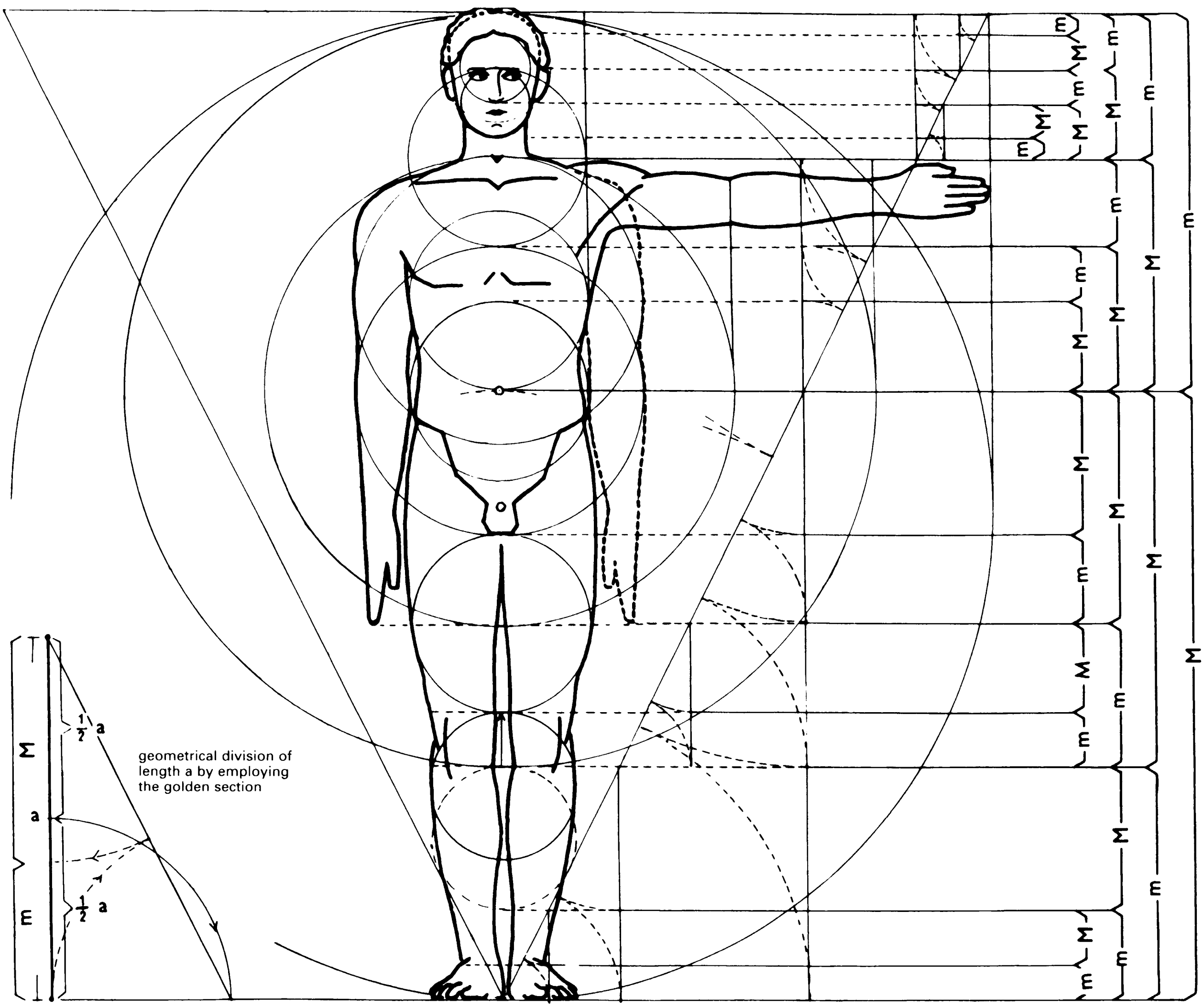


Man's dimensional relationships

The oldest known code of dimensional relationships of man was found in a burial chamber of the pyramids near Memphis and are estimated to date back to roughly 3000 BC. Certainly since then, scientists and artists have been trying hard to refine human proportional relationships.

We know about the proportional systems of the Empire of the Pharaohs, of the time of Ptolemy, the Greeks and the Romans, and even the system of Polycletes, which for a long time was applied as the standard, the details given by Alberti, Leonardo da Vinci, Michelangelo and the people of the Middle Ages. In particular, the work of Dürer is known throughout the world. In all of these works, the calculations for a man's body were based on the lengths of heads, faces or feet. These were then subdivided and brought into relationship with each other, so that they were applicable throughout general life. Even within our own lifetimes, feet and ells have been in common use as measurements.

The details worked out by Dürer became a common standard and were used extensively. He started with the height of man and expressed the subdivisions as fractions:

$1/2$ h = the whole of the top half of the body, from the crotch upwards
$1/4$ h = leg length from the ankle to the knee and from the chin to the navel
$1/6$ h = length of foot
$1/8$ h = head length from the hair parting to the bottom of the chin, distance between the nipples
$1/10$ h = face height and width (including the ears), hand length to the wrist
$1/12$ h = face width at the level of the bottom of the nose, leg width (above the ankle) and so on.

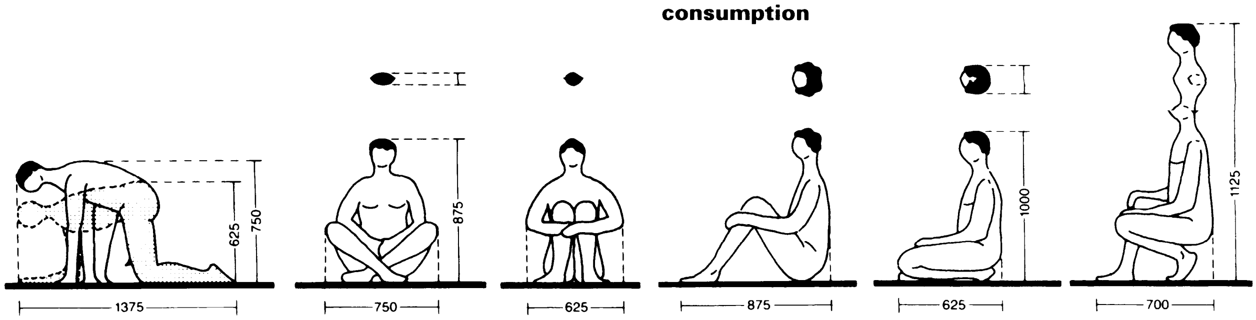
The sub-divisions go up to $1/40$ h.

During the last century, A. Zeising, brought greater clarity with his investigations of the dimensional relationship of man's proportions. He made exact measurements and comparisons on the basis of the golden section. Unfortunately, this work did not receive the attention it deserved until recently, when a significant researcher in this field, E. Moessel, endorsed Zeising's work by making thorough tests carried out following his methods. From 1945 onwards, Le Corbusier used for all his projects the sectional relationships in accordance with the golden section, which he called 'Le Modulor' → p. 30.

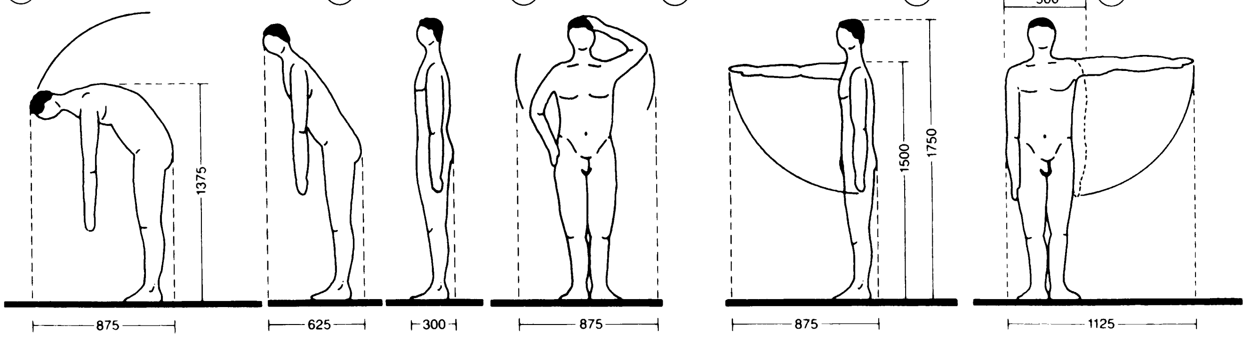
MAN: DIMENSIONS AND SPACE REQUIREMENTS

Body measurements

In accordance with normal measurements and energy consumption



① ② ③ ④ ⑤ ⑥



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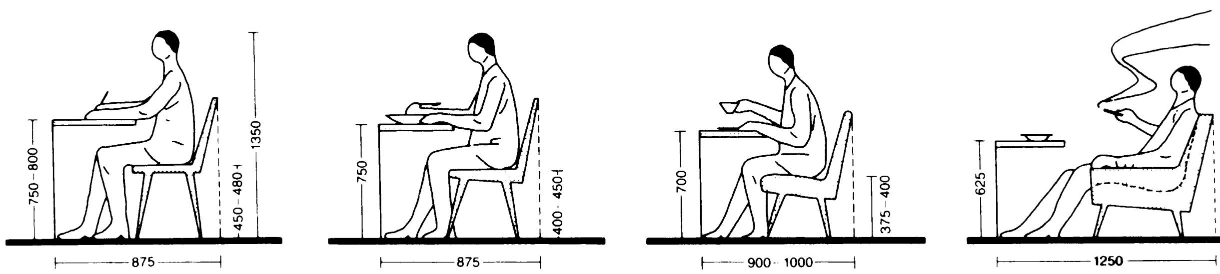
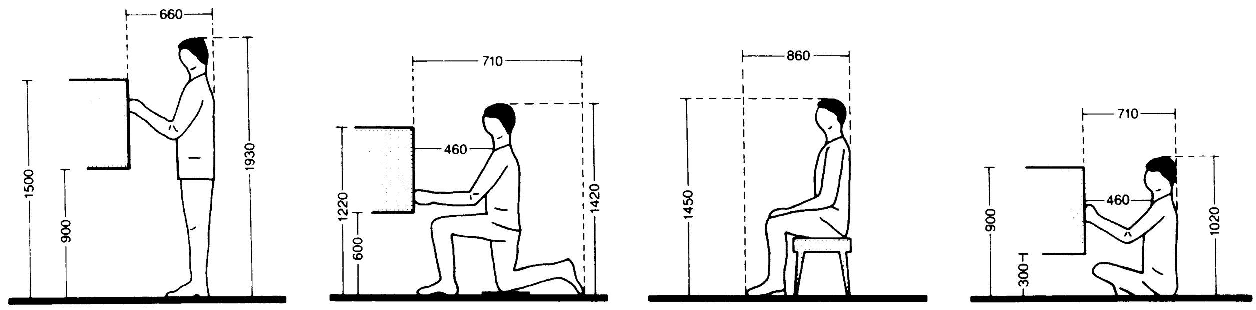


⑬ **Dimensions: work table**

⑭ **Dimensions: sitting and dining room chair**

⑮ **Dimensions: small easy chair**

⑯ **Dimensions: armchair**

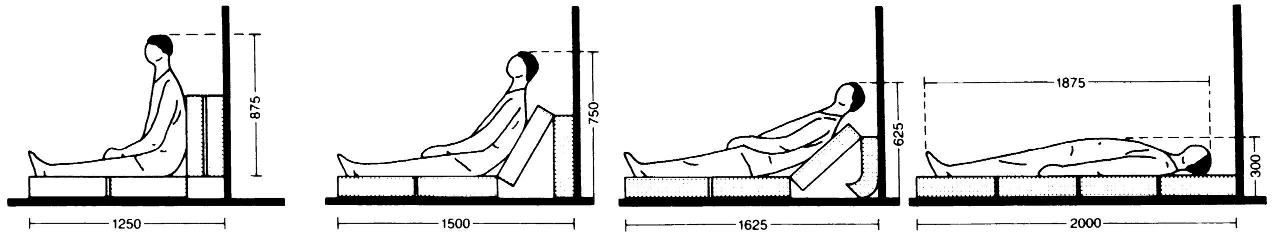


⑰ **Working while standing**

⑱ **Kneeling**

⑲ **Sitting**

⑳ **Squatting**



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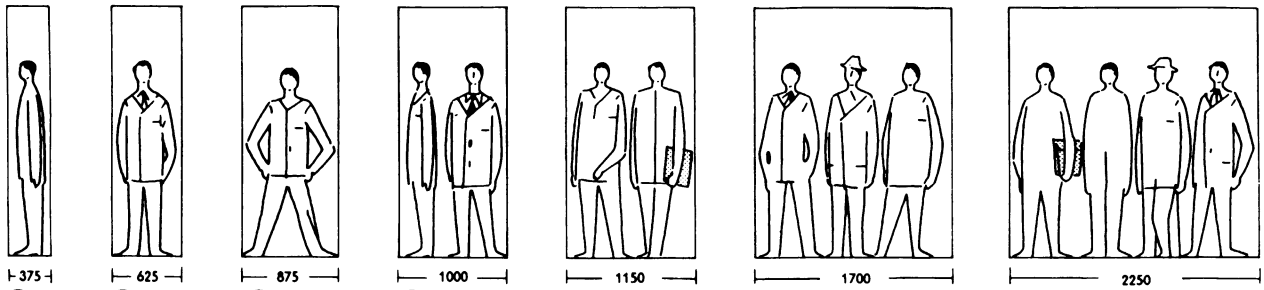
MAN: DIMENSIONS AND SPACE REQUIREMENTS

Space Requirements

In accordance with normal measurements and energy consumption

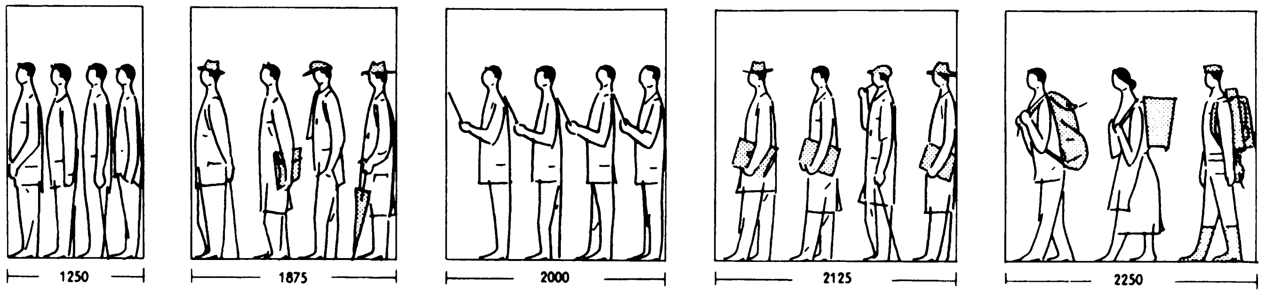
SPACE REQUIREMENTS BETWEEN WALLS

for moving people, add ≥10% to widths



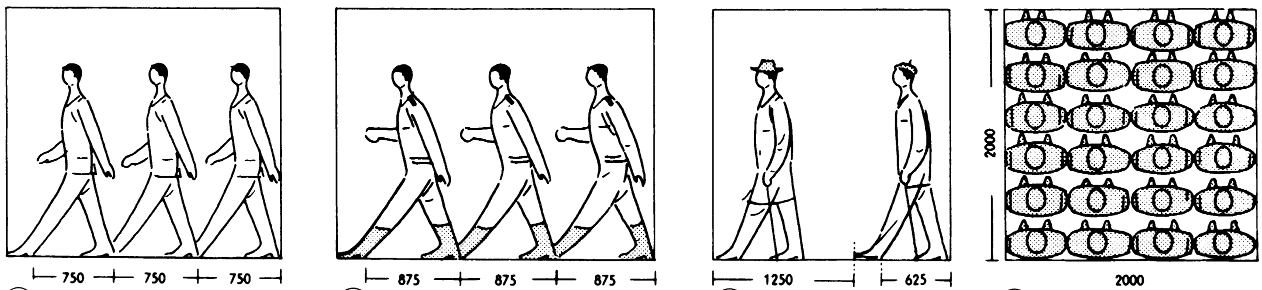
(1) (2) (3) (4) (5) (6) (7)

SPACE REQUIREMENTS OF GROUPS



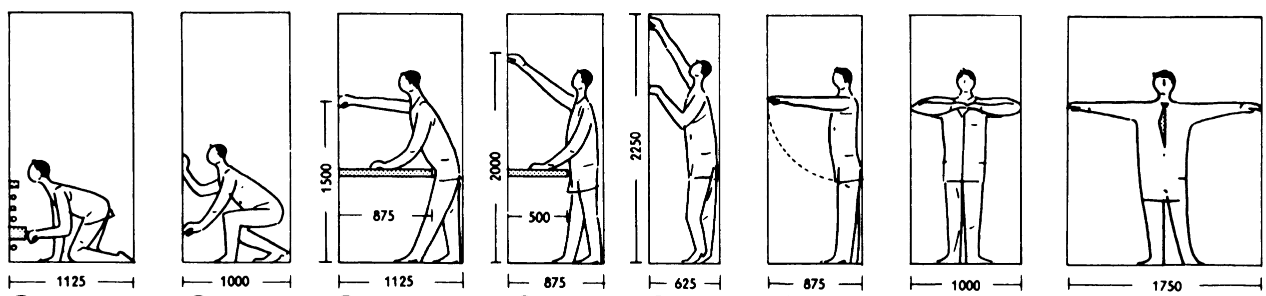
(8) **Closely packed** (9) **Normal spacing** (10) **Choir** (11) **Waiting queue** (12) **With back packs**

