Josef Kolb

Systems in Timber Engineering

Birkhäuser Lignum DGfH

Systems in Timber Engineering

holz bois

Förderprogramm des Bundesamts für Umwelt BAFL

holz 21 is the Swiss Federal Office for the Environment's wood promotion scheme, which cooperates with forestry and timber industries, universities, and environmental organisations. Its principal objectives are to increase the sales and use of Swiss timber products and to strengthen the efficiency and functionality of the wood chain from forest to market.
www.holz 21.ch

Lignum
Holzwirtschaft Schweiz
Economie suisse du bois
Economia svizzera del legno

Lignum, Holzwirtschaft Schweiz, is the umbrella organisation for the Swiss forestry and timber industries. It brings together all the main associations and organisations in the timber chain, institutions in the fields of research and education, public corporations, and a large number of architects and engineers. By means of its technology and communication services throughout Switzerland, Lignum provides publicity for an industry with more than 80 000 jobs in forestry, sawmills, timber merchandising, production of wood-based products, paper manufacturing, packaging and pallet industries, carpentry, joinery, and furniture production.
www.lignum.ch

DGfH
DEUTSCHE GESELLSCHAFT FÜR HOLZFORSCHUNG

Deutsche Gesellschaft für Holzforschung e.V. (DGfH) German Society for Wood Research. The DGfH has been registered as a non-profit association since 1931. It is a joint research organisation of the German forestry and timber industries. According to its byelaws, the DGfH funds and coordinates non-competitive science and research related to the production, processing, finishing, and utilisation of wood, wood-based materials and wood preservation. The forestry and timber industries benefit mainly from an active network of 30 DGfH committees acting on an honorary basis, where more than 1000 experts from all sectors of the economy, science, public authorities, and users cooperate. The DGfH prefers to cooperate with all renowned wood research institutions and numerous other specialised research institutes rather than having to rely on a single institute. A practice-oriented knowledge transfer plus the European networking and focusing of sectoral interests are increasingly gaining ground.
www.dgfh.de

kolb

Josef Kolb AG is a consulting engineering practice based in Switzerland. The firm's international operations focus on structural engineering, fire protection, sound insulation, building physics, and energy-efficient construction. Opening up new markets for timber is the central idea that links our activities with the competent use of timber systems. The craftsmanship of the woodworking trade and proven engineering methods, together with scientific research and development, form the foundation for safe, intelligent, and high-quality timber engineering in the 21st century. Everyday problems and their solutions in timber at Josef Kolb AG provide a sound background for publications such as Systems in Timber Engineering. We hope the timber projects of readers and users benefit from this book and would be happy to provide any necessary support to this end.
www.kolbag.ch

Josef Kolb

Systems in Timber Engineering

Loadbearing Structures and Component Layers

Edited by:
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Preface

The system concept determines the character of timber structures. Up until the mid-1990s it was sufficient to be familiar with traditional systems such as log construction, timber-frame construction, and stud construction, and to be aware of panel construction and modern frame construction, which were new at the time. In the meantime, the situation has changed completely. Structures have become much taller and also larger. New loadbearing systems have been introduced. And it is no longer the loadbearing systems alone that are important – the building envelope, too, as a result of system solutions, has become a self-contained functional medium which is coordinated, however, with the loadbearing structure. The same applies to walls and suspended floors.

The design concept is decisive for the creation of a successful timber structure. We understand "design concept" to include the architectural idea, the interior layout, and technical measures. An early decision regarding the choice of loadbearing system and the associated conceptual and constructional considerations, together with fire protection and sound insulation plays a key role. At the same time, the systems for thermal performance, airtightness, and moisture control, the needs of the building services, measures concerning durability, maintenance, and the operation of a building, right up to its end-of-life deconstruction, must all be considered. For design and construction teams it is vital to link the demands of the project with the possibilities and limits of the technical concepts in such a way that a credible whole ensues. The aim of *Systems in Timber Engineering* is to encourage and assist such conceptual and planning activities. The detail must always be part of the whole, and the whole can only be perfect when all the details are correct.

I would like to take this opportunity to thank Stefan Schuppisser, Rico Kaufmann, Jakob Studhalter, Urs Tappolet, and Stefan Rusch for their help and encouragement; all four are engineers, designers, and planners specialised in timber, who helped me considerably with texts, layout, and drawings. For proofreading of the manuscripts and for advice concerning technical matters I would like to thank the timber specialists Christoph Fuhrmann, Bernhard Furrer, Hanspeter Kolb, Klaus Richter, and Reinhard Wiederkehr, the building physics and acoustics specialists Markus Zumoberhaus, Karl Menti, Georg Stupp, Heinz Weber, and Beat Kühn plus the experts from DGfH and Lignum. The patient, meticulous team from the Birkhäuser publishing house was always on hand throughout the work. I am also grateful to the advisory committee for its constructive criticism and support, Ueli Rhiner for the design of the book, and Charles von Büren for his help in all matters related to publishing. And it is only thanks to "holz 21", the Swiss Federal Office for the Environment FOEN, and funds to promote forest and timber research that this book could be produced at all. Further valuable assistance was provided by Lignum (the umbrella organisation for the Swiss forestry and timber industries), DGfH (German Society of Wood Research), and a number of supplier companies to the timber industry.

Uttwil, Switzerland, January 2007 Josef Kolb

The German edition of this book appeared for the first time only a year ago, but a second edition has already become necessary. It would seem that the book closes a gap in the specialist literature on timber building systems. Since the publication of the first edition, many readers, including those on the practical side of the building industry, have spontaneously told me that this book meets the needs of the modern construction industry, indeed, in some respects is ahead of its time. And this is especially the case where the system model gives rise to optimised loadbearing structures and system solutions, highly effective in terms of energy issues, for building envelopes and separating components in contemporary construction concepts.

At the same time this updated second edition also forms the basis for the editions in other languages currently in preparation. The interested reader will find more information on products and manufacturers at www.timbersystems.info.

Uttwil, Switzerland, January 2008 Josef Kolb

a

Principles

Material-related

b

Construction systems

Loadbearing structure, building structure, design

C

Building envelope, walls, suspended floors

Functions, layers, construction

d

Boundary conditions

Moisture content, protecting timber, fire protection

e

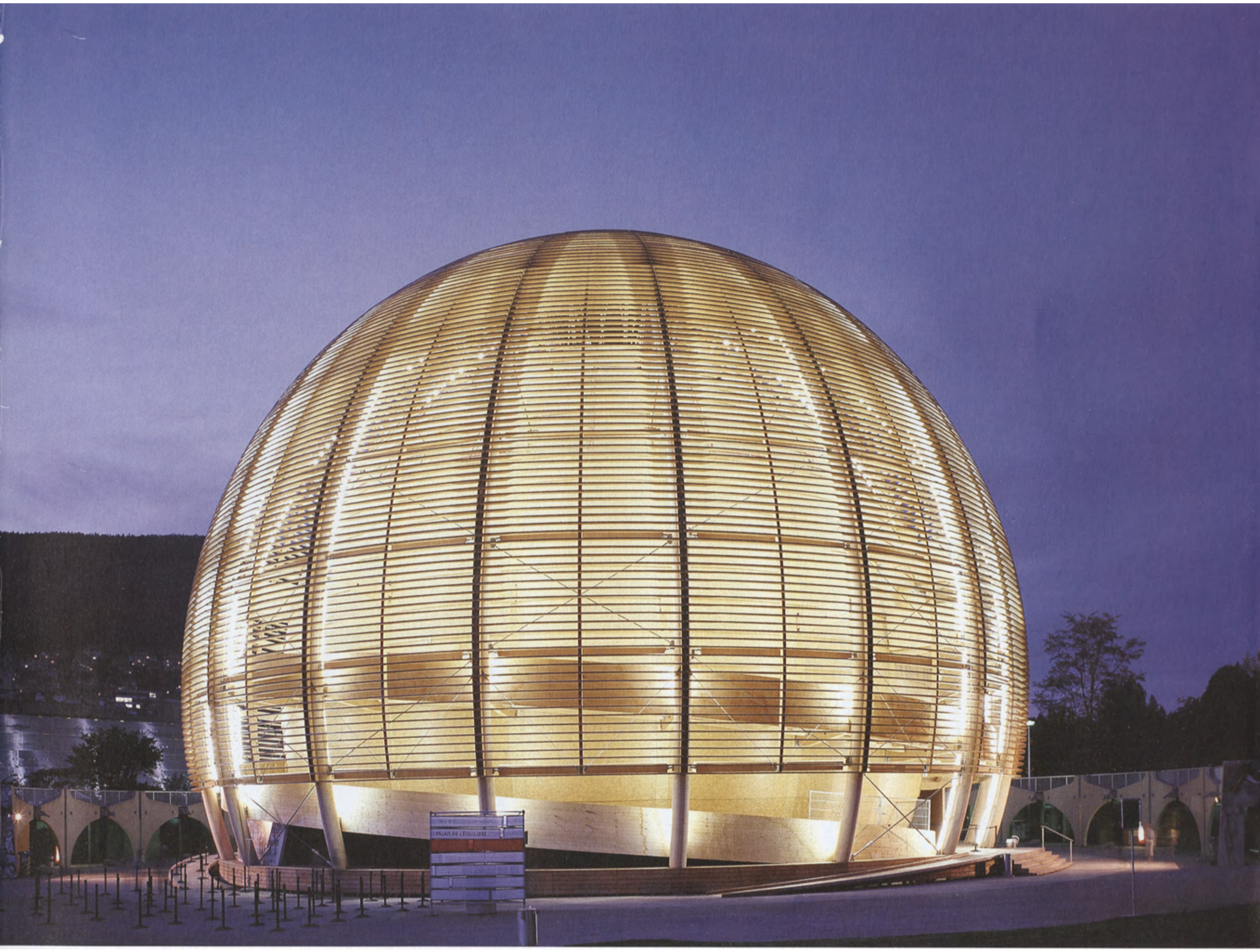
Appendix

Disclaimer, notes, references

a

Principles

Material-related



a1 Wood – natural building material with potential

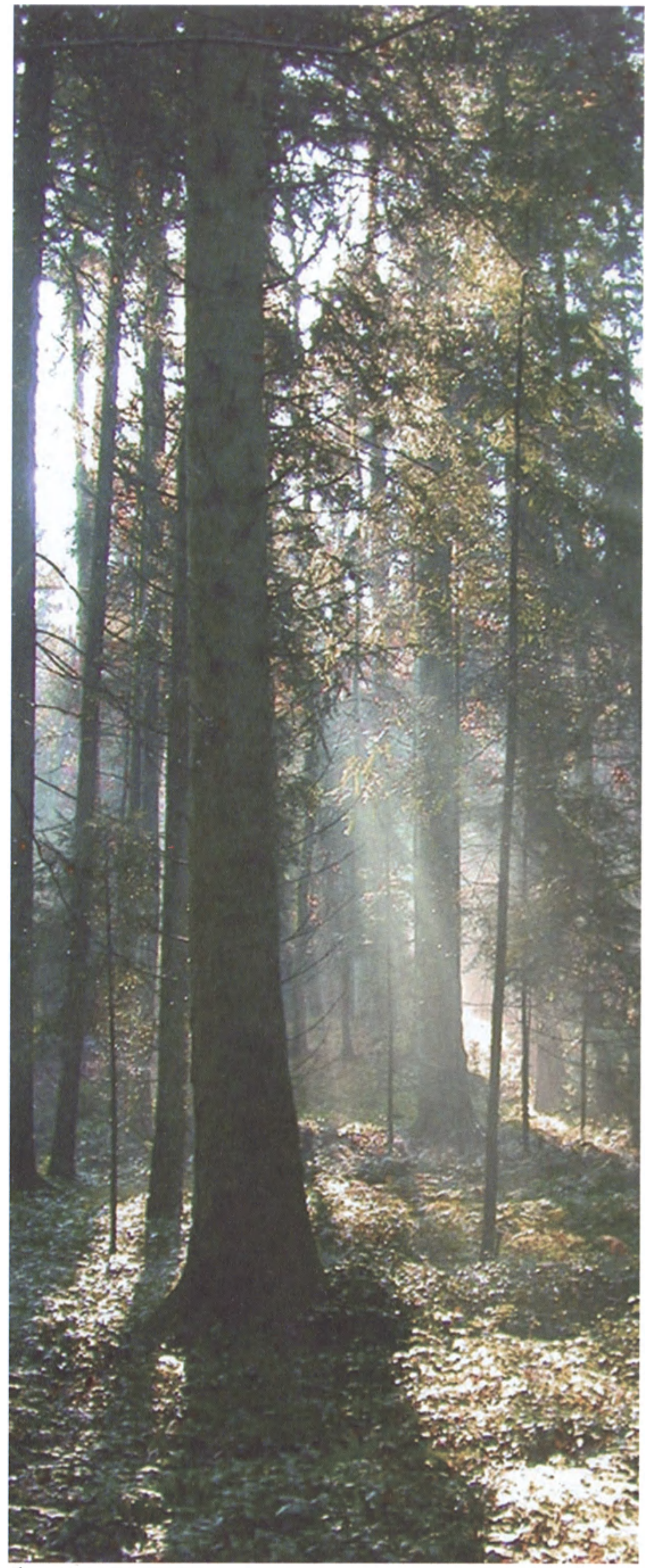
Building with timber means planning, designing and building with a material supplied by nature, a material that is constantly being replenished. The impressiveness of a tree, with its long, overhanging branches, and the grandeur of its growth upwards over the years, is matched by the efficiency of the timber it gives us. The fascination of the forest and the respect its trees command, are transferred to the material wood.

Children enjoy wood. They play with wooden building bricks, sense the warmth, smell the naturalness, feel its texture and see the pleasant colours. Studies have shown that children value wood more than any other building material. It is virtually impossible to tell which criteria really trigger such sympathies. Is it the appearance, the smell, the textures? Is it the surface temperature, or is it the characteristic of being able to adapt its moisture content? Certainly all these factors together give wood its unique character and its aura.

Architects, builders, tradesmen and their employers, clients and developers have also been building with wood for thousands of years, using, shaping and changing this natural building material again and again. Almost anything can be built with wood: from furniture to ships, from mills to houses. It opens up immeasurable freedoms for design and construction and even helps unusual ideas become reality. It is no surprise that new forms of building are derived from wood. Wood sets trends.

a1 10 Progress rooted in tradition

Building and building technology are based on tradition and experience, and depend on different conditions. Forms and methods of construction are determined by habits, climate, and cultural characteristics; primarily, however, on the availability of building materials, tools and the state of the building art. Until not very long ago, builders used materials available locally virtually without exception. What the possibilities of modern transport have now made commonplace, i.e. the worldwide availability of almost all building materials, was either unthinkable, impossible, or an expensive exception 100 years ago.



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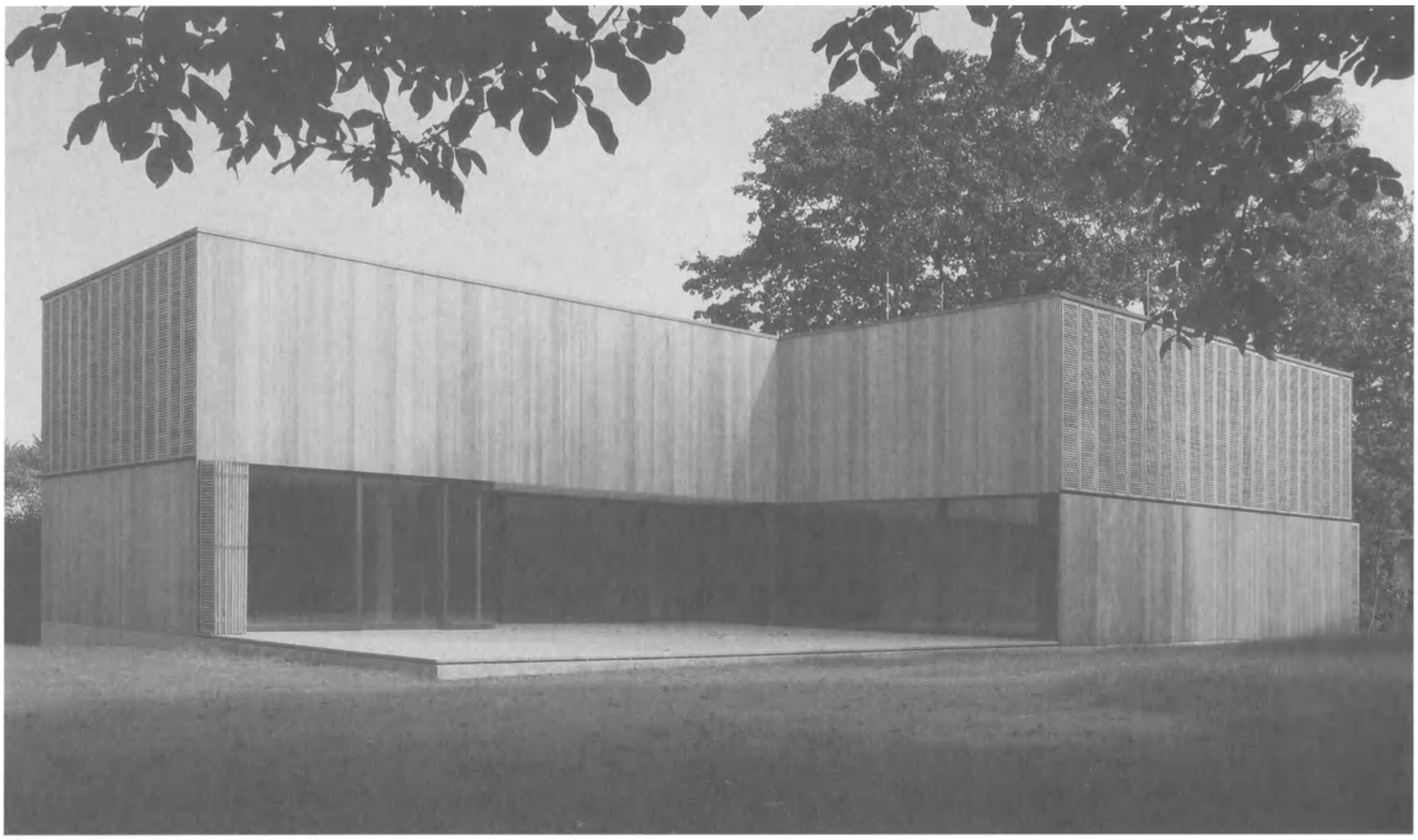
Overleaf: Palais de l'Equilibre at the Swiss National Exhibition, Expo 02

a1 The natural vigour of forests and trees makes them fascinating.



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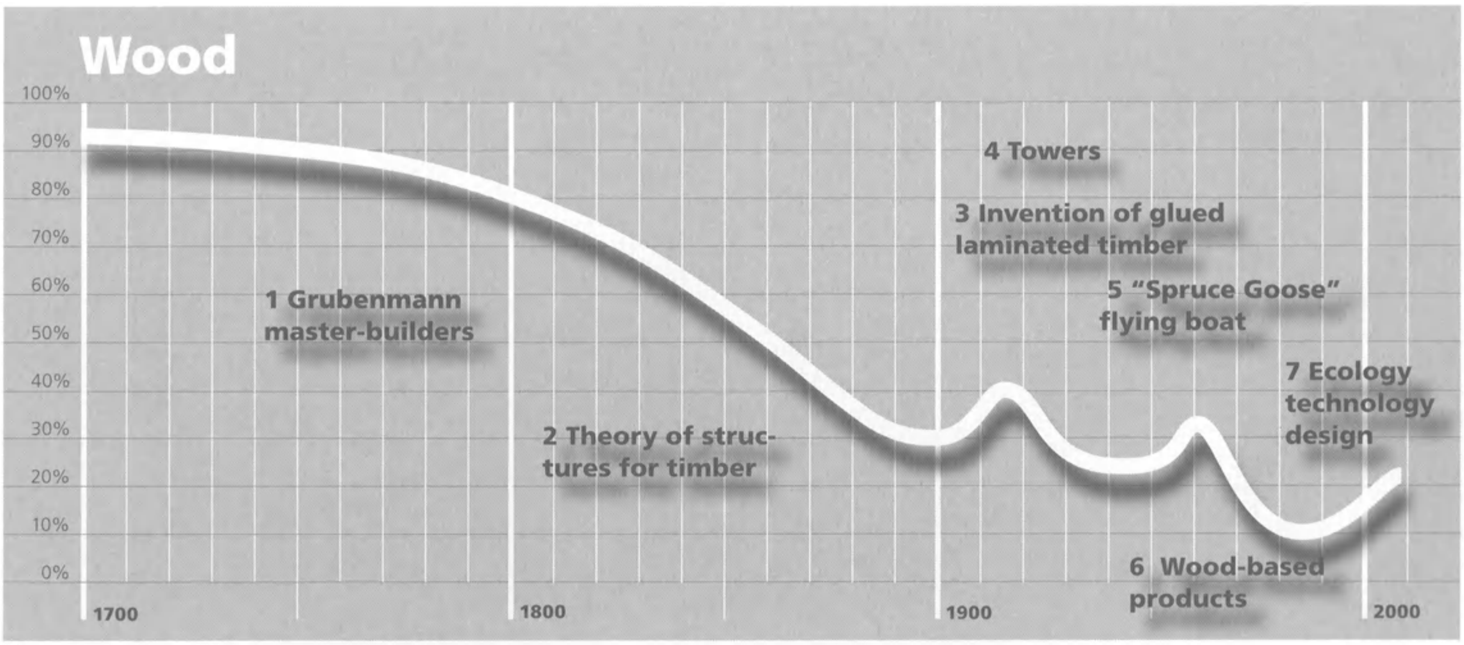
Traditional, rural forms of construction or unadorned utility buildings for commercial purposes bear witness to these facts even today. For example, in mountainous regions the use of stone was the obvious choice, but in forested regions it was wood, on the treeless plains loam, and in tropical rainforests the quick-growing, lightweight trunks, branches and plants suitable for lattice-work. In the warmer countries around the Mediterranean, building with stone generally prevailed, whereas in heavily forested Central and Northern Europe building with wood was the norm. In the 19th century, industrialisation had a powerful influence on building which is still felt today. It led to new methods of processing and building (iron, steel, concrete, plastics) whose introduction was further promoted through research, development, and theory. The cost-effective transport of new materials over long distances became possible. All these factors together virtually supplanted conventional building techniques. During the same period, towns and cities experienced swift population growth. This was accompanied by a rapid development in the mechanisation of workplaces and households, with new and higher demands placed on domestic hygiene, convenience, and comfort.

In the 20th century, wood was especially in demand during the crisis years of the late 1920s and early 1930s as well as during the two World Wars of 1914–18 and 1939–45. A scarcity of resources made the use of indigenous and readily available raw materials the obvious choice for construction. And now, at the beginning

a2 Wood allows design freedoms and therefore enables pioneering architecture; private house in Stuttgart, Germany

a1 Wood – natural building material with potential



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of the 21st century, wood has become the building material that has certainly undergone the most effective developments for construction practice. Following the spate of consumption which started in the 1950s and continued until the 1980s, a search for more essential things began. A slowing of economic development lead to cutbacks in architecture and construction, and often to minimalist solutions. At the same time, technical demands grew noticeably. Energy-saving and environmentally compatible forms of building nevertheless had to satisfy the high demands of building users and occupants. Minimal solutions for maximum demands were and still are needed. These are the principles that characterise current building with timber and they will lead to new horizons.

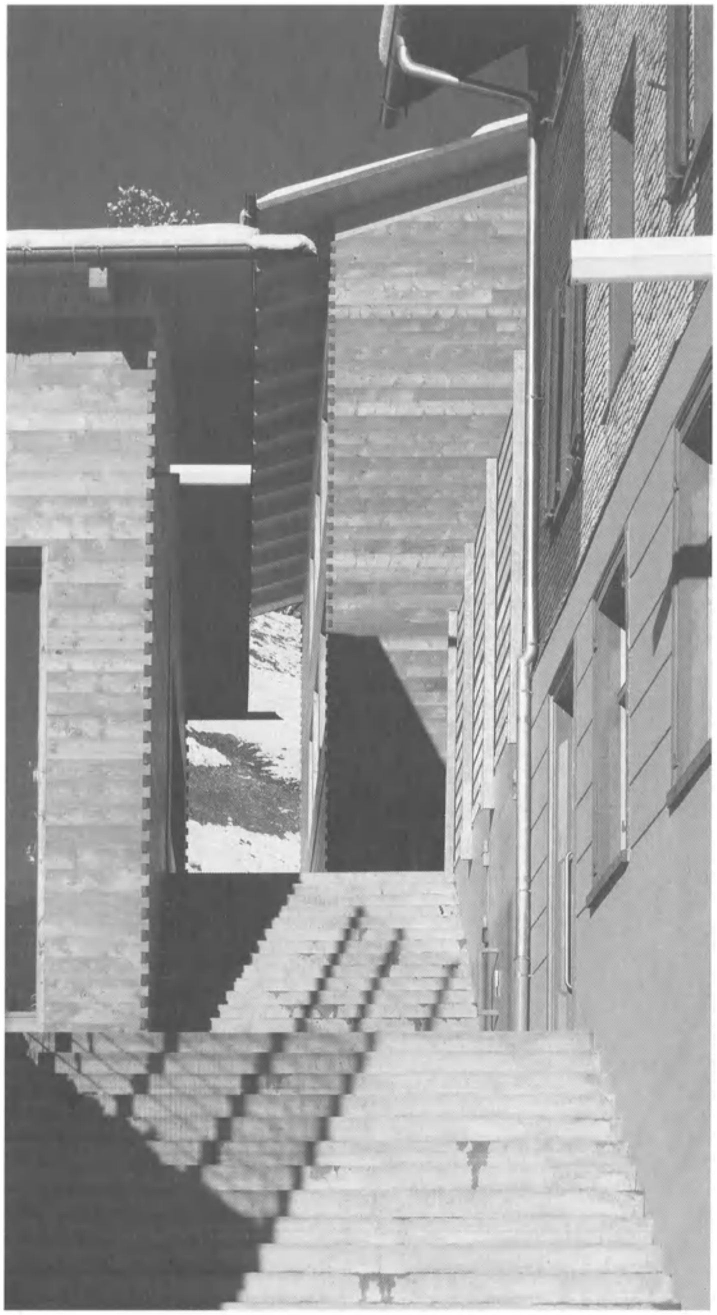
Contemporary timber construction

Today's timber engineering has nothing whatsoever to do with historical forms of construction, with the log cabin, or low-cost buildings for less prosperous social groups. Neither is it restricted to residential or industrial buildings. What is new is that thanks to complex technical developments and forms of construction, and also a better understanding of individualistic, contemporary architecture, timber structures are successful. Building with timber has made the transition from a purely manual trade to rational manufacturing processes in factories, to efficient industrialisation with the help of semi-finished goods, and to precise and rapid erection on the building site. The traditional carpentry shop has become a business with computer-assisted design processes and robot-controlled precision tools. Individual parts formerly fashioned by hand have become building components which meet previously defined standards of accuracy and quality, and which on the building site can be quickly and precisely connected together to form a whole.

The architect's contribution to this should not be underestimated. Leading advocates of the new timber building culture have encouraged an uninhibited relationship with this natural building material. For them, timber engineering has become a matter of course, and they exploit it successfully for buildings that meet today's requirements. In concrete terms this means that such architects allow themselves to be drawn into a conflict with the conventions of the art of building, but implement these with the opportunities

a3 The use of wood and the development of timber engineering after 1700 [1, 2]

1 Long-span bridges and structures in timber, built by the Grubenmann family
2 Timber loadbearing structures are included in theory of structures
3 From 1906: developments in and patents for glued timber (Hetzer construction, today's glued laminated timber)
4 Example: timber radio tower, Erdinger Moor, Upper Bavaria, Germany, 1932–83, 150 m high
5 "Spruce Goose", a huge flying boat made of wood with a wingspan of 97.5 m, a record to this day
6 Use of diverse wood-based products in board form
7 Around 2000: general influences from ecology, technology and design lead to a wider use of timber following a drop in the second half of the 20th century.



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of the modern world. A new understanding of building and a new timber building culture thus unites the construction with a form of design whose aim is simple but efficient solutions, and helps modern building with timber to reach new dimensions.

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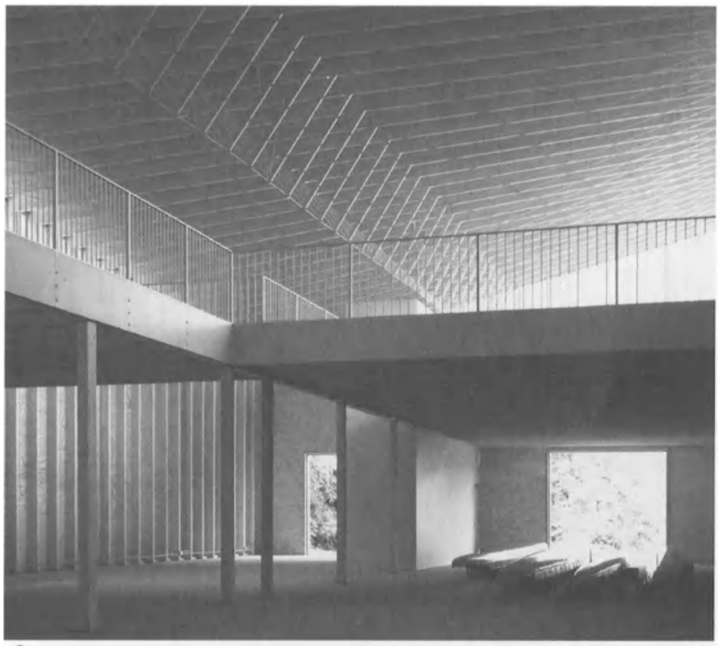
a1 20 Timber engineering

The effects of the campaigns to promote timber and building with timber carried out during the 1980s and 1990s are now being felt. Networked research and development work on a broad front has led to striking progress. New materials based on wood, modern fasteners, rational processing techniques, and efficient lifting and transport equipment have rendered possible new forms of timber engineering. Thanks to the education programme for promoting timber in numerous European countries and to reliable aids in the form of information, planning, and calculation principles for designers and users, the quality of timber structures has risen noticeably. In addition, coordinated activities in the timber industry with respect to the development of timber structures with better fire protection led to a changed attitude in the issuing of new fire protection regulations. Just ten years ago, larger timber structures were the exception; today, there is a constant growth in multi-storey and large-volume buildings made from timber, even in heavily built-up, urban locations. And timber has been used successfully in housing for a number of decades; indeed, in the low-energy

a4 Contemporary log construction; school building and multipurpose centre in St. Peter, Switzerland

a5 Modern facade design; university hospital in Tübingen, Germany

a1 Wood – natural building material with potential



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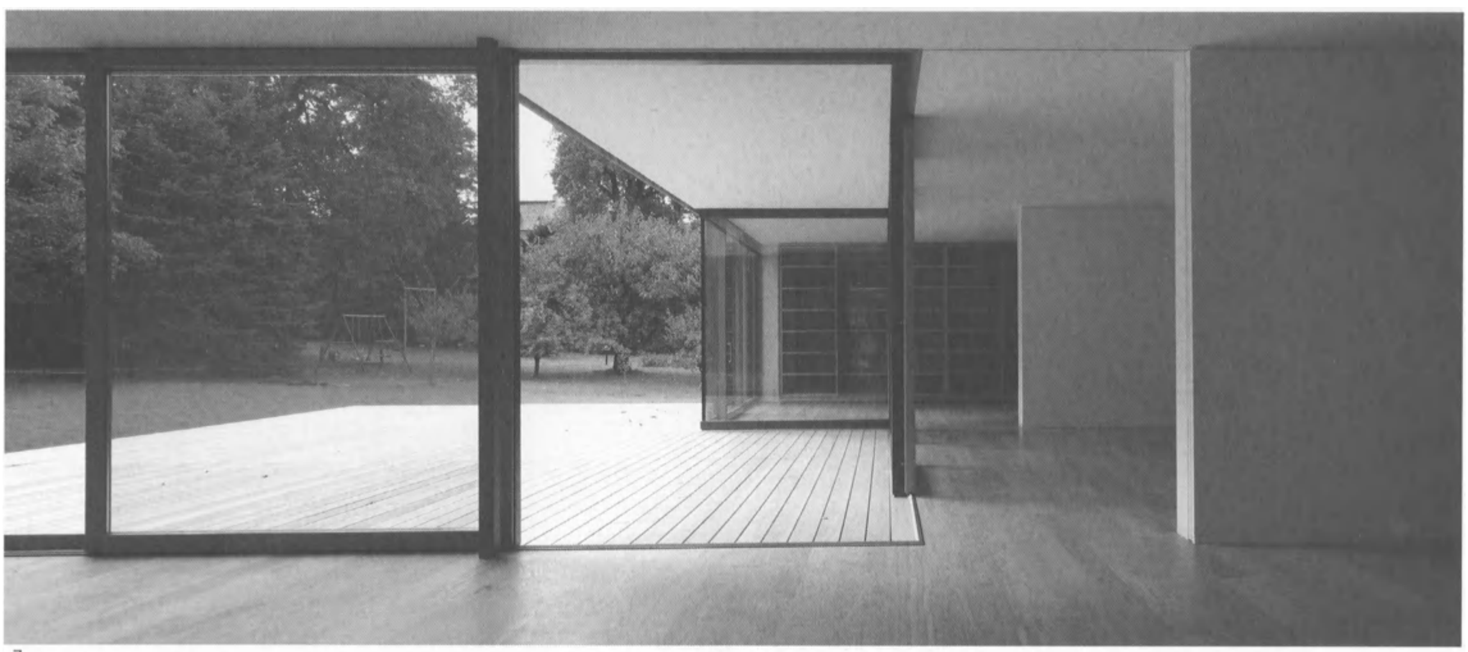

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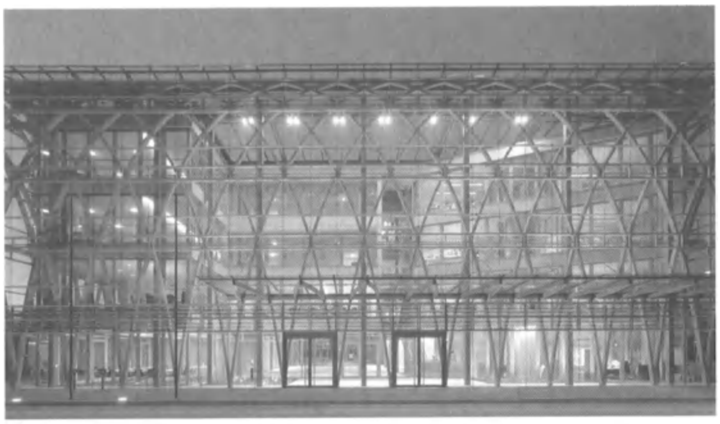
a6 Structural design with timber; boathouse in Minneapolis, USA

a7 Seamless transitions from inside to outside; private house in Stuttgart, Germany

a8 Research and development for new forms of timber construction and load-bearing behaviour, Swiss Federal Institute of Technology, Zurich, Switzerland [3]



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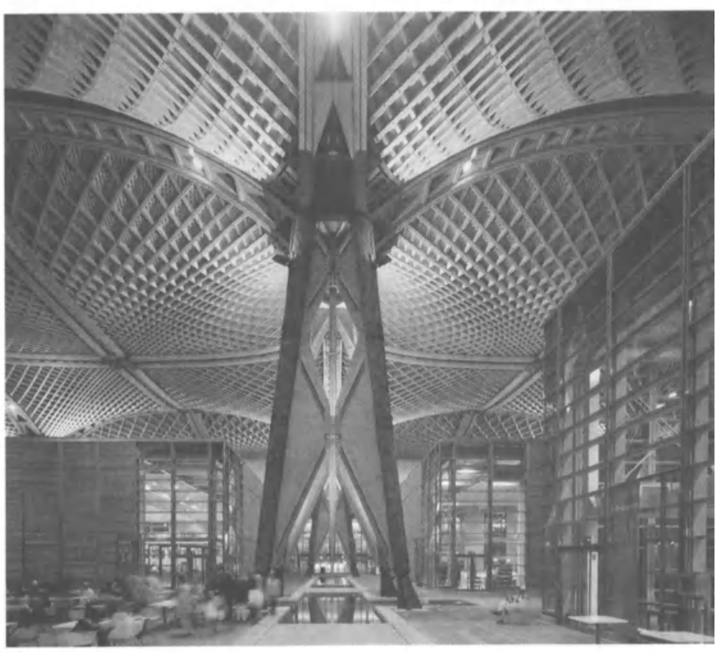

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and passive-energy house sector, timber points the way forward. Modern residential buildings are technically advanced and certainly correspond to the living standards we expect in the future. Technical developments in timber engineering have also become established in multi-storey buildings. Office and apartment blocks and schools constructed in timber have become serious alternatives to the materials that prevailed in the past; numerous completed projects bear witness to this. Four- to six-storey buildings can be built according to standardised specifications and concepts (according to a defined protection of persons and property value) in a rational timber construction method. Besides the fireprotection requirements, multi-storey buildings also have to consider technical aspects such as loadbearing behaviour, building physics and protection from the weather. The following sections contain extensive information on all these aspects.

a1 30 Facade

The arrangement, form and size, and the design of a facade, are responsible for the architectural impression of a building. The facade is the "face" of the building, and its design knows virtually no boundaries. In the past it was often thought necessary to achieve a relationship between the loadbearing structure and the enclosing facade – a timber structure should also appear as such to the outside world. This approach is now outdated. Timber structures are now also clad in other materials. And vice versa: a building of clay bricks or concrete can be given a timber facade. Combinations of steel or reinforced concrete loadbearing frames with walls of highly insulated timber elements are becoming more and more popular. It still holds true that intelligent construction and the choice of materials adds up to an architecturally pleasing design. The materials used should be those that best meet the fundamental requirements – for the loadbearing structure, the enclosing elements, and also for the building envelope. To a large extent, the facade can be considered independently from the loadbearing construction. Therefore, loadbearing structure and building structure (part b) are treated separately from the layers of the building envelope and the internal components (part c). In this way it is possible to achieve an ideal synthesis between loadbearing structure and envelope. This eases the task of achieving an optimum

a9 to a11 Structural timber, new forms of loadbearing technology and expression

a9 Delicate, curving loadbearing structure, clad with glass; federal state representation offices in Berlin, Germany

a10 Large-scale timber engineering for a school building in Mirecourt, France

a11 Roof of impressive size and architecture, built for Expo 2000 in Hannover, Germany

a1 Wood – natural building material with potential


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loadbearing structure and enclosing this in an optimum envelope (external walls and roof) in combination with the internal partitions and suspended floors. Wood has been characterising the external appearance of buildings for centuries, and old buildings illustrate the durability of wooden facades. In recent times, forms of timber cladding have again become popular with designers and clients. New forms of cladding, however, appear totally different when compared to the conventional types. Different species of wood, surface finishes and treatments, dimensions, and cross-sectional forms enable a huge variety of architectural concepts.


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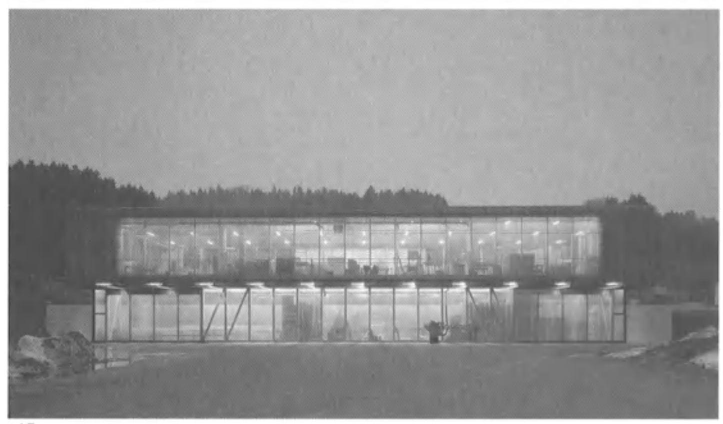
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a12 to a16 Timber facades

a12 Industrial building in Triengen, Switzerland
a13 Sheltered housing in Glarus, Switzerland
a14 Residential development in Arlesheim, Switzerland
a15 Production building in Böhen, Germany
a16 Office block in Sursee, Switzerland

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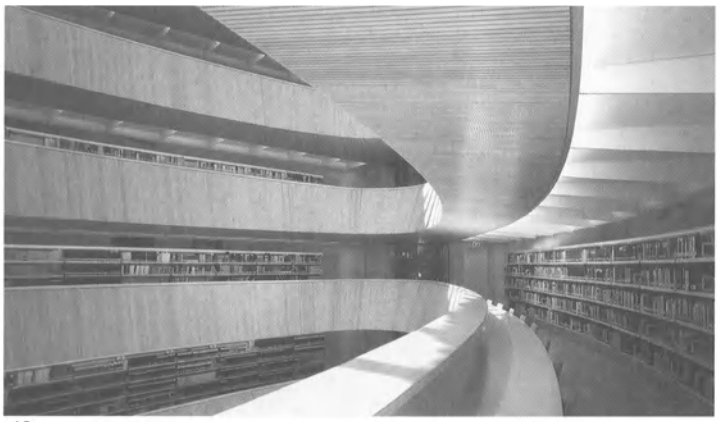

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a17 to a20 Timber for fitting out

a17 Interior design with plasterboard and wood-based board products
a18 Solid timber (maple) as cladding for low-level walls and curving linings

a19 Interior fittings made from wood-based products in combination with an exposed loadbearing structure

a20 Timber loadbearing structure and interior fittings for a swimming pool

a1 40 Fitting out

Alongside loadbearing structure and facade, fitting out should be considered as a third component. Fitting out is the critical aspect for the comfort of occupants and users.
Fashions and trends determine the fitting out of a building; from plain, almost sterile designs to bold colours and more rustic approaches, anything and everything is possible. Wood offers even more design freedoms in the interior fitting out than on the facade design because the technical requirements are different. Added to the species of wood feasible for external applications are those species ideally suited for interior uses. In addition, a number of wood-based products can be employed to achieve special effects and surfaces.

The various species of wood give architects, interior architects and joiners a unique range of colours, textures and forms. The basic principle is: every fitting out concept has its own character because no two pieces of wood are ever identical. Besides the aspects of design and use, the choice of a species of wood is closely related to ecological and ethical considerations. We know today that uncontrolled deforestation, particularly in the forests of the Southern Hemisphere, has devastating effects. There are certified tropical woods (e.g. PEFC, FSC) available on the market which are regarded as safe to use. But in the properly managed, sustainable forests of our regions, large stocks of different species of wood are replenished. It is therefore certainly not wrong to use regional species whenever possible.

a2 Ecology, sustainable building

a21

Wood is an efficient natural building material and has a series of positive effects within the eco system which play an ever greater role in conjunction with the foundation for all our lives: the Earth. It is generally known and accepted that a prudent use of the Earth's resources is essential if we are to guarantee a sustainable development for the future.

The term "sustainable development" has become a buzzword in recent years, with different definitions and interpretations. The origin of the principle of sustainability is to be found in Central European forest management. In Switzerland as long ago as 1870 there was a rule that the number of trees felled must be matched by the number replanted. This principle of using no more than the basic stock, your "capital", has proved worthwhile not only in the timber trade, and indeed has taken on a global significance today. Sustainable actions in building and the use of buildings means consuming only as many resources (materials, energy, water, air, living space, etc.) as nature can "reproduce". Builders who use timber are therefore already making an important contribution. And those who go one step further and design highly insulated building envelopes using ecologically compatible products, and optimise the production methods, forms of transport, and erection techniques, come very close to the goal of consuming only as many resources as nature can "reproduce".

The following sections outline the facts concerning the life cycle of wood in its product form and its positive influence on the ecology of the planet. Many publications and specialist books are available if the reader wishes to find out more (e.g. *Nachhaltig handeln* [4], or the brochures of "Informationsdienst Holz" [5, 6]).

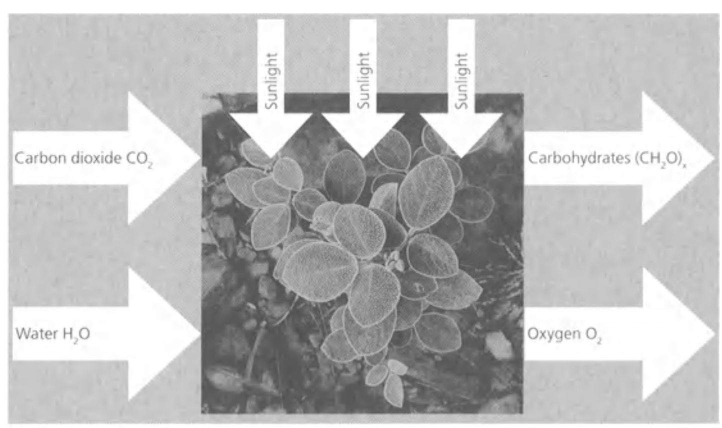
a2 10 Wood – a building material with ecological benefits

The word "ecology" is made up of the Greek words *oikos* (= house, household) and *logos* (= a subject of study or interest, a branch of knowledge); so it means the "study of the household". Ecology is a subdiscipline of biology and denotes the science of the interactions between organisms plus the interactions between organisms and their inanimate surroundings.

As already mentioned, wood is regarded as an ecologically advantageous building material. If we look more closely at its growth, astounding findings come to light. The photosynthesis process produces carbohydrates and the oxygen (O_2) crucial to human life from water, carbon dioxide (CO_2) and sunlight. So growing wood extracts carbon dioxide via the photosynthesis of the tree and this is stored in the felled timber. Carbon dioxide is the main contributor to the greenhouse effect. The use of timber therefore extracts the corresponding quantity of carbon dioxide from the atmosphere for the lifetime of the products (Fig. a22). Long-lasting timber products are consequently especially effective. In addition to this, the combustion of wood is neutral in terms of carbon dioxide and the heat generated spares the use of fossil fuels. For example, the calorific value of one cubic metre of dry beech wood corresponds to about 300 litres of heating oil.

a2 20 The wood life cycle and processing chain

Thinking in life cycles is the prerequisite for sustainable development. Every product passes through its own life cycle. The wood life cycle passes through all the stations of growth, acquiring the raw material, processing and use, to reuse. As a polyvalent, renewable raw material rich in tradition, wood is perfect for helping to understand sustainable development in everyday situations and ideal as a model for future building.



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a21 The principle of living off the interest originated in forest management.

a22 Photosynthesis: carbohydrates and oxygen generated from water, carbon dioxide and sunlight.

	Area of forests as percentage of area of country	Area of forests as ha/head of population	Timber reserves in forests in m³/ha	Annual increase in timber in m³/ha	Annual consumption of timber in m³/ha (as percentage of annual increase)	Annual consumption of timber in m³/head (2001)
Germany	30 %	0.13	271	5.9	4.4 (= 75 %)	0.23
Austria	47 %	0.50	286	6.6	5.2 (= 79 %)	0.62
France	24 %	0.25	140	5.3	3.9 (= 74 %)	0.18
Italy	22 %	0.15	169	4.1	1.8 (= 44 %)	0.10
Switzerland	31 %	0.18	354	9.2	5.1 (= 55 %)	0.21

a23

a2 21 The forest – acquiring the raw material

The forest is the starting point of the wood life cycle. Besides producing the wood, it performs countless functions important for our society and its sustainable development. The use of wood and forest management influence both the quality of our forests and landscapes, and the quality of the wood as a raw material.

The forest can be seen as our "capital" in the wood life cycle, also earning us interest if we handle it properly. In Switzerland and Germany about 31%, and in Austria about 47% of the land is covered with coniferous or deciduous forests. The increase in wood in, for example, Switzerland is 8 to 10 million cubic metres annually. Or expressed in another way: 0.30 cubic metres of wood grows every second, which means that every four to six minutes we obtain enough wood to build a timber house! However, Swiss forests are required to supply only about 5 million cubic metres every year, i.e. about half of the amount theoretically feasible.

