which bend flexibly, and with the cavity filled to prevent the internal reflection of the sound, makes use of the repeated transfers air–element–air–element → ❸.

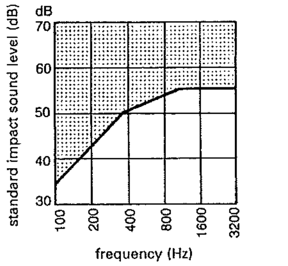
BUILDING PHYSICS
Thermal insulation
Sound insulation
Room acoustics
Lightning protection

BS 8233
BS EN ISO 717
DIN 4109

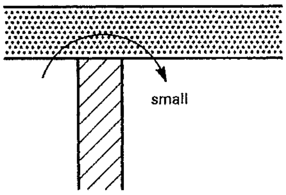
Building services



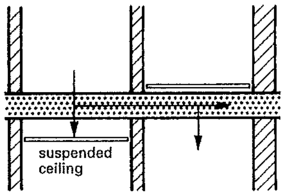
❶ Airborne sound transmission



❷ Standard curve for airborne sound



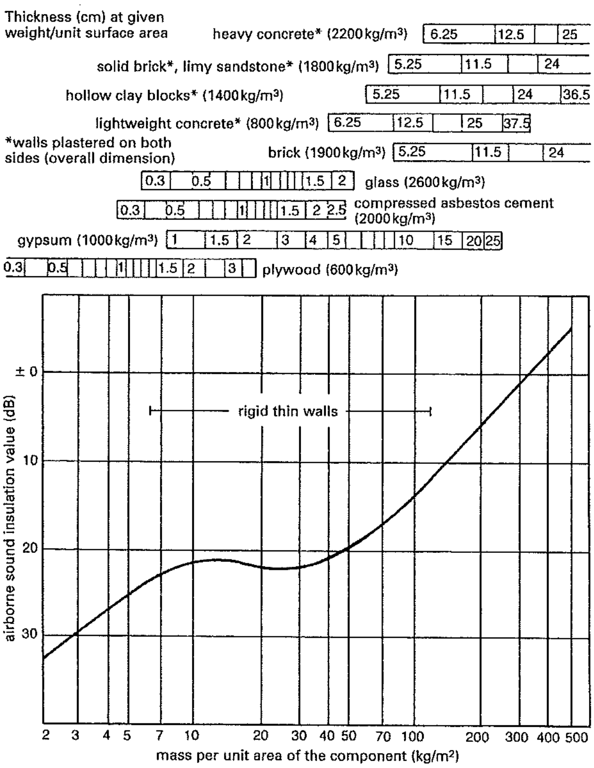
❸ Secondary path for sound through adjacent single-layer building element



❹ Diagonal transmission

1	simple door with threshold, without special sealing	up to 20 dB
2	heavy door, with threshold and good sealing	up to 30 dB
3	double doors with threshold, without special sealing, opening individually	up to 40 dB
4	heavy double doors, with threshold and good sealing	up to 50 dB
5	door with sound insulation	up to 15 dB
6	simple window, without additional sealing	up to 25 dB
7	simple window, with good sealing	up to 25 dB
8	double window, without special sealing	up to 30 dB
9	double window, with good sealing	up to 32 dB
10	double glazing 4/12–16/4 mm	up to 32 dB

❺ Sound insulation of doors and windows



❻ Airborne sound insulation, weight per area and component thickness (Gösele)

With **airborne sound,** the sound wave excites the building element → ❶, so the influence of the boundary frequency on the sound insulation increases → ❻. DIN 4109 lays down values for the sound insulation required to prevent sound transmission from neighbouring homes or workplaces (weighted building sound reduction including 'secondary path' transmission R'_w) → ❼.

Secondary path transmission reduces the effectiveness of airborne sound insulation more than that of impact sound insulation. For this reason, test certificates for sound-insulated walls should always include the consideration of secondary paths normal in a building. Particularly effective as secondary paths are panels which bend stiffly and have a density of 10–160 kg/m²; for this reason, party walls between flats or houses should always weigh at least 400 kg/m².

Doors and windows with their low sound insulation values → ❺ have a particularly negative influence on airborne sound insulation. Even if their proportion of the wall area is small, the resulting sound insulation value is mostly less than the arithmetic mean of insulation values of wall and opening, which makes the sound insulation of the door or window always the first priority.

Walls with insufficient sound insulation can be improved with an insulating layer → p. 477 ❸. These have particularly good sound insulation if they bend flexibly and are supported by soft springy insulation (cavity filling).

Soft, flexible cladding layers are relatively insensitive to small sound bridges (in contrast to hard cladding layers).

Only type-tested construction systems should be used for sound insulation cladding.

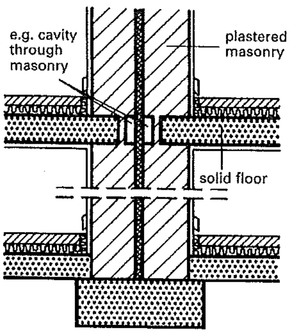
Layers of plaster on insulating materials of normal hardness (e.g. on normal Styrofoam) reduce the sound insulation considerably.

Building element	Airborne sound insulation R'_w [dB]	Impact sound insulation $L'_{n,w}$ [dB]
Multi-storey buildings with residential and working areas		
residential units, party walls	53	
walls between common hallways and stairwells	52	
floor slabs and stairs separating residential units	54	53
floor slabs over cellars, common hallways and stair spaces	52	53
stair flights and landings		58
doors from stairwells into flat corridors	27	
Schools and educational institutions		
walls between classrooms and stairwells	47	
floor slabs between classrooms	55	53
doors from classrooms into corridors	53	
Accommodation, hospitals, sanatoriums		
walls of bedrooms, patient rooms and examination rooms	47	
floor slabs in general	54	53
stair flights and landings		58
doors to examination and consulting rooms	37	

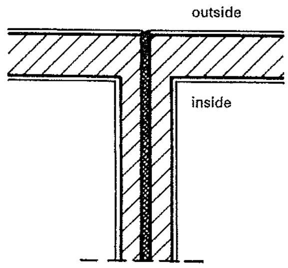
The values given for the **sound insulation** of the partitioning elements count as the **resulting insulation** of all building materials involved in sound transmission and of secondary paths in the installed condition.

The values for doors apply solely to transmission through the door.

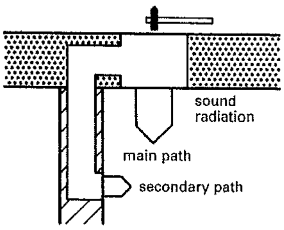
❼ Protection of occupied rooms against sound transmission from neighbouring residential and working areas (minimum requirements, excerpt → refs)



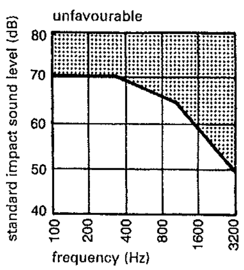
❶ Two-skin party wall with continuous cavity, section



❷ Plan → ❶



❸ Structure-borne sound transmission



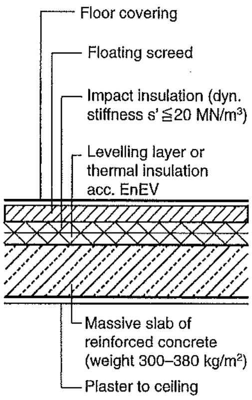
❹ Standard curve for impact sound

Party walls

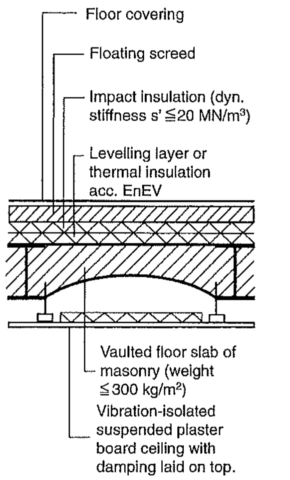
The diagram → ❶ shows a two-skin party wall with a separating joint over the entire depth of the houses. The **mass per unit area** of the individual layers with plaster must be **at least 150 kg/m²**, and the thickness of the separating joint must be at least **30 mm**. With a thickness of the separating joint (layer spacing) of more than 50 mm, the mass of each skin can be 100 kg/m². The **joint cavity** is to be filled with gapless full-surface fibre insulating boards, as in DIN 18165 (impact sound insulation boards or separating joint boards approved for this application) without sound bridges.

If the **skins** are constructed of **in situ concrete,** mineral fibre insulating boards with particular suitability for the high loadings during concreting are to be used. If the single skins have a weight per unit area of **more than 200 kg/m²** and the separating joint has a thickness of **more than 30 mm,** no insulation boards have to be installed as long as suitable construction measures are taken to avoid sound bridges (e.g. through timber guides removed after the wall has been built).

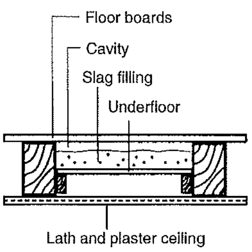
For cavity walls, the **weighted sound reduction $R'_{w,R}$** can be determined from the sum of the weights per unit area of the single skins. The continuous separating joint without sound bridges can then be assumed to be 12 dB better for the two-skin wall construction.



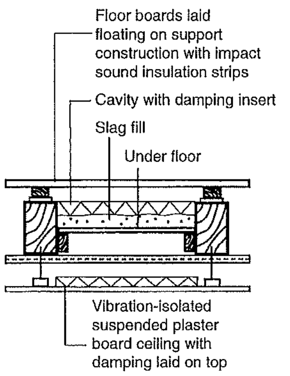
❺ Solid slab with floating screed (R'_w 55–57 dB, $L'_{n,w}$ approx. 50 dB) → p. 478 ❼



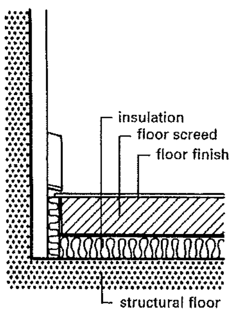
❻ Vaulted floor with improved sound insulation (R'_w approx. 58 dB, $L'_{n,w}$ approx. 47 dB) → p. 478 ❼



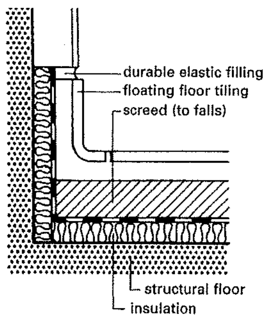
❼ Conventional timber joist floor in existing building (R'_w approx. 45 dB, $L'_{n,w}$ approx. 66 dB) → p. 478 ❼



❽ Timber joist floor with improved sound insulation (R'_w approx. 54 dB, $L'_{n,w}$ approx. 50 dB) → p. 478 ❼



❾ Edge always constructed to permit free movement



❿ Edge sealed with permanently elastic jointing materials

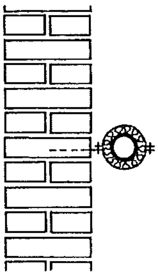
Impact sound insulation

Impact sound is caused by the floor slab being directly excited to vibration. The standard curve → ❹ gives a **standard level of impact sound**, i.e. the maximum level that can be heard in the room below, when a standardised 'stamper' is at work above. The values immediately after completion must be 3 dB, better to allow for the effect of ageing. The normal form of impact sound insulation is a **floating screed** consisting of a gapless soft springy **insulation layer** covered with a **protecting layer**. The actual screed layer can be of cement screed, anhydrite or poured asphalt (thickness laid down in DIN 4109). The floating screed also provides the required protection against airborne sound and is permissible for all types of floor slab (slab groups I and II). The **edge** is always to be constructed to permit free movement → ❾ and can only be sealed with permanently elastic jointing materials → ❿, because the screed layer is prone to bending and is therefore extremely susceptible to sound bridging. When slabs are used which provide adequate insulation against airborne sound (slab groups I and II), the sound insulation can be provided by a soft springy floor covering. Slabs in slab class I can become class II through a suspended soft ceiling. The measurement unit of the improvement of impact sound insulation through floating screed or soft springy floor covering is called the impact sound reduction (dB).

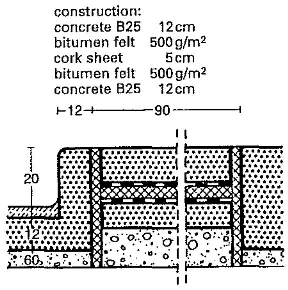
BUILDING PHYSICS
Thermal insulation
Sound insulation
Room acoustics
Lightning protection

BS 8233
BS EN ISO 717
DIN 4109
DIN 18165

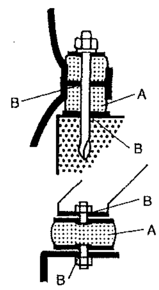
Building services

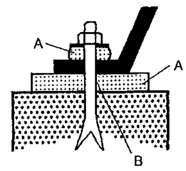


❶ Sound-insulated pipe clip



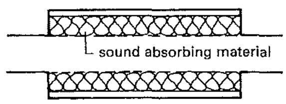
❷ Sound-insulated boiler foundation 90 cm wide



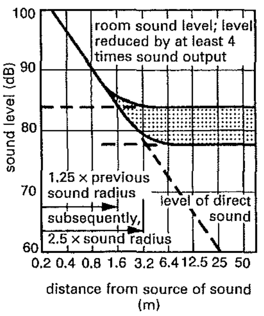


A = sound insulating material, e.g. rubber
B = air space – if necessary, filled with sound insulating material

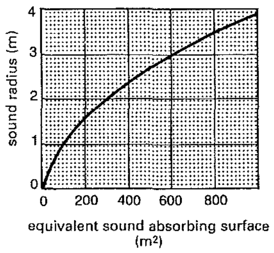
❸ Metal/rubber element



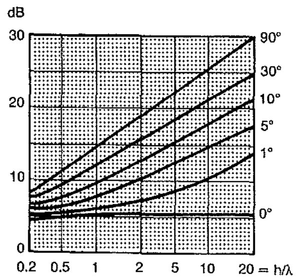
❹ Ventilation duct fitted with sound-absorbing material (silencer)



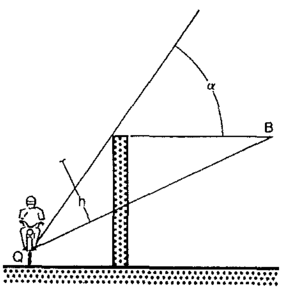
❺ Sound absorption measures can reduce the level of reflected sound; this makes the echo radius larger, and at the same time the sound level within the previous echo radius drops



❻ Echo radius and sound absorbing capacity of a room



❼ Sound reduction effect of open-air obstructions (A.I. King); the y axis shows the sound reduction according to angle a → ❽; example: a = 30°, h = 2.50 m: at 500 Hz (medium range frequency) wavelength λ = 340/500 = 0.68 h/λ = 2.5/0.68 = 3.68, sound reduction = 17 dB



❽ Diagram showing dimensions → ❼
Q = sound source
B = hearer

BUILDING PHYSICS
Thermal insulation
Sound insulation
Room acoustics
Lightning protection

BS 8233
BS EN ISO 717
DIN 4109

Building services

Sound from services

Sound from services can occur as **plumbing fixture sound, pipework sound** or **filling/emptying sounds**. The **maximum permissible sound level** from services in neighbouring residential units is 35 dB (A). Noisy elements of services (water pipes, waste pipes, gas riser pipes, waste disposal units, lifts) may not be installed in the walls of rooms where quiet is required (living rooms, bedrooms).

Plumbing fixture sounds can be reduced through the specification of sound-insulated valves with test certificate. Test group I with ≦20 dB (A) fixture sound level is approved for anywhere; test group II with ≦30 dB (A) fixture sound level is approved only for internal house walls and for walls adjoining services rooms. Installing sound dampers can achieve additional improvement in all fixtures. **Pipework sounds** are caused by the formation of vortices in the pipework. Remediation is possible through the specification of bends instead of sharp angles, adequate dimensioning and sound-insulated fixtures → ❶.

Filling sounds are caused by water pouring into bathtubs etc.; improvement is possible by muffling the objects, fitting aerators on the taps or sound-insulating the feet of the bath (in which case the edge has to be permanently elastically sealed). **Emptying sounds** (gurgling) can be prevented by proper sizing and ventilation of drainpipes. **Heating boilers** can be sound-insulated by supporting them on insulated supports (isolated foundation → ❷), sound-absorbing boiler base, sound-dampening hood for the burner, connection to the chimney with sound-insulated leading-in tube and to the heating circuit with rubber compensators.

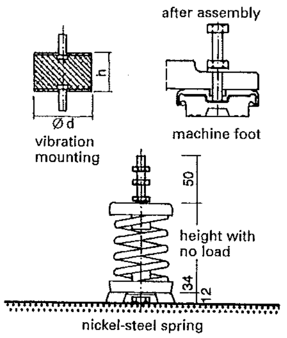
Sound transmission in **air ducts, ventilation and air conditioning systems** can be reduced by the fitting of silencers. These consist of sound-absorbing packing, between which the air flows → ❹. The thicker the packing, the deeper the frequencies which are absorbed. Ventilation ducts should also be sound-insulated → ❹.

Sound absorption

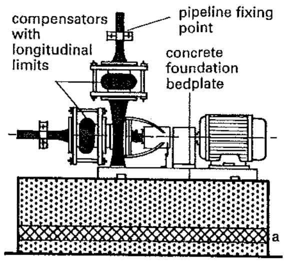
Sound absorption, in contrast to sound insulation, does not normally reduce the transmission of sound through a building component. Neither does it influence the sound, which reaches the ear directly from the source; it **only reduces the reflected sound**. Because the direct sound reduces with distance from the source, the reflected sound is just as loud or louder than the direct sound outside an 'echo' radius around the sound source → ❺. If sound reflection is reduced, then the level of reflected sound sinks outside the previous echo radius. The sound absorption capacity of a room is given in m^2 of equivalent sound absorption area, the ideal sound-absorbing area, which would have the same absorption capacity as the room itself. (For a reverberation time of 1.5 s, the equivalent sound-absorbing area (A) would have to be 0.1 m^2 per m^3 of room volume (V); for half the reverberation time, it would be twice the size.)

Protection from external noise

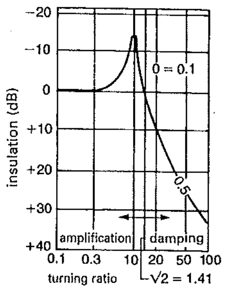
The best protection against noise from outside (traffic noise, etc.): appropriate design of the building – occupied rooms positioned on the side away from the noise; sound-insulated construction of the external walls; above all, sound-insulated doors and windows; installation of sound-insulating blinds on the façade side; and sound protection through landscaping (embankments, walls, planting). The sound reduction effect of these measures can be read from → ❼ for various wavelengths (wavelength approx. 340 m/frequency).



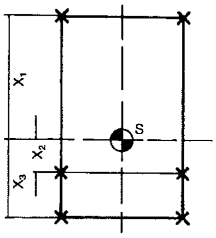
❶ Examples of single-spring elements



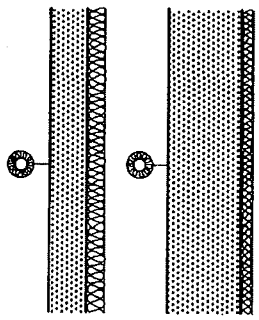
❷ Installing equipment with elastic insert in foundation



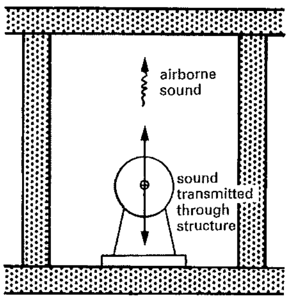
❸ Effect of elastic bearing



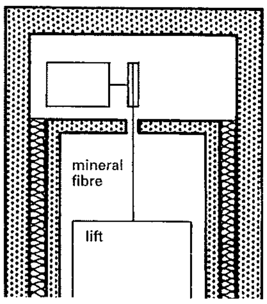
❹ Adaptation of springs to the centre of gravity



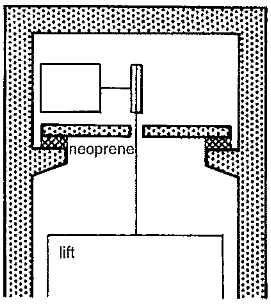
❺ Light wall = great excitation
Heavy wall = little excitation



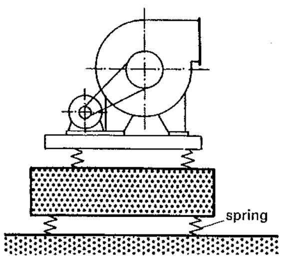
❻ Excitation of structure-borne sound



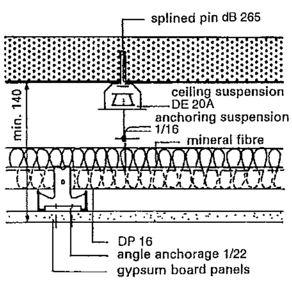
❼ Separate lift shaft with ≧3 cm mineral fibre lining



❽ Top of shaft with neoprene support



❾ Double elastic suspension for ventilator



❿ Example of rubber-bonded metal ceiling element

Structure-borne sound
Vibrations in solid bodies are described as structure-borne sound. This is produced either by airborne sound or by direct mechanical excitation → ❻.

Because the alternating mechanical forces are mostly higher than those caused by pressure fluctuations in the air, the audible result of direct excitation is also normally louder. Resonance phenomena often occur, which can lead to louder audible radiation in narrow frequency ranges.

If the radiated airborne sound is monotonic, then the cause is usually direct structural excitation. Protection from structure-borne sound therefore has to aim at stopping the direct excitation or its propagation.

Precautions against structure-borne sound transmission
In **water installations,** only fixtures of testing mark groups I or II should be used; the water pressure should be as low as possible. The water velocity is of less significance.

Baths and shower trays should be supported on floating screed and separated from the wall. They should be installed with joints to the wall. Wall-hanging **WCs** cause direct structural sound excitation, but a rigid fixing is unavoidable. Elastic layers could perhaps be introduced.

Water and drain pipes must be fixed with elastic materials and should have no contact with the building structure. Pipework is to be fixed in accordance with DIN 4109 to walls with surface loading >250 kg/m^2 → ❺.

Lifts should be installed in separate shafts (joints filled with >3 cm mineral fibre) → ❼; otherwise, the top of the shaft should be elastically supported → ❽.

Pumps and equipment must be supported on structure-borne, sound-insulated foundations and elastically connected. Expansion compensators require stress relievers because the internal pressure also acts along the longitudinal axis of the pipe → ❶.

Rubber granulate panels are particularly suitable for insulating foundations because of their high compression strength. Impact sound insulation of mineral fibre or polystyrene foam could also be used in some cases. Cork and solid rubber are unsuitable because they are too stiff. The more the insulation compresses under loading without being overloaded, the better is the effect.

For flat insulation layers, the loading should normally be >0.5 N/mm^2. If this cannot be ensured, then single elements, designed to add to the weight of the equipment, should be used. The insulation effect is also best in this case if the elements are subjected to maximum loading without being overloaded. These single elements can be made of neoprene or steel.

Steel springs have low stiffness, which leads to the best structure-borne sound insulation → ❶. For some special cases, **air springs** are used. The individual springs should be correctly located in relation to the centre of gravity so they are evenly loaded → ❹.

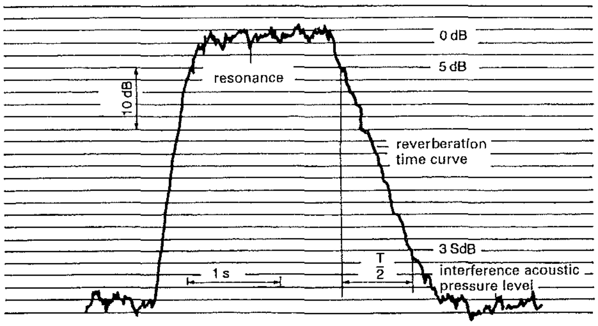
If the excitation is periodic, e.g. vibrating or rotating masses, the excitation frequency must not coincide with the natural frequency of the elastically mounted system. Any resonance could cause large displacements, which could break elements with low damping → ❸.

Particularly good sound insulation is achieved by using double elastic suspension → ❾. Unfavourable interaction, e.g. foundations on floating screed, can lead to a worsening of the situation.

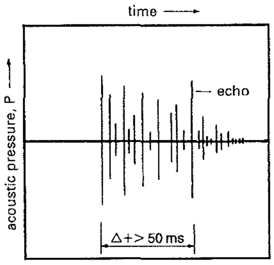
BUILDING PHYSICS
Thermal insulation
Sound insulation
Room acoustics
Lightning protection

BS 8233
BS EN ISO 717
DIN 4109

Building services



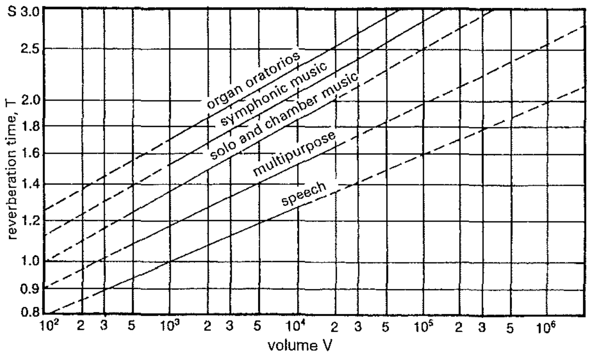
❶ Measurement of reverberation time



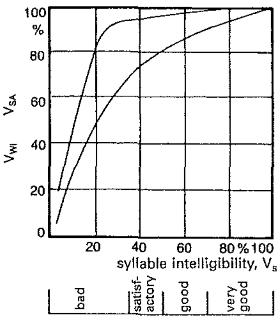
❷ Echo criteria

room function		reverberation time (s)
speech:	cabaret	0.8
	plays lectures	1.0
music:	chamber music	1.0–1.5
	opera	1.3–1.6
	concert	1.7–2.1
	organ music	2.5–3.0

❸ Range of optimal reverberation times



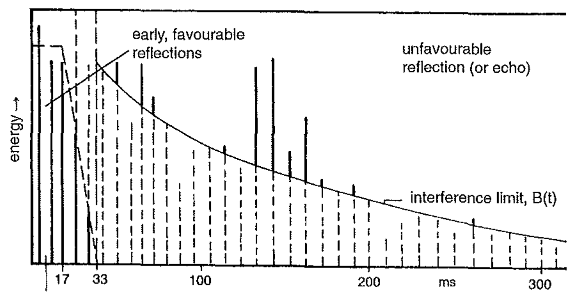
❹ Reverberation time tolerance ± 20%



❺ Speech intelligibility

function	volume factor (m^3/seat)	max. volume (m^3)
assembly room, spoken theatre	3–5	5000
multi-purpose, speech/music	4–7	8000
musical theatre (opera, operetta)	5–8	15 000
chamber music room	6–10	10 000
concert halls for symphonic music	8–12	25 000
rooms for oratorios and organ music	10–14	30 000

❻ Table of specific volumes; V = f (type)



❼ Reflection sequence in a room

The design of room acoustics should produce the optimal conditions for listeners to hear speech or music.

Various factors have to be considered, of which the most important is the **reverberation time**, i.e. the time taken for the sound level to **drop** by 60 dB after the sound source has ceased → ❶. This is evaluated in the range of a drop of –5 to –35 dB.

Another factor is the **absorption surface** of the room, determined by its quantity of absorbing material and the **echo**.

The calculation of the **reverberation time t** of a **room volume V** normally uses the **Sabine formula**:

$$\boxed{t = \frac{0.163 \cdot V}{\alpha_s \cdot S}}$$

The **degree of sound absorption** α_s is material-specific and is determined in echo chambers. The **individual surfaces** S (e.g. people, seating, decoration) of the total sound-absorbing surface in the room are entered into the calculation with their specific values. The reverberation time is calculated for the frequencies f = 125, 250, 500, 1000, 2000, 4000 Hz. References to medium frequency are normally based on 500 Hz.

If a single, subjectively recognisable peak projects from a regularly falling reverberation curve → ❶, this is described as an **echo** → ❷. Different values of time and intensity count as echo criteria for speech and music. Because rooms intended for music should be designed for a longer reverberation time, they are normally regarded as less critical with regard to echoes.

Requirements for rooms

Reverberation time

The optimal reverberation time depends on the intended use (music, speech → ❸) and room volume. The reverberation time is generally dependent on frequency, i.e. it is longer at deeper, and shorter at higher, frequencies. For frequencies of f = 500 Hz, the empirically determined values according to → ❹ can be given as optimal.

Speech intelligibility

This serves to judge the comprehensibility of the spoken word → ❺. This is not standardised, so various concepts – like sentence, and syllable, intelligibility and evaluation with logatomes – are usual.

For the measurement with logatomes, large groups of listeners have to write down individual meaningless syllables, e.g. 'lin', 'ter' (logatomes), and the degree of correctness is used for evaluation. >70% counts as excellent speech intelligibility. Newer, objective processes use modulated rustling signals and lead to reproducible results at less expense.

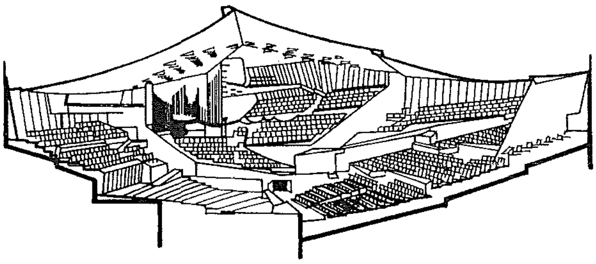
Impression of space

The impression of space describes the perception of the reflections emanating from the room according to time and direction. For music, diffuse reflections are favourable for sound volume, while early reflections with delays of up to approx. 80 ms (corresponding to 27 m of distance) improve clarity compared with direct sound. Speech requires shorter delays, of up to 50 ms, to protect comprehension.

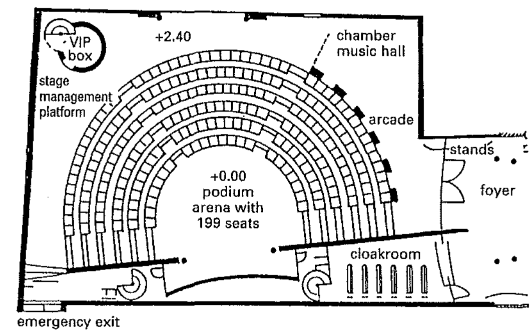
BUILDING PHYSICS
Thermal insulation
Sound insulation
Room acoustics
Lightning protection

BS EN ISO 717
BS EN ISO 3382
BS EN 12354
DIN 52216

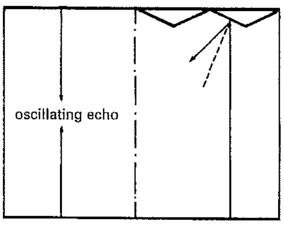
Building services



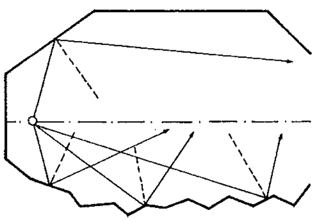
❶ Berlin Philharmonic: staggering the rows of seating



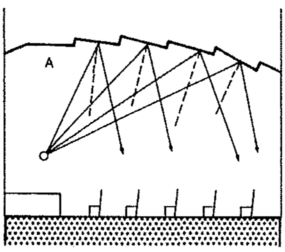
❷ Podium in the small chamber music room, Beethoven Archive, Bonn



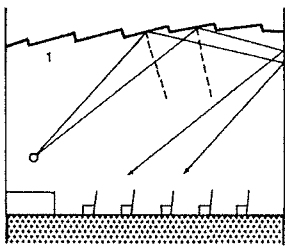
❸ Flutter echo from parallel unstructured walls



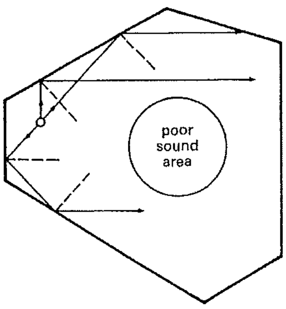
❹ Diffused reflections created through folds in the wall surface



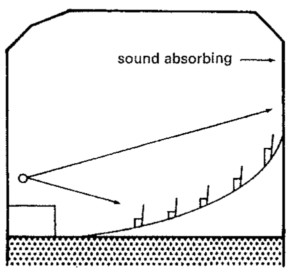
❺ Ceiling shape flat for music, sloping to the back for speech



❻ Unfavourable ceiling shapes



❼ Folding of the wall surface



❽ Uniform direct sound to all places through banking the rows of seats. The curve should follow a logarithmic spiral

Primary structure of rooms
The design of the primary structure of a room is the most important acoustic design criterion. Early side reflections are subjectively considered to be better than ceiling reflections, even with very low delay times (because of the asymmetry of the acoustic impression), because the two ears receive different signals. **Narrow, high rooms with structured, geometrically reflecting walls and diffusely reflecting ceilings** are therefore the most simple for room acoustics.

The **volume required for good sound** depends on the purpose of the room (→ p. 482 ❻). Guideline values are 4 m^3/person for speech and 10 m^3/person for (concert) music. If the volume is too small, this allows too little reverberation.

Room shape
For music, narrow, high rooms with structured **walls** (early side reflections) are particularly suitable. Near the podium, reflection surfaces are necessary for early initial reflections and the balance of the orchestra. The **back wall** of the room should not cause any reflections towards the podium, because this could have an echo effect.

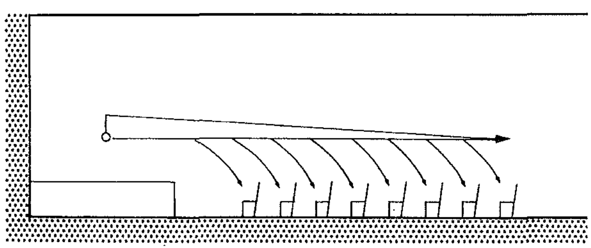
Parallel, unstructured surfaces are to be avoided in order to prevent flutter echoes through multiple refection → ❸. Providing folds in the walls with angles of >5° can remove the parallel effect and achieve diffused reflections → ❹.

Ceilings serve to lead the sound into the back of the auditorium and must be shaped accordingly → ❺ – ❻. If the shape of the ceiling is unfavourable, this causes great fluctuations of volume through sound concentrations.

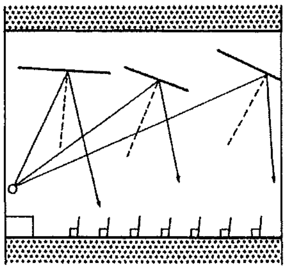
Less favourable are rooms with side walls becoming further apart towards the back, because this could make side reflections too weak → ❼. This disadvantage can be compensated for with **additional reflective surfaces** (Weinberg steps) in the room or a heavy folding of the walls to guide the sound (e.g. Berlin and Cologne Philharmonics → ❶).

Multi-purpose rooms with variable podiums and level floors are often problematic for music. The **location of the podium** should if possible be on the narrow side of the room. For speech or small rooms (chamber music), podiums along the long walls are also possible (Beethoven Archive → ❷). Podiums must be clearly raised above the level of the floor in order to assist direct sound transmission, because otherwise too much volume is quickly lost → ❾.

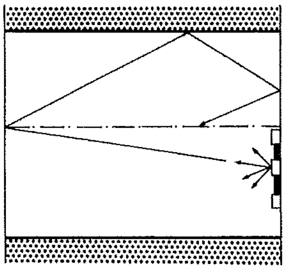
Banking of the seats is also acoustically advantageous (uniform direct sound to all seats). The rise of the curve should follow a logarithmic spiral → ❼.



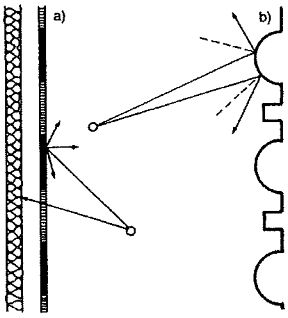
❾ Drop in sound level over absorbing surfaces



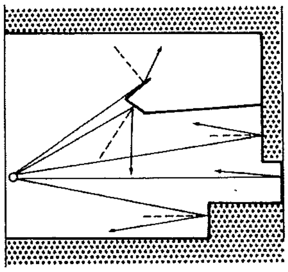
1 Sound-guiding 'sails'



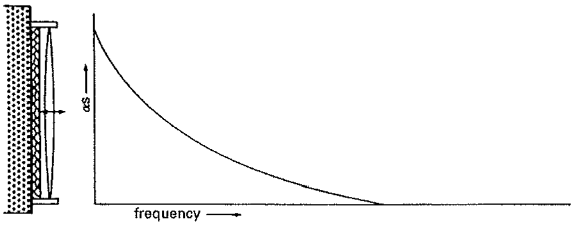
2 Splitting unfavourable reflection surfaces into elements



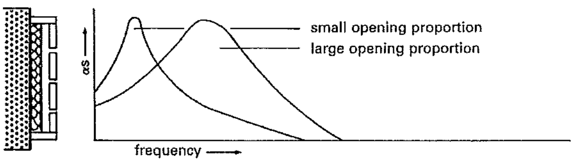
3 Diffuse reflections through
a) change of material;
b) diffusely reflecting surface



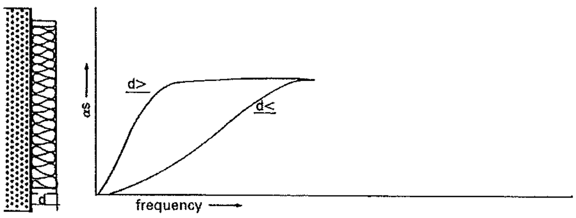
4 Diffusion through reflections occurring at different times



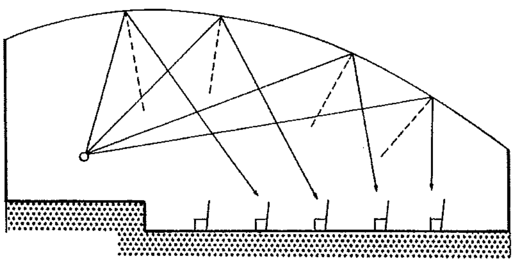
5 Absorption of lower frequencies due to surface oscillator



6 Absorption behaviour of resonators



7 Absorption by porous materials



8 Good sound-guiding through adapted curve

Secondary structures

For the calculation of reverberation time, the entire sound-absorbing surface of the room is taken into consideration, i.e. all individual surfaces in the room (e.g. people, seating, decoration) are taken into account, together with their specific degree of sound absorption (→ Sabine formula p. 482).

The selection, arrangement and material of the **secondary structures** can largely compensate for the disadvantages of an unfavourable primary structure. Flexible (electronically controlled) sound-insulated surfaces can also achieve adjustable reverberation times.

Secondary reflection surfaces

Reflection surfaces can be used to remedy the faults of a primary structure (e.g. walls widening towards the back of the room addressed through folding of wall surface; and an undesirable ceiling shape through suspended sails or splitting surfaces into elements → 1 – 2.) An appropriately curved ceiling can achieve very good sound guidance → 8.

Diffuse reflections: Surfaces from which echoes can be expected must reflect diffusely, i.e. scatter the sound reaching them → 3. Diffuse reflections lead to flat, uniform reverberation time curves through the uniform distribution of sound.

Structuring of walls by folding surfaces necessitates angles >5°. Prominent surface structures (parapets, niches etc.) are also effective, through splitting of the sound waves or delayed reflections → 4.

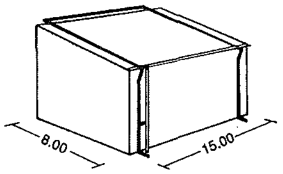
Absorbing surfaces

Absorbing surfaces can avoid sound concentrations and adapt the reverberation time to the required values. The desired reverberation time is balanced using a combination of absorbing surfaces with different properties. This is determined by their structure:

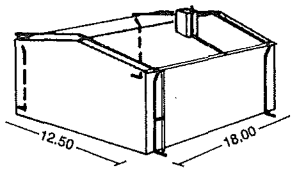
- resonant surfaces (which move with vibrations) absorb **low frequencies**. Area, separation and level of cavity filling can be varied for fine adjustment → 5.
- surfaces with openings in front of cavities mostly absorb **medium frequencies** (Helmholtz resonator); proportion of surface taken by hole, cavity volume and damping of cavity determine frequency, extent and form of maximum absorption → 6.
- porous materials are used for the absorption of **higher frequencies**. Layer thickness and flow resistance influence the distribution towards lower frequencies → 7. An appropriate alternation of reflecting and absorbing surfaces has an effect on the reflection like a serious structuring of the surface → 3.

Seating

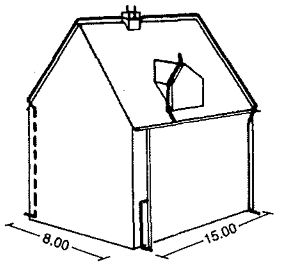
The achievable reverberation time is often determined just through absorption by the listeners and the seating. In order to make the reverberation time less dependent on the number in the audience, a type of seat material is needed which provides such great **absorption**, both on the seat and its backrest, that, occupied or not, its absorption is the same. Additional absorption surfaces for high frequencies are then only necessary if the specific volume of the room is significantly exceeded (→ p. 482 6). If room volume and seating are correctly matched to each other, then it is mostly necessary to correct the reverberation time only for lower frequencies.



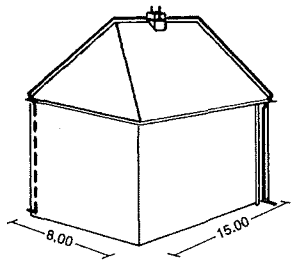
❶ Single-pitch roof



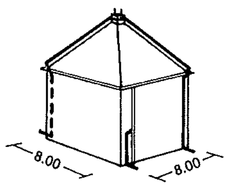
❷ Flat roof



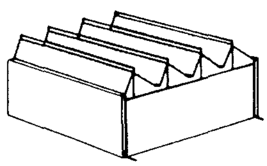
❸ Pitched roof



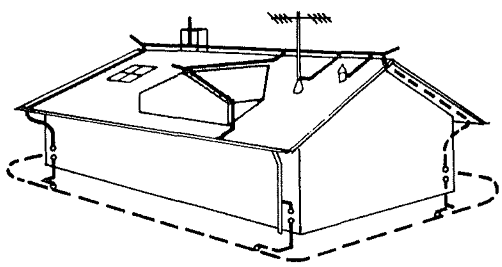
❹ Hipped roof



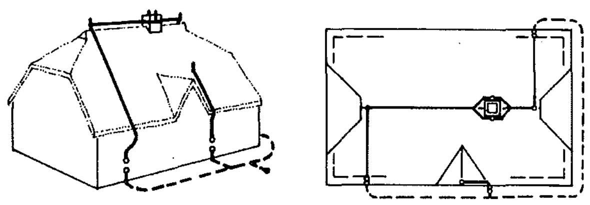
❺ Pyramid roof



❻ Northlight roof



❼ Lightning protection system common today



❽ Thatched building as isometric and plan; ridge conductor on timber supports 60 cm above ridge; conductor 40 cm from roof surface; earth conductor

At a latitude of 50°, each hour of thunderstorm causes about 60 lightning strikes to the ground and 200–250 cloud to cloud discharges.

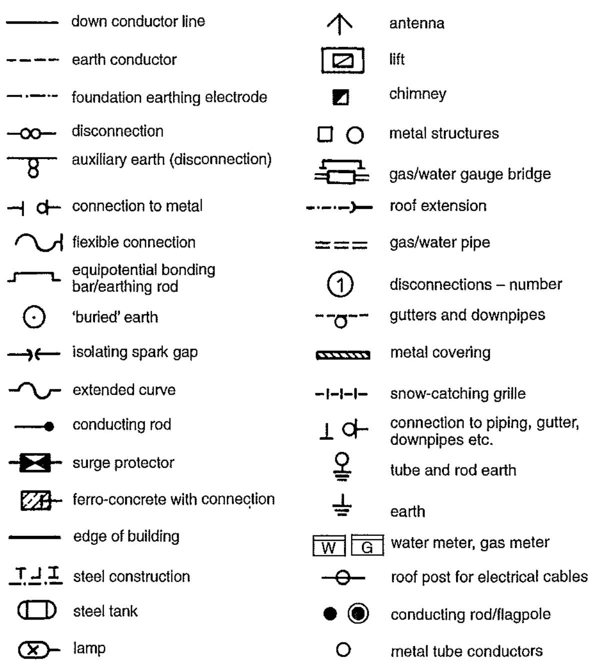
People in the open air are endangered by step voltages within 30 m of the strike location (trees, masonry etc.) Damage to buildings is mostly the result of the heat produced by ground strikes, which can heat and turn the water content of soil to steam, and of excess pressure, which can cause explosive destruction of walls, masts, trees etc.