STEP MEASUREMENTS



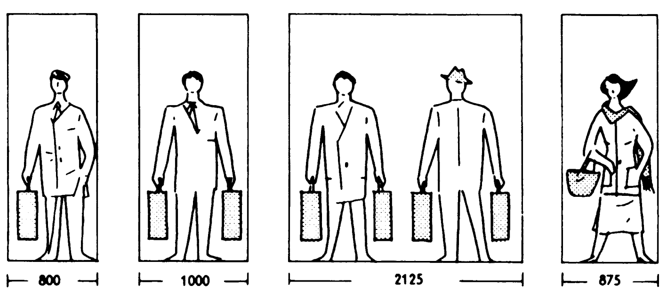
(13) **Walking in step** (14) **Marching** (15) **Strolling** (16) **Max. density: 6 people per m² (e.g. cable railway)**

SPACE REQUIREMENTS OF VARIOUS BODY POSTURES



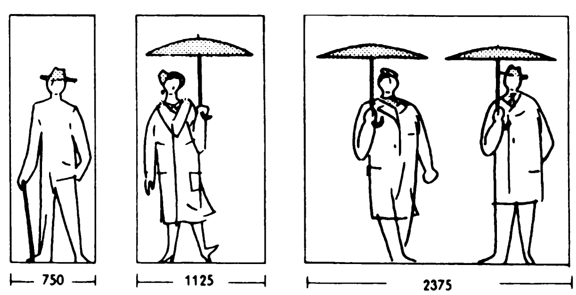
(17) (18) (19) (20) (21) (22) (23) (24)

SPACE REQUIREMENTS WITH LUGGAGE



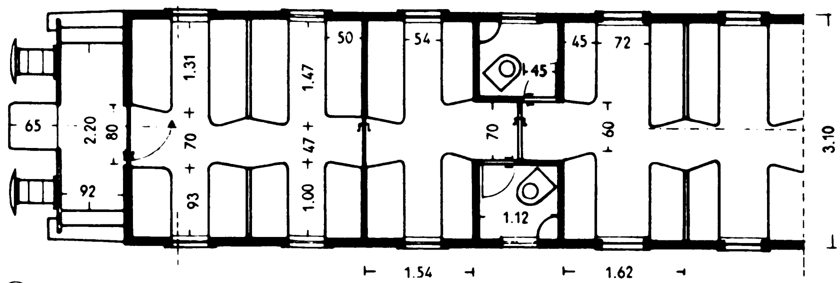
(25) (26) (27) (28)

SPACE REQUIREMENTS WITH STICKS AND UMBRELLAS



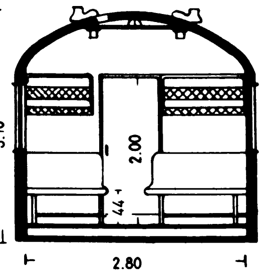
(29) (30) (31)

DIMENSIONS FOR RAILWAY CARRIAGES



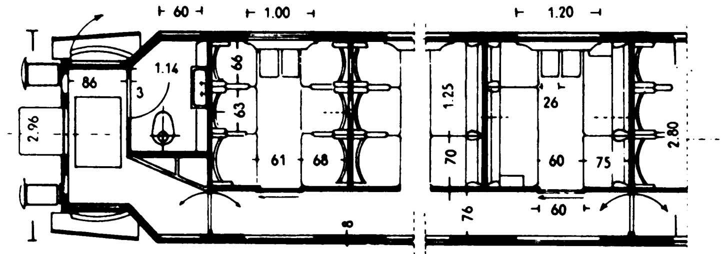
(1) **Local passenger train carriage, plan view**

68 seats, 0.45 m per seat; overall length 19.66 m, compartment carriage length 12.75 m; luggage van length 12.62 m, step height 28–30 cm



cross-section through (1)

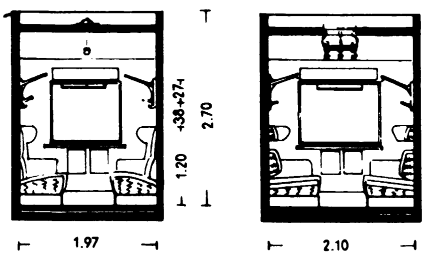
old and new rolling stock as an example of minimum space requirements for passenger transport



48 seats; overall length 20.42 m, luggage van 18.38 m

first class

(2) **Intercity express carriage, plan view**

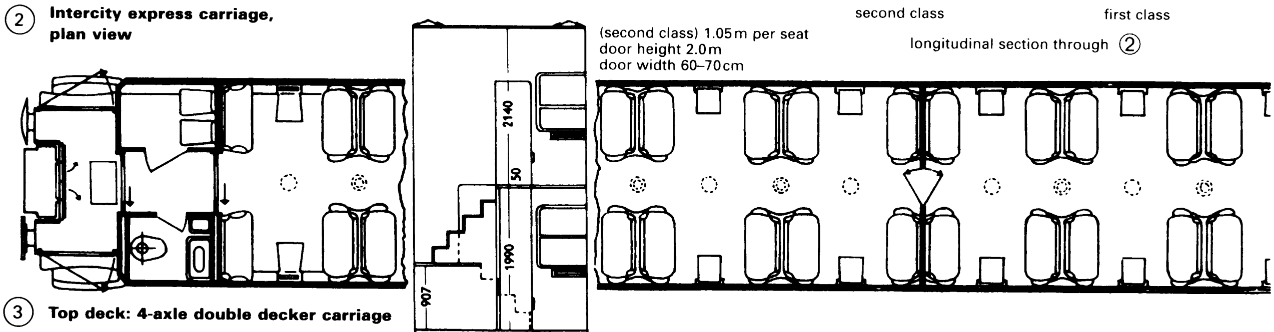


second class

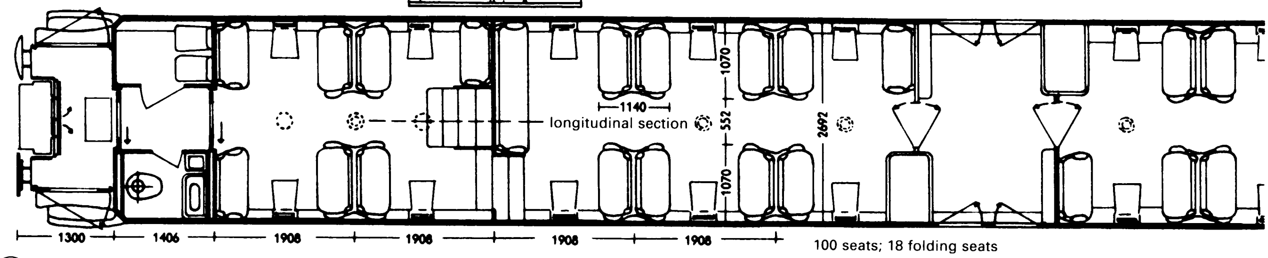
first class

longitudinal section through (2)

(second class) 1.05 m per seat
door height 2.0 m
door width 60–70 cm

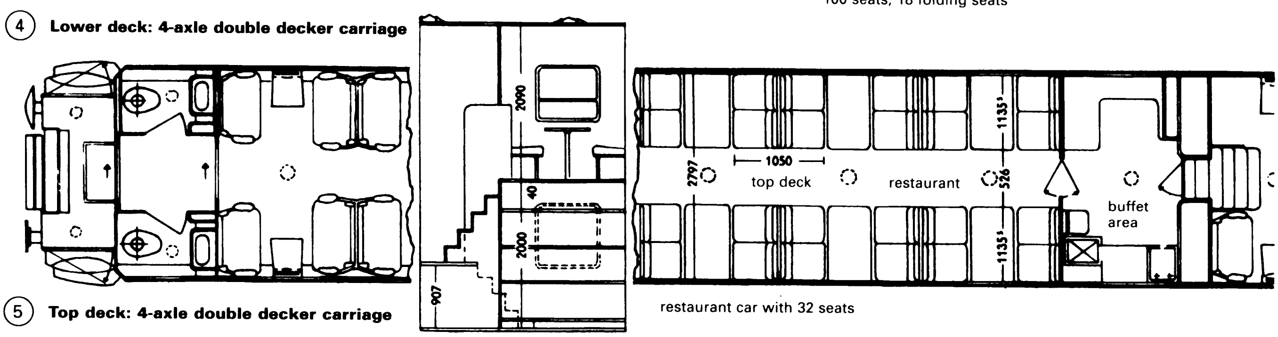


(3) **Top deck: 4-axle double decker carriage**



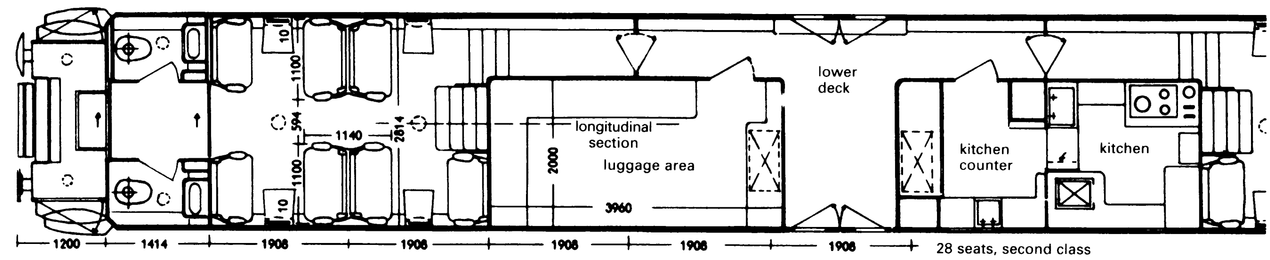
100 seats; 18 folding seats

(4) **Lower deck: 4-axle double decker carriage**



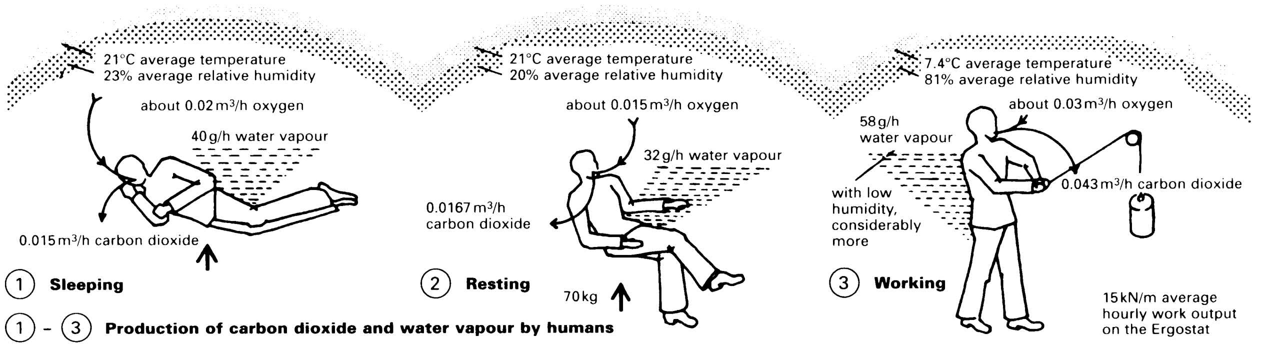
restaurant car with 32 seats

(5) **Top deck: 4-axle double decker carriage**



28 seats, second class

(6) **Lower deck: 4-axle double decker carriage with catering compartment, restaurant and luggage van**



(1) **Sleeping** (2) **Resting** (3) **Working**

(1) - (3) **Production of carbon dioxide and water vapour by humans**

The function of housing is to protect man against the weather and to provide an environment that maintains his well-being. The required inside atmosphere comprises gently moving (i.e. not draughty), well oxygenated air, pleasant warmth and air humidity and sufficient light. To provide these conditions, important factors are the location and orientation of the housing in the landscape (→ p. 272) as well as the arrangement of spaces in the house and its type of construction.

The prime requirements for promoting a lasting feeling of well-being are an insulated construction, with appropriately sized windows placed correctly in relation to the room furnishings, sufficient heating and corresponding draught-free ventilation.

The need for air

Man breathes in oxygen with the air and expels carbon dioxide and water vapour when he exhales. These vary in quantity depending on the individual's weight, food intake, activity and surrounding environment → (1)–(3).

It has been calculated that on average human beings produce 0.020 m³/h of carbon dioxide and 40 g/h of water vapour.

A carbon dioxide content between 1 and 3‰ can stimulate deeper breathing, so the air in the dwelling should not, as far as possible, contain more than 1‰. This means, with a single change of air per hour, a requirement for an air space of 32 m³ per adult and 15 m³ for each child. However, because the natural rate of air exchange in free-standing buildings, even with closed windows, reaches 1½ to 2 times this amount, 16–24 m³ is sufficient (depending on the design) as a normal air space for adults and 8–12 m³ for children. Expressed another way, with a room height ≥2.5 m, a room floor area of 6.4–9.6 m² for each adult is adequate and 3.2–4.8 m² for each child. With a greater rate of air exchange, (e.g. sleeping with a window open, or ventilation via ducting), the volume of space per person for living rooms can be reduced to 7.5 m³ and for bedrooms to 10 m³ per bed.

Where air quality is likely to deteriorate because of naked lights, vapours and other pollutants (as in hospitals or factories) and in enclosed spaces (such as you in an auditorium), rate of exchange of air must be artificially boosted in order to provide the lacking oxygen and remove the harmful substances.

Space heating

The room temperature for humans at rest is at its most pleasant between 18° and 20°C, and for work between 15°and 18°C, depending on the level of activity. A human being produces about 1.5 kcal/h per kg of body weight. An adult weighing 70 kg therefore generates 2520 kcal of heat energy per day, although the quantity produced varies according to the circumstances. For instance it increases with a drop in room temperature just as it does with exercise.

When heating a room, care must be taken to ensure that low temperature heat is used to warm the room air on the cold side of the room. With surface temperatures above 70–80°C decomposition can take place, which may irritate the mucous membrane, mouth and pharynx and make the air feel too dry. Because of this, steam heating and iron stoves, with their high surface temperatures, are not suitable for use in blocks of flats.

Room humidity

Room air is most pleasant with a relative air humidity of 50–60%; it should be maintained between limits 40% and 70%. Room air which is too moist promotes germs, mould, cold bridging, rot and condensation. → (6). The production of water vapour in human beings varies in accordance with the prevailing conditions and performs an important cooling function. Production increases with rising warmth of the room, particularly when the temperature goes above 37°C (blood temperature).

	tolerable for several hours (‰)	tolerable for up to 1h (‰)	immediately dangerous (‰)
iodine vapour	0.0005	0.003	0.05
chlorine vapour	0.001	0.004	0.05
bromine vapour	0.001	0.004	0.05
hydrochloric acid	0.01	0.05	1.5
sulphuric acid	–	0.05	0.5
hydrogen sulphide	–	0.2	0.6
ammonia	0.1	0.3	3.5
carbon monoxide	0.2	0.5	2.0
carbon disulphide	–	1.5*	10.0*
carbon dioxide	10	80	300

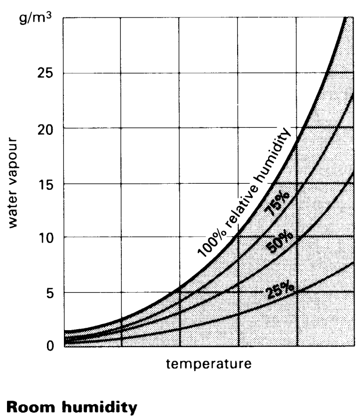
*mg per litre

(4) **Harmful accumulation of industrial gases**

activity	energy expenditure (kJ/h)
at rest in bed (basal metabolic rate)	250
sitting and writing	475
dressing, washing, shaving	885
walking at 5 km/h	2050
climbing 15 cm stairs	2590
running at 8 km/h	3550
rowing at 33 strokes/min	4765

note that this expenditure in part contributes to heating air in a room

(5) **Human expenditure of energy**



(6) **Room humidity**

temperature (°C)	water content (g/m³)
50	82.63
49	78.86
48	75.22
47	71.73
46	68.36
45	65.14
44	62.05
43	59.09
42	56.25
41	53.52
40	50.91
39	48.40
38	46.00
37	43.71
36	41.51
35	39.41
34	37.40
33	35.48
32	33.64
31	31.89
30	30.21
29	28.62
28	27.09
27	25.64
26	24.24
25	22.93
24	21.68
23	20.48
22	19.33
21	18.25
20	17.22
19	16.25
18	15.31
17	14.43
16	13.59
15	12.82
14	12.03
13	11.32
12	10.64
11	10.01
10	9.39
9	8.82
8	8.28
7	7.76
6	7.28
5	6.82
4	6.39
3	5.98
2	5.60
+ 1	5.23
0	4.89
– 1	4.55
2	4.22
3	3.92
4	3.64
5	3.37
6	3.13
7	2.90
8	2.69
9	2.49
10	2.31
11	2.14
12	1.98
13	1.83
14	1.70
15	1.58
16	1.46
17	1.35
18	1.25
19	1.15
20	1.05
21	0.95
22	0.86
23	0.78
24	0.71
25	0.64