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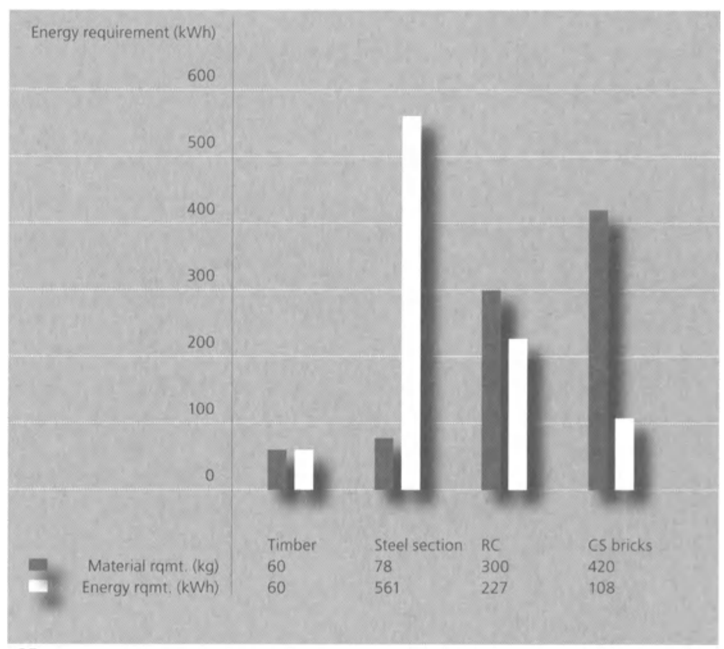

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a23 Forest and timber utilisation in comparison, Central European countries; Austria uses its forest "capital" best of all [7, 8].

a24 All of a felled tree can be used to provide valuable materials – from pith to bark

a25 A comparison of the energy requirements for producing a 3 m high column carrying the same load

a2 Ecology, sustainable building

a2 22 Timber – processing the raw material

Felling the trees and processing the timber are the next steps in the wood life cycle. Short transport routes and regional processing plants are critical in this part of the life cycle. The processing and machining of timber is the foundation of the woodworking industry. The work presumes knowledge and experience, but can be carried out with the simplest means or the very latest industrial equipment. Every part of a felled tree can be used. Besides sections, boards and veneers, wood-based products, pulp, plastics, tanning agents, dyes, and other products can be produced. And at the end of its life wood is also useful as a source of energy. The raw material exhibits not only unique static properties, but is also characterised by its good tensile and compressive strength parallel to the grain plus good acoustic and thermal properties.

a2 23 Buildings and components – production

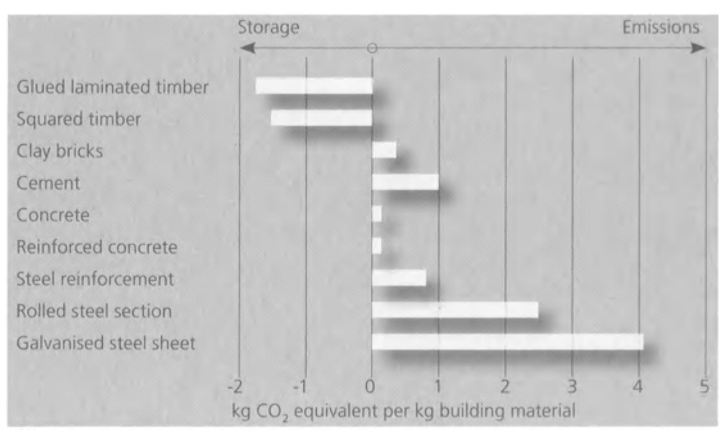
Building and designing with timber means converting a natural raw material into a useful and beautiful product. Technological innovations and modern materials enable the realisation of sophisticated designs and components. A new architectural appearance is the outcome. There are many things that favour the building of timber structures at the beginning of the 21st century. The most important arguments are: this CO_2-neutral raw material is available in great quantities, particularly here in Central Europe; wood is a natural product and at the same time a moisture-regulating, warm, healthy, and reusable material; the processing of the raw material has an impact on the environment that is much lower than that of concrete, clay bricks, or steel; a timber structure requires no polluting additives; and building makes use exclusively of ecologically valuable dry construction methods.

a2 24 Use – consumption

To have a place to live and a place to work are fundamental human needs. How good a building can satisfy the needs of its users depends on its architectural and constructional quality together with its furnishings and fittings. The interior quality benefits from the use of natural materials like wood and components whose building physics properties have been properly studied. The many textures, colours and odours, the moisture-exchange ability, and the warm-to-the-touch surface of wood on the whole create an agreeable, healthy interior climate.


a26

Further, well-insulated building envelopes, which consist mostly of timber elements, ensure a good standard of comfort. On the one hand, highly insulated walls and roofs prevent a temperature drop on the inner surfaces compared to the room temperature and, on the other hand, well-insulated buildings (low-, passive-, or zero-energy) can be built in an energy saving manner. Savings are possible throughout the lifetime of the building – and the life of a building is on average 60 to 100 years (see Figs. a29 and a30).
And in the end, in addition to the advantages listed above, the ecologically valuable building material wood offers the user non-hazardous living and working environments – all in all agreeable interior conditions for both humans and animals alike.



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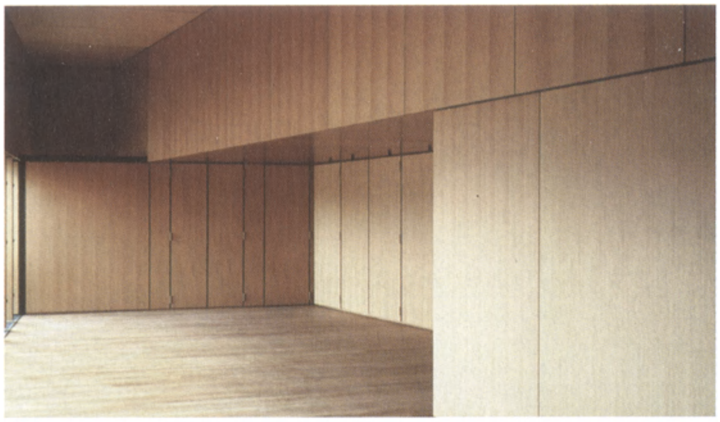
a26 The Palais de l'Equilibre at the Swiss National Exhibition, Expo 02, is an impressive symbol of sustainability. After its first use (exhibition), the accessible, 28 m high and 41 m wide timber construction was dismantled and re-erected in Geneva at CERN (European Organisation for Nuclear Research) for a new purpose.

a27 A comparison of carbon dioxide emissions during the production of various building materials. As it grows, wood stores carbon dioxide. All other materials emit carbon dioxide into the atmosphere [9].

a28 The quality of the interior is influenced by the architectural and constructional qualities and by the use of natural materials such as wood.



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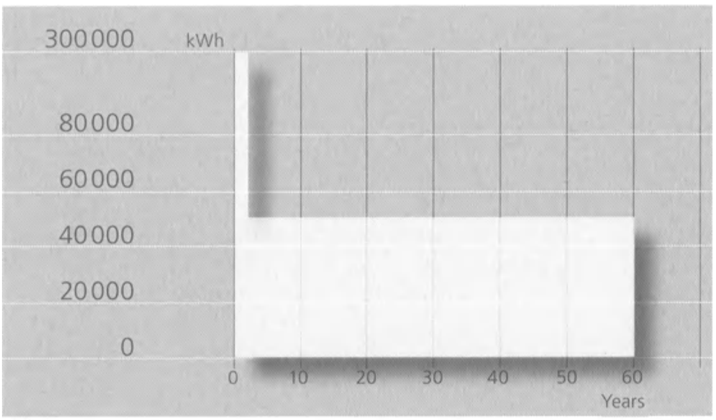

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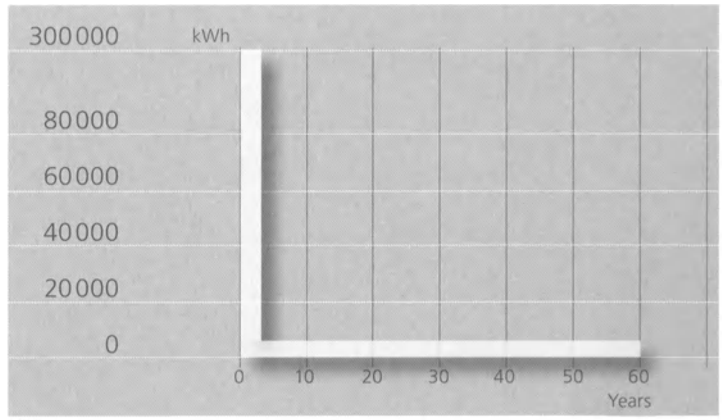

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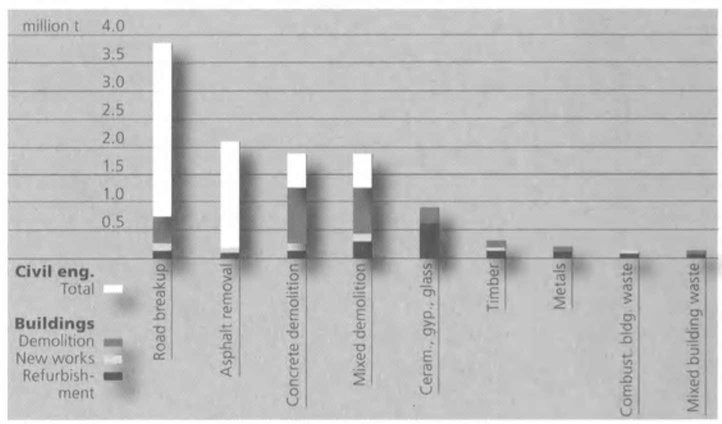
a2 25 Reuse – recovery

At the end of its life cycle, every product should be recycled. Timber building components can be recycled for their materials. This form of cascade use should be continued as long as possible. Once it is no longer reasonable to recover the materials, it is still possible to use the timber components for energy production. Yes, they do release carbon dioxide during this process, but this is absorbed again by the growing forest; the carbon life cycle is therefore complete. Timber waste containing incompatible substances must be disposed of properly in incineration plants. However, untreated timber can be burned without causing any problems, and the ashes can be disposed of with normal domestic refuse.



a31

a29 and a30 Improved building insulation can reduce the consumption of heating energy substantially. The total energy consumption (production energy + consumption over 60 years) is reduced to about 15%.

a29 Total energy requirement (typical values) for a poorly insulated building:
- usable floor area: 150 m²
- production energy required: 300 000 kWh
- annual heating energy requirement: 50 000 kWh
- total energy requirement over 60 years: 3 300 000 kWh

a30 Total energy requirement (typical values) for a well-insulated building:
- usable floor area: 150 m²
- production energy required: 300 000 kWh
- annual heating energy requirement: 6300 kWh
- total energy requirement over 60 years: 678 000 kWh

a31 Building waste in Switzerland [10]

a3 Conception and design

The configurations of timber structures are predestined for system concepts. Conventional systems have been expanded upon in recent years and new systems have been introduced. Whereas just a few years ago it was sufficient to distinguish between the traditional systems of log, timber-frame, and timber-stud construction and to be familiar with the newer systems of platform-frame and frame construction, our system thinking must now be extended. Besides the systems for the loadbearing structure, there are also systems for the building envelope, which through system solutions have become a self-contained functional medium, and for suspended floors or internal partitions as well.

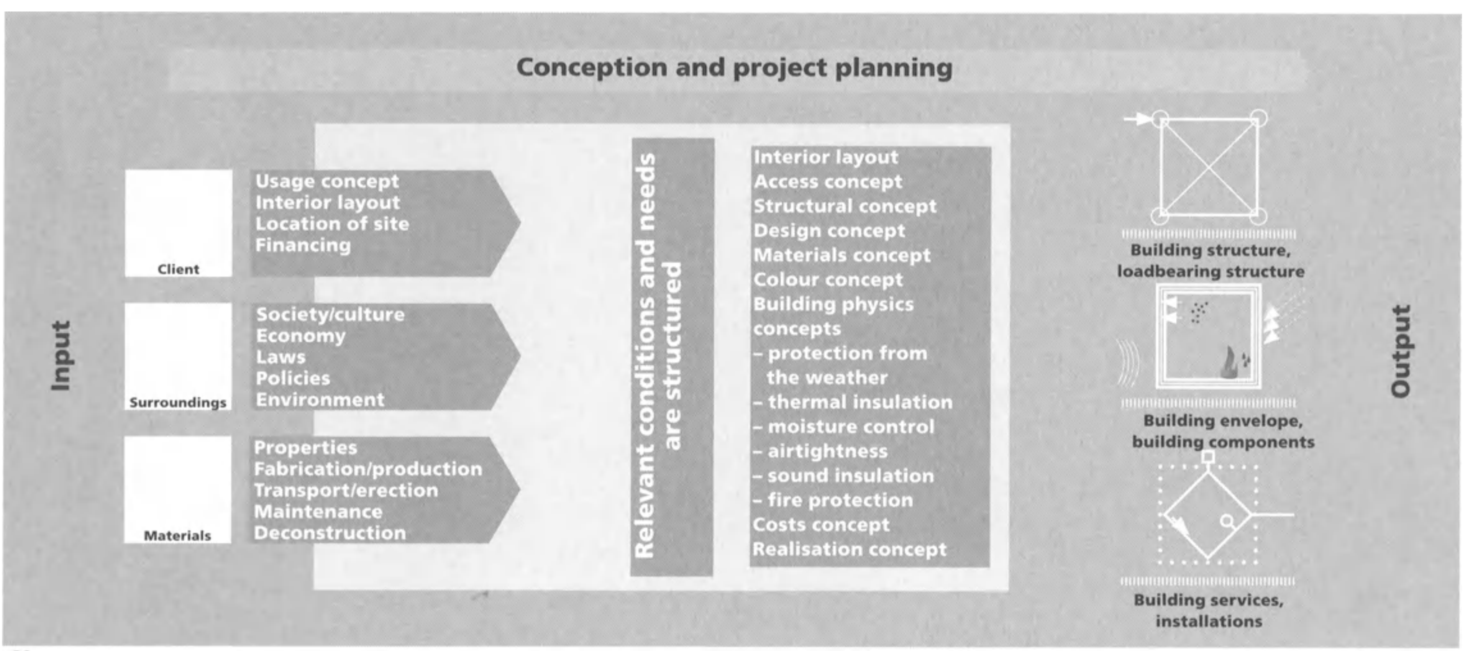
For architects, engineers and technical designers, it is crucial to link these various individual systems to a project-related, tailored overall concept. It is the intention of this book to simplify this conceptual and planning work. The individual systems are therefore illustrated in such a way that the system concept is visible in both the individual components and the overall system of a structure. In this way timber engineering becomes an architectural and constructional task that goes far beyond the correct design of details. Instead, the right detail must ensue from the constructional system, which is part of the overall concept of a structure.

a3 10 The design process

Draft design

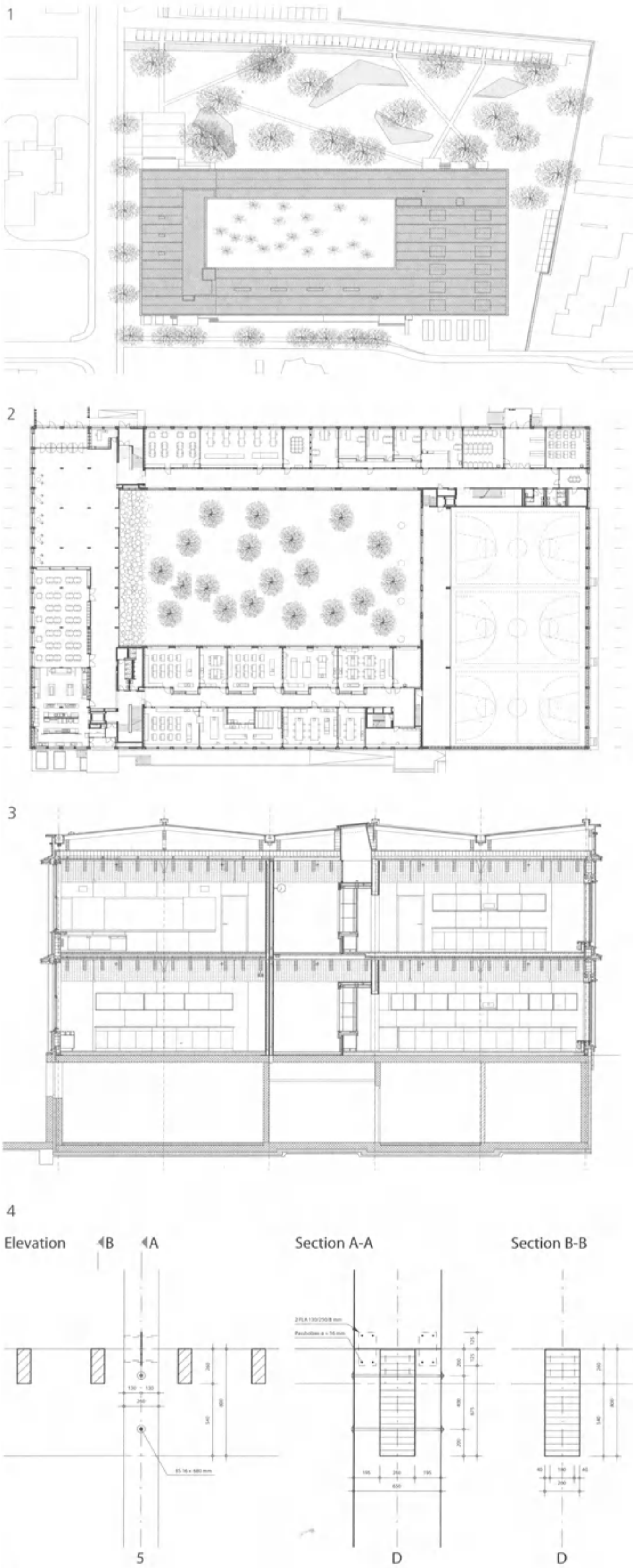
Building is – whether using timber or other building materials – a complex undertaking which does not call for knowledge about individual fields, but rather the recognition of relationships in one field of changing relationships between various requirements. Concepts that take this into account must be available right from the draft design phase.

This applies to the project as a whole, to the situation and location, function and space, construction and materials. If the concepts fit into the draft design, the later project phases and also the building phases will be simplified. Fig. a32 illustrates the interactions between the timber building system selected, the configuration of building structures and loadbearing structures (including the



a32

a32 Information, conditions and interdependencies that influence the constructional concept



a33

a33 Relationship between conception and design using the example of a school complex:

1 Site plan: location
2 Plan of ground floor: spaces, functions, building structure
3 Section: loadbearing structure
4 Details: loadbearing structure

Finished structure, overall view and facade: Figs. a34 to a36

building envelope, building components and building services) and the form. The choice of building structures and loadbearing structures (together with the building envelope and design of building components) is in turn determined by system information (questions of materials and technology, production, transport, erection, ecology and building physics). These have different parameters depending on the timber building system.

The draft design takes into account these considerations and forms the basis for a successful timber structure. The timber building system must be selected at this stage because, like the architectural measures, it will have an influence on the choice of loadbearing system. In addition, there are the issues of fire protection, thermal performance, sound insulation, timber protection, airtightness, durability, and maintenance, which likewise must be compatible with the system. It is therefore obvious that the architectural measures are not concerned solely with the appearance of the building.
Such processes in design and construction can be carried out in various ways and always allow room for individual architectural expression. Fig. a33 shows one possible approach using the example of a large timber structure. Right from the project stage, the architect maintained contact with the structural engineers and discussed the design and choice of the timber building system with them. Further development of the draft design with the help of additional specialists generated the overall plan. The early involvement of the structural engineers made clear the interfaces between conception and design in good time, which simplified planning and construction and also reduced the costs.

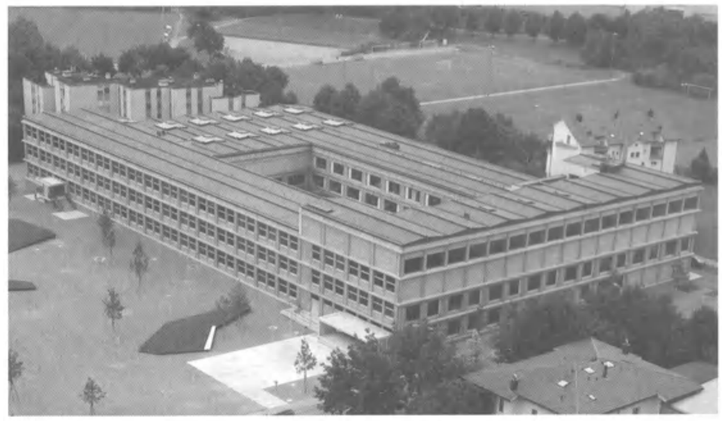
The example of Fig. a33 is just one of many possible solutions. In another formulation of the conception goals, the timber building could certainly have an abstract, cubic or two-dimensional appearance, and the outer leaf of the facade an even, homogeneous effect. Different colours or materials for the cladding can also leave their mark on timber structures internally and externally. But regardless of this, it is true that a good design helps the architecture. Both – conception and design – must be coordinated with each other from the very outset.

Detailed design

Detailed design means turning the conceptual ideas, the draft design, into clearly defined sizes, dimensions, layers and their arrangement, at the same time specifying junctions and details. In doing so, the interactive process between conception and design must always be taken into account, as mentioned above. The ideas often emerge out of the draft design, but the feasibility becomes apparent during the detailed design. During detailed design, the building work is given a clear configuration. Concerning the loadbearing structure the aim is to satisfy the requirements in terms of load-carrying capacity and serviceability. In the case of the walls, roofs and suspended floors, besides the structural engineering requirements, it is the building's physics and energy-related requirements that have to be coordinated with and optimised for the intended use.

Important conditions for simple interfaces between conception and design are a draft design coordinated with the timber building on plan (grid dimensions) and in section (storey heights) and from that the maintenance of system heights and component dimensions. Larger structural depths for suspended floors result in, for example, simpler and more economic constructions and at the same time offer space for services. Section b10 "Suspended floor structures" specifies typical system depths for the loads of residential and office buildings plus places of assembly. The grid dimension likewise influences the loadbearing system of a large timber building with respect to component dimensions and the number of joints.

Another conception and design rule is that component and functional layers should continue uninterrupted through the wall-ground floor and foundation, wall-wall, wall-suspended floor and wall-roof junctions. Contemporary conception and design therefore calls for coordinated concepts or systems for thermal performance, fire protection, sound insulation, moisture control, airtightness, etc. at the draft and detailed design stages. In addition, through the skilful conception of plan and section it is possible to meet ideal sound insulation and fire protection requirements right from the draft design stage. The detailed design phase allows the architectural, technical, economic, and ecological conditions to be refined and optimised. Also important are



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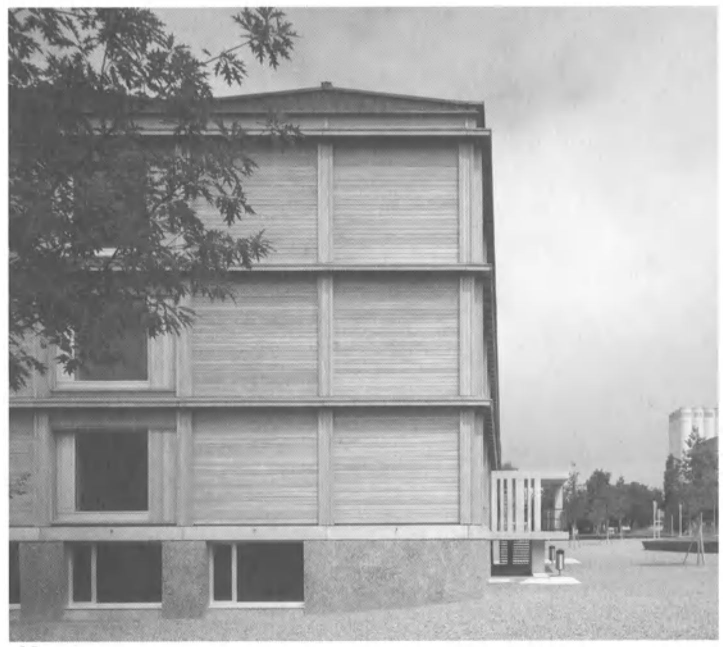

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a36

a34 to a36 Relationship between conception and design using the criteria of timber protection, durability and maintenance taking the school at Wil, Switzerland, as an example.
Whether and how a facade will weather is a key issue and must be answered at the conception stage.

a34 Overall view
a35 Partial view of facade
a36 Close-up of facade

Conception and planning: Fig. a33

the criteria of durability and maintenance. Good solutions can be achieved by choosing a suitable building form, well-thought-out designs and intelligent details. Added to this is the choice of species of wood and the surface finishes, possibly also precautions for chemical wood preservatives.

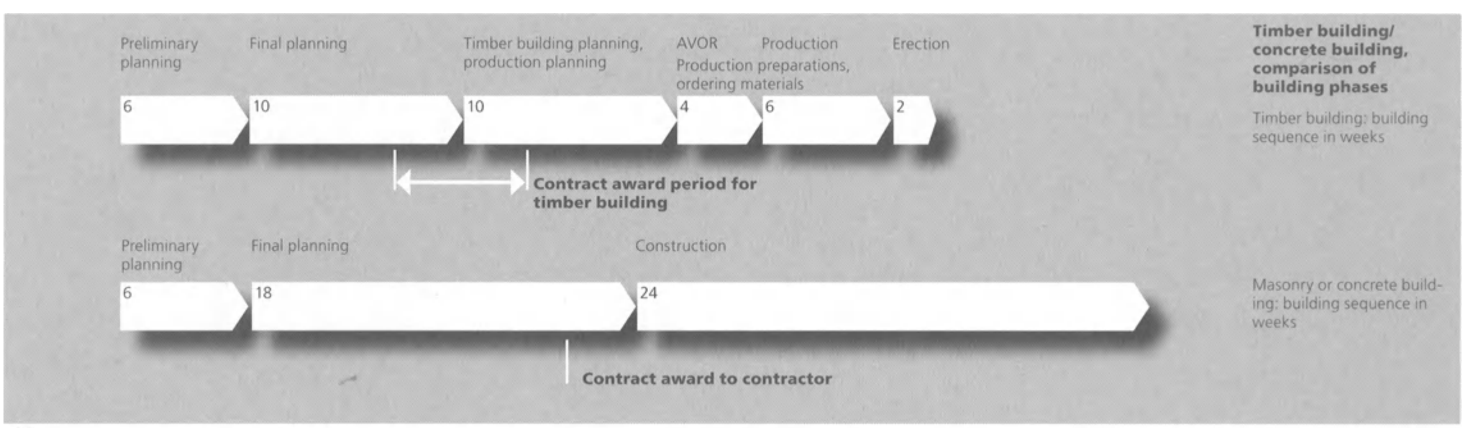
a3 20 Planning

Owing to the increasing industrial fabrication of timber structures, there has been a shift in the chronological order of the critical decision-making process of architects, engineers, specialists, and contractors. Things that in the past were first discussed on the building site, must now be specified well in advance of fabricating the walls, suspended floors, and roofs. Fig. a37 shows the planning, production and erection sequence (in weeks) for a medium-sized timber building in comparison with the conventional approach, which is frequently still the situation with masonry or concrete buildings.

Proper planning, including the full planning of work off and on the building site, is the prerequisite for a successful timber building and leads to a maximum amount of security for the client's investment. On the building site itself all that should be necessary is to join the components together. If implemented correctly, this procedure helps to save time and money.

Project and work planning

In project planning we distinguish between preliminary and final schemes. In work planning we distinguish between the planning of the architect, or the person responsible for the overall planning, and that of the structural engineer, plus the timber building and fabrication planning of the specialist designer or timber engineering company (Figs. a38 and a39). In timber engineering the structural engineering planning is often combined with the timber building and fabrication planning. This is undoubtedly advisable because this approach enables the competencies and responsibilities to be regulated clearly and simply and the interfaces minimised. For a timber structure, the timber building or fabrication planning – preferably carried out by a specialist timber engineer or designer – is very significant and in many cases can also be used when planning the building services or other components such as doors and windows. The working drawings prepared by the architect must include, in addition to the horizontal and vertical dimensions and details, the coordination of all components, related to the whole project. All the information relevant to the production of the timber components must be available on the timber building drawings. The contents of the drawings may well vary. A working drawing prepared by the architect could be limited to comprehensive dimensional coordination and the specification of the system schemes and concepts, but should be complete on the draft design level for building services, fire protection, sound insulation, thermal performance, airtightness, etc., and also with respect to the principal architectural details.



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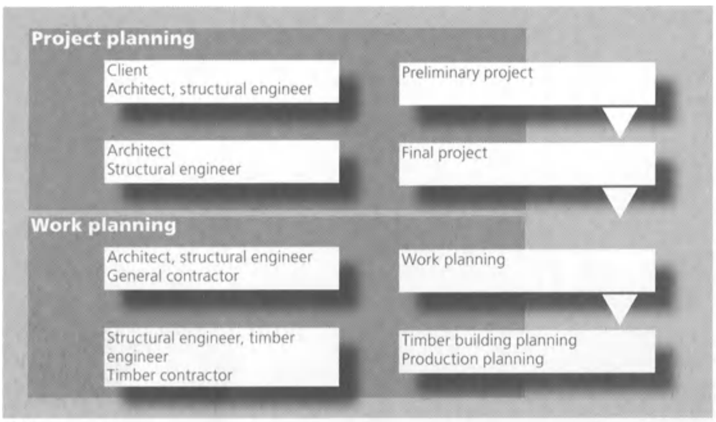
a37 Possible chronological order of planning, production and erection operations (in weeks) for a medium-sized timber building compared to a conventional approach for a masonry or concrete building, for example.



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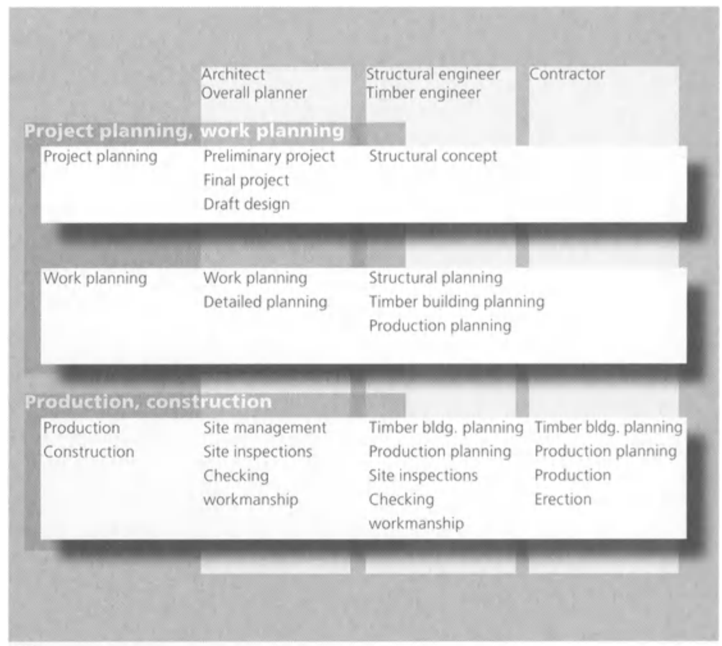
The technical detail solutions are included in the timber building drawings. However, it has been shown that the interface between the working drawings of the architect and the timber building and production drawings is sometimes not so easy to plan! Clear agreements are required because here the most diverse options are available, e.g. how doors or windows are to be integrated into the walls, or the form of the junctions between doors, windows and walls. The configurations and positions of these components and junctions certainly have an influence on the architectural design. Consequently, a clear understanding and agreement is necessary as to how the cooperation is to function and who is responsible for which planning issues. Fig. a39 should be regarded as a supplement to Fig. a38 (planning stages); it shows one possible breakdown of work according to planning participants.

Fig. a40 shows the relationships and conditions that influence the overall concept of the building and which must be checked constantly during the ongoing planning work, and if necessary checked against the overall targets. Experience shows that these conceptual considerations should be set up during the draft design and preparatory phases and checked during the planning phase.



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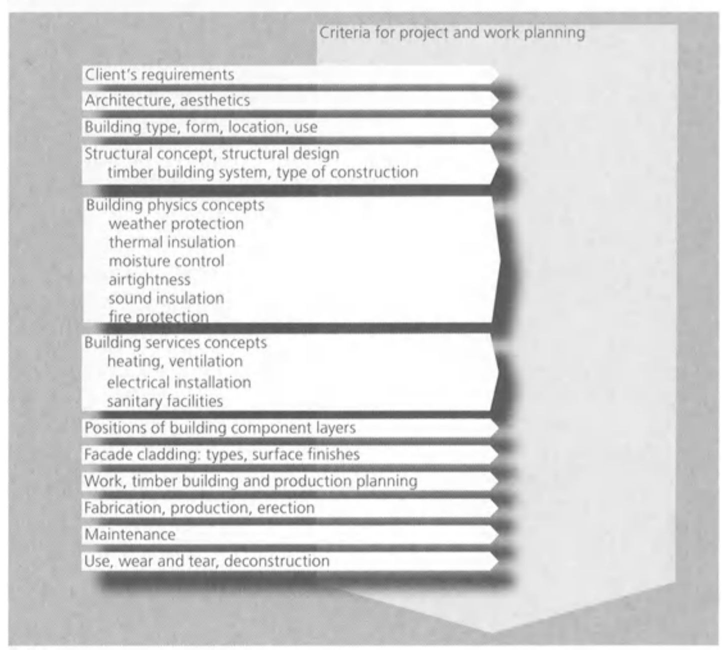


a40

a38 Breakdown according to project and work planning.
Note on terminology: In Switzerland the term "timber engineer" is often used where in other countries "structural engineer" would perhaps be more common.
Structural engineering drawings are layout plans and other drawings showing structural members, loading drawings, etc. The timber building or works planning embraces structural, working and production drawings, elements drawings, plans indicating openings, erection drawings, etc. In practice the terms timber building drawings and production drawings are used.

a39 Allocation of planning steps (to Fig. a38) according to planning participants. Timber building planning and production planning are carried out on a project-related basis, either by the contractor or the structural engineer.

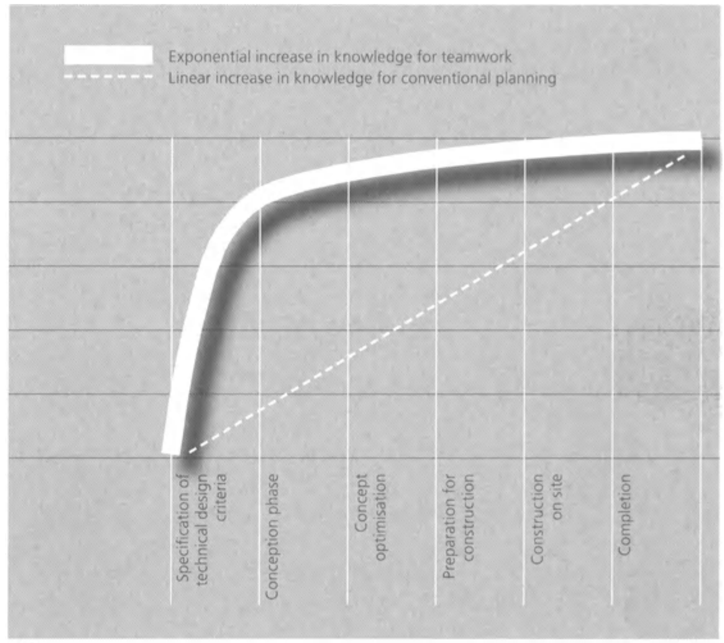
a40 Influences, criteria and conditions that have an effect on the overall conception of a building must be investigated and refined throughout the entire planning process from conception to detailed design.

a3 30 Process sequence

The building process begins with the idea of the building and the formulation of the intent of the building. Right up to the finished structure, all steps have to be planned as part of the detailed project organisation and the steps in the process specified. Experienced planners have a clear notion of use, maintenance, and deconstruction aspects in their plans, which exceed the actual remit of the preliminary and final project phases. The process sequence therefore forms a life cycle (Fig. a41).

Planning

During the planning of the building, the first phases covering quality, costs and deadlines are extremely important. As shown in Figs. a42 and a43, close teamwork during the initial phase results in an exponential increase in overall knowledge. Cost optimisation is also far more efficient during this period. Decisions taken at a later date, which in extreme cases lead to changes on the building site, are inevitably linked with costs and delays, and frequently with a reduction in quality as well.



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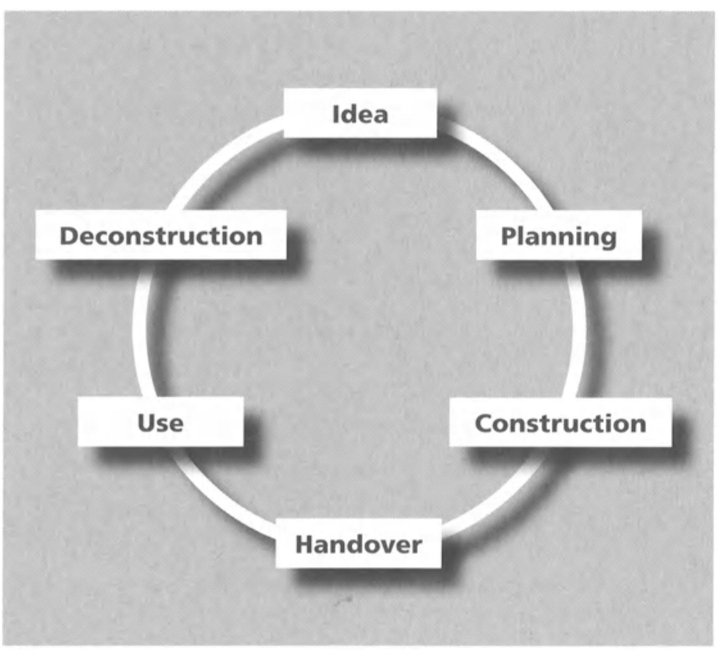

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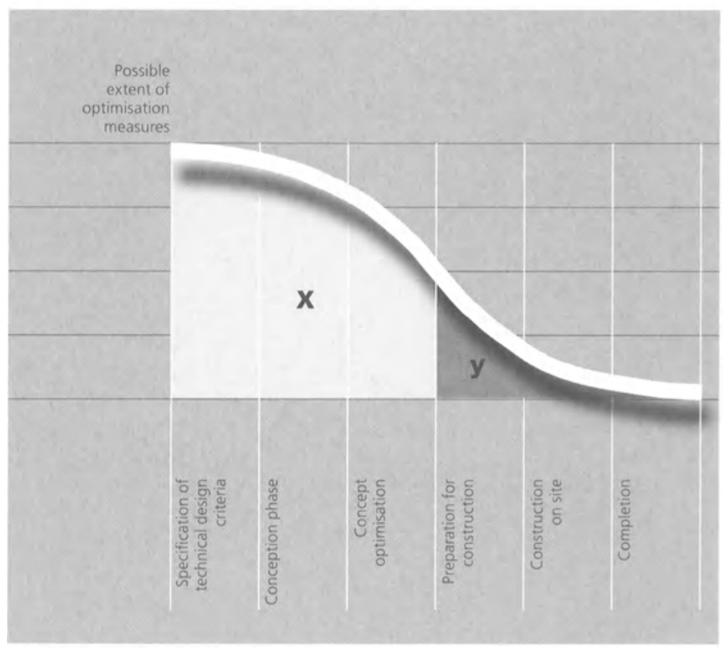

a43

a41 The life cycle of a building

a42 Increase in knowledge plotted against project phases [11]

a43 Extent of cost-savings potential [11]
x – in the planning phase
y – in the construction phase

In a timber building the architect's work planning must be included in the timber building planning at an early date. Production of the elements in the factory requires a lead time and the earlier the corresponding final details and interfaces are available, the easier it is to plan this lead time.
A planning team functioning as a network has short communications paths. Every member is responsible and uses his knowledge to optimise the whole project. Overall management is important because it is responsible for the coordination, the flow of information, and the compilation of all details to form a whole. It is the hub of the entire project.

Computer-assisted planning has made inroads into many areas of architecture and construction. At the same time, electronic media have simplified communications. In production, data can be processed and used for controlling the machines.

Construction
Prefabricated components are being used more and more for timber structures. Among the advantages this brings is more economic, and better-controlled production in an environment protected from the weather. Erection is still dependent on the vagaries of the weather, but the short on-site time does minimise this influence. Nevertheless, the weather still has to be considered. Timber components must be protected against the weather, primarily from precipitation, but also against UV radiation. Appropriate measures must be considered in the plans and concepts for transport, intermediate storage, and erection, but also afterwards, until the building works are complete. This also includes the proper protection of components against soiling or damage from outside influences.

Use
The building work should be checked against a plan drawn up beforehand. Only after the final inspection has been made the building can be handed over to the client. The maintenance and operation of the building should also be defined. Periodic inspections and maintenance work can help to ensure that a structure satisfies the functions appropriate to its use for many decades. There are clear, proven relationships between the functionality and maintenance of value of a building and the frequency of the maintenance intervals.

Deconstruction
Planned deconstruction will gain in significance in the future, especially because of the cost and environmental impact of materials that are difficult to dispose of. Deconstruction should therefore be considered as a part of the overall work. Timber structures are advantageous here.

An aid to structuring the planning and building work, how to specify individual operations and define individual processes, is shown in Fig. a44.

a3 40 Quality assurance

An integral part of a comprehensive building process for any building is quality assurance (QA). However, a large, four-storey office block in timber will of course involve a different type of quality assurance than that of a two-storey house.
Studies have revealed that timber building contractors cannot achieve the desired goals alone; planning and project organisation has a far greater influence on the quality of a building project. A QA system should therefore be developed throughout all project phases (from planning to use) and should aim to embrace all those involved in the building process: client, authorities, specialists from project conception to final and detailed planning, and the workers on site or in the factory.

The timber industry has made great progress in recent years with respect to the safety of structures – to some extent forced by more restrictive legislation, especially in terms of fire protection. The industry has learned how to minimise the fire risk despite the use of a combustible building material, and in some countries, e.g. Switzerland, it has established an effective quality assurance system. The "Lignum" document on quality assurance and fire protection published in 2005 [12] classifies structures according to use, number of storeys, and QA levels. This involves defining requirements according to the level of QA and who is responsible. The application of this document represents an important step in the direction of satisfying quality assurance requirements, and national standards stipulate this. It has become clear that effective quality assurance does not cost more but instead leads to the desired level of safety throughout the entire construction process and, in the long-term, to a building of greater value.

A QA system must fulfil the following tasks:
- Specify project-related safety standards during planning and construction.
- Guarantee safety standards (e.g. loadbearing behaviour, fire protection, thermal performance, moisture control, sound insulation, etc.).
- Safeguard and check these standards by way of continual monitoring by outside institutes as well as internal controls.
- Provide aid for clients, designers and contractors in order to avoid mistakes in the application of the codes of practice and the rationalisation of the work.

The planning and design of the building should include a QA system. Fig. a44 (Planning sequence including fire protection quality assurance) shows a suitable model.
The main points that contribute to quality assurance are as follows:

Planning and design

Competent specialist designers
The early involvement of competent specialist designers and engineers leads to high-quality buildings.

Usage agreement
This is used by the design team as the basis for realising the desired utilisation goals and ensures an ideal relationship between client, architect, specialist designers, and building work.

Scheduling
The scheduling of system-based timber structures differs from that of other buildings. Dates should be agreed with experienced specialist designers and contractors.

Independent engineering consultant and checking engineer
In the case of complex structures such as multi-storey timber buildings or large-volume timber structures, it can be advantageous to engage the services of an independent engineering consultant and checking engineer. In Switzerland, the authorities responsible for fire protection prescribe the appointment of a specialist engineer to supervise five- and six-storey timber buildings because of the fire protection regulations in that country. In Germany, the provisions of construction law must be complied with, depending on the size of the building, and verification of compliance must be presented.

Coordination
The coordination among those involved must be clearly structured. Interfaces must be readily identifiable.

Planning

Timber building and production drawings should be prepared according to the architect's drawings with the concepts for building services, fire protection, sound insulation, etc. plus the agreed architectural details and the drawings of the structural engineer. The planning of the timber building and the fabrication work should not be started until the main steps and all relevant details have been clarified. After the architect or the project manager has approved the timber building and production drawings, materials can be ordered and production can begin. Good-quality workmanship can only be achieved through the use of detailed, comprehensive and archivable planning.

Production

Planners and clients should visit the factory to gain an insight into the fabrication of the components. Such a visit also enables the planning to be checked and tied up with the ideas of the clients. The materials used and the production conditions can be inspected. Production should only be carried out by appropriately equipped companies.

Erection

Erection is dependent on the weather. Moisture and dampness have a detrimental effect on the quality of components. The erection concept must include suitable precautions to exclude all negative weather influences, and other possible outside effects or soiling. An erection concept forces the contractor to investigate erection procedures from the start and certainly has an effect on planning. All key areas should be checked to ensure that the work is proceeding properly and according to schedule.

Process phase	Description of work	Client	Architect (project leader)	Site manager	Structural engineer, timber/glulam specialist	Structural engineer, concrete/masonry	Specialist designer, services, building physics	Timber contractor	Fire protection authority	External fire protection authorities
Planning and design	**Preparation**									
	Idea, targets, use	x								
	Preparatory work	x	•							
	Planning study									
	Feasibility study for timber		•		x					
	Preliminary plans for fire protection, QA level decision		•		x				•	
	Preliminary project									
	Bid and contract negotiations with specialist designers		x		•					
	Drawing up specifications for specialist designers		x		•					
	Drawing up requirements catalogue for structure	•	x							
	Preparation of use agreement	•	x		•	•				
	Concept for fire protection and QA	•	x		•					
	Working out structural and building system concepts		•		x					
	Preliminary structural calculations and system details		•		x	•				
	Building services concept		•		•		x			
	Concept for room acoustics and sound insulation		•				x			
	Estimate of costs		x		•	•	•			
	Organisation of project planners (date, information)	•	•	x	•	•	•			
	Concept for inspection and maintenance plan		x	•	•	•				
	Preliminary drawings and checking of building application	x	•		•				x	•
	Project									
	Definitive fire protection concept		•		x					
	Revision of inspection and maintenance plan	•	x		•	•				
	Definitive system details (window, lintel, blinds)		x		•					
	Definitive building services concept		•		•		x			
	Structural calculations for loadbearing system				x	x				
	Definitive concept for acoustics and sound insulation						x			
	Building project drawings for timber works				x					
	Preparation of inspection plan for production and erection		•	•	x	•				
	Provisional scheduling	•	•	x	•	•				
Construction	**Tendering**									
	Design drawings for tenders				x					
	Tenders for timber works and information sheets		•		x					
	Preparation of suitability and award criteria	•	•	•	x					
	Preliminary evaluation of tenderers	•	•	x	•					
	Request for bids		•	x				•		
	Arithmetical checking of bids		•	x	•					
	Technical checking of bids		•		x					
	Discussions with contractors and assessment of bids	•	•	x	•			•		
	Award of contract	•	•	x	•			•		
	Construction project									
	Choice of materials, detailed planning, component verification	•	•		x					
	Coordination of building services		x	•	•	•	•			
	Production planning for timber	•		•	•			x		
	Final check of construction plan and approval							•		x
	Sending records and checklists to authorities and client	•	•						•	x
	Scheduling for construction and inspections		•	x	•	•		•	•	•
	Discussions with project partners		•	x	•	•	•	•		
	Construction of project							x		
	Site management and inspections									
	General supervision and building work	•		x						
	Internal works and site inspections according to schedule							x		
	Works and site inspections by others according to schedule			•	x	•		•		x
	Instructing the fitting out contractors			x	•					
	Final inspection for fire protection and records for authorities							•		x
	Acceptance of fire protection and approval for use							•	x	
	General building acceptance		•	x	•			•		
	Checking quantities and unit prices		•	•	x			•		
	Documentation									
	Handover of use agreements, definitive inspection and maintenance schedule		x	•	•					
	Instructing client about maintenance	•	•	x				•		
	Archiving of building records		x		•					
	Final discussion with project partners	•	•	x	•	•	•	•		
	Final inspection									
	Monitoring of warranty works		•	x						
	Final inspection	•		x						
Use	**Use of the building**									
	Management and upkeep according to inspection and maintenance schedule	x								
	Periodic inspections depending on use of building	x	•	•					•	
	Deconstruction									

a44

a44 Example of the planning sequence for a (large) timber engineering project. The function and operation steps refer to the timber engineering work.

Participants:
x responsible
• involved

Final inspection

Like with conventional structures, it is also sensible with a timber building to carry out inspections directly after important construction phases. These are voluntary but can also be stipulated by the authorities for certain uses, building components and construction methods. Product manufacturers increasingly offer comprehensive services, which include not only instructing workers on the building site but also carrying out the final inspections.

Such a final inspection not only gives the client a guarantee regarding a product and its application; it also guarantees that both materials and workmanship are acceptable. Individual functions such as sound insulation or airtightness can be checked directly through measurements, too. Technical aids are available for checking airtightness and thermal insulation. Thermographs or airtightness measurements can be carried out on the structural carcass or the finished building before the building is handed over to the client, and any repairs or improvements necessary can be carried out. With larger projects, especially with schools and apartment blocks, etc. a series of tests forms part of the contract and therefore an important quality assurance tool.

However, in this context it must be said that the quality issue cannot be dealt with during the final inspection. Whether a building fulfils the requirements asked of it should be visible from the drawings. Control measurements, e.g. the high degree of airtightness essential for a well-insulated building, will not yield satisfactory results if the design was flawed in the first place. When concepts and systems in design, planning and construction are implemented correctly and with good workmanship, timber structures are completely airtight and require control measurements only in exceptional circumstances.

Completion and use

Final documentation, which includes all drawings, especially the timber building and production drawings, provides clients with an indispensable work of reference for their buildings. The handing-over of a structure to the user or occupant must also include instructions on how to use and maintain the building, and at what intervals the most important parts of the loadbearing structure, building envelope, etc. should be inspected.
Use agreement, monitoring and maintenance drawings, working drawings, as well as timber building and production drawings are important documents and form the basis for modifications or extensions over the many decades in which the building will be in use.

a4 Material

a4 10 Species of wood

The principal indigenous species of wood used for loadbearing constructions are as follows:

Softwoods
- spruce
- fir
- Scots pine
- larch
- Douglas fir

Spruce and fir make up the lion's share of timber for structural work. A distinction between spruce and fir is not usually made in normal grading.

Hardwoods
- oak (Durmast, English)
- beech (European)
- chestnut

Oak and beech are generally used for bearing pads, dowels, wedges and other heavily loaded special components. Oak is also used for components that require high moisture resistance.


a45


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a51


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a45 to a49 Softwoods
a45 Spruce
a46 Fir
a47 Scots pine
a48 Larch
a49 Douglas fir

a50 to a52 Hardwoods
a50 Oak
a51 Beech
a52 Chestnut

a4 20 Properties of wood

Macroscopic wood features, appearance

The colouring and the structural features visible to the naked eye determine the appearance of wood. These features are the result of various biological and physical processes in the wood, temperature influences and the diverse growth forms, annual rings, knots, bark inclusions and resin pockets. The annual rings tell the story of the life of the tree and ensue due to the distribution of early wood and late wood. The clarity of the annual ring structure varies depending on the species of wood. A number of features are explained below.

a53

a53 Woods with a distinctive annual growth ring structure (here the fork of a branch) are especially popular for interior work.

Density

In contrast to other building materials, wood has a high strength at a relatively low oven-dry density. This means that while wood is highly efficient, it is also relatively light. The individual species of wood exhibit different densities depending on their microstructure. This advantage is exploited when using the various species of wood. For example, spruce, as a rather light but strong species, can be used as a structural element for beams and columns, whereas beech is a hard and abrasion-resistant wood suitable for stair treads.

Strength

Wood is a building material with a distinct alignment of its fibres in the direction of growth, i.e. in the longitudinal direction of the trunk (anisotropy). The strength characteristics differ depending on the direction of the action, i.e. perpendicular or parallel to the direction of grain. Parallel with the grain, the tensile and compressive strength is many times that perpendicular to the grain. In addition, when actions are applied perpendicular to the grain, it is important to check whether they are in the direction of the annual growth rings (tangential) or perpendicular to them (radial); the differences here amount to about 50%. Theory and research have provided engineers with reliable values for these properties of wood and for calculating timber loadbearing structures.