Lightning protection systems
A lightning protection system is intended to fix the lightning strike using roof conductors and ensure that the building remains inside a protected zone ('Faraday cage'). A lightning protection system consists of **'roof conductors', conductor lines and earthing rods or electrodes.**

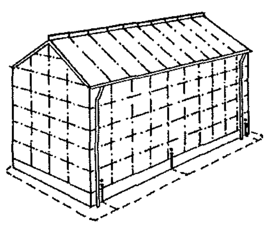
'Roof conductors'
These are metal lightning rods, conductor lines and roof surfaces. No point of the roof should be more than 15 m from the nearest 'roof conductor'. Structures projecting from the roof, bay windows, chimneys and ventilation cowls are of particular significance for the detailing of lightning protection systems and should always be connected.

On account of the danger of ignition from the corona effect, thatched roofs should have metal bands on timber supports 60 cm above the ridge → ❽ – ❾.

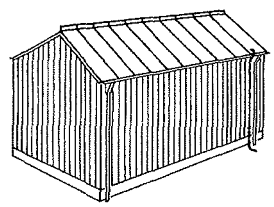
When a lightning current flows through the earthing resistance, this creates a voltage drop, e.g.: 100 000 A × 5 cm = 500 000 V. The entire lightning protection system and all parts with metal connections to it are subjected to this potential at the moment of a lightning strike. The very effective measure of connecting all large metal parts and cables to the lightning protection system is described as equipotential bonding.



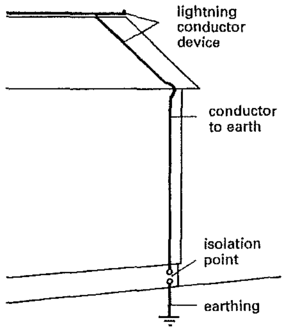
❾ Graphic symbols for lightning protection system components



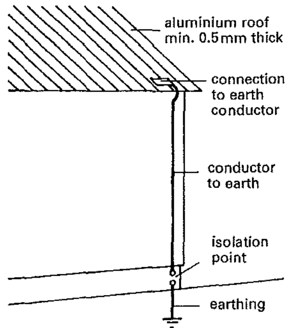
❶ Steel framed building: steel frame connected to the 'air terminal' and also to the conductor to earth



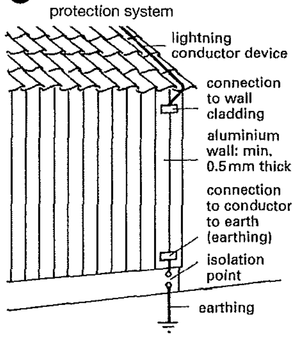
❷ Metal roof with timber-clad walls: roof connected to ridge conductor and conductor to earth



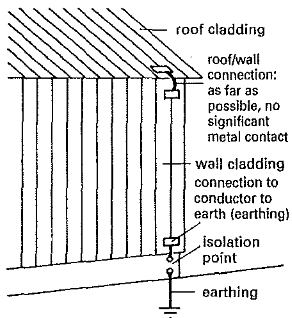
❸ Main components of a lightning protection system



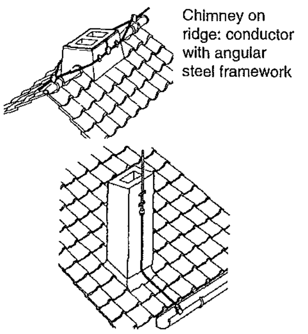
❹ Aluminium roof covering as an 'air terminal'



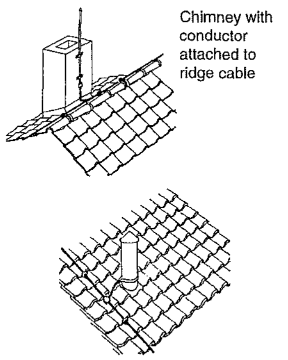
❺ Aluminium wall cladding as conductor to earth



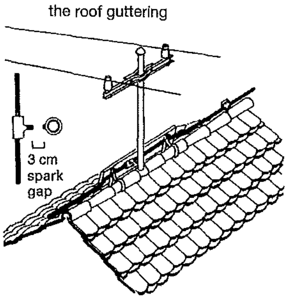
❻ Aluminium roof and wall



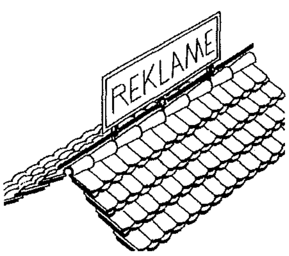
❼ Lightning conductor on chimney close to the eaves and connected to the roof guttering



❽ All metal structures and ventilation ducts on the roof are connected to the lightning protection system



❾ Do not directly connect roof mast for high-voltage cable; the open transmission path has a spark gap of 30 mm



❿ Install voltage surge protection device in steel structures with electrical installations

Earthing electrodes

The earthing system has the task of conducting the lightning current quickly and uniformly into earthing electrodes. These can be tapes (surface) or rods (underground, sometimes called 'buried') earthing electrodes:

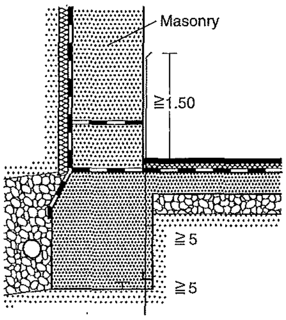
Surface earthing electrodes (earthing tapes) are laid as a ring or strip, preferably embedded in the foundation concrete. Earthing tapes consist of galvanised steel strip (30 × 3.5 mm/25 × 4.0 mm) or round steel (diameter = 10 mm) → ⓬ – ⓭.

Underground earthing electrodes (rods). These are round or with an open profile. They are driven, inside tubes, so deep into the ground without insulation that a low ground resistance is achieved → ⓬ – ⓭. The level of the ground resistance varies according to soil type and moisture content → ⓫. If earthing electrode rods are driven more than 6 m into the ground, they are described as 'buried'.

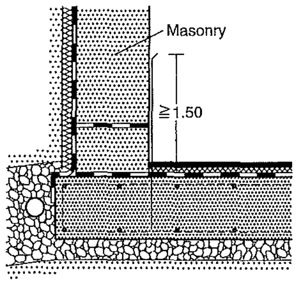
A star-shaped earthing electrode consists of individual tapes projecting outward in a star shape from a conductor.

Type of earthing electrode	Marshy soil	Loam, clay, arable soil	Damp sand	Damp gravel	Dry sand and gravel	Stony ground	Ground resistance (Ω)
tape (length, m)	12	40	80	200	400	1200	
rod (depth, m)	6	20	40	100	200	600	5
tape (length, m)	6	20	40	100	200	600	
rod (depth, m)	3	10	20	50	100	300	10
tape (length, m)	4	13	27	67	133	400	
rod (depth, m)	2	7	14	34	70	200	15
tape (length, m)	2	7	13	33	67	200	
rod (depth, m)	1	3	7	17	33	100	30

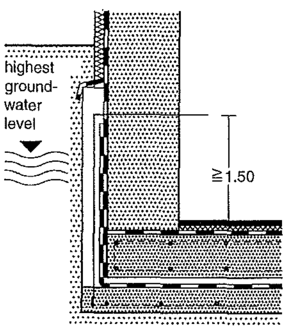
⓫ Ground resistance of tape and rod earthing electrodes in various soils



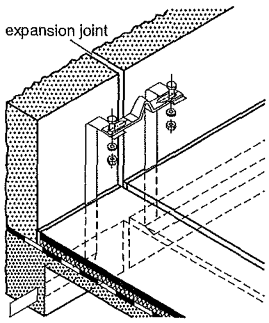
⓬ Earthing electrode in unreinforced concrete foundation



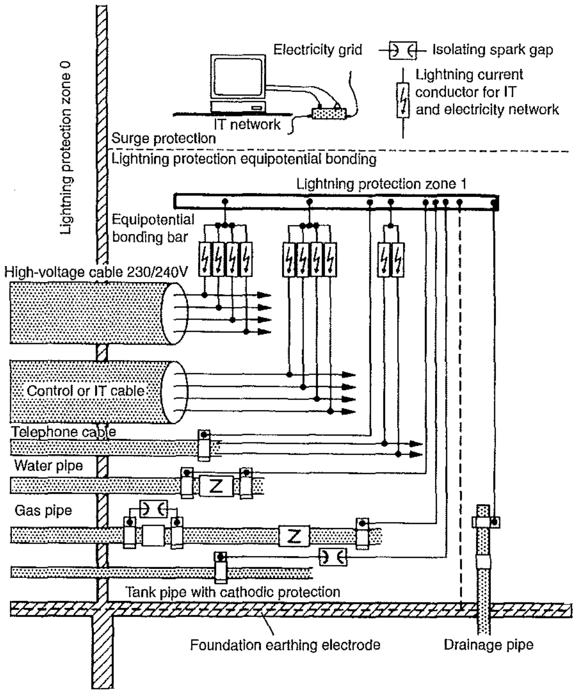
⓭ Earthing electrode in reinforced concrete foundation



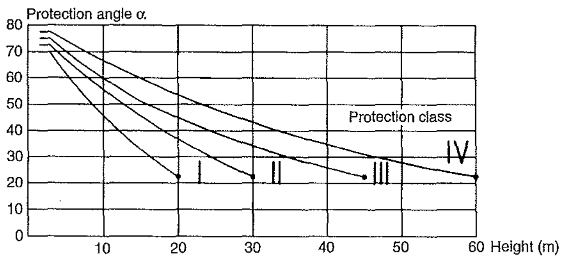
⓮ Layout of a foundation earthing electrode with waterproofing of tanks



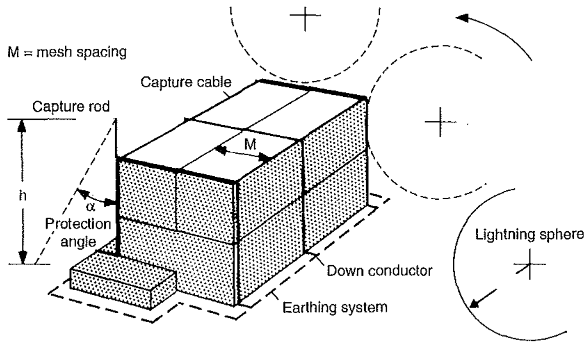
⓯ Bridging of movement joints with expansion joint on inside of building work



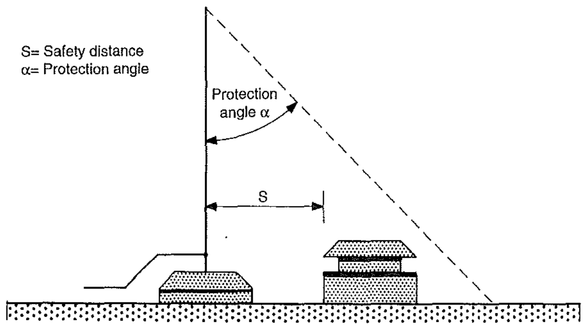
❶ Principle of lightning protection equipotential bonding



❷ Protection angle depending on the lightning protection class and the height above the area to be protected



❸ Procedure for designing lightning protection systems: lightning sphere, protection angle and mesh process



❹ Roofs protected by lightning rod

Lightning protection zones

The property to be protected is categorised into various lightning protection zones (LPZ) → ❻.

Protection zone 0A:
This is outside a building to be protected. Direct lightning strikes are possible in this area, and there is an undamped field of lightning discharge.

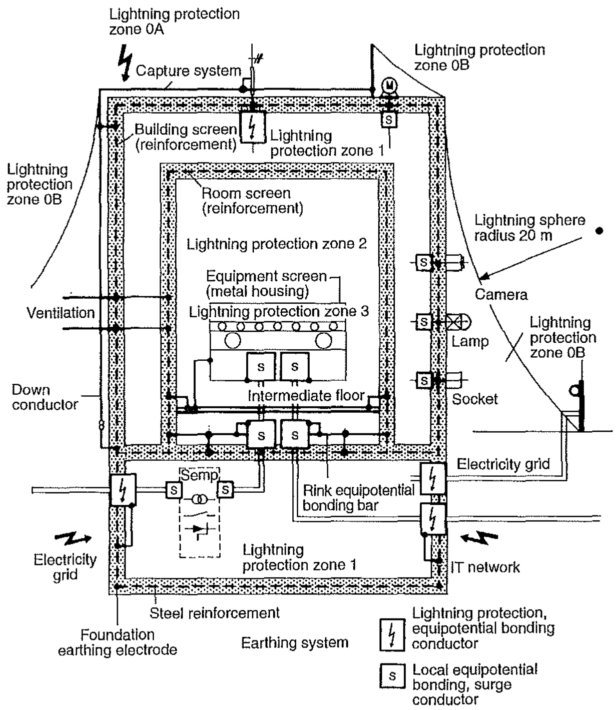
Protection zone 0B:
The lightning protection equipment on the building to be protected results in areas in which direct lightning strikes can be ruled out according to the protection class. There is an undamped field of lightning discharge. Such areas outside the building are described as protection zone 0B.

Protection zone 1:
This describes the actual building to be protected The boundary of protection zone 0 is normally the roof, the external walls and the cellar floor of the building to be protected, of which the characteristics (shielding of the external envelope of the building) have to fulfil certain requirements.

Protection zone 2 and higher:
It can be sensible, or requested, to provide further protection zones inside protection zone 1. For example, the central server room as protection zone 2 and individual electronic devices as protection zone 3.

lightning protection class (P)	effectiveness (E)	lightning sphere radius (r)	mesh width (w)	typical down conductor spacing	protection angle (α)	peak lightning current (i)
I	98%	20 m	5 m × 5 m	10 m	→ ❷	200 kA
II	95%	30 m	10m × 10 m	15 m		150 kA
III	90%	45 m	15 m × 15 m	20 m		100 kA
IV	80%	60 m	20 m × 20 m	25 m		

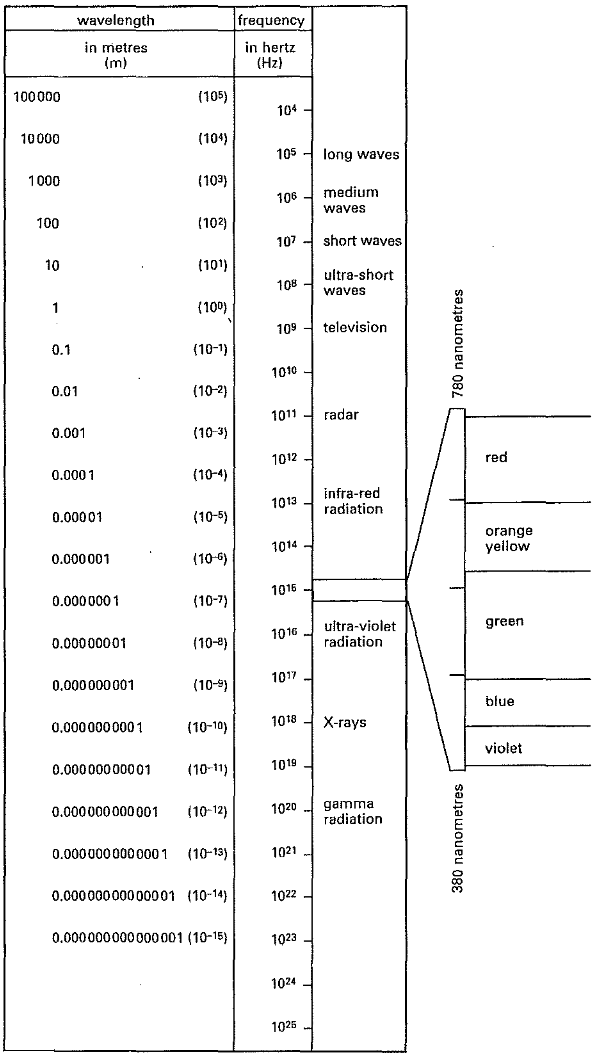
❺ Lightning protection classes



❻ Categorisation of a building into lightning protection zones

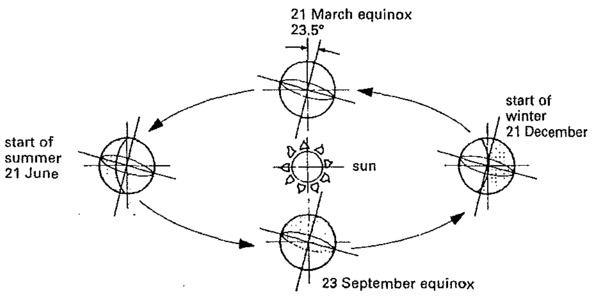
BUILDING PHYSICS
Thermal insulation
Sound insulation
Room acoustics
Lightning protection

Building services

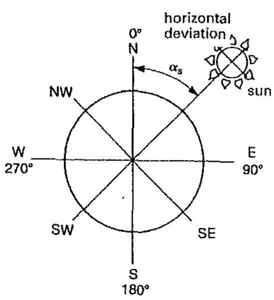


(1 nanometre = 1 × 10^{-9} metres)

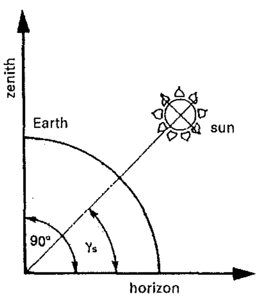
1 Energy spectrum of electromagnetic radiation (1 nanometre = 1 millionth millimetre)



2 The seasons – in the northern hemisphere



3 Azimuth angle – α_s



4 Elevation angle – γ_s

Requirements for daylight in internal rooms

All rooms for permanent human occupation should be lit with sufficient daylight. There should also be a reasonable visual connection with the outside. The corresponding requirements are essentially laid down in DIN 5034, in the Workplace Guidelines and in the state building regulations.

Light, wavelength, colour, unit

Within the range of electromagnetic radiation, visible light is a relatively small part, with wavelengths of approx. 380–780 nm → **1**. Light (daylight and artificial light) is the range of electromagnetic radiation between ultra violet and infra red, which can be processed by the eye. The colours of the spectrum in daylight all have their wavelength, from violet with relatively short wavelength to red with the longest wavelength. Daylight, which is experienced by the human eye as white, contains all wavelengths. The analysis of wavelengths is of significance for architectural design.

The intensity of light or illuminance – particularly for artificial light – is measured in lux (lx), and daylight in internal rooms is given in %.

Astronomical basics: the sun

The sources of radiation and light-producing daylight are not constant. The sun is our 'primary source' for the creation of daylight, independent of the time and various weather situations. The angle of the earth's axis of 23.5°, the daily rotation of the earth around its own axis and the annual rotation of the earth around the sun result in the position of the sun depending on date and time for any particular place on earth → **2**. This is described by two angles:

azimuth α_s and elevation angle γ_s

Azimuth α_S: projection on plan of the position of the sun, measured as the horizontal angle from 0°. 0° = north, 90° = east, 180° = south, 270° = west → **3**, as seen by the observer. Elevation angle γ_S: projection of the position on elevation of the sun above the horizon, as seen by the observer → **4**.

Determination of sun's position

There are various methods of determining the position of the sun for a particular location, e.g. determination of the azimuth and elevation angle.

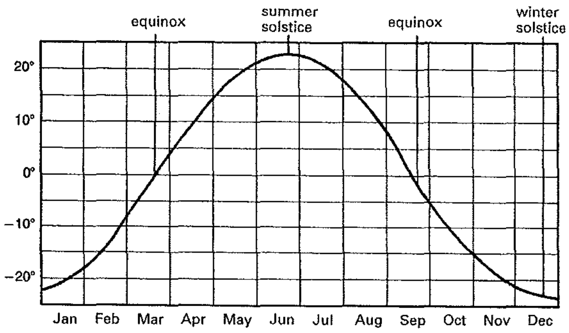
On account of the declination of the sun in the course of the year → **2** there are four essential sections of the year (seasons) or sun positions: on the equinox dates of 21 May and 23 September, the day and night are of equal length and the declination of the sun is 0°.

On 21 December is the winter solstice (shortest day) with solar declination –23.5°, and the 21 June is the summer solstice (longest day) with solar declination +23.5°.

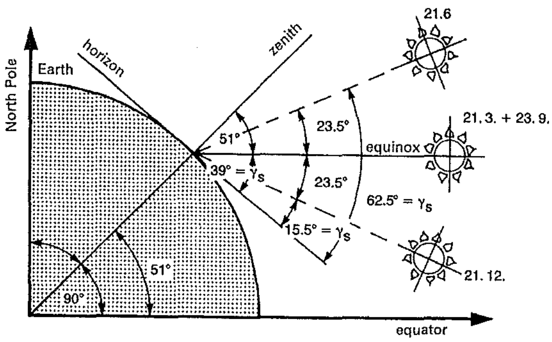
The position of the sun results from the latitude. On the 21/3 and the 23/9 at noon (α_s = 180°), the sun has the same zenith angle at each latitude. For example, at latitude 51° north (London), the zenith angle at noon (α_s = 180°) is 51°→ p. 489 **2**. The elevation angle of the sun above the horizon is then 90° – 51° = 39°.

The sun at noon (α_s = 180°) stands about 23.5° higher on the 21/6 than on the 21/3 and the 23/9, that is 39° + 23.5° = 62.5°, and on the 21/12, the sun is about 23.5° lower than at the equinoxes, that is 39° – 23.5° = 15.5°. These differences are the same for all latitudes.

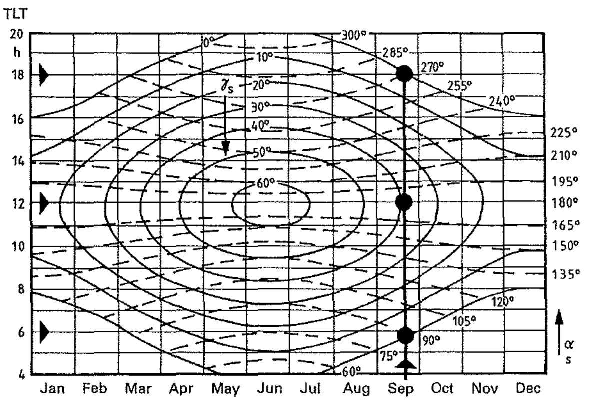
This enables the corresponding elevation angle of the sun to be determined for all latitudes and times of year.



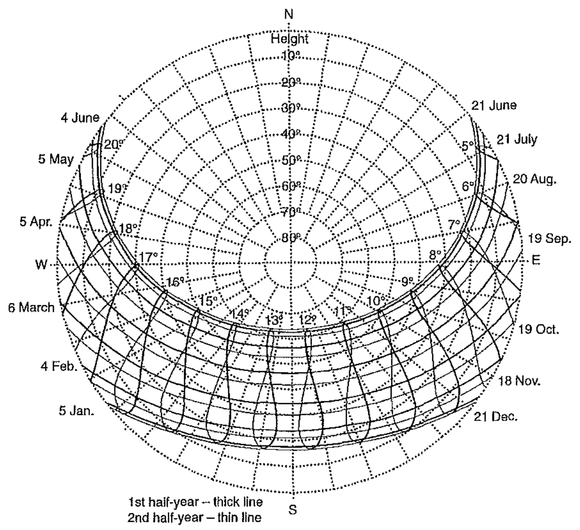
❶ Solar declination δ in the course of the year



❷ 51° latitude and elevation angle γ_s



❸ Solar azimuth α_s and solar elevation angle γ_s 51° north (Brighton, UK), according to time of year and day



❹ Solar position diagram, Darmstadt, Germany: longitude = 8.65° east, latitude = 49.87° north

Sun position diagram

→ ❸ shows the positions of the sun for Brighton, UK, i.e. for 51° north. The diagram shows the projection of the sun's position on plan at real local time, i.e. for Brighton on 23/9, sunrise is at 6:00 at $\alpha_s = 90°$ (east); at 12:00; $\alpha_s = 180°$ (south) and the elevation angle is 39°; and at sunset at 18:00 $\alpha_s = 270°$.

To determine the path of the sun's position for any location, Shell Solar in Hamburg provide a colour sun position diagram → ❹. This contains the plan projection of azimuth α_s and elevation angle γ_s according to day and date for each latitude and with a statement of the reference meridian.

To determine the position of the sun, loop-shaped curves are drawn for each full hour, with the thick line representing the first half of the year and the thin line the second. The loop shape of the hourly curves results from the elliptical orbit of the earth and the inclination results from the ecliptic. The times given refer to the time reference meridian in each case, i.e. the local time at the relevant location (Darmstadt).

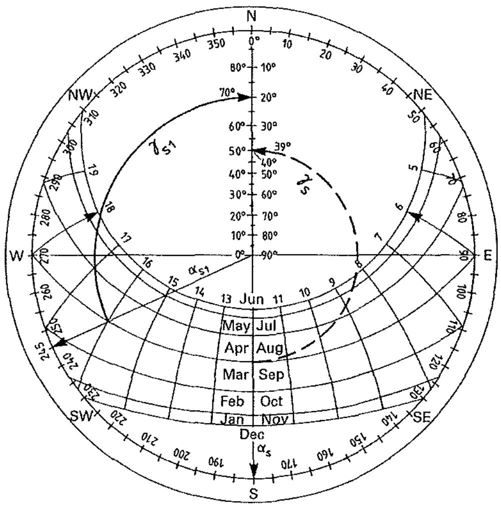
The intersection points of the daily curves with the hourly curves with the same line thickness mark the position of the sun to the day and the hour. In the polar diagram, the position of the sun can be read from the right angle of the sun (azimuth) and the vertical angle of the sun (elevation) → ❹.

Projection of the path of the sun

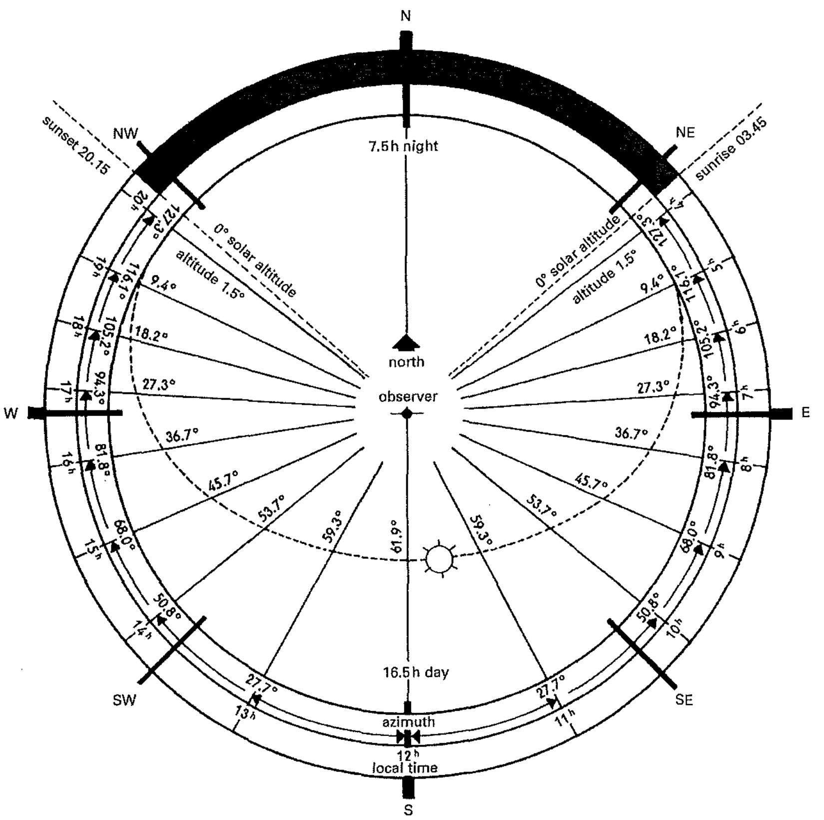
With the stereographic projections → ❺, the discs supplied can be used to determine the path of the sun (in each case on 21st of the month) according to season and time.

Sun position, time and date determination

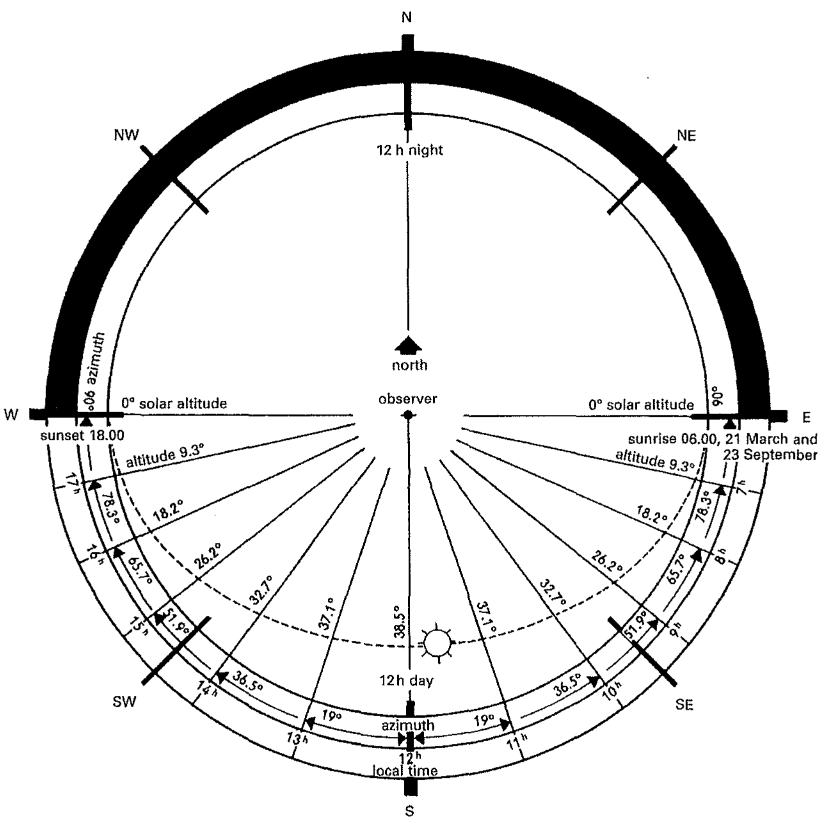
The position of the sun determines daylight conditions according to time of day and date. For purposes of determining daylight (e.g. for sun position diagrams) solar time is normally given. Each location is part of a time zone with uniform local time: if the local time is of interest, then the solar time has to be converted into local time = solar time + time conversion + time difference, including possible consideration of summer time.



❺ Stereographic projection of the path of the sun, e.g. for latitude 51°. On 21/3 or 23/9: sunrise at 6:00, sunset at 18:00, γ_s = 39° at 12:00



❶ Path of the sun at the **summer solstice** (about 21 June), longest day of the year, at latitude 51.5° north (London – Cardiff – Dortmund)



❷ Path of the sun at the **spring equinox** (about 21 March) and **autumn equinox** (about 23 September)

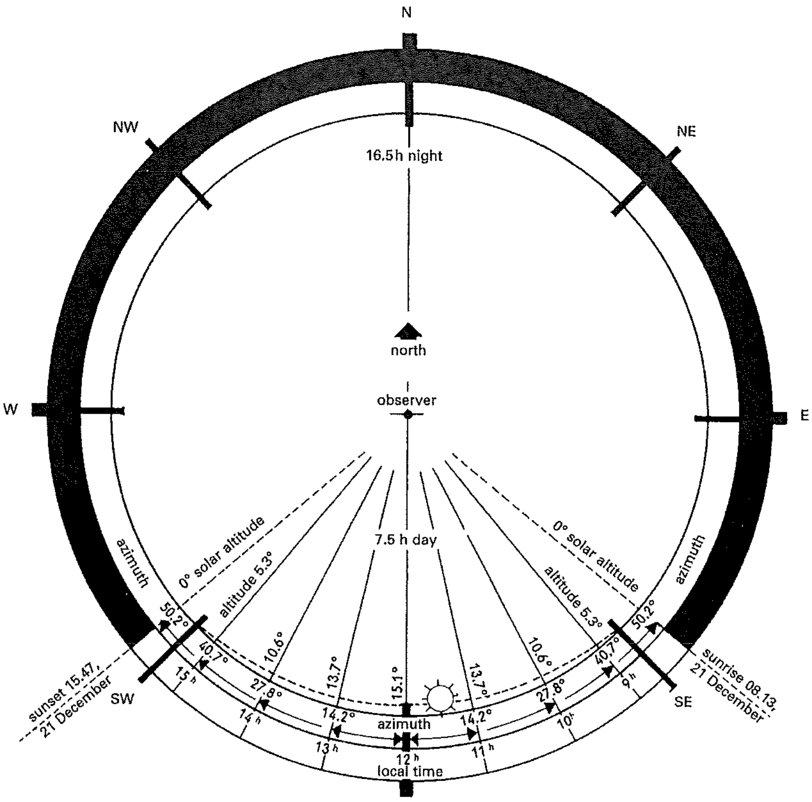
Determination of insolation on buildings
This process enables the insolation on a planned building to be read immediately by laying a plan drawn on transparent paper according to its actual compass direction over the table of the sun's path or vice versa. The following details of the sun's path refer to the area at latitude 51.5° north (London – Cardiff – Dortmund) → ❶.

For the southern area at latitude 48° north (Freiburg im Breisgau – Munich – Salzburg – Vienna), 3.5° should be added to the calculated solar elevations.

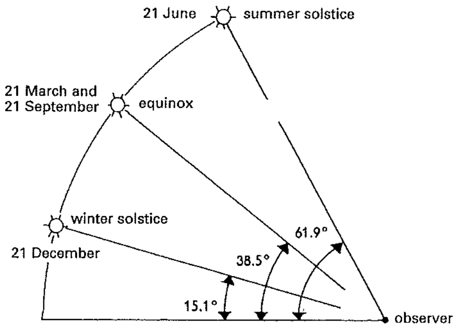
For the northern area at latitude 55° north (Edinburgh – Newcastle – Bornholm – Königsberg), 3.5° should be deducted. The degrees shown in the second outer ring refer to the azimuth, i.e. the angle of the projection of the apparent east–west movement of the sun on the horizontal plane. The standard local times given on the outer ring refer within Germany to locations at longitude 15° east (Görlitz – Stargard – Bornholm = meridian of Central European Time). For locations at longitudes to the east of this, the local time is 4 minutes earlier than the standard time for every degree of longitude; for locations to the west of 15° = 4 minutes later than the standard time per degree. In London, specifically in Greenwich at 0° longitude, the local time is therefore 60 minutes later than the standard time.

Duration of insolation
The possible duration of insolation during the days from 21 May to 21 July = 16–16¾ hours, and from 21 November to 21 January = 8¼–7½ hours. In the months between these ranges, the duration of insolation changes by almost 2 hours per month. The actual amount of insolation is scarcely 40% of the above figures on account of clouds and mist. The actual degree of insolation is highly variable according to location. Berlin has relatively favourable conditions (in July almost 50%, Stuttgart 35%). Exact details can be obtained from the official weather services covering the particular area.

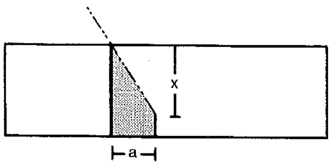
Sun and warmth
The natural warmth in the open air depends on the position of the sun and the release of heat by the ground. The warmth curve is delayed by about 1 month compared to the solar elevation curve, which means that the warmest days are not around 21 June but rather the later days of July, and the coldest days are not around 21 December but in the later part of January. Naturally the conditions at any specific location can vary widely in this respect as well.



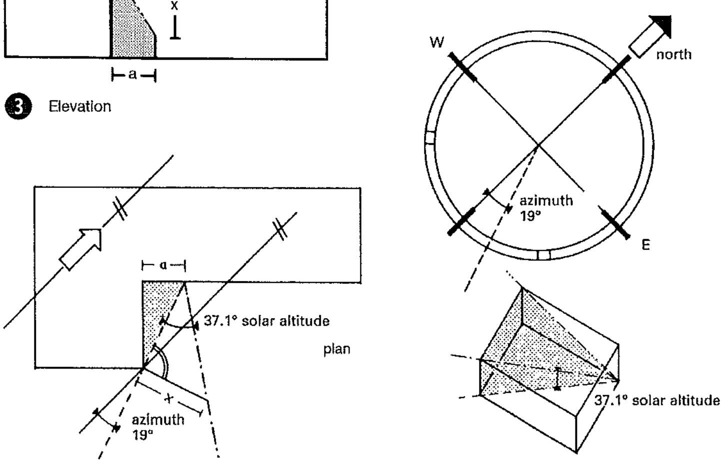
1 **Path of the sun:** winter solstice (about 21 December), shortest day of the year, latitude 51.5° north (London – Dortmund)



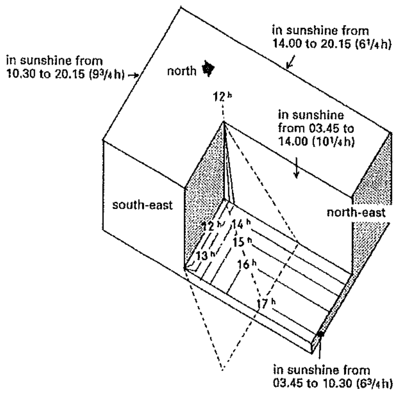
2 **Position of the sun** at midday on significant days of the year. The distance of the sun from the observer corresponds to the inner radius of the sun path diagrams → **1**, p. 490 **1** – **2**, with the dotted sun path on plan, which represents a projection of the relevant sun height on plan.



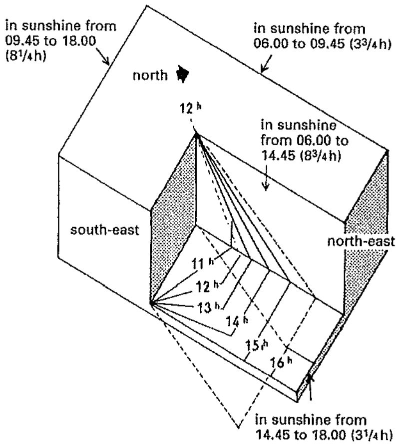
3 Elevation



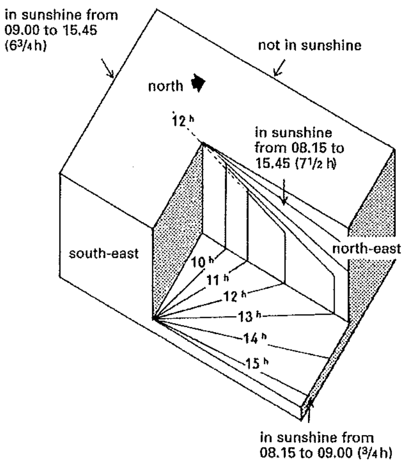
4 **Shadow construction:** to establish sunshine or shadow at any particular time of year and day (e.g. equinox at 11.00), the azimuth angle is drawn on the plan from the relevant corner. This represents the boundary of the shadow on the plan, on which the height of the sun (actual ray of light) is then drawn folded down onto the plan. The length x, measured perpendicularly onto the plan shadow, is entered onto the elevation to give, in connection with the building's upper edge, the boundary of the shadow on the front



5 **Summer solstice.** Shadowing starts on the north side shortly after 11:00, the south-east side is also in shadow shortly after 13:00, during which times the other sides are in sunshine.



6 **Equinox.** The north-east side is in shadow shortly after 10:00, and the south-east side shortly before 15:00.



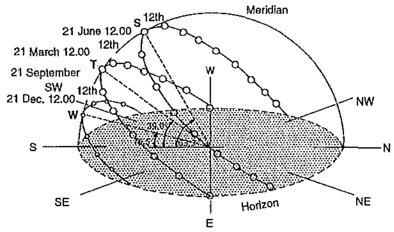
7 **Winter solstice.** The north-east side has scarcely an hour of sun and the south-east side is in shadow shortly after 15:00.

DAYLIGHT
Physical basics
Position of the sun
Insolation
Shadow
Radiation energy
Window lighting
Rooflighting
Quality criteria
Directing sunlight
Shading

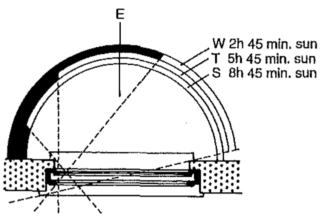
BS 82062
DIN 5034

Building services

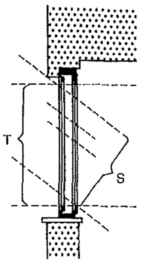
The correct alignment of a building and its windows to the sun, in order to exploit its beneficial effects or to provide protection against its excessive heat, is decisive for the practicality of a building. Sunshine entering all rooms in the autumn and winter, and in the morning, is desirable. Sunshine at midday and in the afternoon in June to August is not desirable. Correct alignment of the building → ⑩ – ⑬ and the appropriate construction measures → ⑭ – ⑰ can fulfil these requirements. The form of window reveals and glazing bar profiles should not unduly impair the entry of sunlight. High windows allow the sun to shine deeply into a room → p. 499 Directing sunlight.



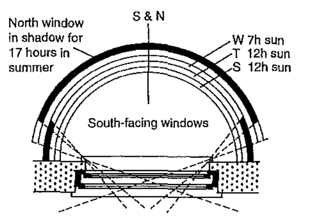
❶ **Path of the sun** at the winter solstice = W, at the equinoxes = T, at the summer solstice = S, as experienced by a house or observer in north European countryside (51.5° latitude)



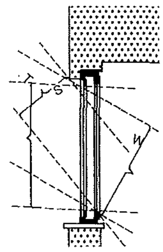
❷ **East and west windows,** at the equinoxes, receive horizontal rays of sunlight, which become higher until the summer solstice. W = winter solstice, T = equinoxes, S = summer solstice.



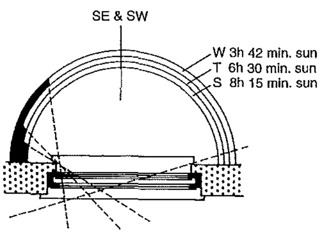
❸ Section of ❷



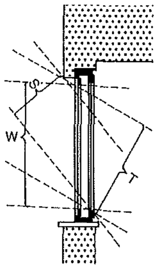
❹ **North windows** receive only a little sunlight in the summer, around the summer solstice. South windows have flat rays of sunshine in the winter and steep rays in the summer, making these particularly suitable for rooms which should be sunny in the summer and winter



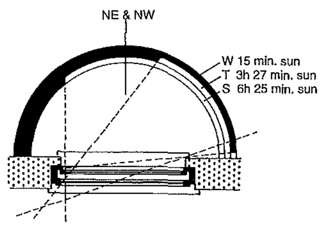
❺ Section of ❹



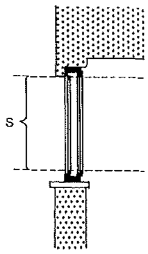
❻ **South-east and south-west windows** receive pleasant sunshine in the summer and winter through flat, deeply penetrating rays



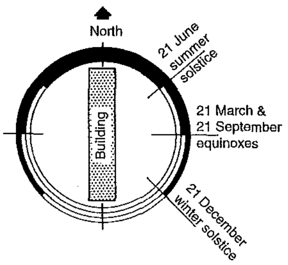
❼ Section of ❻



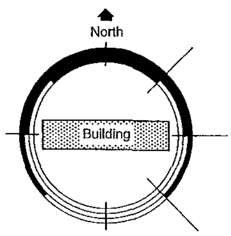
❽ **North-east and north-west windows** receive no sun in the winter but effective sunshine in the early year and the autumn; in the summer, the sun comes in horizontally



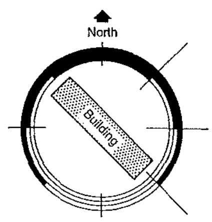
❾ Section of ❽



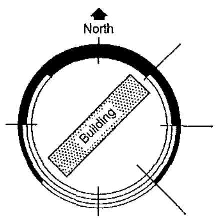
❿ **A north–south block** receives sunshine on both sides, but has no windows on the north or south sides and therefore no sun into any rooms in November, December and January



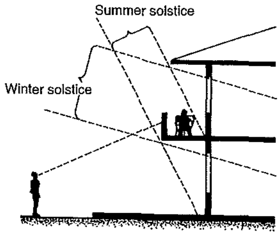
⓫ **An east-west block,** the best layout for small flats with 1–2 rooms: living rooms and bedrooms to the south (or open plan to the north); stairs, bathroom, lobby, kitchenette etc. to the north.