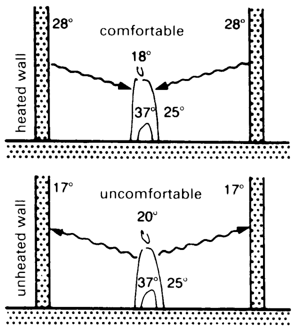
maximum water content of one cubic metre of air (g)

ROOM CLIMATE

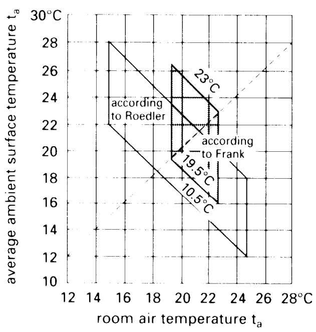
physical conditions
- air movement (draughts)
- relative humidity
- ambient surface temperature
- air temperature
- atmospheric charge
- air composition and pressure
- room occupancy
- optical/acoustic influences
- clothing

physiological conditions
- sex
- age
- ethnic influences
- food intake
- level of activity
- adaptation and acclimatisation
- natural body rhythms
- state of health
- psycho-sociological factors

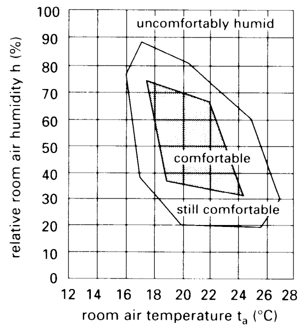
(1) **Factors that affect thermal comfort**



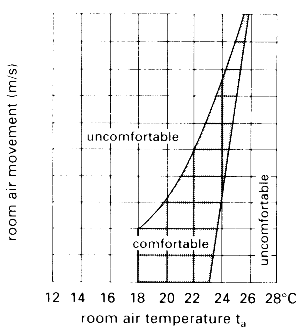
(2) **Heated walls**



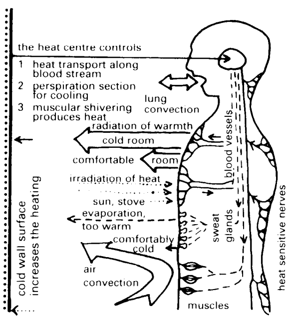
(3) **Field of comfort**



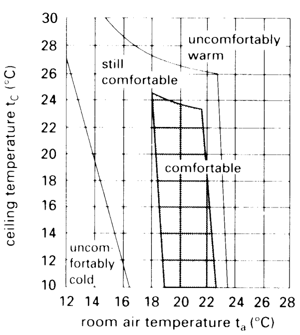
(4) **Field of comfort**



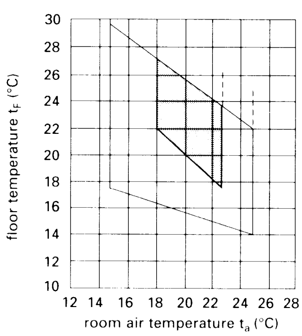
(5) **Field of comfort**



(6) **Human heat flows**



(7) **Field of comfort**



(8) **Field of comfort**

water content of the air (g/kg)	suitability for breathing	sensation
0 to 5	very good	light, fresh
5 to 8	good	normal
8 to 10	satisfactory	still bearable
10 to 25	increasingly bad	heavy, muggy
over 25	becoming dangerous	very humid
41	water content of the air breathed out 37°C (100%)	
over 41	water condenses in pulmonary alveoli	

(9) **Humidity values for air we breathe**

In the same way as the earth has a climate, the insides of buildings also have a climate, with measurable values for air pressure, humidity, temperature, velocity of air circulation and 'internal sunshine' in the form of radiated heat. Efficient control of these factors leads to optimum room comfort and contributes to man's overall health and ability to perform whatever tasks he is engaged in. Thermal comfort is experienced when the thermal processes within the body are in balance (i.e. when the body manages its thermal regulation with the minimum of effort and the heat dissipated from the body corresponds with the equilibrium loss of heat to the surrounding area).

Temperature regulation and heat loss from the body

The human body can raise or lower the rate at which it loses heat using several mechanisms: increasing blood circulation in the skin, increasing the blood circulation speed, vascular dilation and secreting sweat. When cold, the body uses muscular shivering to generate additional heat.

Heat is lost from the body in three main ways: conduction, convection and radiation. Conduction is the process of heat transfer from one surface to another surface when they are in contact (e.g. feet in contact with the floor). The rate of heat transfer depends on the surface area in contact, the temperature differential and the thermal conductivities of the materials involved. Copper, for example, has a high thermal conductivity while that of air is low, making it a porous insulating material. Convection is the process of body heat being lost as the skin warms the surrounding air. This process is governed by the velocity of the circulating air in the room and the temperature differential between the clothed and unclothed areas of the body. Air circulation is also driven by convection: air warms itself by contact with hot objects (e.g. radiators), rises, cools off on the ceiling and sinks again. As it circulates the air carries dust and floating particles with it. The quicker the heating medium flows (e.g. water in a radiator), the quicker is the development of circulation. All objects, including the human body, emit heat radiation in accordance to temperature difference between the body surface and that of the ambient area. It is proportional to the power of 4 of the body's absolute temperature and therefore 16 times as high if the temperature doubles. The wavelength of the radiation also changes with temperature: the higher the surface temperature, the shorter the wavelength. Above 500°C, heat becomes visible as light. The radiation below this limit is called infra-red/heat radiation. It radiates in all directions, penetrates the air without heating it, and is absorbed by (or reflected off) other solid bodies. In absorbing the radiation, these solid bodies (including human bodies) are warmed. This radiant heat absorption by the body (e.g. from tile stoves) is the most pleasant sensation for humans for physiological reasons and also the most healthy.

Other heat exchange mechanisms used by the human body are evaporation of moisture from the sweat glands and breathing. The body surface and vapour pressure differential between the skin and surrounding areas are key factors here.

Recommendations for internal climate

An air temperature of 20–24°C is comfortable both in summer and in winter. The surrounding surface areas should not differ by more than 2–3°C from the air temperature. A change in the air temperature can be compensated for by changing the surface temperature (e.g. with decreasing air temperature, increase the surface temperature). If there is too great a difference between the air and surface temperatures, excessive movement of air takes place. The main critical surfaces are those of the windows.

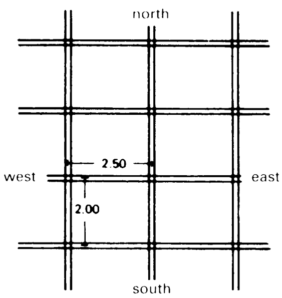
For comfort, heat conduction to the floor via the feet must be avoided (i.e. the floor temperature should be 17°C or more). The surface temperature of the ceiling depends upon the height of the room. The temperature sensed by humans is somewhere near the average between room air temperature and that of surrounding surfaces.

It is important to control air movement and humidity as far as possible. The movement can be sensed as draughts and this has the effect of local cooling of the body. A relative air humidity of 40–50% is comfortable. With a lower humidity (e.g. 30%) dust particles are liable to fly around.

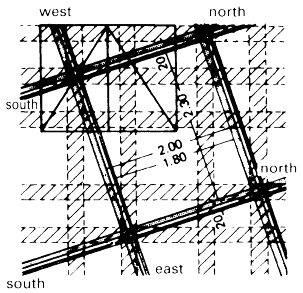
To maintain the quality of the air, controlled ventilation is ideal. The CO_2 content of the air must be replaced by oxygen. A CO_2 content of 0.10% by volume should not be exceeded, and therefore in living rooms and bedrooms provide for two to three air changes per hour. The fresh air requirement of humans comes to about 32.0 m^3/h so the air change in living rooms should be 0.4–0.8 times the room volume per person/h.

absolute water content (g/kg)	relative humidity (%)	temperature (°C)	description
2	50	0	fine winter's day, healthy climate for lungs
5	100	4	fine autumnal day
5	40	18	very good room climate
8	50	21	good room climate
10	70	20	room climate too humid
28	100	30	tropical rain forest

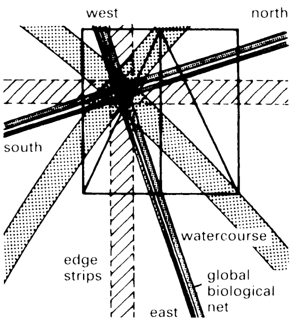
(10) **Comparative relative humidity values**



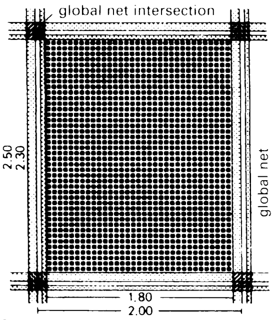
(1) **Global net, magnetically ordered, with pathogenic intersection points**



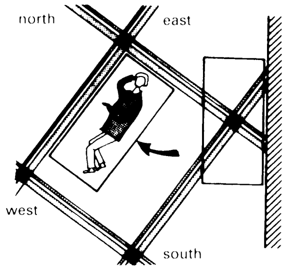
(2) **Left bed on an intersection point; right bed is crossed by edge zone; the hatched edge strips are not deleterious**



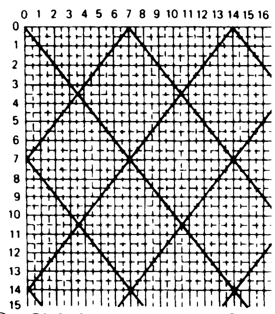
(3) **Left bed is particularly at risk – crossed by net intersection and a watercourse, which intensifies the bad effects**



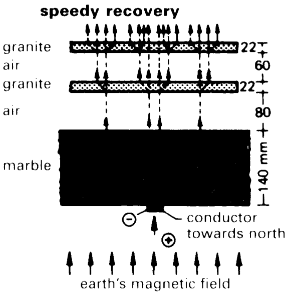
(4) **Disturbance-free zone between net strips 1.80 × 2.30 m**



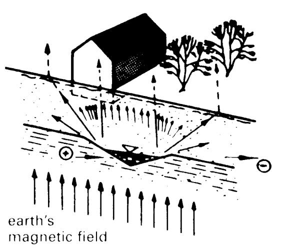
(5) **With bed against the wall, health suffered; moving it as shown resulted in a speedy recovery**



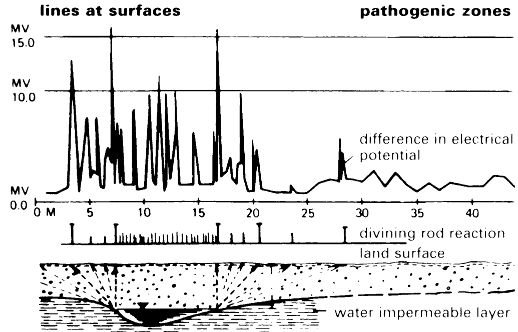
(6) **Global net at centres of 4 × 5 m, with dashed half-distance lines 2 × 2.5 m centres → (1)**



(7) **Experimental model showing how quadrant lines of force split/multiply to vertical lines at surfaces**



(8) **Electrical field lines from an underground watercourse bundle to cause the pathogenic zones**



(9) **Measured differences in electrical potential and divining rod reactions above an underground watercourse**

For over a decade, medical doctors such as Dr Palm and Dr Hartmann at the Research Forum for Geobiology, Eberbach-Woldbrunn-Waldkatzenbach, among others, have been researching the effects that the environment has on people: in particular the effects of the ground, buildings, rooms, building materials and installations.

Geological effects

Stretched across the whole of the earth is a so-called 'global net' → (1) consisting of stationary waves, thought to be induced by the sun. However, its regularity, according to Hartmann, is such that it suggests an earthly radiation which emanates from inside the earth and is effected by crystalline structures in the earth's crust, which orders it in such a network. The network is orientated magnetically, in strips of about 200 mm width, from the magnetic north to south poles. In the central European area these appear at a spacing of about 2.50 m. At right angles to these are other strips running in an east/west direction at a spacing of about 2 m → (1).

These strips have been revealed, through experience, to have psychologically detrimental effects, particularly when one is repeatedly at rest over a point of intersection for long periods (e.g. when in bed) → (2). In addition to this, rooms which correspond to the right angles of the net do not display the same pathogenic influences.

These intersection points only become really pathogenic when they coincide with geological disturbances, such as faults or joints in the ground, or watercourses. The latter, in particular, are the most influential → (3). Hence, there is a cumulative effect involved so the best situation is to make use of the undisturbed zone or area of 1.80 × 2.30 m between the global strips → (4). According to Hartmann, the most effective action is to move the bed out of the disturbance area, particularly away from the intersection points → (5).

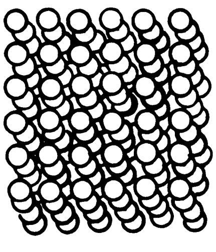
According to Palm, the apparent global net of about 2 × 2.50 m is made up of half-distance lines. The actual network would be, as a result, a global net with strips at 4–5 m and 5–6 m centres, running dead straight in the east/west direction all round the earth. Every 7th one of these net strips is reported to be of a so-called 2nd order and have an influence many times greater than the others. Also based on sevenths, an even stronger disturbance zone has been identified as a so-called 3rd order. This is at a spacing of about 250 and 300 m respectively. The intersection points here are also felt particularly strongly.

Also according to Palm, in Europe there are deviations from the above norm of up to 15% from the north/south and the east/west directions. Americans have observed such strips with the aid of very sensitive cameras from aeroplanes flying at a height of several thousand meters. In addition to this, the diagonals also form their own global net, running north-east to south-west and from north-west to south-east → (6). This, too, has its own pattern of strong sevenths, which are about one quarter as strong again in their effect.

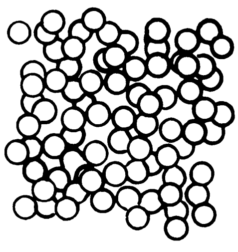
It is stated that locating of the global strips depends on the reliability of the compass, and that modern building construction can influence the needle of the compass. Thus variations of 1–2° already result in faulty location and this is significant because the edges of the strips are particularly pathogenic. Careful detection of all the relationships requires much time and experience, and often needs several investigations to cross-check the results. The disturbance zones are located with divining rods or radio equipment. Just as the radiation pattern is broken vertically at the intersection between ground and air (i.e. at the earth's surface), Endros has demonstrated with models that these breaks are also detectable on the solid floors of multistorey buildings → (7). He has shown a clear illustration of these breaks caused by an underground stream → (8) and measured the strength of the disturbances above a watercourse → (9).

The main detrimental effect of such pathogenic zones is that of 'devitalisation': for example, tiredness, disturbances of the heart, kidneys, circulation, breathing, stomach and metabolism, and could extend as far as serious chronic diseases such as cancer. In most cases, moving the bed to a disturbance-free zone gives relief within a short space of time → (5). The effect of so-called neutralising apparatus is debatable, many of them having been discovered to be a source of disturbance. Disturbance does not occur, it seems, in rooms proportioned to the golden section (e.g. height 3 m, width 4 m, length 5 m) and round houses or hexagonal plans (honeycomb) are also praised.

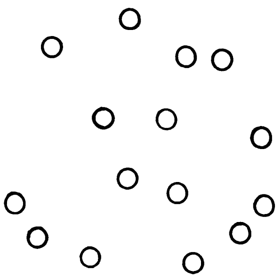
BUILDING BIOLOGY



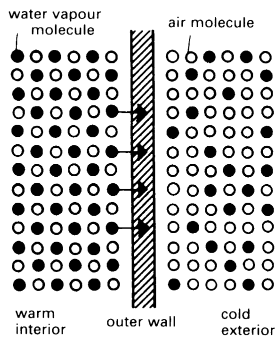
① **Arrangement of atoms: metal in solid phase**



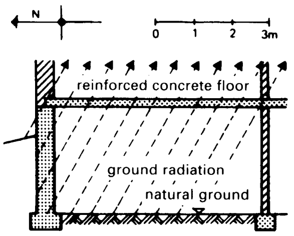
② **Arrangement of atoms: metal in liquid phase**



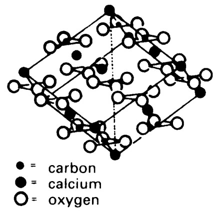
③ **Arrangement of atoms: metal in gaseous phase**



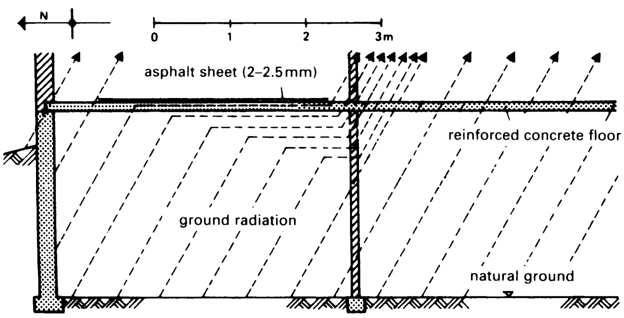
④ **Water vapour moves from warm interior of a building, hindered by outer wall, to cooler outside air; air molecules move inside in exchange**



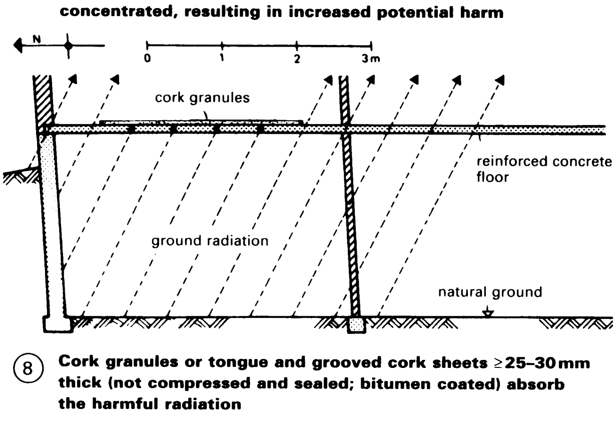
⑤ **Radiation from the ground passes unhindered through concrete floors**



⑥ **Atomic structure of calcite**



⑦ **Asphalt sheeting diverts the southerly inclined radiation away but emanations at the beginning of the next room are concentrated, resulting in increased potential harm**



⑧ **Cork granules or tongue and grooved cork sheets ≥25–30mm thick (not compressed and sealed; bitumen coated) absorb the harmful radiation**

Physicists recognise that matter exists in three 'phases', depending on its temperature and external pressure: (a) solid, (b) liquid and (c) gaseous. For example, with water, when under 0°C it exists as a solid (a), namely ice; at normal temperature = (b) = water; when over 100° = (c) = steam. Other materials change phase at different temperatures.