Moisture content, shrinkage and swelling

Wood is able to absorb moisture in vapour form and release it again. This property known as hygroscopy is the reason for the agreeable interior climate in a timber house. Simultaneously with the absorption and release of moisture, the wood swells and shrinks. In the majority of timber building systems used today, the wood used is already dried to the moisture content of the intended use during processing. Nevertheless, the shrinkage and swelling behaviour that takes place, and which varies parallel with and perpendicular to the grain, must be taken into account by constructional measures.

Durability

As different species of wood contain different quantities of so-called resistant substances, the weathering resistance of wood varies. The heartwood of Scots pine, larch and Douglas fir is in its natural condition somewhat more durable than that of spruce and fir. Oak is one of the most resistant indigenous hardwoods (for detailed information on durability, see d2 "Protecting timber").

a4 30 Grading

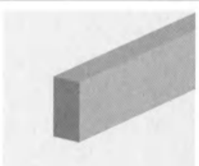
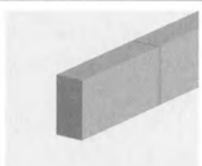
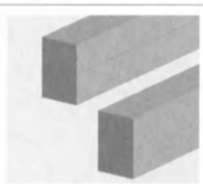
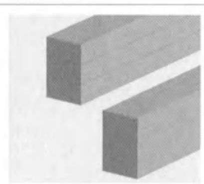
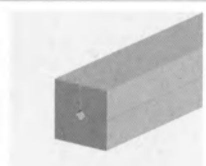
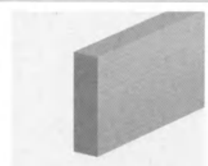
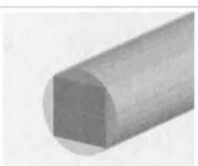
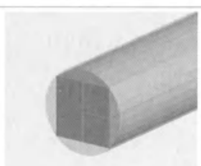
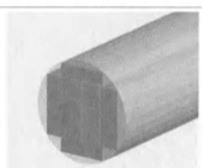
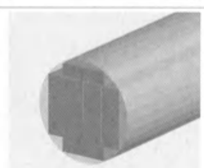
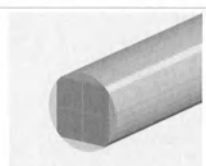
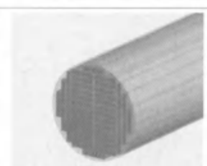
In grading timber we distinguish between the following two types of use:

- Timber with a primarily loadbearing function, for which the strength and deformation properties plus the durability are important (generally structural timber), is graded according to strength classes.
- Timber with a primarily non-loadbearing, space-dividing, cladding or otherwise stiffening function, for which the appearance (aesthetics) and properties of the surface plus the dimensional stability and durability are important (e.g. so-called sawn or planed timber), is graded according to quality classes.

Both grading criteria are used when timber with a loadbearing function, graded according to strength classes, also has to satisfy aesthetic requirements, e.g. in the case of exposed loadbearing members.

Structural timber (with a primarily loadbearing function)
Fig. a54 shows an overview of the classes of "timber with a primarily loadbearing function", which is divided into solid timber, compound sections and glued laminated timber. All three terms are nowadays subsumed under the heading "structural timber".

Structural timber

	Solid timber		**Compound sections**			**Glulam**
Type	Squared section	KVH	2 pieces	3 pieces	4 pieces	Multiple pieces
Designation		Solid structural timber, finger-jointed	Duo® beam	Trio® beam	four-piece beam	GL
System sketch						
Use of log						
Strength classes	C20, C24, C27, C35, C45	C20, C24, C27, C35, C45	C20, C24, C27, C35, C45	C20, C24, C27, C35, C45	C20, C24, C27, C35, C45	GL24k, GL24h, GL28k, GL28h, GL36k, GL36h
Usual strength class	C24	C24	C24	C24	C24	GL24h
Cross-sections	60 x 80 to 240 x 300 mm	80 x 100 to 120 x 200 mm	60 x 60 to 140 x 240 mm	60 x 100 to 140 x 240 mm	100 x 100 to 160 x 240 mm	80 x 100 to 260 x 2000 mm
Lengths	up to 8 m, sometimes 12 m	12–18 m	12–18 m	12–18 m	12–18 m	up to 18 m, sometimes 40 m
Availability	conversion according to catalogue	conversion according to catalogue	ex stock	ex stock	on request	ex stock or production according to catalogue
Drying	costly, problematic	costly	simple (laminations)	simple (laminations)	costly	simple (laminations)
Form	straight	straight	straight	straight	straight	straight, curved
Surface finish	sawn, planed	sawn, planed	planed	planed	planed	planed

a54

a54 Overview of structural timber (timber used primarily for loadbearing functions)

Solid timber

Squared sections are sawn from baulks of timber or logs, and solid structural timber (KVH®) is made up of solid sections which may be made from shorter sections joined by way of finger joints. Solid structural timber is generally available planed. In Switzerland, critical for the grading of loadbearing solid timber are the standards SIA 265 "Timber structures" or SIA 265/1 "Timber structures – Supplementary specifications", or also EN 338 "Timber structures – Strength classes", which distinguish between five (EN 338 has even more) strength classes:

- C20 timber with a low strength, visual grading
- C24 timber with a normal strength, visual grading (standard structural timber)
- C27 timber with a higher strength, visual grading
- C35 timber with a higher strength, machine grading (availability must be ascertained)
- C45 timber with a higher strength, machine grading (availability must be ascertained)


a55

The structural timber normally used is strength class C24. Timbers of strength classes C27 to C45 are hardly used for solid timber owing to the high grading requirements.

The moisture content (or degree of drying) of the timber is not considered directly during grading. It must therefore be specified explicitly irrespective of the prescribed grade if special requirements are to be met (see d1 "Moisture content").

a55 Timber with a loadbearing function

Compound sections

"True" solid timber is hardly used these days in timber building systems. The wood for timber buildings must be dry, dimensionally accurate and straight. Dried and finger-jointed solid structural timber or Duo®, Duplex or Trio® beams (two or three laminations glued together) are therefore used instead. Compound sections with laminations finger-jointed separately are also suitable for suspended floor systems. Fig. a54 shows further types.

Glued laminated timber

The laminations for the production of glued laminated timber (glulam) members are covered in Switzerland by SIA 265 "Timber structures" and SIA 265/1 "Timber structures – Supplementary specifications", which are based on EN 1194 "Timber structures – Glued laminated timber – Strength classes and determination of characteristic values". They are divided into classes T11, T14.5, and T18 for visually graded laminations plus T22 and T26 for machine-graded laminations.

After the lamination process has been completed, the finished glued laminated timber is divided into strength classes GL 24, GL 28 and GL 36. In addition, a distinction is also made between homogeneous (e.g. GL 24h) and compound cross-sections (e.g. GL 24k) with laminations of different classes, e.g.

- strength class GL 24h: all laminations of class T14.5
- strength class GL 28k: outer laminations (min. h/6) of class T18, inner laminations of class T14.5

Beams of strength class GL 24h form the lion's share of products.

The visible surfaces of glued laminated timber are divided into the following classes (based on publications by the Swiss Timber Building Association, the Swiss Glulam Trade Association, and SIA 118/265 "General conditions for timber building works"):

- selected (A)
- normal (N)
- industrial (I)

In practice mainly the normal quality (N) and the industrial quality (I) are used.

There are national associations of glulam manufacturers in Switzerland, Germany and Austria which define appearance criteria more precisely.


a57

Timber for fitting out (timber with an essentially non-loadbearing, space-dividing function, appearance grading of sawn timber)

Sawn timber
Appearance grading divides softwoods into the following quality classes:
- spruce/fir, Scots pine, larch, Douglas fir, hemlock and redwood into classes I, II, III
- Nordic spruce and Nordic pine into classes II and III

Planed goods
Planed goods are divided into classes A and B. A hybrid grading A/B is also possible upon request. Another frequent classification method is according to species of wood and place of origin: Nordic spruce (wood from Northern Europe), and indigenous spruce/fir (wood from Central Europe). Other, readily available species of wood are larch and Scots pine. (Basis: Swiss Timber Association and Association of Swiss Planing Works, SIA 118/265).

Solid timber boards
Solid timber boards are classified as single- or multi-layer boards according to the board lay-up and according to the main properties such as usage conditions, mechanical characteristics, appearance of surface (softwood or hardwood boards), surface characteristics (untreated board, sanded board, etc.), and according to the requirements of the users (EN 12775 " Solid wood panels – Classification and terminology"). Standards EN 13017–1 "Solid wood panels – Classification by surface appearance – Part 1: Softwood" and EN 13017–2 for hardwood provide specific information on the general requirements for single- or multi-layer solid timber boards and their appearance classifications.
Multi-layer solid timber boards are divided into appearance classes A, B, C and S for assessing the surface quality. Class A is intended for high-quality fitting out work, B and C for general work, and class S is suitable for loadbearing purposes such as concrete formwork or building and structural boards. The assessment is carried out for both faces, back and front; the grades of the two faces are separated by a slash, e.g. A/B, B/B, B/C, A/C, S/S.
Single-layer solid timber boards are divided into appearance classes A, B and C in a similar way to the multi-layer boards in order to assess the surface quality. However, when describing the board, only the class of the better face is given, e.g. A, B, or C.


a56

OSB, particleboards
Particleboards for loadbearing applications must satisfy the requirements of EN 312 "Particleboards – Specifications" and EN 13986 "Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking", and oriented strand boards (OSB) EN 300 "Oriented Strand Boards (OSB) – Definitions, classification and specifications" as well as EN 13986. The minimum thickness for a loadbearing application is 8 mm for both OSB and particleboards 6 mm when used as a stiffening board.

The requirements placed on board-type wood-based products are covered in SIA 265/1 "Timber structures – Supplementary specifications" and EN 13986. There are also many products with building authority approvals on the market.

a56 and a57 Timber with non-loadbearing, space-dividing, and cladding functions (timber for fitting out)

b

Construction systems

Loadbearing structure, building structure, design

b1 Overview of systems

b1 10 Building systems in timber construction

In timber construction, new and advantageous solutions characterise the formation and arrangement of the layers of the building envelope in the technical sense. Similarly, a re-orientation is evident in the different loadbearing systems, and hence the ac-tual timber construction systems. Figs. b1 to b7 provide a pictorial overview of the most common systems, which are illustrated and described individually in the subsequent chapters b3 to b8.

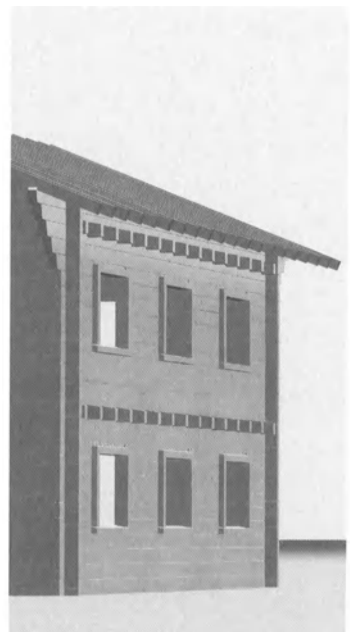
The basic building systems are:
- log construction
- timber-frame construction
- balloon- and platform-frame construction
- panel construction
- frame construction
- solid timber construction

Log and timber-frame systems (once the traditional forms of construction on the European mainland) as well as balloon- and platform-frame construction (the preferred forms in the UK and the USA), all erected using skilled labour under the supervision of an experienced person, have long since lost much of their importance. They are now only found in isolated instances. Modern building with timber is not confined to the imitation of these traditions. Quite the contrary: current developments in timber construction correspond to modern ways of thinking, and modern ways of working. Building professionals must try to understand the traditions in building, but above all they must understand building with timber as a new and modern assignment.

The building systems that currently dominate the market are dealt with in detail in the following chapters:
- panel construction: chapter b6
- frame construction: chapter b7
- solid timber construction: chapter b8

These systems are very different in terms of design and appearance. And they are also sometimes designated differently according to country, region or particular form of construction.

Overleaf:
Canton school, Wil, Switzerland, entrance foyer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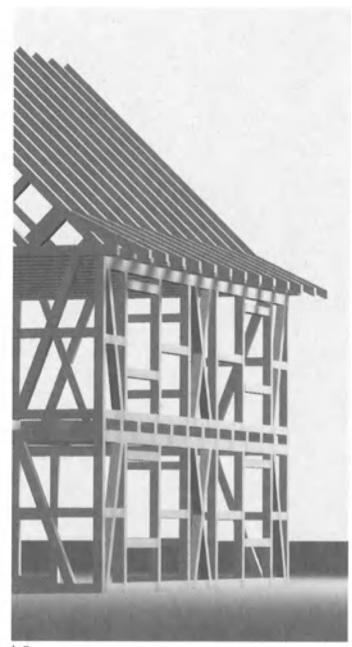
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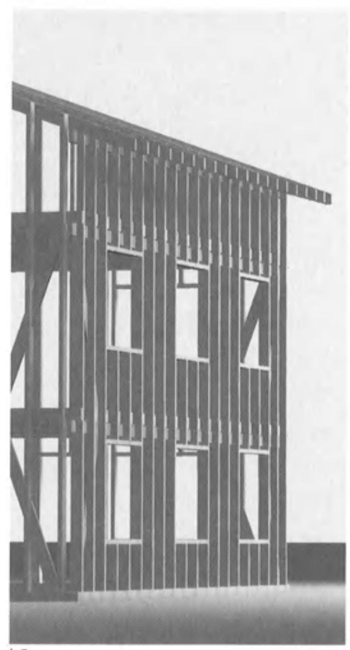
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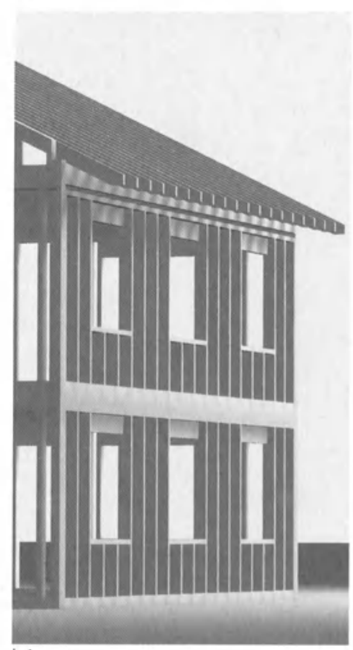
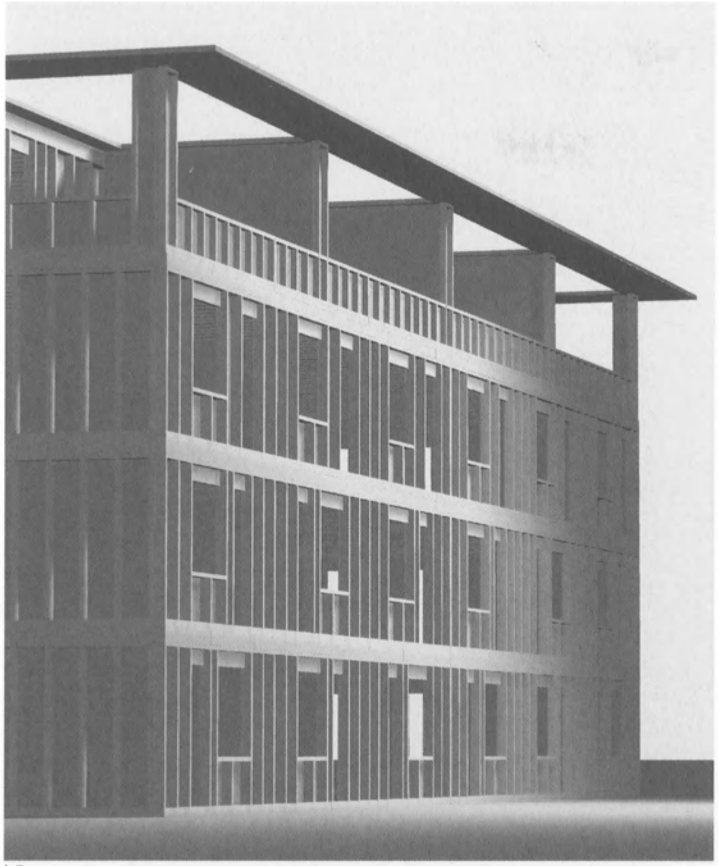

b4

b1 to b7 Overview of systems
b1 Log construction, see chapter b3
b2 Timber-frame construction, see chapter b4
b3 Balloon-frame construction, see chapter b5
b4 Platform-frame construction, see chapter b5
b5 Panel construction, see chapter b6
b6 Frame construction, see chapter b7
b7 Solid timber construction, see chapter b8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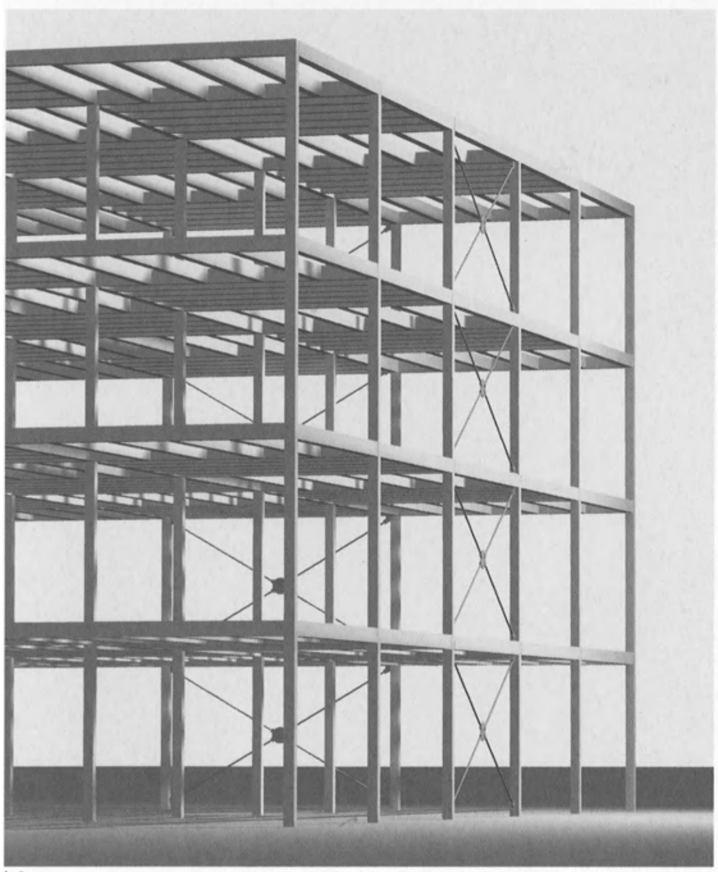
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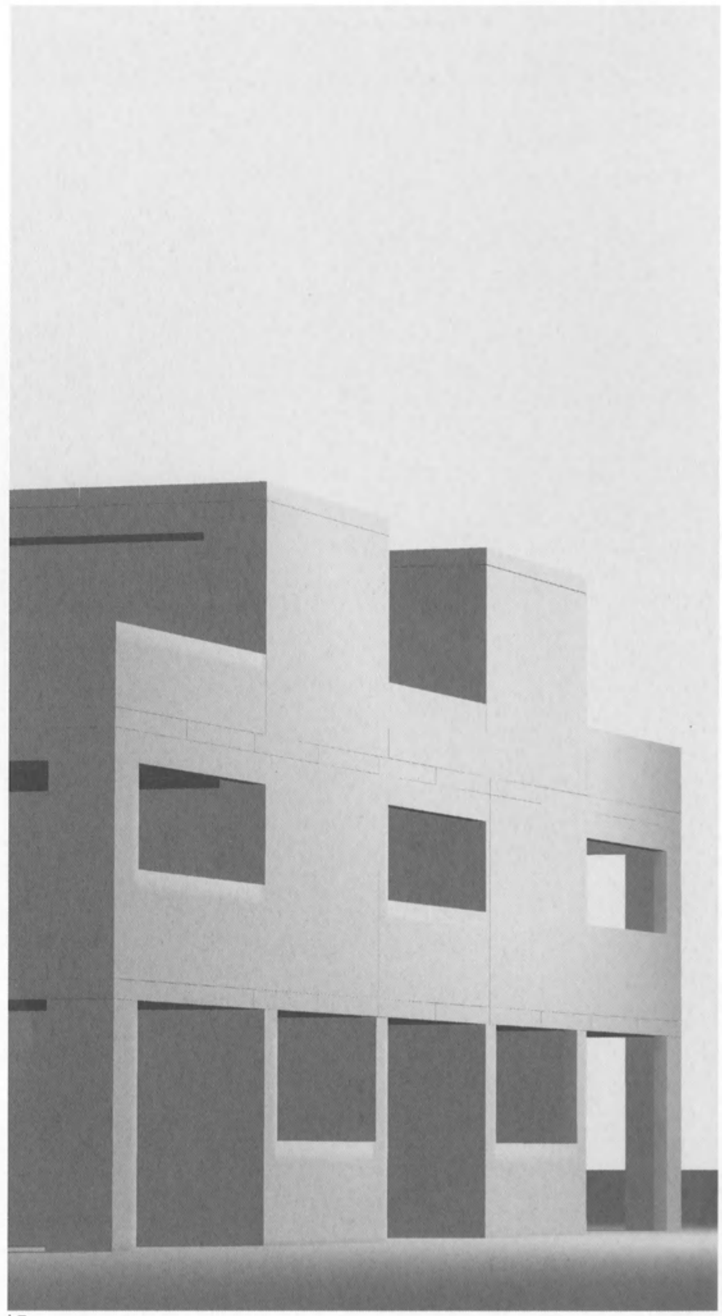
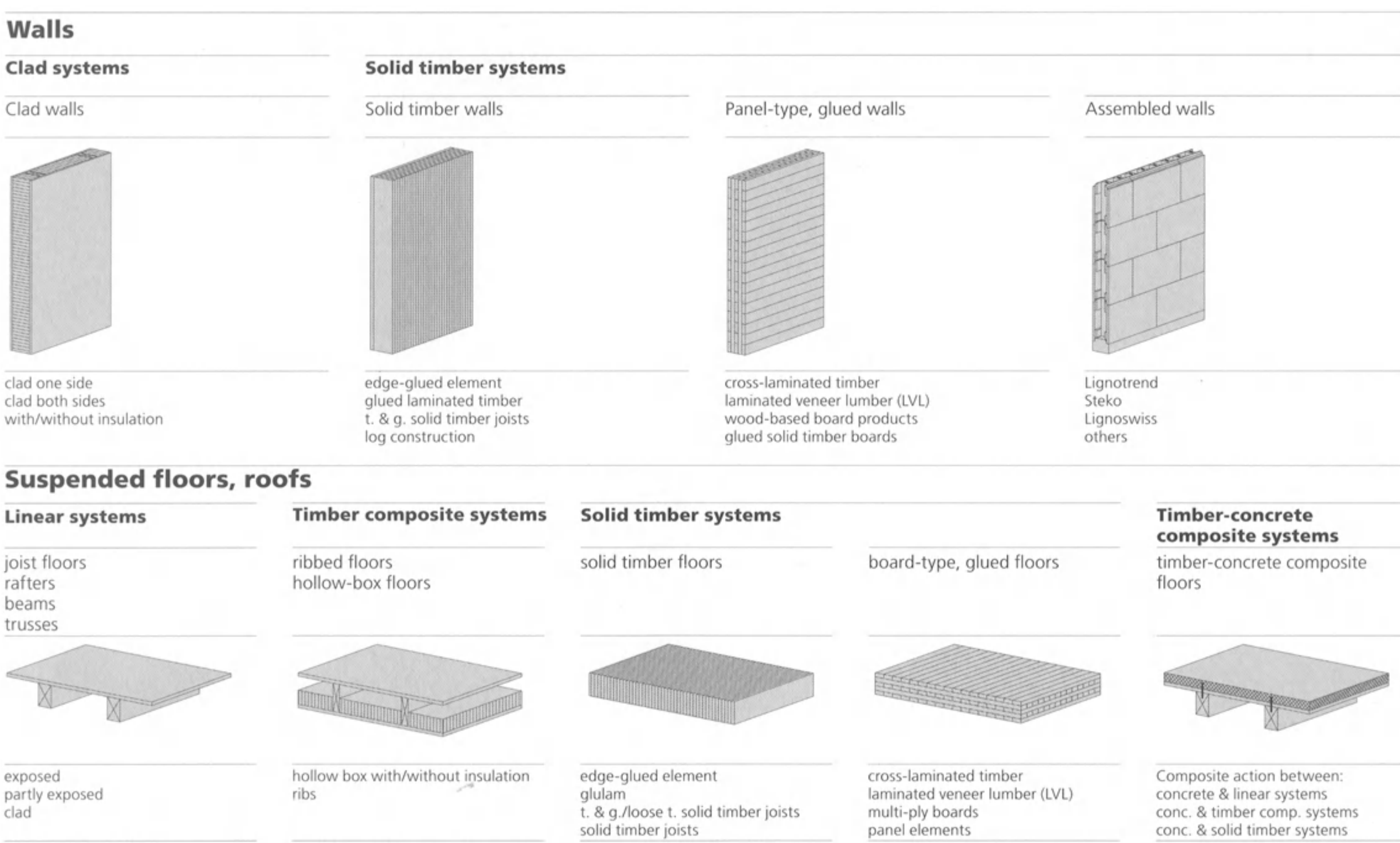

b7

b1 Overview of systems

Those systems produced and marketed under registered brand names are called product-related systems. Such building systems, mostly produced in large batches, are considered to be among the solid timber construction systems when the content of solid timber in the actual loadbearing system exceeds 50%.

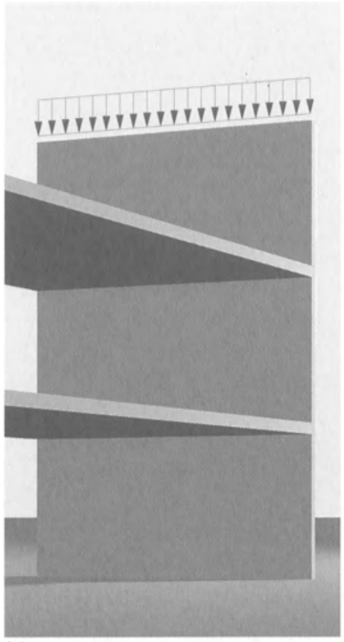
b1 20 Walls, suspended floors, roofs

The aforementioned overall systems can be broken down into individual building component systems in terms of walls, suspended floors, and roofs. These building component systems form either an overall system or can be combined and then in the form of a composite system have a relationship with the overall system. The log and timber-frame construction systems in particular represent self-contained systems, i.e. the walls, the suspended floors, and also the roof are designed according to their specific system, and therefore form a whole. The same is true for contemporary systems such as panel and solid timber construction, although in practice the boundaries are blurred, and combinations have become commonplace. For example, walls and suspended floors in panel construction can be designed as solid timber systems with a solid cross-section. And vice versa, solid timber walls can be combined with suspended floors of separate linear members. Such combinations are not at all unusual in frame construction because the loadbearing structure of individual,



b8

b8 Overview of walls, suspended floors and roofs (building component systems) that can be used in combination to form a complete system



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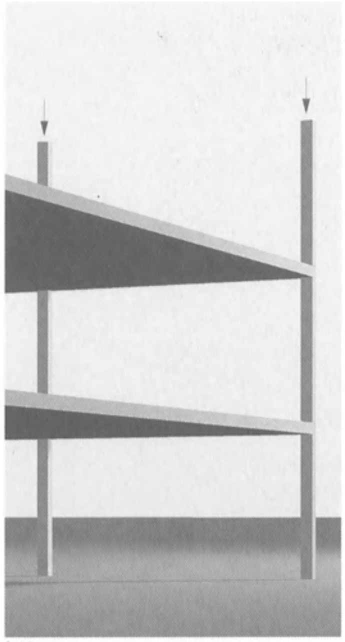


b10

linear members is supplemented by a diverse range of building component systems. And these combinations are certainly beneficial. Depending on building physics requirements (fire protection, sound insulation, thermal insulation), the plan layout, the size of the building, or the magnitude of the loads to be carried, but also with respect to the fabrication options, combinations can be understood as optimisation. The only conditions are that they assist the building structure as a whole, and the architecture of the finished structure is not impaired by combining different systems.

Building component systems are summarised in Fig. b8. As mentioned above, walls, suspended floors, and roofs can be combined at will provided proper transfer of the loads, and proper bracing of the structure is guaranteed. Frequent combinations are clad wall constructions, and composite timber systems for the suspended floors and roof.

b1 30 Choosing a building system

Space requirements and functions, situation and location, and design and materials are all fundamental criteria for the choice of a building system. The building structure to be formed, together with the loadbearing structure for proper transfer of the loads, and considerations regarding the building envelope are important criteria for selecting the timber construction system (see also chapter a3 "Conception and design"), which must be considered at an early stage. The conceptual planning of a building, and hence the choice of system, is essentially influenced by the load-carrying requirements. Here we must distinguish between linear- and point-supported structures. It is advantageous for a building concept to have only one of these two load-carrying systems. Concepts in which both linear- and point-supported arrangements occur represent exceptions, and are only recommended for dealing with specific problems.

b9 Linear-supported structure

b10 Point-supported structure

b1 31 Linear-supported structures

The characteristic feature of the linear-supported structure is the distribution of incoming loads along a linear element. In the majority of cases these are walls or wall plates that transfer loads from the roofs and suspended floors to the foundations (Fig. b9). The advantage of linear support lies in this distribution, and hence the reduction of loading actions on the building components. Furthermore, the building components can also perform other functions such as bracing the structure, serving as enclosing partitions or party walls, or forming part of the building envelope. Depending on the system, the building components can then satisfy loadbearing as well as enclosure requirements. A well-thought-out linear structural concept is characterised by walls aligned vertically. Log, timber-frame, panel and solid timber construction systems all belong to the linear supported variety.

b1 32 Point-supported structures

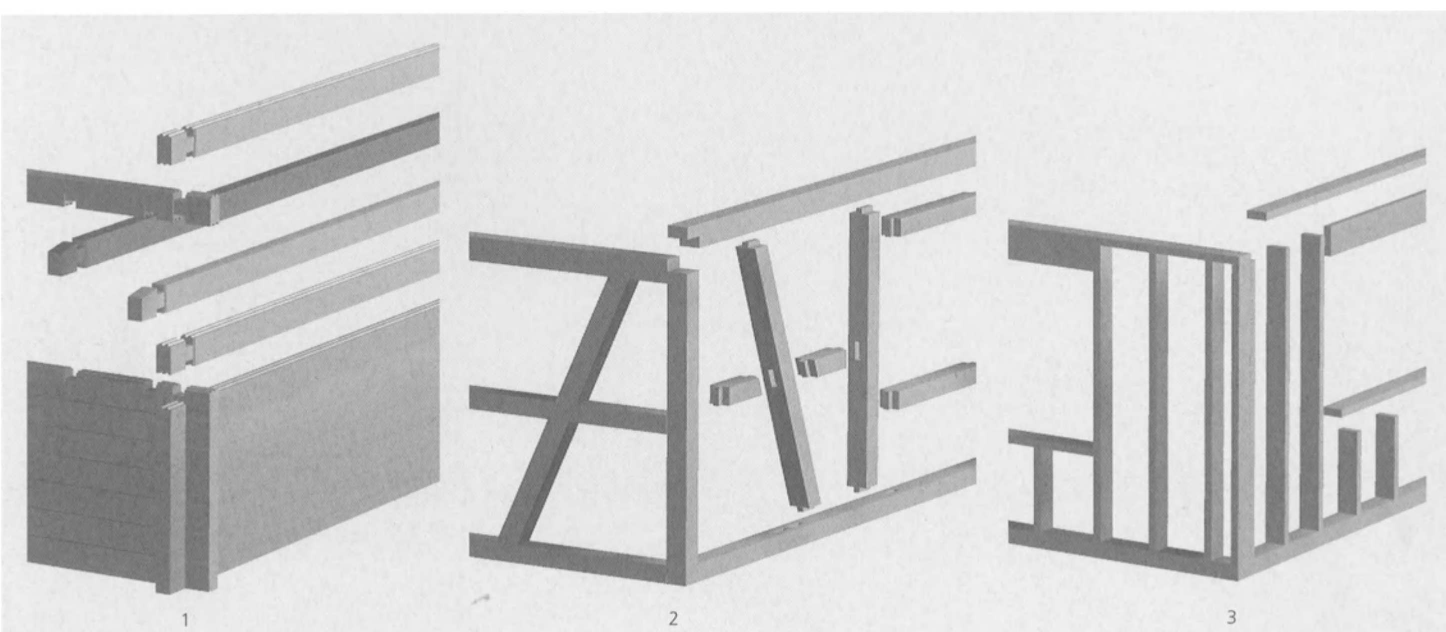
In contrast to the linear-supported structure, the point-supported structure tries to concentrate loading actions. Typical examples of this are frame constructions with their clear separation between the load-carrying function of the loadbearing structure and the enclosing function achieved by means of two-dimensional, non-loadbearing components. Columns positioned on a grid carry the loads down to the foundations (Fig. b10). The loading paths are defined and readily apparent. Transferring loads from the beams to the columns usually requires special measures because major loading concentrations occur at the supports.

b2 10 Fabrication processes related to building systems

The assembly of individual parts and layers in factories to form complete components is called prefabrication or off-site work. The manufacturing depth or the degree of prefabrication tells us to what extent this method of production is used.

All timber construction systems involve some degree of prefabrication, albeit modest in some cases: the timber is assembled according to the fabrication drawings, and mostly already provided with the fasteners for connections. Such fabrication noticeably reduces the working time on the building site. The on-site work for a loadbearing structure to a timber-frame, panel, or frame construction is therefore completed within a few days.

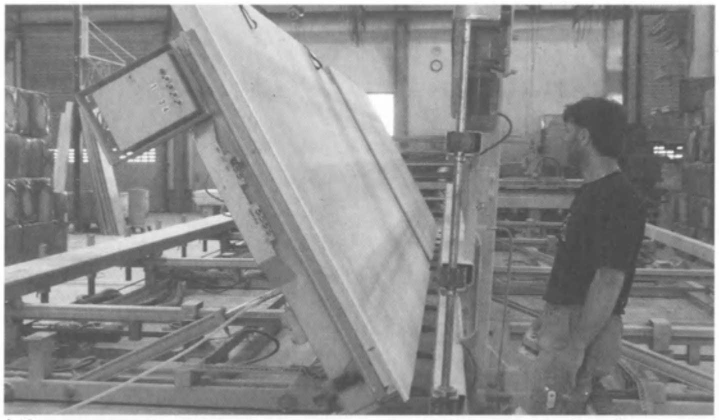
Three basic systems in timber building prevail when trying to maximise the amount of off-site work: panel construction, solid timber construction, and, for larger structures, frame construction (Fig. b11). Panel construction with its linear load-carrying arrangement allows the loadbearing structure, and the enclosing elements to be combined with the layers of the partitions and suspended floors or the building envelope, the windows and doors, with the building services integrated in some cases, in a single building component (Fig. b11, example 5). Contrasting with this is frame construction (example 4), with its clear separation between the loadbearing structure and enclosing elements in which the two-dimensional elements for suspended floors, walls, and roof are added to the loadbearing structure in a second step. But as with panel construction, frame construction also permits the whole spectrum from minimum prefabrication right up to the complete integration of doors, windows, building services, facade etc. for the non-loadbearing, enclosing components (see Fig. b23 "Fabrication stages"). And the loadbearing frame can be of timber, steel or reinforced concrete (see also b2 40 "Building with elements").



b11

b11 Comparison of manufacturing depth for different timber building systems

1 Log construction
2 Timber-frame construction
3 Stud construction (Balloon-Frame, Platform-Frame)
4 Frame construction
5 Panel/solid timber construction



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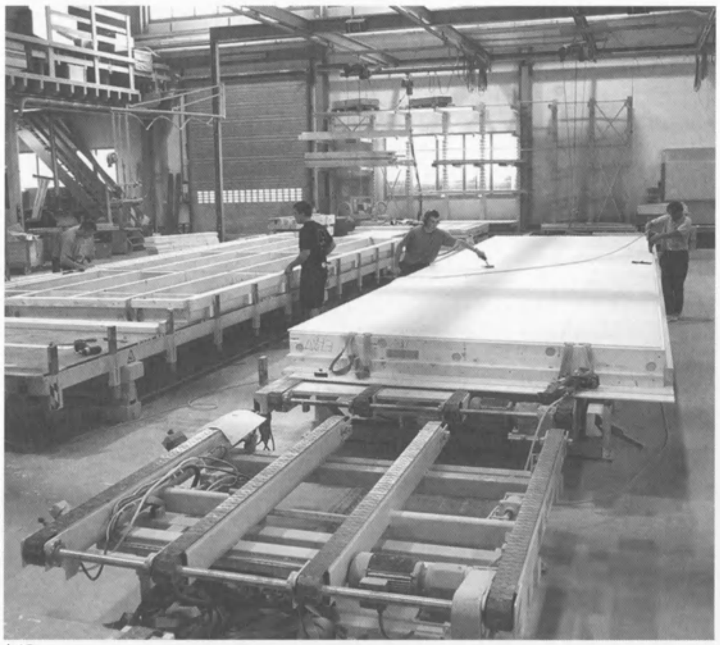

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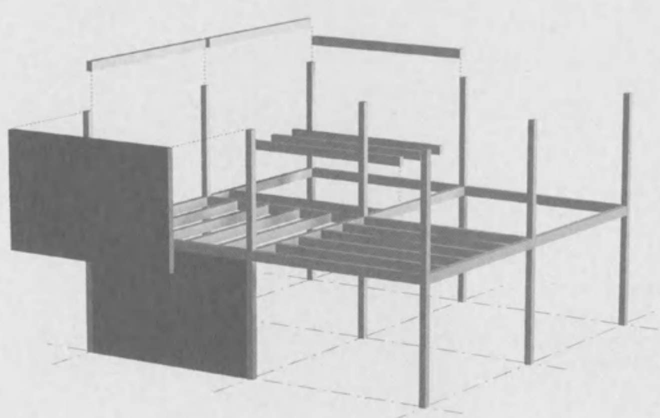

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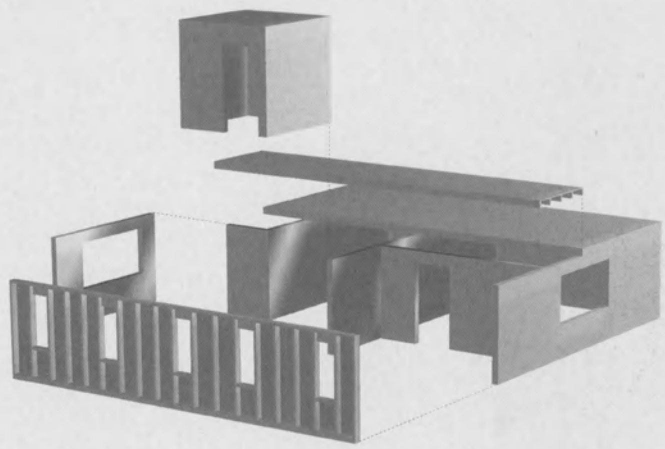

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b12 to b14 Manufacturing building components in the factory

b12 Wall element
b13 Suspended floor element
b14 Room module

b2 20 Building principles

Timber elements are employed as loadbearing or non-loadbearing internal and external wall elements plus suspended floor and roof elements. Many of these elements are composite assemblies involving timber frames and cladding materials of timber or wood-based products or other board products which are attached to one or both sides during the prefabrication phase. In other systems a panel of solid timber or wood-based products forms the backing plate, or a panel is made up of small-format modules which act as both loadbearing and enclosing element. Figs b15 to b18 show four different building principles, and Fig. b22 lists the dependencies and influences of these building principles.


b19

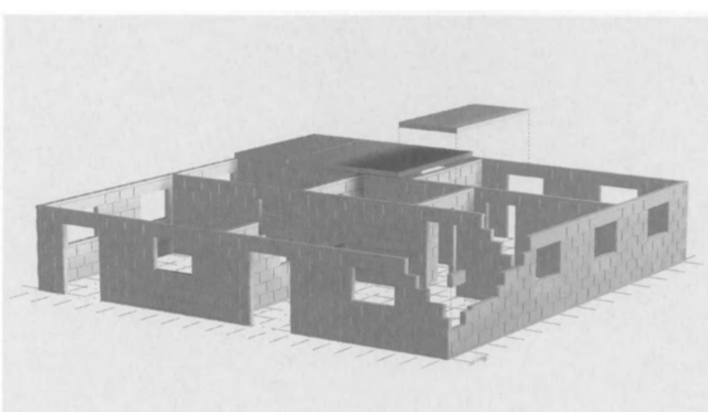

b20

Small units based on a modular dimension

Handy-sized units based on a small modular dimension (e.g. 160 mm) are simply placed in rows and stacked on top of each other. Internal and external walls built in this way are both loadbearing and enclosing elements at the same time. The plan dimensions of the building are multiples of the modular dimension.

Elements based on a modular dimension

Here, 1-storey-high elements are produced in widths to match a modular dimension (e.g. 1000, 1200, or 1250 mm wide). The plan dimensions of the building are multiples of the modular dimension.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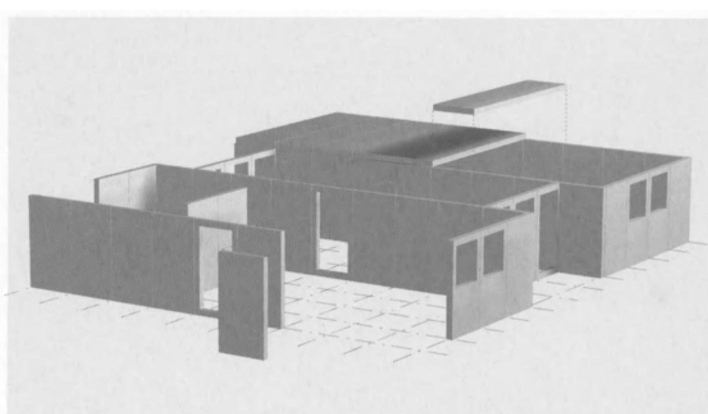
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b15 Small units based on a modular dimension
b16 Elements based on a modular dimension
b17 Elements with the room or plan dimensions
b18 Room modules

b19 Erection of small units based on a modular dimension

b20 Erection of elements with the room or plan dimensions

b21

Dependencies of building principles

			Small units based on mod. dim.	Elements based on mod. dim.	Elements with room/plan dims.	Room modules
			– +	– +	– +	– +
Modular dimensions	– dependent	independent +				
Planning	– intensive	simple +				
Design freedoms	– low	high +				
Batch production	– limited	possible +				
Specialisation, manufacturer	– high	low +				
Specialisation, erection	– high	low +				
Production time	– long	short +				
Erection time	– long	short +				
Transport	– elaborate	simple +				
Crane operations	– elaborate	simple +				

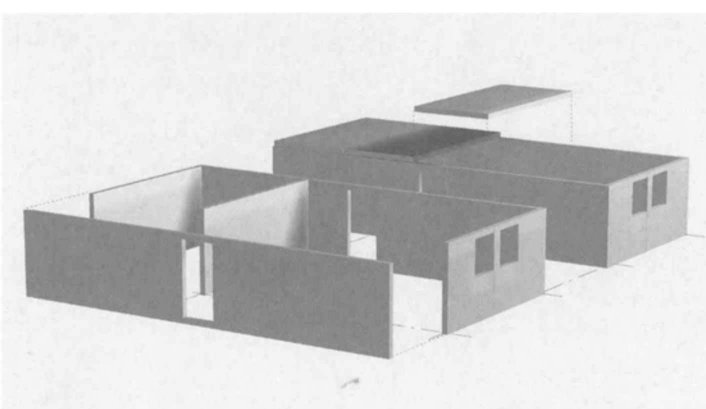
b22

Elements with room or plan dimensions

The length of these elements can range from a single room to the whole width of the building. The height of each element matches the storey height.

Room modules

Room modules are assembled off-site as complete units including the floor, walls, and roof, transported to the building site, and then simply placed side by side or stacked on top of each other.



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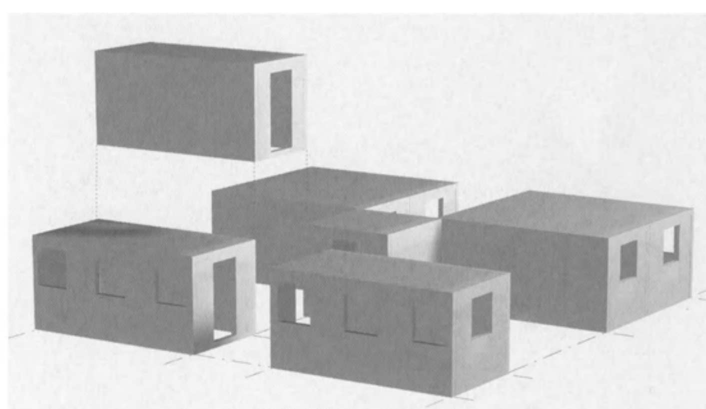


b18

b21 Erection of room modules

b22 Dependencies of building principles

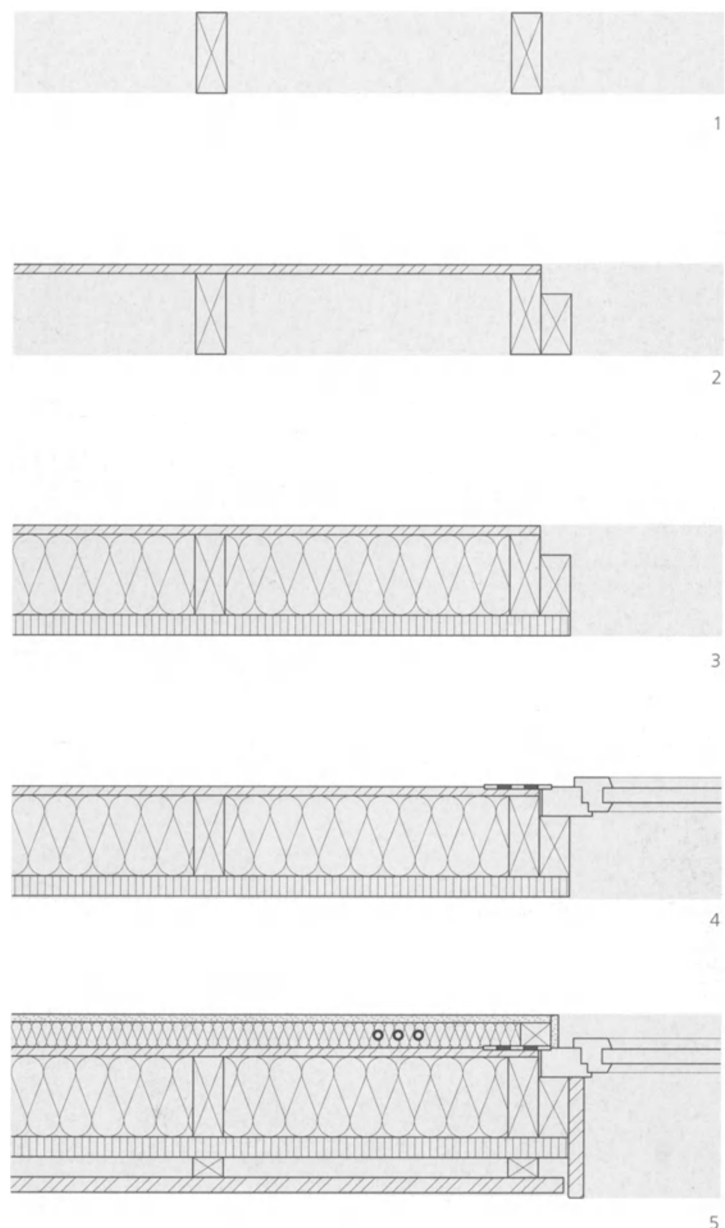
Example 1: Elements based on a modular dimension (Fig. b16) are moderately to highly dependent on the modular coordination of the structure.
Elements produced with room dimensions (Fig. b17) are not based on a modular dimension.

Example 2: Transport and crane operations are simple for small units based on a modular dimension, but expensive for room modules.

b2 30 Fabrication stages related to the building components

The various fabrication or prefabrication stages govern the degree of (pre)fabrication building components have when they leave the works, and how erection on the building site is to be carried out. Whereas in the past loose parts were delivered to the building site, two-dimensional elements are now the norm. The first fabrication stage for such two-dimensional elements involves assembling parts of the loadbearing structure, and at least one planar layer to form a two-dimensional component whose length or height and width conform to a given format and precise openings are already prepared for doors and windows (fabrication stage 2 in Fig. b23).
In the third stage insulation is added and cladding on the other side completed. Adding conduits for building services constitutes one intermediate stage. Adding doors and windows to the two-dimensional components at the works represents yet another fitting out stage. A high degree of prefabrication is achieved when the facade construction and facade cladding are also added off-site, and, if necessary, the internal lining is attached. Currently some manufacturers even go so far as to applying the surface finishes in the works! This is certainly possible, but complete protection of the components is essential during transport, erection, and further work on site right up to the handover of the building.