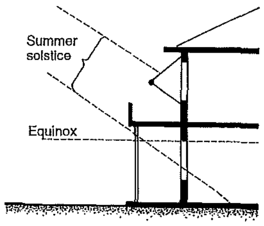
⓬ **A north-west to south-east block** is favourable for larger flats with bedrooms and utility rooms to the north-east and living rooms and children's rooms to the south-west



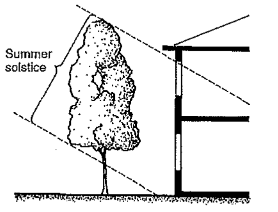
⓭ **A north-east to south-west block** is the best orientation for three- and four-room flats with living rooms and bedrooms to the south-east and utility and subsidiary rooms to the north-west



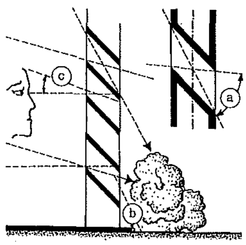
⓮ **South side:** sun and warmth penetrate deep into the house. In summer, sun and heat is kept out by windows and walls



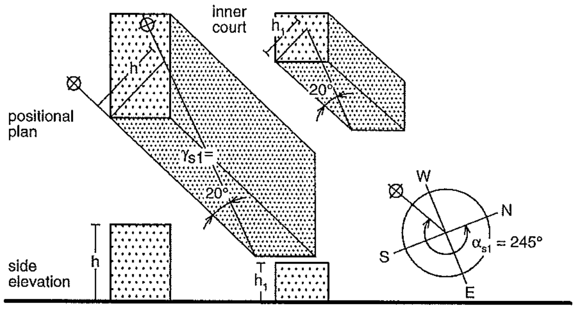
⓯ **East side:** the flat sun rays from the east permit broad, mostly also wind-protected, terraces without hindering the entry of sunshine into the rooms



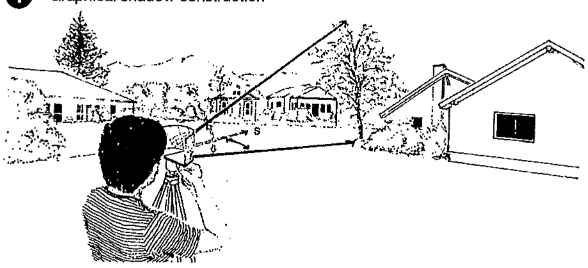
⓰ **West side:** disagreeable sunshine from the west and summer weather are best shaded by deciduous trees, which in the winter lose their leaves and permit the sun to enter



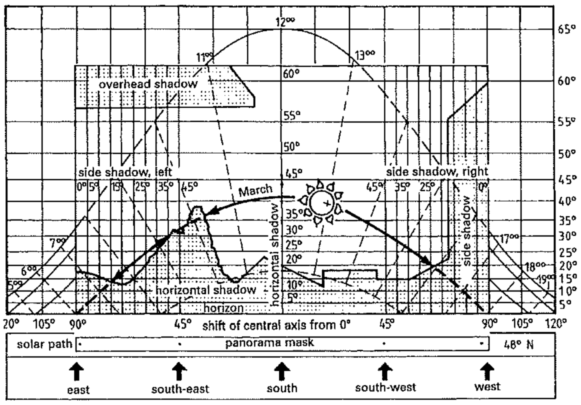
⓱ **A planked fence or balcony parapet** in this form lets most sunshine through → ⓐ, deflects the remaining rays → ⓑ and protects against overlooking and wind → ⓒ



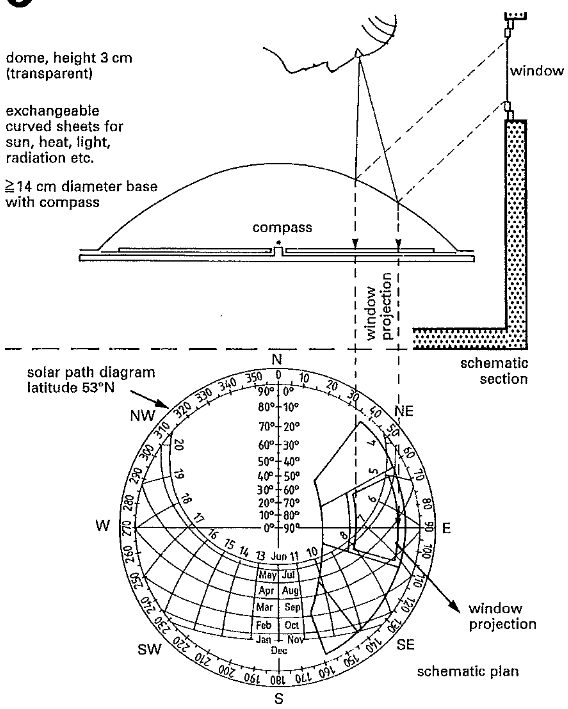
❶ Graphical shadow construction



❷ Panorama mask (curved) in position



❸ Possible shadow distributions on the film



❹ Horizontoscope with projection of a window – east side

Sun position, shadow, aids

The following equipment is available for the determination and checking of the actual sunshine or shadowing inside and outside a building according to geographical location, time of day and year, construction details and local conditions:

Graphical shadow construction

The determination of the shadow thrown by a building can be constructed using the projected path of the sun → p. 489 ❹ + ❺ on plan and in elevation. For example, the shadowing of a courtyard in Brighton, UK, latitude 51° north, is to be constructed for 21 March at 16:00. The sun is shining at this time at an azimuth angle (α_{s1}) of 245° and an elevation (γ_{s1}) of 20° → p. 489 ❺. The layout plan is aligned with north. The shadow direction is determined by the horizontal building edges and a parallel displacement of the sunshine direction (α_{s1} = 245°) through the corners of the building. The length of the shadow is determined by the vertical building edges, so the actual building height (h) is constructed folded down onto the plan and with the elevation angle of 20°. The intersection with the shadow direction gives the shadow length.

Panorama mask

In many countries, a representation of the path of the sun is available for various geographical areas with details of azimuth and elevation, day and time of year. These panorama masks are copied onto transparent film and used at the location under investigation by holding them in the direction the sun will come from → ❷. Looking through the panorama template, any shadowing from the surroundings, including overhead shadows, can be transferred at 1:1 onto the copied path of the sun → ❸. The film can therefore be used to determine shadowing and sunshine on façades or in building recesses to the correct scale.

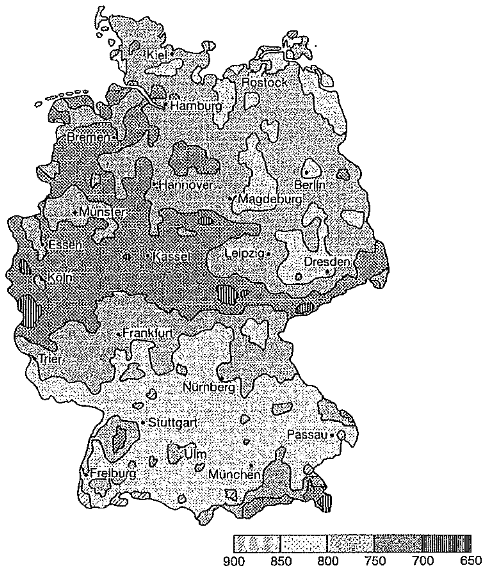
Horizontoscope

This is a tool to determine the real sun and shadow conditions on the building site, on or in a building. The horizontoscope consists of a transparent dome representing the sky, a compass, a base and exchangeable curve sheets, which can be laid underneath for light, radiation or heat as required.

The principle of the horizontoscope is to construct the prev. ailing light and shadow conditions, e.g. for a room → ❹. At a particular point in the room, the projection of a window opening on the sky dome, and at the same time the curve sheet beneath it, can be used to show the actual opening section and the incoming light. This makes it possible to determine the sunshine conditions and also the lighting effects for any point in the room, depending on the alignment of the building, for any time of day and year → ❹.

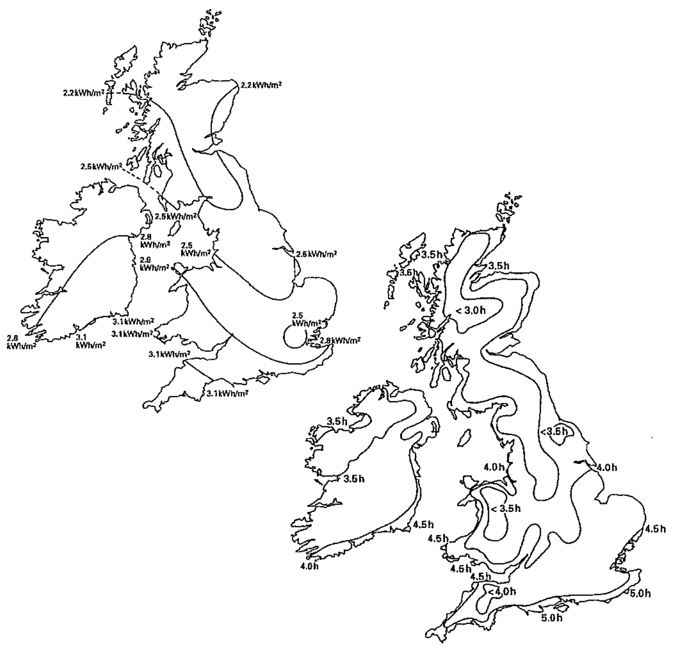
Model and computer simulation

In order to be able to establish the exact annual shadowing or sunshine around, in and on a building, it is recommended to construct a scale model under an artificial sun and also to test the design with a computer simulation. The model gives an immediate idea of the rooms and the effect of the lighting. Because the parallel sunlight is modelled with a 60–100 cm concave mirror, the model cannot be larger. Computer simulations can be used to determine exact daylight quotients, illuminances and distributions of luminance, but normally do not give information about the mood and effect of lighting in the room.



Average global radiation in kWh/m², April to September (1976–1989)

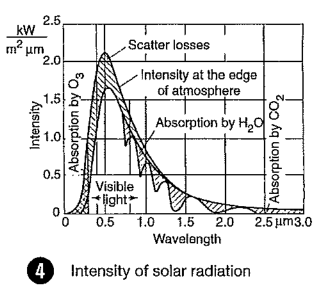
❶ Solar radiation map for Germany for the summer half year



❷ Mean daily solar radiation (above) and hours of sunshine (below) in the UK

condition of sky, e.g. latitude 51°N			
weather	clear, cloudless blue sky	misty, cloudy; sun visible as white disc	full cloud cover
horizontal radiation strength (W/m²)	600–800	200–400	50–150
horizontal illuminance (lx)	60000–100000	19000–40000	5000–20000
proportion of diffused light	10–20%	20–30%	80–100%

❸ Annual variation in radiation intensity and changing daylight qualities for various weather conditions



❹ Intensity of solar radiation

Meteorological conditions

The heat radiation and the intensity of daylight reaching the earth's surface over the course of a year is determined by the geographical latitude, the weather and various states of the sky (clear, clouded, hazy, partially clouded etc.) → ❸. The following facts are relevant to typical daylight and sunshine duration:

The year has 8760 hours. The duration of 'bright daylight' averages approx. 4300 hours per year.

The number of hours of sunshine in Germany varies between 1300 and 1900 hours per year → ❶, of which at least ¾ are in the summer half of the year → European Sun Atlas.

For most of the year, that is about ⅔ of the daylight hours, only more or less diffuse sunlight reaches the earth on account of the local weather conditions.

Global radiation

Direct and indirect solar radiation on the earth's surface (global radiation) creates a locally variable climate and light environment on the surface → ❶ – ❷. The global radiation creates 'heat and light' simultaneously, i.e. the short-wave solar radiation is converted into long-wave radiation (heat) at the surface – the greenhouse effect. This heat should be exploited passively and actively in architecture, and also the simultaneous daylight.

The locally specific light and heat conditions therefore require a precise analysis in order to exploit them for optimal daylight in and around a building.

Radiation: physical basics

Solar radiation is a very 'fickle' source of light and heat. Only a small part of the sun's energy is transferred to the ground as heat because the earth's atmosphere weakens the solar radiation or makes it seem irregular in intensity. This reduction is essentially due to various diffusion processes like scattering, reflection and absorption of the radiation by dust and mist particles (the cause of diffused daylight) and the water vapour, carbon dioxide and ozone content in the air → ❹.

Distribution of the total energy at the surface: about 6% of ultra violet radiation in the wavelength range 0.2–0.38 µm, about 50% of visible radiation in the wavelength range 0.38–0.78 µm (the maximum lies at 0.5 µm in the visible range) and about 40% infra red radiation in the wavelength range 0.78–3.0 µm.

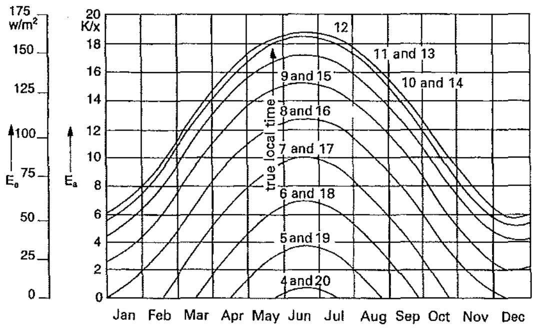
Solar radiation reaching the ground is shown in → ❹. The solar constant to be applied in the central European region is about 1300 W/m² on a vertically radiated area.

Lighting and radiation strength

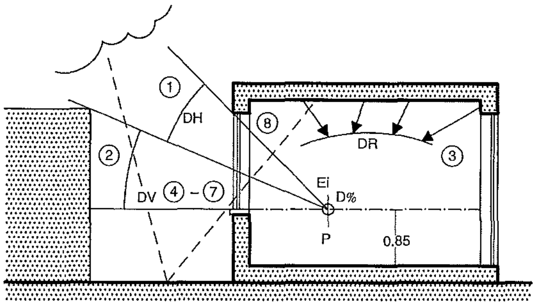
The power of the radiation is reduced by very thick cloud cover to about 200 W/m² and with only diffused radiation (cloudy sky with completely covered sun) to about 50–200 W/m² → ❹. This also applies analogously to the strength of the daylight in lux → ❸.

DAYLIGHT

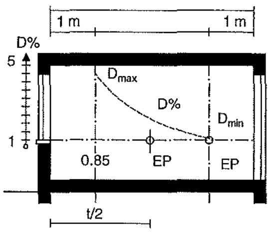
Window Lighting

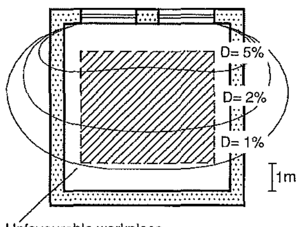


❶ Horizontal illuminance Ea under a clouded sky at 51°N, depending on time of year and day. E_e = horizontal irradiance



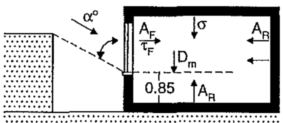
❷ Factors influencing daylight in interiors, e.g. at point P





❸ Daylight factor D% with reference plane in section

❹ Daylight distribution D% on a plan with two side windows

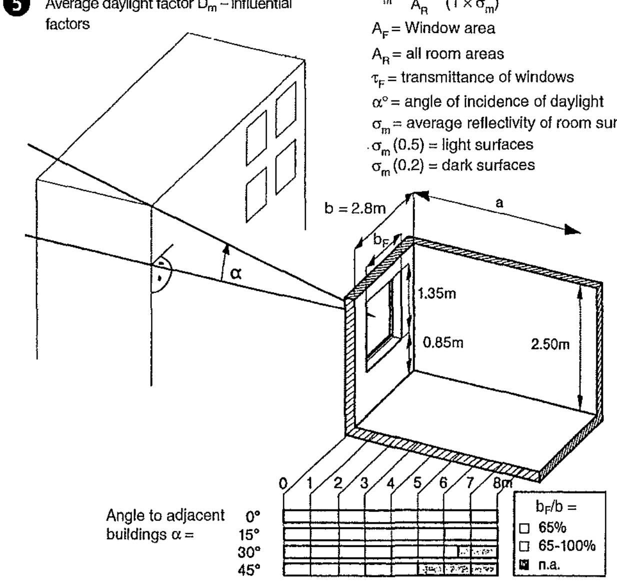


❺ Average daylight factor D_m – influential factors

Determination

$$D_m = \frac{A_F}{A_R} \times \frac{\tau \times \alpha^\circ}{(1 \times \sigma_m)} \%$$

A_F = Window area
A_R = all room areas
τ_F = transmittance of windows
$\alpha°$ = angle of incidence of daylight
σ_m = average reflectivity of room surfaces
σ_m (0.5) = light surfaces
σ_m (0.2) = dark surfaces



❻ The minimum window width as a percentage, before finishings, should not be less than 65% of the room width. For larger room depths and a wide angle to adjacent buildings, even a window width of 100% may not be sufficient.

Daylight inside buildings with window lighting

The daylight inside buildings can be evaluated according to the following quality criteria and scales: illuminance and brightness; uniformity, D_{min}/D_{max}; reflection; colour rendering; glare; room lines, shadowing; view out.

Basics

The evaluation of the daylight inside buildings is always based on the illuminance of the clouded sky (i.e. diffuse radiation). Daylight entering an interior through a window at the side is measured by the daylight factor D. This describes the ratio of the interior illuminance (Ei) to the illuminance outside at the same time (Ea): $D = E_i : E_a \times 100\%$. The daylight in interiors is always given in per cent, for example outside illuminance 5000 lx and inside illuminance 500 lx gives D = 10%. The daylight factor is always constant, and the interior illuminance alters only in relationship to the outside illuminance at the same time. The outside illuminance of the clouded sky varies according to the time of day and year: 5000 lx in the winter, and up to 20,000 lx in the summer → ❶.

Daylight distribution in interiors

The daylight factor at a point (P) is a combination of many influential factors: $D = (DH + DV + DR) \times \tau \times k_1 \times k_2 \times k_3$ → ❷. where:

1. DH = component of light from sky – daylight incidence < α°
2. DV = building component
3. DR = interior reflection component
4. τ = light transmittance of glazing
5. k_1 = glazing bars and window construction component
6. k_2 = glazing bars
7. k_3 = angle of incidence of daylight
8. window position and size → ❷.

The reference plane for the horizontal illuminance of window lighting is provided in DIN 5034 → ❸. The level of the windowsill is assumed at 0.85 m and the distance to the surrounding surfaces of the room is 1 m. On this reference plane, the points (EP) to be named for the horizontal illuminance are determined. The corresponding (to be determined) daylight factors can then be displayed as a curve of daylight factors → ❸ + ❺. The shape of this curve in section and on plan provides information about the horizontal illuminance on the reference plane (at the corresponding points), and can be used to determine D_{min} and D_{max} (uniformity). The daylight factor curve also supplies information about the daily lighting curve in the room.

Required daylight factors D%

The applicable regulations for this are in DIN 5034. While this gives exact details of the minimum requirements for daylight distribution in interiors and workrooms, the distribution of daylight is not precisely defined in the Workplace Guidelines:

- $D_{min} \geqq 1\%$ in residential rooms: reference point – middle of the room, windows in workrooms: reference point = deepest point in room
- $D_{min} \geqq 2\%$ in workrooms – with windows on two sides
- G = uniformity: $D_{min}/D_{max} \geqq 1{:}6$ indirect light
- D_m = average daylight factor. It gives information about the average daylight lighting in the room → ❺.

View out and visual connections

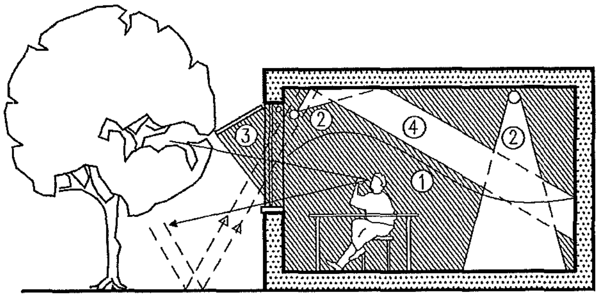
Visual contacts from inside to outside are a necessary part of life. The standard therefore gives tables of minimum window widths depending on room depths, room widths and building angles: window width should be ≧65% of room width → ❻ → DIN 5034, state building regulations.

DAYLIGHT
Physical basics
Position of the sun
Insolation
Shadow
Radiation energy
Window lighting
Rooflighting
Quality criteria
Directing sunlight
Shading

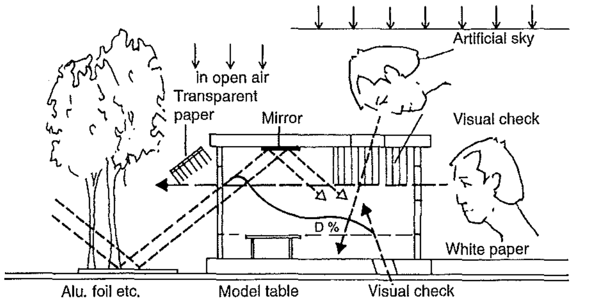
BS 8206-2
DIN 5034

LBO

Building services



❶ Control of daylight and artificial lighting: 1, daylight pattern D%; 2, daylight-enhancing lighting; 3, prevention of glare; 4, reflecting surface



❷ Experimenting with daylight on a model in the open air and under an artificial sky

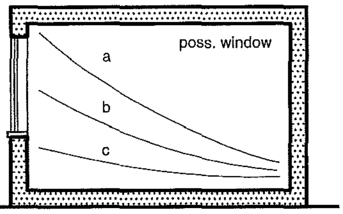
Aims → ❶ – ❽
- no glare, direct or indirect
- differentiated shadowing
- optimal daylight lighting, control
- view out at all times of year
- balanced lighting environment day and night
- colourful daylight-enhancing but similar lighting, in the depths of the room
- reduced artificial lighting component
- matt, light, pastel-coloured surfaces

Requirements
- DIN 5034
- European Standard for Computer Workplaces
- German state building regulations

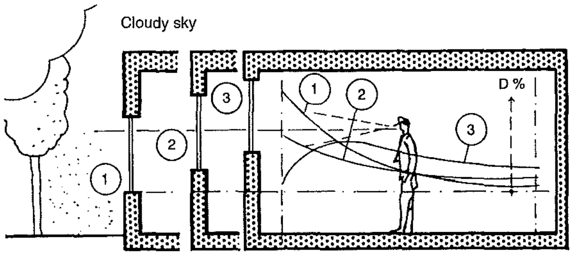
In detail:
- $D_{min} \geqq 2\%$
- $G \geqq 1:6$ (uniformity D_{min}/D_{max})
- estimated window sizes for room depths, approx.:
  $\leqq$8 m approx. 16–20%
  $\leqq$8–11 m approx. 25%
  $\leqq$11–14 m approx. 30%
  $\leqq$14 m approx. 35% of the room area

Window orientation

a) To sun, clear sky some lighting intensity everywhere
b) Cloudy sky
c) Clear sky without sun



❸ Daylight level in a room with various sky lighting conditions



❹ Different distributions of daylight with various positions of window

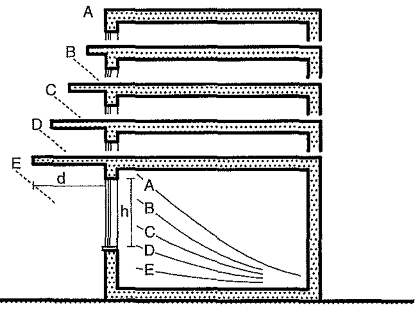
DAYLIGHT
Physical basics
Position of the sun
Insolation
Shadow
Radiation energy
Window lighting
Rooflighting
Quality criteria
Directing sunlight
Shading

BS8206-2
DIN 5034

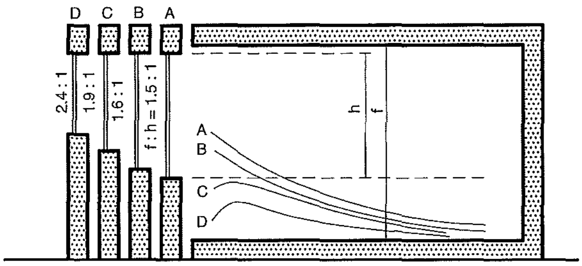
European Standard for Computer Workplaces
LBO

Building services

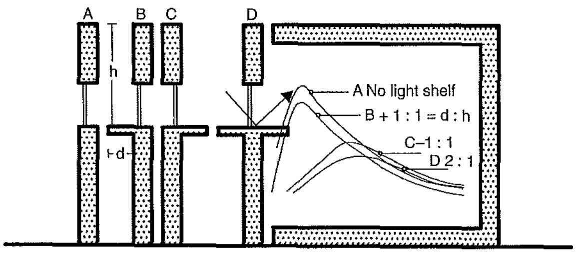
No roof overhang
0.25 : 1 = d : h
0.50 : 1
0.75 : 1
1.00 : 1



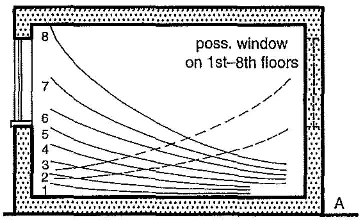
❺ Daylight distributions in a room with various projections under a cloudy sky



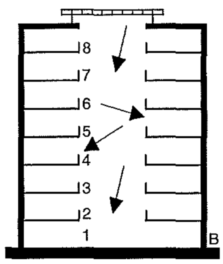
❻ Daylight distributions in a room with various windowsill heights



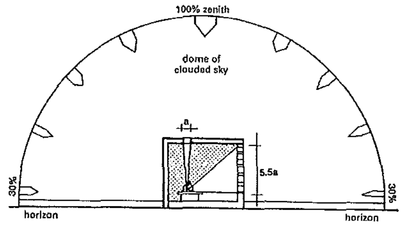
❼ Daylight distributions in a room with various light shelf layouts



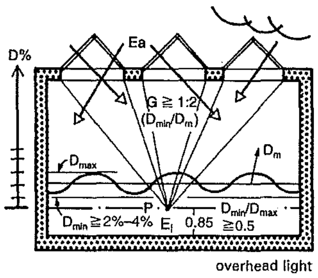
❽ Daylight situations from the first to the eighth floor in an atrium, excerpt → ❾



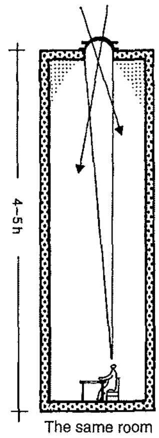
❾ Section of atrium, first to eighth floors, with glass roof



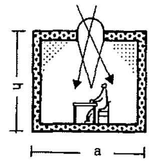
❶ Room with roof opening and side window, according to distribution of light from the zenith



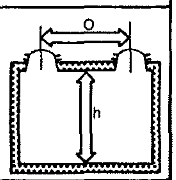
❷ Section through a room with rooflight



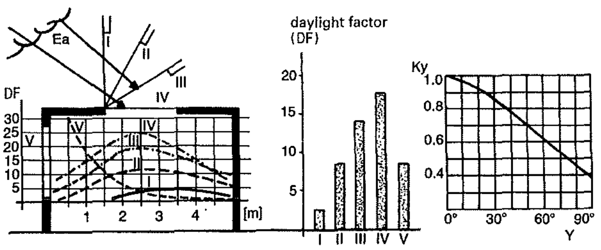
The same room with a height of 12–15 m and a roof opening



❸ Square room with a height of 3 m

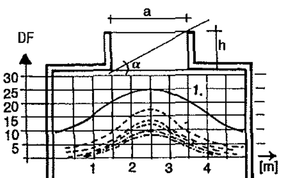
ratio Dmin:Dmax	recommendation	ke value = O/h 90°	60°	45°	O = h·ke
approx. 1:1	target values	< 1 . . . 1.1			
1:1.5		1.2	1.3	1.4	
1:2	tolerable	1.4	1.5	1.7	
1:2.5	critical	1.6	1.8	2.0	
1:3	avoid	1.7	2.0	2.2	

❹ Rooflight spacing, room height and the uniformity of lighting which is sought, including corresponding detailing of the rooflight (ke factor)



❺ (a) Comparative variations in daylight factor for side windows and rooflights, depending on four differently pitched rooflight openings

(b) Reduction factor ky, depending on pitch y of glazing in shed roofs



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

❻ Uniformity of lighting, depending on height of rooflight shaft

Basics

The lighting of interiors with daylight from above is subject to the same basic principles and conditions as for windows at the sides, that is natural lighting under a cloudy sky. Whereas light from the sides creates relatively poor uniformity, this is different with lighting from above. In interiors the quality of daylight coming from rooflights is mainly determined or influenced by the following factors: light density at the zenith, room proportions, room reflection, rooflight opening and reduction factors. The work area → ❶ in a room is placed precisely as far from a window as from the rooflight above. If the same illuminance is to be produced on the reference plane (0.85 m above sill level) through the side window as through the rooflight, then the window area would have to be 5.5 times larger than the roof opening.

Reason: light from above is brighter. The zenith illuminance is three times that at the horizon. So 100% of the light from the sky reaches the rooflight, whereas only 33.3% of the light from the sky reaches the windows at the sides. The lighting of a room 'from above' (light incidence) depends on the room proportions, i.e. the length, width and height. The 'cave effect' should be avoided → ❷.

Required minimum daylight factors

In order to guarantee adequate lighting in a room, the following points have to be noted:
$D_{min}/D_{max} \geqq 0.5$, $D_{min} \geqq 2\%$, in workrooms $\geqq 4\%$
Uniformity G ≧ 1:2, a corresponding opening area of approx. ≧ 16–22% of the plan area → ❸.

Rooflight openings

The advantage of lighting with daylight 'from above' is influenced by the following design factors: room height and clear opening (ke factor). An ideal uniformity is achieved if the spacing of the rooflights (O) corresponds to the room height (h), i.e. a ratio of 1:1. In practice, the following rule applies: the ratio of rooflight spacing to room height should be 1:1.5 to 1:2 → ❹. This table shows these relationships and their effect. The insertion of light shafts is also recommended.

Type and construction of rooflight opening

The pitch of a rooflight determines the percentage of light from the section of the sky framed by it. In → ❺, the amount of light entering through a side window is compared with the amount of light entering through a rooflight at various pitches. The greatest amount of light comes in though a horizontal opening.

The maximum illuminance through a side window, in contrast, is achieved only near the window. With a vertical rooflight, the lowest illuminance is on the reference plane. There is therefore a reduction factor (ky) for the amount of light entering, depending on the different pitches of the roof openings. In → ❺ (b), the corresponding reduction factors (ky) are shown for sheds with various pitches.

The diffused radiation falling on the rooflight is, however, also affected by its construction and installation depth before it supplies the interior with daylight. → ❻ demonstrates the different amounts of light entering through various proportions of the shaft below the rooflight cover. Excessively high and massive shaft construction or installation depths should therefore be avoided. A delicate, highly reflective construction is recommended.

DAYLIGHT
Physical basics
Position of the sun
Insolation
Shadow
Radiation energy
Window lighting
Rooflighting
Quality criteria
Directing sunlight
Shading

BS 8206-2
DIN 5034

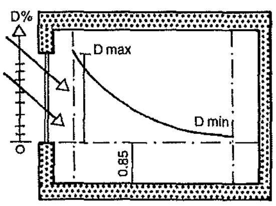
Building services

Type of work	Daylight D%
coarse	1.33
medium fine	2.66
fine	5.00
very fine	10.00
note: 10% is too much on the south side, but good on the north side	

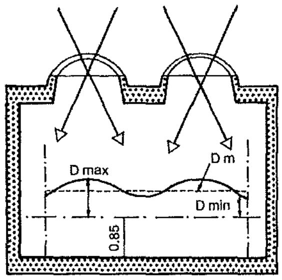
❶ Illuminances D%

Colour by brightness		Materials without colour treatment		Floor coverings: rolls and tiles	
(dark to bright)		(dark to bright)		(dark to bright)	
red	0.1–0.5	smooth concrete	0.25–0.5	dark	0.1–0.15
yellow	0.25–0.65	facing brick		medium	0.15–0.25
green	0.15–0.55	red brick	0.15–0.3	bright	0.25–0.4
blue	0.1–0.3	yellow brick	0.3–0.45		
brown	0.1–0.4	lime sandstone	0.5–0.6		
white (medium)	0.7–0.75	timber surfaces			
grey	0.15–0.6	dark	0.1–0.2		
black	0.05–0.1	medium	0.2–0.4		
		bright	0.4–0.5		

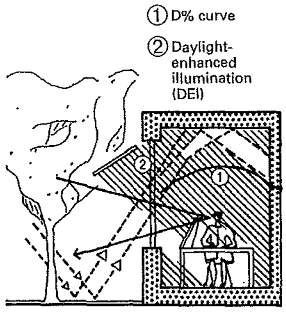
❷ Degree of reflection (further details and material colours → p. 506)



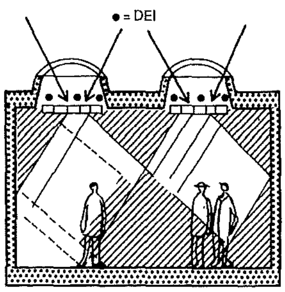
❸ Uniformity of lighting from the side



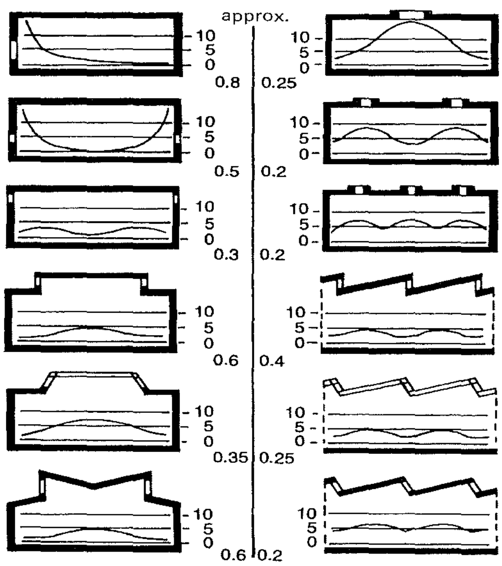
❹ Uniformity of lighting from above



❺ Shadow formation with lighting from the side



❻ Shadow formation with lighting from above



❼ Influence of daylight openings (for the same main dimensions of the room, k_F = window area/plan area = 1:6) on the variation in daylight factor. D_{min} = 5% of necessary k_F value is also given.

Illuminance, degree of reflection and colour rendering

The interaction of these parameters of daylight has a great influence on the brightness inside a room. In order to fulfil certain visual tasks, various levels of illuminance are required, according to the type of activity → ❶.

So the specification of the degree of reflection for the surrounding surfaces of the interior has to be appropriate for the visual tasks to be carried out. The different structuring of brightness in a room is directly dependent on the degree of reflection of the surfaces and the different arrangements of windows in the façade → ❷ → p. 496 ❹.

The uniformity (G) of the daylight in the interior should be G ≧ D_{min}/ D_{max} 1:6 for lighting from windows → ❸, and G ≧ 1:2 → ❹ for lighting from above. This generally determines the characteristics of light distribution in the interior. Rooflight lighting is more uniform because the light density at the zenith is three times greater than at the horizon.

The uniformity can be influenced by variation of the following factors:
– degree of reflection (if very high)
– deflecting the light with shades
– arrangement of the windows.

Glare

Glare is caused by direct and indirect reflection from surfaces and by unfavourable contrasts of light density. Measures to avoid glare are:
– external sun protection (shades)
– glare protection inside and outside in combination with sun protection
– matt surfaces
– correct positioning of daylight-enhancing lighting

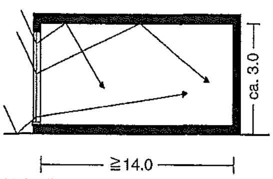
Shadow formation

Shadow formation is beneficial to some extent in order to be able to differentiate objects in the room → ❺. Measures to increase three-dimensional shadow formation under side lighting are:
– sun protection
– glare protection (even in the north)
– balanced daylight distribution
– no direct glare
– multi-layered or staggered façade.

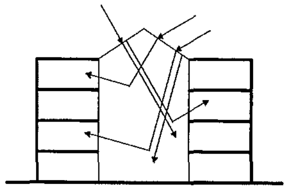
Measures for such shadow formation with rooflights:
– → ❻. Filter incoming daylight at the underside of the light opening with translucent materials, light grating or similar.
– daylight-enhancing lighting
– bright, matt surfaces combined with coloured differentiation (e.g. supporting structure).

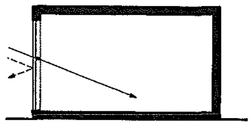
Summary: quality criteria for daylight from side windows

It is generally best to implement the above daylight quality criteria so as to create spatial identity. The distribution of daylight in interiors and the possibilities of seeing out are mainly determined by the design of the façade at the transition from inside to outside. A staggered, multi-layered and at the same time transparent transition from interior to exterior can cope with the various requirements for daylight during the changing seasons.

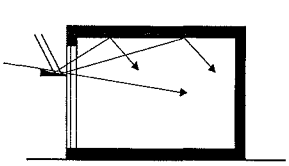


Light direction within the facade with appropriately reflecting room surfaces for large room depths

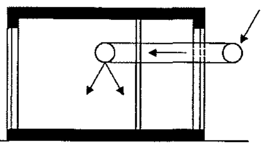

Light direction in the roof for the lighting or rooms, e.g. in atriums, museums, sport halls. . . pale floor!


Selective reflection of solar radiation through coated glasses. Undesirable part of the radiation is reflected.

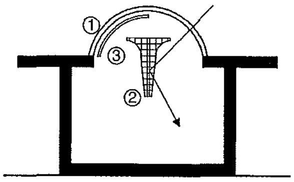
1 Principles of light direction


- Redirection
- Curved reflecting surface, projection in transom area

2 Light blade

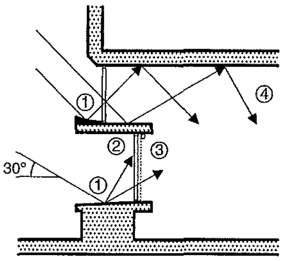

- Light direction in the room depth
- Highly reflecting tubes or glass fibres (e.g. Schott)

3 Light pipe



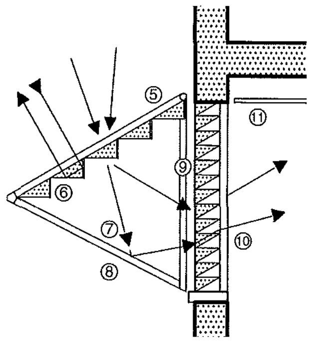
(1) Glass dome (2) Mirror (3) Sun protection
- e.g. Reichstag building, Berlin, Arch. Foster
- Light redirection: direct and indirect light as light reflection

4 Mirror



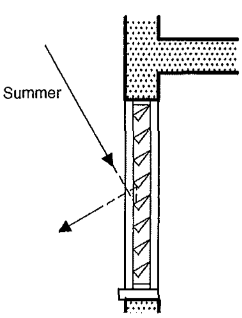
① Light or reflective surfaces
② Light or reflective transoms
③ Glare protection
④ Light, gloss ceiling

5 Light shelf direction

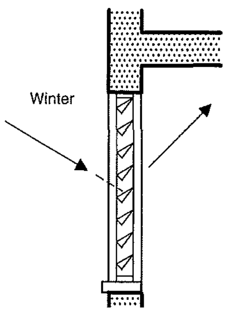


⑤ Glazing
⑥ Glass prism
⑦ Mirroring
⑧ Insulation
⑨ Glass prisms
⑩ Glazing
⑪ Reflective ceiling

6 Prisms: shading and directing according to the time of year

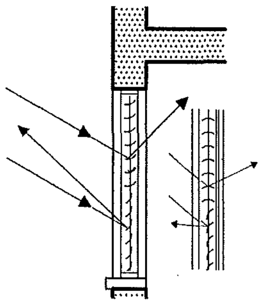


Shading

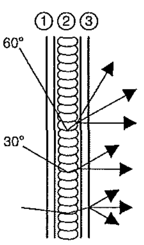


Redirection to ceiling

7 Mirror profiles: between insulated glazing, light direction in accordance with the position of the sun in summer and winter



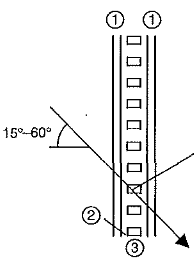
8 Venetian blind: between insulated glazing, with different setting angles for glare protection in lower part and ceiling lighting in upper part



① Float glass
② Profile / acrylic glass
③ Cast / clear glass

Redirection for direct and also for diffused light
Take note of the limitation of transparency

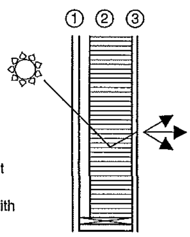
9 Light-directing glass types



① Glass
② Transparent Plexiglas
③ Laminate with laser cuts

- Light redirection
- Laser cuts: cuts between double glazing
Take note of the limitation of transparency

10 Laser cuts



① Float glass
② Capillary system
③ Cast glass scattered light

- Light redirection
- High light transmission
- Flooding with light
Take note of the limitation of transparency

11 Translucent thermal insulation

Integrated light direction and sun protection systems

Aims

- separation and control of incoming light according to angle of incidence
- avoid glare
- increase harvest of light
- enable greater room depths
- lighter environment
- reduce heat build-up
- reduce proportion of artificial lighting

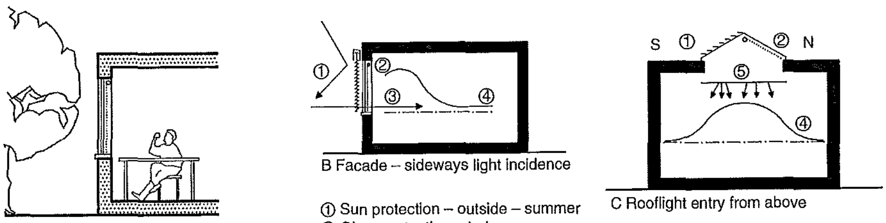
Systems

The following systems are available for light direction:

1. **Reflection** of undesirable heat radiation with special coatings (combi-glass). Different types of coating and sequences of panes can be used to determine the energy transmittance (g-value), the light transmittance (LT-value), the light reflectance (mirror effect) and the colour rendering.
2. **Shading** of direct sunshine and exploitation of diffused zenith light. Mainly rigid systems, which reflect the direct sunshine's light. Mirrors, prisms, or other light-directing components are integrated permanently into the window or glass construction. They must be selected according to their alignment to the sun.
3. **Direction and scattering** of direct sunlight, normally reflection onto the ceiling in order to avoid glare. Movable systems, which can be adapted to the current angle of the sun, are necessary for this purpose.
4. **Collection and forwarding** of direct sunlight. Heliostats collect sunlight and transport it to the intended location by mirroring. The necessary precision of these systems requires expensive production and maintenance. In particular, the wide dimensional tolerances in the building have to be taken into account.

see also: Glass pp. 104 and 100

BS 8206-2
DIN 5034



A Natural sun protection

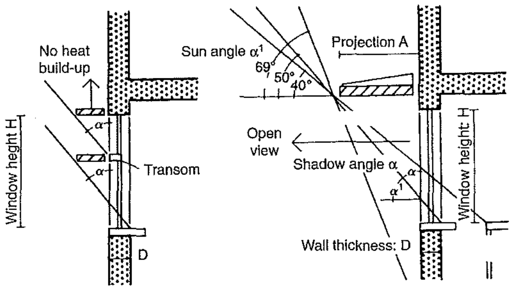
B Facade – sideways light incidence

① Sun protection – outside – summer
② Glare protection – indoors

C Rooflight entry from above

③ Winter sun in room
④ Daylight course
⑤ Possible light-scattering ceiling

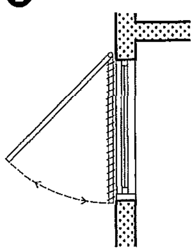
1 Principles of sun protection



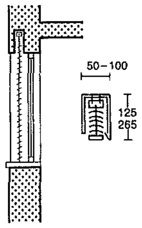
Sun angle α' and shadow angle for a south wall less than 50° northern latitude (London)

21 June (summer solstice), midday α' = 63°, α = 27°; 1 May and 31 July, midday α' = 50°, α = 40°; 21 March and 21 September (equinoxes) midday α' = 40°, α = 50°.
Projection A = tan shadow angle α × window height H;
but min. projection A = (tan shadow angle α × window height H) – wall thickness D

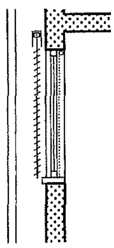
2 Calculation of necessary projection of sun protection components



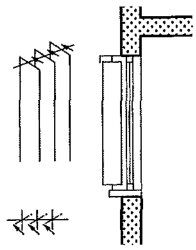
3 **Folding and sliding shutters**
provide very effective and constructionally simple sun protection. Possibly with adjustable slats



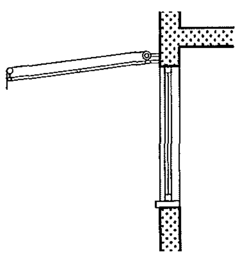
4 **Sun protection slats**
External blinds
Most adaptable sun protection, suitable for all directions



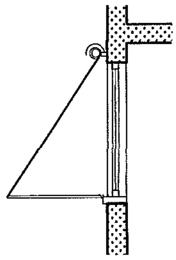
5 **Sun protection slats**
Blinds between glass façade and wall; greenhouse effect must be avoided by use of a suitable ventilation system



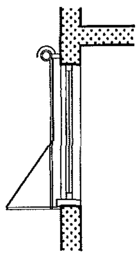
6 **Sun protection slats**
Vertical blades are suitable for all compass points; no heat build-up problems



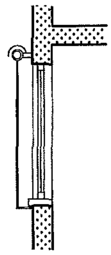
7 **Horizontal awning**
Good sun protection but very susceptible to weather damage, thus if possible automatic operation in connection with a weather station



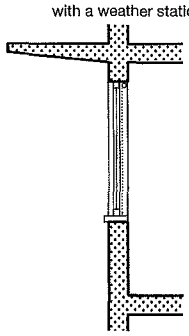
8 **Falling arm awning**
Good sun protection, better weather stability but less view to the outside than **7**



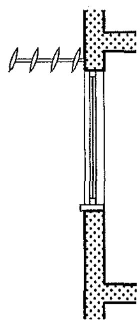
9 **Falling arm awning**
Closeness to window brings danger of overheating and impaired window ventilation



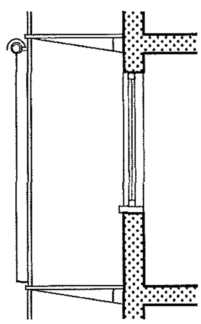
10 **Roller awning**
Awnings directly in front of the window should have the narrowest possible widths and spacing from the wall in order to enable ventilation



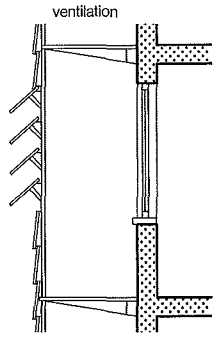
11 **Projections**
Roof overhangs, balconies etc. Rigid, the projection depends on the direction



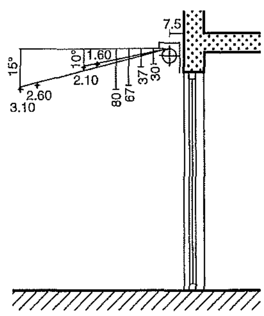
12 **External blinds**
Rigid sun and glare protection; translucent grating or slats, rigid



13 **Double façade**
Sun protection in front of façade, avoids greenhouse effect, susceptible to weather damage



14 **Double façade**
Glass panes, transparent sun protection and light direction system, controllable



15 **Horizontal awning** Dimensions for all large awnings over shop windows and displays

Additive light direction and sun protection systems – aims:

- avoidance of excessive incoming heat radiation and light differences (glare) through windows or façades
- individual control by the user
- no hindrance of individual control of ventilation.