The atoms or molecules that make up the material are in constant motion. In solid metals, for example, the atoms vibrate around fixed points in a crystalline structure → ①. When heated, the movement becomes increasingly agitated until the melting point is reached. At this temperature, the bonds holding specific atoms together are broken down and metal liquefaction occurs, enabling the atoms to move more freely → ②. Further heating causes more excitation of the atoms until the boiling point is reached. Here, the motion is so energetic that the atoms can escape all inter-atom forces of attraction and disperse to form the gaseous state → ③. On the reverse side, all atomic or molecular movement stops completely at absolute zero, 0 kelvin (0K = –273.15°)C).

These transitions in metals are, however, not typical of all materials. The atomic or molecular arrangement of each material gives it its own properties and dictates how it reacts to and affects its surroundings. In the case of glass, for example, although it is apparently solid at room temperature, it does not have a crystalline structure, the atoms being in a random, amorphous state. It is, therefore, technically, a supercooled liquid. The density of vapour molecules in air depends on the temperature, so the water molecules diffuse to the cooler side (where the density is lower). To replace them, air molecules diffuse to the inside, both movements being hindered by the diffusion resistance of the wall construction → ④.

Many years of research on building materials by Schröder-Speck suggests that organic materials absorb or break up radiation of mineral origin. For instance, asphalt matting, with 100mm strip edge overlaps all round, placed on concrete floors diverted the previously penetrating radiation. The adjacent room, however, received bundled diverted rays. → ⑤ – ⑦. In an alternative experiment, a granulated cork floor showed a capacity to absorb the radiation. Cork sheets 25–30mm thick (not compressed and sealed), tongued and grooved all round are also suitable → ⑧.

Clay is regarded as a 'healthy earth' and bricks and roofing tiles fired at about 950°C give the optimum living conditions. For bricklaying, sulphur-free white lime is recommended, produced by slaking burnt lime in a slaking pit and where fatty lime is produced through maturation. Hydraulic lime should, however, be used in walls subject to damp. Lime has well known antiseptic qualities and is commonly used as a lime wash in stables and cow sheds.

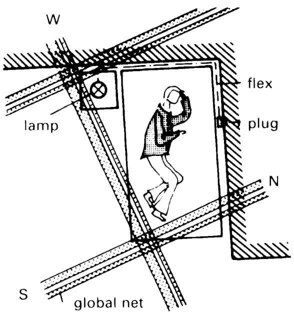
Plaster is considered best when it is fired as far below 200°C as possible, preferably with a constant humidity similar to animal textiles (leather, silk etc.). Sandstone as a natural lime-sandstone is acceptable but should not be used for complete walls.

Timber is light and warm and is the most vital of building materials. Timber preservation treatments should be derived from the distillation of wood itself (e.g. as wood vinegar, wood oil or wood tar). Timber reacts well to odours and it is therefore recommended that genuine timber be used for interior cladding, if necessary as plywood using natural glues. Ideally, the 'old rules' should be followed: timber felled only in winter, during the waning moon, then watered for one year in a clay pit before it is sawn. However, this is very expensive.

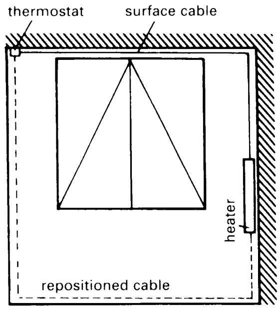
For insulation, natural building materials such as cork granules and cork sheets (including those with bitumen coating) are recommended, as well as all plant-based matting (e.g. sea grass, coconut fibre etc.), together with expanded clay and diatomaceous earth (fossil meal). Plastics, mineral fibres, mineral wool, glass fibre, aerated concrete, foamed concrete and corrugated aluminium foil are not considered to be satisfactory.

Normal glass for glazing or crystal glass counts as neutral. Better still is quartz glass (or bio-glass), which transmits 70–80% of the ultra-violet light. Doubts exist about coloured glass. Glazing units with glass welded edges are preferable to those with metal or plastic sealed edges. One is sceptical about coloured glass.

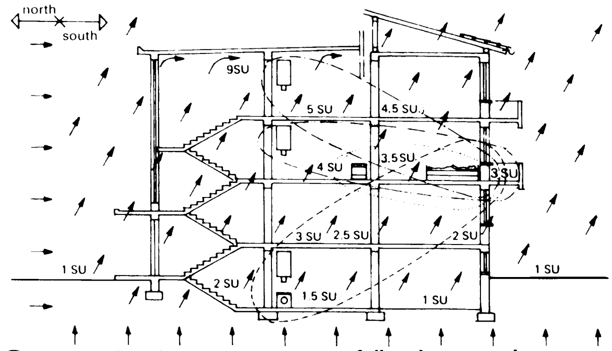
Metal is rejected by Palm for exterior walls, as well as for use on large areas. This includes copper for roofs on dwellings (but not on churches). Generally the advice is to avoid the extensive use of metal. Copper is tolerated the best. Iron is rejected (radiators, allegedly, cause disturbance in a radius of 4m). Zinc is also tolerated, as is lead. Bronze, too, is acceptable (≥75% copper) and aluminium is regarded as having a future. Asbestos should not be used. With painting it is recommended that a careful study is made of the contents and method of manufacture of the paint in order to prevent the introduction of damaging radiation. Plastics are generally regarded as having no harmful side effects. Concrete, particularly reinforced concrete, is rejected in slabs and arches but is, however, permitted in foundations and cellars.



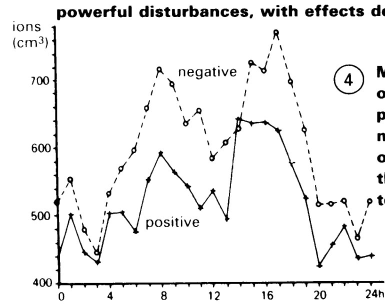
① The flex running around the bed head to the lamp disturbs the sleeping space. Health is best preserved if the plug is pulled out (according to Hartmann)



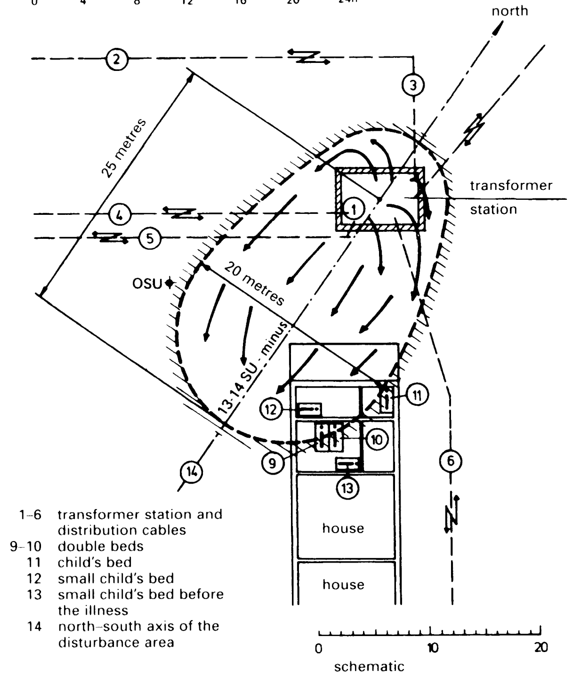
② Similarly to ① disturbances can be eliminated by moving the cable behind the bed head to the other side of the room (according to Hartmann)



③ Electrical equipment creates areas of disturbance, made stronger by concrete floors: radiation ≥2.9 SU produced no problem; >3 SU, more colds, rheumatism, bladder disorders etc.; >6 SU, powerful disturbances, with effects dependent on constitution



④ Mean annual concentration of convertible negative and positive ions on days with moderate rainfall in the centre of Philadelphia depending on the time of day (according to R. Endrös)



⑤ Disturbance area around a transformer station, with harmful effects on people in beds 9 to 12 (according to K.E. Lotz)

A differentiation should be made between concrete with clinker aggregate and man-made plaster (which have extremely high radiation values) and 'natural' cement and plaster. Lightweight concrete with expanded clay aggregate is tolerable.

All pipes for water (cold or hot), sewage or gas radiate to their surroundings and can influence the organs of living creatures as well as plants. Therefore, rooms that are occupied by humans and animals for long periods of time (e.g. bedrooms and living rooms) should be as far away as possible from pipework. Consequently, it is recommended that all installations are concentrated in the centre of the dwelling, in the kitchen or bathroom, or collected together in a service wall (→ p. 277 ⑤).

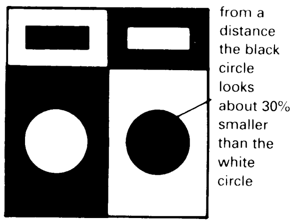
There is a similar problem with electrical wiring carrying alternating current. Even if current does not flow, electrical fields with pathogenic effects are formed, and when current is being drawn, the electromagnetic fields created are reputed to be even more harmful. Dr Hartmann found an immediate cure in one case of disturbed well-being by getting the patient to pull out the plug and therefore eliminate the current in the flex which went around the head of his bed → ①. In another case similar symptoms were cured by moving a cable running between an electric heater and the thermostat from behind the head of the double bed to the other side of the room → ②. Loose cables are particularly troublesome, as they produce a 50 Hz alternating field syndrome. In addition, electrical equipment, such as heaters, washing machines, dish washer, boilers and, particularly, microwave ovens with defective seals, situated next to or beneath bedrooms send out pathogenic radiation through the walls and floors, so that the inhabitants are often in an area of several influences → ③. Radiation can largely be avoided in new buildings by using wiring with appropriate insulating sheathing. In existing structures the only solution is to re-lay the cables or switch off the current at the meter. For this purpose it is now possible to obtain automatic shut-off switches when no current is being consumed. In this case, a separate circuit is required for appliances that run constantly (e.g. freezers, refrigerators, boilers etc.).

Additionally, harmful radiation covers large areas around transformer stations (Schröder-Speck measured radiation from a 10–20000 V station as far away as 30–50 m to the north and 120–150 m to the south), electric railways and high-voltage power lines. Even the power earthing of many closely spaced houses can give rise to pathogenic effects.

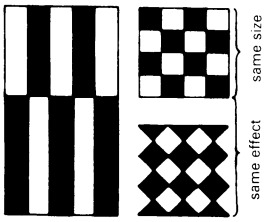
The human metabolism is influenced by ions (electrically charged particles). A person in the open air is subjected to an electrical voltage of about 180 V, although under very slight current due to the lack of a charge carrier. There can be up to several thousand ions in one cubic metre of air, depending on geographical location and local conditions → ④. They vary in size and it is the medium and small ions that have a biological effect. A strong electrical force field is produced between the mostly negatively charged surface of the earth and the positively charged air and this affects the body. The research of Tschishewskij in the 1920s revealed the beneficial influence of negative ions on animals and humans, and showed a progressive reduction in the electrical potential of humans with increasing age. In addition, the more negative ions there are in the air, the slower the rate at which humans age. Research in the last 50 years has also confirmed the beneficial effects of negative ions in the treatment of high blood pressure, asthma, circulation problems and rheumatism. The positive ions are predominant in closed rooms, particularly if they are dusty, rooms; but only negatively charged oxygenated air is biologically valuable. There is a large choice of devices which can be placed in work and utility rooms to artificially produce the negative ions (i.e. which produce the desirable steady field). Such steady fields (continuous current fields) change the polarisation of undesirably charged ions to create improved room air conditions. The devices are available in the form of ceiling electrodes and table or floor mounted units.

(SU is a measurement value; derived from Suhr, the home town of Schröder-Speck)

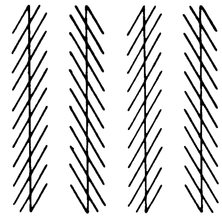
THE EYE: PERCEPTION



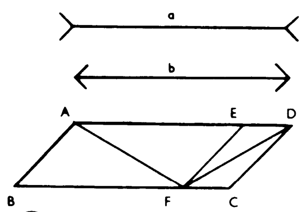
① Black areas and objects appear smaller than those of the same size which are white: the same applies to parts of buildings



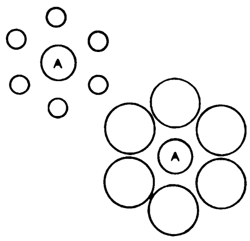
② To make black and white areas look equal in size, the latter must be drawn smaller



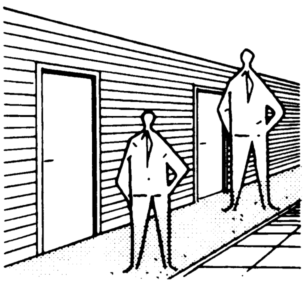
③ These vertical rules are actually parallel but appear to converge because of the oblique hatching



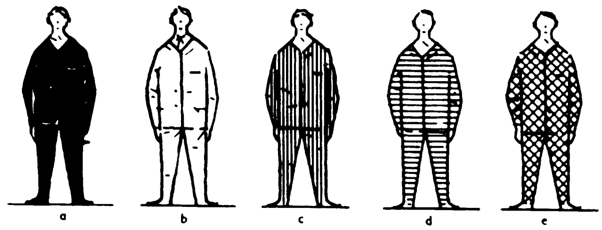
④ Lengths a and b are equal, as are A–F and F–D, but arrowheads and dissimilar surrounds make them appear different



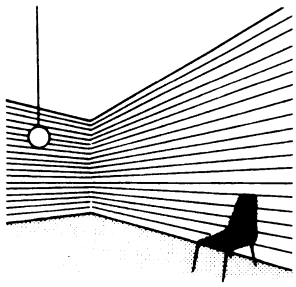
⑤ Although both are equal in diameter, circle A looks larger when surrounded by circles that have a smaller relative size

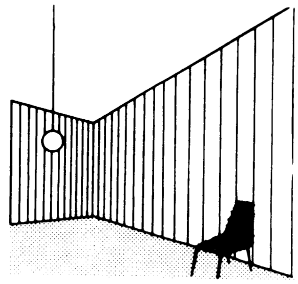


⑥ Two identical people seem different in height if the rules of perspective are not observed



⑦ The colour and pattern of clothing can change people's appearance: (a) thinner in black (black absorbs light); (b) more portly in white (white spreads light); (c) taller in vertical stripes; (d) broader in horizontal stripes; (e) taller and broader in checked patterns

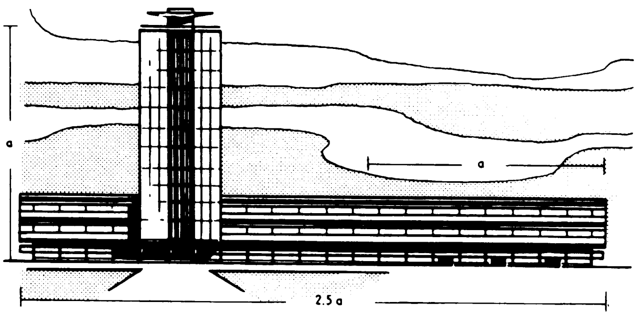




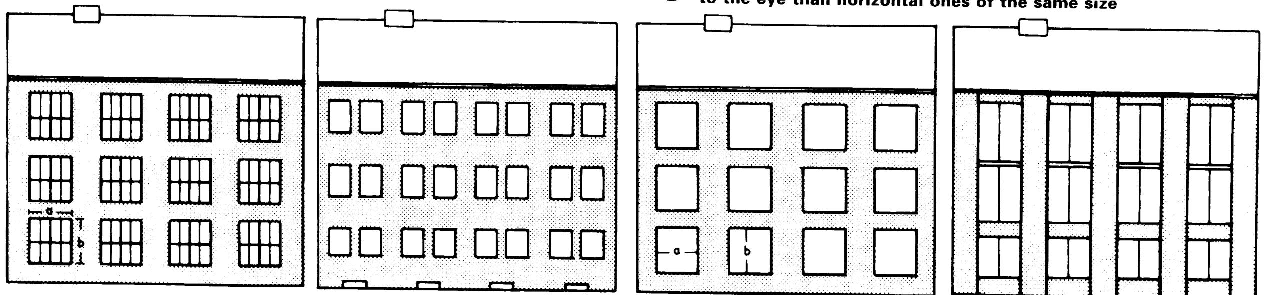
with different divisions, identical rooms can appear to differ in size and form