The advantages of off-site prefabrication differ for every building project, depending on the technologies available during planning, production, transport, and erection. Considerations regarding the risk of soiling and injuries are also relevant. Structural carcass elements are less vulnerable to climatic influences such as moisture, rain or UV radiation than elements that already have their final surface finishes, which require better protection. This is also true for damage caused by subsequent on-site trades. Intermediate steps between the fitting out stages shown are also possible.



b23

b23 Fabrication stages

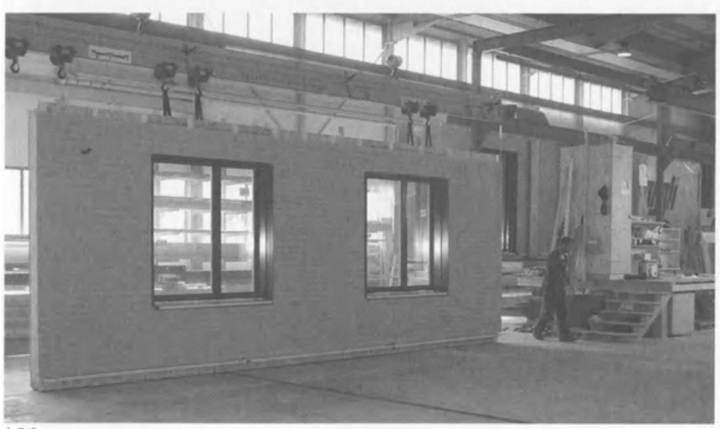
1 Assembly of separate, linear parts.
2 Assembly of elements; parts of the loadbearing structure and at least one planar layer are pre-assembled.
3 The elements are clad on both sides, insulated, and conduits for later building services possibly installed.
4 Elements including fixtures and fittings such as doors and windows, glazing.
5 Elements including facade assembly, internal lining, and external cladding.


b24

b2 40 Building with elements

Efforts to rationalise and industrialise the building industry and the subsequent shift in the production process from the building site to weather-proof factories have led to the use of elements, and has now reached a high level of development. Off-site production in factories has advantages. For example, work can be carried out more accurately than on the building site, and individual building components such as doors or windows can be integrated into large or small prefabricated panels as required. In the end, this leads to higher-quality buildings – provided the planning work has been carried out professionally and the sequences of building operations have been properly planned.


b25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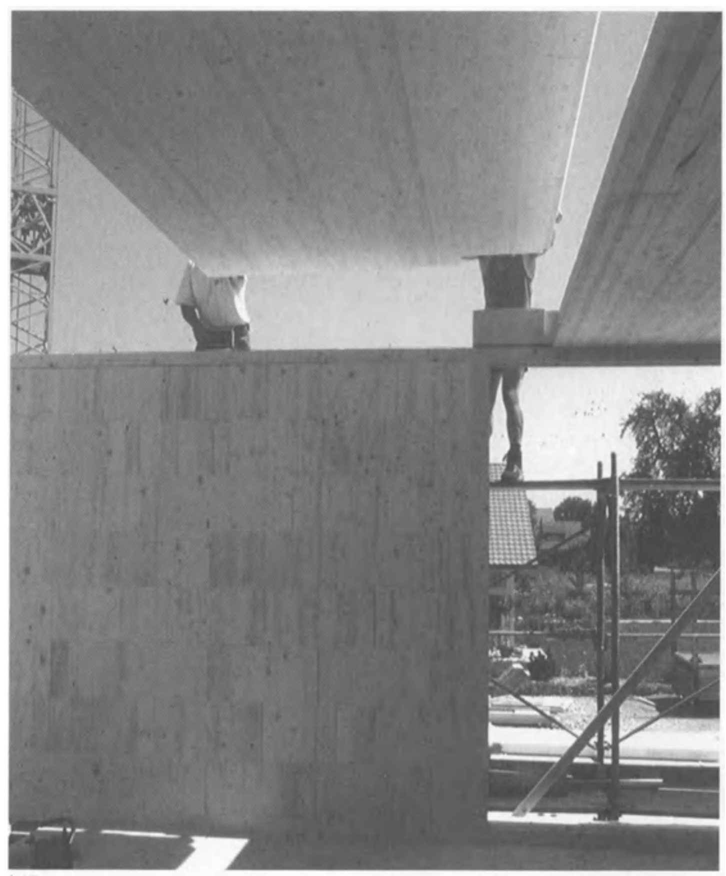
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b24 Fabrication stage 2 according to Fig. b23: the structural carcass for an apartment block during erection

b25 and b26 Fabrication stage 5 according to Fig. b23: wall elements including windows, facade construction, internal lining, and external cladding

b27 Erection of suspended floor elements; combination of building principles: walls in the form of small-format modules, suspended floors as elements; fabrication stage 3 according to Fig. b23.

Applications

Building with loadbearing or non-loadbearing elements is suited to a wide range of building tasks. Prefabricated components are primarily used when buildings are required at short notice, and where restrictions are placed on weight, transport, and erection options. Pavilions which can be dismantled and transported in the form of room modules for schools, nurseries, offices, accommodation, etc. have been specially developed to meet temporary needs. These systems gradually gave rise to prefabricated building systems designed for longer use. At the same time, development proceeded in the direction of prefabricated houses with one or two storeys. Off-site industrial fabrication on a small or large scale has now enabled timber to become a serious contender for larger and multi-storey structures.

The industrial production of large and small elements and even complete room modules has undergone continuous development to such an extent that the expression "prefabricated components = prefabricated house" is becoming ever more valid. The building components are delivered to the building site virtually as complete, finished units, including building services and often the internal furnishings and fittings. The planners and manufacturers of such building components or prefabricated houses have pushed back the boundaries of optimum prefabrication further and further. They can supply house components ex-stock with certified, quality-assured features for precisely timed, short on-site construction periods at contractually guaranteed fixed prices.

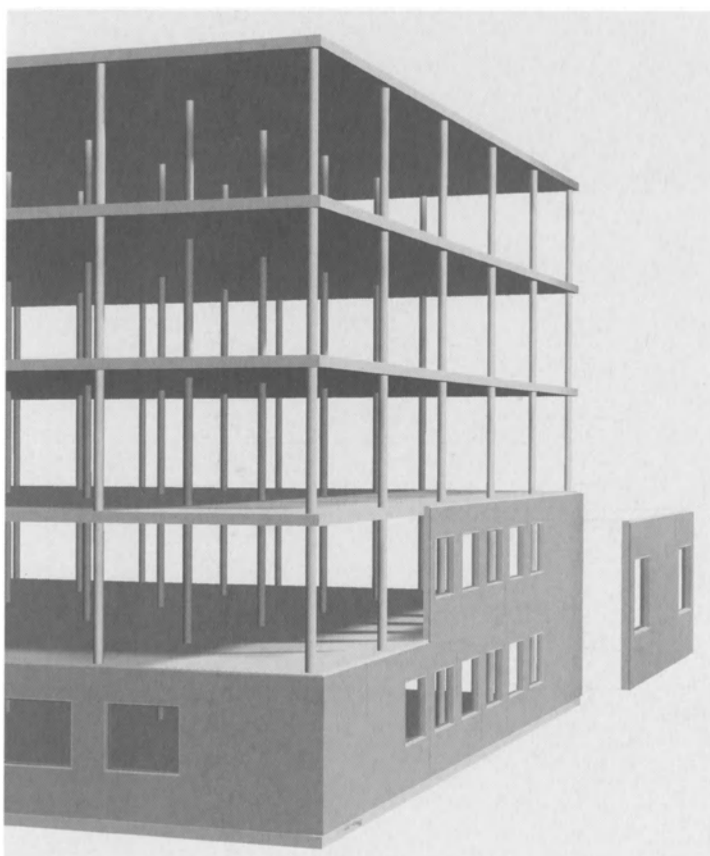
b28

b28 An example of the combination of different materials: eight-storey apartment block, Grand-Saconnex, Geneva, Switzerland; loadbearing construction in reinforced concrete, facade elements in timber, incombustible facade cladding (for sketch of this principle see Fig. b30)

b29

Combinations of materials

Frame structures in reinforced concrete with insulating wall elements in timber is a combination that is appearing more and more. The columns can be of steel or reinforced concrete and the concrete suspended floors are cast on site. Highly insulated but slim timber elements, or in the case of special thermal and sound insulation demands also in the form of double- or triple-leaf timber elements, make up the building envelope (see Fig. b30 for an illustration of the principle, Figs b28 and b29 for typical applications). The whole spectrum of prefabrication options is available for these non-loadbearing, enclosing walls, as shown in Fig. b23 – from minimal prefabrication right up to the complete integration of doors, windows, building services, cladding, etc.



b30

b29 Example of the combination of different materials: residential development, Schwyz, Switzerland; loadbearing construction in reinforced concrete, facade elements in timber, larch wood shingles as external cladding (for a sketch of this principle see Fig. b30)

b30 Combination of materials: loadbearing construction in reinforced concrete, non-loadbearing, highly insulated external walls in timber (sketch of principle)

Batch production

One important prerequisite for economic building is batch production. However, batch production and individual design would appear to be wholly incompatible. At first glance, batch production involving short on-site times and low building costs seems to be at the other end of the scale to the desire for individual design. This is because with the batch production of given plan layouts, i.e. whole room modules, it is hardly possible to produce individual building solutions. Individualistic housing ideas can thus only be considered to a limited extent. Manufacturers therefore restrict themselves to the standardisation of building elements which then permit differentiated planning and the most diverse uses through numerous different combination options. And indeed, the first systems are now appearing in which components can be produced in large numbers for keeping in storage ready for the next appropriate construction project. The field of product-related systems is showing great promise in this respect, where small-format modules or wall and floor components are produced in a large series. However, the majority of manufacturers still base their ideas on element-type fabrication per project. This project-related fabrication is, however, based on the use of identical construction details, materials, and products. The advantages of manufacturing depth can be used while allowing for individual design.

The features of off-site fabrication

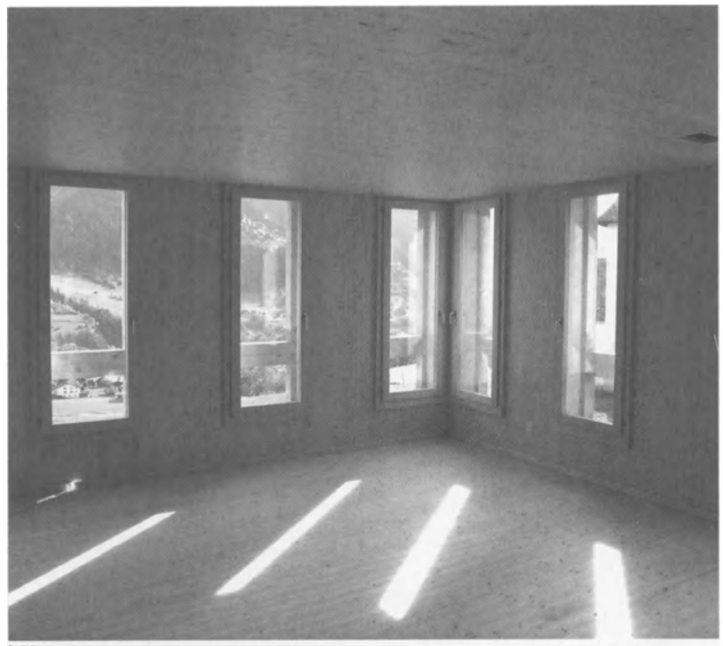
- Grid and modular arrangements
- Definition of planning steps and planning depth
- Design of joints
- Restrictions regarding transport
- Defined timetables and building sequences
- Production regardless of the weather
- Good manufacturing depth
- Monitored and certified production
- Short erection times
- Batch production and manufacture for storage

b3 Log construction

b3 10 General

Log construction has a long tradition in many countries. This form of construction had a considerable influence on the development of early European timber architecture and is very widespread. For example, in Russia and Scandinavia we encounter log structures that determine the look of the traditional surroundings. In such regions we not only find houses in log construction, but also palaces, towers, and churches. And in the mountainous regions of Central Europe, principally in the Alps, log construction has also played an important role in housing for the local inhabitants.

Even today, log structures are still built in mountainous areas, e.g. the Bernese Oberland, Valais, the Fribourg Alps and Grisons in Switzerland, the Bavarian Alps in Germany and in the mountainous regions of Austria. The knowledge of generations of carpenters, which was handed down from generation to generation primarily by word of mouth, is still used today in the erection of new log structures. However, that knowledge has to be adapted to suit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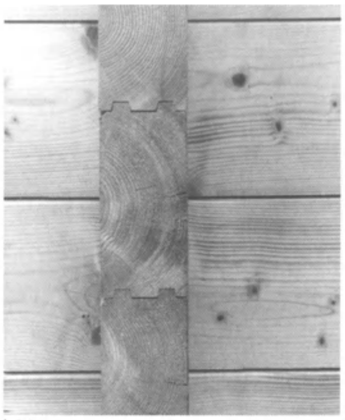
b31


b33

b31 Modified log construction, school building in St Peter, Switzerland. The wall construction involving several compatible layers enables trouble-free shrinkage and swelling of the construction.

b32 Log structures remain visible internally or can be lined with solid timber.

b33 Exterior architectural elements used in the interior of a building



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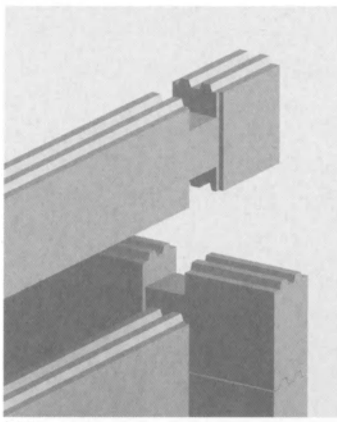

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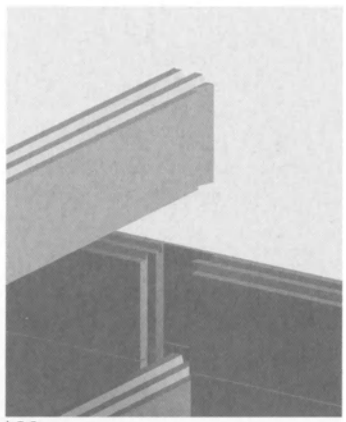


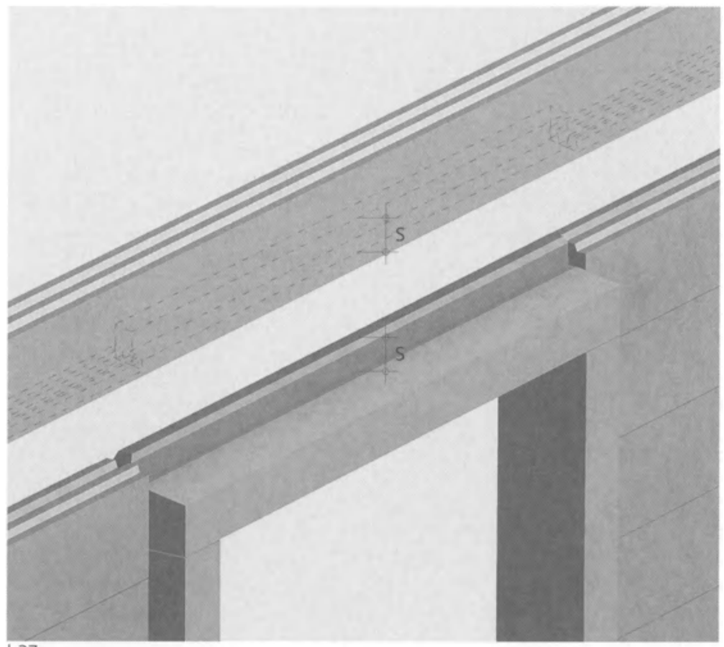
b36

modern standards of living – which guarantees that this form of construction maintains its independence, the design rules are upheld, and the characteristic regional features are preserved.

However, log structures that are erected where log construction is not one of the traditional forms do not correspond with our view of contemporary building. Nevertheless, this happens again and again. Furthermore, these "alien" structures are usually planned and built without observing the rules of log construction based on centuries of experience. Traditional log construction belongs to the particular environment, i.e. in mountainous regions, and it requires specialists who are in the position of being able to design and erect such buildings properly.

Settling allowance

In log construction settling allowances are attributed a special significance. Settling of up to 25 mm must be allowed for every storey, i.e. by way of constructional measures. Junctions with vertical masonry, e.g. a chimney stack, are constructed in such a way that the log wall can settle unhindered. Studs with free ends are used around openings like doors and windows. The building services must be installed in such a way that they remain unaffected by any settling.



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b3 20 Further development

Fig. b41 (p. 53) shows possible cross-sectional forms for log walls – a development that ranges from simple round logs to glued sandwich elements. "Imitation" log structures are also found in which a timber frame or timber studding serves as the loadbearing construction and the corners are built from solid timber sections. The external cladding is in the form of boards or planks which imitate the solid timber sections.

b3 21 Log construction with new types of building elements

In the past, the building envelope in log construction was a single layer which provided the cladding, enclosing and loadbearing functions. However, modern standards of living require a much higher level of insulation and comfort. These enhanced demands have led to the building envelopes and timber components common today, with several layers performing different functions.
Various systems, some of them prefabricated, can be used for log construction. Such systems are an attempt to unite thermal insu-

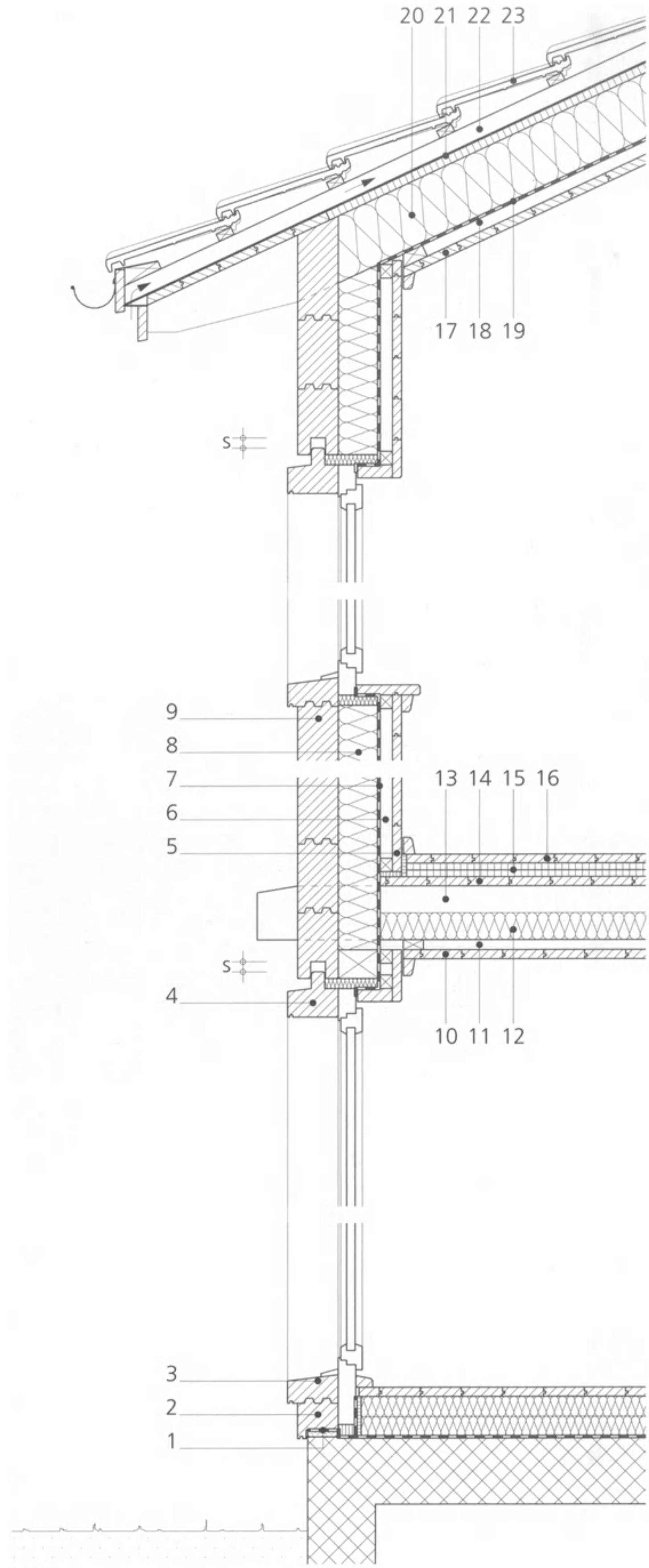
b34 Corner joint in traditional log construction

b35 Corner joint, double notch with projection

b36 Internal partition connection by means of dovetail housing joint

b37 Infill piece over door and window openings; s = settling allowance required lation, space for services, cladding or supporting frameworks plus the loadbearing construction in one element. The model for these structures is still traditional log construction with its horizontal logs stacked one upon the other. Assembled to form planar components, these elements constitute the actual core of a wall that is erected in a similar way to buildings of masonry or concrete. However, this form of construction is not widespread.

There is one pleasing development in mountainous regions, started by architects who design log structures with a great awareness of their regional importance and a new understanding for this form of construction (see Figs. b31 to b33, b39 and b40). Understanding the loadbearing and cladding functions as design potential has given log construction a new outlook. Corners and edges, projections and steps, joists and beams remain visible in this new approach. Architecture and construction in harmony.



b38

1 Mortar bed, damp proof course
2 Bottom plate
3 Window sill
4 Lintel
5 Internal lining
6 Framework of battens with space for services
7 Vapour barrier (with adaptive moisture properties), airtight membrane
8 Framework of battens with insulation between
9 Log wall (loadbearing structure)
10 Ceiling
11 Framework of battens with space for services
12 Sound insulation in void
13 Timber floor joists (loadbearing structure)
14 Structural sheathing
15 Impact sound insulation
16 Wooden floorboards or underlay for floor covering
17 Internal lining, ceiling
18 Framework of battens with space for services
19 Vapour barrier (with adaptive moisture properties), airtight membrane
20 Rafters (loadbearing structure) with insulation between
21 Secondary waterproofing layer, possibly additional insulation
22 Counter battens
23 Roof covering

b38 Section through construction: log construction, external wall showing window opening, junction with ground floor, suspended floor and roof;
s = settling allowance required; the compact wall construction and the junctions are generally difficult.

The construction shown here corresponds to a traditional form of log construction with internal thermal insulation. Independent, multi-layer wall constructions are now recommended for new buildings.

b39

The features of log construction

- Highly skilled labour
- Careful selection of wood
- Artistic corner joints
- Rigid plan layout
- High timber consumption
- Settling allowance

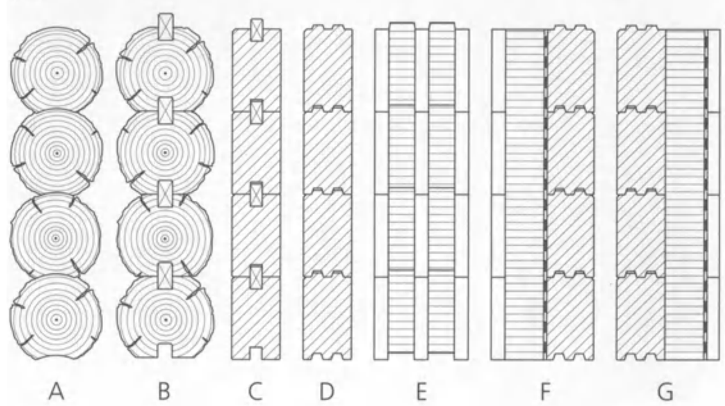
Multi-storey buildings in log construction

- Old, well-preserved buildings demonstrate the possibilities of building multi-storey structures.
- Design and construction should be such that settling does not cause any detrimental effects.
- For constructional and economic reasons, multi-storey log construction buildings are virtually a thing of the past.

b40

Development (Fig. b41):

A Round logs
B Round logs with bearing faces and joined with loose tongues
C + D Squared sections with loose tongue and groove or double tongue and groove joints
E Prefabricated sandwich elements
F Thermally insulated log wall: the layers are built on the building site in individual operations; the log wall remains visible internally and the facade cladding consists of solid timber and may need a ventilated cavity in some situations.
G Thermally insulated log wall: the layers are built on the building site in individual operations; the log wall remains visible externally and the internal lining consists of solid timber.



b41

b39 and b40 Modified log construction carefully integrated into the local built environment

b39 Private house in Rumein, Grisons, Switzerland

b40 Private house in Blatten, Valais, Switzerland

b41 The development of log construction in terms of the make-up of the wall (left: outside; right: inside)

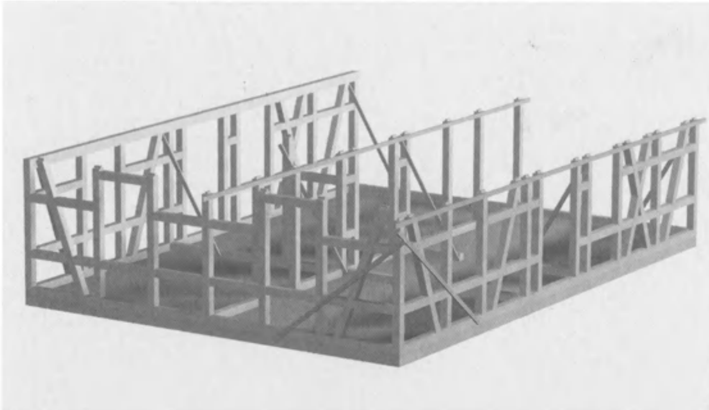
b4 Timber-frame construction

b4 10 Past and present

In many timber-frame structures the loadbearing timber framework remains visible. Timber-frame structures are found in many countries of Eastern and Central Europe, but also in England, northern Germany, Denmark and the Netherlands. In northern countries the timber frame is positioned on a regular grid and usually forms a rather closely spaced mesh of rectangles and squares, including the windows as an integral part of the system. The timber-frame construction of northern France is very similar in terms of its rigorous structure; however, the architecture and the proportions are different. In France in particular, it is the constructional logic that is emphasized; the decorative elements merely serve to underline the whole structure. A particularly rich tradition of timber-frame architecture can be seen in southern Germany and the neighbouring Swiss cantons of Thurgau, Zurich, Schaffhausen, Appenzell and St Gallen. Despite the fact that this tradition is not spread over a very wide area, the buildings exhibit numerous regional characteristics. Timber-frame construction initially developed in regions where timber was not available in the quantities required for log construction. In addition, timber-frame construction permits the use of the somewhat shorter components made from hardwood species. Up until the middle of the 19th century, most timber-frame structures were built so that the loadbearing framework (and hence the infilling) remained visible. But the rendering of timber-frame buildings in order to imitate stone and

b42

b42 Traditional timber-frame buildings in a rural setting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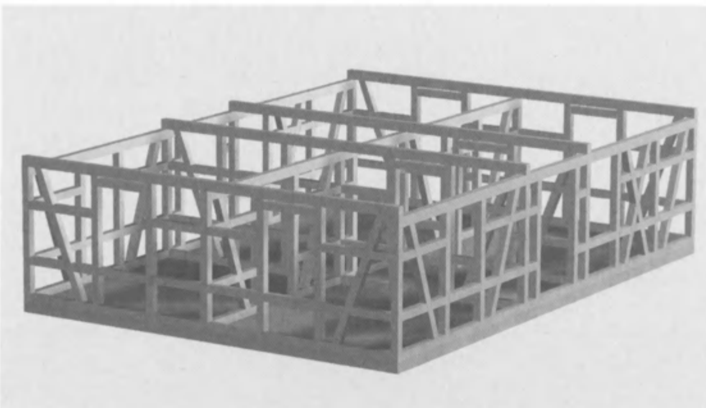
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brickwork had already begun in the towns before 1800 and became widespread in the second half of the 19th century. Builders believed that this gave their buildings an improved fire resistance, but there was also a desire to give an "urban" look to timber construction, which was regarded as a "rural" form of construction.

Timber-frame construction today

The traditional form of timber-frame with its visible external loadbearing structure is seldom employed any more for new buildings. Classical arrangements with diagonal braces have been superseded by the development of new wood-based products and board materials and also by methods of fabrication more interesting in terms of both economics and construction. However, carpenters are still familiar with the struts and angle braces of olden times. Timber-frame structures can still prove to be an economic solution in various situations such as agriculture or simple one- or two-storey utility buildings, albeit usually with the timber-frame concealed behind some form of cladding. For such buildings precise modern assembly machines or computer-controlled assembly plants, together with new findings and new methods for drying wood, have turned timber-frame construction into an economic building system for the aforementioned uses. Mortise and tenon and oblique dado joints are cheaper forms of connection than preformed sheet metal or steel parts. The reason for this is the fact that when timber members are placed close together, the connections carry only low loads. In addition, in timber-frame construction the vertical loads are transferred directly via contact between the faces of the timber components.

A selection of the most important construction principles and construction components is given below. Detailed information about timber-frame construction can be found in the book *Systembau mit Holz* [13].

The features of timber-frame construction

- The loadbearing framework can be clad on both sides, but traditionally it remains visible on the outside.
- Storey-by-storey form of construction
- Primarily wood joints with mortise and tenon, oblique dado and halving joints
- Structural timbers have a larger and usually square cross-section
- Simple assembly and erection

Multi-storey buildings in timber-frame construction

- Historical structures also demonstrate the reliability of timber-frame construction for multi-storey buildings.
- Construction should be designed so that settling is avoided as far as possible.
- Procuring the timber is costly and involved, and dried wood must be used.
- Construction must be protected from the weather during erection.
- Maintenance is expensive for externally exposed timber-frame structures.
- Multi-storey buildings in timber-frame construction are no longer advisable for reasons of cost but also because of problems with erection and construction.

b43 and b44 Building a timber-frame structure

b43 The head binders of the first longitudinal walls are already fitted.

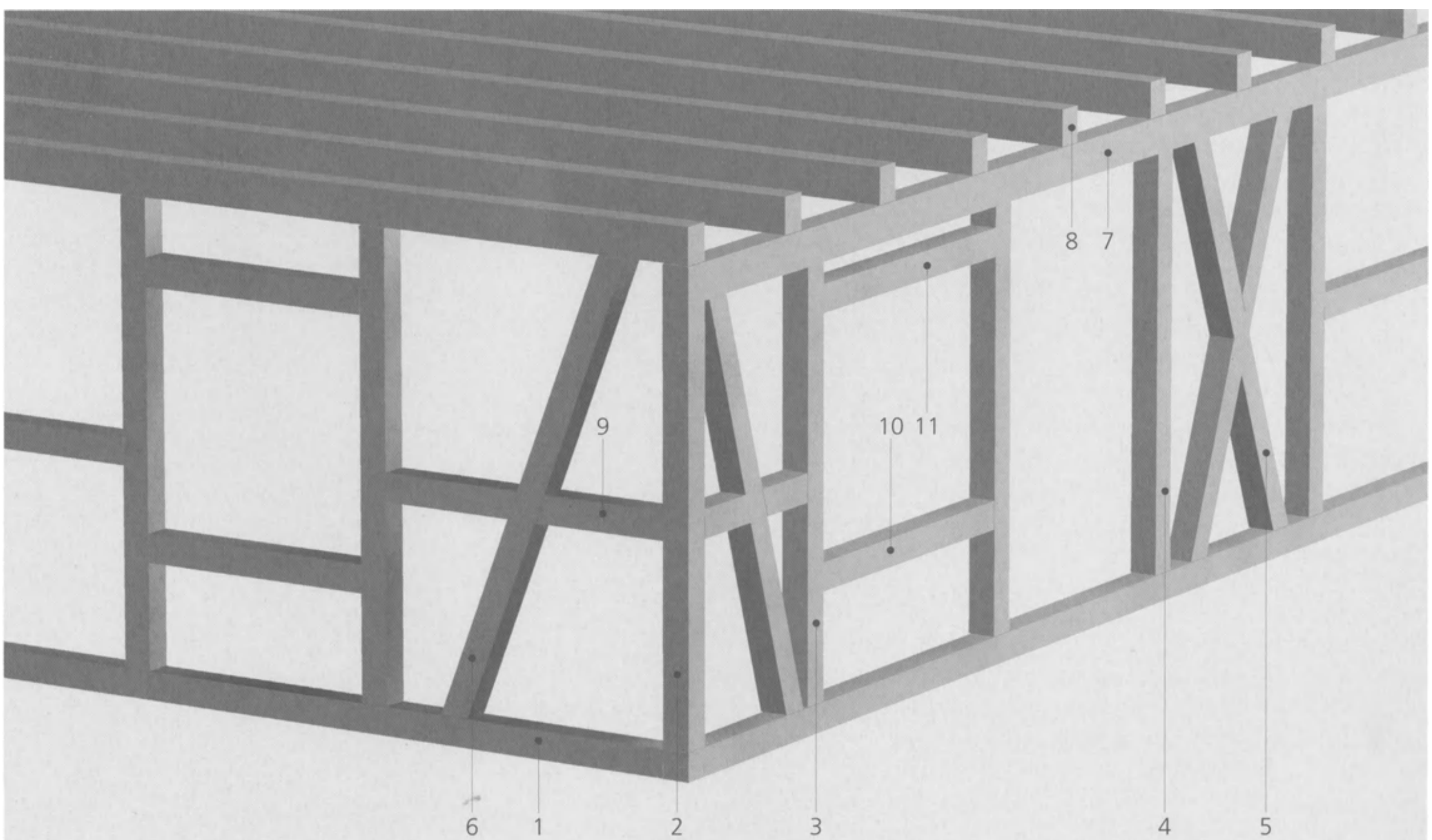
b44 The longitudinal and transverse walls are complete; the next phase would be to lay the timber joist first floor.

b4 20 The parts of the construction

Timber-frame walls consist of a rigid framework of squared sections for both internal and external walls. All structurally effective forces are transferred through these linear members; the infill panels of the past – now usually filled with insulating material – play no structural role. The wood joints can transfer compressive forces from member to member, but not tensile forces. In the past the wood joints, secured with wooden pegs, were sometimes very elaborate as well as decorative. Today, bottom plates and head binders are joined via halving joints, i.e. half of each member is cut away and then the two parts are overlapped. Studs, braces and rails are joined exclusively with mortise and tenon joints, although oblique dado joints may be necessary for braces carrying heavier loads. To prevent movement at the joints, nails are now often used and, occasionally screws, close-tolerance bolts, or shear-plate/split-ring connectors.

Bottom plate

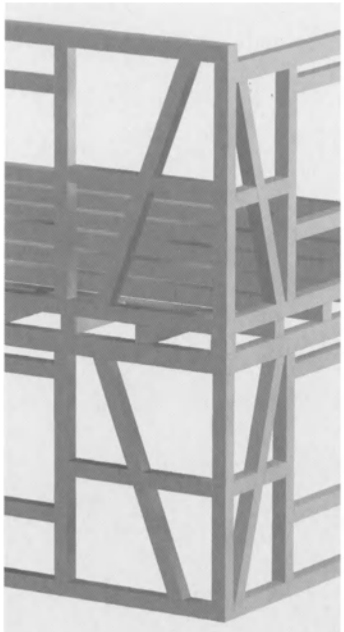
The bottom plate (also known as sole plate or sill) is the starting point of the timber-frame wall and is used to connect the wall to the ground floor construction. The bottom plate is supported over its entire length in the case of a concrete ground floor slab or a masonry plinth, or at individual, closely spaced points in the case of a timber joist ground floor. In either case the strength of the timber member is hardly used, except in the sense of compres-



b45

b45 The parts of a solid timber-frame wall

1 Bottom plate
2 Corner stud
3 Window jamb stud
4 Door jamb stud
5 Cross-bracing
6 Brace
7 Head binder
8 Joist
9 Rail
10 Window sill rail
11 Window lintel rail



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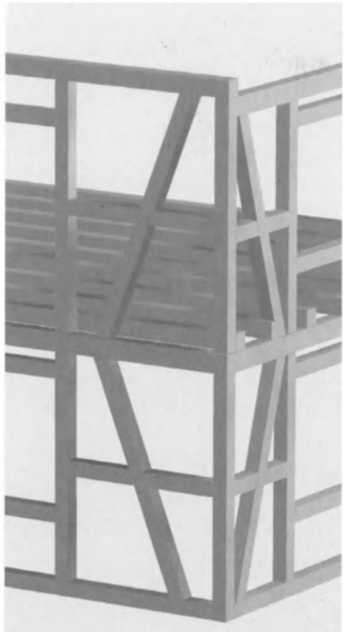


b47

sion perpendicular to the grain. This is why deep squared sections are not used for bottom plates, but rather sections placed on their broader side and with the sapwood side facing the ground.
Timber-frame walls mainly make use of spruce and fir. In the case of high compressive forces perpendicular to the grain, which can be the case with bottom plates, oak or beech may prove worthwhile, although beech may only be used when the construction is protected against the effects of moisture.

Studs

The vertical members in a timber-frame wall are generally called studs, but are sometimes referred to as posts or uprights. Studs also form the jambs to doors and windows and can be doubled up where heavier loads, e.g. from upper floor or roof, are to be carried locally. A cripple stud is an additional, shorter stud sometimes fitted alongside a principal stud in order to support a lintel over a door or window.
The spacing of the studs on plan depends on the arrangement of doors and windows. The positions of larger (or pairs of) studs for carrying heavier loads from the roof or suspended floors must also be determined.
The studs direct the forces vertically downwards. At the same time, the structure can be anchored to the foundations via the studs with fasteners capable of resisting tension. The normal spacing of studs in a standard wall lies between 800 and 1200 mm. In structural terms, the studs are also subjected to buckling and bending (wind loads). Calculations must take account of a weakening of the cross-section at the joints due to the mortises for the tenons.

Braces

Inclined bracing within the plane of the wall lends the timber-frame its necessary stiffness. Braces transfer the horizontal forces (e.g. wind) via the top and bottom plates to the supports. Braces are always arranged in pairs because they can only accommodate compression forces (and as such are struts).

Rails

The rails support the sheathing or cladding, or its supporting framework of battens. Depending on the arrangement and type of sheathing or cladding, rails may prove superfluous because they generally play no structural role in a timber-frame wall. The exception to this is where tall timber-frame walls require rails to prevent buckling of the studs. A structural analysis may be required if this is the case. Rails acting as lintels and sills trimming the doors and windows are, however, always necessary. They can be used to attach the doors and windows and the adjoining sheathing or cladding.

Top plate, head binder

Top plates and head binders align the studs and hold them in position, and form the top of the timber-frame wall. The head binder also acts as the support for floor joists and rafters. It therefore carries the loads of a suspended floor or the roof, which it transfers to the studs below.

b4 30 Settling allowance

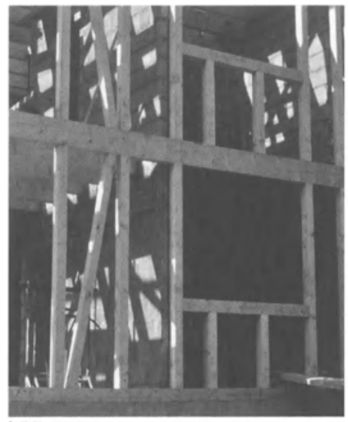
Due to the inclusion of horizontal timber members, a timber-frame wall exhibits a relatively large amount of shrinkage. The shrinkage and swelling movements of timber in radial and tangential directions are 10 to 20 times larger than those in a longitudinal direction. The amount of shrinkage of horizontal bottom and top plates, head binders, and floor joists in radial and tangential directions has a particular influence on the settling allowance (Fig. b46). The settling allowance is the difference in the height between a timber-frame wall at the time of assembly and its height after erection, i.e. when the timber members have adjusted to the equilibrium moisture content. The higher the moisture content of the wood during assembly, the higher the settling

b46 and b47 Timber-frame walls with timber joist floor

b46 The settling allowances are essentially determined by the timber sections installed horizontally, e.g. bottom plates, joists and head binders. The correct moisture content of the wood during construction (i.e. degree of drying) is also important.

b47 The studs and braces are connected directly to the head binder of the lower wall; the number of horizontal timber sections is thus minimised, which allows the settling allowance to be reduced.

b4 Timber-frame construction



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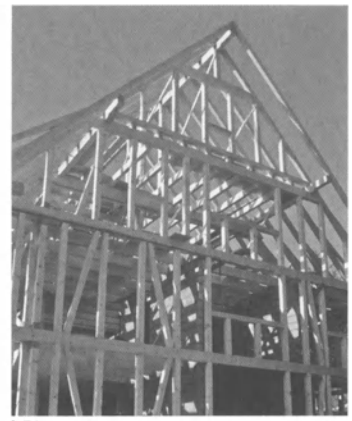

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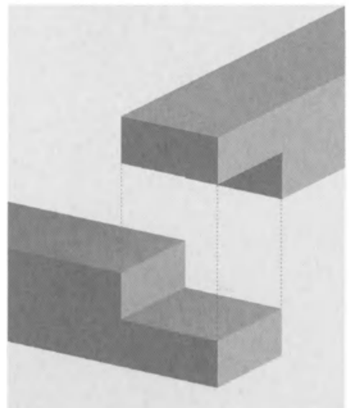

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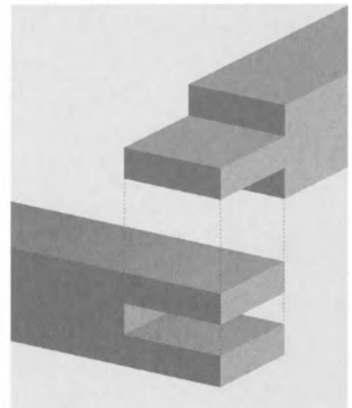

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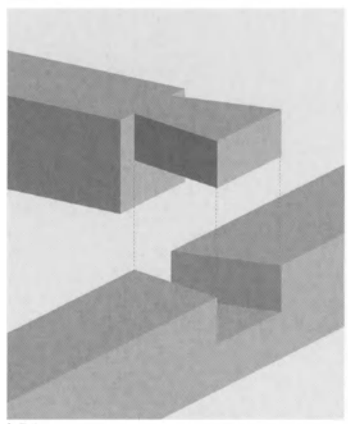

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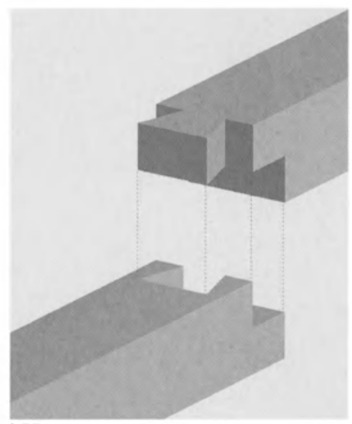

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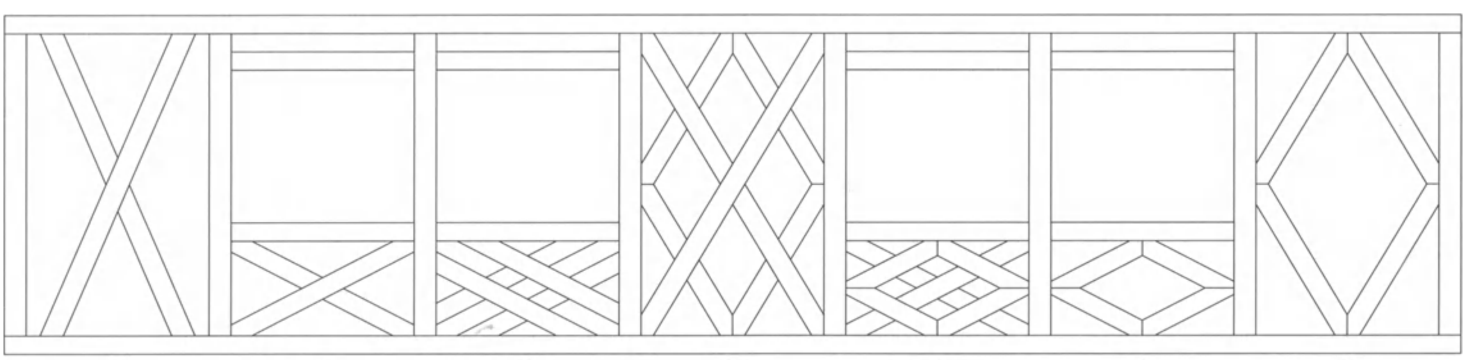

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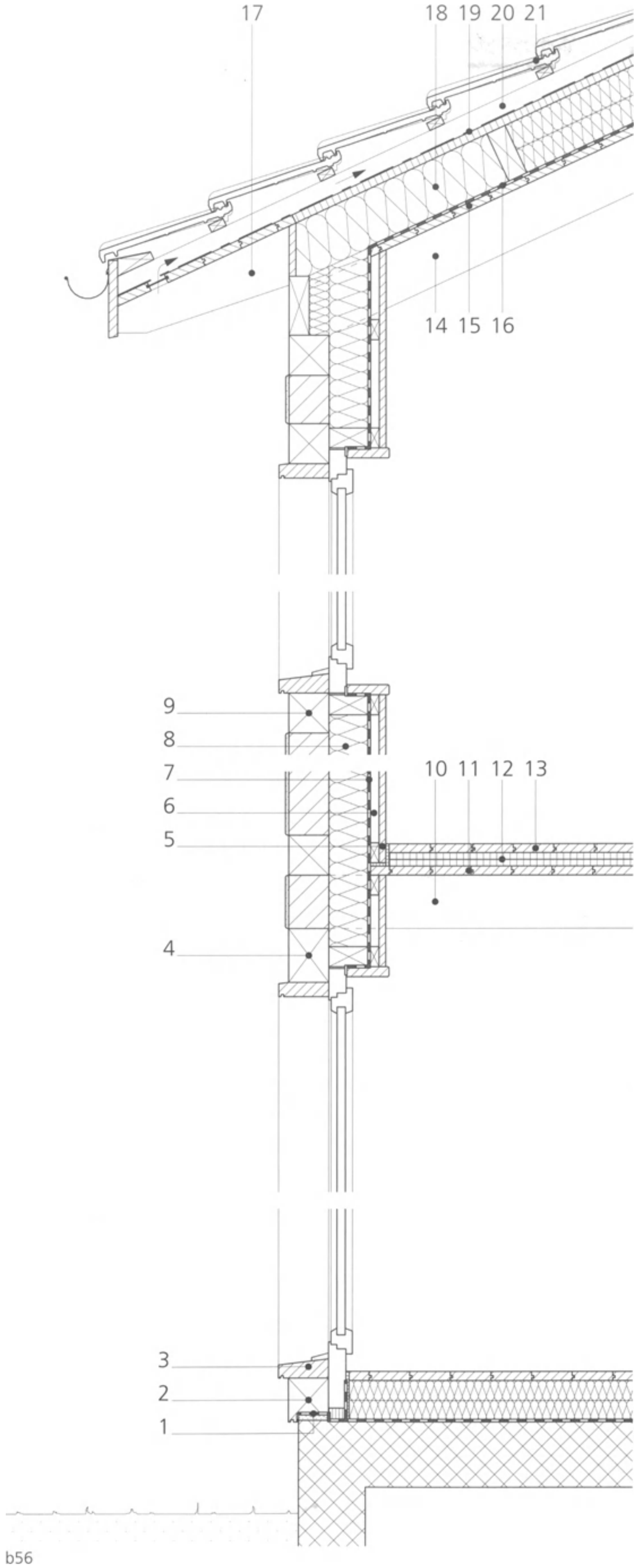
b48 Wood joints are used almost exclusively in timber-frame construction.
b49 Traditional constructions for bracing a timber-frame wall; the various inclined braces installed are also key decorative elements of a timber-frame building:

A + B Cross-bracing
C Double cross-bracing
D + E Cross-bracing plus diamond
F + G Diamond

b50 View of bracing and rails in timber-frame construction
b51 A completed timber-frame house; the work proceeds storey by storey.

b52 to b55 Wood joints
b52 Halved corner joint
b53 Bridle joint
b54 Through dovetail joint
b55 Dovetail plus overlap



allowance of a timber-frame wall will be. The use of specially developed types of construction with a minimum number of horizontal members (Fig. b47) is an attempt to minimise the settling allowance when using insufficiently dried timber. This is possible, provided the subsequent drying-out of the timber is guaranteed and any deformations will not be detrimental. The right way of dealing with the settling allowance and avoiding deformations, however, is to build the wall with properly dried wood. These days, the normal requirement is that the moisture content of the timber should have reached the level required for the final purpose of the timber by the time the timber is processed. In addition, timber that is installed next to the thermal insulation layer but does not adjacent to a ventilated space must exhibit a moisture content less than 16% by wt. at the time of installation (see chapter d1 "Moisture content"). In the case of multi-storey buildings, the timber should certainly be kiln-dried to an average value of 12–15%, and possibly even lower, depending on the particular structure. Kiln-dried timber or glued laminated timber is also necessary for all parts of construction that remain exposed.

1 Mortar bed, damp proof course
2 Bottom plate
3 Window sill
4 Lintel
5 Internal lining
6 Framework of battens with space for services
7 Vapour barrier (with adaptive moisture properties), airtight membrane
8 Framework of battens with insulation between
9 Timber-frame wall (loadbearing structure) with infill panels
10 Timber joist floor (loadbearing)
11 Structural sheathing
12 Impact sound insulation
13 Wooden floorboards or underlay for floor covering
14 Rafters (loadbearing structure)
15 Soffit lining
16 Vapour barrier, airtight membrane
17 Rafter extension
18 Thermal insulation
19 Secondary waterproofing layer, possibly additional insulation
20 Counter battens
21 Roof covering (tiles)

b56 Section through building: timber-frame construction, external wall showing window opening, junction with ground floor, suspended floor and roof. Wall construction and junctions are regarded as difficult in terms of durability and are only suitable when used in conjunction with constructional measures such as generous oversailing eaves.

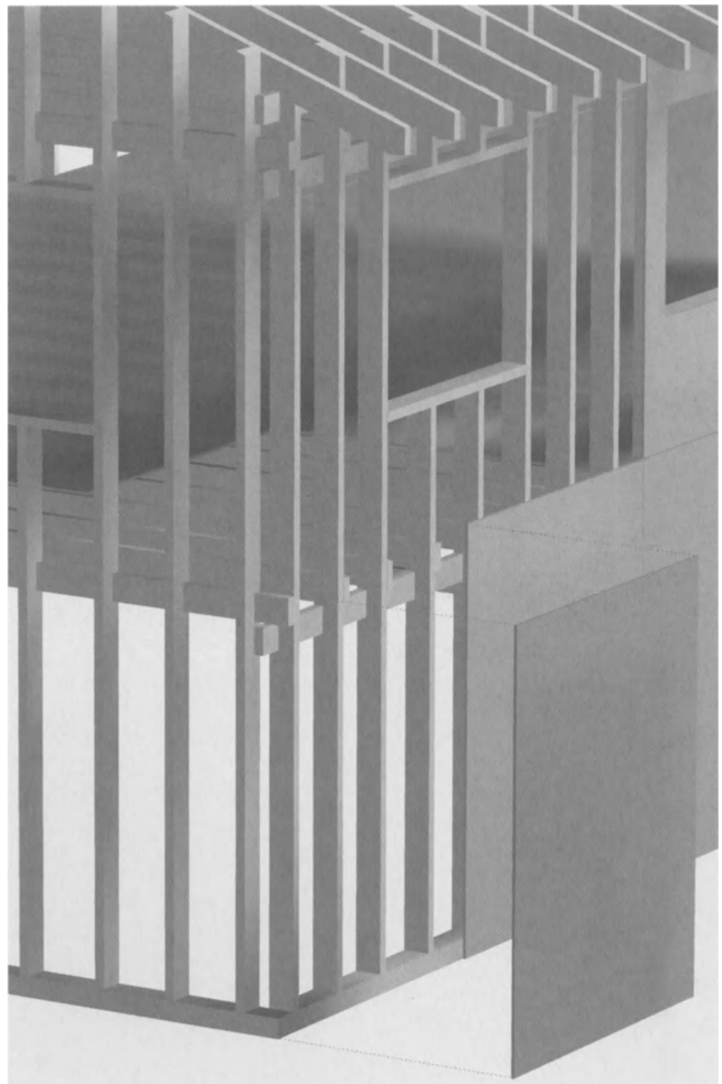
b5 Balloon frame, platform frame

b5 10 Two basic forms

Numerous new machine-based means of production supplanted conventional manual techniques to a large extent by the middle of the 19th century. Together with the much less expensive transport options that started to appear around the end of the 19th century, this led to new materials becoming available that had hitherto been inconceivable. The effects of this were felt in architecture and construction technology as well. New ideas replaced traditional ones, and timber structures were for a time unfashionable in Europe. In the rapidly developing United States, with its huge demand for quickly erected buildings, a special form of timber construction and architecture enjoyed a breakthrough around 1850: the balloon frame. One of the reasons for its success was the steam-powered, industrial mass production of nails. The balloon frame, a structure of timber ribs, consists of closely spaced timber studs which are stiffened by planks or boards nailed to them. Two forms of construction became popular in North America:

Balloon frame
In the balloon-frame system (Fig. b57) the ribs (i.e. studs) of the wall continue over two or more storeys. Horizontal members (bottom plates and head binders) form the top and bottom terminations. The joists for suspended floors are supported on a horizontal binder let into notches cut in the vertical studs.