Natural sun protection

Deciduous trees offer natural sun protection in summer. In winter, the leafless trees allow warmth and light into the room.

Systems

System selection depends mainly on the compass direction of the window to be protected. On north sides, direct sunshine can only be expected in the mornings in June and July and simple internal systems are sufficient. If the alignment is largely west or east, movable systems should shade the low sun.

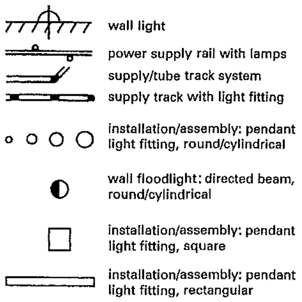
South windows need effective shading above all in the early year and autumn, with low sun. In the high summer, slight roof overhangs are sufficient to avoid direct sunshine.

If external closed shading components (awnings, shutters) are used, it must be possible for the heat build-up behind the component to escape. Such systems are not suitable for rooms with natural ventilation.

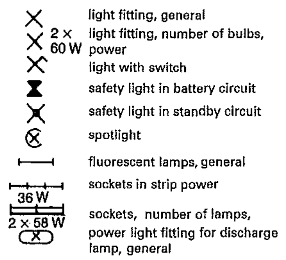
BS 8206-2
DIN 5034

Radiometric quantity	Photometric quantity and symbol	Photometric unit and abbreviation
radiant flux	luminous flux F	lumen (lm)
radiant intensity	luminous intensity I	candela (cd)
irradiance	illuminance E	lux (lx)
radiance	luminance L	cd/m^2
radiant energy	luminous energy Q	(lm × h)
exposure	luminous exposure H	(lx × h)

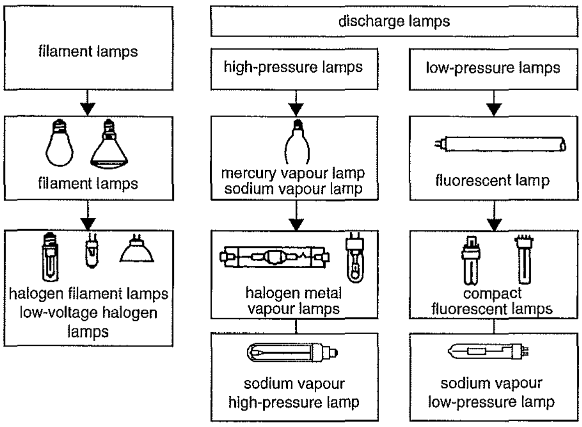
❶ Physical units in radiometry and photometry



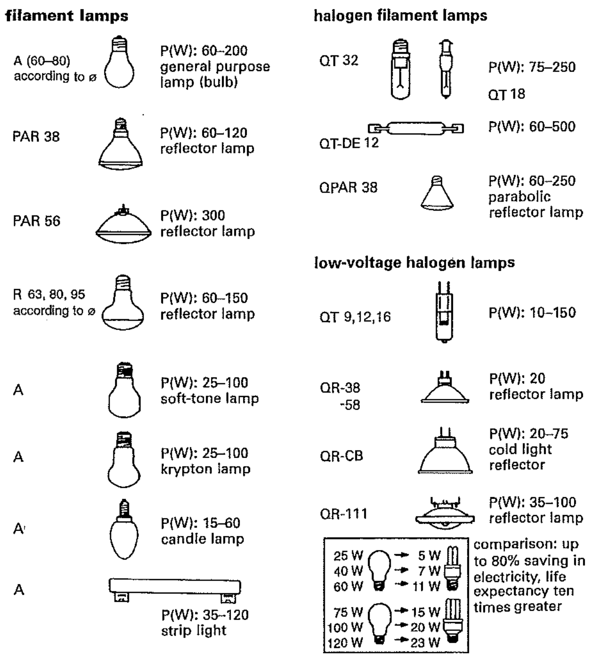
❷ General lighting symbols for architectural plans



❸ Lighting symbols for architectural plans, acc. DIN 40717



❹ Categorisation of lamps



❺ Descriptions of filament lamps according to ZVEI (Central Association of the Electrical and Electronic Industry)

Lighting parameters

The radiated power perceived by the eye is described as luminous flux F. The luminous flux radiated per solid angle in a defined direction is the luminous intensity I. The luminous intensity of a lamp in all directions of radiation gives its distribution, generally displayed as a luminous intensity distribution curve (LIDC) → p. 503 ❷. The LIDC describes the radiation of a lamp as narrow, medium or wide beam and as symmetrical or asymmetrical. The luminous flux reaching a unit of area is the illuminance E. Typical values are:

Global radiation (clear sky)	max. 100,000 lx
Global radiation (cloudy sky)	max. 20,000 lx
Optimal for seeing	2000 lx
Minimum at workplace	200 lx
Orientation lighting	20 lx
Street lighting	10 lx
Moonlight	0.2 lx

Luminance L is a measure of the perceived brightness. The luminance of lamps is relatively high and can lead to glare. This results in the requirement for shading of lamps in interiors. The luminance of surfaces in a room is a function of the illuminance E and the reflectance (L = E x r/p). Lamps convert electrical power (W) into luminous power (lumen, lm). A further measure is luminous efficacy (lm/W).

Lamps

Artificial lighting sources consist of lamp and fitting. The part producing the light is described as the lamp. Fittings serve to hold the lamp and distribute the light (scattering, glare shading). Lamps are differentiated, according to the principle of light production, into filament lamps and discharge lamps → ❹.

1. Filament lamps

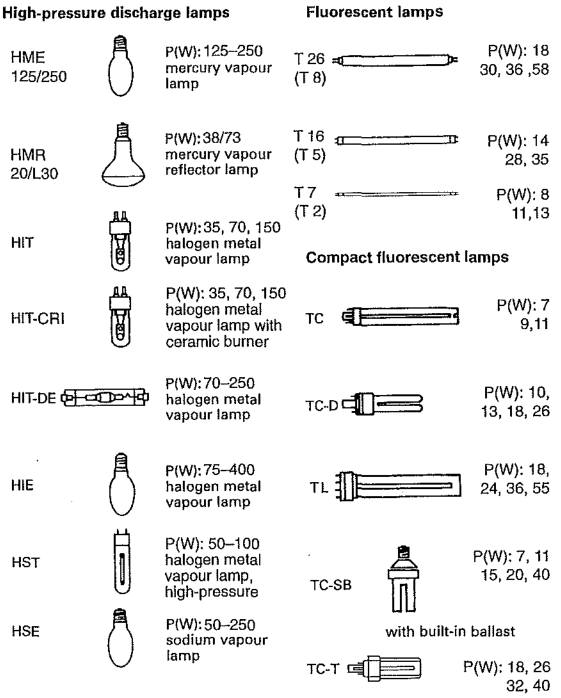
Filament lamps are temperature radiators, in which a filament is made to glow to produce light. A large part of the energy produced is therefore heat radiation (infra red) and a relatively small part is visible light (approx. 15–20%). Typical features of filament lamps: light warm white colour, can be dimmed without limitation, very good colour rendering, operation without flickering. Further characteristics: low luminous efficacy (approx. 6–12 lm/W), short lifetime of lamps at about 1000 hours.

Halogen filament lamps achieve high luminance with their compact construction. The bulb contains a halogen gas, which prevents tungsten from the glowing filament being deposited on the inside of the bulb and reducing the luminous efficacy. The small dimensions of the lamps enable compact fittings with very good bundling properties, thus making them very suitable for narrow beam spotlights. Halogen lamps produce brilliant light, further properties: better luminous efficacy (up to 24 lm/W) than simple light bulbs; lamp lifetime approx. 4000–6000 hours (for low-voltage halogen lamps). For lamp power ratings of up to 75 W, low-voltage 12 V lamps are mostly used, which require a transformer for connection to mains power. For power ratings of 75–2000 W, 220 V mains lamps are suitable.

LIGHTING
Artificial lighting
Lamps
Types of lighting
Lighting layout
Quality criteria
Illuminance
Application
Workplace
Guidelines

BS EN 60432
BS EN 12665
DIN 5035
DIN EN 12464
DIN 40717

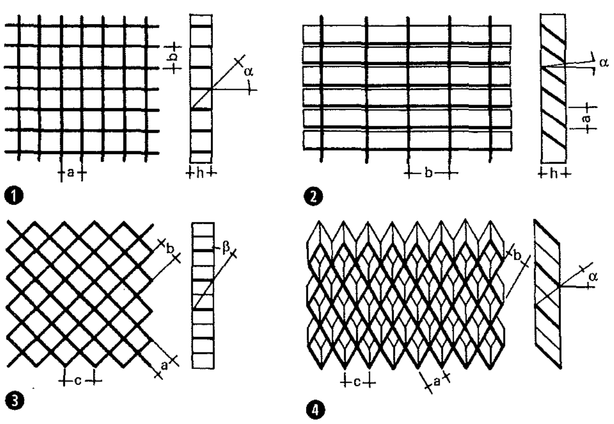
Building services

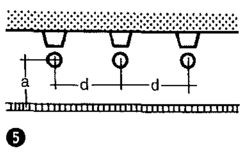


❶ Description of discharge lamps according to ZVEI (Central Association of the Electrical and Electronic Industry)

Type of lamp	Lifetime (h)	Luminous efficacy (lm/W)	Abbreviation (→ ❶ above and → p. 501 ❺)
filament lamp	1000	6–12	A...
parabolic reflector lamp	2000	15	PAR...
halogen filament lamp	1500–2000	12–24	Q...
low-voltage halogen lamp	2000–6000	12–24	Q...
mercury vapour lamp (high-voltage)	6000–8000	70–120	HM...
metal vapour and halogen lamp (high-pressure)	6000–12 000	70–120	HI...
sodium vapour high-pressure lamp	8000–10 000	70–120	HS...
fluorescent tube	20000	80–104	T...
compact fluorescent tube	8000–12000	60–75	TC...

❷ Lamps: lifetime and luminous efficacy





Grid diffuser designs:
❶ Parallel grid
❷ Parallel slanting grid
❸ Diagonal grid
❹ Diagonal slanting grid
❺ Arrangement of lamps a ≧ ⅔ d

❸ Grid patterns for suspended ceiling luminaires

2. Discharge lamps:
Light bulbs or tubes contain a gas, which is made to glow by the application of a voltage. Typical characteristics of discharge lamps: operation generally with ballast and in some cases starter device; high luminous efficacy and relatively long lamp lifetime, 5000–20,000 h; little heat production; light colour, according to the type of lamp: warm white, neutral white or daylight white; colour rendering moderate to very good; lamps cannot always be dimmed. Flicker-free operation is only possible with the use of an electronic ballast. Discharge lamps are differentiated according to the type of gas used and the gas pressure in the tube.

Fluorescent lamps
Also known as fluorescent tubes, these are the commonest discharge lamp. The discharge causes mostly UV radiation inside the tube and this is converted into visible radiation by a coating inside the tube. Luminous efficacy 104 lm/W. In the description, the number after the T gives the diameter of the tube in mm (T 16 = 16 mm diameter) or in ⅛ in (T 5 = 5 × ⅛ in ~ 16 mm). Smaller diameters enable more precise direction of light in the lamps. The ballast is nowadays normally controlled electronically.
Fluorescent lamps are used in offices and commercial buildings in **ceiling grids**. The light mostly shines directly downwards → ❸ or in **light bands** and **linear luminaires** (shining directly or indirectly). This enables uniform overall lighting, similar to daylight, with mild shadow formation.

Compact fluorescent lamps
These have been developed as a replacement for filament light bulbs. The ballast is normally integrated into the screw base. Their luminous efficacy is not as good as that of fluorescent tubes.

Fluorescent tubes for advertising displays
Glass tubes filled with inert gas (e.g. neon, thus the common name neon lighting) are subjected to a voltage. The tubes then light up in various colours according to the gas. The tubes can be curved as required before filling with gas, so that writing, ornaments and depictions of figures are possible. They are easily controllable using regulating resistors or transformers and are often used in cinemas, theatres, sales outlets and advertising.

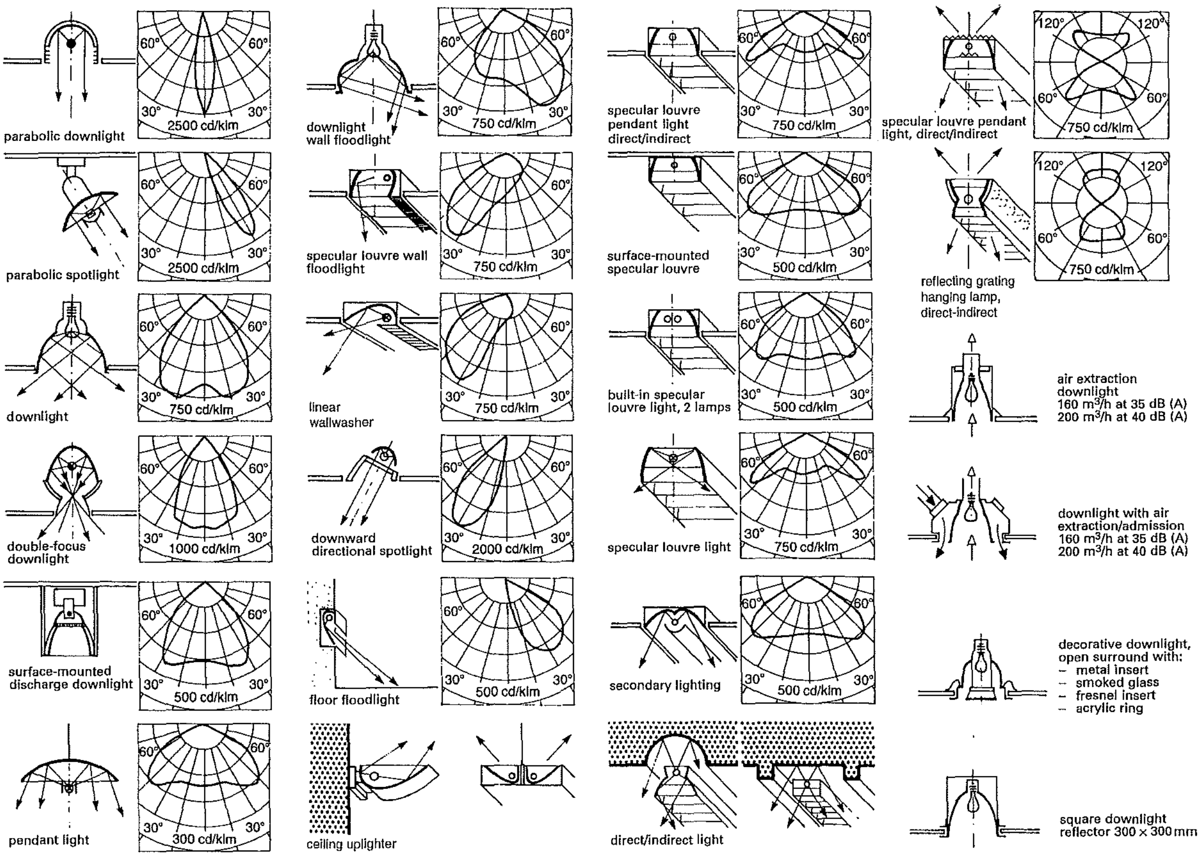
Mercury vapour and sodium vapour high-pressure lamps
In high-pressure lamps, an arc between electrodes creates the light. They have a long lifetime and high luminous efficacy, but poor colour rendering (mercury: blue, sodium: yellow). They are therefore mostly used for the lighting of factories, works sheds, stores and street lighting. Coated mercury high-pressure lamps have improved colour rendering.

Metal vapour and halogen high-pressure lamps
These produce a light with good colour rendering values (the light colours white, warm tone, and daylight are possible) and high luminous efficacy. The compact point light source enables precise direction of the light. The high luminance and a high UV share of the light must be taken into account in the selection of lamps to avoid glare, reflection and the fading of objects susceptible to UV radiation. If fitted with ceramic burners, these lamps are more colour-stable over their lifetime.

Light-emitting diode (LED) lamps
A solid-body crystal is made to glow by the application of direct current (recombination of electrons in a semi-conductor). The colour is determined by the choice of crystal. White light is produced by a combination of coloured LEDs or through luminescent phosphors, which convert the originally coloured light into white. The luminance values today are similar to low-voltage halogen lamps, but will be improved further in the future. Advantages: small size of the light source, little degradation of the lighting performance over the lifetime, no infra red or ultra violet radiation, no impact susceptibility, long lifetime (approx. 25,000–50,000 h)

lighting type			flood lighting	spotlights	uplights	downlights	grid lighting: square grids	grid lighting: rectangular grids
	A	general purpose lamp 60–200W		○		○		
	PAR, R	parabolic reflector lamp reflector lamp 60–300W		○		○		
	QT32	halogen filament lamp 75–250W	○	○	○	○		
	QT–DE	halogen filament lamp, sockets both sides 100–500W	○		○			
	QT–LV NV	low-voltage halogen lamp 10–150W		○		○		
	QR–LV NV	low-voltage halogen reflector lamp 20–100W		○		○		
	T 16 8 2	fluorescent lamp 8–58W	○		○		○	○
	TC TC–D TC–L	compact fluorescent lamp 7–55W	○	○	○	○	○	○
	HME	mercury vapour lamp 50–400W				○		
	HSE/ HST	sodium vapour lamp 50–250W				○		
	HIT HIT-DE CDM-T	halogen metal vapour lamp 35–250W	○	○	○	○		

1 Suitability of lamps and fittings



2 Light fittings and light distribution

LIGHTING
Artificial lighting
Lamps
Types of lighting
Lighting layout
Quality criteria
Illuminance
Application
Workplace
Guidelines

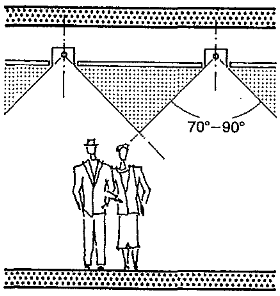
BS EN 12665
DIN 5035
DIN EN 12464

Building services

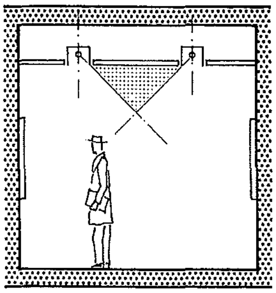
Room height	Nominal illuminance	Rooms	A ≤ 100 W	A > 100 W	PAR 38	PAR 56	R	QT ≤ 250 W	QT – DE	QT > 250 W	QT – LV	QR – CB – LV	QR – LV	T	TC	TC – D	TC – L	HME ≤ 80 W	HME > 80 W	HSE	HST	HIT – DE ≤ 70 W	HIT – DE > 70 W	HIT ≤ 70 W	HIT > 70 W	HIE
up to 3 m	up to 200 lx	parking garages, packing rooms												●				●		●	●					
		side rooms												●	●	●	●			●	●					
		workshops												●												
		restaurants	●				●				●	●	●													
		foyers	●	●	●						●	●			●	●										
	up to 500 lx	standard offices, teaching rooms, counters and cash desks												●		●	●									
		sitting rooms	●	●							●	●		●	●	●	●									
		workshops												●				●	●							
		libraries						●						●			●									
		sales rooms									●	●		●	●	●	●					●		●		
		exhibition rooms			●						●			●	●	●	●	●				●		●		
		museums, galleries, event rooms	●	●	●	●	●	●		●	●	●	●	●			●									
		entrance halls	●	●				●			●			●	●	●	●									
	up to 750 lx	data processing, standard offices with higher visual requirements												●			●									
		workshops												●					●				●		●	
		department stores												●			●	●								
		supermarkets												●												
		display windows						●	●	●	●	●	●									●	●	●	●	
		hotel kitchens												●			●									
		concert stages				●		●	●																	
		technical drawing, open-plan offices												●												
3–5 m	up to 200 lx	storerooms												●				●	●	●	●					
		workshops												●				●								
		industrial sheds												●				●		●	●	●		●		
		foyers	●	●	●						●				●	●										
		restaurants	●				●				●	●	●		●	●										
		churches	●	●	●			●								●										
		concert halls, theatres	●	●				●																		
	up to 500 lx	workshops												●					●				●		●	
		industrial sheds												●					●				●		●	
		lecture theatres, auditoriums, assembly rooms		●				●						●			●									
		sales rooms												●		●	●	●					●		●	
		exhibition rooms, museums, art galleries		●	●	●	●	●	●	●				●		●	●									
		entrance halls		●	●	●		●						●	●	●	●						●		●	
		pubs														●	●									
		sports halls, multi-purpose and gymnastics halls						●						●					●				●		●	●
	up to 750 lx	workshops												●				●	●				●		●	●
		drawing offices												●			●									
		laboratories												●												
		libraries, reading rooms						●						●			●									
		exhibition rooms												●			●		●				●		●	●
		exhibition halls																	●							●
		department stores												●			●						●		●	●
		supermarkets												●												
		large kitchens												●												
		concert stages			●	●		●	●																	
over 5 m	up to 200 lx	industrial and machine sheds, switchrooms												●					●	●	●					●
		storerooms of high-bay warehouses												●					●							
		churches		●		●		●																		
		concert halls, theatres		●		●		●																		
	up to 500 lx	industrial sheds												●					●				●		●	●
		museums, art galleries				●		●						●			●									
		airports, stations, traffic zones												●			●		●	●	●		●		●	●
		event halls				●		●																		
		sports and multi-purpose halls						●						●									●		●	●
	up to 750 lx	industrial sheds																	●	●	●					●
		auditoriums, lecture theatres						●						●			●									
		exhibition rooms							●					●			●						●		●	●
		exhibition halls																	●				●		●	●
		supermarkets												●					●				●		●	●

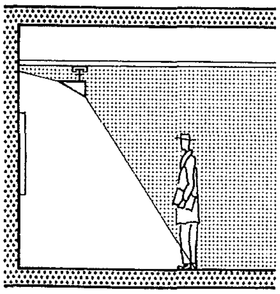
A = general purpose lamps
PAR = parabolic reflector lamps
R = reflector lamps
QT = halogen filament lamps
QT – DE = halogen filament lamps, 2 sockets
QT – LV = low-voltage halogen lamps
QR – LV = low-voltage reflector lamps
QR – CB – LV = low-voltage reflector lamps, cold light
T = fluorescent lamps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

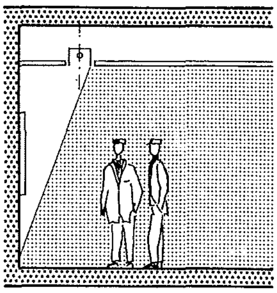
1 Usual lamps for interior lighting

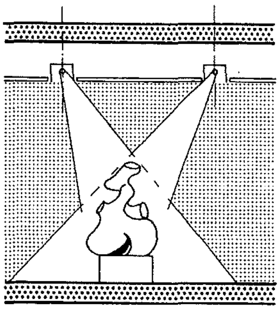


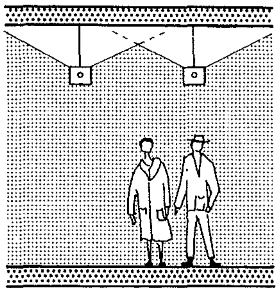
❶ Direct lighting, symmetrical

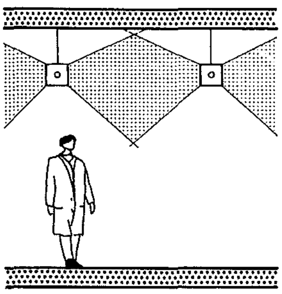

❷ Wallwasher, direct lighting

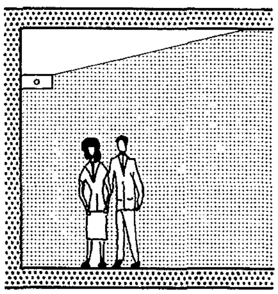

❸ Wallwasher on power supply rail with partial room lighting

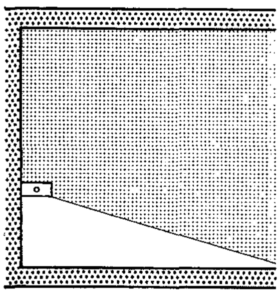

❹ Wallwasher

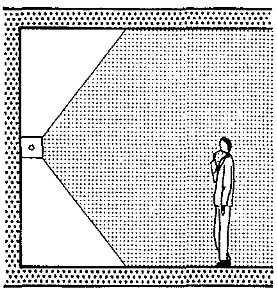

❺ Directional spotlights


❻ Indirect lighting


❼ Direct/indirect lighting


❽ Ceiling uplighter


❾ Floor downlighter


❿ Wall light, direct/indirect lighting

Types of interior lighting

Direct, symmetrical lighting → ❶ is preferred for the general lighting of workrooms, meeting rooms, rooms with public access and traffic zones. Relatively little electrical power is required to achieve a specified lighting level. Guideline values for specific mains consumption → p. 508 ❶. The shading angle of the light fittings in work and meeting rooms is 30°, in conditions of very high visual comfort 40° and more. For the design of a lighting system, a radiation angle of between 70° and 90° should be the first assumption.

Downlight wallwasher, ceiling grid wallwasher → ❷. For use near the wall for uniform wall illumination. The effect in the room is of indirect lighting.

Wallwasher on power supply rail → ❸. Uniform illumination of the wall with a part also lighting the room. According to the chosen spacing of the light fittings, illuminance of up to 500 lx (vertical) can be achieved. The use of fluorescent or halogen filament lamps is also possible (see below also and → ⓫).

Wallwasher for ceiling installation → ❹. With no room component, this only illuminates the wall, using halogen filament or fluorescent lamps.

Downlight directional spotlight → ❺. Regular arrangement of light fittings in the ceiling can achieve spatially differentiated lighting. The relatively closely bundled reflectors can be rotated vertically up to 40° and horizontally through 360°. Halogen filament lamps can be used, particularly low-voltage.

Indirect lighting → ❻. This approach to lighting can produce a bright impression in the room, even at a low level of lighting and without reflected glare. Sufficient room height is a precondition. Careful matching of the lighting and the ceiling architecture is necessary. For the lighting of workplaces, an upper limit to ceiling luminance of 1000 cd/m^2 (above the radiation angle of 65°) should be observed. Indirect lighting requires up to three times the energy consumption of direct.

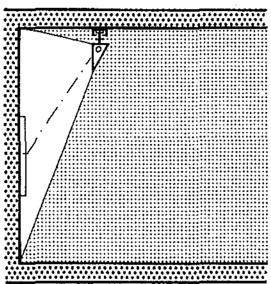
Direct/indirect lighting → ❼. On account of the bright impression in the room and the reasonable energy consumption (70% direct, 30% indirect), direct/indirect lighting is preferred as long as the ceiling height is sufficient ($h \geqq 3$ m). Fluorescent tubes are mostly used, or in combination with halogen filament and filament lamps (seldom).

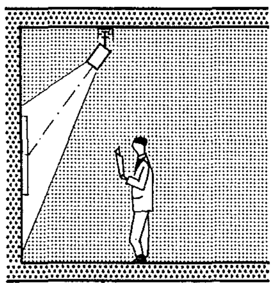
Ceiling uplighter, floor downlighter → ❽ – ❾ are used for the area lighting of ceilings or floors. The lamps can be halogen filaments, fluorescent tubes or high-pressure discharge lamps.

Wall light → ❿. Predominantly for decorative wall lighting – also light effects, e.g. colour filters and prisms. There is also some limited lighting of the ceiling and floor.

Wallwasher on power supply rail → ⓫ does not light the room and is used particularly for exhibitions and in museums. Vertical lighting level from 50 lx, 150 lx and 300 lx can be produced for the lighting of displays.

Narrow beam on power supply rail → ⓬. Preferred radiation angles: 10° ('spot'), 30° ('flood'), 90° ('washer'). The light cone from narrow beam lights can be altered with lenses (sculpture lenses and Fresnel lenses); the spectrum can be altered with ultra violet or infra red filters (in museums, exhibitions, shops) or colour filters. Glare protection is through louvres or anti-glare flaps.

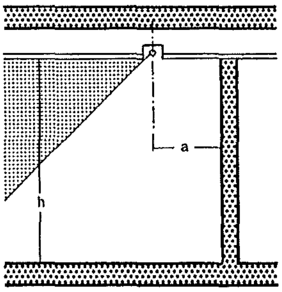

⓫ Wallwasher on power supply rail


⓬ Spotlight on power supply rail

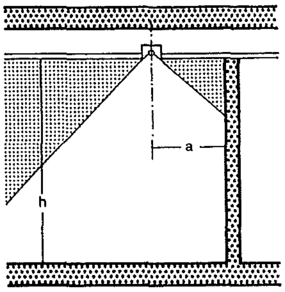
LIGHTING
Artificial lighting
Lamps
Types of lighting
Lighting layout
Quality criteria
Illuminance
Application
Workplace
Guidelines

BS EN 12665
DIN 5035
DIN EN 12464

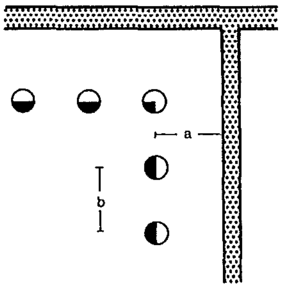
Building services



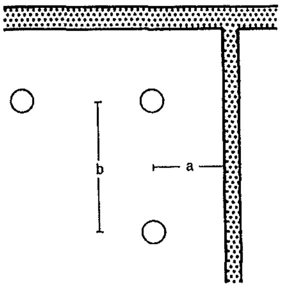
❶ Downlight wallwasher; distance from wall: a ≈ ⅓h



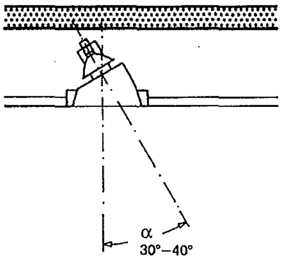
❷ Downlight; distance from wall: a ≈ ⅓h



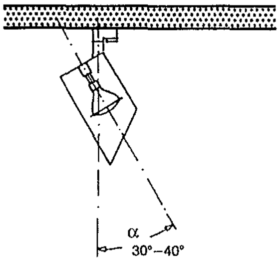
❸ Downlight wall washer; spacing of lights: b = 1–1.5a



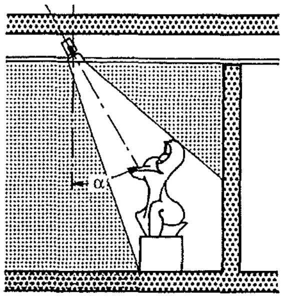
❹ Downlight; spacing of lights: b ≈ 2a



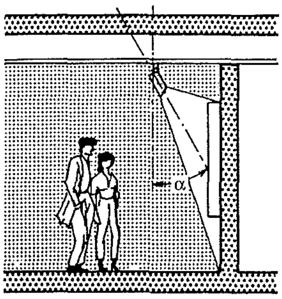
❺ Inclination angle of directional spotlights and downlighters: α = 30–40° (optimal)



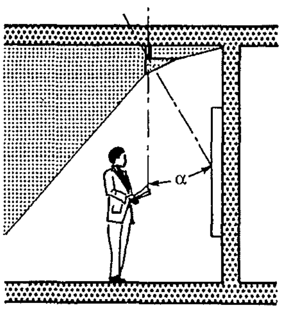
❻ Inclination angle of spotlights for lighting objects and wall: α = 30–40° (optimal)



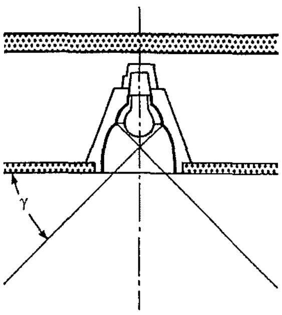
❼ Lighting an object



❽ Wall lighting; spotlight



❾ Wall lighting; downlighter



❿ Shading angle (γ = 15°/20°/30°)

Geometry of the lighting layout

The spacing of lights, between each other and from the wall, is related to room height → ❶ – ❹.

The preferred incidence of light onto objects and areas of wall is between 30° (optimal) and 40° → ❺ – ❾. The shading angle for downlights is between 30° (wide light, adequate glare protection) and 50° (deep light, high glare protection) → ❿, for grid lights between 30° and 40°.

Recommended illuminance			Area, activity
20	30	50	paths and working areas outdoors
50	100	150	orientation in rooms with short occupancy
100	150	200	workrooms not used constantly
200	300	500	visual tasks with few demands
300	500	750	visual tasks with medium demands
500	750	1000	visual tasks with high demands, e.g. office work
750	100	1500	visual tasks with high demands, e.g. fine assembly
1000	1500	2000	visual tasks with very high demands, e.g. checking activities
	over	2000	additional lighting for difficult and special visual tasks

⓫ Recommended illuminance values, Commission International de l'Eclairage (CIE)

code: IP	example IP 44
1st number: 0–6	degree of protection against contact and foreign bodies
2nd number: 0–8	degree of protection against water penetration

	1st number, degree of protection against contact/foreign bodies		**2nd number**, degree of protection against water penetration
0	no protection	0	no protection
1	protection against large foreign bodies (>50 mm)	1	protection against vertical water drops
2	against medium foreign bodies (>12 mm)	2	water drops at incidence up to 15°
3	against small foreign bodies (<2.5 mm)	3	against splashing water
4	against granular foreign bodies (<1 mm)	4	against spraying water
5	against dust deposits	5	against water jets
6	against dust entry	6	against water penetration from flooding
		7	against dipping in water
		8	against immersion in water

⓬ Protection classes for light fittings

Stage	Ra colour rendering index	Typical applications
1A	>90	paint sampling, art gallery
1B	90 > Ra > 80	residence, hotel, restaurant, office, school, hospital, printing/textile industry
2A	80 > Ra > 70 70 > Ra > 60	industry
3	60 > Ra > 40	industry and other areas with low requirements for colour rendering
4	40 > Ra > 20	ditto

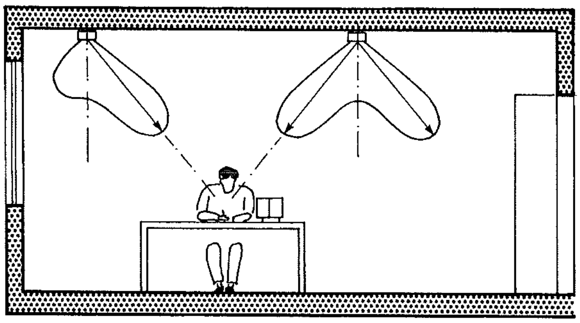
⓭ Colour rendering of lighting

Reflector type	Property
parabolic	directs light rays in parallel from point light source
spherical	reflects light into focal point of reflector
ellipsoidal	collects light to second focal point

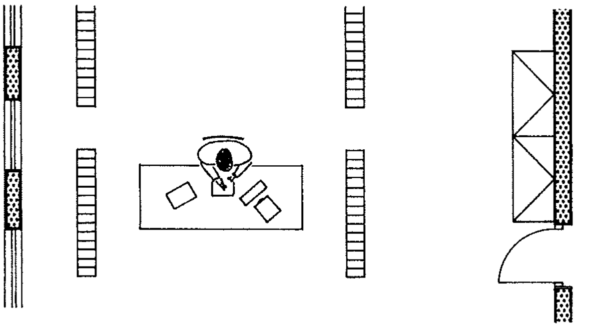
⓮ Reflector forms

Lamp luminance (cd/m²)	20 000 ≦ 50 000	50 000 ≦ 500 000	<500 000
Minimum shading angle γ	15°	20°	30°

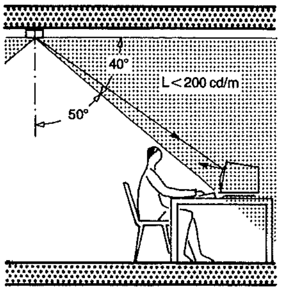
⓯ Shading angle against glare



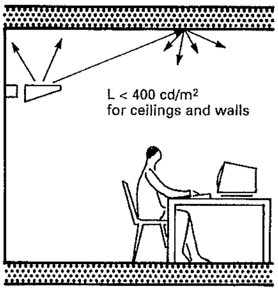
❶ Correct arrangement of lights for a work area, falling from the side



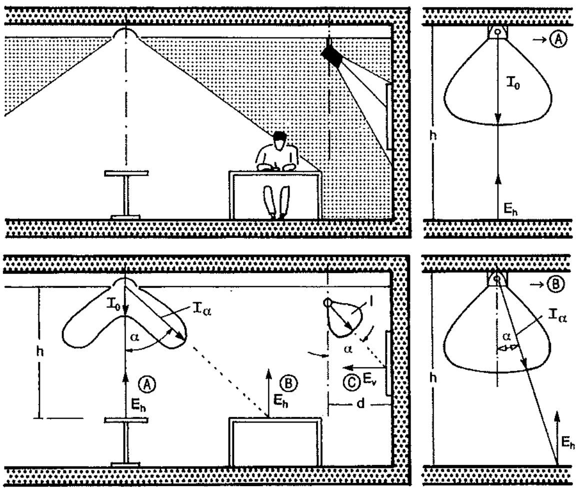
❷ Working surfaces, monitor screens, keyboards and paper should have matt surfaces



❸ Lights which could cause reflections should have low luminance in the critical lighting area



❹ Luminance of indirect lighting

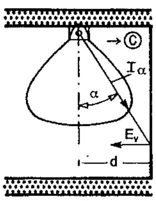


❺ Point illuminances

Ⓐ $E_h = \frac{I_0}{h^2}$

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

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



❻ Law of photometric distance

Quality criteria for lighting

A good lighting design must satisfy functional and ergonomic requirements while taking cost-effectiveness into account. In addition to these quantitative demands, qualitative, above all architectural, criteria must be observed.

Quantitative criteria

Lighting level

In contrast to former standards, DIN EN 12464 no longer specifies an average illuminance, but an illuminance at locations where visual work is carried out. In such places, the uniformity must be 0.7, and 0.5 in comparison with the surroundings.

Light direction → ❶

The light should preferably fall sideways onto the work area; the precondition for this is a wing-shaped LIDC → p. 503 ❷.

Glare limitation → ❷ – ❸

The glare to be limited includes direct glare, reflection glare and mirroring on monitor screens. Limitation of direct glare is achieved by the use of luminaires with shading angles of ≧30°.

The formation of reflections is prevented by the light falling sideways onto the work area in connection with using matt surfaces around the working environment → ❷ + ❺. Mirror reflections on screens can be limited through appropriate screen positioning. Lights which could nonetheless cause screen reflections must have a luminance of ≦200 cd/m² (use of high-gloss reflectors).

Distribution of luminance

The harmonic distribution of luminance is the result of a careful matching of all reflectances in the room → ❼. The luminance of indirect lighting should not exceed 400 cd/m².

Colour of light and colour rendering → p. 505 ⓭

The colour of the light is determined by the choice of lamps. There are three light colour groups: warm white light (colour temperature under 3300 K), neutral white light (3300 K–5000 K) and daylight white light (over 5000 K). In offices, lighting is normally chosen to produce warm white and neutral white. The colour rendering, which is determined by the spectral composition of the light, should generally be 1 (very good colour rendering).

Calculation of point illuminance levels → ❺ – ❻

Illuminances (horizontal E_h and vertical E_v) produced by individual lights can be determined from the luminous intensity and the spatial geometry using the law of photometric distance (height h, distance d and lighting angle α).