⑧ Dynamic effect

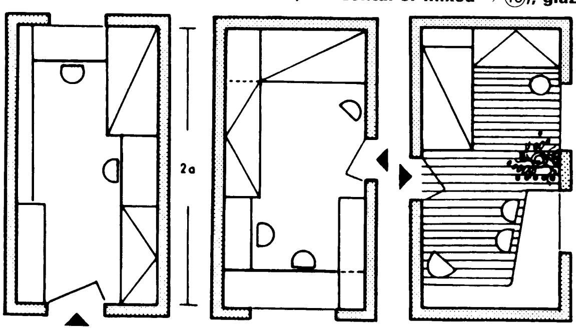
⑨ Static effect



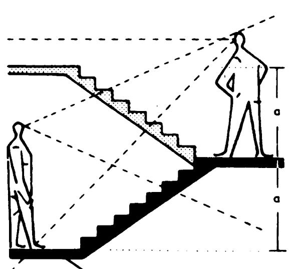
⑩ Vertical dimensions appear disproportionately more impressive to the eye than horizontal ones of the same size



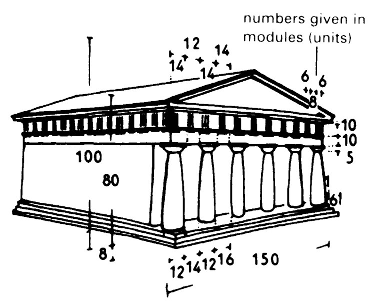
⑪–⑭ The perception of scale is changed by the ratio of the window area to the remaining area of wall as well as by architectural articulation (i.e. vertical, horizontal or mixed → ⑩); glazing bars can contribute substantially to this



⑮–⑰ The positioning of windows, doors and furnishings can give a room different spatial appearances: ⑮ long and narrow; ⑯ seems shorter with the bed across the room, or the table below the window; ⑰ with windows opposite the door and appropriate furniture, the room seems more wide than deep



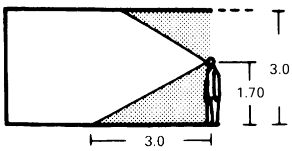
⑱ A structure can appear taller if viewed from above; there is a greater feeling of certainty when looking up



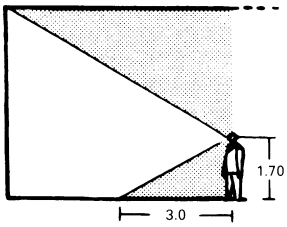
⑲ The walls slanting suitably inward seem vertical; steps, cornices and friezes when bowed correctly upwards look horizontal

THE EYE: PERCEPTION

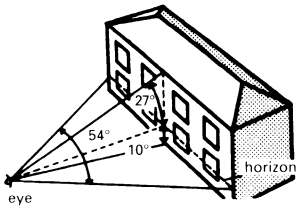
Interpretation



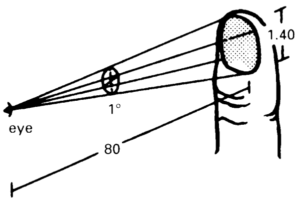
① **The perception of a low room is gained 'at a glance' (i.e. still picture)**



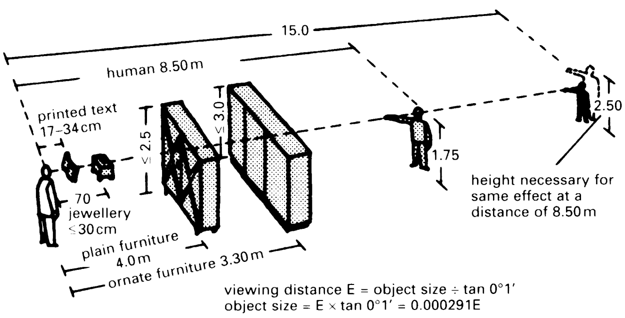
② **In higher rooms, the eyes must scan upwards (i.e. scan picture)**



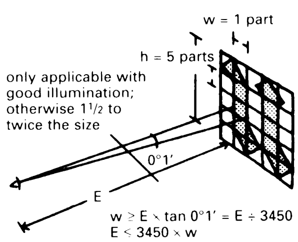
③ **The human field of vision (head still, moving the eyes only) is 54° horizontally, 27° upwards and 10° downwards**



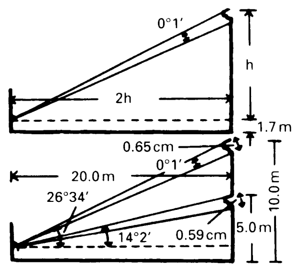
④ **The field of view of the normal fixed eye takes in a perimeter of 1° (approx. the area of a thumbnail of an outstretched hand)**



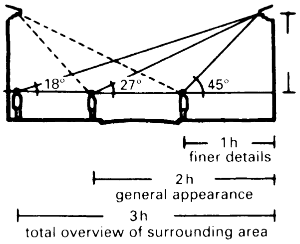
⑤ **The eye can resolve detail within a perimeter of only 0°1′ (the field of reading), thus limiting the distances at which objects and shapes can be distinguished accurately → ⑥**



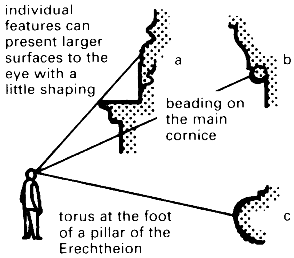
⑥ **To be readable at a distance of, say, 700m the width w of the letters must be: ≥700×0.000291 = 0.204; height h is usually 5w: 5×0.204 = 1.020m**



⑦ **As in the previous examples, the size of structural parts which are differentiable can be calculated using the viewing distance and trigonometry**



⑧ **Street widths play an important role in the level of detail which is perceived from ground level**



⑨ **Parts of buildings meant to be seen but sited above projections must be placed sufficiently high up (see a)**

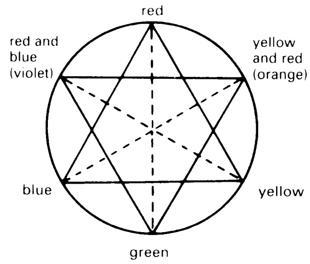
The activity of the eye is divided into seeing and observing. Seeing first of all serves our physical safety but observing takes over where seeing finishes; it leads to enjoyment of the 'pictures' registered through seeing. One can differentiate between a still and a scanned picture by the way that the eye stays on an object or scans along it. The still picture is displayed in a segment of the area of a circle, whose diameter is the same as the distance of the eye from the object. Inside this field of view the objects appear to the eye 'at a glance' → ③. The ideal still picture is displayed in balance. Balance is the first characteristic of architectural beauty. (Physiologists are working on a theory of the sixth sense – the sense of balance or static sense – that underpins the sense of beauty we feel with regard to symmetrical, harmonious things and proportions (→ pp. 27–30) or when we are faced with elements that are in balance.)

Outside this framework, the eye receives its impressions by scanning the picture. The scanning eye works forward along the obstacles of resistance which it meets as it directs itself away from us in width or depth. Obstacles of the same or recurring distances are detected by the eye as a 'beat' or a 'rhythm', which has the same appeal as the sounds received by the ear from music. 'Architecture is Frozen Music. This effect occurs even when regarding a still or scanned picture of an enclosed area → ① and ②.

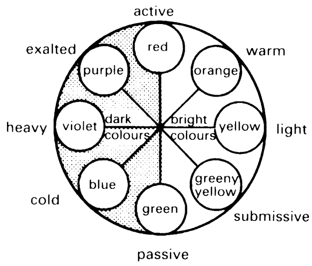
A room whose top demarcation (the ceiling) we recognise in the still picture gives a feeling of security, but on the other hand in long rooms it gives a feeling of depression. With a high ceiling, which the eye can only recognise at first by scanning, the room appears free and sublime, provided that the distance between the walls, and hence the general proportions, are in harmony. Designers must be careful with this because the eye is susceptible to optical illusions. It estimates the extent of width more exactly than depths or heights, the latter always appearing larger. Thus a tower seems much higher when seen from above rather than from below → p. 24 ⑩ and ⑱. Vertical edges have the effect of overhanging at the top and horizontal ones of curving up in the middle → p. 24 ① – ⑨, ⑲. When taking these things into account, the designer should not resort to the other extreme (Baroque) and, for example, reinforce the effect of perspective by inclined windows and cornices (St Peter's in Rome) or even by cornices and vaulting painted in perspective and the like. The decisive factor for the measurement of size is the size of the field of view → ③ and, if applicable, the field of vision → ④ and, for the exact differentiation of details, the size of the field of reading → ⑤ and ⑥. The distance of the latter determines the size of the details to be differentiated.

The Greeks complied exactly with this rule. The size of the smallest moulding under the cornice of the individual temples of varying height is so dimensioned that, at an angular distance of 27° → ⑦, it complies with the reading field of 0°1′. From this also results the reading distances for books (which varies with the size of the letters) and the seating plans for auditoriums etc.

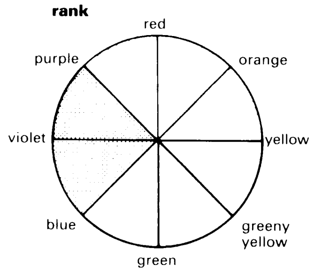
MAN AND COLOUR



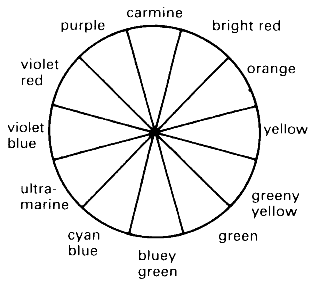
① **Goethe's natural colour circle: red–blue–yellow triangle are basic colours (from which all colours can be mixed); green–orange–violet triangle shows colour mixtures of the first rank**



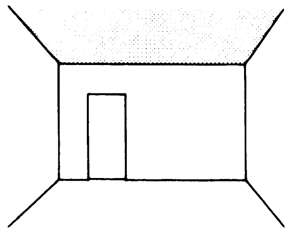
② **Bright and dark colours and their effect on humans**



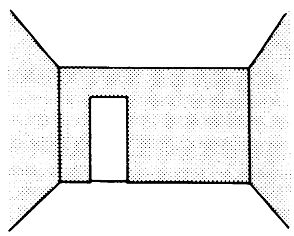
③ **Light and heavy colours (not the same as bright and dark colours → ②): create a 'heavy' feeling**



④ **The colour circle's twelve segments**



⑤ **Dark colours make a room heavy: rooms seem to be lower, if ceilings are heavily coloured**



⑥ **Bright colours give a lift: rooms seem higher with emphasis on walls and light ceilings**

Colours have a power over humans. They can create feelings of well-being, unease, activity or passivity, for instance. Colouring in factories, offices or schools can enhance or reduce performance; in hospitals it can have a positive influence on patients' health. This influence works indirectly through making rooms appear wider or narrower, thereby giving an impression of space, which promotes a feeling of restriction or freedom → ⑤ – ⑦. It also works directly through the physical reactions or impulses evoked by the individual colours → ② and ③. The strongest impulse effect comes from orange; then follow yellow, red, green, and purple. The weakest impulse effect comes from blue, greeny blue and violet (i.e. cold and passive colours).

Strong impulse colours are suitable only for small areas in a room. Conversely, low impulse colours can be used for large areas. Warm colours have an active and stimulating effect, which in certain circumstances can be exciting. Cold colours have a passive effect – calming and spiritual. Green causes nervous tension. The effects produced by colour also depend on brightness and location.

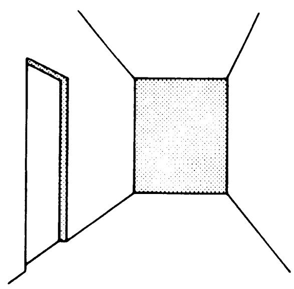
Warm and bright colours viewed overhead have a spiritually stimulating effect; viewed from the side, a warming, drawing closer effect; and, seen below, a lightening, elevating effect.

Warm and dark colours viewed above are enclosing or dignified; seen from the side, embracing; and, seen below, suggest safe to grip and to tread on.

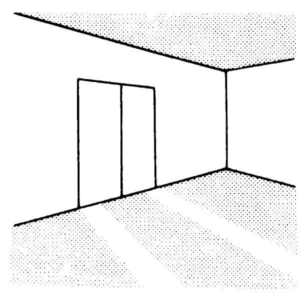
Cold and bright colours above brighten things up and are relaxing; from the side they seem to lead away; and, seen below, look smooth and stimulating for walking on.

Cold and dark colours are threatening when above; cold and sad from the side; and burdensome, dragging down, when below.

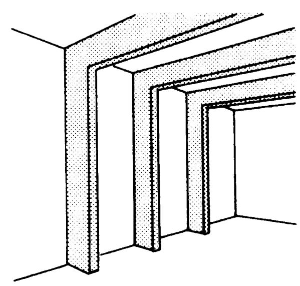
White is the colour of total purity, cleanliness and order. White plays a leading role in the colour design of rooms, breaking up and neutralising other groups of colours, and thereby create an invigorating brightness. As the colour of order, white is used as the characteristic surface for warehouses and storage places, for road lines and traffic markings → ⑧.



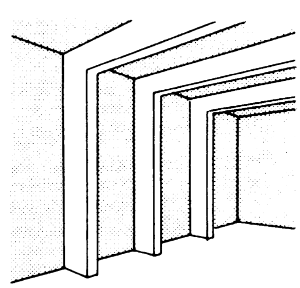
⑦ **Long rooms seem shorter if end cross walls stand out heavily**



⑧ **White as a dominant colour, e.g. in laboratories, factories etc.**



⑨ **Dark elements in front of a bright wall give a powerful effect**



⑩ **Bright elements in front of a dark background seem lighter, particularly when over-dimensioned**

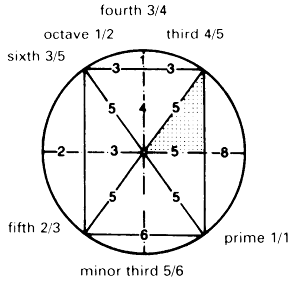
Brightness of surfaces

Values between theoretical white (100%) and absolute black (0%)

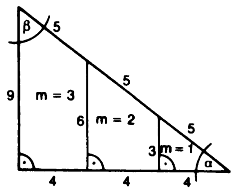
white paper	84	light brown	approx. 25	grass green	approx. 20	asphalt, dry	approx. 20
chalky white	80	pure beige	approx. 25	lime green, pastel	approx. 50	asphalt, wet	approx. 5
citron yellow	70	mid brown	approx. 15	silver grey	approx. 35	oak, dark	approx. 18
ivory	approx. 70	salmon pink	approx. 40	grey lime plaster	approx. 42	oak, light	approx. 33
cream	approx. 70	full scarlet	16	dry concrete, grey	approx. 32	walnut	approx. 18
gold yellow, pure	60	carmine	10	plywood	approx. 38	light spruce	approx. 50
straw yellow	60	deep violet	approx. 5	yellow brick	approx. 32	aluminium foil	83
light ochre	approx. 60	light blue	40–50	red brick	approx. 18	galvanised iron sheet	16
pure chrome yellow	50	deep sky blue	30	dark clinker approx.	10		
pure orange	25–30	turquoise blue, pure	15	mid stone colour	35		

DIMENSIONAL RELATIONSHIPS

Basis



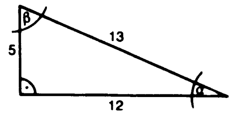
(1) **Pythagoras's rectangle includes all interval proportions and excludes the disharmonious second and seventh**



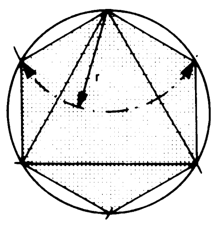
(2) **Pythagoras's triangle**

α	a	b	c	β	m	x	y
36°87'	3	4	5	53°13'	1	1	2
22°62'	5	12	13	67°38'	1	2	3
16°26'	7	24	25	73°74'	1	3	4
28°07'	8	15	17	61°93'	0.5	3	5
12°68'	9	40	41	77°32'	1	4	5
18°92'	12	35	37	71°08'	0.5	5	7
43°60'	20	21	29	46°40'	0.5	3	7
31°89'	28	45	53	58°11'	0.5	5	9

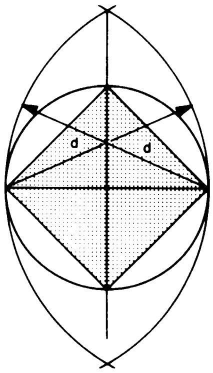
(3) **Some numerical relationships from Pythagoras's equations**



(4) **Example**



(5) **Equilateral triangle, hexagon**



(6) **Square**

There have been agreements on the dimensioning of buildings since early times. Essential specific data originated in the time of Pythagoras. He started from the basis that the numerical proportions found in acoustics must also be optically harmonious. From this, Pythagoras developed his right-angled triangle → (1). It contains all the harmonious interval proportions, but excludes both the disharmonious intervals (i.e. the second and seventh).