Platform frame
The particular feature of the platform frame (Fig. b58) is its assembly in storey-high sections. The platform can be used during erection as a working platform by all the trades on the building site. The platform-frame system is still a common method of building in North America for one-and two-storey houses. This building system presents options for standardisation and prefabrication, and allows for the use of standardised building components. Furthermore, it is a very flexible form of construction in terms of both design and architecture.



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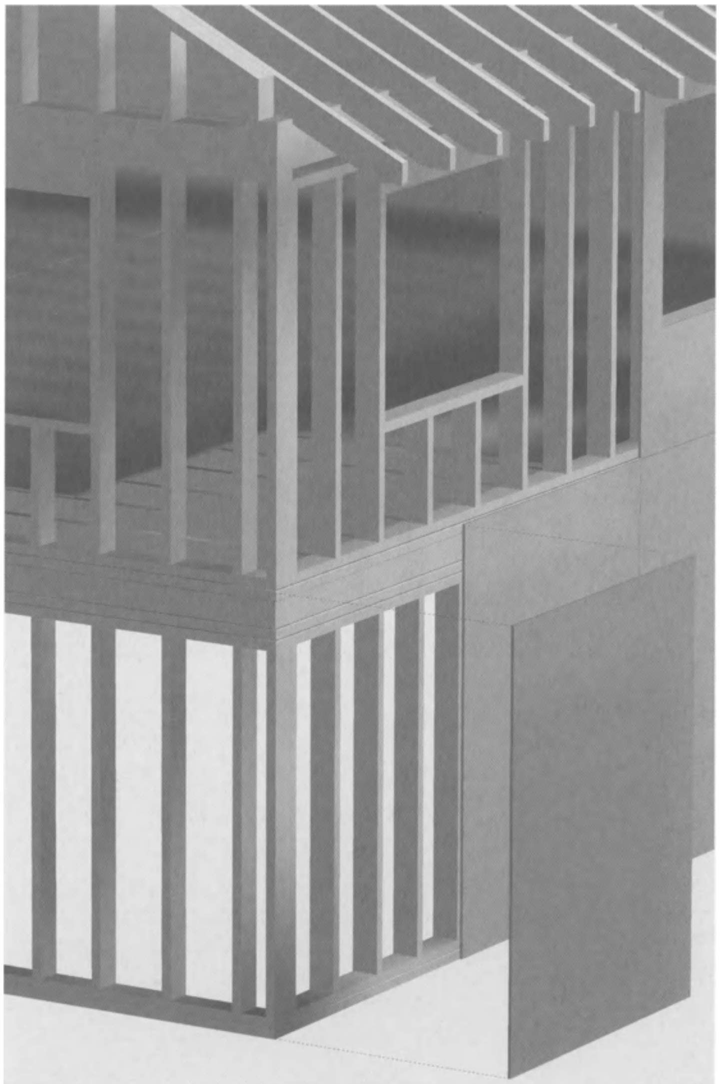
Timber stud construction – panel construction
Inspired by American experiences and successes, the first systems based on this model appeared in Europe around 1930 – and were designated timber stud construction. However, this form of timber construction has only really become widespread in Europe over the past two decades with the further development of previous forms of timber stud construction and the introduction of prefabricated panel construction. However, this takes place in a totally different manufacturing structure to that of the United States and in a way more suitable to European conditions and quality demands.

The timber panel construction (see chapter b6) now practised in the countries of Central Europe has definite advantages. It has been particularly successful in Germany and Switzerland.

b57 Balloon frame construction with continuous vertical studs



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The features of timber stud construction

- Low manufacturing depth, high labour input on the building site
- Building braced by planks or cladding
- Construction clad on both sides
- Slender, tall cross-sections
- Close spacing of uprights

Multi-storey buildings in timber stud construction

- In Canada and the United States multi-storey buildings are erected using the platform-frame form of construction.
- Due to the low degree of prefabrication, the erection phase is relatively long and protection against the weather must be considered.
- Construction should be designed to avoid settling.
- This form of construction is hardly used in Europe.

b5 20 Timber stud construction today

The timber stud structures built towards the end of the 1920s in Europe according to the model of the American construction systems developed over time into different construction systems. The older timber-frame type of construction was therefore given further development potential. Certainly the most important difference between timber stud construction and timber-frame construction is the way the structure is braced. The loadbearing framework of a timber-frame structure is itself stiffened by the inclusion of inclined braces, whereas in timber stud construction the loadbearing framework is given the necessary stability by attaching solid timber sheathing to the outside, or by wood-based board products, and the vertical loadbearing members continue over the full height of the building (balloon frame). In timber stud construction the connections are achieved via direct contact between the timber members (compression), through nailing, through lap and halving joints, and in some cases by way of mortise and tenon joints. Today timber stud construction and balloon frame or platform frame construction have been superseded in Europe by panel construction due to its far superior quality.

b58 Platform frame construction with storey-by-storey assembly

b6 Panel construction

b6 10 General

The loadbearing structure in panel construction consists of loadbearing ribs of squared sections and a sheathing that stabilises the ribs. The individual straight vertical members carry the vertical loads from roof and suspended floors, whereas sheathing these members with wood-based board products resists the horizontal forces due to wind and the effects of bracing.
The basic idea behind modern panel construction relates to prefabrication in the factory, where various wall, floor and roof assemblies are planned and manufactured as elements to suit different building uses. As was customary with the predecessor of panel construction, the platform frame, structures built using panel construction are planned, designed, manufactured and erected storey by storey.
The fabrication of the elements is carried out in production buildings, i.e. in an indoor climate which offers optimum working conditions. Computer-controlled materials-handling and production facilities are available to ensure accurate fabrication. Appropriate and powerful lifting and transport equipment is used for transport and erection processes. Thanks to such aids, prefabricated elements with dimensions significantly greater than those of the past are now possible. However, the constraints of road transport still limit the maximum sizes of components that can be delivered by road. The transport conditions should therefore be considered right from the planning stage. Erection is very fast, i.e. one or two days for a detached house.

Today's panel construction

Panel construction, which grew out of balloon-frame and platform-frame forms of construction, has long since become a customary, proven, and everyday building system in the United States, Canada and Scandinavia. According to estimates, up to 90% of all detached one- and two-storey houses in those countries are built using this method of construction. In Central Europe the market share for timber panel construction is also rising steadily. The Federation of German Master Carpenters published its first catalogue for this form of construction, *Holzrahmenbau* [14], in 1985 (the fourth, revised edition appeared in 2006); it is a useful aid for building designers and contractors. In Switzerland, a publication

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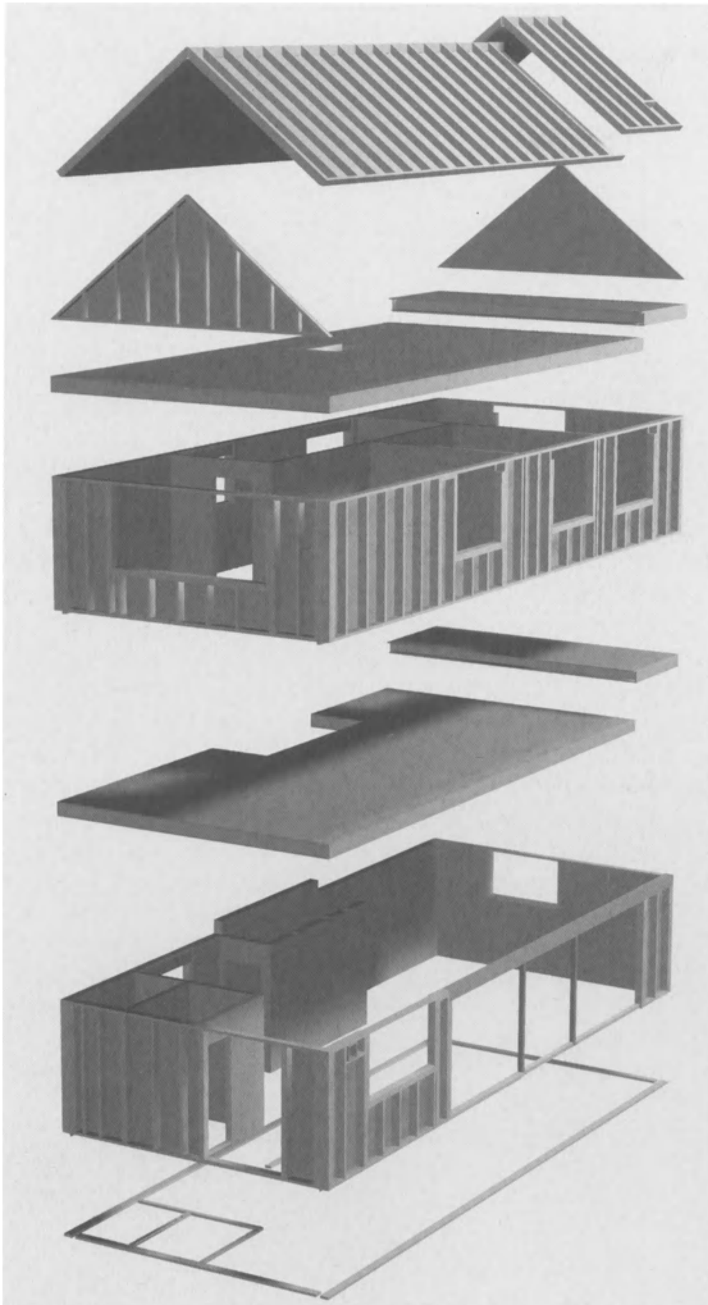
b59 Timber structures in panel construction; housing estate in Karlsruhe, Germany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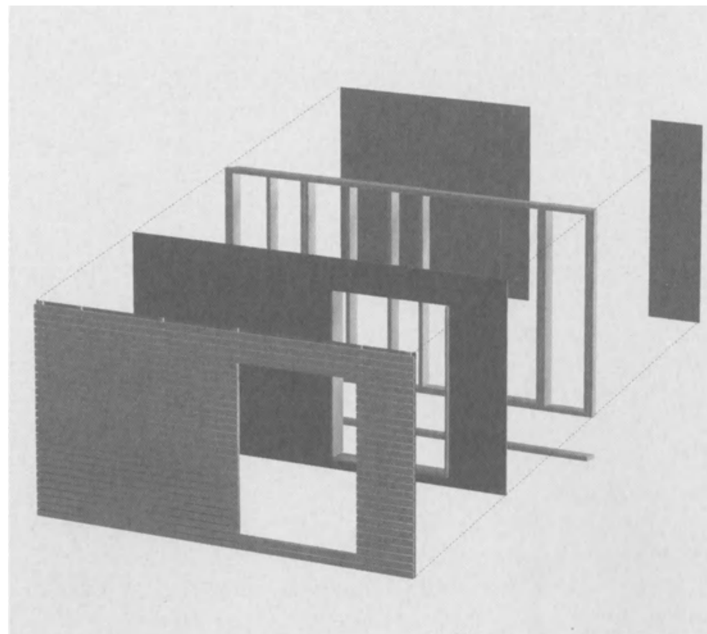
with the same name [15], and designed to encourage this form of construction, was first published in 1988.

In many respects, the external appearance of buildings designed for this form of construction does not conform with the traditional Central European notion of a timber building. The loadbearing ribs of panel construction remain completely concealed, both inside and outside. Facade cladding is frequently of wood-based board products or solid timber, with good, long-lasting protection in the form of opaque surface treatments. And the structural carcass of a building in panel construction is in some locations finished with a thermal insulation composite system (insulation + render). The inner lining of the walls is made up of wood-based board prod-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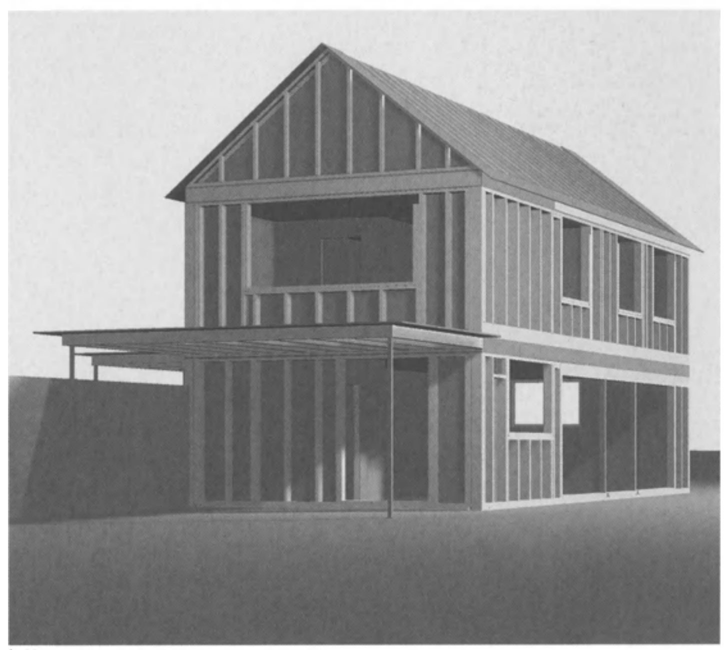
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b60 to b62 Construction principle of panel construction: loadbearing ribs with stabilising sheathing and storey-by-storey assembly

b60 Exploded view showing individual structural elements

b61 Exploded view showing the individual components of a wall

b62 View of assembled building without external sheathing

b6 Panel construction


b63

ucts, gypsum fibreboard, or plasterboard plastered white and then finished with a coat of paint or wallpaper. Panel construction, primarily a standardised form of building, has only become typical on the building market over the past two decades – and can now be regarded as an established form. In some respects the traditions of and conditions prevalent in Central Europe seem to differ from those in the countries where panel construction originated, and therefore the characteristics of this timber construction system have been adapted to suit those conditions. It is therefore reasonable to assume that owing to its economic benefits, simple construction and architectural freedoms within the system, this building system will continue to gain ground. In addition, the timber sections employed and the board-type wood and gypsum materials used can always be supplied in good quality at short notice. In Switzerland and its neighbouring countries, as well as in Scandinavia, Canada, and the United States, multi-storey buildings in panel construction have already been built. The experience gained is very positive and demonstrates that with a modified form of panel construction, multi-storey buildings are possible too. Technical solutions in sound insulation and fire protection, in structural engineering and building physics aspects, but also in fabrication and erection, have proved worthwhile. These are described below.

The features of panel construction
- Design freedoms
- Simple form of construction
- Repetitive details
- Loadbearing ribs of slender, standardised sections
- Building braced by sheathing
- Simple materials procurement
- Storey-by-storey assembly
- Connections achieved by direct contact and with mechanical fasteners
- Modular dimension 400–700 mm, preferably 625 mm
- Construction clad both sides
- Short on-site time, different manufacturing depths possible

Multi-storey buildings in panel construction
- Well suited (in a modified form)
- Choose a structural system not susceptible to settlement.
- Optimise details, also with respect to settlement behaviour.
- If possible, avoid combining different materials (composite construction).
- Accuracy of fabrication and erection is a top priority.
- Early involvement of specialist engineers is essential.

Chapter b11 contains further information regarding multi-storey building in timber.

b6 20 The parts of the construction

For one- and two-storey buildings, timber sections measuring 60 x 120 mm are sufficient for the structural members. This could therefore be the basic element from which the main structure of the building is constructed: a squared section measuring 60 x 120 mm. However, thermal insulation thicker than 120 mm is now often required in the external walls. The depth of the section must therefore either be increased from 120 to 160, 180, 200 mm, etc., or a second layer of insulation, independent of the loadbearing construction, must be added. As the addition of a second insulating layer also eliminates thermal bridges, this variation is the clear favourite. A hybrid solution, i.e. a deeper loadbearing construction plus a second layer of insulation on the outside, is also possible (see section b6 41 "Wall construction"). In the case of multi-storey panel construction, larger sections will be needed for structural reasons anyway.

In panel construction, the main components are as follows:

Loadbearing ribs
Structural timber (solid timber, compound sections), strength grade C24
  Species: spruce, fir
  Moisture content: 12% ± 2%
To ensure good dimensional stability, the use of compound (solid) sections is recommended for panel construction.

b63 Students' accommodation in panel construction, Lausanne, Switzerland

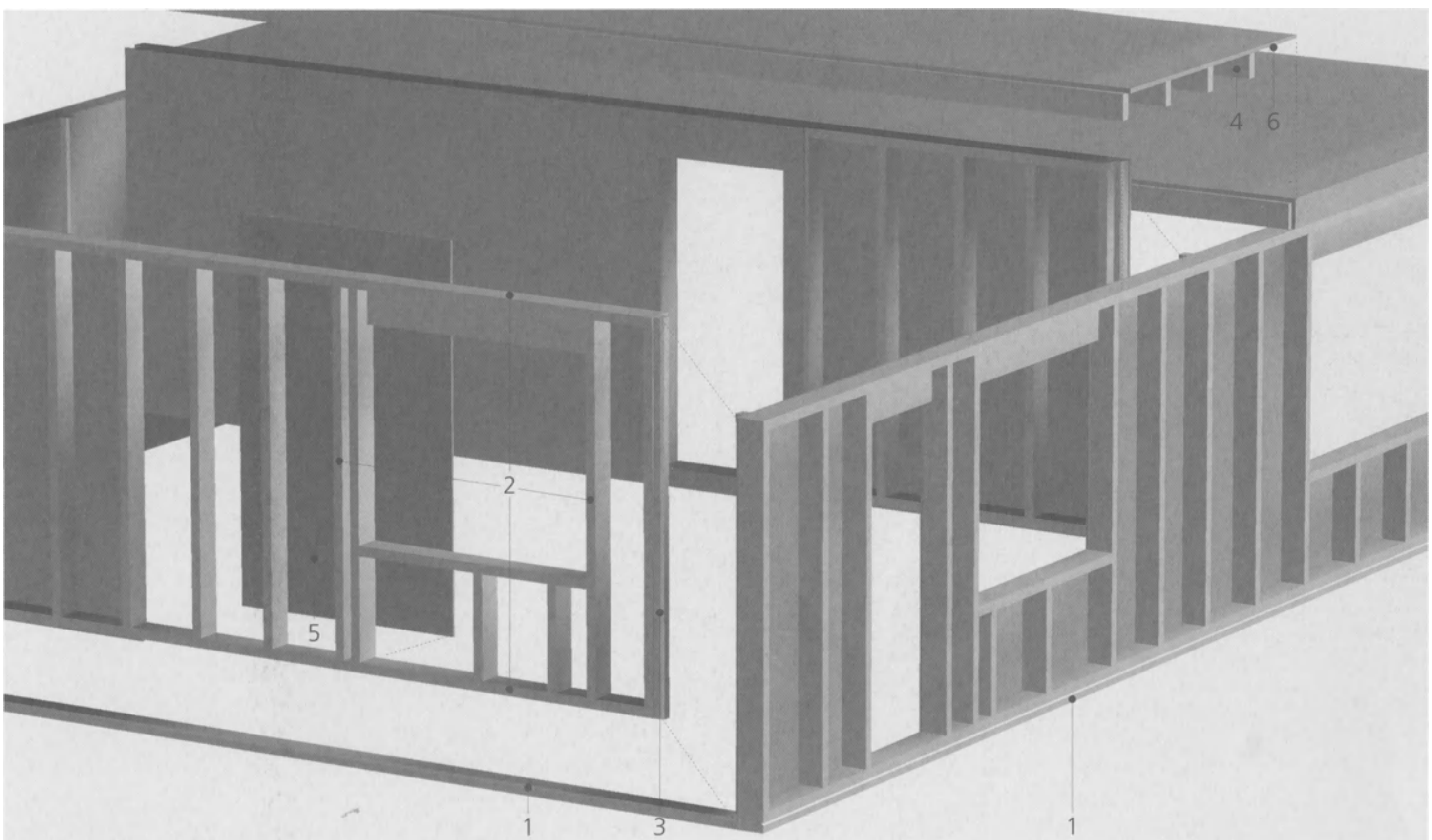
b64

Stiffening wall and floor sheathing
- 3-ply core plywood
- OSB, MDF, particleboard
- Gypsum fibreboard
- Veneer plywood

Thermal insulation
- Mineral-fibre boards
- Cellulose fibres
- Wood fibreboards
- Diverse insulating materials

b6 30 Settling allowance

The settling allowance is governed by the number and dimensions of the timber sections installed horizontally (shrinkage and deformation caused by compression perpendicular to the grain). The higher the proportion of horizontal timber members, the more attention needs to be paid to this aspect. In panel construction, the proportion of horizontal timber components such as top and bottom plates, and joists accounts for between 240 and 500 mm per storey. This means that only dried timber (moisture content around 12%) should be installed. And in the case of multi-storey buildings, further constructional measures are required (see chapter b11).



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b64 Scout troop accommodation in panel construction, Baden, Switzerland

b65 The parts of panel construction elements

1 Base plate
2 Bottom and top plates, studs
3 Assembly post
4 Rib, joist
5 Structural wall sheathing
6 Structural floor sheathing

Note: The separate head binder often used in the past is now generally combined with the top of the wall construction.

b6 40 Building structure and wall construction

b6 41 Wall construction

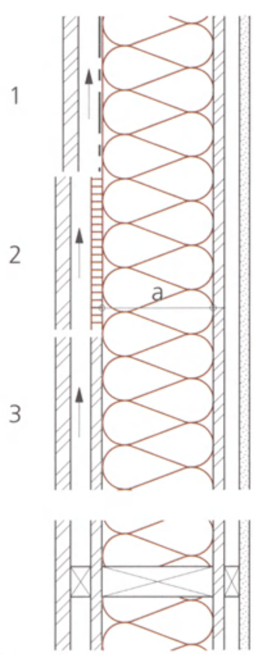
The wall construction varies depending on the thermal performance requirements placed on the building envelope, and also depending on the specification for the inner lining and the wall construction on the outside. In recent years, different types of construction have been seen. The choice of the right wall construction is governed by the use of the building, the building physics, and energy-related requirements, and the demands placed on the quality of the wall construction. The building physics values can be found in section c3 "External walls".

Loadbearing structure and position of insulation

(Figs. b66 to b72)

Loadbearing walls built using timber sections measuring 60 x 120 mm are suitable for the majority of cases. Top and bottom plates – the continuous longitudinal components – can also be made from timber sections measuring 60 x 120 mm, but placed horizontally. Walls carrying heavy loads or subject to special requirements might need stud sections measuring 80 x 120 mm or even larger. A structural analysis will be necessary to determine the dimensions required in the case of heavy loads (e.g. in multi-storey structures), larger openings (e.g. for windows), or other specific deviations on plan or elevation, or in the case of high snow loads.

Today, higher demands are placed on thermal insulation than a stud depth of 120 mm will allow for, and this determines the thickness of the wall. Accordingly, deeper sections, usually 160 to 220 mm, are specified in many cases together with a second, continuous layer of insulation (as already mentioned in b6 20 "The parts of the construction"). This form of construction, which is becoming ever more popular, results in, for example, a loadbearing depth of 160 mm and an additional layer of insulation 40, 60 or 80 mm thick (or even more) on the outside (i.e. cold side). This external insulation is made from wood-fibre insulating materials, cellulose, or from mineral wool. The advantage of wood-fibre insulating materials is that they are usually of such a density that a framework of battens – essential for insulating materials with a low compressive strength – is unnecessary. Figs. b66 to b72 show



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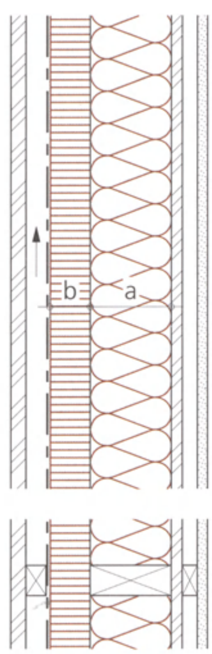

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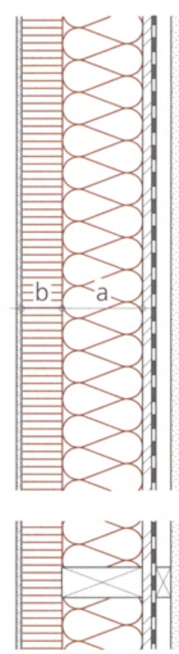

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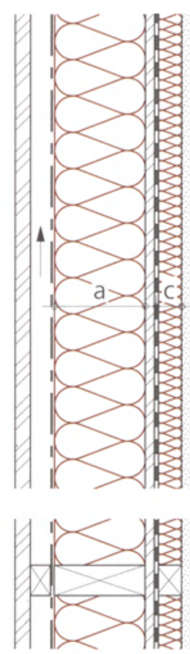


b69

b66 External wall construction with one layer of insulation (a). (left = outside, top = vert. section, bottom = horiz. section)
1 to 3 Different arrangements of outer face of loadbearing structure (layer protecting insulation)
1 Sheeting
2 Wood-fibre insulating board
3 Wood-based product/gyps. fibreboard

b67 External wall construction with two layers of insulation (a and b). The thickness of insulation layer b can be determined according to the thermal performance requirements irrespective of the loadbearing structure. Thermal bridges are easily eliminated in this system.

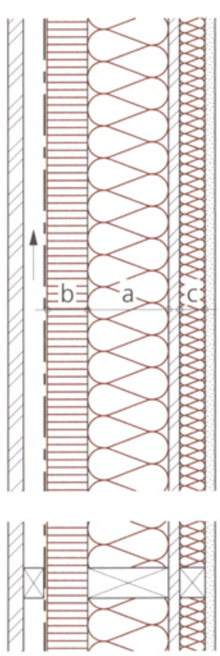
b68 External wall construction with two layers of insulation (a & b). Insulation layer b formed by thermal insulation composite system (insulation + render). Insulation layer b thickness can be determined according to thermal requirements irrespective of loadbearing structure.

b69 External wall construction with additional insulation in the space for services (c). The thickness of insulation layer c depends on the overall thickness of this space.

the variations for one, two, or even three layers of insulation in various combinations.

In order to improve the U-value, insulation can also be placed between the battens and in the space for services (Figs. b69 and b70). This results in a different position for the airtight membrane and the vapour barrier (separate functions, see chapters c1, c2). Special attention must therefore be paid to building physics aspects in order to ensure that no damaging condensation forms within the construction of the wall itself. However, such an analysis is unnecessary when there is no additional thermal insulation on the inside of the airtight membrane and vapour barrier. In practice, the form of construction with insulation between the battens and in the space for services is, however, rare. External insulation, as shown in Figs. b67 and b68, is straightforward in terms of building physics and can be readily adapted to achieve the desired U-values, which can be 0.15 W/m²K (or even lower). The U-values of wall components can be found in section c3 "External walls".

Consequently, insulation for modern panel construction buildings is preferably arranged in two layers. The first of these is in the plane of the loadbearing elements and the second is attached to the outside face of the loadbearing elements (Figs. b67 and b68). This ensures an uninterrupted layer of insulation at the junctions with suspended floors and roof, and also at the building's corners. Thermal bridges, caused by the position of the timber sections within the loadbearing layer, are thus reduced to a minimum. Wall constructions with two or three layers of insulation are also suitable for structures complying with, for example, zero-energy, passive house, and the Swiss Minergie standards. In addition to the two- and three-layer methods, which are based on the conventional loadbearing principle of panel construction, further, modified forms can also be considered. Figs. b71 and b72 show wall construction and loadbearing system principles developed for highly insulated buildings.



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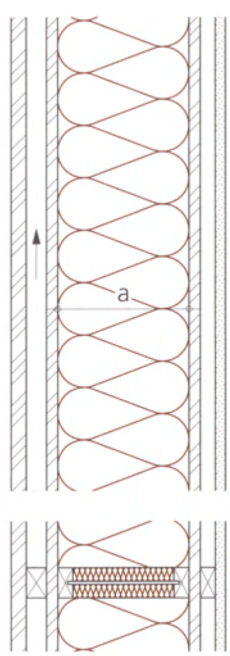

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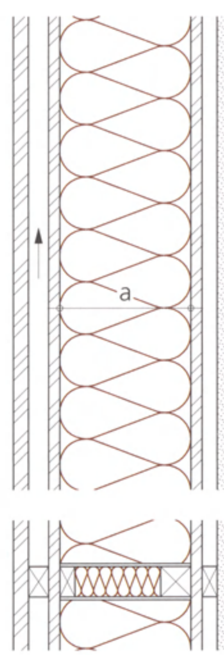


b72

b70 External wall construction with three layers of insulation: between structural members (a), attached to outside of structural members (b), in services space (c). Layer b thickness can be determined according to thermal requirements irrespective of structure. Layer c thickness depends on depth of services space.

b71 External wall construction with one layer of insulation (a). The thickness of insulation layer a depends on the depth of the structural members. In order to minimise thermal bridges, I-beams or other slender, glued compound structural timber members are used.

b72 External wall construction with one layer of insulation (a). This loadbearing system specially devised to minimise thermal bridges is made up of loadbearing structure, insulation and spacers. The thickness of insulation layer a depends on the depth of the structural members.

b6 Panel construction


b76

Loadbearing structure and position of structural sheathing (Figs. b73 to b75)

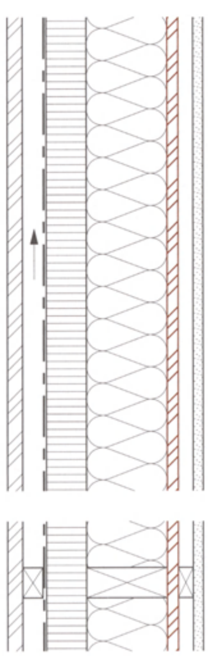
According to the traditional form of panel construction, the structural sheathing, structural in the sense that it is necessary for bracing the construction, is connected to the outside of the loadbearing ribs. However, in modern practice the structural sheathing is usually attached to the inside. This ensures that the loads can be transferred easily, and such a sequence of layers from inside to outside also results in advantages for the building physics. The structural sheathing can therefore also take on the functions of the airtight membrane and the vapour barrier.

The various positions of structural sheathing can be seen in Figs. b73 to b75 and are also discussed in section b6 50 "Structural engineering" (Figs. b113 and b114). Fig. b75 shows the version reduced to a minimum; the structural sheathing here also acts as airtight membrane, vapour barrier, and inner lining.

Battens, space for services and inner lining
(Figs. b77 to b80)

Further variations on this form of construction result from the arrangement and nature of the space for services and the inner lining. The supporting framework for the inner lining is generally in the form of a framework of battens, which at the same time provides space for building services because electric cables and similar installations have to be placed on the inside (i.e. warm side) of the airtight membrane (Figs. b78 and b80). The depth of the battens creates space for pipes and cables and at the same time this arrangement avoids having to penetrate the airtight membrane and the vapour barrier. A depth of 30 mm should be regarded as the absolute minimum for services, but 50 mm is better, and indeed power sockets and junction boxes require 60 mm. To improve the U-value even further, insulating material can be fitted between the battens, as described in "Loadbearing structure and position of insulation" (Figs. b69, b70, b78, b80).

Another construction option is to attach the internal sheathing, (the inner lining), directly as one layer (Fig. b77) or as two layers (Fig. b79) to the loadbearing members. The framework of battens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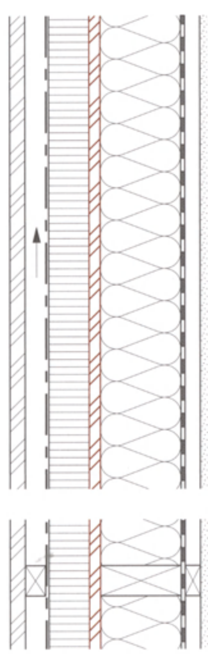
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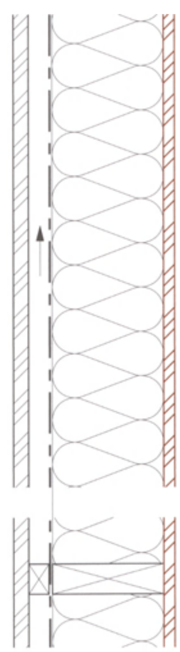
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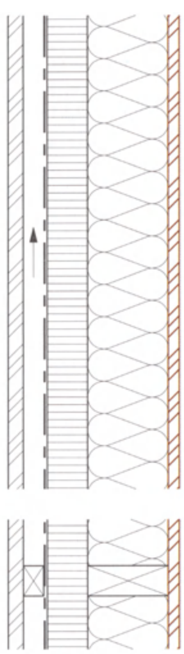
b73 External wall construction with structural sheathing on the inside. (left = outside, top = vertical section, bottom = horizontal section) In recent years, this form of construction has started to become more popular than that shown in b74.

b74 External wall construction with structural sheathing on the outside.

b75 External wall construction with structural sheathing on the inside. The sheathing bracing the building at the same time acts as airtight membrane, vapour barrier, and inner lining.

b76 Completed wall in panel construction is then no longer required, but the sheathing layers then have to perform several functions. In the case of the two-layer arrangement, the layer affixed directly to the loadbearing members is structural, i.e. braces the building, and the second layer forms the actual inner lining. The advantage of this type of construction lies in the more massive sheathing (because of the two layers). The disadvantages are that a different installation system is required for the building services and the compatibility of the two, adjacent layers of the sheathing must be checked. The optimum solution is to attach a framework of battens to the structural layer, to create a services space, and to attach a double layer of inner lining (Fig. b80).

Airtight membrane and vapour barrier (Figs. b81 to b84)
The diffusion resistance of the vapour barrier should generally be matched to the requirements of the outer layers. If the structural sheathing, for bracing the structure, is placed on the outside of the thermal insulation, the diffusion resistance of the vapour barrier requires careful consideration (Fig. b74). In the case of a normal panel construction wall (Figs. b81 to b84), a vapour barrier with a low diffusion resistance – but still matched to the requirements of the construction – to regulate the migration of water vapour from inside to outside (diffusion-equivalent air layer thickness s of approx. 2 to 5 m depending on application and function, but much higher or indeed even lower for special structures) is sufficient. Part c (section c1 33 "Moisture control") includes figures showing forms of construction that do not need to be assessed according to the Swiss standard SIA 180. In wet rooms (showers, bathrooms) and also at junctions between different components (especially external wall/suspended floor), the properties of this regulatory layer must be determined separately. At such junctions where the position of the vapour barrier changes (e.g. Figs. b90, b91, b93, b94), sheet materials with a variable diffusion resistance (PA sheeting, vapour control layer with adaptive moisture properties) are recommended.
As already mentioned, instead of sheet materials, board-type sheathing layers can serve as the airtight membrane and vapour barrier (Figs. b81 and b84). However, the function of the airtight membrane in this way is limited to the main surfaces of the wall; at junctions with suspended floors and roof, also around openings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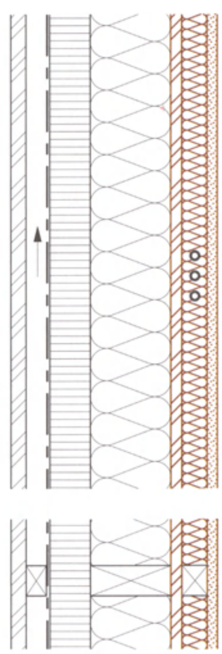
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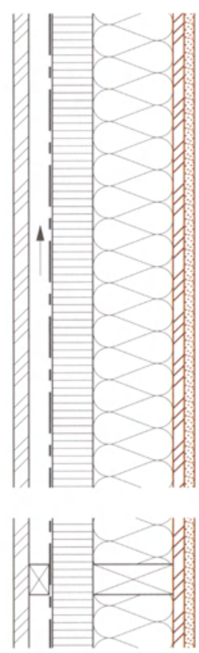
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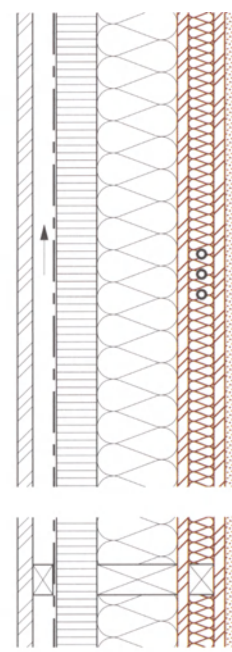

b80

b77 External wall construction with single layer of inner lining. The inner lining at the same time acts as airtight membrane, vapour barrier, and the sheathing bracing the building.

b78 External wall construction with single layer of inner lining on battens to create a space for services, and structural sheathing. The advantages of this form of construction lie in the clear separation and allocation of functions.

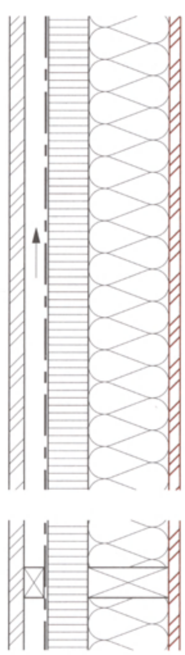
b79 External wall construction with two layers of inner lining. The inner lining and structural sheathing functional layers are separate.

b80 External wall construction with two layers of inner lining, separate framework of battens creating a space for services, and structural sheathing. This is the optimum variation, but the most costly and labour-intensive.

for doors and windows, board-type layers must be supplemented by sheet materials or other sealing concepts (see b6 42 "Junctions, walls, suspended floors, loadbearing structure", e.g. Figs. b89 to b94). And it is obvious that the airtight membrane and the vapour barrier, regardless of whether they are in the form of boards or flexible sheeting, must not be penetrated by building services, fixings or other components, and all junctions must be sealed tight. Part c contains further information regarding airtight membranes and vapour barriers, also on the conception, design, and construction of buildings with controlled airtightness.
Figs. b81 to b84 show different arrangements and materials for airtight membranes and vapour barriers.

b6 42 Junctions, walls, suspended floors, loadbearing structure (Figs. b85 to b88)
Figs. b85 to b88 illustrate four options for the junction between a suspended floor and an external wall, with particular reference to the loadbearing construction. In the first variation (Fig. b85) the suspended floor is supported on the full width of the loadbearing members of the external wall construction; it is easy to transfer the loads from the floor and the upper storeys. In variation two (Fig. b86) the suspended floor is not supported on the full width of the loadbearing members of the external wall construction. Consequently, insulation can be placed around the edge of the floor. In the third variation (Fig. b87) the suspended floor is fixed to the inside of the loadbearing members of the external wall construction and only the upper sheathing of the suspended floor construction continues into the external wall. In the final variation (Fig. b88) the suspended floor is supported on an additional inner leaf; thermal insulation, airtight membrane, vapour barrier, and entire external wall construction remain intact. Structural calculations are required for each of these support solutions; the eccentricity of the support must be taken into account.

Airtight membrane and vapour barrier
(Figs. b89 to b94)
The nature of panel construction means that the joists in a suspended floor, or a least individual layers of the suspended floor construction, penetrate the airtight membrane and vapour barrier. Part c of this book explains that such penetrations must be air-



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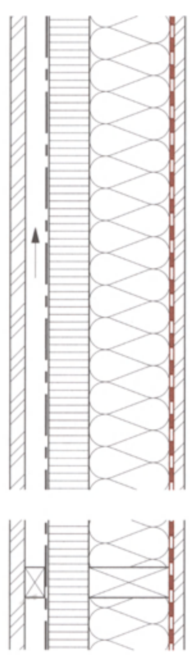

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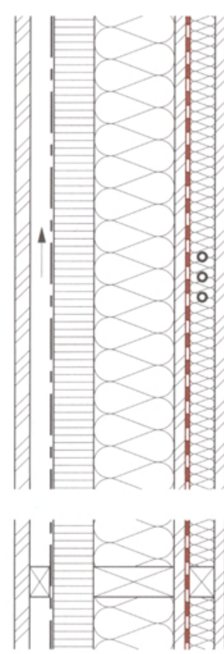

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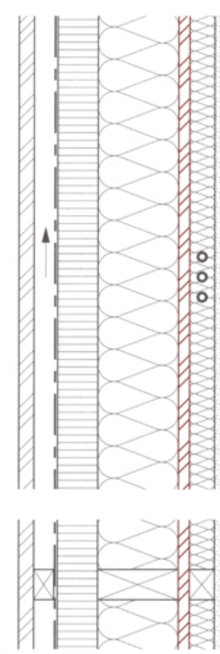

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b81 The inner lining and structural sheathing layers at the same time act as airtight membrane and vapour barrier. (left = outside, top = vertical section, bottom = horizontal section) Special care is required at junctions with other components, e.g. doors, windows, suspended floors, roof.

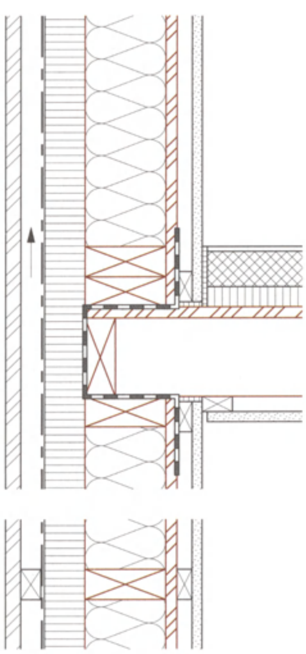
b82 Sheeting as airtight membrane and vapour barrier. This form of construction simplifies the details at junctions.

b83 Separate functional layers – the optimum arrangement. Sheeting is used for airtight membrane and vapour barrier. This form of construction simplifies the details at junctions.

b84 Mainly separate functions – the optimum arrangement. The structural sheathing also acts as airtight membrane and vapour barrier. Special care is required at junctions with other components, e.g. doors, windows, suspended floors, roof.

b86-1

tight, but that achieving this is not always easy. The forms of construction shown in Figs. b89 to b94 illustrate appropriate potential solutions for suspended floors.
Figs. b89 and b90 show two alternatives – matched to the type of construction – for supporting a suspended floor on the full width of the external wall construction (according to Fig. b85). In Fig. b89 the airtight membrane is fitted between and attached to every joist and to the floor sheathing. In Fig. b90 the airtight membrane (flexible sheeting) is laid around the floor construction during erection and glued to the airtight membrane of the wall during the later fitting out work. As this arrangement means that the airtight membrane and the vapour barrier pass through the cold area (i.e. outside the insulation), a layer of thermal insulation (min. 50 mm thick, otherwise a building physics analysis is necessary) must be attached on the outside. Besides the general improvement in the U-value, a layer of insulation on the outside also helps to prevent interstitial condensation at the junction with the suspended floor.
Fig. b91 shows a very practical solution corresponding to the support situation shown in Fig. b86. Just like the arrangements shown in Figs. b89 and b90, the junctions in Fig. b92 are fixed individually, or the airtight membrane and the vapour barrier are taken around the outside, as shown in Fig. b93. This in turn enables a combination with external insulation. Certainly the simplest configuration is that shown in Figs. b94 and b88, where the external wall continues uninterrupted past the junction. The suspended floor is supported on an inner leaf designed to take the load of the floor. External wall corners are shown on plan in Figs. b95 to b98. The corresponding wall constructions are explained in the captions to the drawings Figs. b99 and b100 show junctions between internal and external walls, and the corresponding wall constructions are explained in the captions.



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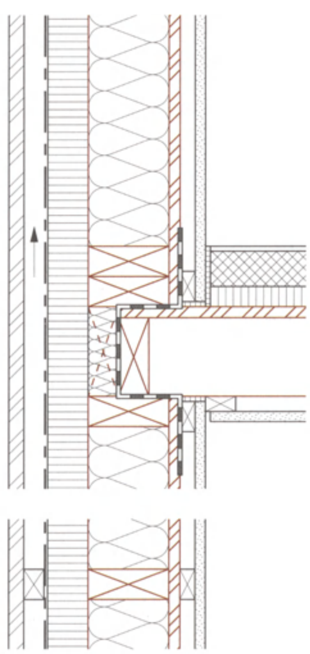

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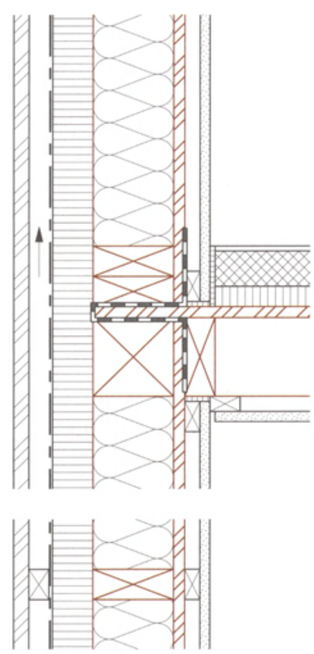

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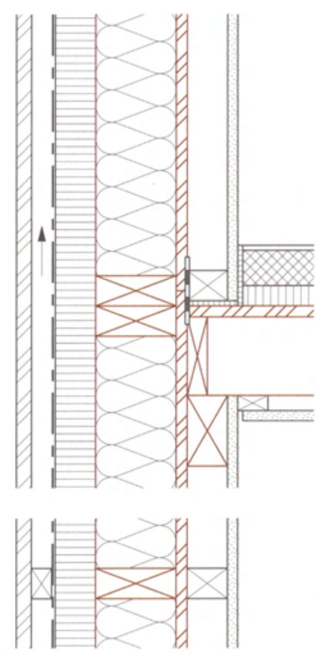


b88

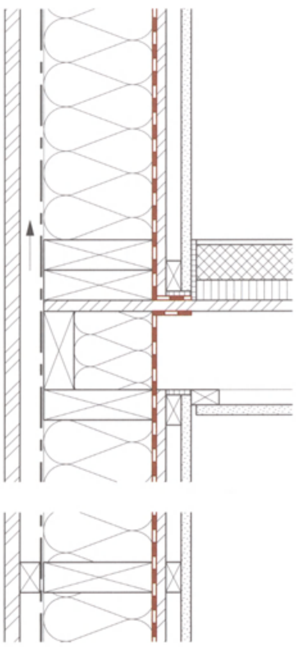
b85 Suspended floor supported on the full width of the external wall loadbearing members. Connection of airtight membrane according to Fig. b90, or according to Fig. b89 if the second layer of external insulation is omitted.

b86 Suspended floor not supported over full width of external wall loadbearing members. Connection of airtight membrane according to Fig. b91. The detail must take into account the unfavourable force transfer.

b86-1 Junction between components according to Figs b86 and b91

b87 Only the floor sheathing continues over the full width of the external wall loadbearing members, the floor is fixed to the inside face of the wall. Connection of airtight membrane according to Fig. b93 or b92. The detail must take into account the unfavourable force transfer.

b88 The floor construction is supported on an additional inner leaf, which requires a structural analysis. Connection of airtight membrane according to Fig. b94.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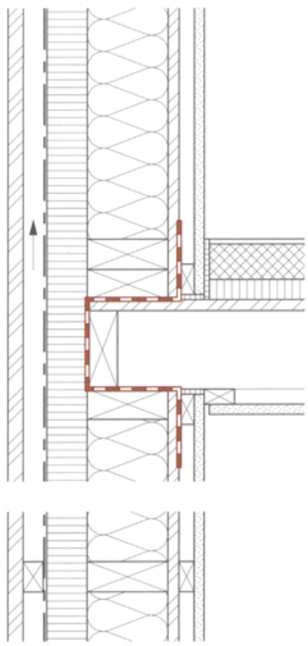
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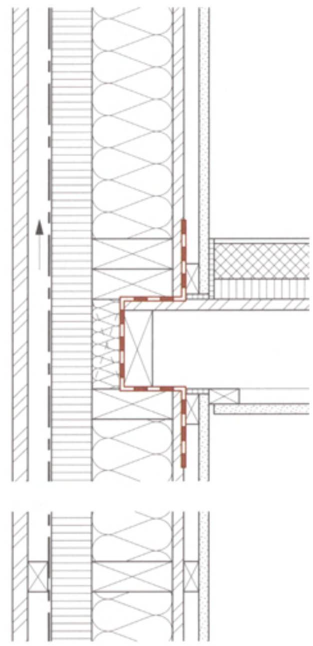
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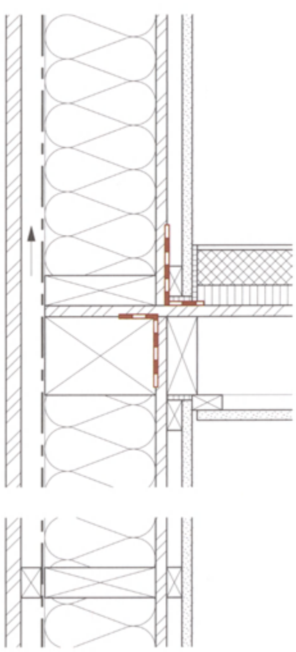
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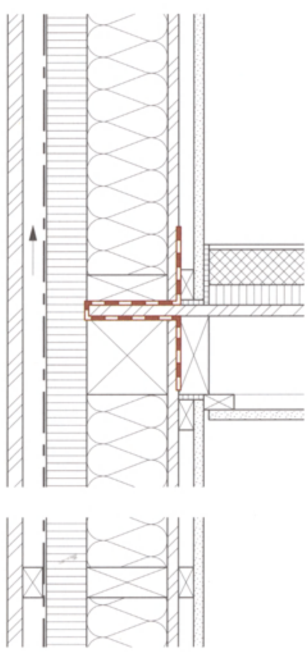
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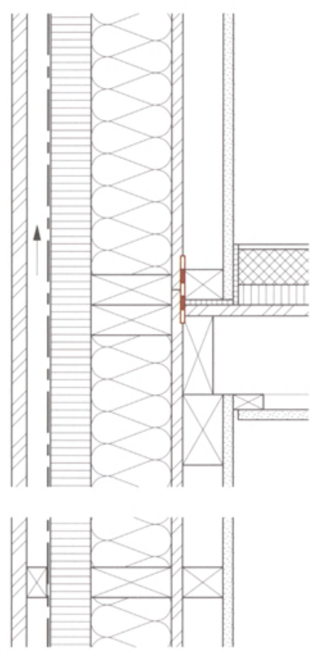

b94

b89 Suspended floor supported on the full width of the external wall loadbearing members. (left = outside, top = vertical section, bottom = horizontal section) Connection of airtight membrane and vapour barrier separate, and required at every joist and the sheathing (difficult, problems at butt joints!). As there is no second layer of insulation on the outside, the airtight membrane cannot continue around the outer edge of the floor.

b90 Suspended floor supported on the full width of the external wall loadbearing members. The airtight membrane and the vapour barrier enclose the outer end of the floor without any joints. As there is additional, external insulation in this case, the airtight membrane and the vapour barrier can continue around the outer edge of the floor. Sheet material with a variable diffusion resistance (PA sheeting, vapour control layer with adaptive moisture properties) is recommended for this junction.

b91 Similar to Fig. b90, but with additional insulation around the outer edge of the suspended floor.

b92 Only the floor sheathing continues over the full width of the external wall loadbearing members, the floor is fixed to the inside face of the wall. Airtight membrane and vapour barrier connected to sheathing (difficult, problems at butt joints!).

b93 Only the floor sheathing continues over the full width of the external wall loadbearing members, the floor is fixed to the inside face of the wall. The airtight membrane and the vapour barrier enclose the outer end of the floor without any joints. As the sheet material continues into the cold area, external insulation is necessary. Sheet material with a variable diffusion resistance (PA sheeting, vapour control layer with adaptive moisture properties) is recommended for this junction.

b94 The floor construction is supported on an additional inner leaf, which requires a structural analysis. The actual external wall construction remains intact.

b95 External wall corner detail (horizontal section), wall construction according to Fig. b77.