	Reflectance (%)		Reflectance (%)
Light fittings material		mortar, light, lime mortar	40–45
aluminium, pure gloss	80–90	mortar, dark	15–25
aluminium, anodised, matt	80–85	sandstone	20–40
aluminium, polished	65–75	plywood, rough	25–40
aluminium, matt	55–76	cement, concrete, rough	15–30
aluminium coatings, matt	55–65	brick, red, new	10–15
chrome, polished	60–70		
enamel, white	65–75	**Paints**	
paint, pure white	80–85	white	70–75
copper, highly polished	60–70	light grey	40–60
brass, highly polished	70–75	medium grey	25–35
nickel, highly polished	50–60	dark grey	15–25
paper, white	70–80	light blue	40–50
silvered mirror behind glass	80–90	dark blue	15–20
silver, highly polished	90–92	light green	45–55
		dark green	15–20
Building materials		pale yellow	50–65
oak, light, polished	25–35	brown	10–40
oak, dark, polished	10–15	light red	35–50
granite	20–25	dark red	10–35
limestone	35–55		
marble, polished	30–70		

❼ Reflectances of light fittings materials and building materials

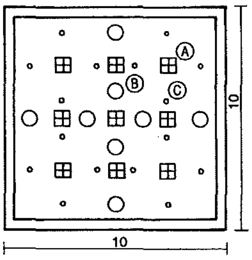
BS EN 12665
DIN 5035
DIN EN 12464

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

❶ Specific mains load P* for various types of lamps

Correction factor k				
Height H	Area A (m²)	Light reflectance		
		070502 light	050201 medium	000 dark
Up to 3 m	20	0.75	0.65	0.60
	50	0.90	0.80	0.75
	≧100	1.00	0.90	0.85
3–5 m	20	0.55	0.45	0.40
	50	0.75	0.65	0.60
	≧100	0.90	0.80	0.75
5–7 m	50	0.55	0.45	0.40
	≧100	0.75	0.65	0.60

❷ Correction factor table

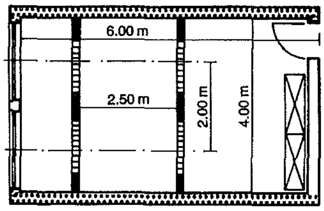


❸ Calculation of illuminance for an interior

example
room area A = 100 m³
room height H = 3 m
reflection factor 0.5/0.2/0.1 (medium)
type of light A
P* = 4W/m² × (compact fluorescent lamp)
P* = 9 × 45W = 405W
type of light B
P* = 12W/m² × (general purpose lamp)
P* = 8 × 100W = 800W
type of light C
P* = 10 W/m² × (halogen filament lamp)
P* = 16 × 20 W = 320 W
formula → ❽

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

$E_n = 180\,\text{lx}$

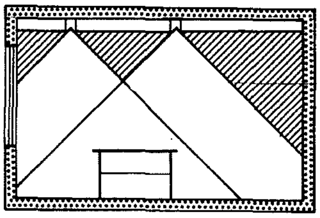


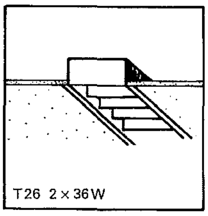
A = 24 m²
k = 0.75 (bright reflection)
P = 4 × 90 W = 360 W

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

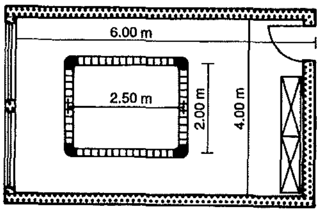
$E_n = 375\,\text{lx}$

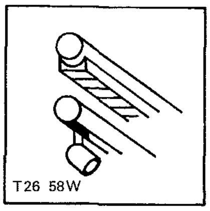
❹ Calculation for an office



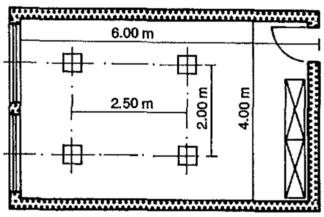


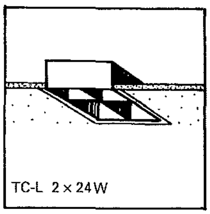
❺ Ceiling grid light fitting (ERCO)





❻ Light structure (ERCO)





❼ Ceiling grid light fitting (ERCO)

Calculation of mean illuminance

In practice, it is often necessary to make a rough determination of mean illuminance values (E_n) for a given amount of electrical power used by lights, or to determine the use by the lights of electrical power P for a required illuminance level. E_n and P can be approximately determined by using the formula → ❽. The required mains power P* depends on the type of lights used → ❶, referring to direct lighting. The correction factor k depends on the size of the room and the reflectance of the walls, ceiling and floor → ❷. If calculations have to be made for rooms containing various types of lighting then the components are calculated singly and added together → ❸.

The calculation of illuminance using the specific mains power is also applicable to office spaces. A two-axis room with an area of 24 m² is in this example → ❹ fitted with four lights. With an assembly of 2 × 36 W (mains power including ballast 90 W), then according to → ❽ the illuminance is approx. 375 lx.

In offices, in addition to conventional mirrored ceiling grid fittings, square ceiling luminaires with compact fluorescent lamps → ❼ or light structures → ❻ are often installed. Light structures enable the combination with busbars for the mounting of spotlights.

Floodlighting buildings

The luminous flux required for floodlighting can be calculated using the formula → ❾. The luminance levels are between 3 cd/m² (free-standing buildings) and 16 cd/m² (buildings in very bright surroundings).

$E_n = \dfrac{100 \times P}{A \times P} \times k$ $P = \dfrac{E_n \times A \times P^*}{100} \times \dfrac{1}{k}$	E_n nominal illuminance (lx) P connected load (W) P* specific connected load (W/m²) → ❶ A room floor area k correction factor → ❷

❽ Formula for mean illuminance E_n and mains load P

formula for calculation of luminous flux of lights

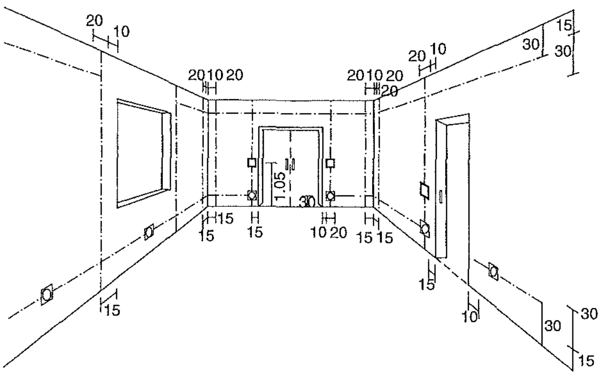
$$\Phi = \frac{\pi \times L \times A}{\eta_B \times \rho}$$

luminance of building to be floodlit	cd/m² L
free-standing	3–6.5
dark surroundings	6.5–10
medium surroundings	10–13
very bright surroundings	13–16
lighting effectiveness, building	η_B
large and small area	0.4
great distance	0.3
towers	0.2

Φ = required luminous flux
L = mean luminance (cd/m²)
A = surface to be floodlit
η_B = lighting effectiveness
ρ = reflectance of building material

reflectance for floodlighting	
building material	ρ
brick, white glazed	0.85
white marble	0.6
light render	0.3–0.5
dark render	0.2–0.3
light sandstone	0.3–0.4
dark sandstone	0.1–0.2
light brick	0.3–0.4
dark brick	0.1–0.2
light timber	0.4–0.5
granite	0.1–0.2

❾ Required luminous flux for floodlights



❿ Preferred dimensions for electrical cabling of residential buildings (cm)

LIGHTING
Artificial lighting
Lamps
Types of lighting
Lighting layout
Quality criteria
Illuminance
Application
Workplace
Guidelines

BS EN 12665
DIN 5035
DIN EN 12464

Recommendations for application

	Warm white				Neutral white		Daylight white		
light colours	827	927	830	930	840	940	950	865	965
colour rendering value	1B	1A	1B	1A	1B	1A	1A	1B	1A
sales areas									
foodstuffs	●		×						
textile, leather goods		×	●	×	●	×			
furniture, carpets	×	×	●	×					
sport, games, stationery			×		×				
photography, clocks, jewellery			×	●	×	●			
cosmetics, hairdressing	●	×	●	×	●	×			
flowers				×		×			
bakery products	×								
refrigerated counters, chests	×								
cheese, fruit, vegetables	×								
fish	×		×		×				
department stores, supermarkets	×	×	×	×	×	×			
industry, trades									
workshops					×				
electrical, mechanical engineering					×			×	
textile manufacture					●	×	×	●	×
printing, graphic trades					●	×	×	●	×
paint shops							●	×	●
warehousing, despatch					×				
woodworking					×		×	×	
steelworks, rolling mills					×				
laboratories			●	×	●	×	×	×	●
colour testing							×		×
office and administration									
offices, corridors			×		×				
meeting rooms	×		×		×				
education									
lecture theatres, classrooms, kindergartens			×	●	×				
libraries, reading rooms	×	●	×						
social spaces									
restaurants, pubs, hotels	×	×							
theatres, concert halls, hotels	×								
event spaces									
exhibition and trade fair halls	×		×		×				
sports and multi-purpose halls			×		×				
galleries, museums		×		×					
clinics, medical practices									
diagnosis and treatment				×		●			
patients' rooms, waiting rooms		×		×					
residential									
living rooms	×		●						
kitchen, bathroom, hobby room, cellar	×		×		×	×			

1 Light colour recommendations for various application areas

● = recommendation   × = possible

Workplace Guidelines 'Artificial Lighting', 7/3; DIN EN 12464-1 (Excerpt)

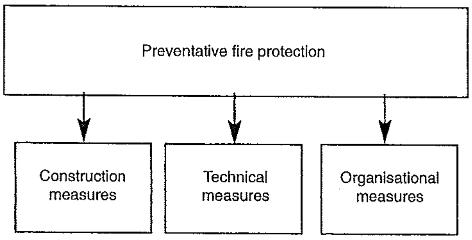
Indoor workplaces

type of interior or activity	E_n/lx
General rooms:	
traffic zones in storage rooms	50
service point	200
canteens, tea kitchens	200
break rooms	100
gymnastic rooms	300
changing, washing and toilet rooms	200
sanitary rooms	500
service rooms, switchrooms	200
telex and post rooms, telephone switchboards	500
despatch and packing areas	300
pantry and storage areas	100
(High-bay) warehouse	
traffic route with no pedestrians	20
traffic route with pedestrians	150
Vehicle and/or traffic routes:	
– no pedestrians	20
– for pedestrians	100
– for pedestrians and vehicles	150
stairs, escalators, moving walkways	150
loading ramps, loading areas	150
Offices and similar rooms:	
filing, copying	300
traffic zones in workrooms	300
writing, typing	500
reading, data processing	500
technical drawing	750
meeting rooms	500
reception desk	300
rooms for public access	200
CAD workplaces	500
Chemical industry:	
plants with remote control	50
plants with occasional manual inputs	150
constantly manned locations in process plants	300
maintenance	300
laboratories	500
work with increased visual tasks	500
colour testing	1000
Ceramics, tiles, glass, glassware:	
drying	50
mixing, material preparation, working at kilns	200
enamelling, rolling, pressing, forming simple parts, glazing, glass blowing	300
grinding, engraving, polishing glass, forming glass instruments	750
manual grinding and engraving	750
fine work	1000
making/polishing artificial gems	1500
Steelworks, rolling mills, large foundries:	
production plants without input	50
production plants with input	150
constantly manned workplaces in production plants	200
maintenance	300
checking stations	500
Metal preparation and processing:	
free-form cutting	200
drop forging	200
welding	300
coarse and medium machine work	300
fine machine work	500
checking stations	750
cold rolling mills	200
wire drawing plants	300
processing of heavy sheet metal	200
processing of light sheet metal	300
manufacture of hand tools	750
coarse assembly	200
medium-fine assembly	300
fine assembly	500
foundries, cellars etc.	50
scaffolding	100
sanding	200
cleaning cast metal	200
workplaces at mixers	200
foundry halls	200
emptying positions	200
machine moulding shop	200
manual moulding shop	300
core-making shop	300
model making	500
galvanising	300
painting	300
checking stations	750
tool making, fine mechanical work	1000
bodybuilding	500
spraying	750
retouching sprayed paint	1000
upholstery	1000
finished assembly	500
final checking	1000
Power stations:	
fuel supply plants	50
boiler house	100
pressure compensation room	200
machine halls	200
side rooms	200
switching gear in buildings	100
switching gear in the open air	20
switching maintenance	500
repair work	500
Electrical industry:	
cable and conductor manufacture, assembly work, winding coarse wire	300
assembly of telephones	750
winding medium wire	500
assembly of fine devices	750
adjusting, testing	1500
assembly of very fine components, electronic components	1500
Jewellery and clock industry:	
manufacture of jewellery	1000
processing gemstones	1500
optician and watchmaker workshop (manual work)	1500
Timber processing and manufacture:	
wet pits	150
sawmill	300
assembly	300
selection of veneers, varnishing, model joinery	750
work on timber processing machines	500
timber treatment	500
quality control	1000
Paper making, and processing, graphical trades:	
wood grinding	200
paper machines, cardboard manufacture	300
bookbinding, printing wallpaper	500
Printing plant	
cutting, gilding, embossing, etching blocks, working on stones and plates, printing machines, preparation of stencils, hand printing, sorting paper	500
retouching, lithography, hand and machine use, preparing type	1000
expert checking of colour printing	1500
steel and copper etching	2000
Leather industry:	
working at vats	200
processing skins	300
saddler	500
leather dying	750
leather colours, mechanical	500
quality control	1000
colour testing	1000
Textile manufacture and processing:	
workplaces at baths	200
spinning shops	300
dyeing	500
spinning, knitting, weaving	500
sewing	750
millinery	750
cleaning	1000
goods checking, colour checking	1000
invisible mending	1500
printing fabric, automatic	500
Food, drinks and tobacco industry:	
general workplaces	200
mixing, packing	300
abattoirs, dairies, mills	500
cutting and sorting	300
making fine foods and cigarettes	500
product control, decorating, sorting	500
laboratories	500
colour checking	1000
Wholesale and retail:	
sales rooms, permanent workplaces	300
cash desks	500
Trade: (examples for various branches)	
painting of steel components	200
preliminary assembly of heating and ventilation systems	200
metalwork	300
vehicle workshops	300
joinery	300
repair workshops	500
radio and television workshops	500
Service companies:	
reception/cash desk	300
kitchens	500
dining rooms, restaurants	200
buffets	300
self-service restaurants	200
conference rooms	500
washing and chemical cleaning	300
ironing and pressing	300
control and retouching	750
hair care	500
cosmetics	750
Plastic processing:	
injection moulding	500
plastic blowing	300
plastic pressing	300

Outdoor workplaces

type of outdoor workplaces, traffic routes, traffic zones and workshops	E_n/lx
Traffic routes in the works area, works roads	
gate facilities	50
footpaths	5
cycle ways $E_{min} \geqq$	3
works roads with loading and unloading or with heavy crossing traffic and with speed limit $\leqq$30 km/h	10
works roads with loading and unloading or with heavy crossing traffic and with speed limit	20
Car parks	3
Harbours	
container handling areas	
parking areas and traffic zones	20
loading and unloading containers	100
quay facilities	
quay edge	5
loading unit goods	20
loading bulk goods (loose goods, liquids)	10
working areas in storage facilities	
unit goods	20
bulk goods	5
dangerous liquids	5
landing stage for passenger traffic	30
landing stage for mixed traffic	50
docks	50
repair workshops in harbours	50
handling areas, loading areas	30
Working areas in storage and stacking facilities:	
unit goods	30
bulk goods	10
Rail facilities:	
track yards, marshalling yards	
1 public transport	3
2 other traffic	5
platforms	
cargo handling	30
at-grade level crossings	20
Construction sites:	
building	20
civil engineering	20
steelwork, metalwork	30
tunnelling	30
Large chemical works, power stations:	
traffic zone	10
1 traditional power station	10
2 nuclear power station	20
switching gear	20
Open cast mining:	
1 orientation lighting	3
2 extra area lighting	20
Water treatment works:	
routes	5
Petrol stations	100

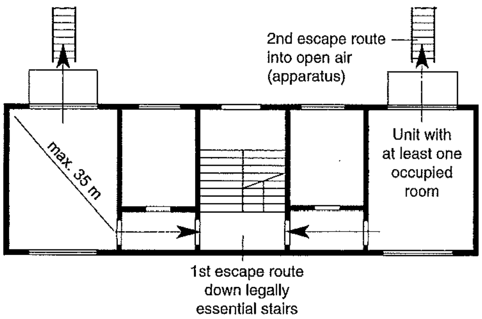
❶ Nominal guideline illuminance values for workplaces



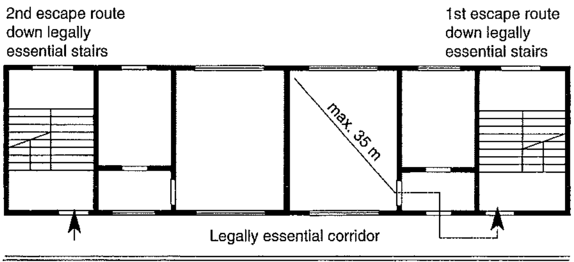
❶ Preventative fire protection measures (in contrast to the fire-fighting measures of the fire brigade)

Regulation	Content
DIN 4102	Fire behaviour of building materials and components
DIN EN 13501	Classification of building products and building types according to fire behaviour
MBO	Model building regulations with the general constructional requirements for preventative fire protection
MIndBauR	Guideline for constructional fire protection in industrial buildings
MVStättV	Regulations for the construction and operation of places of assembly
MSchulBauR	Guidelines for the building supervision requirements for schools
MHHR	Guidelines for the building supervision treatment of high-rise buildings
ArbStättV/ASR	Workplace Regulations/Workplace Guidelines
BGV	Regulations of the accident insurers for trades
VdS/CEA	Regulations and notices of the specialist insurers

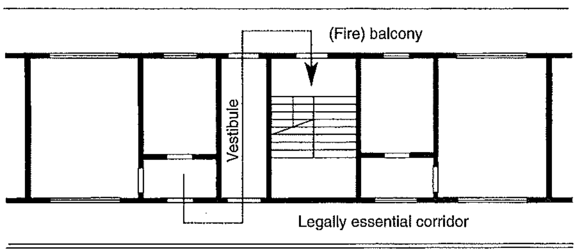
❷ Technical rules for fire protection (excerpt)



❸ First and second escape routes for occupied units not on the ground floor (theoretical diagram, MBO)



❹ First and second escape routes via two legally essential stairwells and legally essential corridor (theoretical diagram, MBO)



❺ Escape route via safety stairwell (theoretical diagram, MBO) → p. 246 High-rise buildings

Buildings must be constructed so that the **start of fire,** and the **spread of fire and smoke,** are prevented, and **rescue of people** and animals and **effective fire fighting** are possible. Consequently there are requirements concerning flammability of building materials, building components' duration of fire resistance (fire resistance rating), the sealing of closures to openings and the provision of escape routes.

There are basically three categories of preventative fire protection measures → ❶:

Construction measures apply to the design (e.g. escape routes, number and construction of stairwells and the formation of fire compartments). They also apply to all construction solutions for the building and its components (e.g. minimum cross-sections, envelope, claddings and coatings, provision of riser pipes, installation of fire protection doors and glazing etc.). **Technical fire protection measures** include all technical precautions, which activate automatically in case of fire (e.g. smoke and fire detector systems, sprinkler systems, smoke and heat extraction systems). **Organisational fire protection measures** describe the appointment of a fire protection representative and the creation of a fire safety organisation and plans.

The general construction requirements for preventative fire protection are based on the state building regulations (LBO) or the **model building regulations (MBO)** that they are derived from:

For buildings in **building classes 1–5,** the MBO include, in addition to fire protection requirements, the provision of clearance or setback areas → p. 64 and regulations for the detailing of load-bearing walls, columns, external walls, partitions, fire compartment walls, slabs and roofs → p. 514–516 and requirements for the provision of escape routes.

Special buildings are subject to special fire protection requirements, which are laid down in additional regulations and provisions. **At the design phase of such a building, a fire protection expert must be appointed to produce a fire protection plan.**

For a selection of significant technical rules for fire protection → ❷.

Escape routes

Residential or commercial units with at least one occupied room must have at least **two independent escape routes leading to the open air** on each storey. (If the units are not at ground level, the first escape route must be via a **legally essential staircase, if required in its own (legally essential) stairwell**, and the second escape route via a second essential staircase or a single unified location which is accessible with the rescue equipment of the local fire brigade → ❸. From every location in an occupied room, there must be within max. 35 m at least one exit into a legally essential stairwell or into the open air → ❹. A second escape route is not required if escape is via a **safety stairwell** → ❺, into which fire and smoke cannot penetrate due to the provision of 'fire balconies' or safety vestibules with forced ventilation → p. 246 High-rise buildings.

The material and construction of legally essential staircases and the location, construction, surfaces and openings of legally essential stairwells are subject to special fire protection requirements. For **legally essential corridors,** through which the escape routes from occupied rooms or units lead to legally essential stairwells or to the open air, there are also particular fire protection requirements.

FIRE PROTECTION

Classification

The model building regulations (MBO) differentiate requirements for fire resistance into: fire-resistant, highly fire-retarding and fire-retarding **building components** made of completely non-flammable materials or with just the structural parts made of non-flammable materials; special building components (with special fire protection requirements); and associated **building materials,** divided, according to their fire behaviour, into non-combustible, flame-resistant, normally flammable and readily flammable.

Building components and materials are categorised into classes according to their fire behaviour. For purposes of classification, the state building regulations (LBO) differentiate between **regulated, non-regulated** and other building products. Regulated building products essentially comply with the standards and other technical regulations included in the **construction products lists** of the German Institute for Building Technology (DiBt). The permissibility of using non-regulated products must be verified by a national technical test certificate, a national technical approval or a single-case approval.

Classification is according to DIN 4102 or DIN EN 13501. These standards classify building materials according to building material classes → ❹ and building components according to fire resistance classes → ❶ – ❷. **Classifications are applicable according to either DIN 4102 or DIN EN 13501 for the verification of the fire behaviour of building materials.**

Fire resistance duration (min) DIN 4102/ DIN EN 13501-2	30	60	90	120	180
building components	F 30/ *R 30*	F 60/ *R 60*	F 90/ *R 90*	F 120/ *R 120*	F 160/ *R 160*
non-load-bearing external walls	W 30/ *E 30* 1) *EI 30* 2)	W 60/ *E 60* 1) *EI 60* 2)	W 90/ *E 90* 1) *EI 90* 2)	W 120/ *E 120* 1) *EI 120* 2)	W 180/ *E 180* 1) *EI 180* 2)
fire protection boundaries	T 30/ *EI 30 C* 2)	T 60/ *EI 60 C* 1)	T 90/ *EI 90 C* 2)	T 120/ *EI 120 C* 2)	T 180/ *EI 180 C* 2)
F-glazing	F 30/ *EI 30*	F 60/ *EI 60*	F90/ *EI 90*	F 120/ *EI 120*	F 180/ *EI 130*
G-glazing	G 30/ *E 30*	G 60/ *E 60*	G 90/ *E 90*	G 120/ *E 120*	G 180/ *E 180*

1) from inside to outside
2) from outside to inside

❶ Fire resistance classes of building components, DIN EN 13501-2 and DIN 4102-2, -3, -5

Building regulations requirements	Fire compartment boundaries		Smoke protection doors	Cable stopping	Pipe stopping
fire-resisting	*EI 30 C* 2)	F 60/ *R 60*	F 90/ *R 90*	F 120/ *R 120*	F 160/ *R 160*
highly fire-resisting	W 30/ *E 30* 1) *EI 30* 2)	W 60/ *E 60* 1) *EI 60* 2)	W 90/ *E 90* 1) *EI 90* 2)	W 120/ *E 120* 1) *EI 120* 2)	W180/ *E 180* 1) *EI 180* 2)
fireproof	T 30/ *EI 30 C* 2)	T 60/ *EI 60 C* 2)	T 90/ *EI 90 C* 2)	T 120/ *EI 120 C* 2)	T 180/ E^2 *180 C* 2)
fire resistance 120 min.	F 30/ *EI 30*	F 60/ *EI 60*	F 90/ *EI 90*	F 120/ *EI 120*	F 180/ *EI 180*
smoke-proof and self-closing	G 30/ *E 30*	G 60/ *E 60*	G 90/ *E 90*	G 120/ *E 120*	G 180/ *E 180*

1) from inside to outside
2) from outside to inside

❷ Fire resistance classes of special building components according to DIN EN 13501-2, -3, -4 and their categorisation by building regulations requirements (excerpt)

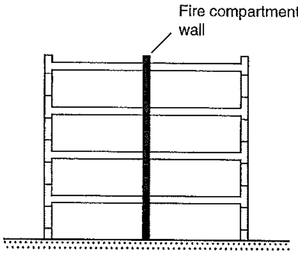
	1	2	3
	Description in building regulations	Description according to DIN 4102	Short code
1	fire-retarding	fire resistance class F 30	F 30-B[2)]
2	fire-retarding and consisting of structural parts of non-combustible building materials	fire resistance class F 30 and with essential parts[1)] of non-combustible building materials	F 30-AB[2)]
3	fire-resisting and consisting of non-combustible building materials	fire resistance class F 30 and consisting of non-combustible materials	F 30-AB[2)]
4	fire-retarding and consisting of structural parts of non-combustible building materials	fire resistance class F 60 and with essential parts of non-combustible building materials	F 60-AB
5	highly fire-retarding and consisting of non-combustible building materials	fire resistance class F 60 and consisting of non-combustible materials	F 60-A
6	fireproof (e.g. walls); fireproof and consisting of structural parts of non-combustible building materials	fire resistance class F 90 and with essential parts[1)] of non-combustible building materials	F 90-AB[2)]
7	fireproof and consisting of non-combustible building materials (e.g. walls)	fire resistance class F 90 and consisting of non-combustible materials	F 90-A[2)]

[1)] The **essential parts** include:
[a)] all load-bearing or bracing parts, and in the case of non-load-bearing parts also constructions which produce their structural stability (e.g. frame construction of non-load-bearing walls).
[b)] for building components forming the boundary of a room, a continuous layer in the building component, which may not be destroyed during the test according to this standard.
For ceilings, this layer must have a total thickness of at least 50 mm; voids within this layer are permissible.
In the evaluation of the fire behaviour of building materials, paint or coatings up to a thickness of approx. 0.5 mm are not considered.
[2)] For the complete description of building components according to DIN 4102 the **building materials** class is given after the **fire resistance class.**

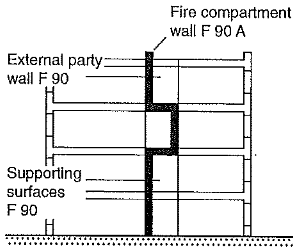
❸ Listing of fire resistance designations according to MBO and DIN 4102, according to the model introduction decree to DIN 4102 (→ refs)

Building regulations requirements according to MBO	Additional requirements		DIN EN 13501-1	DIN 4102-1
	no smoke	no falling burning parts/drops)		
non-combustible	x	x	A1	A1
at least	x	x	A2 s1 dO	A2
flame-resistant	x	x	B,C-s1 d0	B1
		x	A2 -s1 d0 A2,B,C-s3 d0	
	x		A2,B,C-s1 d1 A2,B,C-s1 d2	
at least	x	x	A2,B,C-s3 d2	
normally flammable		x	D-s1 d0 D-s2 d0 D-s3 d0 E	B2
			D-s1 d2 D-s2 d2 D-s3 d2	
at least			E -d2	
readily flammable			F	B3

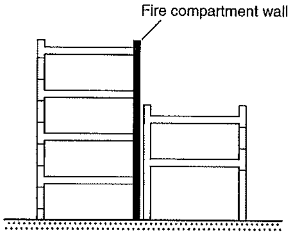
❹ Classification of the fire behaviour of building materials, MBO, DIN EN 13501-1 and DIN 4102-1 (DiBt → refs)



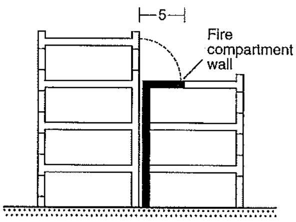
❶ Continuous fire compartment wall in one plane



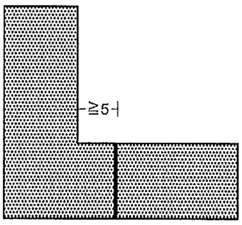
❷ Staggered fire compartment wall



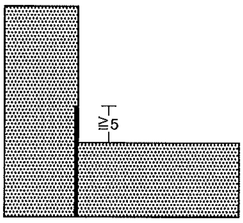
❸ Fire compartment wall must extend above the roof of the higher building



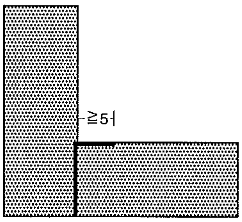
❹ If the fire compartment wall is in the lower building, then the roof slab must be constructed of fire compartment wall quality



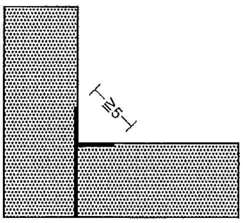
Arrange fire compartment wall ≧5 m from internal corners



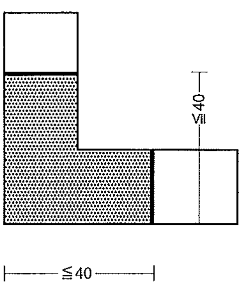
Extend fire compartment wall in an internal corner by ≧5 m to both sides (variant 1)



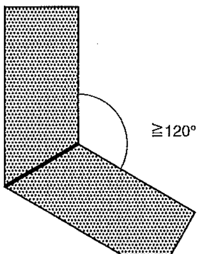
Extend fire compartment wall to one side by ≧5 m (variant 2)



Extend fire compartment wall to both sides



Fire compartment wall is to be located ≦40 m from the external corner

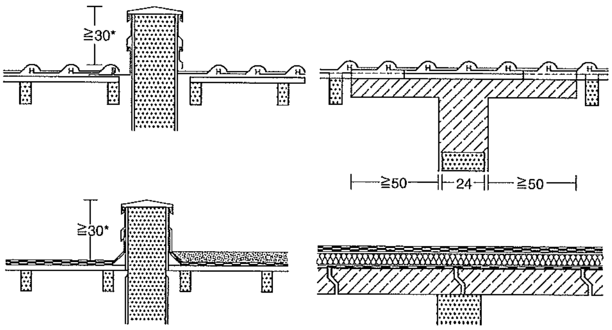


Fire compartment wall must not project at an angle over 120°

❺ Layout of fire compartment walls at building corners

According to the MBO, **fire compartment walls** are to be constructed in the following locations: the **external walls** of buildings, when the wall is less than 2.50 m from the plot boundary; between terraced buildings on the same plot boundary; and to **sub-divide** larger buildings into fire compartments of not more than **40 m.**

Fire compartment walls must be fireproof, structurally stable when exposed to fire and consist of non-combustible materials **(F 90A).** They must normally extend continuously from the foundations to **min. 30 cm above the roof** (min. 50 cm for a soft roof covering and in industrial buildings) or be capped with a projecting slab → ❻. For low buildings, they must continue to immediately under the roof covering. **Cables and pipes** which penetrate fire compartment walls must have a 90 min fire resistance class. **Openings in fire compartment walls** are generally **impermissible.**They can be allowed through fire compartment walls within buildings and then have to be provided with fireproof self-closing doors (**T 90 door or gate**) → p. 512 ❷.



Continue fire protection wall min. 30 cm above roof (min. 50 cm in industrial buildings)

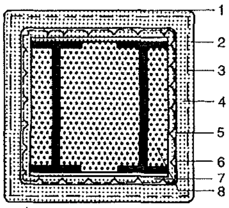
Closure with fireproof slab of non-flammable materials.

❻ Top of fire compartment walls in buildings with hard roof covering

Construction material for fire compartment walls	Min. thickness (mm) Single-skin	Two-skin
Masonry		
according to DIN 1053-1, with mortar group II, IIa, III or IIIa when using bricks according to DIN 105-1 of		
bulk density class ≧1.4	240	2 × 175
bulk density class ≧1.0	300	2 × 175
calcium silicate blocks according to DIN 106-1, 1 A1, 2 of bulk density class ≧1.8	240	2 × 175
Pre-cast brick components		
according to DIN 1053-4 using vertically		
cored brick panels with fully mortared butt joints	165	2 × 165
composite panels with two skins of brick	240	2 × 165
Normal concrete		
unreinforced concrete according to DIN 1045	200	2 × 180
reinforced concrete according to DIN 1045 in the form of non-load-bearing horizontal or vertical wall components	120	2 × 100
load-bearing wall components or in situ concrete	140*)	2 × 120*)
Lightweight concrete		
with porous structure according to DIN 4232 of		
bulk density class ≧1.4	250	2 × 200
bulk density class ≧0.8	300	2 × 200
Aerated concrete		
reinforced min. strength class 4.4 non-load-bearing, vertical or horizontal		
wall components of bulk density class ≧0.7	175	2 × 175
load-bearing vertical components, vertical wall components of bulk density class ≧0.7	200*)	2 × 200*)

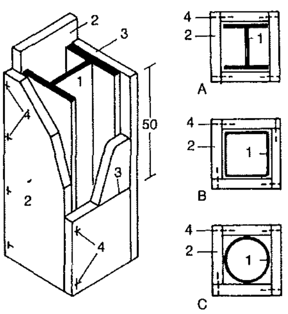
*) as long as no higher value is required due to high wall stresses (see DIN 4102-35, table 44).

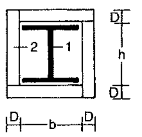
❼ Minimum thicknesses of building materials for single- and double-skin fire compartment walls (excerpt from DIN 4102-4, table 45 → refs)



1. Edge protector
2. ≧5 mm ground lime or lime cement plaster, of mortar group I or II acc. DIN 18550
3. Wired fabric
4. ≧35 mm vermiculite-cement plaster
5. Binding wire
6. Ribbed expanded metal
7. Expanded metal and round steel ≧5 mm as spacer
8. Core, min. 1.5 m above the floor, brick/masonry lined or cemented

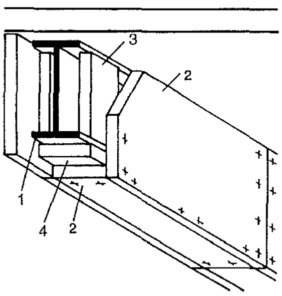
❶ Steel column with conventional plaster surround F 90

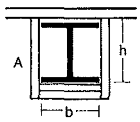




1 Steel column
2 Fire protection board (e.g. PROMATECT®)
3 Staggered joints to boards
4 Wire clamps or drywall screws
h Profile height
b Profile width
D Thickness of the fire-protection cladding

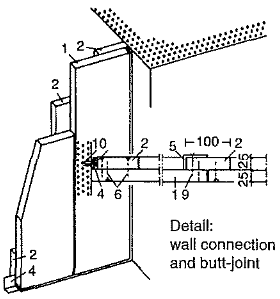
❷ Steel column with fire protection boards F 30 A–F 180 A



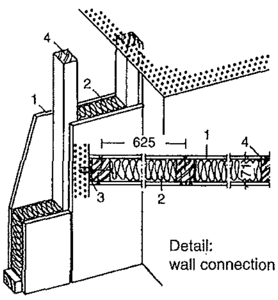


1 Steel support beam
2 Fire protection board (e. g. Promatect®)
3 Fixing piece
4 Extra piece behind joint
5 Profile height
6 Profile width

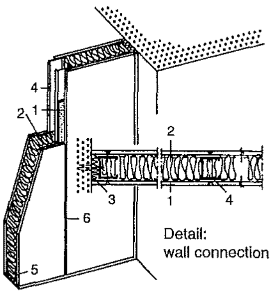
❸ Fire protection cladding for steel support beams F 30 A–F 180 A



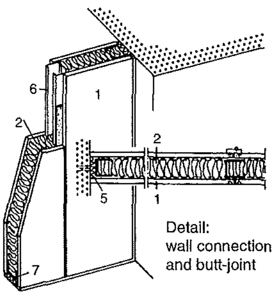
❹ Lightweight fibre silicate partition F 30 A (principle)



❺ Timber stud wall F 30 B (principle)



❻ External wall component with thermal insulation W 90 (principle)



❼ Stable fibre silicate partition with C-profile studs F 90 A

Walls, columns

The **MBO** lay down requirements for walls and columns, of which the essential features are:

Load-bearing and **bracing walls** and **columns** must be constructed **fireproof** in buildings of class 5, **highly fire-retarding** in buildings of class 4 and **fire-retarding** in buildings of classes 1 and 2). This does not apply to the uppermost storeys of roof spaces without occupied rooms above them and balconies. In **cellars,** they have to be constructed **fireproof** and, in buildings of classes 1 and 2, **fire-retarding.**

Non-load-bearing external walls and non-load-bearing parts of load-bearing external walls are (except for buildings of building classes 1–3) to be constructed of non-combustible (at least fire-retarding) materials. **External wall claddings,** including insulation and support construction, have to be made of flame-resistant materials. For buildings of classes 1 and 2, external wall claddings of normally flammable materials are permissible, if the spread of fire to neighbouring buildings is effectively prevented.

Building materials	Class	Certificate	Mark
sand, gravel, loam, clay, natural stone, minerals, earth, lava clinker, natural pumice	A1	cl. B.	no
mineral fibres without organic supplements	A1	cl. B.	no
mineral fibre boards, mats, felt, shells	A½	approval mark	yes
cement, lime, anhydrite, clinker and foamed slag, expanded clay, slate, perlite, vermiculite	A1	cl. B.	no
mortar, concrete, reinforced and pre-stressed concrete, blocks and building boards of mineral composition	A1	cl. B.	no
brick, stoneware, ceramic slabs	A1	cl. B.	no
glass, foam glass	A1	cl. B.	no
glass fibre boards, mats, felt, wadding	A½	approval mark	yes
plexiglass	B1	approval mark	yes
plaster wall and ceiling boards[1]	A1	cl. B.	no
coated and uncoated	A1	approval mark	yes
particle board, veneered boards	B1	approval mark	yes
roofing felt and waterproofing	B2	cl. B.	yes

This table contains:
– classified building materials, according to DIN 4102, which can be included in the given building material class without further verification (cl. B)
– building materials which have to be included in certain building material classes under applicable standards. The verification is normally through a test certificate.
– building materials of classes A and B1, for which approval marks have been issued; these are normally issued to the manufacturer.

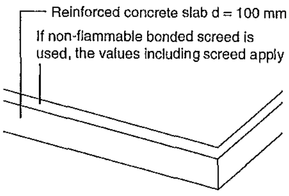
❽ Combustibility of construction materials (selection)

Separating walls

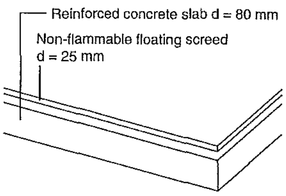
The fire resistance duration of separating walls between residential or commercial units (or units and rooms used otherwise) must correspond to the quality of the load-bearing components of the storey. These must extend to the structural slab (in roof spaces up to the roof cladding). Openings are limited to the size and number required for their use and must be closed by components which are at least fire-retarding, sealed and self-closing.

Construction

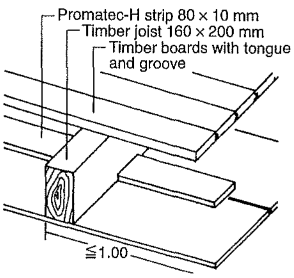
Classified materials for the construction of conventional massive load-bearing or non-load-bearing walls are shown in → ❽. Steel columns and steel supporting beams are today normally fitted with box-shaped **claddings** of fire protection boards, whose thickness depends on the profile dimensions and the required fire resistance class → ❶ – ❸. There are also **non-foaming coatings** (to F 90) and composite constructions with concrete filling, if necessary with additional reinforcement (F 60). Non-load-bearing separating walls can be constructed as stud partitions of various qualities → ❹ – ❻.



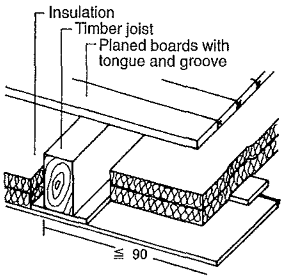
❶ Reinforced concrete slab F 90 A



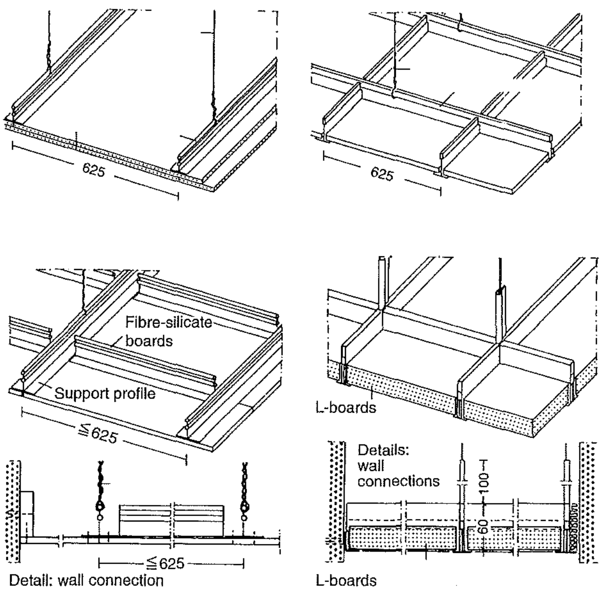
❷ Reinforced concrete slab F 90 A with floating screed



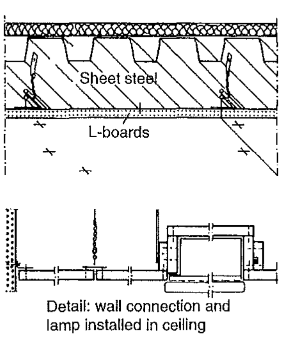
❸ Timber joist floor F 30 B



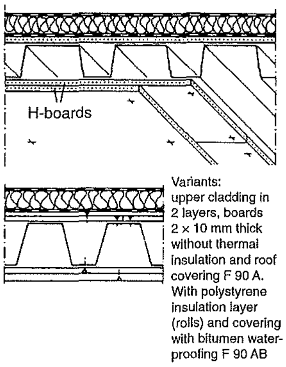
❹ Timber joist floor F 90 B (with thermal insulation)



❺ Fibre-silicate suspended ceiling F 90 A (principle)



❻ Trapezoid metal sheet roof (fibre silicate suspended ceiling) F 30 AB



❼ Trapezoid metal sheet roof F 90 A, F 90 AB

Slabs and ceilings

The **MBO** contain fire protection requirements for ceilings, floor slabs acting as ceilings, slabs over cellars and openings through these, of which the most important aspects are described here:

Ceilings must be fireproof, or at least fire-retarding, and **slabs over cellars** must be fireproof. **Openings in ceilings and floor slabs** for which a fire resistance duration is necessary are prohibited. If openings are required, they must be fitted with fire protection closures (doors, etc.) constructed with a fire resistance duration corresponding to that of the slab.

Exceptions apply for buildings of classes 1 and 2, slabs and ceilings above roof spaces, and balconies, slabs and ceilings within residential dwellings.

Construction

The following constructional types of slab and ceiling are differentiated for purposes of fire protection:

Solid slabs (e.g. reinforced concrete slabs → ❶, hollow pot floors) have sufficient fire resistance under certain conditions without additional protection measures. Numerous construction types are classified in DIN 4102 → ❽. Floors consisting of **timber joists, steel joists or concrete slabs on profiled metal decking** must be protected against fire from below (suspended ceiling → ❺) and above (covering, screed), in which case the connections at walls and any inserts in the floor have to be taken into account. The fire resistance achieved is normally verified with a test certificate → p. 512. In this case, the **entire construction** is included in the evaluation. Also usual is the installation of self-supporting suspended ceilings with their own fire resistance class (e.g. to protect the installations in the ceiling void).

Building material and construction	Min. unfinished thickness (mm) for:				
	F 30 A	F 60 A	F 90 A	F 120 A	F 180 A
fully reinforced concrete slabs (exstg.) without cladding beneath	60	80	100	120	150
as above, but with floating screed¹⁾	60 (25)²⁾	60 (25)²⁾	60 (25)²⁾	60 (30)²⁾	80 (40)²⁾
hollow pot slabs	115	140	165	240	290
as above, but with screed¹⁾	90	90	115	140	165

¹⁾ non-combustible screed ²⁾ screed thickness

❽ Classified slab constructions, DIN 4102 (excerpt)

Roofs

The **MBO** also include fire protection requirements for roofs. The essential requirements are:

The roofing must generally consist of 'hard covering' and be resistant against airborne spread of fire and radiated heat. **Roof overhangs, cornices, roof projections, rooflights, transparent roofing,** etc. must have a minimum spacing from fire compartment walls.