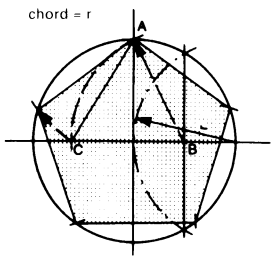
Space measurements are supposed to have been derived from these numerical proportions. Pythagoras or diophantine equations resulted in groups of numerals → (2) – (4) that should be used for the width, height and length of rooms. These groups can be calculated using the formula $a^2 + b^2 = c^2$.

$a^2 + b^2 = c^2$
$a = m(y^2 - x^2)$
$b = m \cdot 2 \cdot x \cdot y$
$c = m(y^2 + x^2)$

In this x and y are all whole numbers, x is smaller than y, and m is the magnification or reduction factor.

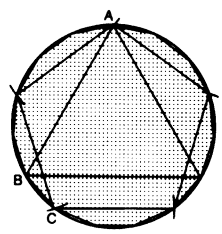
The geometric shapes named by Plato and Vitruvius are also of critical importance (i.e. circle, triangle → (5) and square → (6) from which polygonal traverses can be constructed). The respective bisection then results in further polygonal traverses. Other polygonal traverses (e.g. heptagon → (9), nonagon → (10)) can only be formed by approximation or by superimposition. So we can construct a fifteen-sided figure → (8) by superimposing the equilateral triangle on the pentagon.

The pentagon or pentagram has a natural relationship with the golden section, just like the decagon which is derived from it (11), (12) and → p. 30. However, in earlier times its particular dimensional relationships found hardly any application. Polygonal traverses are necessary for the design and construction of so-called 'round' structures. The determination of the most important measurements (radius r, chord c, and height of a triangle h) are shown in → (13) and (14).

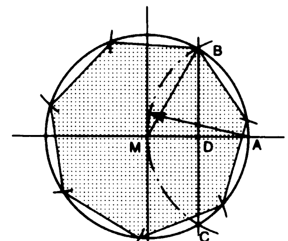


bisection of the radius → B;
arc at B with AB → C
A–C → side of a pentagon

(7) **Pentagon**

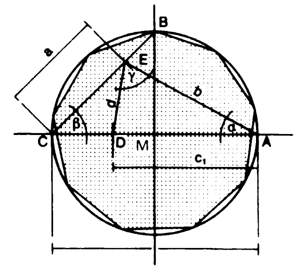


(8) **Fifteen angle BC = $\frac{2}{5} - \frac{1}{3} = \frac{1}{15}$**



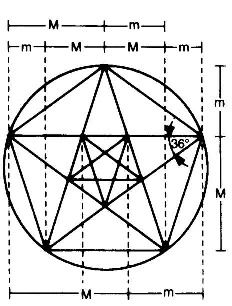
straight BC bisects AM at D;
BD is approx. 1/7 of the circumference of the circle

(9) **Approximated heptagon**

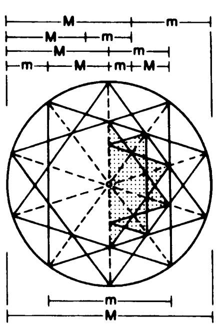


arc of the circle at A with AB results in point D on AC = c_1;
arc of the circle at C with CM results in point E on arc of BD = a;
segment DE approximately corresponds with 1/9 of the circle's circumference → D

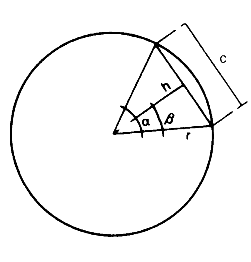
(10) **Approximated nonagon**



(11) **Pentagon and golden section**



(12) **Decagon and the golden section**



(13) **Measurement calculation in polygonal traverse → p. 28**

$h = r \cdot \cos\beta$

$\frac{c}{2} = r \cdot \sin\beta$

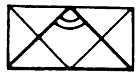
$c = 2 \cdot r \cdot \sin\beta$

$h = \frac{c}{2} \cdot \cot\beta$

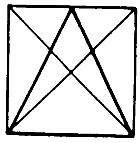
(14) → (13) **formula**

DIMENSIONAL RELATIONSHIPS

Basis



A right-angled isosceles (i.e. having two equal sides) triangle with a base-to-height ratio of 1:2 is the triangle of quadrature.



An isosceles triangle with a base and sides that can be contained by a square was successfully used by Knauth, the master of cathedral construction, for the determination of the dimensional relationships for the Strasbourg Cathedral.

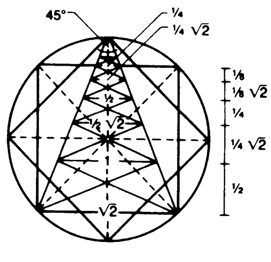
Drach's π/4 triangle → ① is somewhat more pointed than the previous one described, as its height is determined by the point of a slewed square. It, too, was successfully used for details and components.

Apart from these figures, the dimensional proportions of the octagon can be detected on a whole range of old structures. The so-called diagonal triangle serves as a basis here. The triangle's height is the diagonal of the square built on half the base → ② – ④.

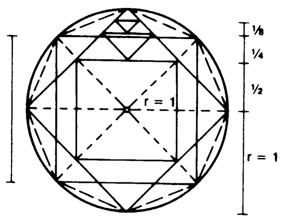
The sides of the rectangle depicted in ⑤ have a ratio of 1:√2. In accordance with this, all halvings or doublings of the rectangle have the same ratio of 1: √2. The 'step ladders' within an octagon make available the geometric ranges in ② – ④. The steps of square roots from 1–7 are shown in ⑥. The connection between square roots of whole numbers is shown in ⑦.

The process of factoring makes possible the application of square roots for building in non-rectangular components. By building up approximated values for square figures, Mengeringhausen developed the MERO space frames. The principle is the so-called 'snail' → ⑧ – ⑩. The inaccuracies of the right angle are compensated for by the screw connections of the rods at the joints. A subtly differentiated approximated calculation of square roots of whole numbers √n for non-rectangular components is available from the use of continued fractions (→ p. 30) in the formula expressed as G =

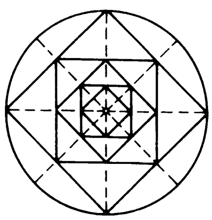
$$\sqrt{n} = 1 + \frac{n-1}{1+G} \rightarrow ⑪.$$



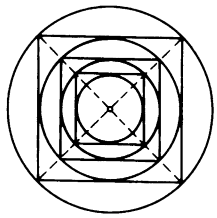
① π/4 triangle (according to A. V. Drach)



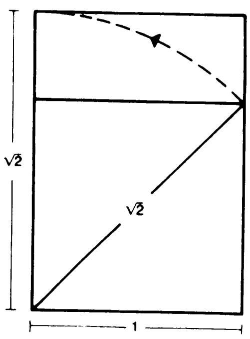
② Squares developed from the octagon → ② – ④



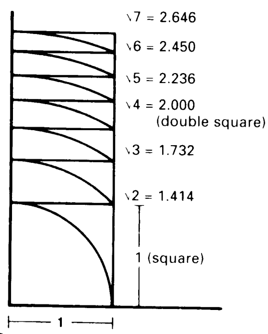
③ → ②



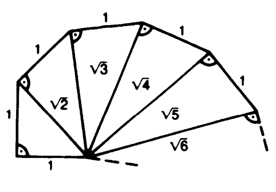
④ → ②



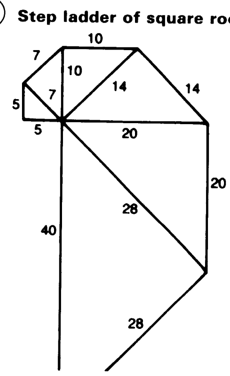
⑤ 1:√2 rectangle



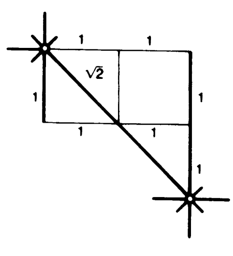
⑥ Step ladder of square roots



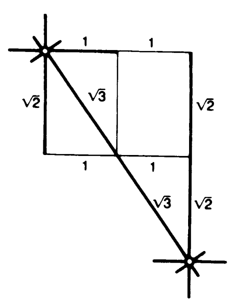
⑦ Connection between square roots



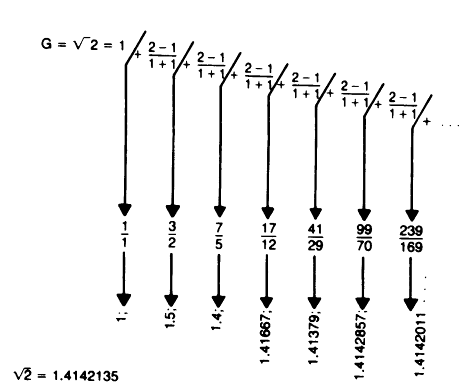
⑧ The 'Snail'



⑨ Non-rectangular co-ordination – MERO space frames: building on √2 and √3 → pp. 90–91



⑩ √3



1	1	1	1
0.5	2	3	1.5
0.6	5	7	1.4
0.58333 . . .	12	17	1.41667 . . .
0.58621 . . .	29	41	1.41379 . . .
0.5857143 . . .	70	99	1.4142857 . . .
0.5857989 . . .	169	239	1.4142011 . . .
0.5857865 . . .		√2	1.4142135 . . .

⑪ Continued fraction √2

DIMENSIONAL RELATIONSHIPS

Application

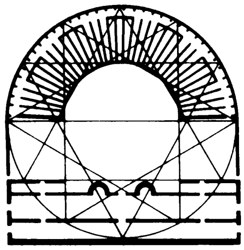
The application of geometrical and dimensional relationships on the basis of the details given earlier was described by Vitruvius. According to his investigations, the Roman theatre, for example, is built on the triangle turned four times → ① the Greek theatre on a square turned three times → ②. Both designs result in a dodecagon. This is recognisable on the stairs. Moessel has tried to detect the use of proportional relationships in accordance with the golden section → ③, although this is not obvious. The only Greek theatre whose plan view is based on a pentagon stands in Epidaurus → ④.

In a housing estate recently uncovered in Antica-Ostia, the old harbour of Rome, the golden section is recognised as being the design principle. This principle consists of a bisection of the diagonal of a square. If the points at which the arc of the circle cuts the sides of the square are joined with $\sqrt{2}/2$, a nine-part grid is obtained. The square in the middle is called the square of the Holy Section. The arc AB has up to a 0.6% deviation and the same length as the diagonal CD of the base square. Thus the Holy Section shows an approximate method for squaring the circle → ⑤ – ⑧. The whole building complex, from site plan to the general arrangement details, is built with these dimensional proportions.

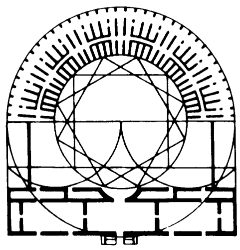
In his four books on architecture, Palladio gives a geometrical key, which is based on the details given by Pythagoras. He uses the same space relationships (circle, triangle, square, etc.) and harmonies for his structures (→ ⑨ and ⑩).

Such laws of proportion can be found formulated in absolutely clear rules by the cultures of the ancient peoples of the Far East → ⑪. The Indians with their 'Manasara', the Chinese with their modulation in accordance with the 'Toukou' and, particularly, the Japanese with their 'Kiwariho' method have created structural systematics, which guarantee traditional development and offer immense economic advantages.

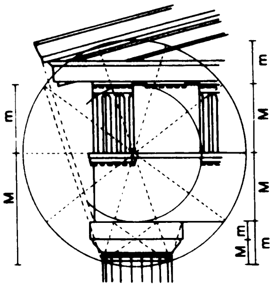
In the 18th century and later, it was not a harmonic but an additive arrangement of dimensions which was preferred → ⑫. The Octameter system developed from this. It was only with the introduction of the modular ordering system that the understanding of harmonic and proportional dimensional relationships returned → ⑬ and ⑭. Details of the coordination system and coordination dimensions are given on pp. 34–5.



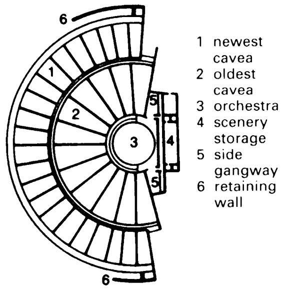
① **Roman theatre (according to Vitruvius)**



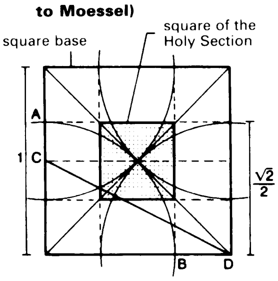
② **Greek theatre (according to Vitruvius)**



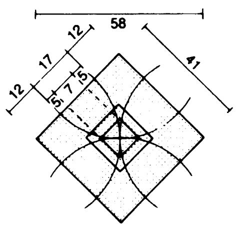
③ **Dimensional proportions of the gable corner of a Doric temple on the basis of the golden section (according to Moessel)**



④ **Theatre at Epidaurus**

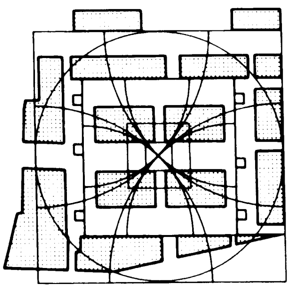


⑤ **Holy Section, building in Antica-Ostia**

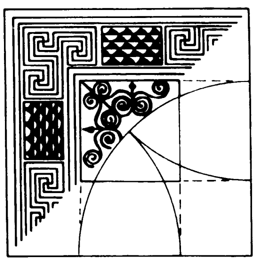


x	x	y/x (√2 = 1.4142...)
1	1	1
2	3	1.5
5	7	1.4
12	17	1.4/66...
24	41	1.4/37...

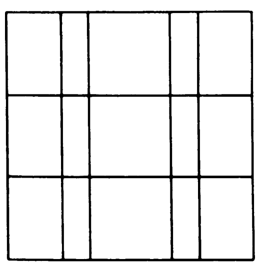
⑥ **Geometrical principle**



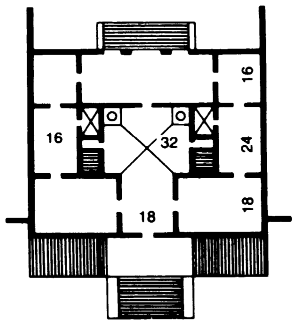
⑦ **Plan view of the whole installation**



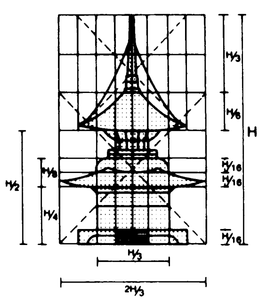
⑧ **Floor mosaic in a house at Antica-Ostia**



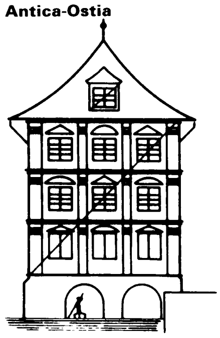
⑨ **Geometric key to Palladio's villas**



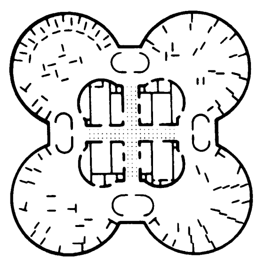
⑩ **Palladio, Villa Pisani at Bagodo**



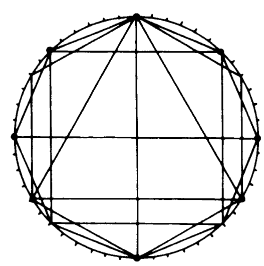
⑪ **Japanese treasury building**



⑫ **Guildhouse Rügen in Zurich**



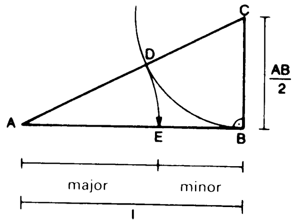
⑬ **Plan view of the BMW Administration Building in Munich**



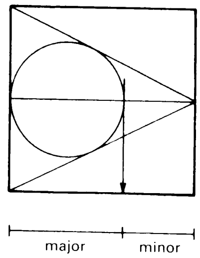
⑭ **Octagonal coordination system for columns made of squares, each subdivided into six façade elements, 48 angles developed from a triangle → ⑬**

DIMENSIONAL RELATIONSHIPS

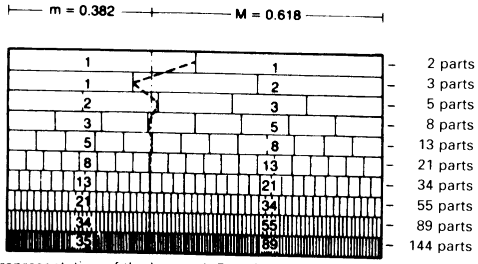
Application of Le Modulor



① **Geometric design of the golden section**

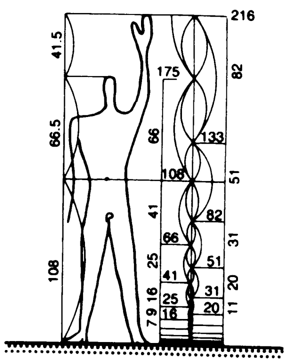


② **Connection between square, circle, and triangle**



representation of the Lamesch Row from Neufert 'Bauordnungslehre'

③ **Continued fraction: golden section**



$$G = 1 + \frac{1}{G}$$

$$G = 1 + \cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1\ldots}}}}}$$

④ **Proportional figure**

The architect Le Corbusier developed a theory of proportion, which is based on the golden section and the dimensions of the human body. The golden section of a segment of a line can be determined either geometrically or by formulae. It means that a line segment can be divided so that the whole of the line segment can be related to a bigger dividing segment, just as the larger is to the smaller → ①.