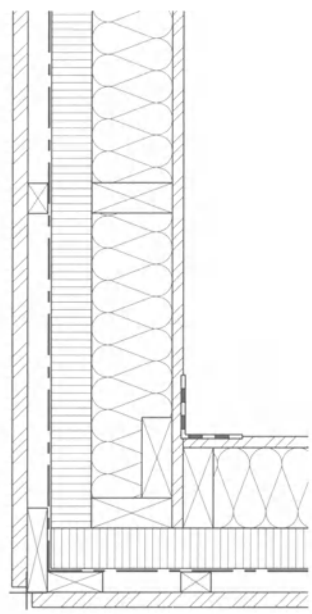
b96 External wall corner detail, wall construction according to Fig. b74.

b97 External wall corner detail, wall construction according to Fig. b79.

b98 External wall corner detail, wall construction according to Fig. b80.

b99 External wall/internal wall junction, external wall construction according to Fig. b78.

b100 External wall/internal wall junction, external wall construction according to Fig. b79.



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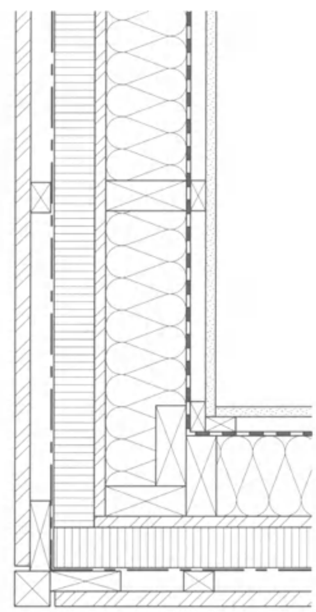

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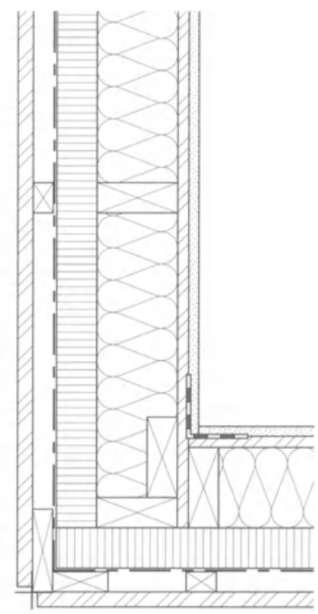

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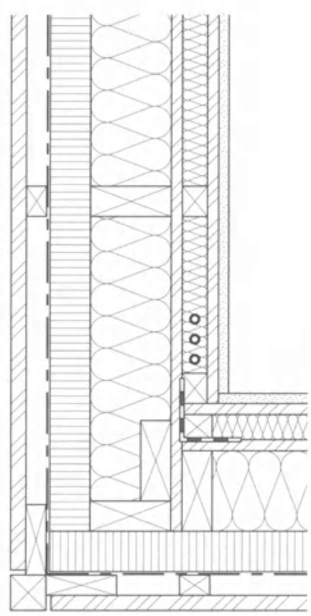

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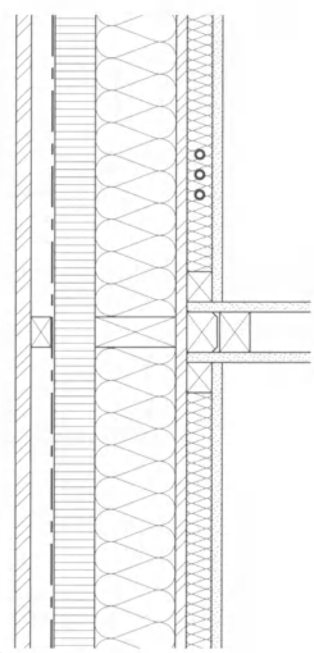

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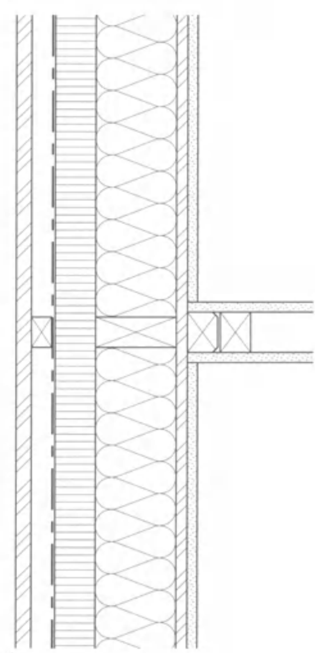
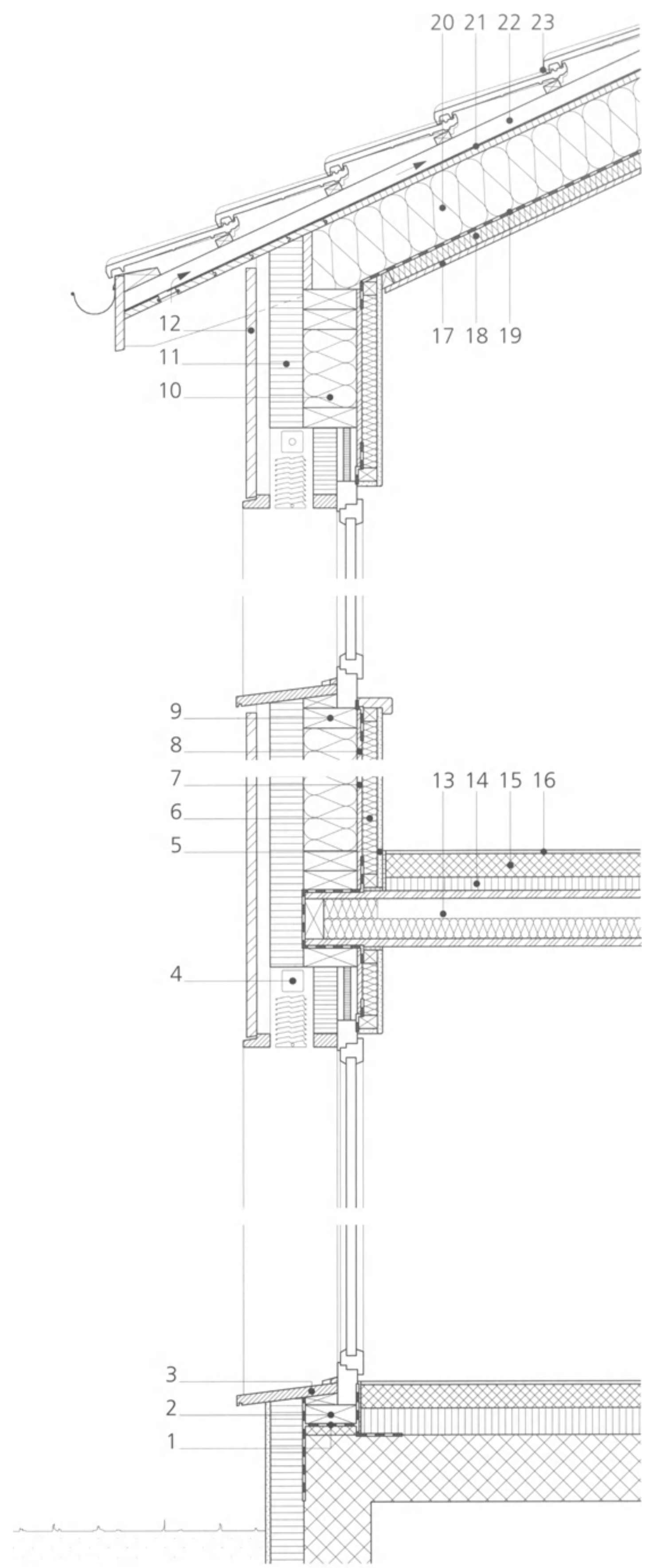


b100

b6 Panel construction

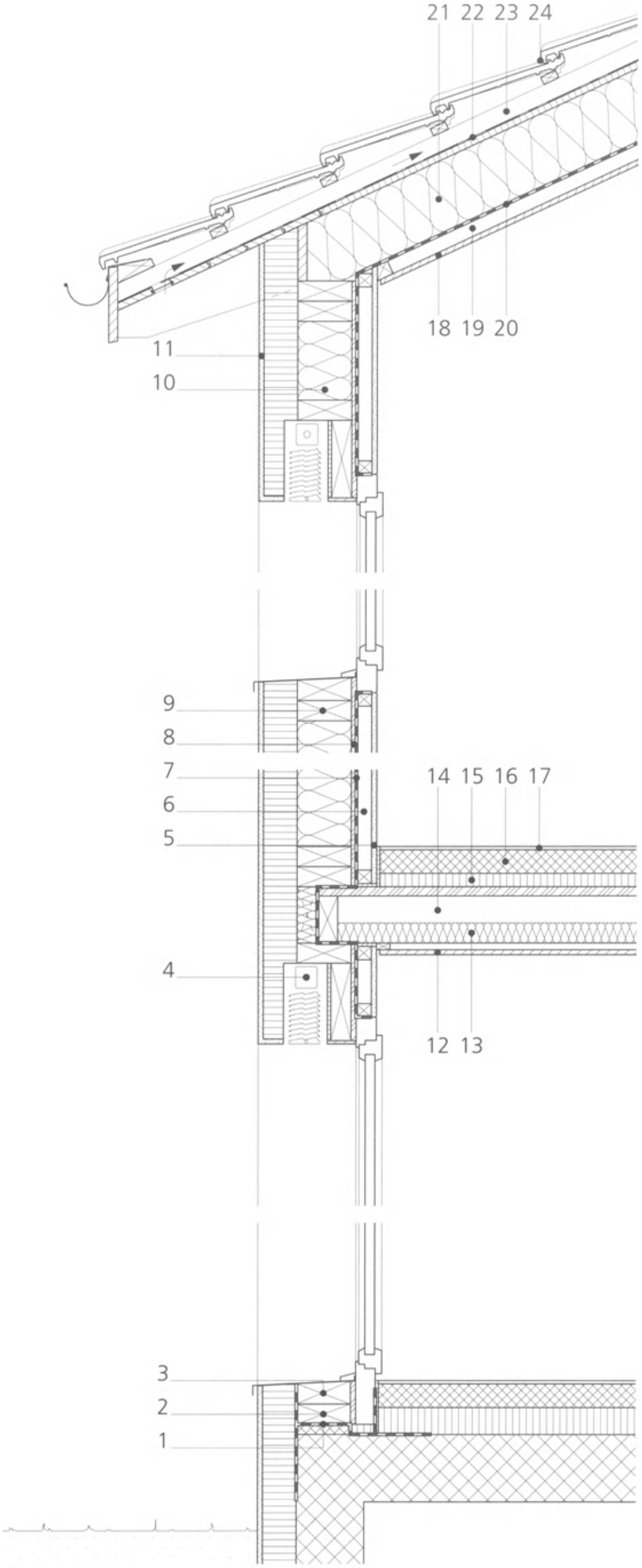


b101

1 Mortar bed, waterproofing, damp proof course
2 Bottom plate
3 Window sill, normally covered
4 Louvre blind in storage compartment
5 Internal lining
6 Framework of battens with space for services and insulation between
7 Airtight membrane (all joints/seams sealed airtight), vapour barrier
8 Structural sheathing
9 Loadbearing members
10 Insulation between loadbearing members
11 External insulation, additional insulation
12 External cladding with ventilated cavity behind
13 Hollow-box floor with sound insulation in void
14 Impact sound insulation
15 Cement screed or dry subfloor
16 Floor covering
17 Soffit lining
18 Framework of battens with space for services and additional insulation
19 Airtight membrane, vapour barrier
20 Thermal insulation
21 Secondary waterproofing layer, possibly additional insulation
22 Counter battens, ventilation space
23 Roof covering

b101 Section through construction: panel construction, external wall (with ventilated cavity behind cladding) showing window opening, junction with ground floor, suspended floor and roof.

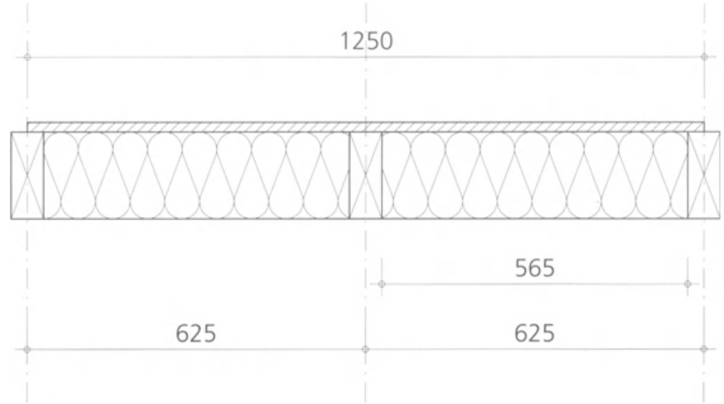
Positions of component layers according to the following figures:
b70 Position of insulation
b73 Position of structural sheathing
b78 Battens, space for services
b84 Airtight membrane, vapour barrier
b85 Wall/floor structural connection
b90 Wall/floor airtight membrane connection
b98 External wall corner



1 Mortar bed, waterproofing, damp proof course
2 Bottom plate
3 Window sill, normally covered
4 Louvre blind in storage compartment
5 Internal lining
6 Framework of battens with space for services
7 Airtight membrane, vapour barrier
8 Structural sheathing
9 Loadbearing members
10 Insulation between loadbearing members
11 Thermal insulation composite system (open to diffusion)
12 Soffit lining
13 Sound insulation
14 Ribbed suspended floor (loadbearing)
15 Impact sound insulation
16 Cement screed or dry subfloor
17 Floor covering
18 Soffit lining
19 Framework of battens with space for services
20 Airtight membrane, vapour barrier
21 Thermal insulation
22 Secondary waterproofing layer, possibly additional insulation
23 Counter battens, ventilation space
24 Roof covering

b102 Section through construction: panel construction, external wall with thermal insulation composite system (render + insulation) showing window opening, junction with ground floor, suspended floor and roof. The floor support detail must take into account the unfavourable force transfer.

Positions of component layers according to the following figures:
b68 Position of insulation
b73 Position of structural sheathing
b78 Battens, but no additional insulation in space for services
b83 Airtight membrane, vapour barrier
b86 Wall/floor structural connection
b91 Wall/floor airtight membrane connection



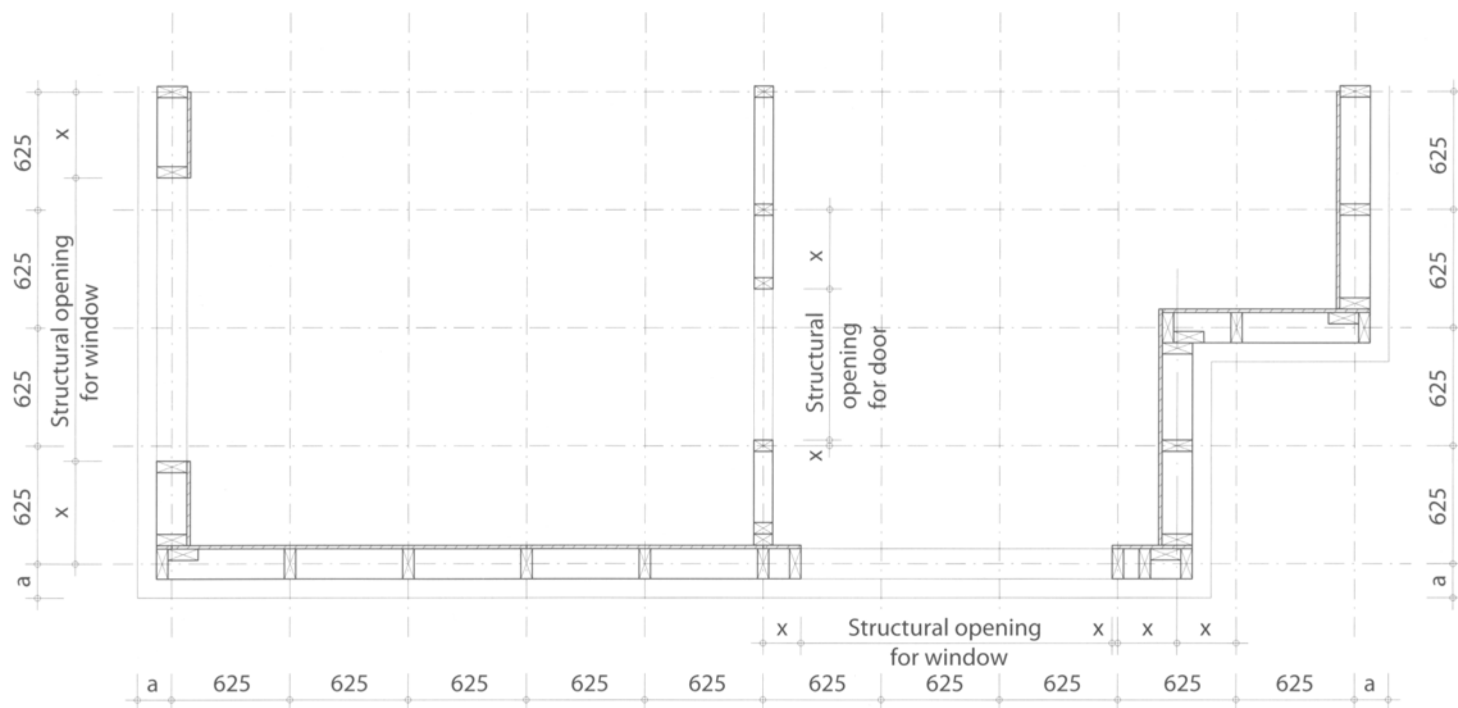
b104

b6 43 Modular grid

There is a completely free choice of plan layout and modular dimensions, although, besides clarification with respect to the structural requirements, considerations regarding the type of construction and the production of the elements should also play a role in this choice. Whereas in frame construction the layout of the loadbearing structure is based on a large grid, it is normal for panel construction to be based on a (small) modular dimension. It is advantageous for structural timber members with a width of 60 mm to be placed on a 625 mm modular grid. The chosen grid determines the structural arrangement of the building project. When using solid timber planks or particleboards as sheathing to stiffen the structure, a grid dimension of 650 mm was customary in the past.

Today, when using wood-based board products and gypsum fibreboard sold in widths of 1250 mm, a 625 mm grid is employed for planning and building. When using other building materials, however a different modular grid may be more sensible (Figs. b103 and b104). The criteria for specifying the modular grid are:

- Format of insulating material
- Customary formats of sheathing materials
- Dimensional coordination of doors and windows
- Facade design
- Interior layout



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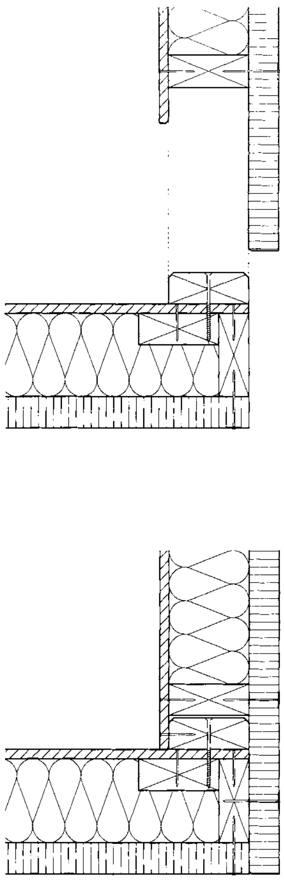
b103 Plan showing 625 mm modular grid

b104 Stud spacing and width of wood-based board product or gypsum fibreboard with a modular dimension of 625 mm



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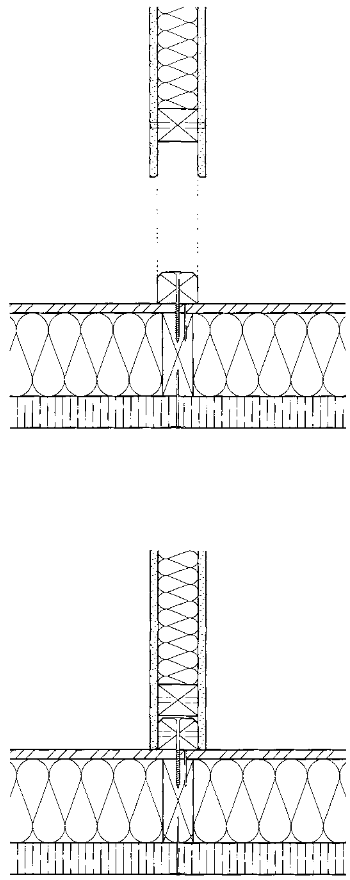
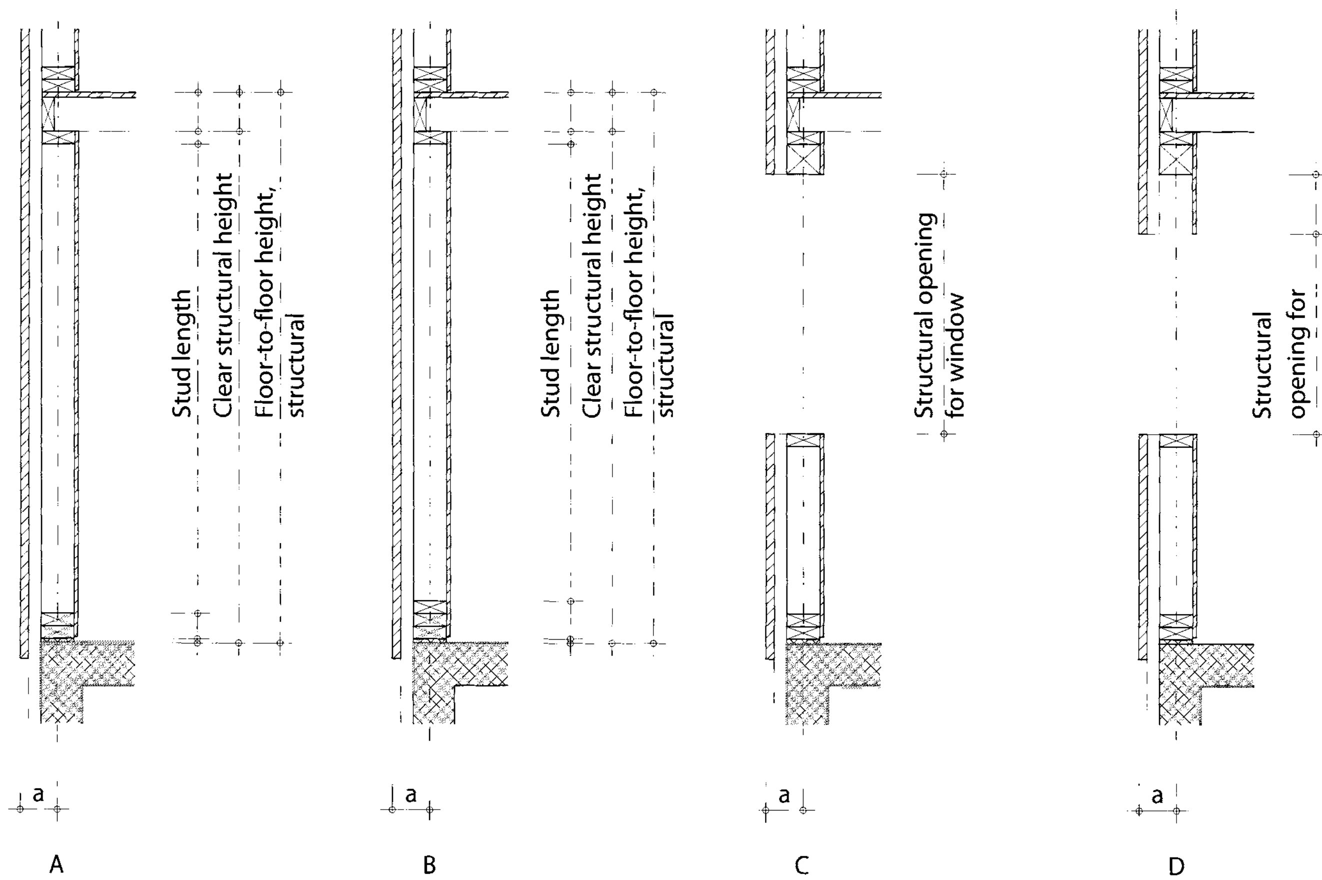


b106

b6 44 Vertical dimensions

Starting with the clear ceiling height required, the necessary design dimensions are specified (Fig. b107). The following must be known first:

- Floor finishes on top of reinforced concrete slab or other suspended floor elements
- Section through suspended floor including construction of floor and soffit finishes
- Customary formats of wood-based board products
- Height of threshold required
- Types and sizes of windows
- Installation and position of louvre blinds
- Heights of spandrel panels and depths of lintels



b107

b105 External wall corner detail (horizontal sections, top = exploded view, bottom = connected)

b106 External wall/internal wall junction (horizontal sections, top = exploded view, bottom = connected)

b107 Vertical dimensions
A with two bottom plates
B with additional bottom plate to accommodate deeper floor finishes (take settling allowance into account)
C window opening without louvre blind
D window opening with louvre blind

b6 Panel construction

b108

b6 50 Structural engineering

b6 51 General

The ultimate load capacity and the serviceability of structures in panel construction must be assessed according to the relevant standards and codes of practice. In the case of simple structures, empirical values or the use of construction catalogues [14, 15] can render structural calculations for every little detail unnecessary. But it is essential for designers and contractors to agree on who is responsible for the loadbearing behaviour and the stability of the structure. Enlisting the services of a consulting engineer or structural engineer is to be recommended and will be advantageous during the course of further planning for the timber building (see also chapter a3 "Conception and design").

Thanks to the standardisation of member sections, modular dimensions, connections and construction details, panel construction represents a simple timber building system. Employed once, the knowledge gained can be used again and again. This is particularly true for the construction of detached or semi-detached homes. The overview given below is related to such buildings.

In panel construction the stiffening or bracing, i.e. the stability, of the building must be given extra attention. It must always be considered as a whole. Moreover, proper anchorage of the ensuing construction must also be taken into account.

In this book the structural engineering aspects are considered from a general point of view only; an insight into the loading criteria and the way the structural system works are the only intentions. Such an overview will allow the structural relationships of the building system to be considered during the conception and planning of a construction project. Please refer to the suggestions for further reading on p. 313 for further information on this subject.

b6 52 Suspended floors

Selection of constructional criteria:

Joists

- Spacing of joists: 500–700 mm, generally 625 mm
- Column spacing: l < 5 m
- Total load: dead load (permanent load) + imposed load from suspended floor + (possibly) loads from partitions
- Permissible deflection according to national standards, stiffer suspended floors may be necessary for some structures.
- Creep deformation must be taken into account.
- In the case of joists with h/b > 2.5, the joists must be secured against lateral buckling.
- Stiffening requirements for the floor plates must be taken into account.
- Openings in the timber joist floors must be considered.
- Trimmer joists with adjoining floor joists must be sized accordingly.

Sheathing

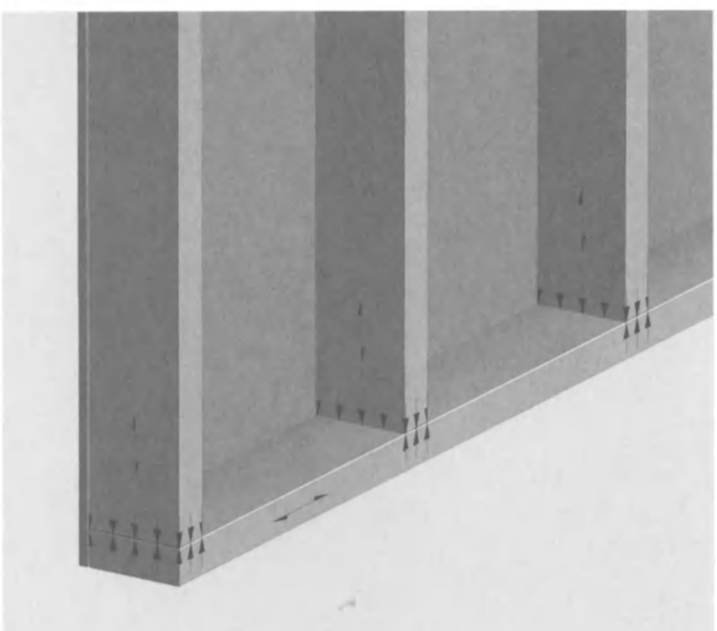
- Formats according to spacing of joists: 500–700 mm, generally 625 mm
- Total load: dead load (permanent load) + imposed load
- Stiffening requirements for the floor plates

In the case of suspended floors in housing carrying normal loads and with a joist spacing not exceeding 650 mm, a timber particleboard 25 mm thick or solid timber sheathing with a plank thickness of 22 mm is sufficient. The layers of sheathing material should extend over at least two bays, i.e. three joists.

Chapter b10 contains details of other forms of floor construction. Suspended floor elements made from wood-based products can be erected rationally, are efficient, and can be produced cost-effectively.

b108 Private house in panel construction, Nussbaumen, Switzerland

b109



b110

b109 Semi-detached houses in panel construction, Küssnacht, Switzerland

b110 Carrying the loads in internal and external walls. The compressive strength of the bottom plate perpendicular to the grain is usually critical.

b6 53 External walls

Several criteria:

- Wind loads
- Vertical and horizontal loads from roof and suspended floors plus the dead load of the construction
- Critical buckling length of timber studs
- Spacing of timber studs: e = 625 mm
- Compressive stress perpendicular to the grain

Buckling of the loadbearing timber studs in the plane of the wall is prevented by the sheathing. Consequently, for these vertical wall members, compression, and bending about the major axis are the critical loading components. Studs measuring 60 x 120 mm with a critical buckling length of 2750 mm and a maximum stud spacing of 650 mm are able to carry the uniformly distributed loads of one- and two-storey residential buildings in locations up to 800 m above sea level (snow loads!). The maximum possible load on the loadbearing internal and external walls is generally limited by the permissible compressive stress perpendicular to the grain in top and bottom plates (Fig. b110). Besides the loads, this stress is also dependent on the dimensions of the studs, the species of wood, and the position of the studs on the top and bottom plates. In the case of multi-storey buildings, the construction must be analysed by a structural engineer.

b6 54 Internal walls

The loads on internal walls is – like the external walls – determined by the loads from roof, suspended floors and the dead load of the internal wall itself. The permissible compressive stress perpendicular to the grain usually governs the dimensions (Fig. b110)

b6 55 Stability of the structure

The necessary stability to withstand horizontal loads is guaranteed by the bracing elements and the anchorage of the elements. Figs. b111 and b112 illustrate how the horizontal and vertical bracing works.

Structural system

Wind loads acting on the roof and wall surfaces are transferred from the rafters, the joists and the wall studs into the roof and floor plates. These horizontal plates in turn transfer the forces to the vertical wall plates from where they are transferred to the storey below. In a normal situation the wall plates are anchored to a concrete slab over the basement or to solid concrete or masonry walls.

Roof surface

The roof surface can be braced by:

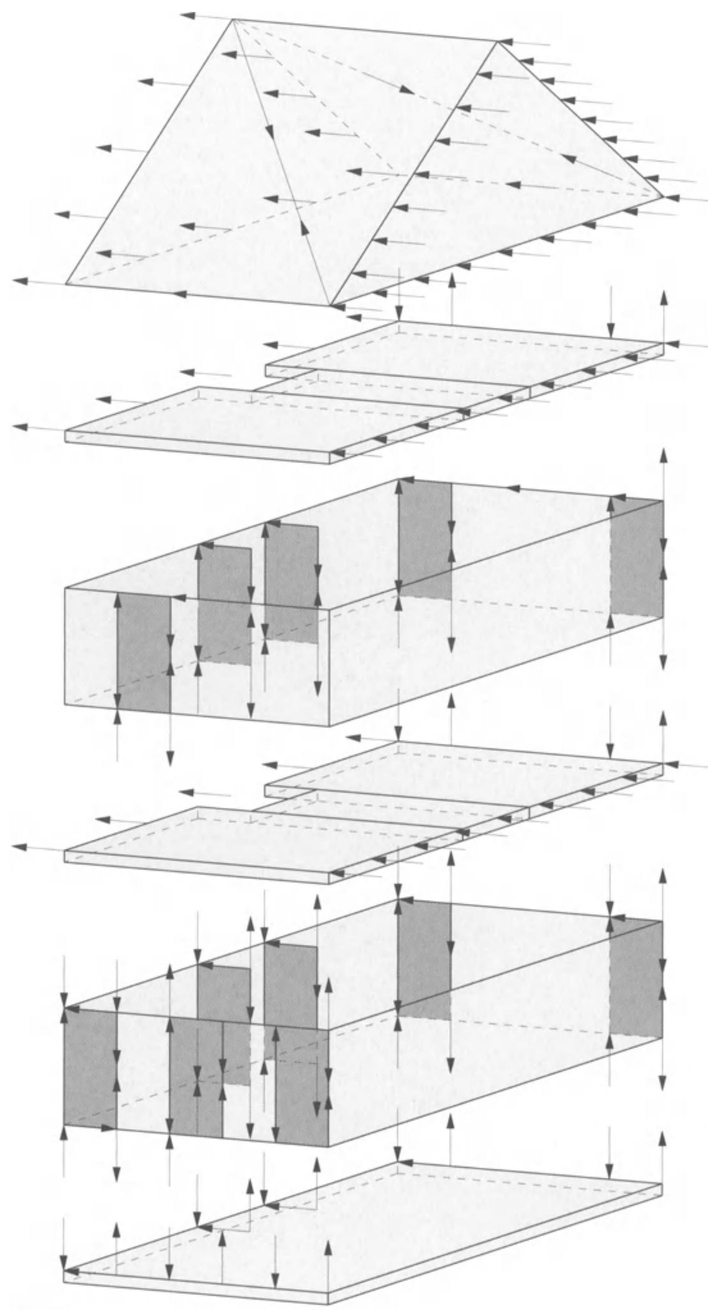
- Solid timber wind girders
- Diagonal steel wind braces
- Solid timber sheathing with tongue and groove joints
- Wood-based board products

Solid timber wind girders can accommodate both tensile and compressive forces, steel wind braces, however, only tension.

The best solution is to arrange the solid timber sheathing diagonally; the bracing effect of planks placed parallel to eaves or verges is inferior because they become effective only at greater deformations.

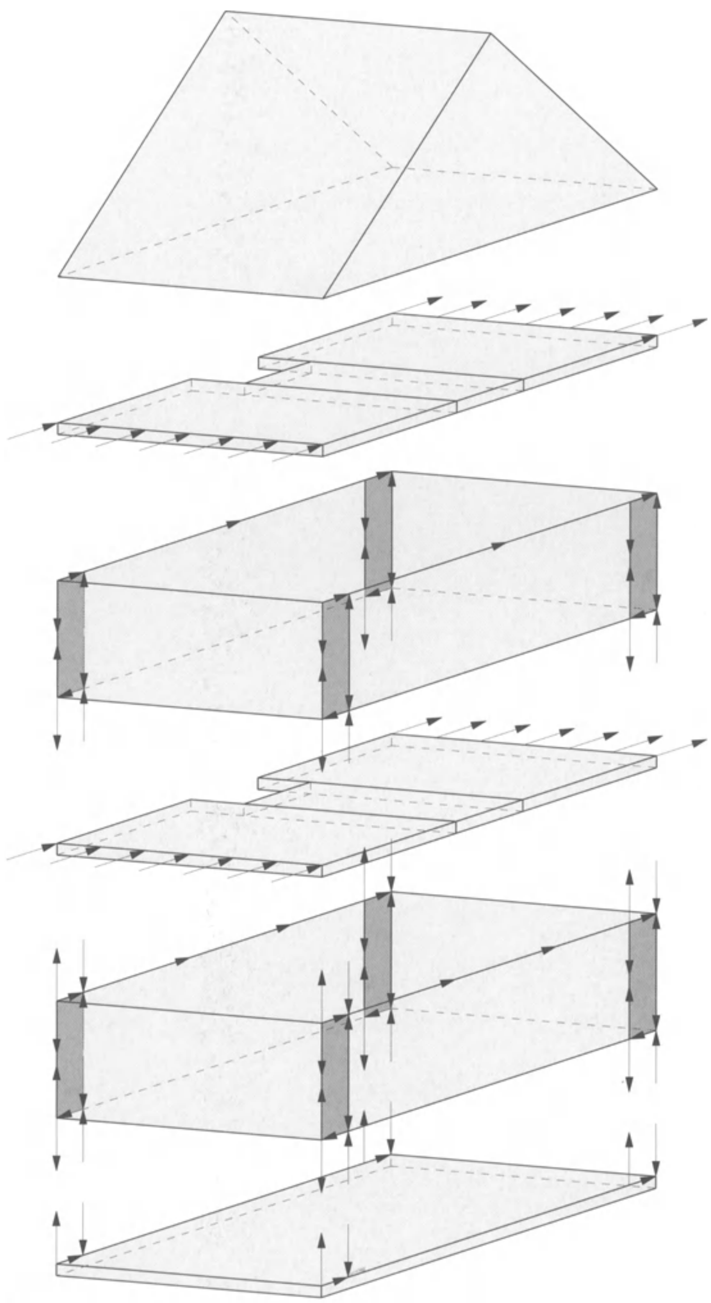
Suspended floor

The bracing of a suspended floor is achieved in panel construction by using wood-based products, solid-timber sheathing, or solid timber elements. The resulting floor plate subjected to shear and bending is secured to the floor and perimeter joists with annular-ringed shank nails or screws at a calculated spacing. The floor joists supported on the internal walls or the perimeter joists supported on the external walls accommodate the flange forces in the floor plates. Accordingly, they must be capable of resisting tension and compression. The assumption here is that the floor and perimeter joists, which act as the flanges of the floor plates, are continuous or include suitable tension- or compression-resistant joints.



b111

b111 Flow of forces for a wind load perpendicular to the gable



b112

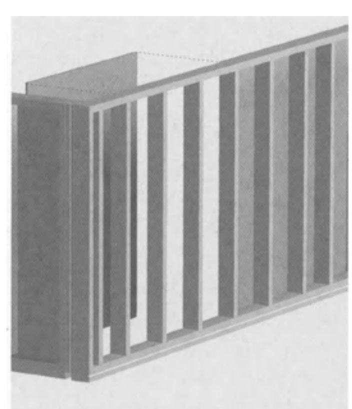
The shear forces have to be transferred to the stiffening wall plates. In the case of the floor joists in stiffening plates, the edge distances of the fixings must be considered. Openings like those for stairs must be taken into account when determining the load paths.

Wall plates

Depending on the number, positions, and sizes of window and door openings or the number of walls available for the structural system, sheathing attached to the structural timber members with closely-spaced nails is adequate for providing horizontal bracing. Together with the timber framework, the wood-based products affixed with nails form shear diaphragms that can accommodate the horizontal forces from the floor plates and transfer them to a lower level. More efficient materials such as laminated veneer lumber (LVL) or cross-laminated timber are used in special cases. The stiffening plates can be mounted on the inside or outside of the loadbearing construction (Figs. b113 and b114; see also section b6 40 "Building structure and wall construction", "Loadbearing structure and position of structural sheathing"). The vapour diffusion behaviour must also be taken into account.

Anchorage

The bracing walls must be anchored to the concrete ground slab or the foundations. Large forces can occur here. Anchorage is achieved by bolts through the bottom plate of each element, steel angles, or welded steel components (Figs. b117 to b119). Continu-



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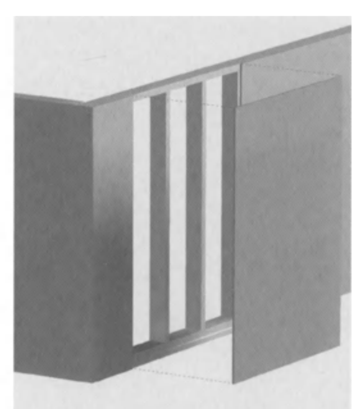


b114

b112 Flow of forces for a wind load parallel to the gable

b113 Stiffening sheathing fitted to the inside of the loadbearing members

b114 Stiffening sheathing fitted to the outside of the loadbearing members ous ties or interconnected wood-based board products ensure the necessary anchorage, i.e. tying, of the upper storeys.

b6 60 Loadbearing construction

b6 61 Position of base plate

The storey-by-storey assembly in panel construction starts with the setting-out and installation of the base plates, which are laid on a mortar bed 20–30 mm thick. The level of this bed is prepared by the contractor to ensure an accuracy of ±2 mm and to ensure that the base plate is bedded across its full width and length and does not require any additional grouting after being installed.

Although the use of a base plate offers many advantages, it is not essential. If a base plate is not used, the elements are placed directly on the mortar bed and fixed to the concrete ground slab by means of steel angles. However, this method is more expensive and more labour-intensive.

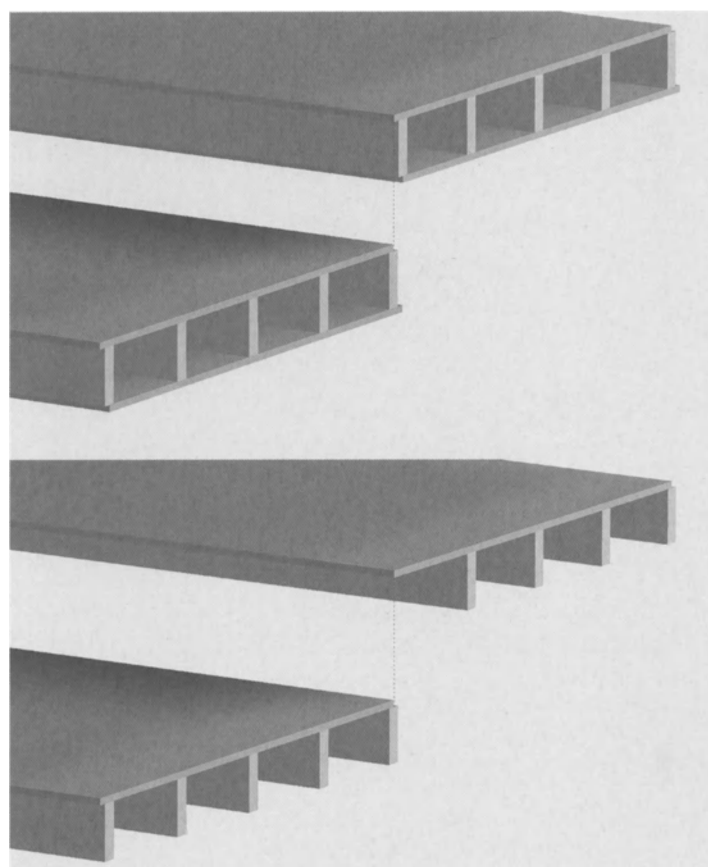
Irrespective of the method used, a damp proof course (dpc) must be laid between mortar bed and timber to prevent any rising moisture. Expanding anchors or similar fasteners are used to attach the bottom plate or the steel angles to a concrete floor slab, or wood screws in the case of a timber floor.

b6 62 Wall construction

Once the base plates are in position, at the right level and fixed, the external walls can be erected. Walls prefabricated in a factory can then be erected storey by storey. At junctions with adjacent components, the structural sheathing must be connected according to structural (to ensure continuity of the plate effect) and constructional requirements; nails at a close pitch (approx. 50 mm), screws or special connectors are suitable.
The length of an element is normally the full length of a wall in the case of a detached house, and therefore transport requirements must be planned accordingly. The elements are lifted into place on the building site by means of a stationary or mobile crane.
Internal walls are erected in the same way. To improve access for the diverse trades to follow (e.g. electrics, plumbing, heating) on the building site, such walls are often supplied with sheathing on one side only, which allows easy installation of pipes, cables, etc. in the voids. The sheathing to the other side is then attached after all services have been installed.

b6 63 Suspended floor

Various systems such as solid timber floors or timber joist floors depending on the client's requirements regarding the appearance of the soffit. Ribbed or hollow-box floors are frequently used (Fig. b115). These can be manufactured rationally and erected quickly (for further floor options see chapter b10 "Suspended floor structures").
Suspended floors have to provide a plate effect; horizontal shear forces are resisted by the upper sheathing (e.g. a wood-based



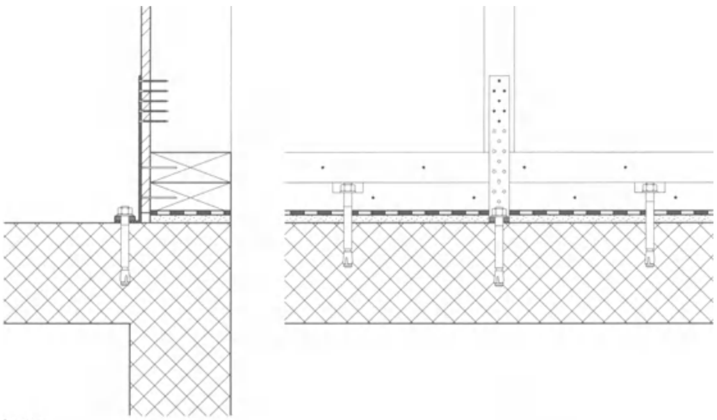
b115

b115 Suspended floors for timber panel construction: hollow box (top) and ribbed panel (bottom) product such as OSB or 3-ply core plywood). Structural calculations are required for the nails attaching the sheathing to the floor members. Alternatively, the floor can be built according to a suitable construction catalogue [14, 15].