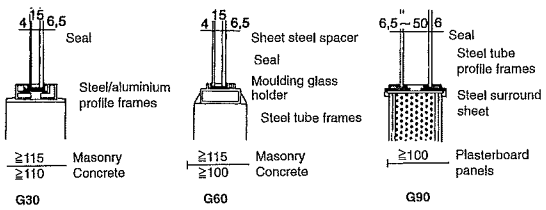
There are additional fire protection requirements for buildings in rows (e.g. **terraced houses**) joined at the eaves. The roofs of extensions or components projecting from external walls with openings or without fire resistance must, including any load-bearing and bracing building components within a safety distance (5 m), have the fire resistance of the slabs of the connecting building component.

For buildings in classes 1–3 and partial roof areas, exceptions to these requirements are possible.

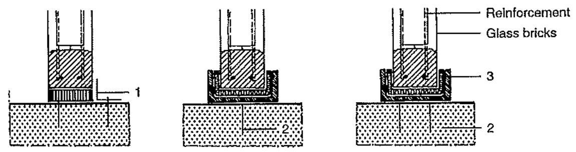
FIRE PROTECTION
Basics
Fire compartment walls
Building components
Fire protection glazing
Fire protection door sets
Extinguisher pipelines
Smoke and heat extraction systems
Sprinkler systems
Other extinguisher systems

BS ISO 10295
BS EN 13501
BS EN 13823
DIN 4102
DIN EN 13501
MBO

Building services



❶ Glazing of fire resistance class G



1 Angle steel 50 × 55 mm length ≥100 mm, at least 4 per glass panel
2 Plugs and steel screws M 10 permissible for fire protection
3 Sheet steel for the fixing of the glass brick wall (weld)

❷ Installation details – fire-retarding glazing with glass bricks

Fire resistance duration (min) DIN 4102/ *DIN EN 13501-2*	30	60	90	120	180
F-glazing	F 30/ *EI 30*	F 60/ *EI 60*	F 90/ *EI 90*	F 120/ *EI 120*	F 180/ *EI 180*
G-glazing	G 30/ *E 30*	G 60/ *E 60*	G 90/ *E 90*	G 120/ *E 120*	G 180/ *E 180*

❸ Fire resistance classes of F- and G-glazing, DIN EN 13501-2 and DIN 4102-2, -5

G-glazing → ❶

Fire-resistant glazing of fire resistance class G (G-glazing) is defined as transparent building components arranged vertically, inclined or horizontally, which, corresponding to their fire resistance duration, can **prevent the spread of fire and smoke, but not the transmission of thermal radiation.**

Construction

The manufacture of G-glazing is possible in the following forms:
- glass bricks, DIN 18175
- wired glass with a spot-welded mesh.
- expensive, special toughened glass combination in a double-glazed unit.
- pre-stressed borosilicate glass, e.g. Pyran.

Scope of application

Under building regulations, G-glazing may be installed only where there are no higher requirements for fire protection reasons. A typical area of application for G-glazing is the openings for lighting installed in corridor walls, which have to be constructed fire-retarding (F 30) as the side walls of escape routes. The lower edge of the glass must in this case be at least 1.80 m above floor level, so that in case of fire the corridor remains usable in the radiation shadow.

G-glazing is also used in the façades of **high-rise buildings,** which are divided into horizontal fire compartments in order to prevent flames leaping from storey to storey → p. 246. For buildings with internal corners, however, the unhindered spread of fire at the window area can be prevented only through the use of F-glazing.

Fire-resistant glazing units are transparent building components consisting of special glass types (single pane size up to approx. 1.20 × 2.40 m) in special thermally separated frame constructions and, when installed in solid building components, can resist fire for 30, 60, 90 or 120 min., corresponding to their classification.

Fire-resistant glazing units are **building components requiring approvals.** The approvals are normally obtained by the manufacturers as part of a general technical approval under building regulations for defined system constructions → p. 512.

Many types of fire-resistant glazing units are not UV-resistant, which should be noted for external applications.

Fire-resistant glazing units are divided into **fire-resistance classes** under DIN EN 13501-2 and DIN 4102-13 → ❸:

F-glazing

Fire-resistant glazing units with fire resistance class F (F-glazing) are defined as transparent building components arranged vertically, inclined or horizontally, which, corresponding to their fire resistance duration, can **prevent the spread of fire and smoke, and also the transmission of thermal radiation.** There must be thermal isolation for the entire duration, which means that the surface of the F-glazing toward the fire may not heat up by more than a certain value (140 K) on average during this time. Additionally, the structural safety must be verified with a strength test under self-load. F-glazing units become opaque in case of fire and behave like walls for purposes of fire protection.

Construction

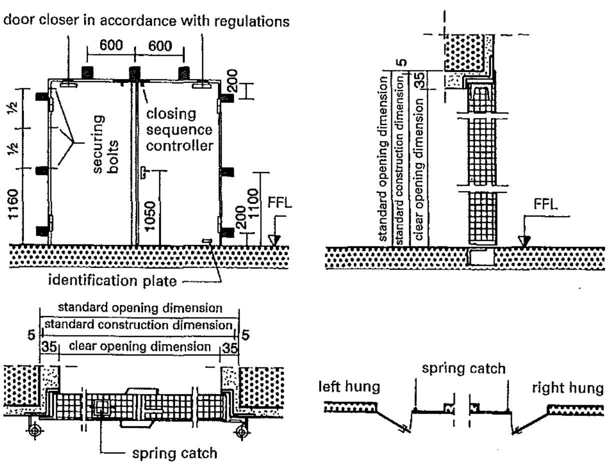
The manufacture of F-glazing is possible in the following forms:
- pre-stressed glass panes constructed as double-glazed units with the space filled with an organic substance (gel) which contains water
- multi-pane units of three or four float glass panes, between which are placed layers of inorganic composition (e.g. sodium silicate), which produce the fire-retarding effect.

The units are installed, in accordance with the general technical approval, in dry-wall partitions, masonry, reinforced concrete etc.

In the case of a fire, the pane on the fire side bursts and the sodium silicate foams, or the gel resists the heat of the fire by releasing water. (The gel itself consists of a polymer, in which an inorganic salt solution with a high water content is bedded; in the presence of fire, a thermally insulating isolation layer is formed and considerable quantities of energy are consumed. This process repeats itself layer by layer until the gel-type substance has been used up over the entire space between the panes.) The combustion process at the surface of the fire protection layer also colours the glass and makes it impervious to radiation.

Scope of application

F-glazing units are mostly used indoors, but there are also special developments and constructions for outdoor use. Because the panes on the side away from the fire remain at temperatures below the burning through limit for the duration in the fire resistance classification, hardwood can be used for the frame in addition to steel profiles. For fire resistance class T (= doors), the same requirements apply to the glazing as with fire resistance class F.



❶ Fire-retarding T 30 double door, DIN 18082

Fire resistance duration (min) DIN 4102/ *DIN EN 13501-2*	30	60	90	120	180
fire-resistant closures	T 30/ *EI 30 C* ¹⁾	T 60/ *EI 60 C* ¹⁾	T 90/ *EI 90 C* ¹⁾	T 120/ *EI 120 C* ¹⁾	T 180/ *EI 180 C* ¹⁾

¹⁾ from outside to inside

❷ Fire resistance classes of fire protection closures, DIN EN 13501-2 and DIN 4102-2, -5

Description	Width – modular building size (mm)	Height – modular building size (mm)
T 30-1 hatch	625	625–1750
T 30-1 steel door, DIN 18082	625–1250	1750–2250
T 30-1 hollow section framed door, glazed	625–1250	1750–2250
T 30-2 hollow section framed door, glazed	1250–2500	1750–2250
T 30-1 hollow section framed door with fanlight and fixed glazing of sides	unlimited	≦4000
T 30-1 all-glass door	625–1250	1750–2250
T 30-2 all-glass door	1250–2500	1750–2250
T 60/T 90-1 timber-derived material door, if required with light cut-out	625–1250	1750–2125
T 60/T 90-1 timber-derived material door (see above) with upper part	625–1250	1750–3000
T 90/T 120 roller door	2000–10000	1800–4000
T 30/T 60/ 90 steel sliding door	2000–4500	2000–3500

The dimensions given are in each case the smallest and largest approved sizes (modular building sizes) in mm. Other tested fire-resistant closures:
T 30-1 fire-retarding single-leaf door
T 30-2 fire-retarding double-leaf door
T 60-1 highly fire-retarding single-leaf door
T 60-2 highly fire-retarding double-leaf door
T 90-1 fireproof single-leaf door
T 90-2 fireproof double-leaf door

❸ Size ranges for tested fire-resistant closures (selection)

Fire-resistant door sets (or closures) serve to provide resistance to the spread of fire in walls or slabs which form rooms and are subject to fire resistance requirements, according to their classification → ❸.

Application (selection)
If the provision of openings in **fire compartment walls** inside buildings is permitted under building regulations, then these have to be provided with closures which are self-closing, sealed and fireproof (e.g. T 90 door). Openings in **fireproof separating walls** have to be provided with at least fire-retarding closures (e.g. T 30 door).

Cellars, unoccupied roof spaces, workshops, shops, etc. must have self-closing, smoke-proof and fire-retardant closures (e.g. **T 30 door**) into the stairs.

Closures between **stairways and corridors** legally essential as escape routes and also for the division of legally essential corridors more than 30 m long must be self-closing and smoke-proof → p. 511.

Components
A fire-resistant door set is a **unit** comprising: **door leaf** or leaves, glazing (if present), **metal frame** and fixings for the frame, **heavy-duty steel hinges**, self-closing device in the form of **spring hinges** or **door closer**, selector for double-leaf door sets, specific equipment for sliding, lifting or roller doors, hold-open device with automatic closing for doors which have to be held open for operational reasons and closed in case of fire, and **electrical and other actuators**.

Construction forms
Fire-resistant door sets can be single-leaf **hatches** in the size range up to 62.5 × 175 cm, single- or multi-leaf **hinged or sliding doors** (also as hollow tube frame constructions, sometimes with large-area glazing, timber or timber-derived construction and all-glass doors of special glass) in the size range up to approx. 250 × 250 cm or as **large sliding, lifting or roller doors** in sizes over 250 × 250 cm → ❸.

Certification of suitability
Steel doors which comply with the requirements of DIN 18082-1 or 18082-3 count as T 30 doors without specific certification, according to DIN 4102 → ❶.

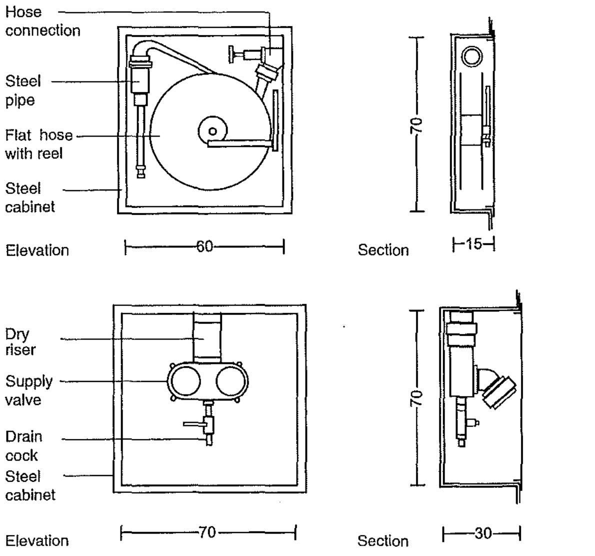
For all other fire-resisting closures, certification of suitability is necessary within the framework of a technical approval process under building regulations and classification according to DIN 4102 or DIN EN 13501 → p. 512. Because there is an interaction between wall and door set, fire-resistant door sets are always tested with the type of wall construction for which they are to be approved.

Details of the required certification of suitability are contained in the **construction products list** of the German Institute for Building Technology (DiBt) → p. 512.

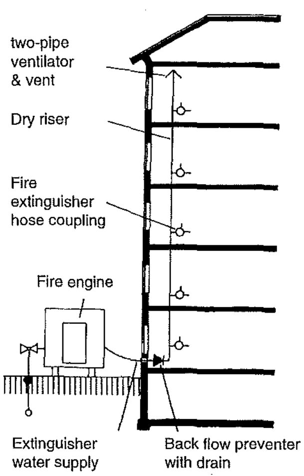
Smoke control doors
In certain situations, the authorities demand smoke control doors (DIN 18095), which prevent the penetration of smoke when installed and closed (see above). Smoke control doors also require certification of suitability (see above). Fire-resistant doors are normally also smoke control doors.

BS 8214
BS EN 1634
DIN 4102
DIN EN 13501

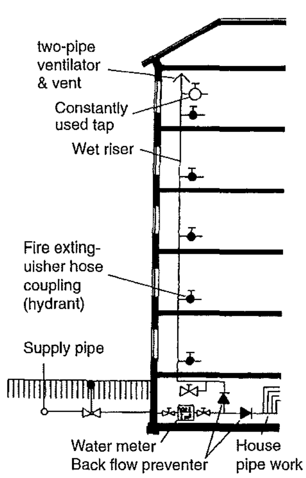
MBO



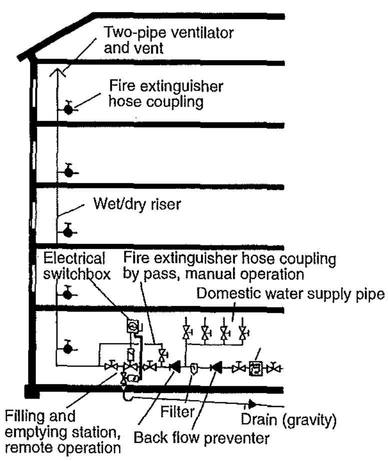
❶ Connection for supply of extinguisher water to a dry riser pipe (below) and wall hydrant (above), DIN 14461-3 etc. (diagram)



❷ Dry riser system



❸ Wet riser system



❹ Wet/dry riser system (example for nominal diameter 50–150 mm, nominal pressure PN 16)

Extinguisher water pipelines are those installed in buildings with connections to unlockable fire hoses at water outlet locations. They serve to transport water in sufficient quantities to each storey or fire compartment of a building to extinguish fires. Extinguisher water pipelines are required under building regulations and can be required by the authorities for various types of buildings.

Systems
The following systems are differentiated according to the method of water supply:

Systems with permanently installed **dry riser** vertical pipes → ❷, into which water is pumped by the fire service when required. The water is normally supplied from a hydrant connected to the public water supply network. Dry risers are **not** directly connected to the drinking water network. They must have a nominal diameter of at least 80 mm, be capable of being drained and be fitted with automatic vent valves at their ends.

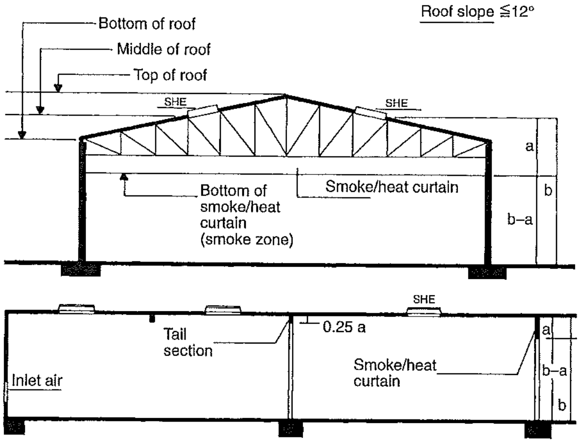
Systems with permanently installed **wet riser** vertical pipes → ❸ are pipelines for extinguisher water which are constantly under water pressure and therefore immediately available. They are equipped at the outlet locations on each storey with wall hydrants → ❶, with hoses, installed in niches, built-in or in wall cupboards, already coupled and ready for use. Standing water is forbidden in these pipes on account of possible microbial contamination!

Wet risers are therefore normally supplied by a **combined system:** together with the drinking water system of a building through a common supply pipe. This should be sized so that the withdrawal of drinking water can never endanger fire fighting; in larger complexes this may make several water supply connections necessary. In combined systems, **constant renewal of the water** in the riser pipes is necessary in order to guarantee the quality of drinking water at all locations. There must be constant abstraction of water at the upper end of the riser or an (automatic) flushing system.

Systems with permanently installed **wet/dry riser** vertical pipes → ❹ are extinguisher water pipelines which are normally empty of water but when required can be supplied with water from the mains by remote activation of a valve. The water in this case is also available for fire fighting **with little delay**, while the disadvantages of the combined system (standing water in the riser pipe, danger of freezing) are avoided.

All extinguisher water pipework must be laid with downward gradient towards the emptying location. The minimum nominal diameters laid down in the relevant standards must be complied with. The fixed coupling of the supply connection, according to DIN 14461-2, must be 800 + 200 mm above ground level → ❶.

When riser pipes are installed in slots in walls, the minimum thicknesses according to fire safety regulations must be observed.



❶ Arrangement of smoke and heat extractors (SHEs) in the roofs of industrial units (example)

	Type of facility	Fire hazard
Low fire hazard	schools (certain areas)	**LH**
Medium fire hazard	cement works photo laboratory dye works paint shops (water-based substances)	**OH1** **OH2** **OH3** **OH4**
High fire hazard	printing works car factory tyre manufacture (for cars / HGVs) firework manufacture	**HHP1** **HHP2** **HHP3** **HHP4**

For the classification of stored products into categories, additional factors must be determined, specifically the packaging (combustible/non-combustible), type of packaging (e.g. wooden pallets, sacks, cardboard boxes, tins) and the proportion of plastics by volume and weight.

fire risk	max. storage height	evaluation group (EG)
LH		1
OH 1		2
OH 2		3
OH 3		
OH 4		
HHP 1	6.8	4
HHP 2	5.0	
HHP 3	3.2	3
HHP 4	2.3	4
HHS 1	6.8	3
HHS 2	5.0	4
HHS 3	3.2	5
HHS 4	2.3	3

Assignment of fire risk to evaluation group (example).

Calculated ceiling height b (m)	Calculated smoke layer a (m)	Percentage α			
		EG 1	EG 2	EG 6	EG 7
4.0	1.00	0.30	0.43	1.29	1.46
4.5	1.50	0.25	0.35	1.05	1.19
	1.25	0.31	0.43	1.30	1.47
5.0	2.00	0.21	0.30	0.91	1.03
	1.75	0.26	0.37	1.10	1.24
	1.50	0.31	0.44	1.33	1.50
	1.25	0.38	0.54	1.61	1.82
5.5	2.50	0.19	0.27	0.82	0.92
	2.25	0.23	0.32	0.97	1.10
	2.00	0.27	0.38	1.15	1.30

Evaluation table for the required smoke extraction area (example) – EG: evaluation group

The basis of the design of a naturally ventilated smoke extraction system is the calculation of the required (aerodynamically effective) opening area of the smoke extractor (smoke extraction area)
First, it is necessary to determine the evaluation group of the relevant use of the room independent of the assumed fire spread speed with the relevant fire hazard, the thickness of the calculated smoke layer (min. 2.50 m), dimensions and installation height (top edge as a distance from the calculated smoke layer) and area of the supply air openings (supply area generally 1.5 times smoke extraction area).
Considering the calculated room height and calculated smoke layer thickness, the required opening area for each smoke compartment can be taken from the table and the appropriate smoke and heat extractor can be selected.
The smoke and heat extractors should be arranged as regularly as possible within the roof compartment.
At least one smoke and heat extractor should be installed per 200m².
In addition, the spacing of the extractors between each other and to the edges of the roof areas (5 m < a < 20 m) and to fire compartment walls (5 m) should be observed in order to avoid the danger of fire spreading by flash-over.
In pitched roof surfaces, smoke extractors must be installed as high as possible and must be specially certified in steep roofs (e.g. northlight roofs).
The individual smoke extractors must have minimum dimensions (l = b = 1.0 m) and must not exceed certain maximum dimensions. This makes it practical to specify a larger number of openings, each with a smaller opening area.

❷ Design of a naturally ventilated smoke extraction system, DIN 18232 and VdS CEA 4001 (principle)

Smoke and heat extraction systems consist of the smoke and heat extractor and also activation and control components, opening actuators, power supply wiring, air supply ducts, smoke curtains if required and the appropriate accessories. Smoke and heat extraction systems are intended to **remove smoke and heat** in the event of a fire. They serve to keep escape, rescue and fire fighting routes free of smoke, make fire fighting easier by creating a **low-smoke layer**, delay or avoid flash-over and thus the start of a full fire, protect installations, reduce the damage caused by combustion gases and thermal decomposition products and reduce fire damage to building components.

There are various systems:

Naturally ventilated smoke extraction systems are based on the principle that hot air rises (e.g. via skylight domes). Their function depends on:
– an aerodynamically effective opening area
– the influence of wind
– the size of air supply openings
– timing of their opening
– installation situation (e.g. arrangement and building dimensions).

Mechanically operated smoke extraction systems have **motors** (e.g. with fans) to extract the fumes. **Heat extractors** are openings in wall or roof surfaces which open automatically in case of fire (e.g. through the melting of a thermal link) and allow the heat of the fire to escape.

Scope of application and sizing
The MBO require the general use of smoke extractors for certain areas:

In buildings with internal stairwells and in buildings with more than five storeys above ground, a smoke extraction device (size at least 1 m²) must be installed at the **top of the stairwell**, which must be capable of being opened from the ground floor and from the top landing of the stairs. Smoke extraction equipment must also be installed in **lift shafts** (size 2.5% of the floor area of the lift shaft but at least 0.10 m²).

For special buildings (places of assembly, industrial plants, etc.) the applicable regulations can also demand additional installations → ❶ – ❷. Smoke extraction systems must be installed, for example, in:

– (single-storey) sales areas, over-sized production and storage rooms
– buildings with excessively long rescue and escape routes, if these cannot be kept smoke-free for a sufficiently long time by other means
– buildings where special protection of assets is required in a particular case by relevant regulations
– buildings containing materials or equipment which are particularly valuable or susceptible to damage by smoke or facilities where there is a particular reason for increased protection of assets.

Smoke extraction systems are normally designed by the determination of a desired low-smoke layer and the calculation of the aerodynamically effective opening area required to ensure it → ❷ (as percentage ratio of the floor area of where smoke is to be removed from to the effective area of the smoke extraction opening).

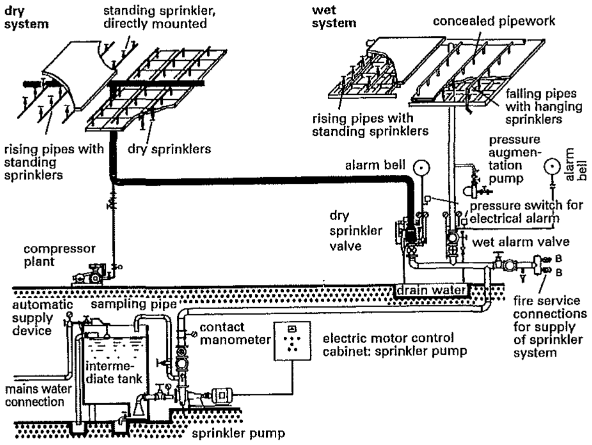
The required values differ according to the application and are laid down in the relevant regulations.

FIRE PROTECTION
Basics
Fire compartment walls
Building components
Fire-resistant glazing
Fire-resistant door sets
Fire fighting installations
Smoke and heat extraction systems
Sprinkler systems
Other extinguisher systems

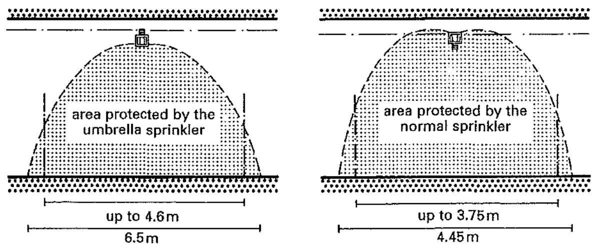
BS EN 1210
DIN 18232

MBO
VdS CEA
Guidelines 4001

Building services



❶ Layout of a sprinkler system: wet and dry systems



❷ Spray characteristics of umbrella and normal sprinklers (example)

Design of sprinkler systems

The design of a sprinkler system is based on the **fire hazard** in the area to be protected. This is defined in the **VdS CEA Guidelines** → p. 511 and areas to be protected by sprinklers are divided into fire hazard classes (**LH, OH, HHP, HHS**).

Further factors significant for the design of sprinkler systems are: the **effective area**, which according to calculations can be covered by the quantity of water; the maximum **protected area per sprinkler,** depending on sprinkler type and fire hazard; the **water quantity,** i.e. how much is to be sprinkled per minute onto the effective area; and the **operating time**, how long the water quantity must be available

Fire hazard class	(Minimum) water quantity (mm/min)	Effective area (m²)	
		wet / pre-action system	dry / wet dry system
LH	2.25	84	prohibited layout according to OH1
OH1	5.0	72	90
OH2	5.0	144	180
OH3	5.0	216	270
OH4	5.0	360	prohibited layout according to HHP1
HHP1	7.5	260	325
HHP2	10.0	260	325
HHP3	12.5	260	325
HHP4	**special consideration required**		

❸ Water quantity and effective area for LH, OH and HHP fire hazard classes, VdS CEA Guidelines 4001

Sprinkler systems are technical, **automatically actuated fire fighting systems.** They consist of a network of permanently installed pipework under water pressure, to which **closed jets** called sprinklers are connected at a regular spacing. The pipework should be exposed or only concealed by a suspended ceiling to enable repair and maintenance and is normally connected through an intermediate tank to the drinking water mains.

If the air temperature increases as the result of a fire and exceeds the **operating temperature** set for the sprinkler (approx. 30°C above the highest normally expected air temperature), then the sprinkler opens and the pressurised water flows out of the pipe through the sprinkler and is sprayed over the protected area by the **deflector**. Each sprinkler system also has a **mechanical-acoustic alarm.**

Scope of application

The use of sprinkler systems is necessary in many cases when the fire safety requirements or the escape route requirements in the building regulations cannot be complied with.

For many special projects (e.g. stores, hotels, high-rise buildings, hospitals, shopping centres, etc.) the installation of sprinkler systems is generally required. Details for the design are given in the relevant regulations and guidelines.

Systems

Wet sprinkler systems → ❶ are the most common type. The pipework behind the **wet alarm valve** is constantly filled with water. When a sprinkler is activated, water sprays out **without delay.**

In **dry sprinkler systems** → ❶, the pipework behind the **alarm valve** is filled with compressed air, which stops water flowing into the sprinkler pipework. If a sprinkler is opened, this preventative air pressure is released and the water sprays out **after a delay.** Dry sprinklers are mostly installed in areas subject to frost.

Rapid reaction dry sprinkler systems are dry sprinkler systems, which operate with **little delay** because the alarm valve is opened by additional smoke or flame detectors **before** a sprinkler opens.

Tandem systems are dry sprinkler systems (e.g. in areas of a building at risk of frost) which are connected to the pipework of a wet system installed elsewhere in the building.

Pre-action sprinkler systems are dry systems designed so that water is sprayed only when a fire is detected and a sprinkler is opened (in order to avoid accidental activation, e.g. if a sprinkler is damaged).

Sprinklers

The most common types are the **glass bulb sprinkler,** with a glass bulb as temperature-dependent activation component, and the **fusible link sprinkler,** with a soldered link that opens when heated. Different types according to the type of spraying pattern are: **normal sprinkler** → ❷, with a ball-shaped water distribution directed to the floor and the ceiling. They can be used in the upright or pendant position. **Umbrella sprinklers** → ❷ feature a parabolic-shaped distribution of water towards the floor. They can be used in the upright or pendant position. Side wall **sprinklers** and further special versions (e.g. **long-throw sprinklers**) are also available.

Water spray extinguisher systems
Water spray extinguisher systems are water distribution systems **with permanently installed pipework**, on which **open nozzles** are mounted at regular intervals. When the system is on standby, the pipework is not filled with water. When the system is activated, this immediately releases the **peak flow** from the water supply into the pipework.

The water spray pattern is based on the shape and dimensions of the room to be protected, the type of building, type and quantity of goods to be protected, height and type of storage, and wind influence, and must spray at a rate of 5–60 l/m^2/min.

Systems arranged into groups normally protect an area of 100–400 m^2 per group. The total effective area for rooms $\geqq$200 m^2, which are divided into group effective areas, is normally the sum of the two effective areas with the largest water requirement. For the determination of the total effective area, a fire breaking out at the intersection of the group effective areas is assumed. This means that all group effective areas which are within a radius of 7 m of the location at most risk for the outbreak of fire can be supplied with water simultaneously.

Water spray extinguisher systems are used, for example, in aircraft hangars, waste bunkers and incineration plants, stages, transformers, tanks and systems with flammable liquids, cable ducts, chipping silos, chipboard works, power stations, hydraulic rooms, and firework and munitions factories.

Oxygen-reducing extinguisher systems
These fire fighting systems work by **reducing the content of oxygen in the air** to a level at which the combustion process no longer continues.

CO_2 is commonly used as a gaseous fire-fighting agent. CO_2 systems are intended to extinguish fires as they are developing and maintain an effectively high CO_2 concentration for so long that there is no danger of reignition. CO_2 floods the relevant area rapidly and uniformly, to provide protection in whole rooms. A CO_2 system essentially consists of **CO_2 bottles** containing a supply of gas, the necessary valves and **permanently installed pipework** with open nozzles in an appropriate arrangement in the area to be protected and **equipment for fire detection, control, alarm and activation.** For systems intended to protect rooms, one nozzle may supply at most 30 m^2 of floor area. If the room is more than 5 m high, the nozzles are installed not only in the ceiling but also at approx. ⅓ of room height.

CO_2 is a suitable agent against fires affecting the following substances and equipment: combustible liquids and other substances which behave like combustible liquids in a fire; combustible gases, in which case it must be ensured that no combustible gas-air mixture can form after the fire has been extinguished; electrical and electronic equipment, and combustible solid materials like wood, paper and textiles, although fires involving these materials require a higher CO_2 concentration and a longer action time. CO_2 is not suitable for some types of fire, for example: deeply seated fires of wood, paper and textiles, etc.; materials and chemicals containing oxygen; materials and chemicals which react with CO_2, e.g. alkali metals and metal hybrids.

Particular attention must be paid to safety in the design of CO_2 systems, because concentrations of over 5% are lethal and strongly corrosive. Systems should therefore be installed only by officially accredited firms. (VdS Guidelines 2093)

Powder extinguisher systems
Fire extinguisher powders are **homogenous mixtures of chemicals** which are suitable for fighting fires. The main ingredients are sodium/potassium bicarbonate, potassium sulphate, potassium/sodium chloride and ammonium phosphate/sulphate.

Because the extinguisher powder can be used under normal conditions at temperatures from –20 to +60°C, it is employed in buildings, enclosed rooms and also in open-air areas of industrial plants.

Powder is suitable for extinguishing fires involving the following substances and equipment: combustible solid materials like wood, paper and textiles, in which case the appropriate powder must be used; combustible liquids and other substances which behave like combustible liquids in a fire; combustible gases; combustible metals like aluminium, magnesium and their alloys, for which only suitable special powder should be used.

Examples of areas of industry where powder systems are often installed are: chemical and process plants, oil cellars, sumps, filling stations, compressor stations, pumping stations, transfer stations for oil and gas. Powder is not suitable for extinguishing fires involving certain plant, equipment and areas, for example: machinery, plant and equipment susceptible to dust; low-voltage electrical equipment (telephone, IT, measurement and regulation systems, distribution cabinets with trips and relays etc.); areas or installations where there is a danger of chemical reaction with the powder. (VdS Guidelines 3038)

Foam extinguisher
Foam for fire extinguishing is made by **foaming a mixture of water and foaming agent with air.** Foaming agents consist of water-soluble protein detergents and may also contain fluorinated agents. Multi-purpose foaming agents are suitable for the production of heavy, medium and light foam. Protein and fluoro-protein foaming agents are suitable for the production of heavy foam.

Foam extinguisher systems are used to extinguish fires in buildings, rooms and the open air. They can also be used for the precautionary coverage of areas. Particular measures are necessary in the case of liquids which destroy foam, e.g. alcohol, ester, ketone etc. A foam extinguisher system should be designed so that in the case of fire sufficient foam can reach the area to be protected or the area is effectively covered.

The essential parameters of a foam extinguisher system are: water quantity, foaming agent consumption, foam ratio (ratio of foam to water-foaming agent mixture) and minimum operating time. When systems with medium and heavy foam are used, the foam must be able to cover the entire area to be foamed, taking into account the flowing and throwing range, any obstacles, and the distance and type of object to be protected. When systems with light foam are used, the foam must be able to effectively fill the room or building.

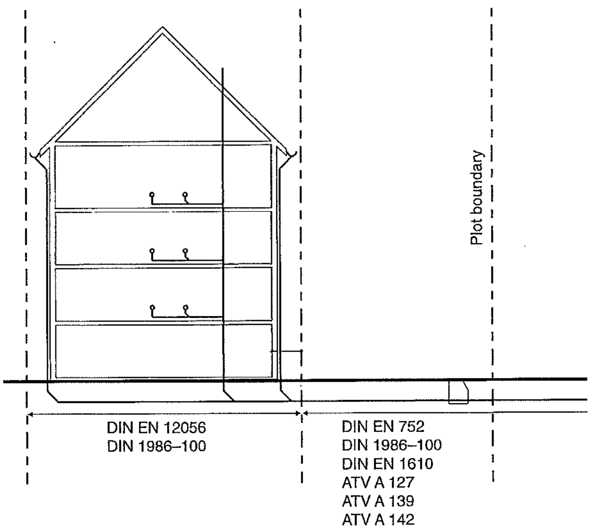
If a number of separate objects are to be protected by the same foam extinguisher system, the water supply requirement is designed for the largest single object. The water supply must be designed for operation for at least 120 min for heavy foam and 60 min for medium foam. (VdS Guidelines 2108)

FIRE PROTECTION
Basics
Fire compartment walls
Building components
Fire-resistant glazing
Fire-resistant door sets
Fire fighting installations
Smoke and heat extraction systems
Sprinkler systems
Other extinguisher systems

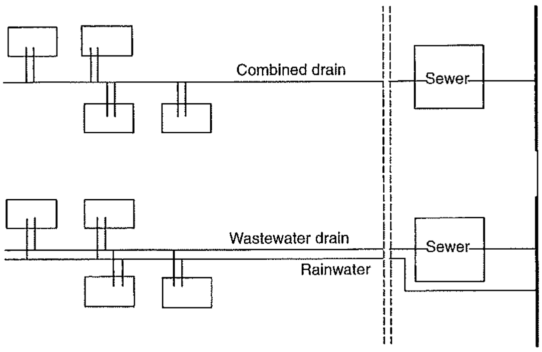
BS 5306
DIN 1988
DIN 14494

VdS Guidelines

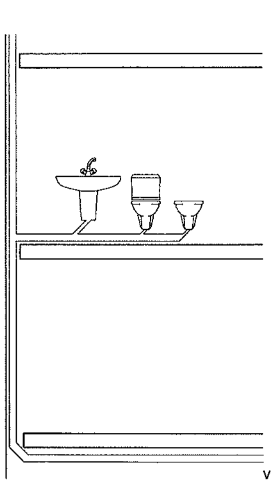
Building services



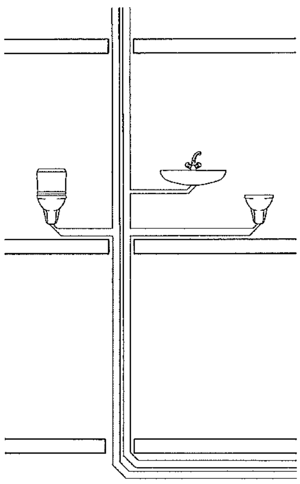
❶ Areas where standards and regulations apply (Wellpott, Bohne → refs)



❷ Combined and separate systems (Wellpott → refs)



❸ Drainage system I (Wellpott, Bohne → refs)



❹ Drainage system IV (Wellpott, Bohne → refs)

System I	single downpipe, partially filled branch pipe, degree of filling 0.5
System II	single downpipe, system branch pipe, partially filled, degree of filling 0.7
System III	single downpipe with full branch pipe, degree of filling 1.0
System IV	separation into two pipe systems (greywater, wastewater)

❺ Drainage systems: for Germany, systems I and IV are permissible

Drainage systems for buildings and sites

Drainage systems for buildings are constructed to work under gravity wherever possible. The European standard DIN EN 12056 applies to all drainage systems operating under gravity inside residential, business, institutional or industrial buildings. Additional requirements for Germany are given in DIN 1986-100. Outside the building, DIN EN 752 and further regulations apply → ❶.

Calculation

Calculations are based on the assumed flow in the pipework, which depends on the type of use and of drainage. A basic distinction is made between wastewater and rainwater, and it needs to be decided whether collected wastewater and rainwater are drained into a combined system or have to remain separated according to local by-laws → ❷.

Description of drainage pipes

A **downpipe** is the vertical pipe in a building carrying wastewater or rainwater down to a horizontal pipe and is ventilated above the roof.

A **ground pipe** is the inaccessible pipe laid underground or under a floor slab, carrying groundwater from downpipes, branch waste pipes and floor drains.

A **vent pipe** is the downpipe's extension above the roof to provide pressure balance above unpressurised drainage by means of ventilation.

Collector pipes have the same function as ground pipes, but they are suspended below the cellar ceiling or on cellar walls.

Branch waste pipes connect the odour trap in the sanitary appliance to the further pipework. The **sewer connection** is the pipe connecting the last shaft on the plot to the public sewer.

Design of wastewater drainage

The expected flow of wastewater can be calculated as follows:

$\mathbf{Q_{ww} = K \times \sqrt{\Sigma(DU)}}$ where:

Q_{ww} wastewater discharge l/s
K discharge factor
DU Design Units l/s

Typical discharge factors are:

Type of building	Discharge factor K
irregular use, e.g. in houses, guest houses, offices	0.5
regular use, e.g. in hospitals, schools, restaurants, hotels	0.7
frequent use, e.g. in public toilets and/or showers	1.0
special use, e.g. laboratories	1.2

The total wastewater discharge is:

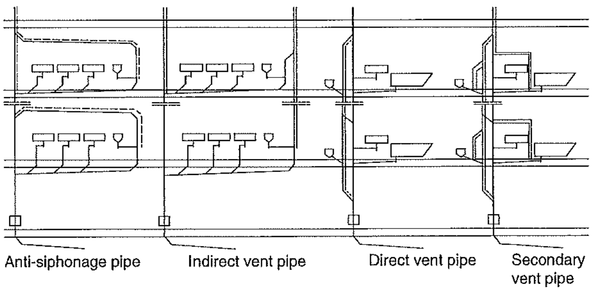
$\mathbf{Q_{tot} = Q_{ww} + Q_c + Q_p}$ where:

Q_{tot} total wastewater discharge l/s
Q_{ww} wastewater discharge l/s
Q_c permanent discharge l/s
Q_p pumped flow l/s

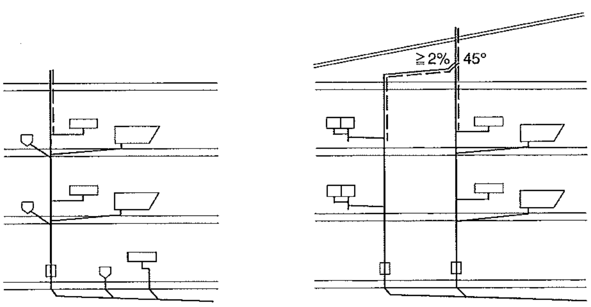
The larger value (Q_{ww} or Q_{tot}) or the value of the wastewater discharge of the sanitary appliance with the largest connection value is decisive for design purposes. DIN EN 12056-2 defines four of the various drainage systems in Europe. These differ according to the degree of filling, the branch waste pipes and the separation or not of the pipework → ❺. For Germany, systems I and IV are permissible → ❸ – ❹.

Sanitary appliance	Design units (DU)	Single branch pipe
washbasin, bidet	0.5	DN 40
shower without plug	0.6	DN 50
shower with plug	0.8	DN 50
single urinal with flush cistern	0.8	DN 50
single urinal with pressure flush	0.5	DN 50
standing urinal	0.2	DN 50
urinal without water flushing	0.1	DN 50
bath tub	0.8	DN 50
kitchen sink and dishwasher*	0.8	DN 50
dishwasher	0.8	DN 50
washing machine up to 6 kg	0.8	DN 50
washing machine up to 12 kg	1.5	DN 56/60
WC with 4.0/4.5 l cistern	1.8	DN 80/DN 90
WC with 6.0 l cistern/pressure flush	2.0	DN 80-DN 100
WC with 7.5 l cistern/pressure flush	2.0	see remark in DIN
WC with 9.0 l cistern/pressure flush	2.5	DN 100
floor gully DN 50	0.8	DN 50
floor gully DN 70	1.5	DN 70
floor gully DN 100	2.0	DN 100
*with common trap		

❶ Design units (DU) to be assumed for various sanitary appliances (Table 4, DIN 1986-100)



❷ Ventilation systems for wastewater drainage (Wellpott → refs)



❸ A soil and vent stack can be joined together with one common vent pipe at the uppermost point of the pipework (Wellpott → refs)

Pipe sizing

The determined dimensions, given as nominal diameters (DN) and the associated minimum internal diameters, are given in → ❹.

Nominal diameter (DN)	Min. internal diameter $d_{i\,min}$ (mm)
30	26
40	34
50	44
56	49
60	56
70	68
80	75
90	79
100	96
125	113
150	146
200	184
225	207
250	230
300	290

❹ Nominal diameters (DN) with the relevant minimum internal diameters $d_{i\,min}$ (corresponds to Table 1, DIN EN 12056-2)

Section of pipework	Minimum fall	Standard and section
unvented branch pipe	1.0%	DIN EN 12056-2, Table 5
vented branch pipe	0.5%	DIN 1986-100, section 8.3.2.2 DIN EN 12056-2, Table 8
ground and collector pipes		
a) for wastewater	0.5%	DIN 1986-100, section 8.3.4.
b) for rainwater (degree of filling 0.7)	0.5%	DIN 1986-100, section 9.3.5.2
ground and collector pipes DN 90 (lavatory pan with flush volume 4.5–6 l)	1.5%	DIN 1986-100, Table A.2
ground pipes for rainwater outside the building (degree of filling 0.7)		DIN 1986-100, section 9.3.5.2
up to DN 200	0.5%*	
from DN 250	1 : DN*	
* flow velocity max. 2.5 m/s. Behind a shaft with open flow-through, design can be based on full filling without over-pressure.		

❺ Minimum falls for pipes, unpressurised drainage

Venting of pipework → ❷ + ❸

Drainage systems are still differentiated according to the type of venting. The main types are soil and vent stack (single-pipe system) and soil stack with separate vent pipe. Apart from the soil and vent stack, different systems use anti-siphonage pipes; indirect vent pipe; direct vent pipe; secondary venting; and soil and vent stack with an additional venting valve. The cross-section of a common vent pipe for more than one stack must be at least as big as half the sum of the single cross-sections of the single stack. The nominal size of a common vent pipe must be at least one nominal size larger than the largest size of the relevant stack.

Application limits	System I	System IV
max. pipe length (l)	4.0 m	10.0 m
max. no. 90° bends	3*	3*
max. drop height (H) (with 45° or more slope)	1.0 m	1.0 m
min. fall	1%	1.5%
* connecting bends not included		

❶ Application limits for unvented single branch pipes (corresponds to DIN EN 12056-2, Table 5)

Application limits	System I	System IV
max. pipe length (l)	10.0 m	no limit
max. no. 90° bends	no limit	no limit
max. drop height (H) (with 45° or more slope)	3.0 m	3.0 m
min. fall	0.5%	0.5%
* connecting bends not included		

❷ Application limits for vented single and combined branch pipes (corresponds to DIN EN 12056-2, Table 8)

DN	max. pipe length (m)	max. 90° bends	max. height difference (m)	min. fall
50	4.0	3	1.0	1%
56	4.0	3	1.0	1%
70	4.0	3	1.0	1%
80	10.0	3	1.0	1%
90	10.0	3	1.0	1%
100	10.0	3	1.0	1%

❸ Application limits for unvented combined branch pipes (corresponds to DIN 1986-100, section 8.3.2.2)

Soil and vent stack	Q_{max} (l/s)	
DN	Branches	Branches with internal radius
60	0.5	0.7
70	1.5	2.0
80*	2.0	2.6
90	2.7	3.5
100**	4.0	5.2
125	5.8	7.6
150	9.5	12.4
200	16.0	21.0

* min. DN for connection of WCs to system II
** min. DN for connection of WCs to systems I, III, IV

❹ Permissible wastewater discharge Q_{max} and nominal diameter DN for soil and vent stacks (corresponds to DIN EN 12056-2, Table 11)

Application limits for the various vented systems (single and combined branch pipes) are given in → ❶ – ❸.