That is: $\frac{1}{\text{major}} = \frac{\text{major}}{\text{minor}}$

and shows the connection of proportional relationships between the square, the circle and the triangle → ②.

The golden section of a line segment can also be determined by a continued fraction

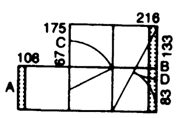
$$G = 1 + \frac{1}{G}$$

This is the simplest unending regular continued fraction. Le Corbusier marked out three intervals in the human body, which form a known golden section series according to Fibonacci. These are between the foot, the solar plexus, the head, the finger of the raised hand. First of all Le Corbusier started out from the known average height for Europeans (1.75m → pp. 16–17), which he divided up in accordance with the golden section into 108.2 – 66.8 – 41.45 – 25.4cm → ④.

As this last dimension was almost exactly equal to 10 inches, he found in this way a connection with the English inch, although not for the larger dimensions. For this reason, Le Corbusier changed over in 1947 to 6 English feet (1.828m) as the height of the body. By golden section division he built the red row up and down → ⑤. As the steps in this row are much too big for practical use, he also built up a blue row, starting from 2.26m (i.e. the finger tips of the raised hand), which gave double the values expressed in the red row → ⑤. The values of the red and blue rows were converted by Le Corbusier into dimensions which were practically applicable.

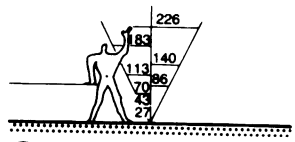
values expressed in the metric system			
red row: re		blue row: bl	
centimetre	metre	centimetre	metre
95280.7	952.8		
58886.87	588.86	117773.5	1177.73
36394.0	363.94	72788.0	727.88
22492.7	224.92	44985.5	449.85
13901.3	139.01	27802.5	278.02
8591.4	85.91	17182.9	171.83
5309.8	53.10	10619.6	106.19
3281.6	32.81	6563.3	65.63
2028.2	20.28	4056.3	40.56
1253.5	12.53	2506.9	25.07
774.7	7.74	1549.4	15.49
478.8	4.79	957.6	9.57
295.9	2.96	591.8	5.92
182.9	1.83	365.8	3.66
113.0	1.13	226.0	2.26
69.8	0.70	139.7	1.40
43.2	0.43	86.3	0.86
26.7	0.27	53.4	0.53
16.5	0.16	33.0	0.33
10.2	0.10	20.4	0.20
6.3	0.06	7.8	0.08
2.4	0.02	4.8	0.04
1.5	0.01	3.0	0.03
0.9		1.8	0.01
0.6		1.1	

⑤ **Explanation of the values and sets of the Le Modulor according to Le Corbusier**

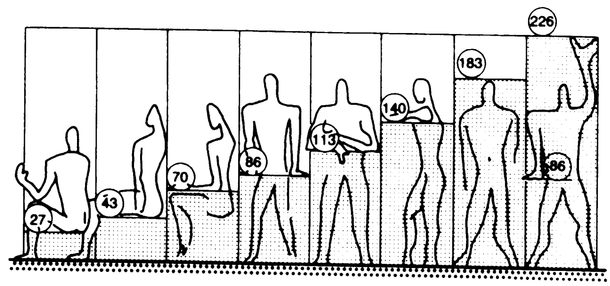


unit A = 108
double B = 216
Ø increase in length of A = C = 175
Ø reduction in length of B = D = 83

⑥



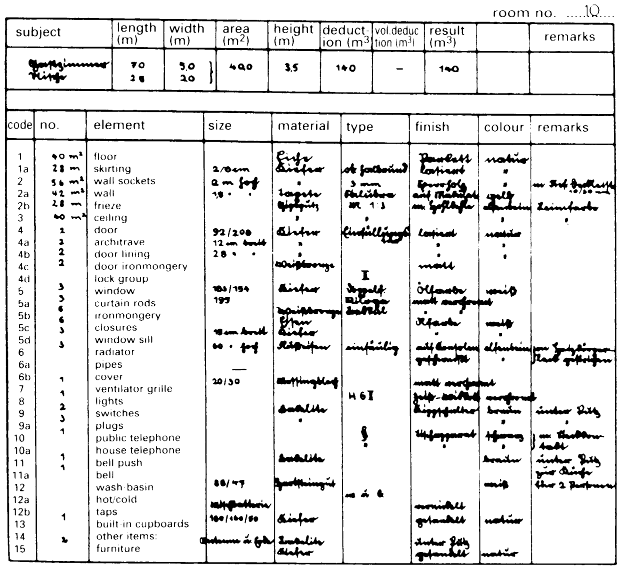
⑦ **Le Modulor**



⑧ **The limitless values of figures**

BUILDING SUPERVISION

For any construction project, completed standard description forms give the most valuable and clearest information, and are ideal for estimating, for the construction supervisor and as a permanent reference in the site office. Any time-consuming queries based on false information are virtually eliminated; the time gained more than compensating the effort involved in completing the record book. At the top of the form, there are columns for entering relevant room dimensions, in a way easily referred to. The inputs are most simply made using key words. The column 'size' should be used merely for entry of the necessary dimensions of the items, e.g., the height of the skirting board or the frieze, the width of the window sill, etc. Finally, several spaces are provided for special components. A space should be left free under each heading, so that the form can easily be extended for special cases. The reverse side of the form is best left free so that drawings may be added to elaborate on the room description on the next sheet. The A4 format pages are duplicated, each position containing exactly the same text; the sheets are kept up to date and eventually bound together. At the conclusion of the building work, the record book is the basis for the settlement of claims, using the dimensions at the head of the room pages. Later, the record book provides an objective record of progress, and is available for those with specialist knowledge.



① **A sheet from the room record book**

BASIC MEASUREMENT

Standard Numbering System

Metric units of linear measurement were first defined in France in 1790, although official recognition did not take place until 1840. The metre was established as the new decimal unit of length on a scientific basis, defined as the length of a simple pendulum having a swing of one second at sea level on latitude 45°. A standard numbering system was devised in Germany, shortly after World War I, to achieve uniformity and standardisation in the measurement of machines and technical equipment – a system also used in France and the USA. The starting point for measurement is the Continental unit of measurement: the metre. In the Imperial system (used in the UK, USA and elsewhere), 40 inches = 1.016 m ≈ 1.00 m.

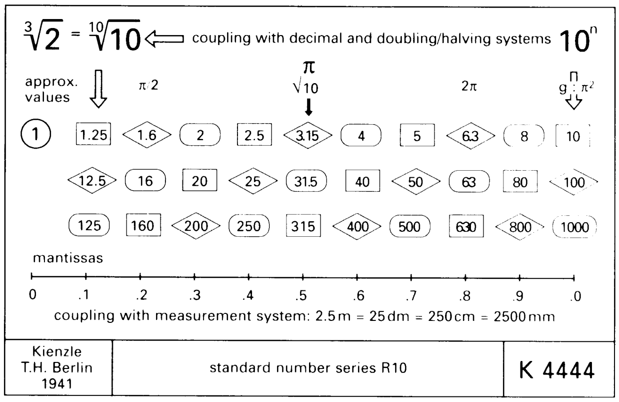
The requirement of building technology for geometrical subdivisions precluded the use of the purely decimal subdivision of the metre, so the Standard Numbering System, based on the structure of 2s, was introduced into the decimal structure: 1, 2, 4, 8, 16, 31.5, 63, 125, 250, 500, 1000 → ②. (The coarser 5-part division and the finer 20- and 40-part division series are inserted appropriately with their intermediate values.) The geometrical 10-part division of the standard number series was formed from the halving series (1000, 500, 250, 125, ...) and from the doubling series (1, 2, 4, 8, 16, ...). Because $\pi = 3.14$ and $\sqrt{10} \approx 3.16$, the number 32, following 16 in the series, was rounded down to 31.5. Similarly, in the halving sequence, 62.5 was rounded up to 63.

Standard numbers offer many advantages in calculations:

1 the product and quotient of any two standard numbers are standard numbers
2 integer powers of standard numbers are standard numbers, and
3 double (or half) a standard number is a standard number.

Building measurements

In contrast to engineering, in building construction, there is little requirement for a geometric division as opposed to the prevailing arithmetic addition of identical structural components (e.g. blocks, beams, joists, girders, columns and windows). Routine measurements for standard components must, therefore, comply with these requirements. However, they should also conform to concepts of technical standardisation and the standard numbering system. A standard system of measurement for building construction was based on the standard numbering system, and this is the basis for many further building standards and of measurement for design and construction, particularly in building construction above ground.

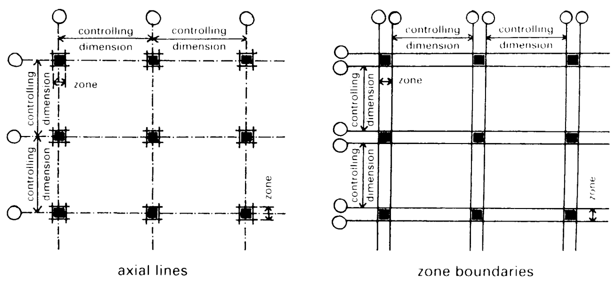


② **Representation of the Standard Number Series (base series 10)**

Standard measurements

The controlling dimensions are dimensions between key reference planes (e.g. floor-to-floor height); they provide not only a framework for design but also a basis which components and assemblies may refer to → ③.

Standard dimensions are theoretical but, in practice, they provide the basis for individual, basic structural and finished measurements; thus all building components are linked in an organised way (e.g. standard building brick length = 250 mm (225 mm in UK), in situ concrete wall thickness = 250 mm.)



③ **Horizontal controlling dimension**

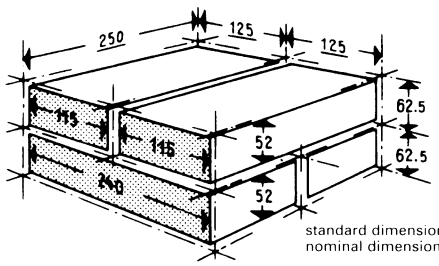
BASIC MEASUREMENTS

preferred series for basic construction			preferred series for individual measurements			preferred series for finishing		
a	b	c	d	e	f	g	h	i
25	25/2	25/3	25/4	25/10 = 5/2	5	2 × 5	4 × 5	5 × 5
				2.5				
				5				
			6 1/4	7.5				
		8 1/3		10	10	10		
	12 1/2			12.5				
			12 1/2	15	15			
		16 2/3		17.5				
			18 3/4	20	20	20	20	
				22.5				
25	25	25	25	25	25			25
				27.5				
			31 1/4	30	30	30		
		33 1/3		32.5				
				35	35			
	37 1/2		37 1/2	37.5				
		41 2/3		40	40	40	40	
			43 3/4	42.5				
				45	45			
50	50	50	50	50	50	50		50
				52.5				
			56 1/4	55	55			
		58 1/3		57.5				
				60	60	60	60	
	62 1/2		62 1/2	62.5				
				65	65			
		66 2/3	68 3/4	67.5				
				70	70	70		
				72.5				
75	75	75	75	75	75			75
				77.5				
			81 1/4	80	80	80	80	
		83 1/3		82.5				
				85	85			
	87 1/2		87 1/2	87.5				
		91 2/3		90	90	90		
			93 3/4	92.5				
				95	95			
				97.5				
100	100	100	100	100	100	100	100	100

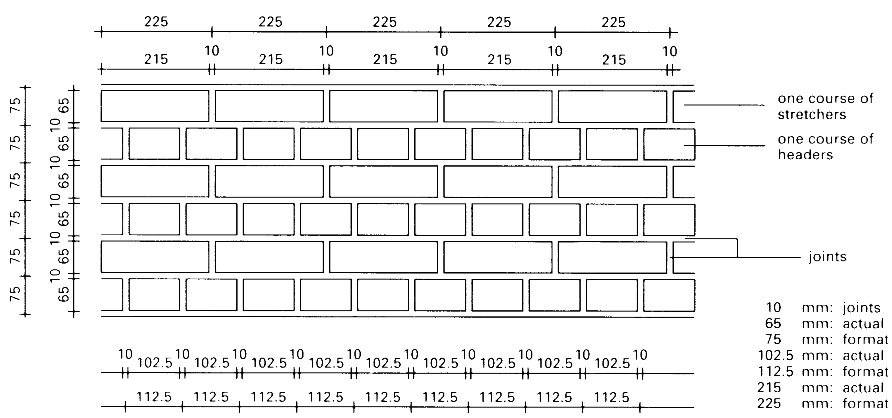
(4) **Standard building dimensions**

Individual (mostly small) dimensions are used for details of basic construction/ finishing (e.g., thickness of joints/ plaster, dimensions of rebates, wall fixings/tolerances). Basic structural measurements relate, for example, to masonry (excluding plaster thicknesses), structural floor thicknesses, unplastered doors and window openings. Finished measurements refer to the finished building (e.g. net measurements of surface finished rooms and openings, net areas and finished floor levels). For building construction without joints, nominal dimensions equal the standard dimensions; with joints, the allowance for the joint is subtracted: e.g. building brick nominal length = standard length (250 mm) – thickness of intermediate joint (10 mm) = 240 mm; nominal thickness of in-situ concrete walls = standard thickness = 250 mm. In accordance with the standard number and measurement systems, small dimensions (≤25 mm), are chosen (in mm) as: 25, 20, 16,12.5, 10, 8, 6.3, 5, 3.2, 2.5, 2, 1.6, 1.25, 1. In many European countries, even small structural components conform with the standard building numbering system, e.g. standardised building bricks. A nominal brick dimension of 240×115 mm reconciles the old non-metric format (250×120 mm or 260×130 mm with joints) with the new standard (250×125 mm with joints). With the appropriate height, with joint, of 62.5 mm (nominal brick dimension = 52 mm), this gives an aspect ratio of 250×125×62.5 – 4:2:1. → (4)

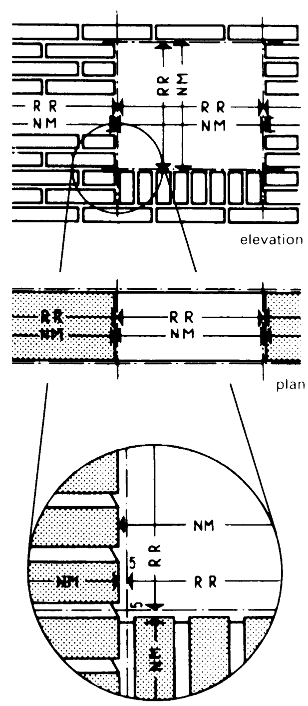
Other basic construction component dimensions (e.g. concrete blocks → p. 63, window and door openings → p. 176–87 and floor levels) are similarly aligned, so these numerical values reoccur. The UK brickwork dimensions differ: in the past, large variations in the size of ordinary fired clay products often led to critical problems when bonding clay bricks; now, BS 3921: 1895 provides one standard for dimensioning (→ (5)): coordinating size (225×112.5×75 mm, including 10 mm in each direction for joints and tolerances), and the relating work size (215 (2 headers plus 1 joint) × 102.5 × 65 mm).



(5) **Nominal and standard dimensions for continental European wall bricks**



(6) **A wall elevation illustrating brick sizes in the UK**



(7) **Standard dimensions for basic construction (RR) and nominal dimensions (NM) for brickwork**
For openings: NM = RR + 2 × 1/2 joint = RR + 2.5 mm

Japan has the oldest building size regulations where, following the great fire in Tokyo in 1657, the style and size of houses were laid down on the basis of systematic measurement according to the 'Kiwariho method'. The basic dimension was the Ken = 6 Japanese feet = 1.818m. The distances between the wall axes were measured in half or whole Ken, windows doors and even mat sizes were determined on this basis, which considerably simplified house building in Japan, making it quicker and cheaper. Examples → BOL.

In Germany, a similar system was developed in the area of half-timbered construction, prior to the introduction of the metre. The determining unit was the Prussian foot, which was most widely propagated and corresponded to the Rhenish and Danish foot.

The dimension between the axes of uprights was mostly 1 Gefach = 2 Ellen = 4 feet → ①. The Prussian, Rhenish and Danish foot, still in use in building practice in Denmark, is translated as 312.5mm, the Elle as 625mm and the Gefach as 1.25m, in the metric system. Private construction firms had adopted a similar system of 1.25m, for their system buildings, particularly for wood panel construction.