Common dimensions are:
- Joist spacing: 500–650 mm (centre to centre)
- Joist width: 60, 80, 100, 120 mm
- Joist hight: 180, 200, 220, 240 mm
- Perimeter joist width: 60 mm, or 80 mm underneath board joints
- Perimeter joist hight: as for the main joists
- Sheathing thickness: 3-ply core plywood 27 mm, OSB 22 mm, solid timber 22 mm, particleboard 25 mm

b116

b116 Erecting hollow-box floors for a timber building in panel construction



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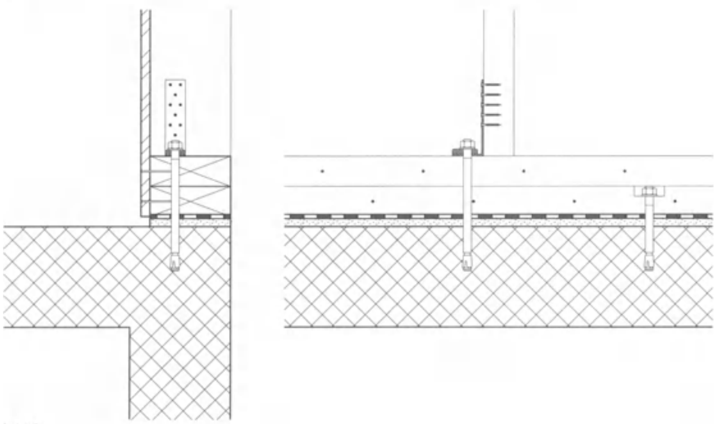

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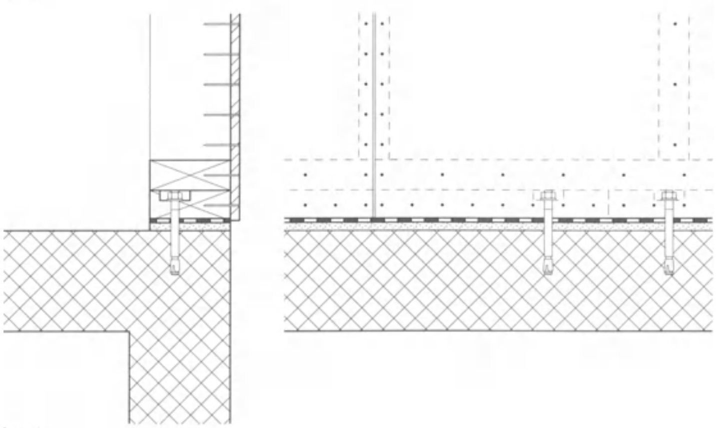

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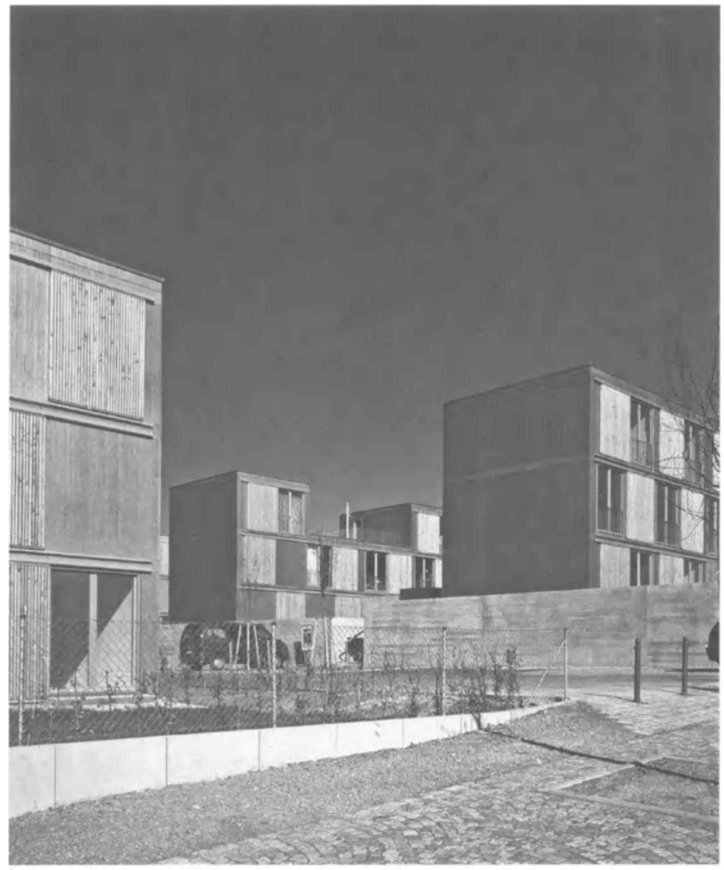


b120

b6 64 Anchorage

The loadbearing plates of the internal and external walls also have to transfer the horizontal forces from the suspended floor elements to the foundations. In doing so, shear and uplift forces have to be resisted. Normally the fasteners attaching the bottom plate to the ground slab/foundation at regular intervals accommodate all the shear forces and part of the uplift. The remaining uplift is resisted by anchoring the timber panels directly. This is done by way of steel flats, round steel bars or perforated sheet metal. Nowadays the fixing to the concrete foundation is carried out directly; leaving pockets in the foundation is costly and time-consuming, and is hardly encountered any more. Direct fixing with the various proprietary fasteners available – expanding, heavy-duty or bonded anchors – is generally preferred. Figs. b117 to b119 show schematic arrangements of fasteners for attaching external walls to a concrete slab.

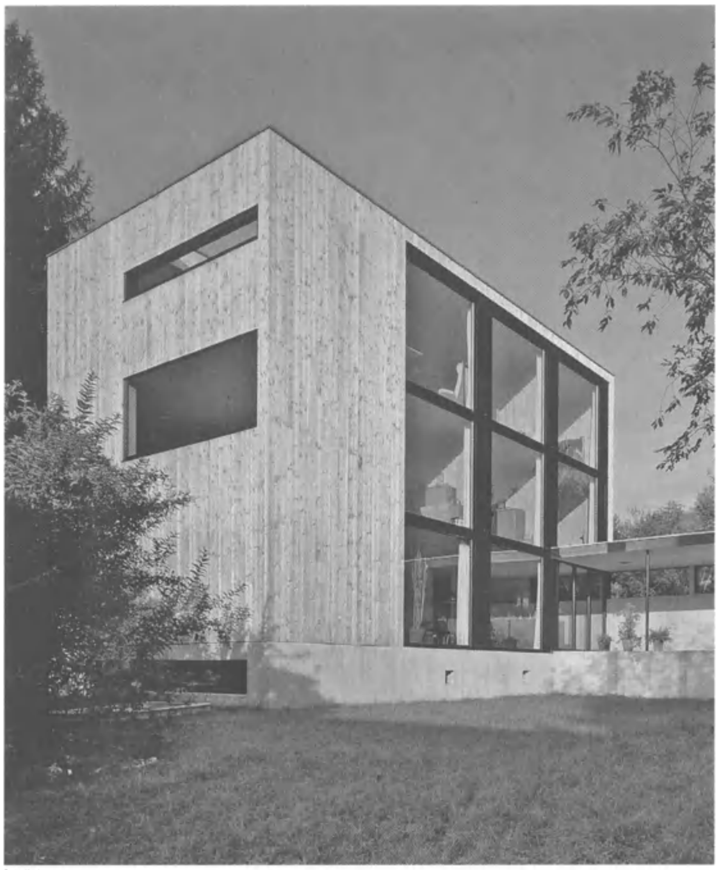
Anchoring, i.e. tying, a storey to the storey below is achieved with the help of perforated sheet metal, wood-based board products, or other types of fasteners. Interconnected sheathing (wood-based board products) is advantageous provided the surfaces are not interrupted too frequently by door or window openings. The method using interconnected sheathing obviates the need for expensive, time-consuming connections – with perforated sheet metal and fasteners or strips of veneer plywood to create a structural connection between the wall elements – at the junctions between storeys. Overlapping strips of veneer plywood enable not only

b117 Schematic arrangement of anchorage with perforated sheet metal strap and anchor bolt (direct connection), positioned on the inside of the wall elements.

b118 Schematic arrangement of anchorage with perforated sheet metal strap and anchor bolt (direct connection), positioned in the plane of the wall elements.

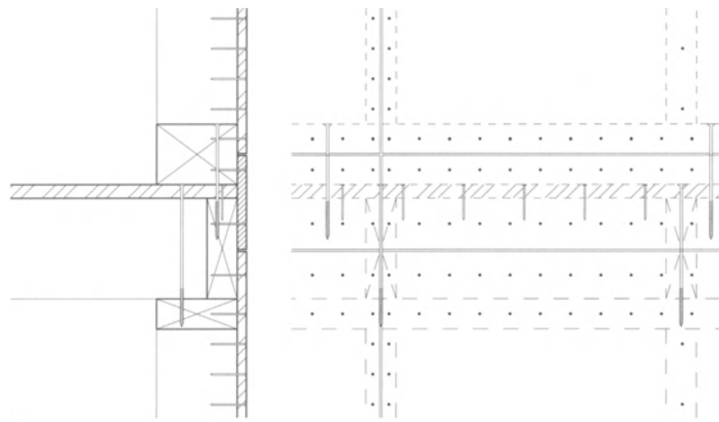
b119 Schematic arrangement of fasteners at the transition between external wall and concrete slab, fixed via base plate.

b120 Residential development in panel construction, Stuttgart, Germany



b121

shear forces (force transfer by way of widely spaced nails over the full area) but also tensile forces (by way of closely spaced nails at the anchorage points). If the structural sheathing is placed on the inside of the loadbearing members, the loads are transferred via top plate, suspended floor and bottom plate, likewise with steel fixings. Figs. b122 to b124 show three schematic alternatives.
The publications on timber panel construction [14, 15] contain detailed descriptions of these forms of construction.



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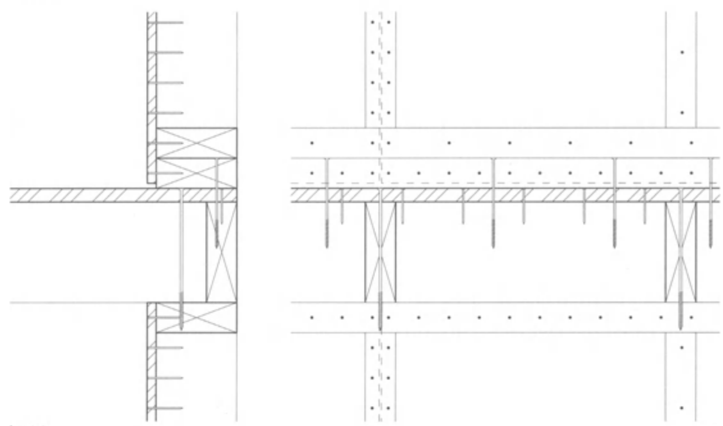

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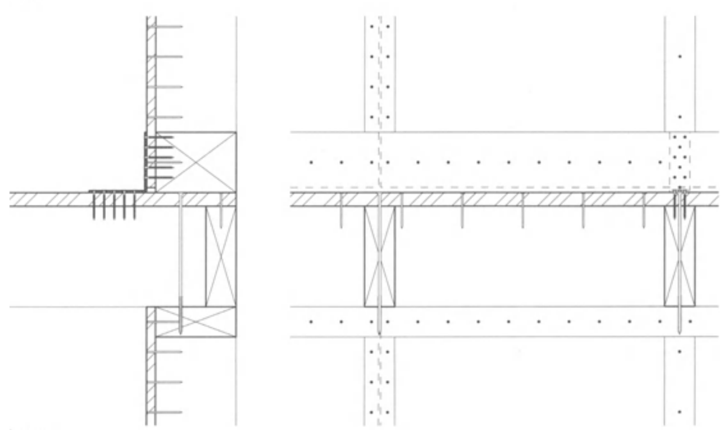


b124

b121 Private house with studio in panel construction, Langenthal, Switzerland

b122 Schematic arrangement of fasteners at the junction between storeys when the structural sheathing, positioned on the outside, is not continuous. Shear and tensile forces (closer nailing) transferred via a structural connection made from strips of veneer plywood and long screws.

b123 Schematic arrangement of fasteners at the junction between storeys when the structural sheathing, positioned on the inside, is not continuous. Shear and tensile forces transferred via long screws.

b124 Schematic arrangement of fasteners at the junction between storeys with structural sheathing on the inside. Shear and tensile forces transferred via long screws. Additional tying by way of steel angles.

b7 Frame construction

b7 10 General

As the importance of timber construction grows for multi-storey and large-volume structures, modern frame construction in timber is taking on a new role. Furthermore, this form of construction with its generally widely spaced columns in timber or in combination with steel or reinforced concrete is also ideal for one- and two-storey buildings. New linear wood-based products and their connection techniques have contributed to this growing importance. Frame construction is probably one of the oldest structural forms. Besides the simple method of log construction, i.e. stacking tree trunks horizontally, one on top of the other, right from early times, round tree trunks were also placed in holes in the ground to create vertical columns; horizontal poles were then laid in convenient forks between trunk and branches. To fill in the openings between vertical columns and horizontal poles, smaller branches were woven into panels and coated with loam (wattle and daub). This early method of building with timber gradually developed into the timber-frame construction that prevailed in many areas of Europe for many centuries. This form of construction offered more options for dividing up the interior. Today, considerably larger window areas are required than was fashionable, or indeed possible, 100 years ago. Modern frame construction in timber has therefore changed with the times: the primary structural members are erected on a widely spaced grid between which the internal and external walls can be positioned as required and constructed

b125

b125 Loadbearing structure in frame construction, school, Wil, Switzerland,

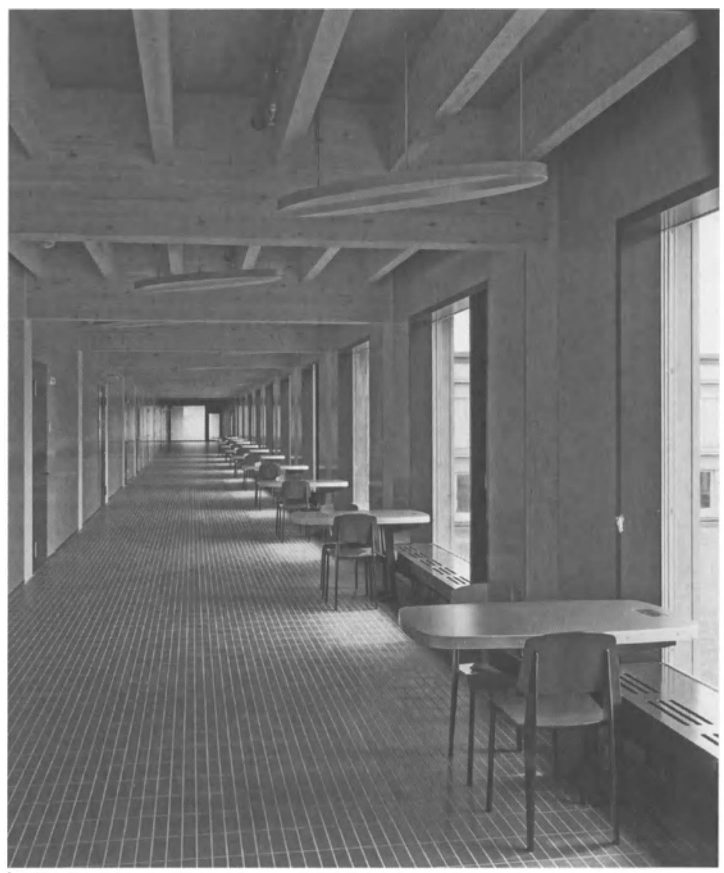
b126

using a variety of methods and materials. This has meant that modern frame construction has evolved into a method of building in which the functions of loadbearing structure and enclosing walls are clearly separated.

Frame Construction is understood to be an independent, modern form of timber construction with the following characteristics: a form of construction comprising columns, beams and bracing elements placed on a regular grid to form a loadbearing structure. This primary structure supports the suspended floors – made up of timber joist floors or planar, prefabricated elements – which are classed as the secondary structure. The walls enclosing the interior spaces can be installed independently of this loadbearing framework because they do not carry any loads, making large windows and glass facades possible.
Wherever possible, the loadbearing structure of a frame building in timber is placed on the inside of the external walls for constructional reasons (protection from the weather and airtightness of the building envelope) and also left exposed internally. The enclosing envelope can therefore be placed around the building without joints or seams. Internally, the arrangement of the loadbearing components determines and emphasizes the architectural character.
In terms of the loadbearing structure, frame construction should be considered as the opposite of solid timber construction and panel construction. Whereas in these latter two forms of building the loadbearing system is based on a linear concept and the walls carry distributed loads, in frame construction the use of individual columns concentrates the loads. Loadbearing members usually remain visible, but are often integrated into suspended ceilings or internal fittings, depending on the architecture of the interior. Owing to longer spans and additional requirements for timber members left exposed in the finished building, glued laminated timber is preferred for timber frames. The connectors and fasteners used sometimes remain visible, but concealed steel components let into the timber are preferred, and occasionally even true wood joints are used.

The modern timber frame

In frame construction, besides the efficiency, it is first and foremost the architectural diversity and the clarity of the constructional form that is so appealing. Frame construction in timber permits longer spans with fewer internal columns than other building systems, which leaves plenty of freedom for the design of the interior layout. More and more, clients and investors are calling for buildings with flexible, variable internal layouts that can be readily adapted to suit individual requirements. And a timber frame permits any number of design options. The glued timber members, now the result of rational production methods, and the fasteners and connectors available ex stock, add up to a building system that complies in full with today's demands regarding quality and engineering. In addition to schools and housing, frame construction is suitable for office, industrial, and commercial buildings, for both public- and private-sector projects.



b127

b126 Housing project with large windows, frame construction with steel X-bracing

b127 Loadbearing structure left exposed internally, school, Wil, Switzerland

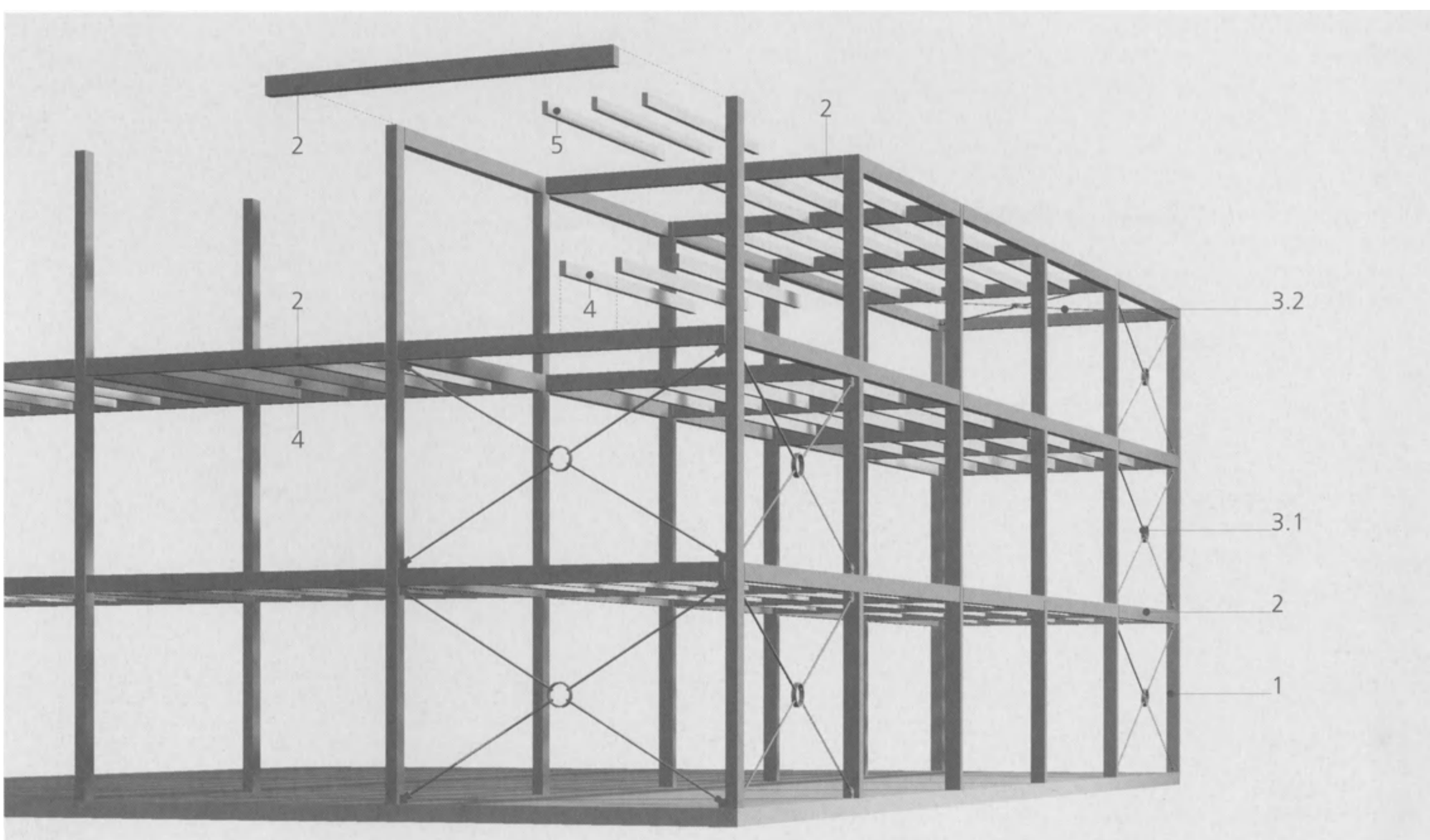
The features of frame construction

- Extensive design freedoms
- Variable interior layout
- Loadbearing frame and enclosing walls independent of each other
- Dimensional system according to grids and modules
- Timber frame can be left exposed internally or externally, or clad on both sides
- Connections mostly by way of steel components
- High manufacturing depth possible for wall, floor, and roof elements

b7 20 The parts of the construction

In frame construction the primary structure carries the loads of the secondary structure and transfers these to the foundations. Glued laminated timber is generally preferred for the primary structure. The secondary structure consists of individual beams or prefabricated elements.

The customary range of timber is:
- Glued laminated timber, strength grade GL24h, appearance class N (normal) or I (industrial)



b128

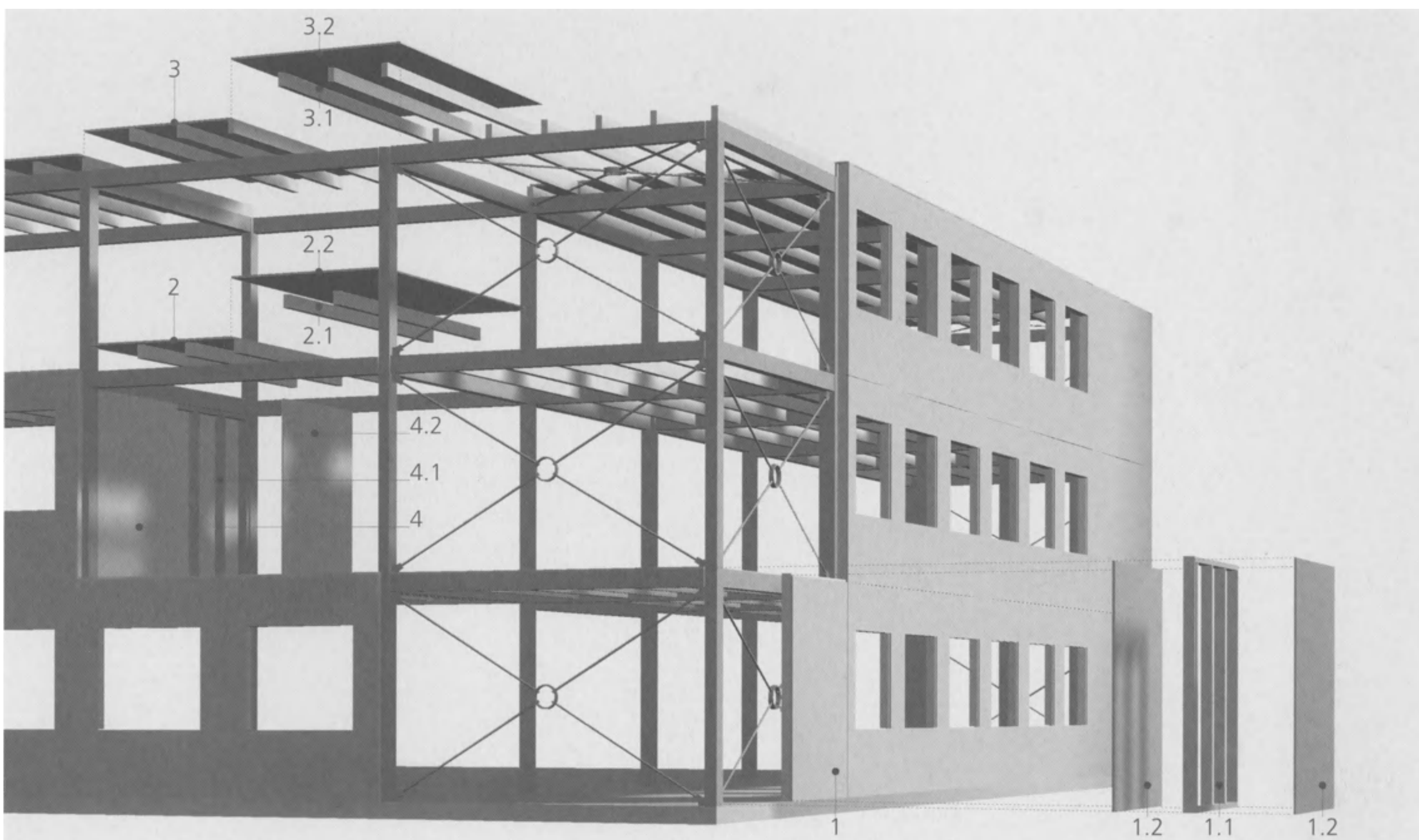
b128 Parts of the construction, primary structure

1 Column
2 (Downstand) beam
3.1 Vertical bracing
3.2 Horizontal bracing
4 Timber joists, flooring elements (secondary structure)
5 Timber rafters, roofing elements (secondary structure)

- Solid timber and compound sections, strength grade C24, appearance class and moisture content according to requirements

Wind loads generate horizontal forces which must be resisted by stiffening plates. Roofs and suspended floors form these plates in the horizontal plane. The resulting forces are transferred to the foundations via vertical bracing.
Horizontal bracing can take the form of
- diagonal steel bracing in the plane of the roof
- diagonal bracing made from steel flats
- wood-based board products

The vertical bracing can take the form of
- steel X-bracing (flat or round sections)
- solid timber diagonals
- wood-based board products (full plates)
- masonry or concrete elements (stair or lift shafts, fire compartment walls)



b129

b129 Enclosing elements, cladding, building envelope

1 External wall, external wall elements
1.1 Studs, framework
1.2 Further component layers
2 Suspended floor, flooring elements
2.1 Timber joists, hollow-box elements, etc.
2.2 Further component layers

3 Roof, roofing elements
3.1 Timber rafters, beams, hollow-box elements, etc.
3.2 Further component layers
4 Internal wall, internal wall elements
4.1 Studs, framework
4.2 Further component layers

b7 Frame construction

b7 30 Building structure

b7 31 Grid dimensions

Frame structures – whether of timber, concrete or steel – are planned based on a horizontal grid, and usually on a vertical grid as well. Once chosen, this basic module determines the layout of the loadbearing structure in terms of the horizontal and vertical dimensions, and the planning of the frame construction. The grid (or modular) dimension, depends on the particular features of the intended layout, the purpose of the building, and also constructional aspects. The ensuing repetitive effect simplifies design and construction.

In principle, it is true to say that the layout of a loadbearing structure based on a large grid dimension results in a greater amount of timber being consumed, but that the overall cost of a timber frame based on such a larger grid is lower. The reason for this is that in timber engineering the overall cost of a loadbearing system is essentially influenced by the number of joints required. The fabrication of such joints is more cost-intensive.

Criteria to be considered when deciding on the grid or modular dimensions are as follows:

Design considerations
- Size of building
- Sizes of rooms and interior layout
- Requirements related to use
- Architecture

Location
- Geography
- Size of site
- Scale in relation to existing buildings

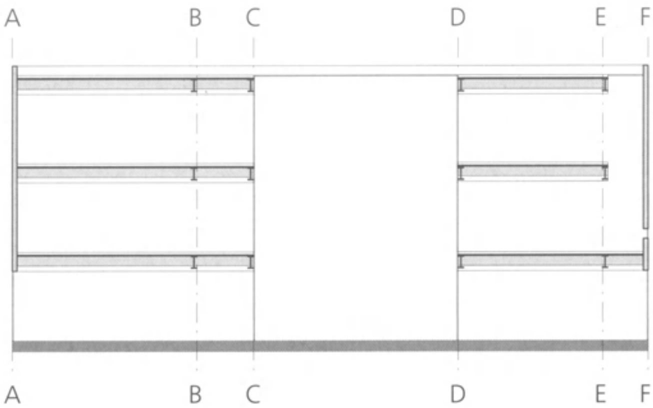
Architecture
- Interior layout
- Facade design
- Interior architecture

Constructional aspects
- Economic spans, planning, design, and construction of joints
- Spacing of joists, rafters, and columns in the secondary structure
- Conventional formats of elements for floors, walls, and roof
- Conventional formats of sheathing and cladding materials
- Standard dimensions of doors and windows

In principle, any dimensions may be chosen for the grid – based on criteria set by the planning team itself. Frame structures are designed and built according to a large grid. Proven grid dimensions for frame construction in timber are:
1250 x 1250 mm, 2500 x 2500 mm, 5000 x 5000 mm, 6250 x 6250 mm, 7500 x 7500 mm, etc.
These dimensions originate from the basic 625 mm module. This guarantees conformity with the joist spacing and sheathing layers based on the 625 mm module, and with standard sheathing/cladding materials (Figs. b134 to b137).

The locations of suspended floors depend on the clear ceiling heights required. They may remain at one level throughout the building or may be stepped to suit particular requirements (Fig. b138). The form of frame construction selected (see section b7 40) must be coordinated with this constructional storey height and the clear ceiling height. If a limited height is necessary for the floor zones, it is advantageous to design the floor members with their upper surfaces flush with the main beams. Downstand beams and flooring systems are economic only when there is sufficient depth for the floor construction.

The choice of grid dimension influences the following aspects:
- the preliminary sizing of the structure
- the choice of frame construction (see section b7 40)
- the planning of the joints
- the specification of the fitting out details, wall, and suspended floor assemblies
- the structural calculations and the planning of the on-site works



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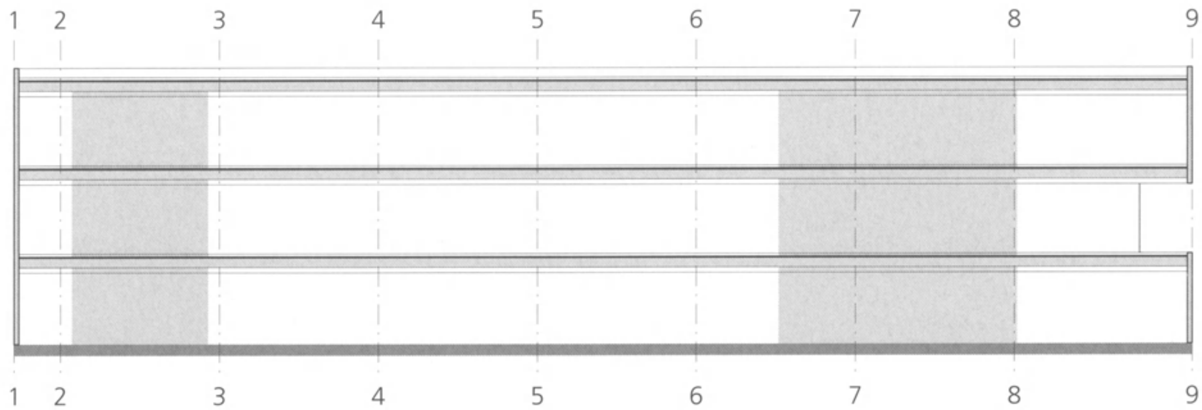

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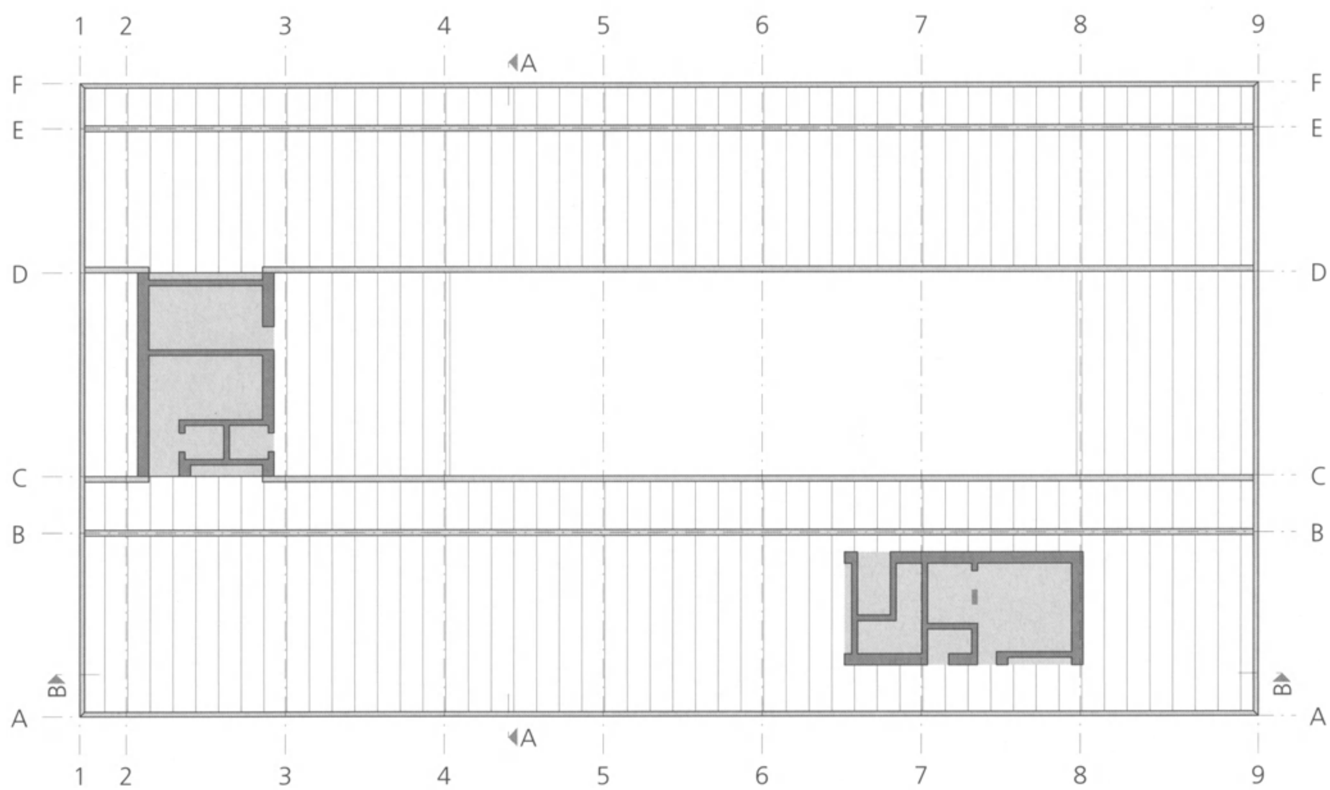


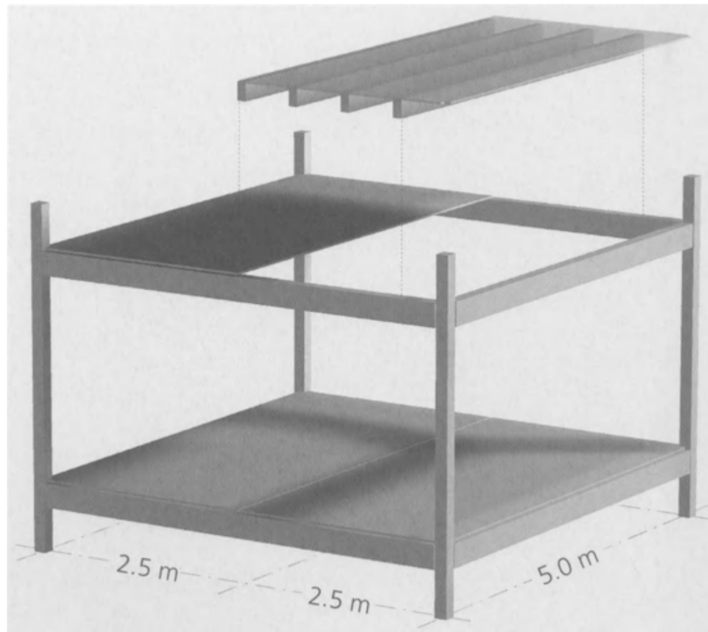
b132

b130 to b133 Grid arrangement related to building use (e.g. school or office building)
Main grid 8.5 x 7.5 m and 8.5 x 10.0 m

b130 Section A-A
b131 Section B-B
b132 Plan
b133 (overleaf) Axonometric view

b7 32 Column spacing

The column spacing depends on the grid chosen. From a structural viewpoint, the columns themselves are not usually a problem. Due to the high efficiency of timber parallel to the grain, they can carry high loads. Attention must be given to the critical buckling length, the joint details (compression perpendicular to the grain), and the spans of downstand beams and suspended floors. Figs. b130 to b133 show one example of a grid coordinated with the use of the building. Useful typical member sizes based on grid dimensions and column spacings are listed in Figs. b135 to b137.



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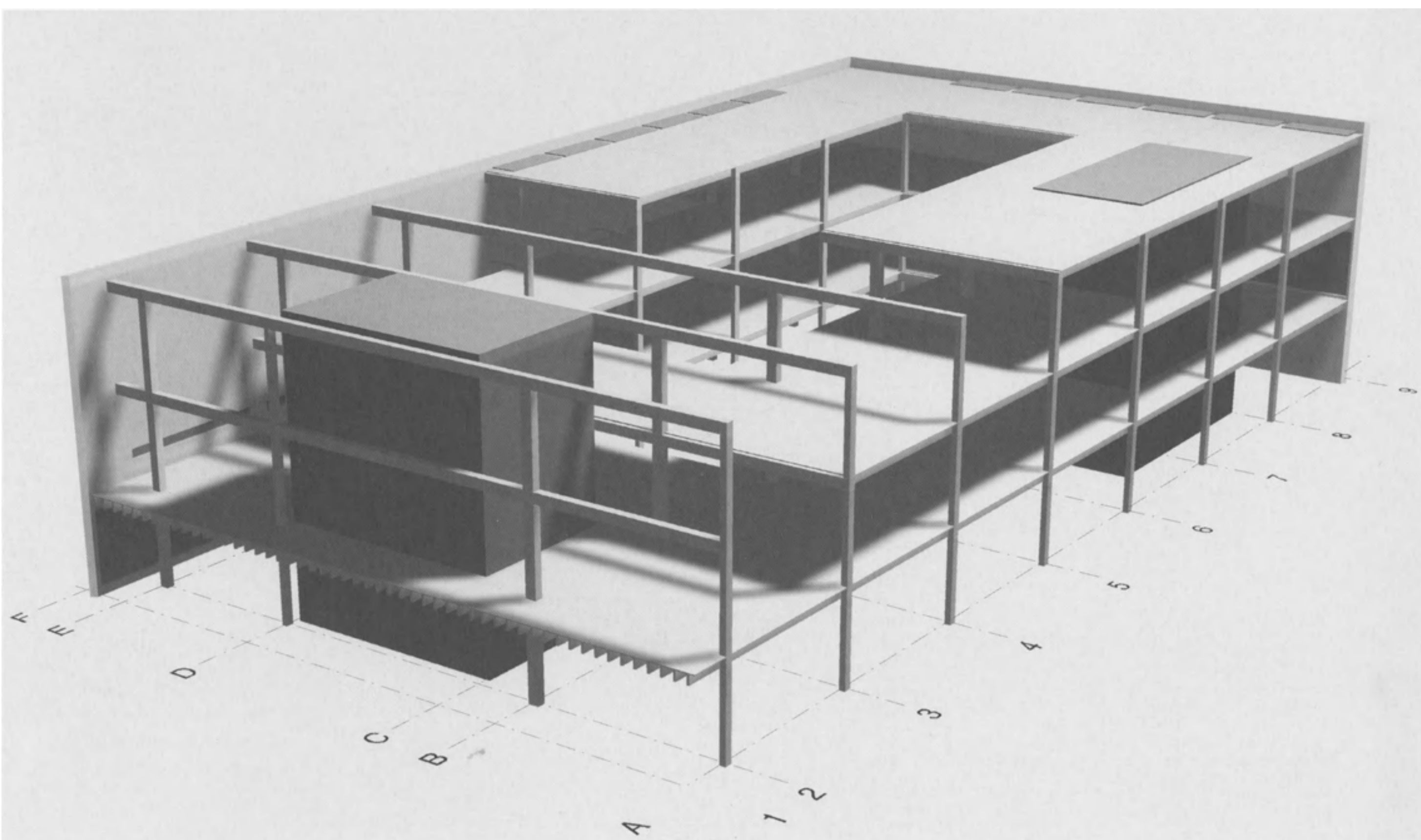
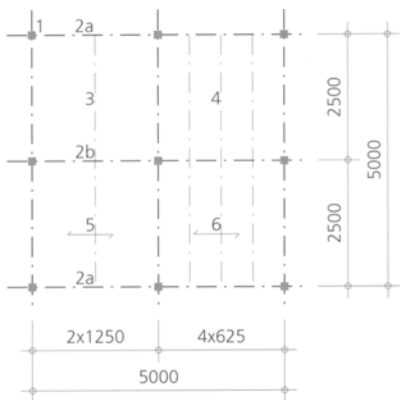


b133

b133 Grid layout related to building use (e.g. school or office building)
Main grid 8.5 x 7.5 m and 8.5 x 10.0 m
Axonometric view; for plan and sections see Figs. b130 to b132 (previous page)

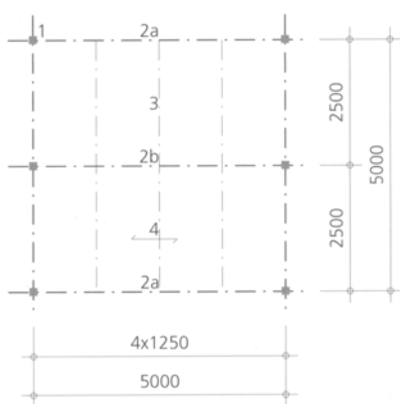
b134 Grid dimension 5.0 m to match the formats of conventional sheathing and cladding materials. Economically affordable spans for housing are 4.0 to 6.0 m.



b135

2500 x 2500 mm grid
(Details of typical sections for the draft design for a total vertical load of approx. 3.0 to 3.5 kN/m²; simply supported floor joists)

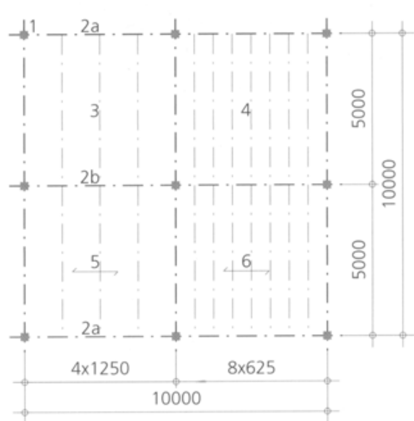
1	Column	
2	Main beams:	span 2500 mm, beam spacing (centre to centre) 2500 mm, glulam grade GL24h
	a) perimeter beams:	(w x h) 120 x 160 mm
	b) other beams:	(w x h) 120 x 200 mm
3	Floor joists:	span 2500 mm, joist spacing (centre to centre) 1250 mm, sawn timber grade C24, (b x h) 100 x 160 mm
4	Floor joists:	span 2500 mm, joist spacing (centre to centre) 625 mm, sawn timber grade C24, (b x h) 100 x 120 mm or 80 x 140 mm
5	Floor sheathing:	span 1200 mm, solid timber, d=32 or 36 mm
6	Floor sheathing:	span 600 mm a) solid timber, d=22 mm b) particleboard (continuous over two bays), d=25 mm



b136

2500 x 5000 mm grid, 2500 x 5000 mm column spacing
(Details of typical sections for the draft design for a total vertical load of approx. 3.0 to 3.5 kN/m²; simply supported floor joists and main beams)

1	Column	
2	Main beams:	span 5000 mm, beam spacing (centre to centre) 2500 mm, glulam grade GL24h
	a) perimeter beams:	(w x h) 120 x 320 mm
	b) other beams:	(w x h) 120 x 400 mm or 200 x 320 mm
3	Floor joists:	typical sections as for Fig. b135
4	Floor sheathing:	typical dimensions as for Fig. b135



b137

5000 x 5000 mm grid
(Details of typical sections for the draft design for a total vertical load of approx. 3.0 to 3.5 kN/m²; simply supported floor joists and main beams)

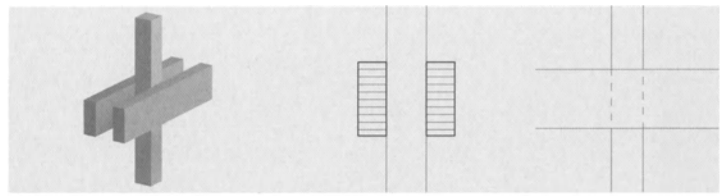
1	Column	
2	Main beams:	span 5000 mm, beam spacing (centre to centre) 5000 mm, glulam grade GL24h
	a) perimeter beams:	(w x h) 120 x 400 mm or 200 x 320 mm
	b) other beams:	(w x h) 120 x 480 mm or 200 x 400 mm or 240 x 360 mm
3	Floor joists:	span 5000 mm, joist spacing (centre to centre) 1250 mm, lulam grade GL24h (b x h) 120 x 320 mm or 160 x 280 mm
4	Floor joists:	span 5000 mm, joist spacing (centre to centre) 625 mm, sawn timber grade C24, (b x h) 100 x 240 mm or 140 x 220 mm
5	Floor sheathing:	typical dimensions as for Fig. b135
6	Floor sheathing:	typical dimensions as for Fig. b135

b135 to b137 The effects of different grid dimensions and different floor beam spacings on the sizes of timber members for residential buildings.

b138

b7 40 Forms of frame construction

We distinguish between various forms of frame construction in timber, which differ depending on the column and beam configuration plus the types of connection. The choice of form of construction depends on the architectural requirements, the grid, and the loads to be carried. It is therefore best to choose the grid first and establish preliminary dimensions for the primary structure and then select the resulting frame construction form.
The five most common forms of frame construction in timber are illustrated in Figs. b139 to b143. These five forms are explored in detail on the following pages.



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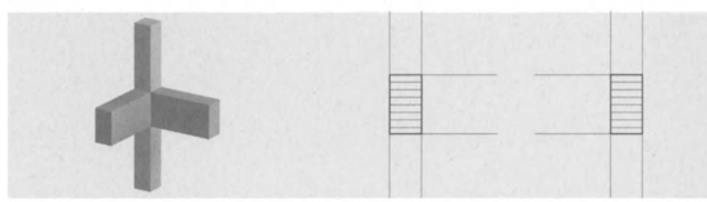
b140

b141



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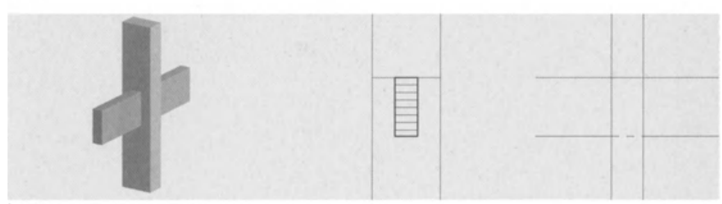


b143

b138 Intermediate floors can remain at the same level throughout the building or can be stepped.

b139 to b143 Forms of frame construction
b139 Columns and compound beams
b140 Compound columns and beams
b141 Columns and oversailing beams
b142 Beams and continuous columns
b143 Forked columns

b144

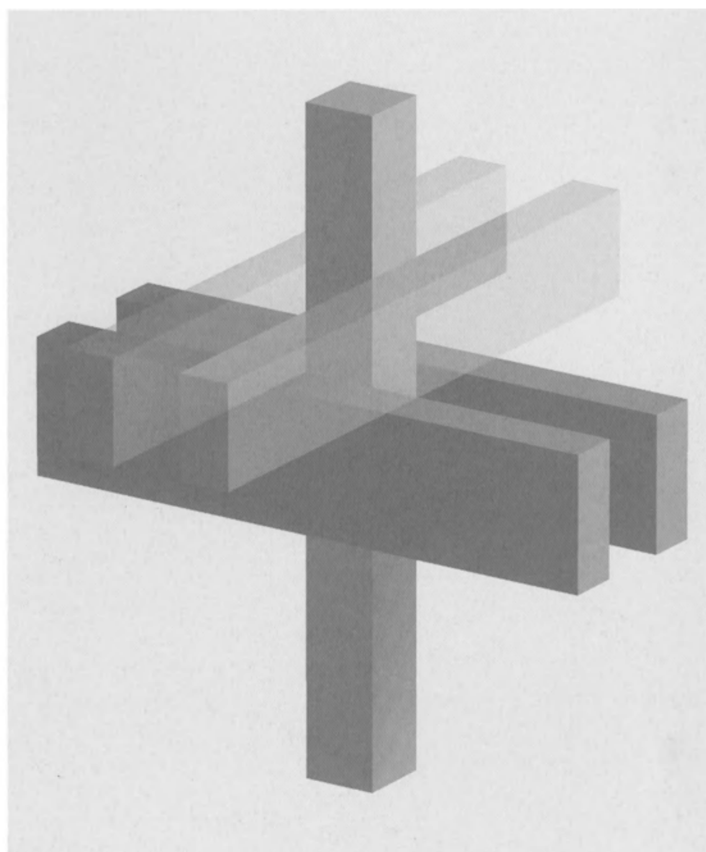
b144 Building in frame construction (main wing), School of Forestry, Lyss, Switzerland

b7 41 Columns and compound beams

The form of construction with columns supporting compound beams has a primary structure consisting of one-part columns and two-part continuous beams. Normally, the secondary structure – the flooring systems – bear directly on the main beams, which calls for a relatively high floor zone. This form of construction is very similar to a collar beam arrangement and is frequently used because of its simplicity, which leads to an overall economic solution. The ends of the compound beams projecting beyond the last column (sometimes needed for the connection between beam and column) is a much-loved architectural feature. The ends of such twin beams are often left exposed externally to create a distinctive characteristic of this type of construction. However, the current trend is to minimise if not avoid totally wall penetrations, and so such protruding compound beams could soon be a thing of the past.