Design of branch pipes
Single and combined branch pipes are designed in accordance with → ❺ – ❻ (from Geberit). The design of downpipes for wastewater differs according to venting system → ❹ + ❼.

K = 0.5	K = 0.7	K = 1.0	DN	d_i (mm)
Σ DU	Σ DU	Σ DU		
1.0	1.0	0.8	50	44
2.0	2.0	1.0	56/60	49/56
9.0	4.6	2.2	70*	68
13.0**	8.0**	4.0	80	75
13.0**	10.0**	5.0	90	79
16.0	12.0	6.4	100	96

* no WCs
** maximum 2 WCs

❺ Design of unvented combined branch pipes (corresponds to DIN 1986-100, Table 5)

K = 0.5	K = 0.7	K = 1.0	DN	d_i (mm)
Σ DU	Σ DU	Σ DU		
3.0	2.0	1.0	50	44
5.0	4.6	2.2	56/60	49/56
13.0	10.0	5.0	70*	68
16.0	13.0	9.0	80	75
20.0	16.0	11.0	90	79
25.0	20.0	14.0	100	96

* no WCs

❻ Design of vented combined branch pipes (simplified design instead of calculation according to rules for combined pipes, by Prandtl-Colebrook)

Soil and vent stack	Separate vent pipe	Q_{max} (l/s)	
DN	DN	branches	branches with internal radius
60	50	0.7	0.9
70	50	2.0	2.6
80*	50	2.6	3.4
90	50	3.5	4.6
100**	50	5.6	7.3
125	70	12.4***	10.0
150	80	14.1	18.3
200	100	21.0	27.3

* min. DN for connection of WCs to system II
** min. DN for connection of WCs to systems I, III, IV
*** this value may be an error in DIN EN 12045-2. Recommendation: correct to 8.4

❼ Permissible wastewater discharge Q_{max} and nominal diameter DN for soil stack with separate vent pipe (corresponds to DIN EN 12056-2, Table 12)

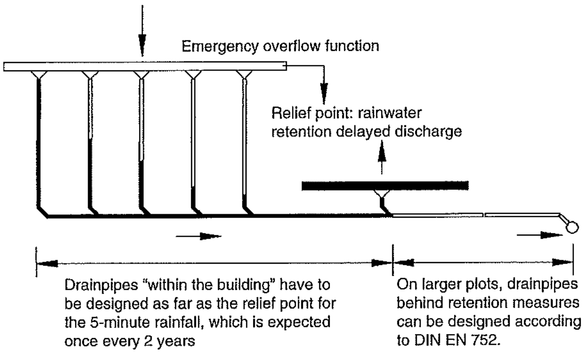
Ground and collector drainage pipes
Inside buildings, collector pipes with a degree of filling of h/D Index i = 0.5 should be installed assuming a minimum fall of 0.5%, and with connection of a drain lift pump, which should be installed with a degree of filling of h/d Index i = 0.7.

Fall	DN 80		DN 90		DN 100		DN 125		DN 150		DN 200		DN 225		DN 250		DN 300	
i	Q_{max}	*v*	Q_{max}	*v*	Q_{max}	*v*	Q_{max}	*v*	Q_{max}	*v*	Q_{max}	*v*	Q_{max}	*v*	Q_{max}	*v*	Q_{max}	*v*
cm/m	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s
0.50	-	-	-	-	1.8	0.5	2.8	0.5	5.4	0.6	10.0	0.8	15.9	0.8	18.9	0.9	34.1	1.0
1.0	1.3	0.6	1.5	0.6	2.5	0.7	4.1	0.8	7.7	0.9	14.2	1.1	22.5	1.2	26.9	1.2	48.3	1.4
1.50	1.5	0.7	1.8	0.7	3.1	0.8	5.0	1.0	9.4	1.1	17.4	1.3	27.6	1.5	32.9	1.5	59.2	1.8
2.00	1.8	0.8	2.1	0.8	3.5	1.0	5.7	1.1	10.9	1.3	20.1	1.5	31.9	1.7	38.1	1.8	68.4	2.0
2.50	2.0	0.9	2.4	1.0	4.0	1.1	6.4	1.2	12.2	1.5	22.5	1.7	35.7	1.9	42.6	2.0	76.6	2.3
3.00	2.2	1.0	2.6	1.1	4.4	1.2	7.1	1.4	13.3	1.6	24.7	1.9	39.2	2.1	46.7	2.2	83.9	2.5
3.50	2.4	1.1	2.9	1.1	4.7	1.3	7.6	1.5	14.4	1.7	26.6	2.0	42.3	2.2	50.4	2.3	90.7	2.7
4.00	2.6	1.2	3.1	1.2	5.0	1.4	8.2	1.6	15.4	1.8	28.5	2.1	45.2	2.4	53.9	2.5	96.9	2.9
4.50	2.8	1.2	3.2	1.3	5.3	1.5	8.7	1.7	16.3	2.0	30.2	2.3	48.0	2.5	57.2	2.7	102.8	3.1
5.00	1.2	2.9	3.4	1.4	5.6	1.6	9.1	1.8	17.2	2.1	31.9	2.4	50.6	2.7	60.3	2.8	108.4	3.2

❶ Permissible wastewater discharge, degree of filling 50% (h/di = 0.5) (corresponds to DIN EN 12056, Table B.1)

Fall	DN 80		DN 90		DN 100		DN 125		DN 150		DN 200		DN 225		DN 250		DN 300	
i	Q_{max}	n	Q_{max}	n	Q_{max}	n	Q_{max}	n	Q_{max}	n	Q_{max}	n	Q_{max}	n	Q_{max}	n	Q_{max}	n
cm/m	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s
0.50	1.5	0.5	-	-	2.9	0.5	4.8	0.6	9.0	0.7	16.7	0.8	26.5	0.9	31.6	1.0	56.8	1.1
1.0	2.2	0.7	2.5	0.6	4.2	0.8	6.8	0.9	12.8	1.0	23.7	1.2	37.6	1.3	44.9	1.4	80.6	1.6
1.50	2.6	0.8	3.0	0.8	5.1	1.0	8.3	1.1	15.7	1.3	29.1	1.5	46.2	1.6	55.0	1.7	98.8	2.0
2.00	3.1	0.9	3.5	0.9	5.9	1.1	9.6	1.2	18.2	1.5	33.6	1.7	53.3	1.9	63.3	2.0	114.2	2.3
2.50	3.4	1.0	4.0	1.1	6.7	1.2	10.8	1.4	20.33	1.6	37.6	1.9	59.7	2.1	71.7	2.2	127.7	2.6
3.00	3.8	1.1	4.3	1.2	7.3	1.3	11.8	1.5	22.3	1.8	41.2	2.1	65.4	2.3	77.9	2.4	140.0	2.8
3.50	4.1	1.2	4.7	1.3	7.9	1.5	12.8	1.6	24.1	1.9	44.5	2.2	70.6	2.5	84.2	2.6	151.2	3.0
4.00	4.4	1.3	5.0	1.3	8.4	1.6	13.7	1.8	25.8	2.1	47.6	2.4	75.5	2.7	90.0	2.8	161.7	3.2
4.50	4.6	1.4	5.3	1.4	8.9	1.7	14.5	1.9	27.3	2.2	50.5	2.5	80.1	2.8	95.5	3.0	171.5	3.4
5.00	4.9	1.5	5.6	1.5	9.4	1.7	15.3	2.0	28.8	2.3	53.3	2.7	84.5	3.0	100.7	3.1	180.8	3.6

❷ Permissible wastewater discharge, degree of filling 70% (h/di = 0.7) (corresponds to DIN EN 12056, Table B.2)



❶ Limits of the scopes of application of DIN EN 12056, DIN 1986-100 and DIN EN 752 (Wellpott, Bohne → refs)

No.	Type of surface	Discharge factor C
1	**impermeable surfaces, e.g.**	
	– roof surfaces	1.0
	– concrete surfaces	1.0
	– ramps	1.0
	– paved areas with pointed joints	1.0
	– blacktop (asphalt)	1.0
	– paving with poured joints	1.0
	– gravel roofs	0.5
	– planted roofs*	
	– for intensive planting	0.3
	– for extensive planting from 10 cm construction depth	0.3
	– for extensive planting under 10 cm construction depth	0.5
2	**partially permeable surfaces or with low run-off, e.g.**	
	– concrete paving laid in sand or clinker, slab paving	0.7
	– paved surfaces with proportion jointed ≧15%, e.g. 10 cm × 10 cm and less	0.6
	– waterbound paving	0.5
	– partially paved children's playgrounds	0.3
	– plastic paving, artificial turf	0.6
	– clay sports surfacing	0.4
	– lawns	0.3
3	**permeable surfaces or with insignificant run-off, e.g.**	0.0
	– parks and areas of vegetation, ballast and clinker surfacing, rolled gravel, also with partial paving, e.g.	0.0
	– garden paths with waterbound surfacing	0.0
	– access roads and parking with grass pavers	0.0

* according to the Guidelines for Design, Construction and Maintenance of Roof Planting – Guidelines for Roof Planting

❷ Discharge factor C for the determination of rainwater run-off (corresponds to DIN 1986-100, Table 6)

Rainwater drainage

Rainwater falling on a roof is drained away via a pipe system. The most important objective is that the rainwater from built-up areas should soak away into suitable percolation systems, on the same plot if possible. If this is not feasible, the rainwater is drained, either separated from the soil drain, or combined. Where the water is drained into a sewer connection, to comply with a discharge limit, rainwater retention may have to be provided in the form of an oversized pipe network or a structure. Each roof surface must have at least one downpipe and one emergency overflow with free discharge. Rainwater must not be fed into soil stacks, even from small roof surfaces. Pipework is designed for average rainfall. Because heavy rainfall has to be expected, however, overloading of the pipework should be countered by suitable measures (emergency overflows, pressure relief for unpressurised pipes) to avoid resulting damage.

Rainwater discharge is calculated according to DIN EN 12056-3 or DIN 1986-100 with the formula:

$$\mathbf{Q = r_{D(T)} \cdot C \cdot A \cdot \frac{1}{10{,}000}} \quad \text{where:}$$

$r_{D(T)}$ calculation of rainfall in l/s/ha, determined on the statistical basis of 5 minutes' rainfall, which must be expected once every 2 years
C discharge factor
A precipitation area projected on the plot (m^2)

The duration of rain for design purposes is D = 5 min. Downpipes, collector and ground pipes are to be designed for the local 5 minute rainfall, which is anticipated once in 2 years ($r_{5(2)}$) (applies without planned retention measures).

The limits of the application examples according to DIN EN 12056, DIN 1986-100 and DIN EN 725-4 are as follows: overloading or overflowing is to be limited by the provision of emergency overflows, and pressure relief for unpressurised pipes. Discharge factor C for determination of rainwater discharge is shown in → ❷ (DIN 1986-100, Table 6). The design is to be based on the chosen rain duration of D = 5 minutes. The repeat interval in years (T) is determined by the particular project and must be determined according to the type and use of the building.

Unpressurised drainage

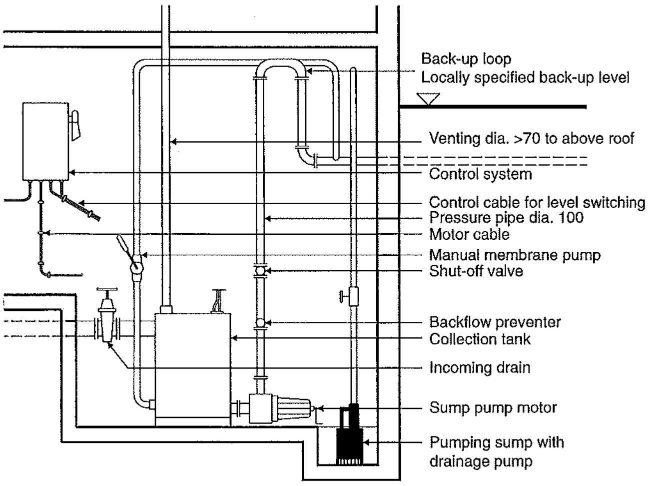
Downpipes must have at least the nominal diameter of the connected roof outlet. The degree of filling can be up to F = 0.33. Collector and ground pipes are to be designed for a degree of filling of 0.7 and a minimum fall of 0.5 cm/m within the building. Outside the building, a maximum velocity of 2.5 m/s should be assumed. The maximum degree of filling here is 0.7.

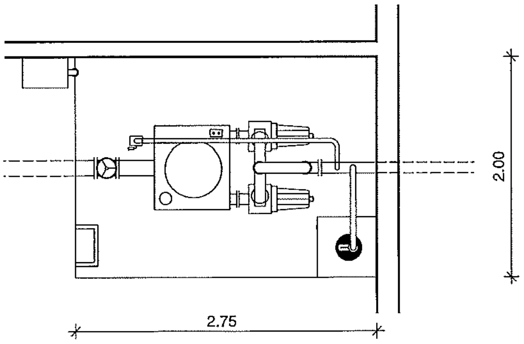
Downstream of a shaft with open flow-through, complete filling without over-pressure can be assumed. The minimum fall is up to DN 200 0.5 cm/m, and from DN 250 1: DN.

Application area	Approved types of backflow prevention device according to DIN EN 13564-1[a]
faeces-free water, precipitation water	types 2, 3 and 5
water containing faeces	type 3 with marking 'F'
rainwater utilisation facilities[b]	types 0, 1, 2

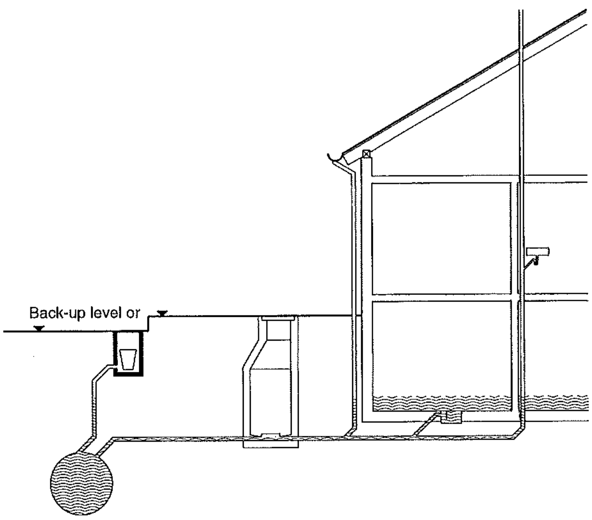
[a] until the introduction of DIN EN 13564-1, DIN 1997 and DIN 19578 apply
[b] only permissible for overflows from underground tanks which are connected to a surface water sewer (see DIN 1989-1)

❶ Application areas for backflow prevention devices (corresponds to DIN 1986-100, Table 2)





❷ Wastewater lifting pump as double system, DIN 12056-4 (Wellpott, Bohne → refs)



❸ Backing-up in the discharge pipe of a combined drainage system, resulting from overloading of the drains after heavy rainfall. Surface water mixed with wastewater pours out of the lowest gullies, unless they are protected (Wellpott, Bohne → refs)

Roof drainage with pressurised flow

For this system, hydraulic certification should be produced for each individual project. The backing-up at the outlet required for the function does not count as flooding of the roof surface, as long as the requirements of outlets according to DIN 19599 are not exceeded.

Roof surfaces with, for example, regular flooding are to be waterproofed up to the flooding level and appropriately structurally designed. At the most the difference in level between the roof outlet and the backing-up level should be assumed for the rainwater pressure drainage system. If a pressure drainage system is fed into an unpressurised system of pipework, conversion of the high kinetic energy should be ensured by the reduction of the flow velocity to <2.5 m/s.

Backing-up

Discharge locations below the sewer backing-up level are to be protected against backing-up in the sewer by automatic wastewater lifting pumps with backing-up loop or backflow prevention device (DIN EN 12056-4). Backflow prevention devices have a limited scope of application → ❶.

Wastewater lifting pumps, in which the flow of wastewater must not be interrupted, are to be installed as double lifting systems → ❷. These pumps should also be provided for precipitation water, which is to be drained below the sewer backing-up level. These should be designed so that the occurrence of a hundred-year event $r_{5(100)}$ cannot cause damage (to surfaces like house entrances, cellar entrances, garage access drives, internal courtyards).

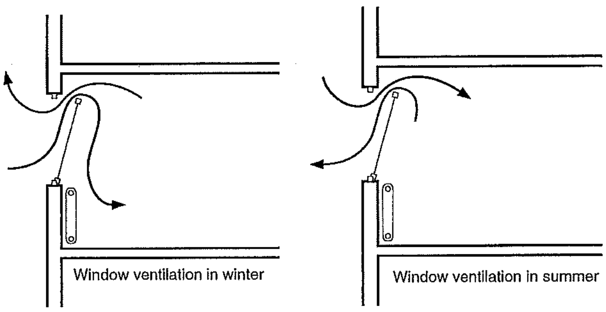
A flooding certification, required by DIN EN 752-4, assuming rainfall of $r_{15(30)}$, is to be produced for larger areas below the sewer backing-up level, which do not endanger buildings or assets. The wastewater lifting pump should be designed for at least $r_{5(2)}$.

For roof surfaces which can be drained without the provision of an emergency overflow, the planned flooding level must be discussed with and checked by the structural engineer. Furthermore, an overloading certification is to be obtained for internally routed drainage systems as far as a pressure relief point. Flooding and overloading certifications are to be obtained for a 100-year rainstorm $r_{5(100)}$.

Special wastewater

Wastewater of commercial and industrial origin is generally to be treated so that it is permissible to feed it into a public foul sewer. This may require the installation of separation or treatment facilities such as grease separators, separators for volatile liquids, starch separators or emulsion splitting plant. For mineral oil or volatile liquids, separators are to be dimensioned according to DIN 1999. These devices normally consist of a silt trap, separator and chamber for taking samples. In particular, areas on which vehicles are washed, maintained or fuelled should be connected to the drains through a separator for volatile liquids.

BS 6229
BS 8490
BS EN 12056
DIN 752
DIN 1986
DIN 1999
DIN EN 12056
DIN 19599



❶ Flow patterns for window ventilation: situation in winter and summer (Wellpott, Bohne → refs)

System I	ventilation from one side through an opening in an external wall
System II	cross-ventilation with openings in opposing external walls or in one external wall and the roof surface
System III	cross-ventilation with openings in one external wall and an opposing shaft. The shaft must have a cross-section of min. 80 cm^2 and 4 m height, of which 3 m is inside the building (may need to protect against excessive cooling).
System IV	cross-ventilation with roof ventilators (domes, deflectors, openings) and openings in one wall or in opposing external walls.

❷ Free ventilation systems, Workplace Guidelines 5

Room group A	workrooms with work areas for predominantly sedentary activities
Room group B	workrooms with work areas for predominantly standing activities (sales and comparable rooms)
Room group C	workrooms with work areas for predominantly sitting and standing activities, where there is heavy odour nuisance, or for heavily physical work

❸ Room groups

System	Clear room height (H)	Max. room depth	Air supply and exit openings (cm^2) per m^2 floor area
I	up to 4 m	2.5 × H	200
II	up to 4 m	5.0 × H	120
III	up to 4 m	5.0 × H	80
IV	over 4 m	5.0 × H	80

❹ Ventilation cross-sections for free ventilation in workrooms with work areas for predominantly sitting activities, Workplace Guidelines 5 (room group A)

Air temperature (°C)	Relative humidity (%)
20	80
22	70
24	62
26	55

❺ Recommended relative humidity according to air temperature

Natural ventilation

The air quality in rooms or buildings is one of the significant user pleasure criteria and an essential factor in personal comfort. If a building is operated without mechanical ventilation equipment, this is called natural ventilation. This is the exchange of air through window ventilation, additional shafts in the building or other openings. Natural ventilation is produced by wind pressure on and around the building, which depends on numerous other factors. The air exchange within a building is also influenced by thermal effects around and in the building. The air exchange within each room is significant for the evaluation of natural ventilation.

If a building is to be predominantly naturally ventilated, then its limitations have to be taken into account. These limitations are determined by:

- the location of the building in a town planning context
- the wind speeds occurring at the building's location
- noise nuisance at the building's location
- building structure, room depths, internal rooms, pressure resistances at the building
- thermal effect in the building and in the rooms

The flow conditions for window ventilation differ in summer and winter according to the temperature difference between inside and outside → ❶. For workrooms, Workplace Guidelines 5 (October 1979 edition) require natural (free) ventilation.

A differentiation is also made here between:

- window ventilation
- shaft ventilation
- supplementary roof ventilation
- ventilation through other air openings

Air quality is defined as adequate when sufficient healthy air for breathing is available in the workrooms and when the air quality essentially corresponds to that of outside air, unless the outdoor air does not have the required quality because of exceptional circumstances (CO_2 concentration, nitrous oxide etc.).

There are four systems of free ventilation: → ❷. The systems apply for a reference area of 6 m^2/worker.

Working rooms are categorised into A, B, C → ❸.

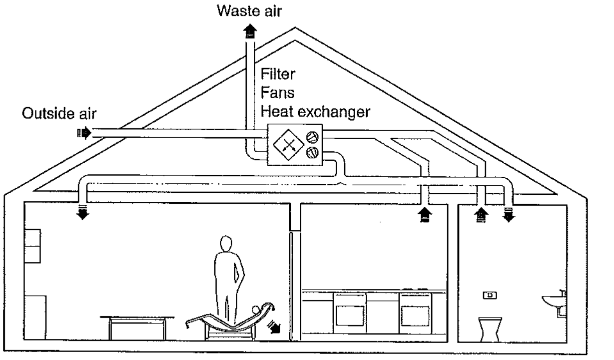
The **ventilation cross-sections** for free ventilation can be determined from → ❹ (excerpt from Workplace Guidelines 5).

It must be possible to reduce ventilation cross-sections through adjustment (shutters). The minimum outside air flows required in the Workplace Guideline correspond approximately to the recommended outside air flows for the maintenance of maximum CO_2 concentrations.

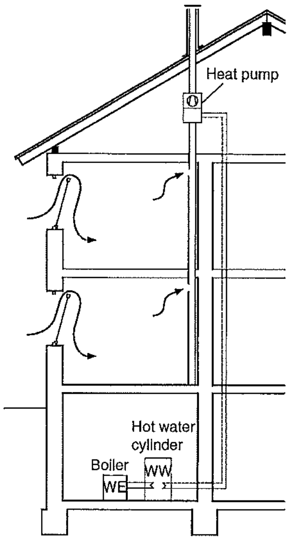
The recommendation:
for predominantly sedentary activities: 20–40 m^3 / h × no. people
for predominantly standing activities: 40–60 m^3/h × no. people
for heavy physical work: 65 m^3 / h × no. people

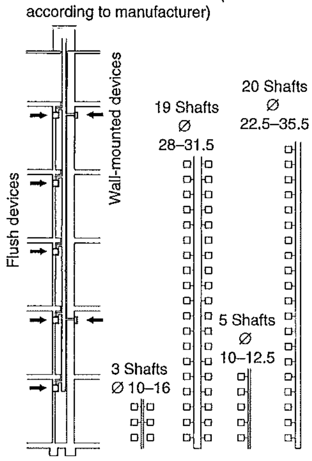
For the first group (predominantly sedentary activities), a more precise consideration in line with holistic concepts is recommended. The necessary volume flow can be determined through the CO_2 impairment of the outside air and the user frequency of the rooms.

DOMESTIC INSTALLATION
Drainage
Ventilation
Heating
Small sewage treatment plants
BS 5925
Building services



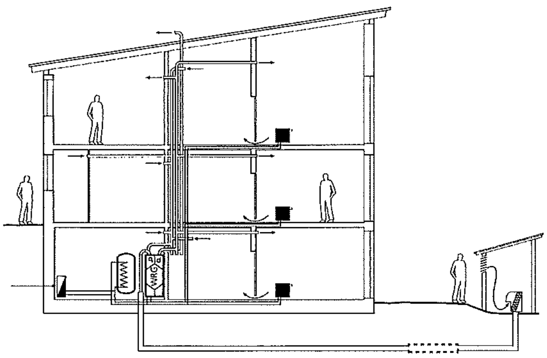
❶ Centralised ventilation of a house with heat recovery. The outside air fed in to renew the inside air is filtered, then passed through a cross-flow heat exchanger, where it receives warmth from the extract air. The warmed air normally flows through a number of rooms before being extracted again. Air from kitchens and bathrooms should not be able to flow into other rooms (Wellpott, Bohne → refs)





❷ Centralised air extract system with heat recovery by a heat pump and storage in a warm water buffer tank (WW). The remaining energy is supplied by a heating device (WE) (Wellpott, Bohne → refs)]

❸ Single ventilation systems with common extract duct replace large batteries of shafts (Wellpott, Bohne → refs)



❹ Controlled residential ventilation with ground-source heat exchanger: detached house (Wellpott, Bohne → refs)

	Operation min. 12 h/day[1]	Any duration of operation[2]
cooking niche	40 m³/h	60 m³/h
kitchen, background ventilation	40 m³/h	60 m³/h
kitchen, intensive ventilation	200 m³/h	200 m³/h
bathroom with/without WC	40 m³/h	60 m³/h
separate WC	20 m³/h	30 m³/h
[1] background operation [2] demand-controlled operation		

❺ Scheduled flow volumes for windowless rooms, DIN 1945-5

Controlled ventilation of homes
For reasons of hygiene and building physics, it is necessary to remove air enriched with odours, water vapour and CO_2 from occupied rooms and replace it with unused oxygen-rich air. There is a difference between background ventilation (for building physics reasons) and demand-controlled ventilation (for hygienic reasons).

Background ventilation: An air exchange at least 0.5–1.0 times per hour can ensure that no damage occurs to a building through normal use. High internal air humidity caused by too little air exchange (airtight joints) can lead to mildew and mould formation. This phenomenon is particularly apparent when new windows with draught seals have been installed without improving the thermal insulation of the external walls of the building.

Demand-controlled ventilation: Bodily odours, cigarette smoke, kitchen and toilet odours pollute the air and make air exchanges necessary.

Air changes recommended for hygienic reasons: 0.5–1.0 times per hour in residential, occupied and bedrooms, 4–5 times per hour in internal sanitary rooms, 0.5–25 times per hour in kitchens (intermittent requirement).

Mechanical ventilation of homes
Mechanical ventilation without heat recovery should have the effect of renewing the inside air sufficiently often and also keeping the heat loss through air extraction within reasonable bounds. Mechanical ventilation with heat recovery → ❶ brings the extract air into thermal contact with the intake air. At least 80% of the waste heat (degree of temperature exchange) can be recovered from the extract air.

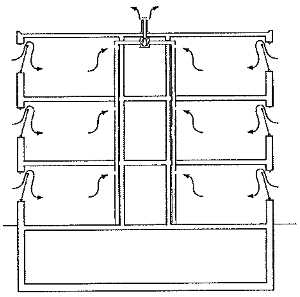
Central air extract system with heat recovery
In extract systems, outside air flows through openings and joints into the rooms. The required heat energy must be supplied by the heating system (normally static radiators or surface heating systems). The thermal energy transported out of the building with the extract air is lost without additional measures. The low temperature level (approx. 20–24°) prevents heat recovery in the heating system. One way of recovering the heat is to use the temperature level of the extract air as a heat source for a heat pump. The energy can then, for example, be saved in a domestic hot water cylinder → ❷.

Single ventilation systems with common extract duct (main duct) → ❸
These require only a single vertical extract duct (DIN 18017-3). This can be, according to the manufacturer, up to 20 storeys high with one or two fans connected on each storey (which can also be from two adjacent living areas). The main extract duct is of 10–35 cm diameter and can be located in an installation shaft with sufficient fire resistance. The box-form radial fans are installed on the plaster or flush and have a capacity of 50 or 90 m³/h. Airtight backflow flaps prevent heat loss or odour nuisance while the fan is not running and provide fire protection (up to fire resistance class L 90) in case of fire.

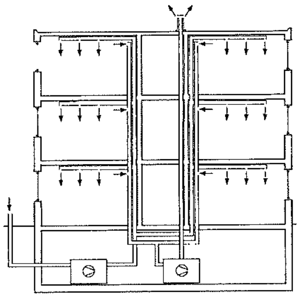
Controlled domestic ventilation with ground-source heat exchanger → ❹
The ground-source heat exchanger provides air cooling in summer. Warm outside air can be cooled from +30°C to +20°C by passing it through one. The heat exchanger is used in the winter to pre-warm the outside air (from –10°C to +2°C). Further heating of the air can heat a well-insulated building on mild winter days.

DIN 18017

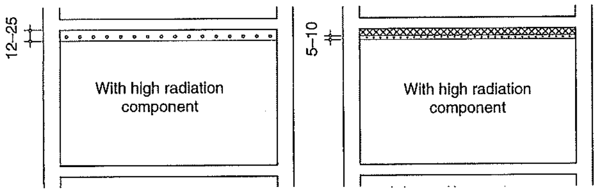
PD CEN/TR 14788



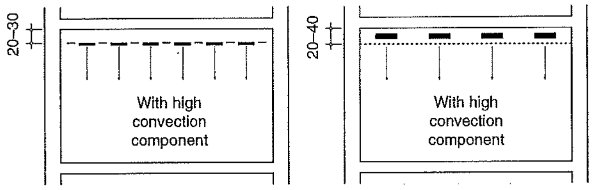
❶ Ventilation with negative pressure: no heat recovery possible (Wellpott, Bohne → refs)



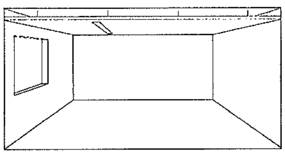
❷ Air supply and extract systems (Wellpott, Bohne → refs)



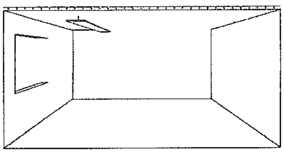
❸ Chilled ceiling system with thin constructional thickness, e.g. metal panel ceiling and capillary pipe ceiling (Wellpott → refs)



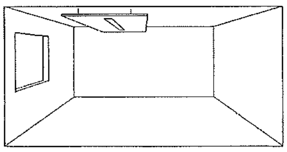
❹ Cooling system in combination with suspended ceiling, e.g. acoustic ceiling. Installation into an existing ceiling is often possible (Wellpott → refs)



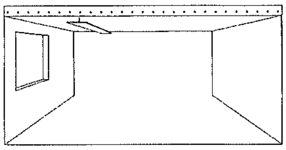
❺ Suspended ceiling with integrated ceiling light (Wellpott, Bohne → refs)



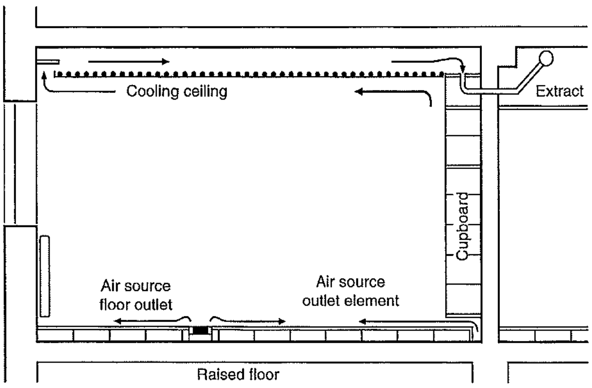
❻ Directly plastered chilled ceiling with hanging light (Wellpott, Bohne → refs)



❼ Suspended chilled beam with integrated ceiling light (Wellpott, Bohne → refs)



❽ Storage chilled ceiling with hanging light (Wellpott, Bohne → refs)



❾ Cooling systems in combination with suspended ceilings, e.g. acoustic ceilings. Installation into an existing ceiling is often possible. (Wellpott, Bohne → refs)

Purposes of ventilation
In occupied rooms, the air should be in a condition to meet our comfort requirements. The following comfort-relevant parameters can be influenced by ventilation systems:

- cleanliness of air/odour level
- room air temperature
- air movement, draughts
- air humidity.

Construction of ventilation systems
A room ventilation system normally consists of an outside air intake with fan, the central processing device, air distribution ductwork and air outlets → ❷. There are various systems, according to the intended purposes. Another consideration is whether the ventilation system can fulfil the intended purpose solely through the transported and processed air, or in combination with a water circulation system.

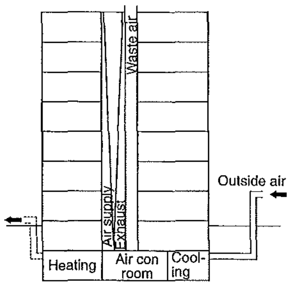
The first categorisation of air handling systems is whether they have a ventilation function or not. Systems with a ventilation function must be provided with a sufficient supply of outside air. In addition to ventilation, such systems can also perform functions like heating, cooling, humidification or dehumidification. Systems without a ventilation function fulfil the same conditions, but cannot exchange used air from rooms.

A further categorisation of air handling systems is according to the type and method of air processing, fundamentally the thermodynamic processing functions: heating, cooling, humidifying and dehumidifying. A system which only transports air and filters it if required is a **ventilation system.** If no outside air is used, then it is a **closed ventilation system.**

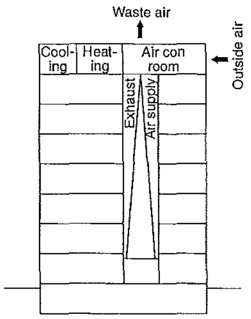
Air-water systems
Air-water systems are air handling systems operated in combination with additional water-circulation heating or cooling. These include, for example:

Chilled ceilings → ❸ – ❾
Chilled ceilings have a passive cooling effect. Instead of mechanical air circulation, there is a radiation exchange between ceiling components with cold water flowing through them and the room. Air exchange can remain at the minimum hygienically required level. In office rooms, the internal cooling load, i.e. the heat produced by people, devices and lighting that has to be removed, is normally greater than the heat loss though the external envelope of the building. In order to deal with this cooling load, normally about 40–80 W/m^2, conventional air conditioning requires high air exchange rates, large ducts and expensive central air handling units. These are increasingly being replaced by chilled ceilings, also referred to as 'silent cooling', because no noise-producing mechanical devices like fans are used. Water is used as transport medium instead of air.

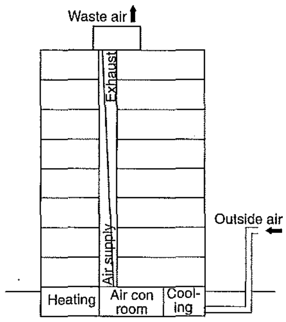
Advantages of chilled ceilings
Little space required for ductwork, shafts and service rooms. Low energy costs, energy saving. High acceptance due to less noise from air movement and less room air velocity. Chilled ceiling systems are available for up to 100 W/m^2 of cooling. A further variant of **'silent cooling'** (cooling system with radiation or free convection) is suspended **chilled beams** → ❼ (which, however, offer less cooling capacity than full-surface systems due to their limited area), plus combinations of ceiling beam with convection component (e.g. convection component increased through perforated plates), storage chilled ceilings and various combinations of the above systems.



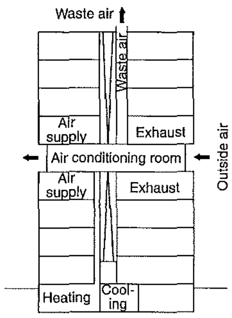
❶ Air conditioning plant rooms in basement (Wellpott → refs)



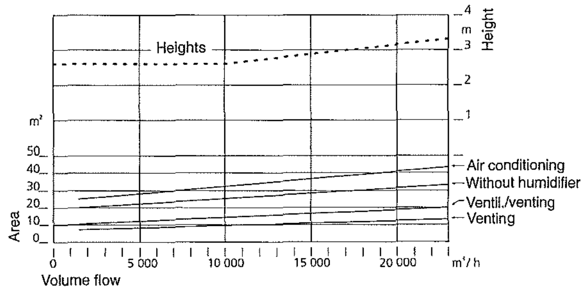
❷ Air conditioning plant rooms on top floor (Wellpott → refs)



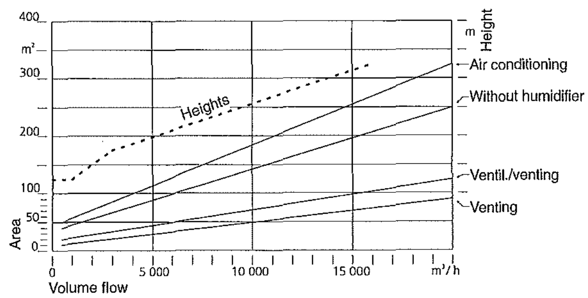
❸ Air supply plant room in basement. Extract air plant room on the roof (induction air conditioning system). No air circulation (Wellpott → refs)



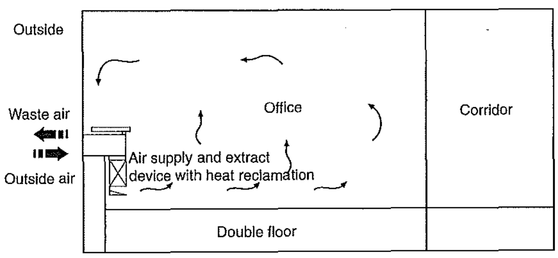
❹ Air conditioning plant room on an intermediate floor. Good solution for high-rise buildings (Wellpott → refs)



❺ Approximate determination of area and room heights required for air conditioning plant rooms in which to site several units for air flows of up to 50m³/s, according to Vdl 3803, for smaller systems (Wellpott → refs)



❻ As ❺, but for larger systems (Wellpott → refs)



❼ Combined parapet air supply and extract unit (Wellpott, Bohne → refs)

Air conditioning plant rooms →❶ – ❹

Arrangement for air handling equipment According to a sample design by the expert Building Supervision (RbAL), air handling equipment must have a dedicated service room (air conditioning plant room) in buildings of more than three storeys, if the connecting ductwork leads into more than one storey or fire compartment.

Ventilation and air conditioning systems mostly have their services rooms on a services floor, near the heating plant room (heating room with distribution) and the cooling plant (chiller). The combination of air conditioning plant and heating plant in one room is not allowed (fire protection). Spatial connection of plant rooms to the building cores with their vertical installation shafts is an important design consideration. The horizontal and vertical distances to the main areas of demand (e.g. large kitchens, canteens or server rooms) from the air conditioning plant room should also be considered.

The formal integration of a services floor into the body of a building can considerably influence its appearance. Placed on one of the upper storeys, a dedicated services floor will have almost no windows or none at all (noise emission), but will need intake and extract louvres and will also contrast with other floors with its different storey height.

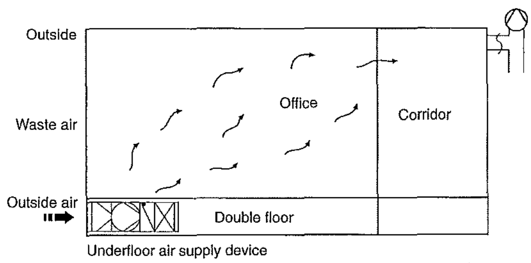
Room sizes

An approximate estimation of the size of an air conditioning plant room can be undertaken using the VDI Guideline 2052, working from the assumed volume flow and the type of air handling. Example calculations for the size of the plant room in an administration building → ❺ – ❻.

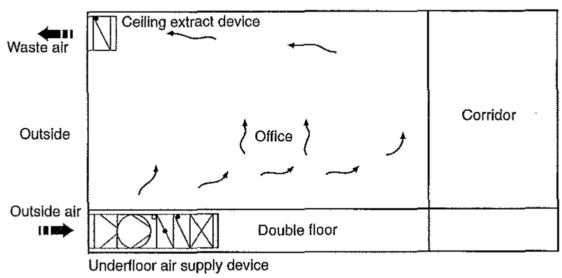
Façade ventilation systems → ❼ – ❾

These are also referred to as **decentralised ventilation systems.** The units are placed near the façades with a direct duct connection. In contrast to fan convectors with recirculation, the flow of outside air is fed directly from the façade to the unit. This means that no more air conditioning installation is required in the building. Façade ventilation units can be designed in various forms such as underfloor air supply units, combined air supply and extract units or with a central extract air plant.

It is important to consider the influence of wind pressure on the volume flow. The temperature boundary layer at the façade can also affect the air supply temperature, depending on the layout and design of the building.

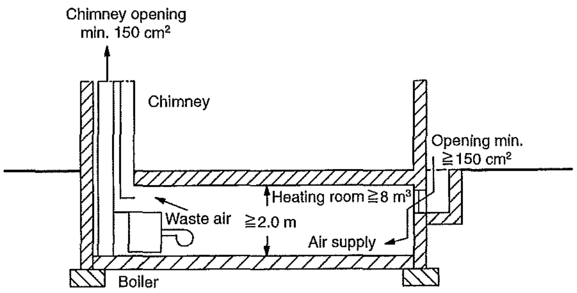


❽ Underfloor air supply unit combined with centralised extract air system (Wellpott, Bohne → refs)

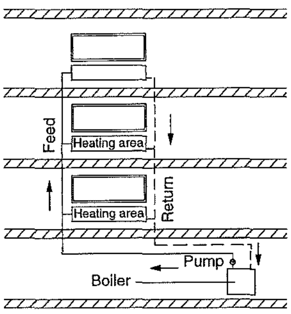


❾ Underfloor air supply unit combined with over-current component (Wellpott, Bohne → refs)

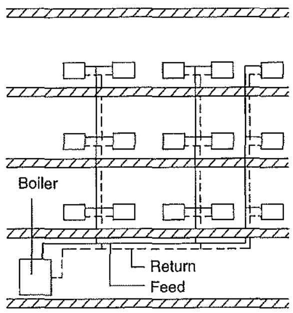
DOMESTIC INSTALLATION
Drainage
Ventilation
Heating
Small sewage treatment plants
Building services



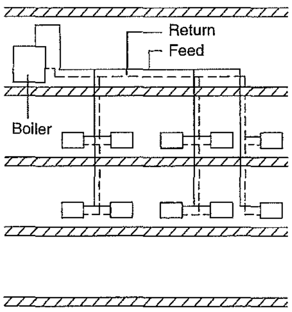
❶ Heating room for solid fuel, min. area 8 m³ necessary for heating capacity ≧50 kW



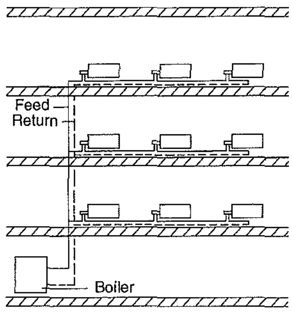
❷ Principle of warm water central heating system: water is heated by the boiler and circulated constantly to radiating surfaces by a pump (Wellpott → refs)



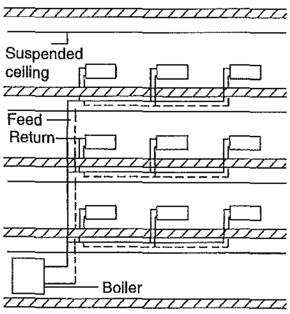
❸ Twin-pipe system with low-level distribution and vertical riser connections



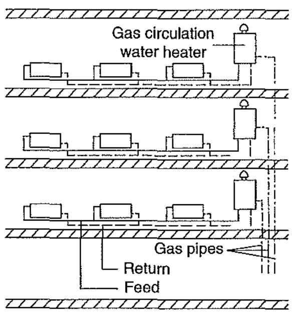
❹ Twin-pipe system with high-level distribution and vertical riser connections



❺ Single-pipe system with special valves and horizontal distribution



❻ Twin-pipe system with horizontal distribution (standard layout for office buildings)



❼ Single-pipe system with horizontal distribution on each floor

Heating systems

Heating systems for buildings normally use water as the heat distribution medium, less often air (steam is used as a heating medium only for industrial purposes). The necessary temperature of the heat distribution medium (water, air, steam) depends on the temperature chosen and the type of heating surface in the rooms. A heat generator provides the necessary temperature. Most existing heating systems use gas or oil as the primary energy source. The heating gas or oil is normally burnt in boilers with a combustion temperature of about 1000°C and the heat is transferred to the distribution medium in a heat exchanger.