The UK and USA adopted a system of measurement based on 4 feet, which is close to 1.25m, with 4 English feet = 1.219m. Building panels (e.g. hardboard) manufactured on US machines are therefore 1.25m wide in countries using the metric system. German pumice boards for roofs also have the standard dimension of 2 × 1.25 = 2.50m, the same as plaster boards. Finally, 125 is the preferred number in the standard number system. The series of measurements resulting from 1.25m was standardised in Germany in 1942 with the corresponding roof slopes → ②. In the meantime, thousands of types of structural components have been produced to this system of measurement. The distance between the axes of beams in finished ceilings today is, accordingly, usually 125/2 = 625mm = the length of the stride of a human adult → p. 17.

Unified distances between axes for factory and industrial premises and accommodation

Industrial structures and structures for accommodation are mostly subdivided in plan into a series of axes at right angles. The line of measurement for these axes is always the axis of the structural system of the construction. The separations between axes are dimensional components of the plan, which determine the position of columns, supports, the centres of walls, etc. In the case of rigid frames, the centre axes of the bearing points of the foundations are decisive. The measurements are always referenced to the horizontal plan and vertical projection plane, even in the case of sloping roofs.

In industrial structures, a basic measurement of 2.5m applies to the spacing of axes. Multiples of this give axis spacing of 5.0, 7.5 and 10.0m, etc. In special cases (accommodation or slab structures), a basic measurement of 2.50/2 = 1.25m, or a multiple thereof, can be used. This results in intermediate dimensions of 1.25, 3.75, 6.25, 8.75m. However, so far as possible, these sub-dimensions should not be used above 10m.

Appropriate geometric steps over 10m are recommended as follows: 12.50m, 15.00m, 20.00m, 25.00m, 30.00m, 40.00m, 50.00m, 60.00m, (62.50m), 80.00m, 100.00m.

Roof slopes depend on the type of roofing and the sub-construction employed. The following roof slopes have been established to correspond with practical requirements:

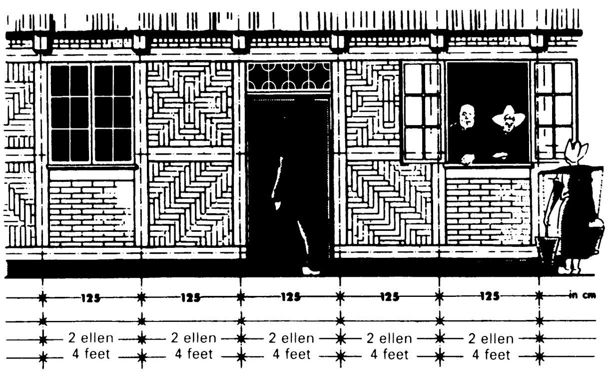
- 1:20 for boarded roofing on steel and reinforced concrete structures and wood cement roofs, with the exception of special designs such as shell and saw-tooth roofs, etc.
- 1:12.5 for boarded roofing on wooden structures
- 1:4 for corrugated cement roofing, ridged zinc roofing, corrugated sheet roofing, steel roofs on lattice work or casings, ribbed steel roofs of galvanised, double folded sheet and roofing in waterproof paper-based materials for accommodation premises
- 1:2 for flat roofs, etc.

The systematic unification of industrial and accommodation structures has been a gradual process of type development.

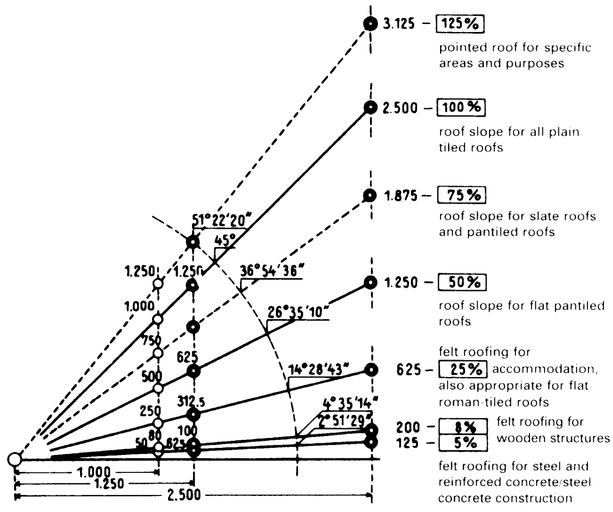
The cited axis spacings influence the individual structural components: columns, walls, ceilings, trusses, purlins, rafters, roof planking, windows, glazing, doors, gates, crane runways and other elements. The establishment of a specified basic measurement for the spacing of axes creates the prerequisites for a hierarchical system of measurement standardisation for individual structural components and their matching interconnection. The spacings between axes are simply added together, without intermediate measurements. However, masonry, glass panes, reinforced concrete panels etc., must include an element for the jointing arrangements.

The points of support for a travelling crane can be unified on the basis of the standardised axis spacings.

The matched, standardised components and assemblies are interchangeable, can be prepared off-site and used in a versatile manner. Mass production, interchangeability of components/assemblies and the availability of standardised components and assemblies in store result in savings in work, materials, costs and time. The arrangement of the structural axes brings considerable simplification to building supervision.

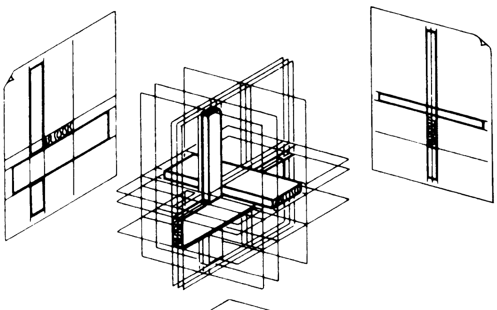


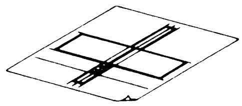
① Old Danish framed building with 1 'Gefach' separation between the axes of the uprights



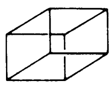
② Roof slopes at regular intervals appropriate to specified types of roof construction

MODULAR SYSTEM

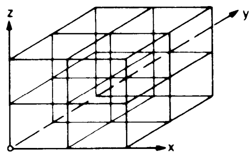




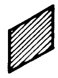
① Components in the coordinate system



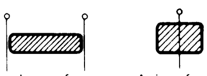
③ Coordinate space (bounded by 6 planes)



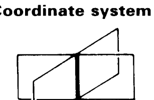
② Coordinate system



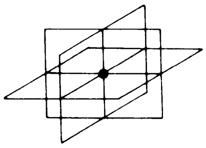
④ Coordinate plane



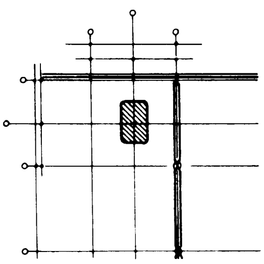
⑦ Boundary reference, axis reference



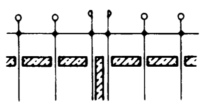
⑤ Alignment of coordinate (intersection line of 2 planes)



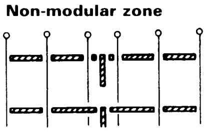
⑥ Coordinate point (point of intersection of 3 planes)



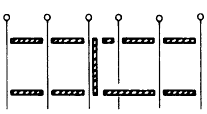
⑧ Superimposed partial coordinate system



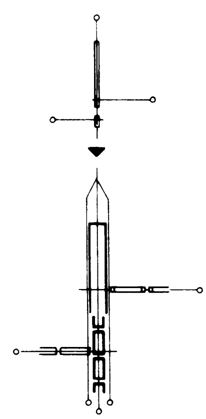
⑨ Non-modular zone



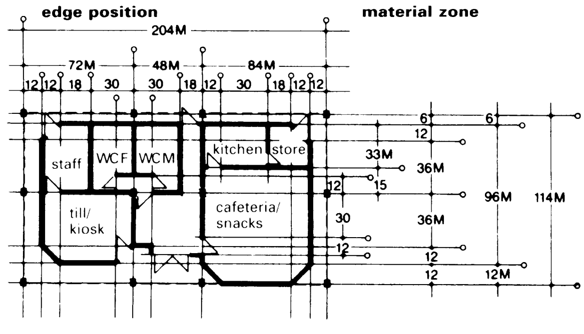
⑩ Laterally connected, non-modular components in a central position



⑪ Laterally connected, non-modular components in an edge position



⑫ Relationship between axis reference and modular material zone



⑬ Preliminary design – motorway service area

International agreements on the planning and execution of building work and for the design and manufacture of building components and semi-finished products are incorporated into national standards. The modular system is a means of coordinating the dimensions applicable to building work.

The term 'coordination' is the key, indicating that the modular layout involves an arrangement of dimensions and the spatial coordination of structural components. Therefore, the standards deal with geometrical and dimensional requirements. The modular system develops a method of design and construction which uses a coordinate system as a means of planning and executing building projects. A coordinate system is always related to specific objects.

Geometric considerations

By means of the system of coordinates, buildings and components are arranged and their exact positions and sizes specified. The nominal dimensions of components as well as the dimensions of joints and interconnections can thereby be derived. → ① – ⑥, ⑬

A coordinate system consists of planes at right angles to each other, spaced according to the coordinate measurements. Depending on the system, the planes can be different in size and in all three dimensions.

As a rule, components are arranged in one dimension between parallel coordinate planes so that they fill up the coordinate dimension, including the allowance allocated to the joints and also taking the tolerances into account. Hence a component can be specified in one dimension in terms of its size and position. This is referred to as boundary reference. → ⑦ → ⑫

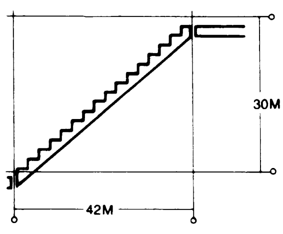
In other cases, it can be advantageous not to arrange a component between two planes, but rather to make the central axis coincide with one plane of the coordinate system. The component is initially specified in one dimension with reference to its axis, but in terms of position only. → ⑦ → ⑫

A coordinate system can be divided into sub-systems for different component groups, e.g. load-bearing structure, component demarcating space, etc. → ⑧

It has been established that individual components need not be modularised, e.g. individual steps on stairways, windows, doors, etc. → ⑭

For non-modular components which run along or across the whole building, a so-called 'non-modular' zone can be introduced, which divides the coordinate system into two-sub systems. The assumption is that the dimension of the component in the non-modular zone is already known at the time of setting out the coordinate system, since the non-modular zone can only have completely specified dimensions. → ⑨

Further possible arrangements of non-modular components are the so-called centre position and edge position within modular zones. → ⑩ – ⑪



Floor-to-floor height:
30M = 300:19 = 15.8
select 16 steps

step rise:

$h = \frac{300}{16} = 18.75$ cm

Overall length:
16.26 = 416cm
select 420 = 42M

Tread going:

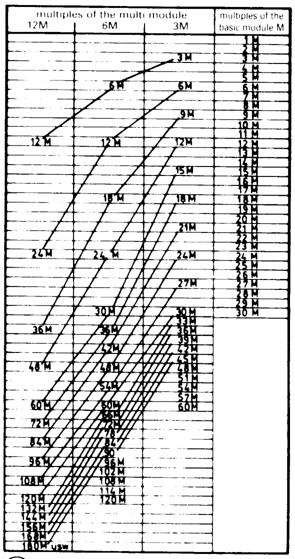
$b = \frac{419}{16} = 26.2$cm

(assuming joint dimension of 1cm)

⑭ Reinforced concrete staircase unit

COORDINATE SYSTEM AND DIMENSIONING

Modular Arrangements in Building Practice



limitation:

horizontal:

12 M series unlimited

6M and 3 M series 20 fold

1 M series 30 fold

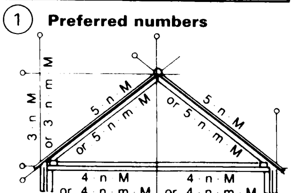
vertical:

12 M and 6 M series unlimited

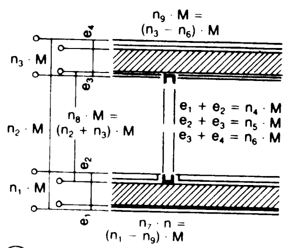
3 M series 16 fold

1M series 30 fold

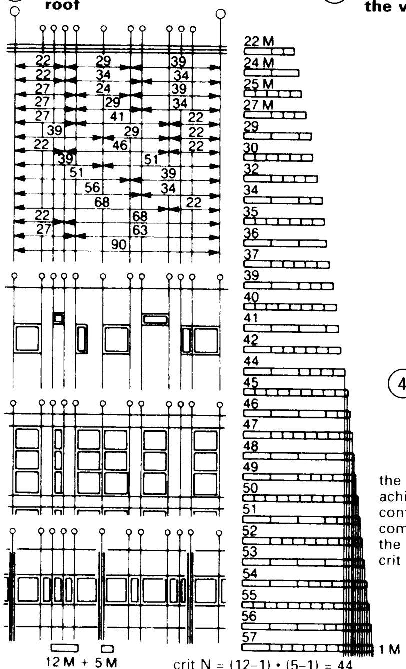
(1) **Preferred numbers**



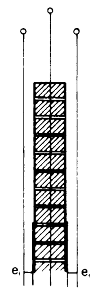
(2) **Example application, sloping roof**



(3) **Compensating measure on the verticals**

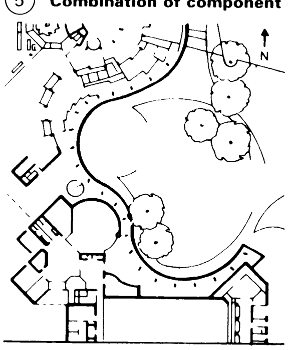


(5) **Combination of component dimensions without a common divisor**

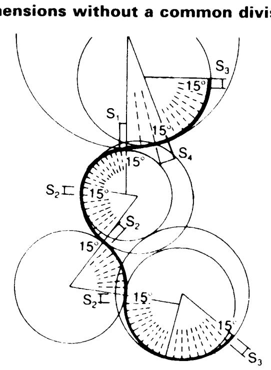


(4) **Compensating measures on the horizontals**

the smallest dimension to be achieved from which a continuous sequence commences, is calculated with the critical number (crit N) crit N = (a −1) × (b −1)



(7) **Construction of a curving roof edge from regular polygonal traverses (site plan)**



(8) **Modular polygonal traverse**

The units for the modular arrangement are M = 100mm for the basic module and 3M = 300mm, 6M = 600mm, and 12M = 1200mm, for the multi-modules. The limited multiples of the preferred numerical series are generated in this way. The coordinate dimensions – theoretical standard dimensions – are, ideally, generated from these. These limitations are the result of functional, constructional and economic factors. → (1)

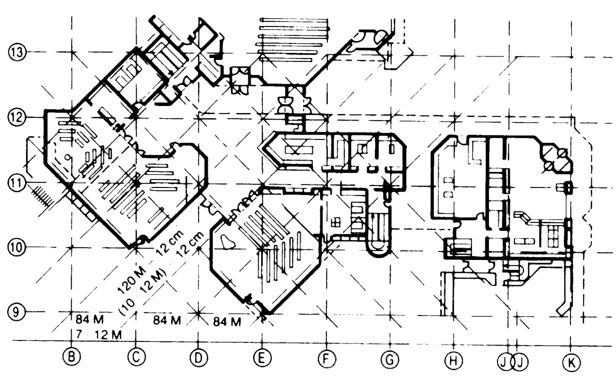
In addition, there are standardised, non-modular extending dimensions, l = 25mm, 50mm and 75mm, e.g., for matching and overlapping connection of components. → (3)

The coordinate system in practical usage

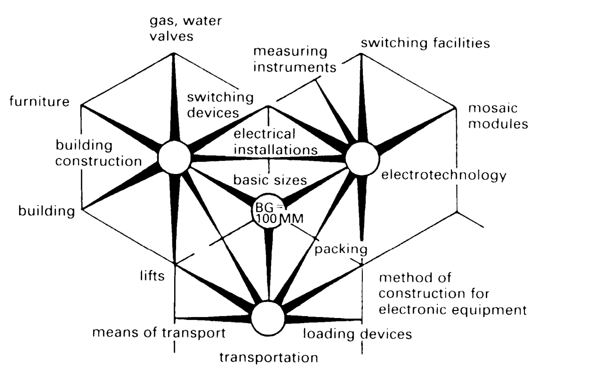
Using rules of combination, different sizes of components can also be arranged within a modular coordinate system. → (5)

With the help of calculations with numerical groups (e.g. Pythagoras) or by factorisation (e.g. continued fractions), non-rectangular components can also be arranged within a modular coordinate system. → (2) + (6)

By constructing polygonal traverses (e.g. triangular, rectangular, pentagonal and the halves of the same), the so-called 'round' building structures can be devised. → (7) – (8) Using modular arrangements, technical areas such as those for structural engineering, electrotechnology, transportation, which are dependent on each other from a geometrical and dimensional viewpoint, can be combined. → (9)



(6) **Application of rotation about 45° using 12M in the plan view**



(9) **Example of the linkage of technical areas using modular arrangements**