Because a temperature of 70°C is typically sufficient for the heat distribution medium, a holistic design will attempt to avoid the burning of fossil fuels. Methods of exploiting renewable energy are: (ground-source) geothermal energy → p. 469 in connection with a heat pump system; combination of heat and power generation (CHP); or perhaps falling back on a CO_2-neutral energy source like wood. It can also be possible to store seasonal sources of energy from the environment (thermal solar energy) during the summer months and make it available in the winter.

Heat distribution

Much the most common system is **warm water central heating.** This transfers the heat produced in the heat generator into water as distribution medium to the radiators, which emit heat. The cooled water returns to the heat generator to be warmed up again (flow and return). Warm water central heating systems have a max. flow temperature of approx. 100°C, but 45–70°C is normally preferred today, described as the low temperature range. Heating systems with flow temperatures of over 120°C count as hot water heating and are more often used with district heating systems.

The heat distribution is normally circulated as **warm water pumped heating**. There are various pipework layouts → ❷ – ❼.

Heat generation with gas or heating oil

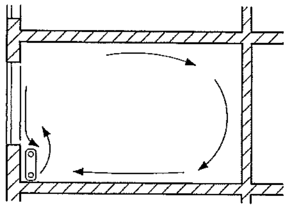
Gas firing: gas has become prevalent in recent years. Advantages: no storage costs, low maintenance costs, payment after use, can be used in groundwater protection zones, easily regulated, high annual efficiency, can be used for the heating of individual flats or rooms (compact gas boilers), little environmental impact. Disadvantages: dependent on public utility network, higher energy costs. A conversion from oil to gas usually makes a new chimney necessary.

Oil firing: is also common today using light heating oil as fuel. Advantages: requires no public utility network, easily controllable. Disadvantages: high cost of storage and tank installation, rent income losses in rented houses due to the oil storage room, only possible under stringent regulations in areas at risk of flooding or groundwater protection zones, payment before use, high environmental impact.

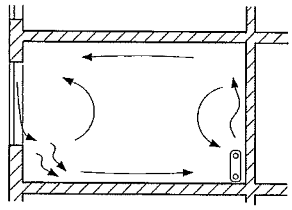
Solid fuel firing

Coal, brown coal and wood are now used less often for heating buildings. Depending on the fuel, large quantities of environmental pollutants can be released, which are subject to stringent controls under the Federal Anti-Emissions Law. Advantages: independent of fuel imports, low fuel costs. Disadvantages: more work for the operator, larger storeroom necessary, high emission of pollutants, poor controllability.

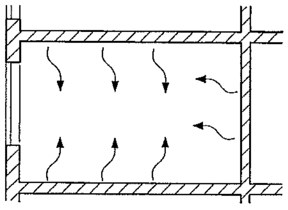
BS 5871
BS EN 12828
BS EN 15316
DIN EN 215
DIN EN 442
DIN EN 1264
DIN EN 12170
DIN EN 12171
DIN EN 12828
DIN EN 12831



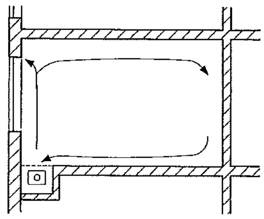
❶ Air movement with sectional radiator at window



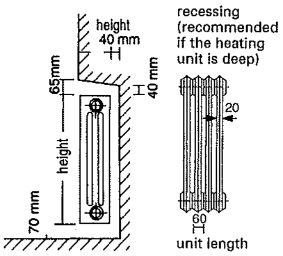
❷ Air movement with sectional radiator at internal wall



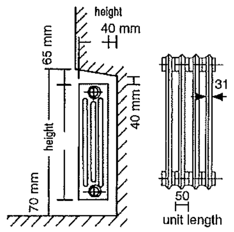
❸ Air movement with surface heating (wall, ceiling or floor)



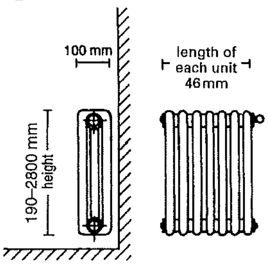
❹ Air movement with underfloor convectors



❺ Cast-iron radiators, DIN 4703



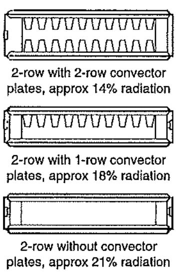
❻ Steel radiators, DIN 4703



❼ Tubular radiator

Height	Boss spacing	Depth
280	220	250
430	350	70, 110, 160, 220
580	500	70, 110, 160, 220
680	600	160
980	900	70, 160, 220

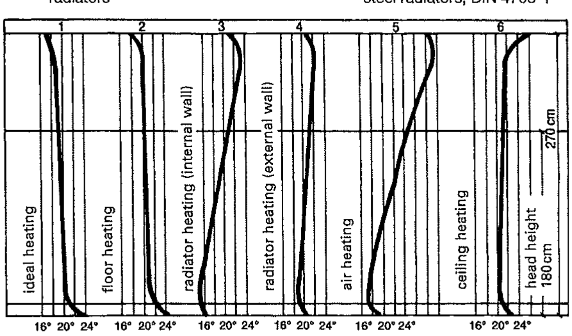
❽ Dimensions (mm) of standardised cast-iron radiators, DIN 4703-1



❾ Horizontal sections through panel radiators

Height	Boss spacing	Depth
300	200	160, 250
450	350	70, 110, 160, 220
600	600	70, 110, 160, 220
1000	900	70, 110, 160, 220

❿ Dimensions (mm) of standardised steel radiators, DIN 4703-1



⓫ Room temperature curves: physiological warmth evaluation of a heating system

Heating surfaces in rooms

Arrangement of heating surfaces and resulting air circulation → ❶ – ❹ Radiators placed below windows can prevent draughts near the windows. The air cooled by the glass surface is intercepted by the air rising from the radiator → ❶.

Located on internal walls, radiators can provoke air circulation with the effect of producing cool air near the floor and warm air near the ceiling. Such relatively large temperature differences between floor and ceiling are not comfortable → ❷.

Surface heating (underfloor, ceiling and wall heating) is operated in room perimeter areas with low temperatures. The heat output is uniform and solely through radiation. The low heating demand of buildings built according to the Energy Saving Regulations (EnEV) means that surface heating systems are ideal in this respect, yet provide a comfortable temperature → ❸.

Convectors transfer heat not by radiation, but by direct heat transfer to the air molecules. For this reason, convectors can be clad or built in without reducing their heating capability. The performance of a convector depends on the recess height above the heater → ❹, see also p. 534.

Types of heating surfaces

Sectional radiators include steel tube, cast-iron and steel radiators. They release 40% of their heat as radiation.

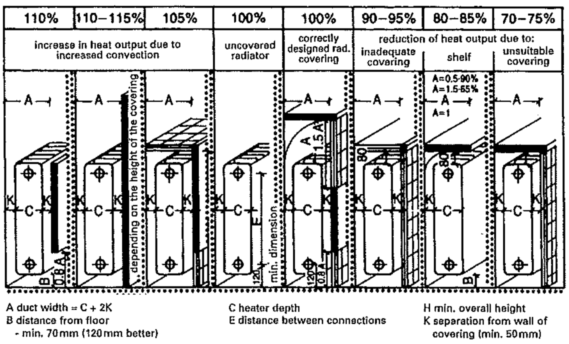
Steel tube radiators are available as 2–6-row tubular radiators, have no sharp edges and provide good performance in relationship to their length → ❼.

Steel radiators → ❻ are welded out of a number of components into a block and have connections between the blocks at the ends. Until a few years ago, these were the standard radiators for warm water heating, but panel radiators are now more usual.

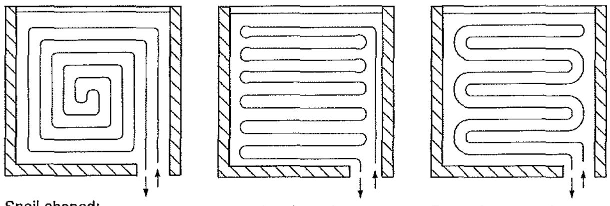
Cast-iron radiators have a small market share. They react slowly to control inputs but are very corrosion-resistant → ❺.

Panel radiators consist of flat and profiled steel plate double panels with water flowing through. The front gives out heat mostly as radiation, the back mostly by convection into the air. If a number of panels are arranged in front of each other, then the proportion of convection increases accordingly. In practice, up to three panels are used.

Because of their shallow constructional depth (2–5 cm), panel radiators require only very shallow window niches. They can emit up to 40% of their heat as radiation and can be operated with relatively low flow temperatures (making them suitable for operation with ground-source heat pumps). In order to improve the heating performance, vertical folded fins (convector plates) can be mounted between the panels → ❾.



⓬ Effect on heat output of various radiator covers

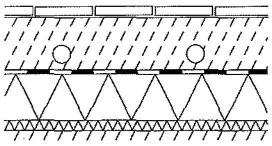


Snail-shaped: uniform temperature distribution

Meander-shaped: Heat gradient from inside to outside

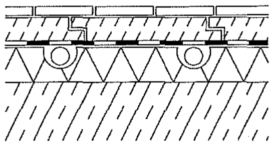
Reversing meander: uniform temperature distribution because feed and return are next to each other

❶ Layout patterns for underfloor heating



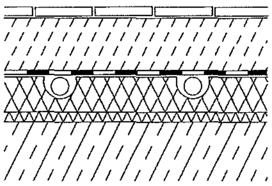
Floor construction:
- Floor covering
- Screed (cover to pipes min. 45 mm)
- PE foil 0.2 mm
- Insulation 40 mm
- Impact sound insulation
- Structural floor slab

❷ Underfloor heating (wet laying)



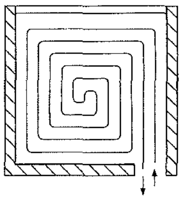
Floor construction:
- Floor covering
- Dry screed 45 mm
- PE foil 0.2 mm
- Laying element/insulation layer 30 mm
- Impact sound insulation
- Structural floor slab

❸ Underfloor heating (dry laying)



Floor construction:
- Floor covering
- Dry screed 45 mm
- PE foil 0.2 mm
- Laying element/insulation layer 30 mm
- Structural floor slab

❹ Underfloor heating – pipes laid within the insulation layer



❺ Layout pattern of a ceiling heating system

The heat output of **convectors** is solely through convection → p. 533. The advantage of this sort of heat transfer is the very short warming-up time. The disadvantages are strong air currents, stirring up dust and noise. In order to improve heat output, convectors with too little recess height (e.g. floor convectors) can be fitted with blowers. Convectors with blowers are seldom suitable in flats and houses due to the noise produced.

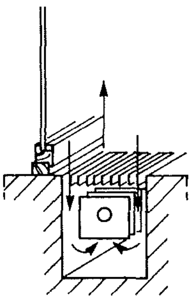
Where glass surfaces extend down to floor level, **underfloor convectors** → ❻ can be used. These replace radiators in front of the glass (particularly with sliding glass components).

Mini- or screed convectors → ❼, which are installed flush with screed level, can be combined successfully with surface heating systems like underfloor heating. These are particularly suitable for seasonal transitions, to avoid having to put the rather sluggishly reacting underfloor heating into operation.

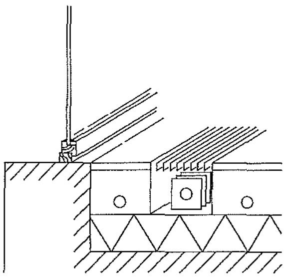
Radiator covers: radiators can be covered in various ways, resulting in a loss of efficiency of 10–15%. If the air intake and outlet openings are insufficiently large, this loss can even increase to 30%, which then has to be compensated for with larger radiator areas to cover the heating demand.

Metal coverings transfer the radiation component almost completely to the air in the room, but coverings of other materials with low thermal conductivity considerably reduce the radiation → p. 533 ⓬.

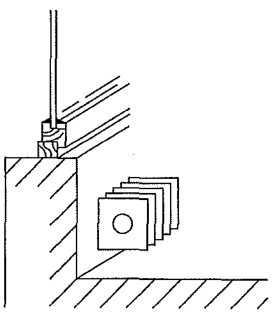
Underfloor heating → ❶ – ❹ transfers the heat from the floor to the air and also to the walls and ceiling. Heat transfer to the air is by convection, i.e. through air movement at the surface of the floor, but heat transfer to the walls and ceiling is by radiation. The heat output, depending on floor construction, can be 70–110 W/m^2. Ceramics, wood or textiles and almost any common floor covering are suitable for the floor construction, but the thermal resistance should not exceed 0.15 m^2 kW. The screed on top of underfloor heating should be in accordance with DIN 18560 or the bulletins of the Central German Building Industry Association. The thickness of the screed depends on its type, method of laying and the assumed load.



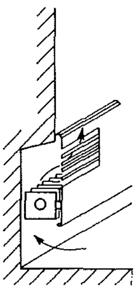
❻ Underfloor convector



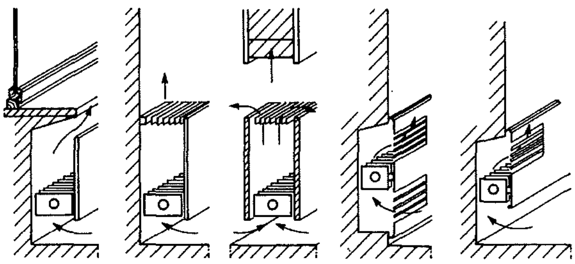
❼ Mini-convector (screed convector) in combination with underfloor heating (principle)



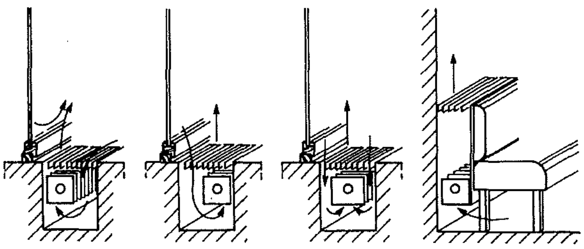
❽ Surface-mounted convector



❾ Convector in recess

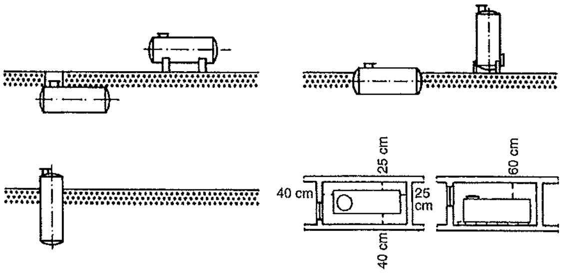


(a) under window
(b) in front of smooth wall
(c) free standing (for heating of 2 rooms)
(d) built into wall
(e) built into wall

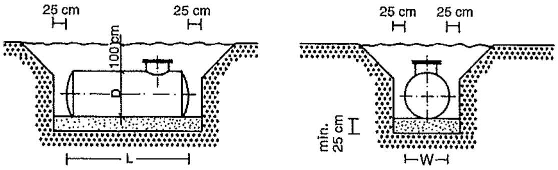


(f) under floor convector with room air intake
(g) under floor convector with cold air intake
(h) under floor convector with intake on both sides
(i) convector behind bench seat

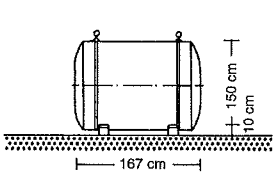
❿ Various ways of installing convectors



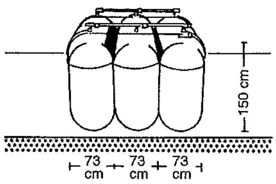
❶ Ways of installing standardised heating oil storage tanks



❷ Underground installation of heating oil storage tanks



❸ Battery storage tank made of nylon (polyamide)



❹ Battery storage tanks made of nylon (polyamide)

Nominal capacity: vol. in litres (dm³)	Max. dimensions (mm)		Weight incl. accessories (kg)
	Length l	Depth d	
1100 (1100)	1100 (1100)	720	approx. 30–50 kg
1500 (1600)	1650 (1720)	720	approx. 40–60 kg
2000	2150	720	approx. 50–80 kg

❺ Available dimensions of plastic battery tanks

Min. capacity: vol. in (m^3)	Min. dimensions (mm)					Weight (kg) of			
	External diameter d_1	Length l	Sheet thickness						
			1-walled	2-walled.	Filler cap diam.	1.1 1-walled		1.2 A/C	B
1	1000	1510	5	3	–	265		–	–
3	1250	2740	5	3	–	325		–	–
5	1600	2820	5	3	500	700		700	790
7	1600	3740	3	3	500	885		930	980
10	1600	5350	5	3	500	1200		1250	1300
16	1600	8570	5	3	500	1800		1850	1900
20	2000	6969	6	3	600	2300		2400	2450
25	2000	8540	6	3	600	2750		2850	2900
30	2000	10120	6	3	600	3300		3400	3450
40	2500	8800	7	4(5)	600	4200		4400	4450
50	2500	10800	7	4	600	5100		5300	5350
60	2500	12800	7	4	600	6100		6300	6350
						Weight (kg) of			
						1.3 A	B	2.1	2.2 B
1.7	1250	1590	5	–	500	–	–	–	390
2.8	1600	1670	5	–	500	–	–	–	390
3.8	1600	2130	5	–	500	–	–	–	600
5	1600	2820	5	3	500	700	745	–	740
6	2000	2220	5	–	500	–	–	–	930
7	1600	3740	5	3	500	885	930	935	–
10	1600	5350	5	3	500	1250	1250	1250	–
16	1600	8570	5	3	500	1800	1950	1850	–
20	2000	6960	6	3	600	2300	2350	2350	–
25	2000	8540	6	3	600	2750	2800	2800	–
30	2000	10120	6	3	600	3300	3350	–	–
	2500	6665	7	–	600	–	–	3350	–
40	2500	8800	7	4	600	4200	4250	4250	–
50	2500	10800	7	4	600	5100	5150	–	–
	2900	8400	9	–	600	–	–	6150	–
60	2500	12800	7	4	600	6100	6150	–	–
	2900	9585	9	–	600	–	–	6900	–

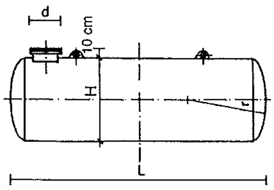
❻ Dimensions of cylindrical oil tanks → ❼

When **cement screed** ZE 20 is laid on heating pipes, which are laid directly on thermal insulation, a minimum cover to the pipes of 45 mm is specified, which results in a total construction thickness of min. 75 mm without floor construction. Screed expands during the operation of the heating, with temperature differences between top and bottom. This differential expansion leads to tension stresses under ceramic flooring, which can only be resisted by an upper reinforcement layer. Reinforcement is not necessary when the floor is covered with carpet or parquet, because the temperature gradient between top and bottom of the screed is less than with ceramic flooring.

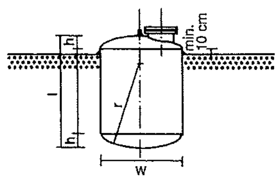
DIN 4725 gives the maximum permissible floor surface temperatures: 29°C for permanently occupied areas, and for the edge zone (no wider than 1 m) 35°C. The maximum permissible floor temperature for bathrooms is 9°C above standard room temperature. Underfloor heating is possible under these conditions in normal circumstances,because the heating demand is seldom above 90 W/m².

Storage of heating oil: the quantity of heating oil should last for at least three months and at the most for one heating period (winter). No more than 5000 l may be stored in the heating room. The tanks must be inside a collecting tank with a volume sufficient to take the entire oil quantity (secondary containment). If the tanks are underground, equipment must be installed to protect against leakage, like double-walled tanks or plastic inner lining. In groundwater protection zones, maximum quantities and additional protection measures are prescribed.

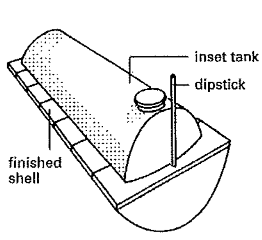
Inside buildings: either plastic battery tanks each containing 500–2000 l or steel tanks welded together on site, which can be any size. The tank storage room must be accessible and the tanks must be regularly checked for leaks. An internal tank room must also be able to contain the entire volume of oil in case of a leak. Tank installations must have filling and venting equipment, and also protection against overfilling. According to the type of storage, leak-warning systems may be required (e.g. with underground tanks).



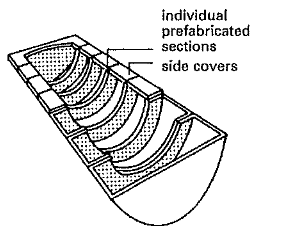
❼ Storage tank for heating oil, side view



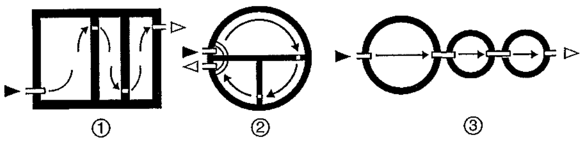
❽ Storage tank for heating oil, front view



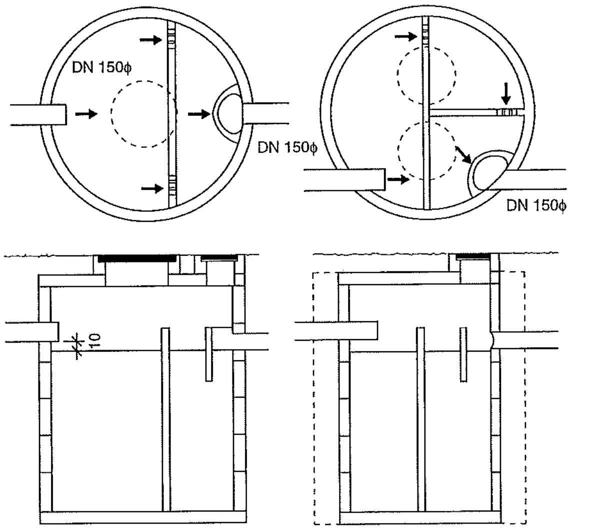
❾ Tank laid in pre-cast protection component



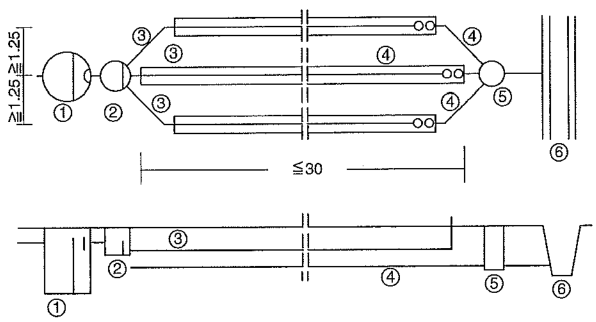
❿ Pre-cast concrete protection trough for oil tanks



❶ Basic layouts of multi-chamber sedimentation tanks



❷ Multi-chamber sedimentation tanks of pre-cast components, with two or three chambers, plans and sections



❸ Principle of a filter trench, plan and section
❶ Multi-chamber sedimentation tank, ❷ distribution shaft, ❸ feed pipes, ❹ drainpipes, ❺ collection shaft, ❻ discharge

Small sewage treatment plants are facilities for the cleaning of wastewater, which are used when the disposal of wastewater in municipal treatment works is not possible for technical, regulatory or financial reasons: maybe there is no public sewer network available, or as a temporary measure. They are only permissible for the treatment of wastewater from, for example, kitchens, laundries, bathrooms, toilets and wash rooms.
Principle of a small-scale sewage treatment plant:
1. Mechanical cleaning, i.e. sludge removal from a multi-chamber sedimentation tank → ❶ – ❷.
2. Biological cleaning in a filter trench or trickle filter or through underground filtration.

The construction of a small-scale sewage treatment system consists of: multi-chamber sedimentation tank, distribution shaft, filter trench (trickle filter or underground filtration), collection shaft, discharge into waterway.

Treatment process
The residential wastewater is first fed into a sedimentation tank (mechanical cleaning), where solid matter settles to the bottom. It then flows into a distribution shaft, from where it is fed intermittently into a filter trench (with perforated pipes) or into a trickle filter (biological cleaning). The outflow pipes from the filter trench drain via a collection shaft into a waterway or soakaway.
The mechanical process of wastewater treatment takes place in a **multi-chamber sedimentation tank**. Undissolved solids and solids capable of settling are sedimented (sludge removal) → ❶ – ❷.
Biological cleaning (secondary treatment) of the wastewater takes place in a **filter trench**. The wastewater percolates from a perforated pipe into a layer of fine gravel (2–8 mm), the filter layer, into a deeper perforated pipe (depth min. 1.25 m). This then transports the water for discharge into a waterway → ❸.

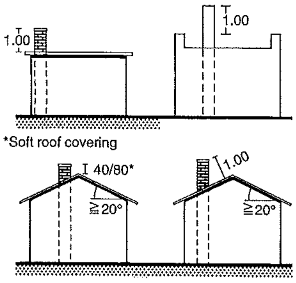
Wastewater production
For a residential building, 150 l of water per occupant per day should be assumed. For other buildings, the equivalent inhabitant value is 150 l for every:
– 3 seats in pubs without kitchens
– 1 seat in pubs with kitchens and max. 3 rotations of each seat in 24 hours.
– 10 seats in pubs with gardens but without kitchens
– 2 employees in factories or workshops without kitchens
– 3 employees in administration buildings without kitchens.

	Multi-chamber sedimentation tanks		Multi-chamber septic tanks
no. chambers	2	3–4	3
specific usable capacity	300 l/RU*	300 l/RU*	1500 l/RU*
total usable capacity (min.)	3000 l	3000 l	6000 l
total usable capacity (max.)	4000 l	—	—
capacity of 1st chamber	⅔ of total capacity	½ of total capacity	½ of total capacity
min. water depth	1.20 m	1.20 m	1.20 m
greatest permissible water depth for usable capacity of 3000–4000 l >4000–10 000 >10 000–50 000 l >50 000 l	 1.90 m — — —	 1.90 m 2.20 m 2.50 m 3.00 m	 1.90 m 2.20 m 2.50 m 3.00 m
*RU, each residential unit with 50 m^2 of residential area is assumed to have 2 inhabitants, over 50 m^2 min. 4 inhabitants.			

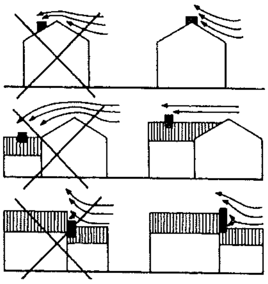
❹ Sizing of multi-chamber sedimentation tanks and septic tanks, DIN 4261-1

CHIMNEYS AND VENTILATION SHAFTS

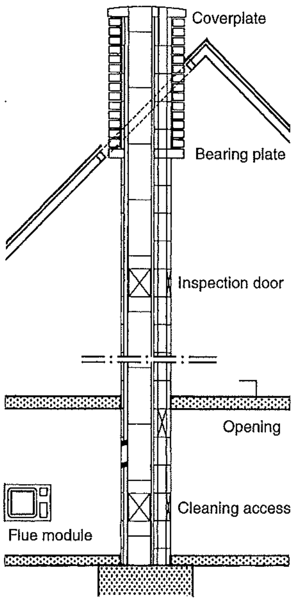
Chimneys



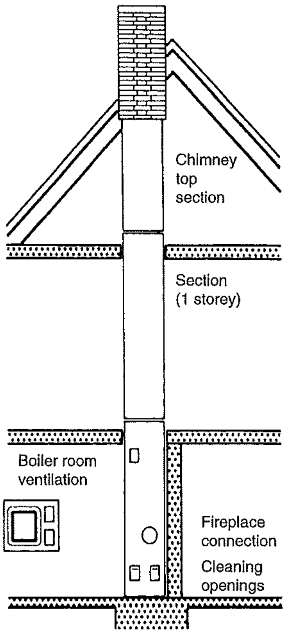
1 Chimney heights above roofs



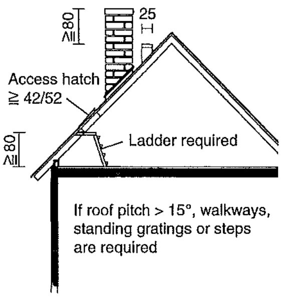
2 Wind and chimney draught



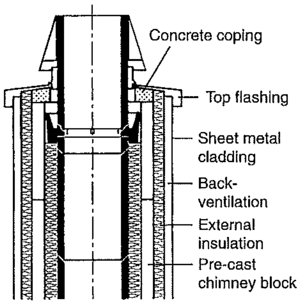
3 Modular chimney installation



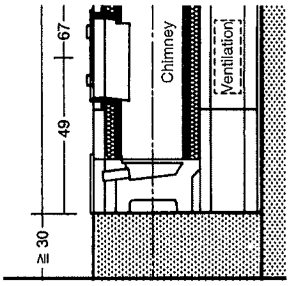
4 Pre-assembled chimney (storey height)



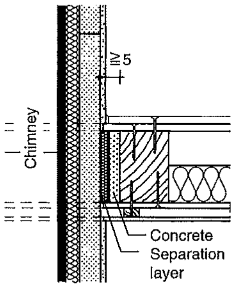
5 Roof access



6 Chimney top/sheet metal cladding



7 Chimney foundation



8 Distance from timber joist floor to chimney

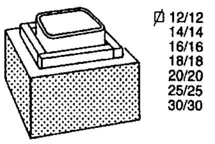
Chimneys are shafts, within or next to buildings, intended to carry flue gases from fireplaces (including ovens and appliances) into the open air above the roof. The following must be connected to their **own chimney**: each fireplace with a nominal heat output of more than 20 kW (for gas fires and appliances, more than 30 kW), each fireplace in buildings of more than five full storeys, each open fireplace, each fireplace with burner and blower. **Shared chimneys** may connect up to three fireplaces for solid or liquid fuel with a nominal heating capacity of up to 20 kW or three gas fireplaces with nominal heating capacity of up to 30 kW.

Cross-sections

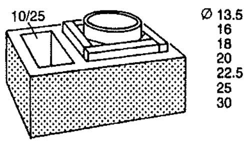
Chimneys must have a circular or rectangular clear cross-section. The **minimum cross-sectional area** for chimneys made of shaped bricks is 100 cm², the minimum side length 10 cm (for masonry chimneys 140 cm², 13.5 cm). The longer side may not be more than 1.5 times the shorter.
The cross-section can be calculated or taken from the approved tables produced by manufacturers of prefabricated chimneys → 9 – 10. In order to prevent condensation, a chimney should be fully utilised.

Fire protection

The external surfaces of chimneys must be ≧5 cm from both combustible and flame-resistant building materials. Non-combustible building materials may be in direct contact or be separated by a 2 cm wide insulated gap.



9 Multi-skin chimney block



10 Chimney block with ventilation ducts (to ventilate the heating room)

Heights

The **minimum height** (distance from fireplace level to chimney top) is 4 m (for joint chimneys 5 m). Chimney tops must be ≧40 cm above the highest point of roofs with a pitch ≧20° or 1.00 m from other roof surfaces. Chimneys which are nearer to roof structures than 1.5–3 times the height of the structure must clear the structure by ≧1 m. Chimney tops above roofs with a perimeter parapet must be ≧1 m above the parapet → 1.

Construction

In addition to the traditional single-skin masonry chimney, **multi-skin systems with shaped bricks** are commonly used today, consisting of flue liner, thermal insulation and chimney block (available with integrated ventilation ducts) → 9 – 10. **Pre-assembled chimneys** are also available → 4 with storey-height assembly units, and completely prefabricated steel-pipe chimneys. Chimneys have to be gas-tight and constructed of **fireproof materials**, and the temperature of the external surface may not exceed 100°C. Chimneys must be built on **foundations** and be braced over the height. Each chimney has a **cleaning opening** → 7 (≧10/18 cm, at least 20 cm below the lowest fireplace connection). Chimneys which cannot be swept from the top must have an additional cleaning opening in the roof space.

CHIMNEYS AND VENTILATION SHAFTS

Chimneys
Open fireplaces
Ventilation shafts

BS EN 1449
BS EN 1857
DIN EN 1443
DIN V 18160

MBO

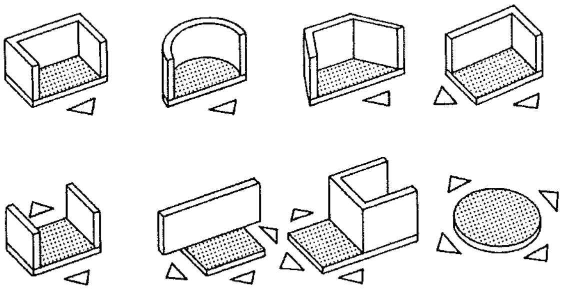
see also: Fire protection pp. 511 ff.

Building services

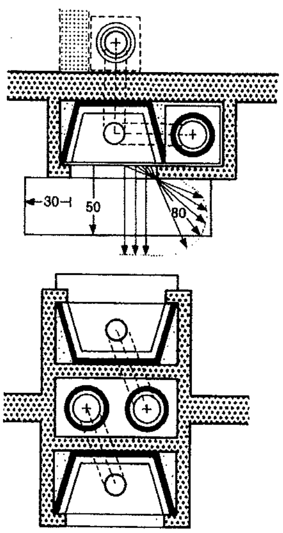
Open fireplaces must be structurally stable and made of **non-combustible building materials.** They can be built of fireclay blocks or slabs, bricks or blocks suitable for chimney construction, fireproof concrete or grey cast iron. Smoke hoods can be made of steel, brass or copper sheet.

Each fireplace must be connected to its **own chimney** with a cross-section suitable for the fire → ❷ – ❸. Fireplace and chimney should be built next to each other. The **effective chimney height** from smoke flue connection to chimney top ≧4.5 m. The flue pipe is connected to the chimney at an angle of 45° → ❻ – ❽.

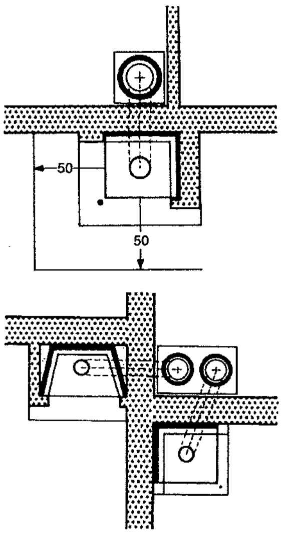
Open fireplaces must not be installed in rooms of less than 12 m^2 floor area. Sufficient air supply must be ensured: **air ducts,** which introduce air near to the combustion chamber opening (e.g. installed under the fireplace), are suitable → ❺. There must be at least **80 cm clear space** from the combustion chamber (to the front, sides and upwards) to combustible building components and objects → ❹ – ❺.



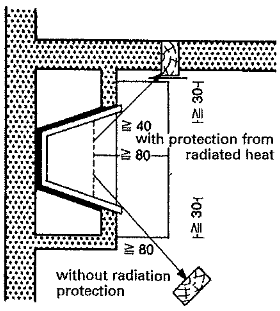
❶ Forms of radiating surfaces



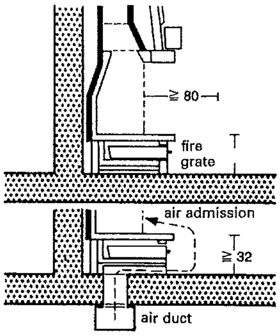
❷ Possible layouts of single-sided open fireplaces



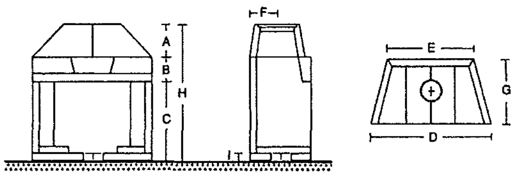
❸ Possible layouts of single- and two-sided open fireplaces



❹ Distance between combustion chamber opening and building components of combustible materials



❺ Protection of combustible floor from combustion chamber/air supply



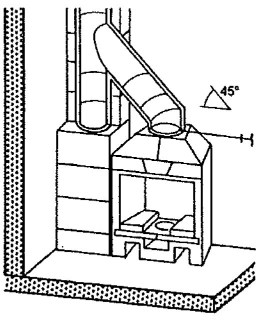
Type		Single-sided open					Two-sided open			Three-sided open		
		1	2	3	4	5	6	7	8	9	10	11
room area approx. (m^2)		small rooms	16–22	22–30	30–35	33–40	25–35	35–45	over 48	35–45	45–55	over 55
room volume approx. (m^3)		small rooms	40–60	60–90	90–105	105–120	90–105	105–150	over 150	105–150	150–150	over 200
size of fire opening (cm^2)		2750	3650	4550	5750	7100	5000	6900	9500	7200	9800	13500
clear dimensions of fire opening (cm)		60/46	70/52	80/58	90/64	100/71						
diameter of flue pipe (cm)		20	22	25	30	30	25	30	35	25	30	35
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 (kg)		165	80	310	385	470	225	300	405	190	255	360

❽ Open fireplaces: dimensions

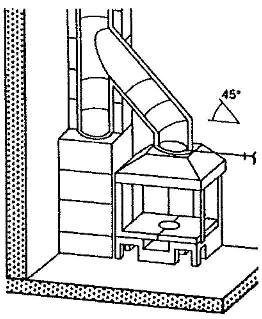
CHIMNEYS AND VENTILATION SHAFTS
Chimneys
Open fireplaces
Ventilation shafts

see also: Fire protection pp. 511 ff.

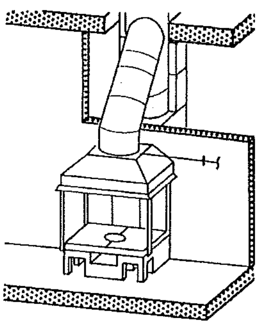
Building services



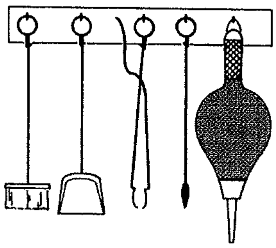
❻ Single-sided open fireplace (Schiedel system)



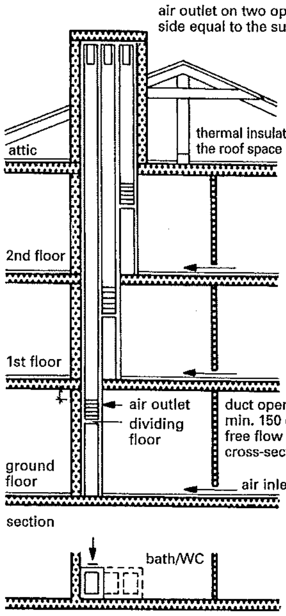
❼ Fireplace open on two sides



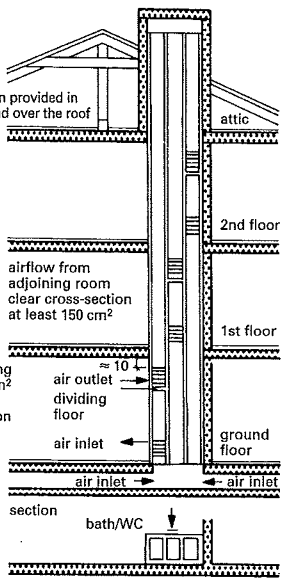
❾ Fireplace open on two sides



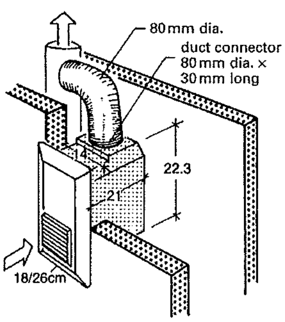
❿ Fireplace tools



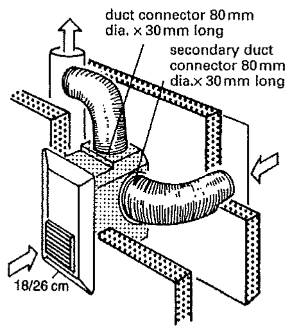
❶ Single-shaft ventilation ('Berlin ventilation')



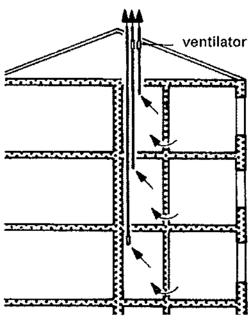
❷ Air supply and extraction ('Cologne ventilation')



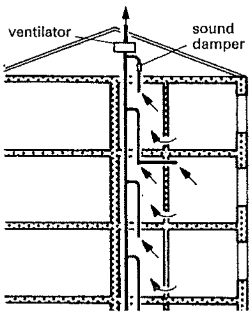
❸ Single-room shaft ventilation for flush-mounted installation



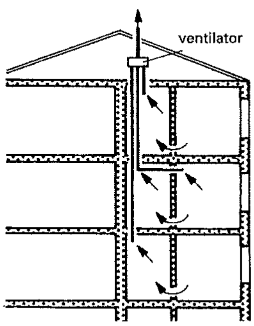
❹ Two-room shaft ventilation for flush-mounted installation



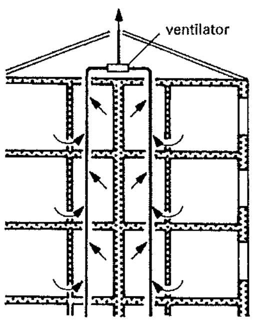
❺ Central extraction system with waste air exhaust above roof



❻ Central extraction system with main duct and branch ducts



❼ Central extraction system with separated main ducts



❽ Central extraction system with a number of main ducts

CHIMNEYS AND VENTILATION SHAFTS

Internal bathrooms and toilets must have air supplied and extracted through shafts or ducts. Traditionally, such shafts were built similarly to chimneys, but today they are more often installed in services shafts as part of the services.

Ventilation systems without fans

Masonry ventilation shafts without fans → ❶ – ❷ are practically maintenance-free but take up a lot of space. Their function (**thermal up-draught**) is highly dependent on the climatic conditions at the time and can often be deficient during high-pressure weather conditions. Because of the sound transfer and heat losses, ventilation systems without fans are now considered out of date and will therefore be found only in older buildings.

A shaft is provided for each room with an extension above the roof, in accordance with the regulations for chimney tops (→ p. 537), and a minimum cross-section of 140 cm². An air supply duct from the open air must be installed at the lower end of the shaft.

Clear cross-section of main shaft	Permissible no. side shaft connections for effective total height of			Internal dimensions	
(m²)	Up to 10 m	10–15 m	Over 15 m	Main shaft (cm)	Side shaft (cm)
340	5	6	7	20 x 17	9 x 17
400	6	7	8	20 x 20	12 x 20
500	8	9	10	25 x 20	12 x 20
340	5	6	7	20 x 17	2 x 9 /17
400	6	7	8	20 x 20	2 x 12/20
500	8	9	10	25 x 20	2 x 12 x 20
340	5	6	7	2 x 20/17	9 x 17
400	6	7	8	2 x 20/20	12 x 20
500	8	9	10	2 x 25/20	12 x 20

❾ Dimensions for collector shaft ventilation with thermal up-draught

Ventilation systems with fans

For the on-demand ventilation of sanitary facilities in residential and commercial buildings like schools, hotels, pubs etc., to ventilate one or more rooms with one shaft → ❸ – ❹. Extraction systems should be designed for at least 4 air changes per hour in the rooms. A sufficient flow of air for bathrooms, including those with WC, is 60 m³/h and for toilets per WC 30 m³/h. Each internal room to be ventilated must also have an air supply opening, which cannot be closed, with a cross-section of 10 cm² per m³ room volume. The air leakage of the door can be assumed to be 25 cm².

In bathrooms, a minimum temperature of 22°C must be maintained during operation of the fan. Airflow speeds in occupied zone ≧0.2 m/s. The air should be extracted into the open air, or for single extraction systems into permanently well-ventilated roof spaces. Each single extraction system must have its own main riser duct. Central extraction systems have common extract ducts for a number of occupied areas → ❻.

Fire protection

According to building regulations, ventilation ducts including cladding and insulation must be of non-combustible materials. Ventilation systems in buildings of more than two full storeys or more than two residential units or systems, which cross fire compartments, must be constructed so that fire and smoke cannot be carried into other storeys or fire compartments.