The connection between column and twin main beam can be accomplished by way of
- close-tolerance bolts and screws
- shear-plate and split-ring connectors
- notched joints
- side plates (Fig. b149)
- welded steel components
- steel sections (Fig. b148, with hollow or solid square sections)

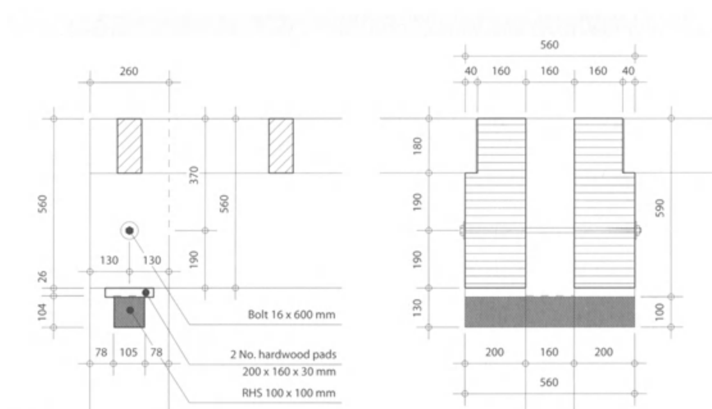

b145


b146

b145 Frame construction in the form of columns and compound beams

b146 The columns are in one part, the beams in two. The floor joists can bear directly on the primary structure (as shown here) or can be installed with their upper surfaces flush with the primary structure.

b147



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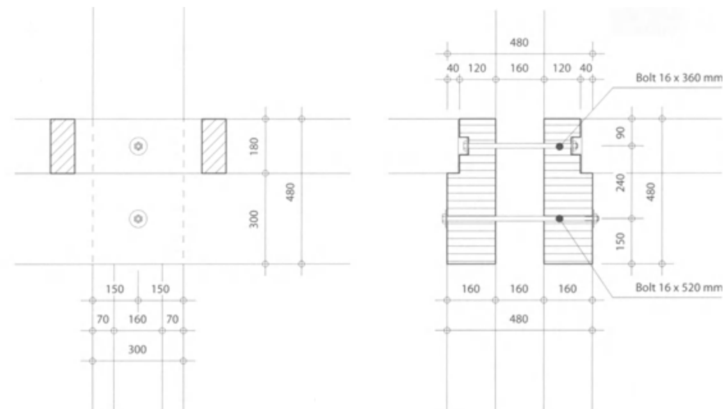

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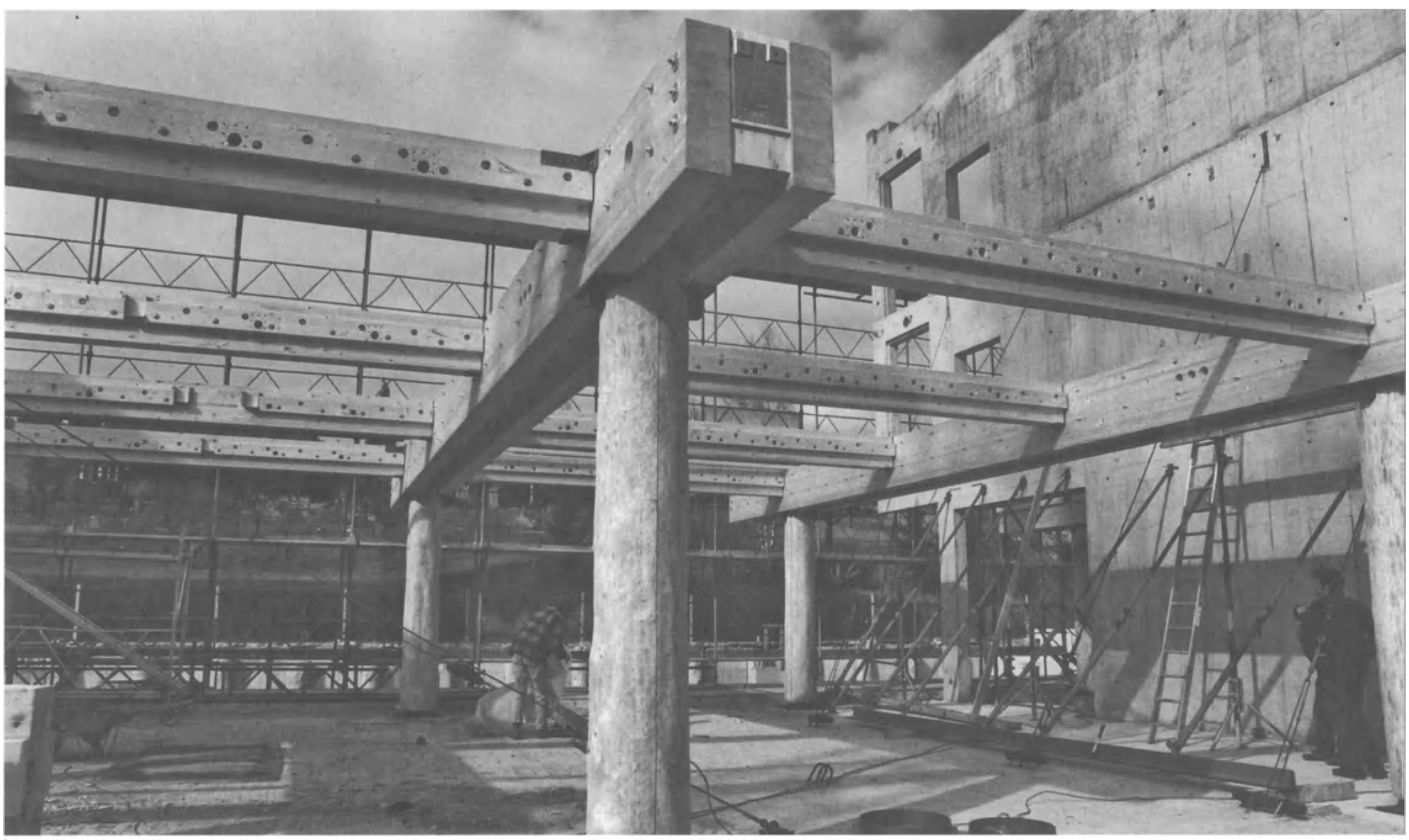


b150

b147 Frame construction renders possible bright interiors flooded with light. Columns and parts of the two-part beams (primary structure) remain exposed.

b148 Connection using steel hollow or solid square sections

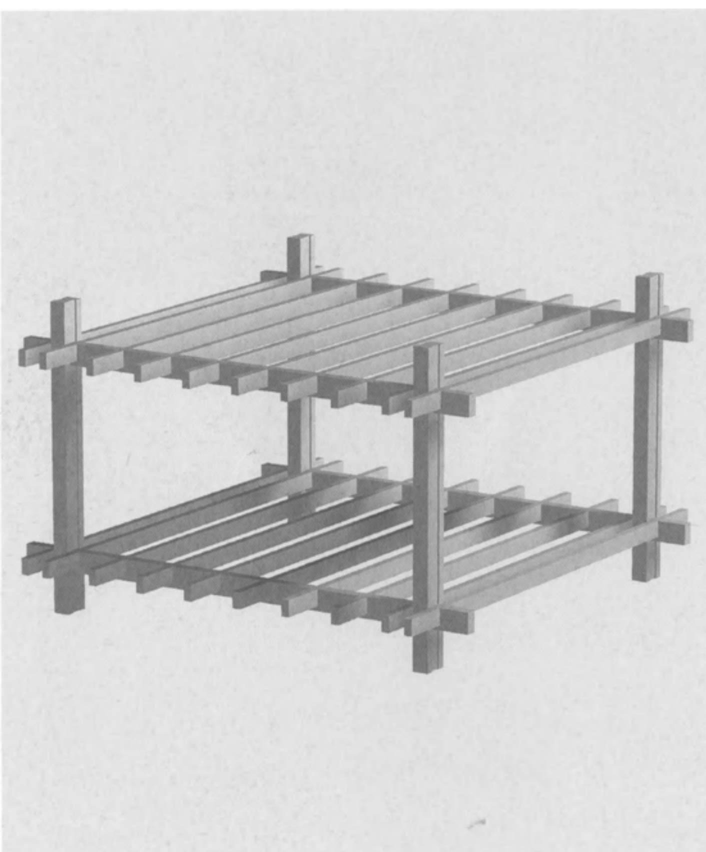
b149 Connection using side plates; the two-part beams bear on the side plates.

b150 Frame construction in the form of columns and compound beams

b7 42 Beams and compound columns

In this form of construction the one-part beams are connected to the continuous two-part columns by means of mechanical fasteners. The high slenderness ratio of the column members usually means it is necessary to include packing timbers between the two parts, which form a useful bearing for the main beams. Continuous packing timbers are often necessary in the case of more stringent fire protection requirements because slender columns are a disadvantage from the viewpoint of their behaviour in fire. The secondary structure in the plane of the suspended floor can be connected flush with the top of the main beams, which results in a reduced construction height. In the case of a floor acting as a plate, this flush arrangement also enables the forces to be transferred directly from the secondary to the primary structure. Construction using compound columns and one-part beams is often preferred owing to the architectural design options. But the main beams must inevitably penetrate the external walls – a disadvantage that can only be avoided by positioning the external walls on the structural frame.

The vertical forces can be transferred from the main beam via the contact face of the packing timber. This connection must be secured with steel components.



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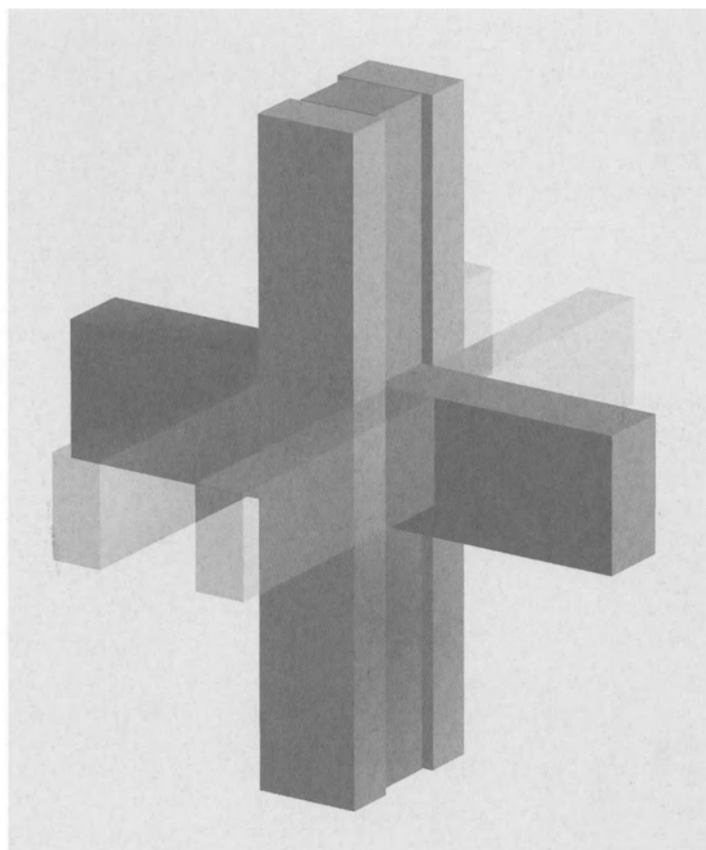


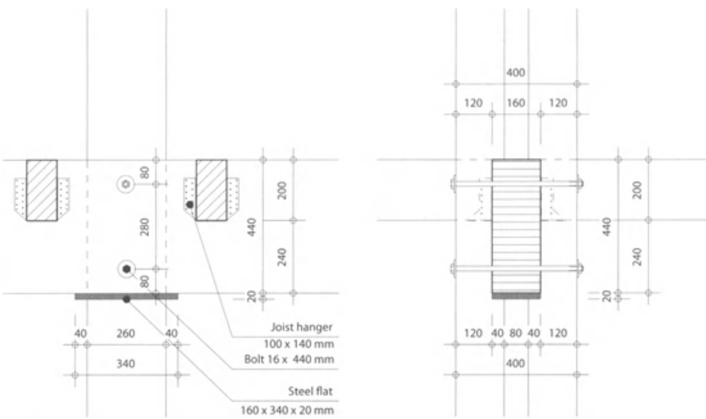
b152

b151 Frame construction in the form of beams and compound columns

b152 The columns are in two parts, the beams in one. The floor joists can bear directly on the primary structure or can be connected as simply supported members with their upper surfaces flush with the primary structure (as shown here).

If a packing timber is not specified, one of the following connection options can be chosen:
- close-tolerance bolts and screws
- shear-plate and split-ring connectors
- notching the columns (Fig. b153)
- welded steel components or steel studs

Joist/main beam connection (vertical load):
- mortise and tenon joint
- sheet steel components (plates let into the timber, joist hangers, Z-sections)
- direct bearing on the main beams



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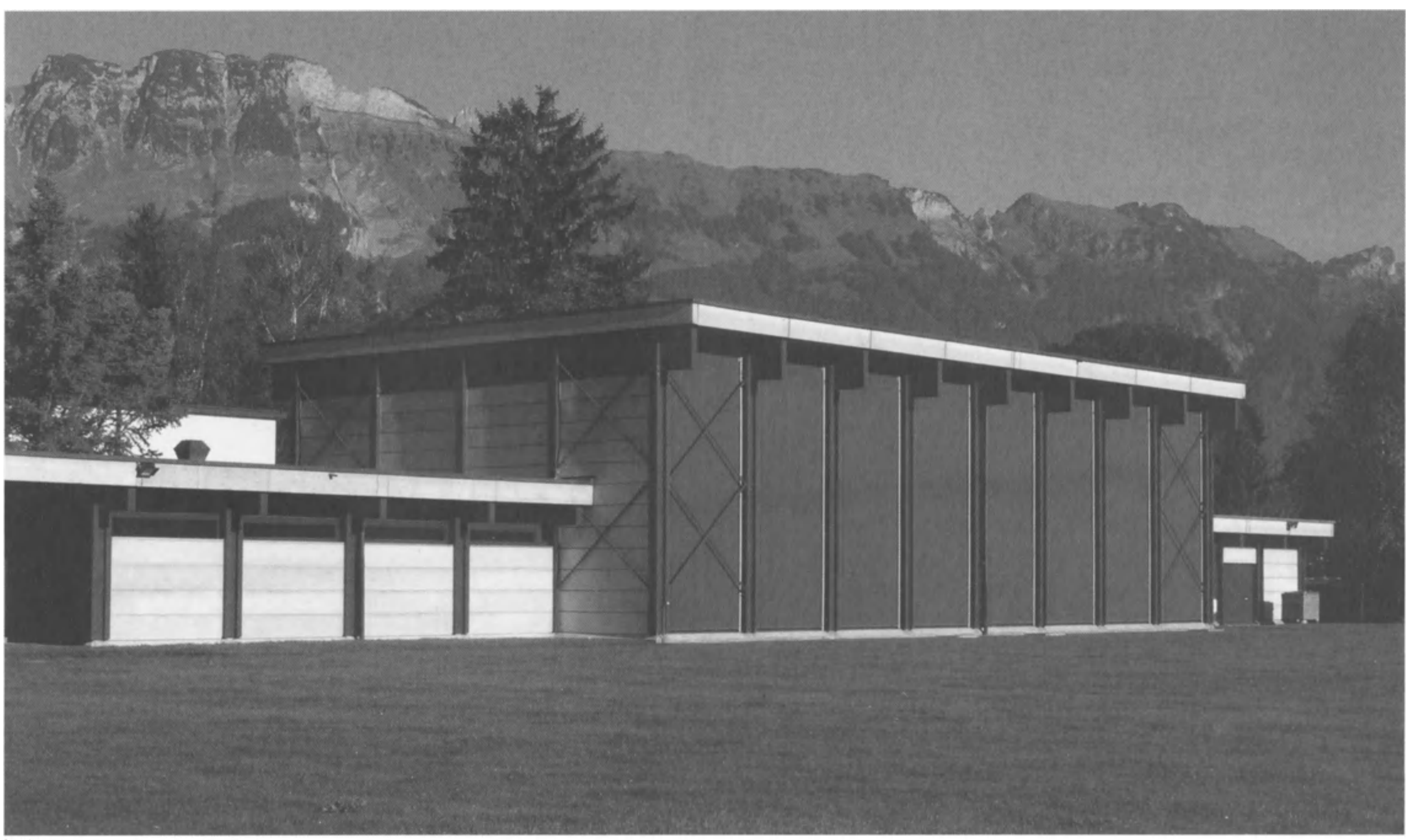
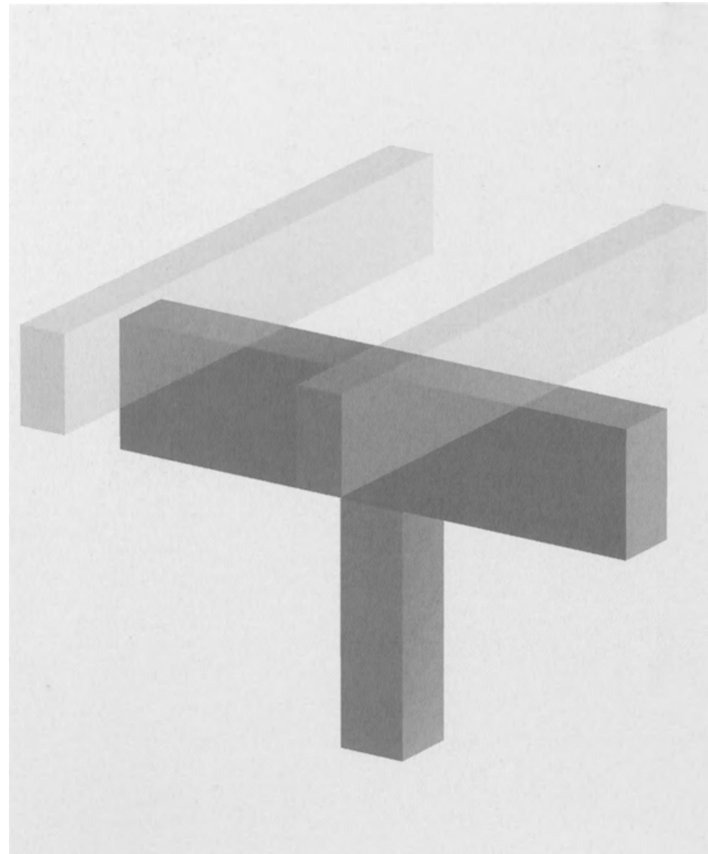


b154

b153 Connection using notched column

b154 Frame construction in the form of beams and compound columns, sports centre, Haag, Switzerland



b156

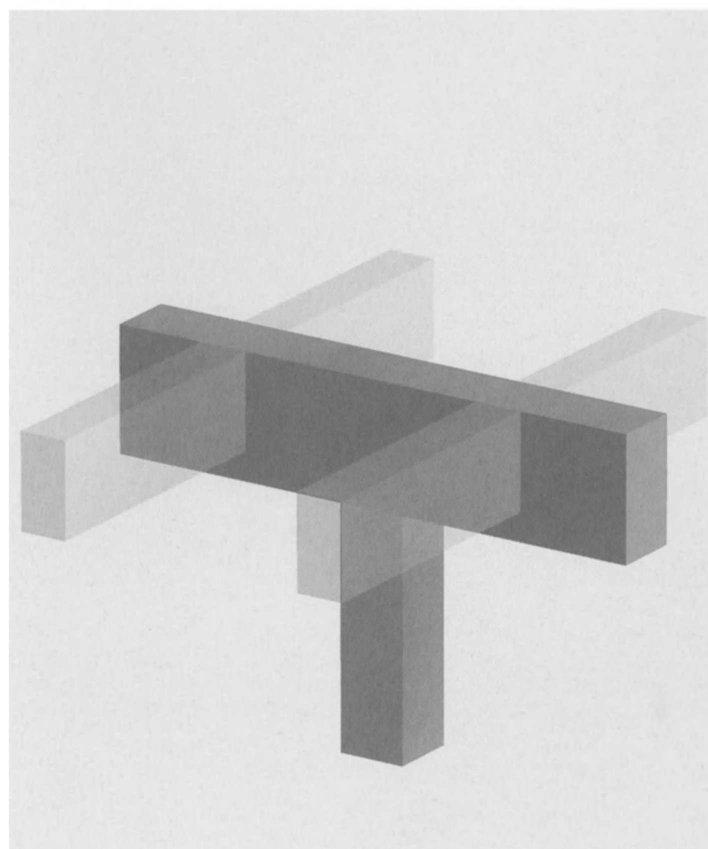
b7 43 Columns and oversailing beams

The simple form of construction with one-part columns and beams is suitable for single-storey flat-roof structures. The beams can be simply supported or continuous over two or more spans. The joists of the secondary structure can bear directly on the main beams or be mounted with their top surfaces flush with the main beams.

The load transfer between main beam and column is by way of direct bearing between underside of beam and end face of column. To secure this connection and also to resist uplift due to wind, the following forms of connection and fasteners can be used:

- mortise and tenon joint
- bonded threaded bars
- wood screws (for tensile forces)
- steel components let into the timber and secured with close-tolerance bolts (Fig. b159)
- hardwood spreader plus fishplates (Fig. b160)

b155

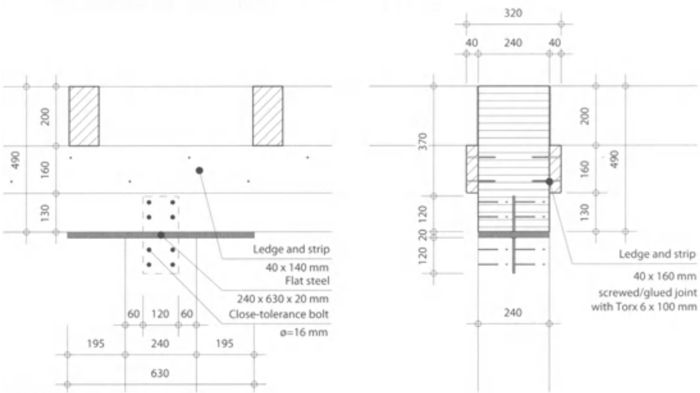


b157

b155 Frame construction in the form of columns and oversailing beams

b156 and b157 The one-part beam bears directly on the top of the column. The secondary beams can bear directly on the primary structure (Fig. b156) or can be connected with their upper surfaces flush with the primary structure (Fig. b157).

b158



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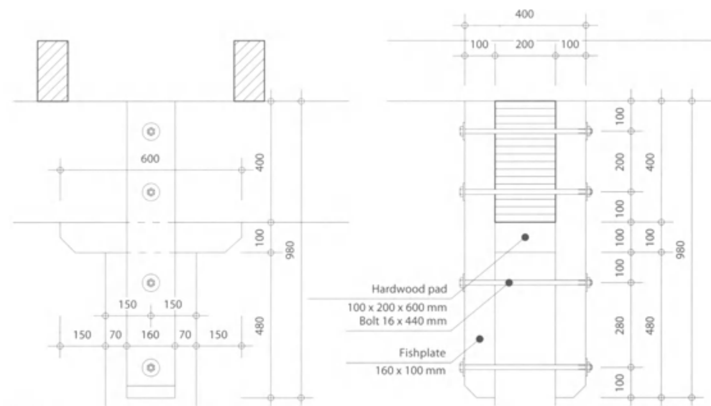

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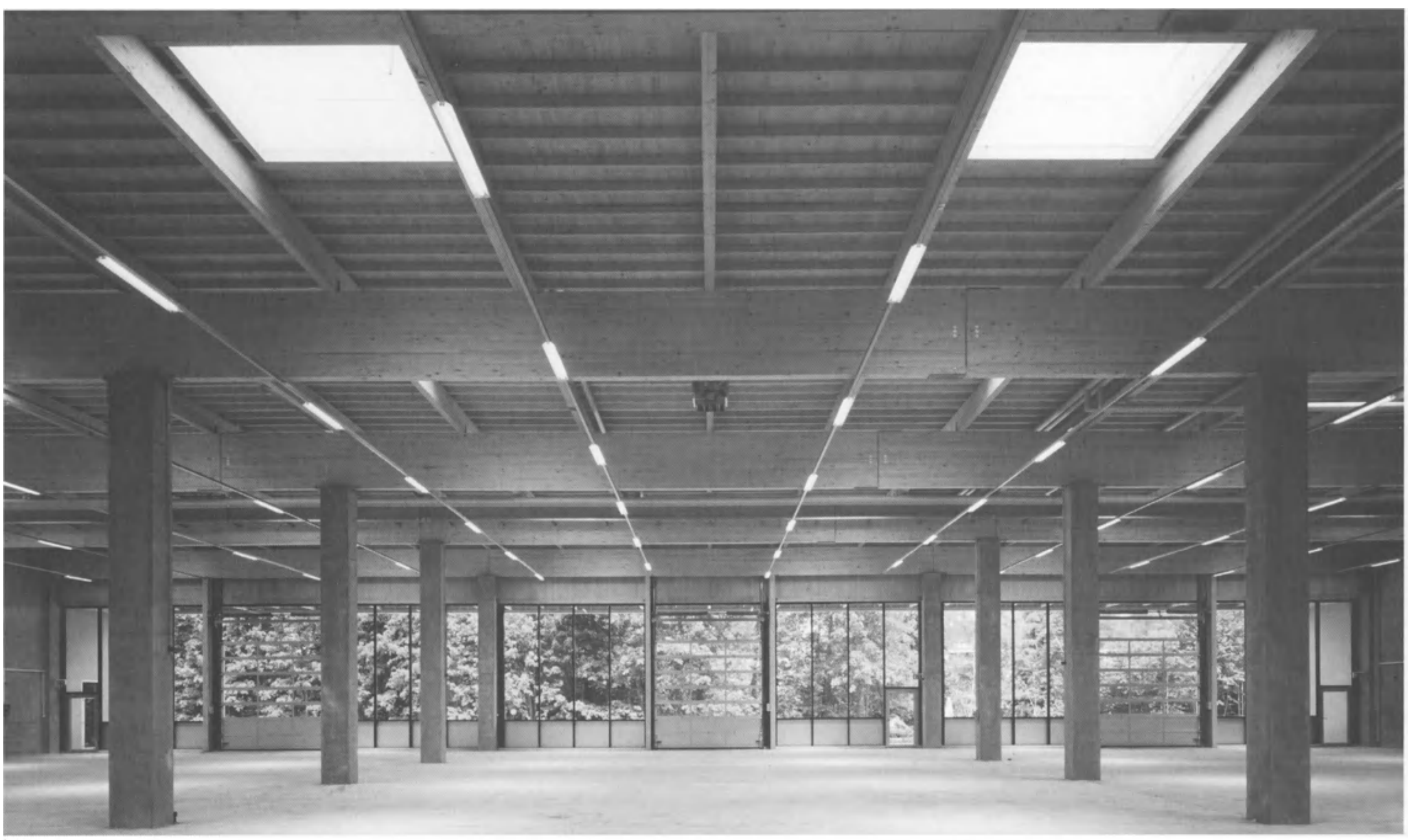


b161

b158 Erection of floor beams (Fig. b161)

b159 Connection using steel bearing plate, steel plate let into timber and close-tolerance bolts

b160 Connecting using bearing pad and fishplates

b161 Industrial building, 8.0 x 16.0 m grid; frame construction in the form of columns and oversailing beams.

b7 44 Beams and continuous columns

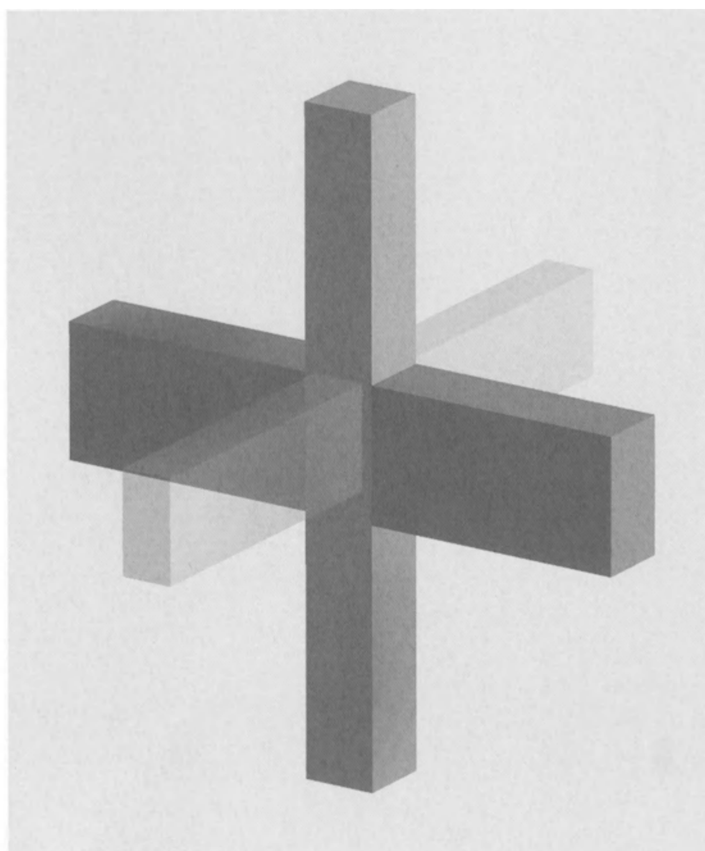
The primary structure of this form of construction consists of continuous columns and main beams designed as simply supported beams spanning between the columns. In this arrangement both the horizontal beams and the vertical columns are one-part members connected in the same vertical plane. The advantages of this system are that connections to the columns are possible in one plane on all four sides, and at the same time the beams can be connected to the columns at any level. As the columns form the perimeter of the loadbearing system and columns and beams are in the same vertical plane, this system is particularly suitable for structures whose structural frame lies on the inside of the building envelope. The external walls are subsequently fixed to the outside of the structural frame so there are no horizontal loadbearing members penetrating the building envelope. Balconies and canopies are designed as independent, external, secondary systems.

The main beam is connected to the column by way of

- preformed sheet metal components, T-sections let into the beam and annular-ringed shank nails (Fig. b165)
- flat steel plates and close-tolerance bolts (Fig. b166)

Furthermore, connection systems suitable for connections in one plane are now available ex stock (Figs. b167 to b169).


b162


b163

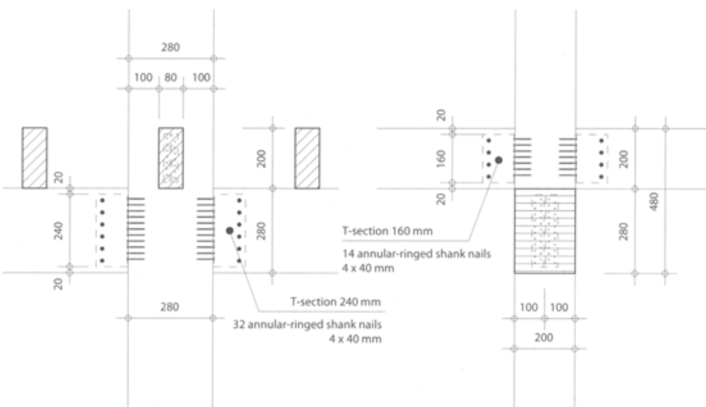
b162 Frame construction in the form of beams and continuous columns

b163 The beams are connected to the continuous columns. Floor joists can span between the main beams or bear directly on them..

b164

The advantages of these connections are:

- concealed connections on all sides
- fast erection
- high load-carrying capacity
- standardised with a defined load-carrying capacity



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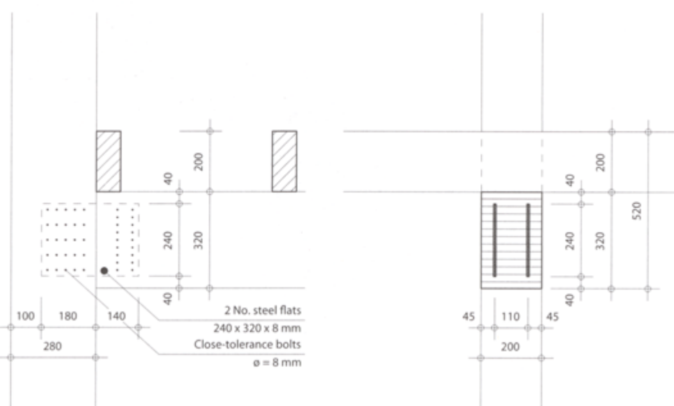

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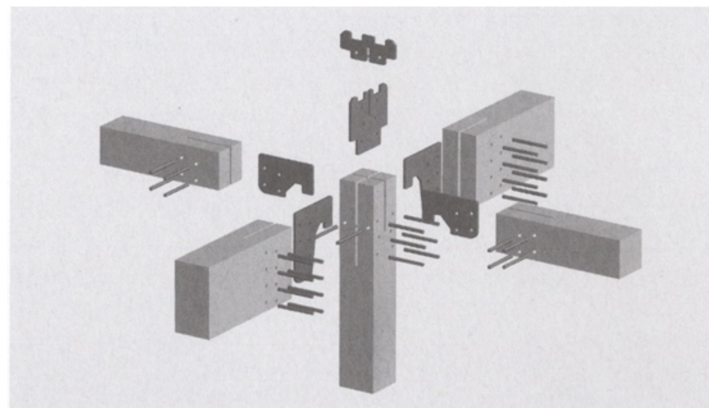

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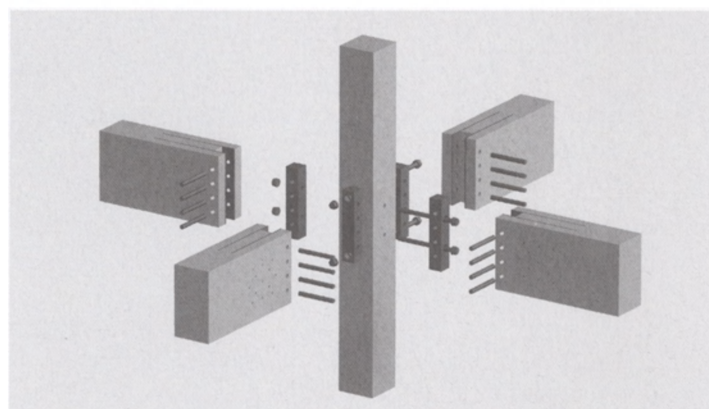

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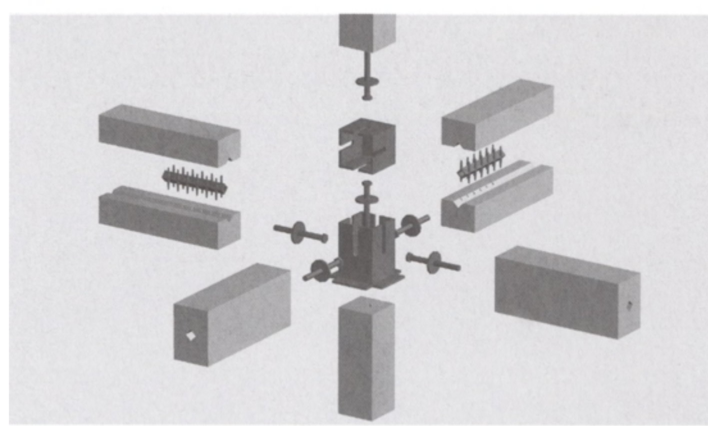


b169

b164 Frame construction in the form of beams and continuous columns, school media library, Küsnacht, Switzerland

b165 Connection using T-sections let into the beams and annular-ringed shank nails

b166 Connection using flat steel plates and close-tolerance bolts

b167 "Janebo" connection

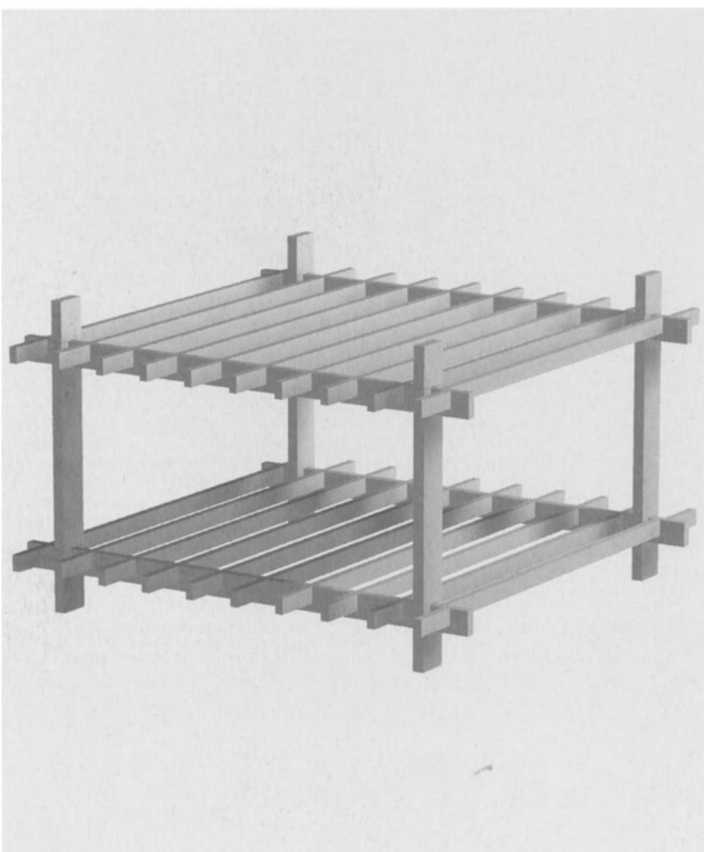
b168 "BSB" connection

b169 "Induo" connection

b7 45 Forked columns

The primary structure is in the form of a one-part continuous beam supported on storey-height columns. The columns are connected together via the forks. This form of support is a simple and effective way of holding the beams in position and transferring the vertical loads. In multi-storey buildings, the load from the upper floors is carried via the forks of the columns. This results in two advantages:

Firstly, the shrinkage and swelling effects over the full height of the building are minimised because only longitudinal timbers are placed on top of each other. Secondly, timber sections carrying loads parallel with the grain have better strength properties than when they are used to carry loads perpendicular to the grain. Consequently, higher loads can be carried. Forked columns with a cruciform section can be used, but a simple square or rectangular section is equally possible, with the forks in the form of additional members on each side. Curtailing these additional members results in cruciform-type sections that enable the wall connections to be easily constructed.



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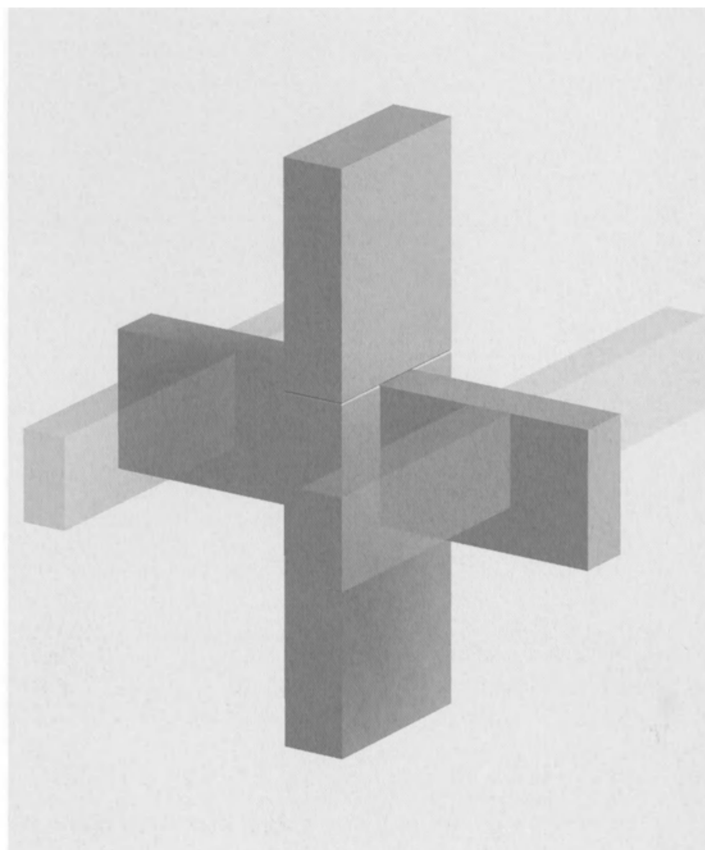
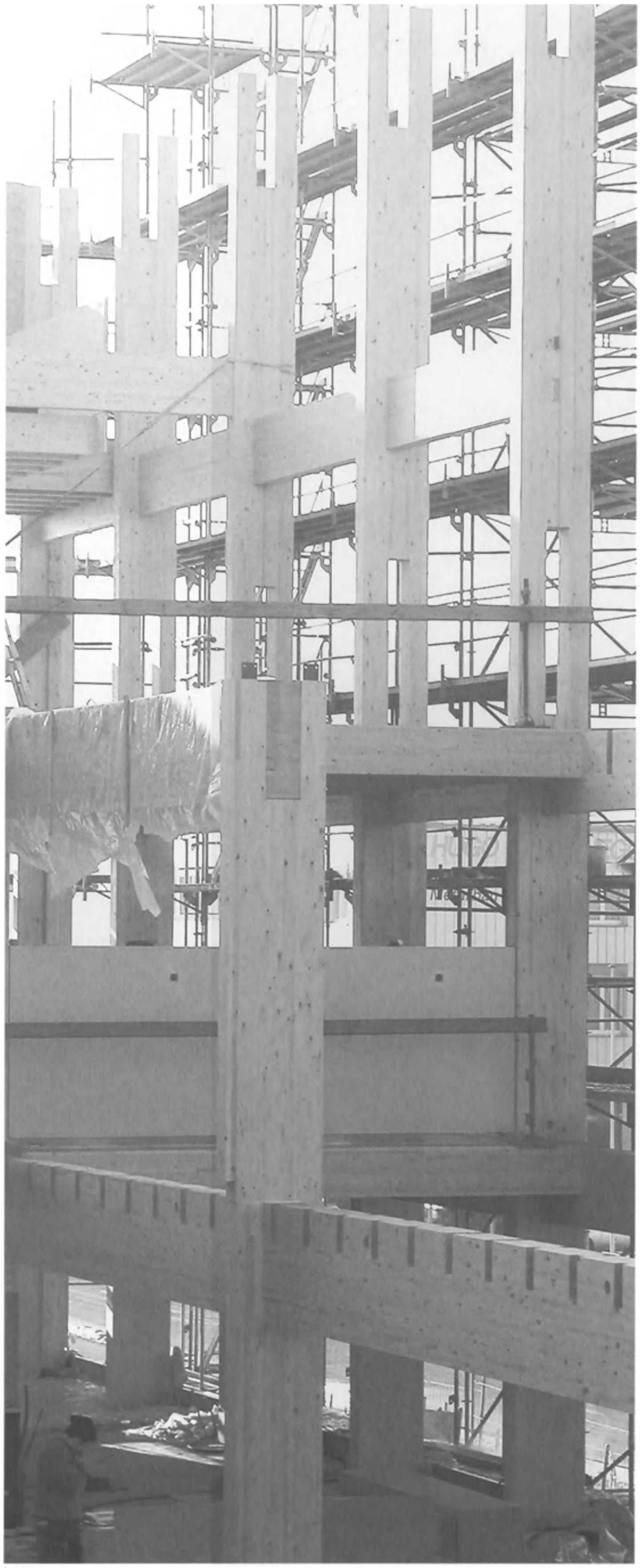


b171

b170 Frame construction using forked columns

b171 The main beam passes through the column. The joists of the suspended floor can bear directly on the main beam or can be connected with their top surfaces flush with the main beam.



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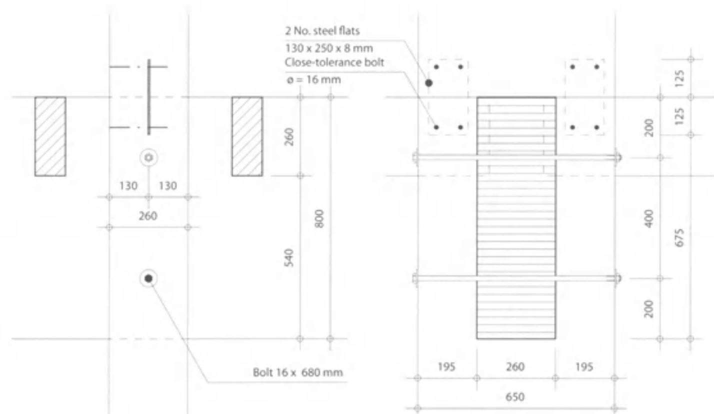

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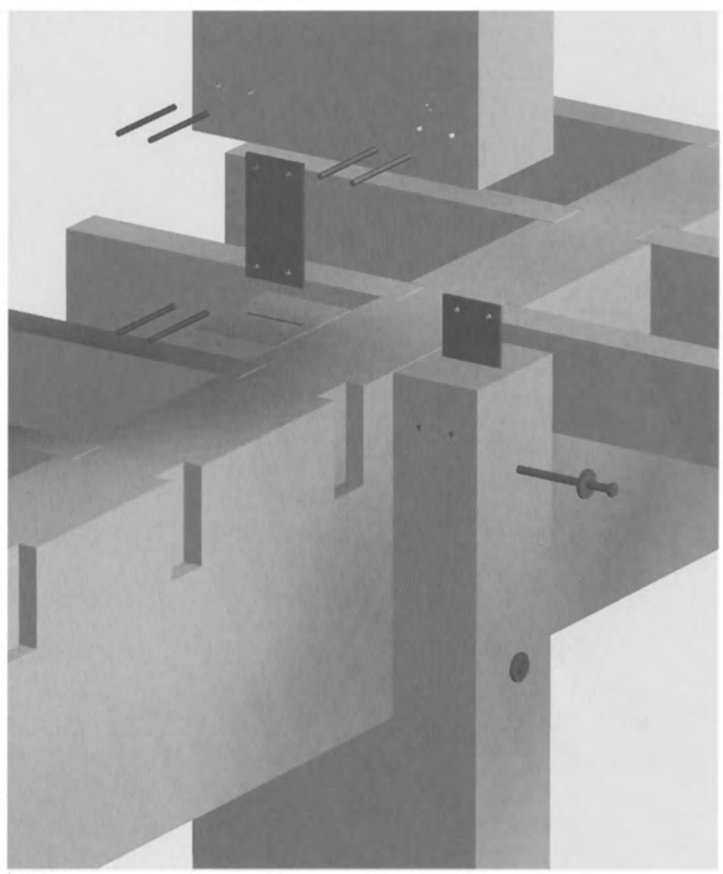


b174

b172 Erection of forked columns and main beams

b173 and b174 Connection between forked column and main beam

b7 50 Structural engineering

b7 51 General

In frame construction the loadbearing functions are separated from the space-enclosing functions. The structure is therefore divided into a primary structure and a secondary structure. The former consists of the loadbearing columns and beams and is positioned on the chosen grid. It carries the loads from the secondary structure and transfers these to the foundations as concentrated loads. The secondary structure – consisting of timber joist floors or planar, prefabricated elements – transfers the loads from roof, suspended floors, and walls to the main beams. The design of frame structures presupposes specialist knowledge and experience and is carried out by a structural engineer. The transfer of heavy point loads must be carried out properly and the details must be planned and built accordingly. A well-thought-out structural concept optimised to meet the needs of the construction as a whole forms the basis for economic structures with a high constructional and architectural relevance. Besides clear, preferably simple load paths, the straightforward transfer of loads into components and down to the foundations, plus the bracing of the structure, are key aspects.

b7 52 Stability of the structure

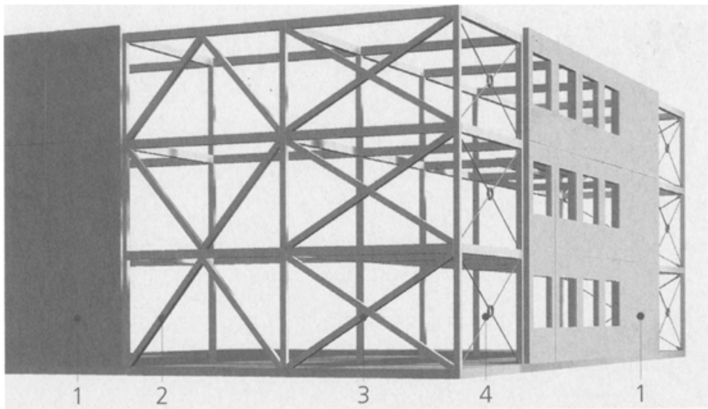
In order to guarantee the stability of frame structures in three dimensions, it must always be ensured that the wind loads and forces due to bracing can be resisted and transferred to other components. We distinguish here between two bracing directions: horizontal and vertical. Imperative from the structural viewpoint is bracing in the vertical direction. If a building includes a sufficient number of vertical plates, i.e. every axis of the grid is braced vertically, horizontal plates are then required in each bay only. Two different bracing systems can be derived from this:
- stability provided by vertical plates alone (Fig. b176)
- stability provided by vertical and horizontal plates (Fig. b177)

If only vertical plates contribute to the stability of the building, every longitudinal and transverse axis must be braced (Fig. b176). This form of bracing is rare because it places restrictions on the design of the interior layout. Frame construction therefore usually relies on a combination of vertical and horizontal plates to brace the structure (Fig. b177). Horizontal stability is provided by wind girders or plates in the plane of the floors or roofs, and vertical stability is ensured by bracing elements or plates in the plane of the walls, or by masonry or concrete structures within the building. As Fig. b177 shows, three vertical plates (shear walls) are sufficient, provided the plates do not intersect at the same point on plan. It is important to remember here that structural connections are required between horizontal and vertical plates to ensure that all forces are transferred.

Horizontal stability (Fig. b177) can be provided by
- diagonal solid timber planks
- wood-based board products
- diagonal steel bracing (flat or round sections)
- diagonal steel bracing in the plane of the roof
- diagonal solid timber bracing
- shear-resistant flooring elements

Timber planks placed parallel with the grid can also be used when the loads are low. However, the bracing effect of planks placed parallel to eaves or verges is inferior because they become effective only after greater deformations haver occured.

Planar or linear bracing constructions are also used for the vertical stability (Figs. b175 and b178). If walls with a sheathing of flat planks have been specified anyway, it is sensible to use these for the bracing as well. If there are no walls, but instead large expanses of glass, slender diagonal bracing in steel or timber is the best option. As glass technology advances, it may become possible to use the panes of glass themselves for bracing purposes, but such a move requires further development, tests, and the necessary building authority approvals. In multi-storey buildings, masonry or concrete elements (e.g. stair or lift shafts) can be used to ensure the necessary stability.



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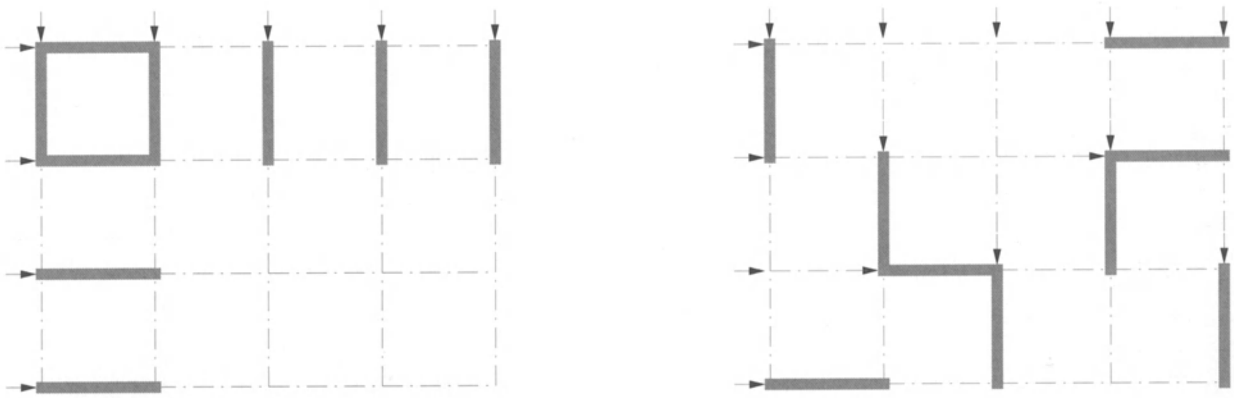

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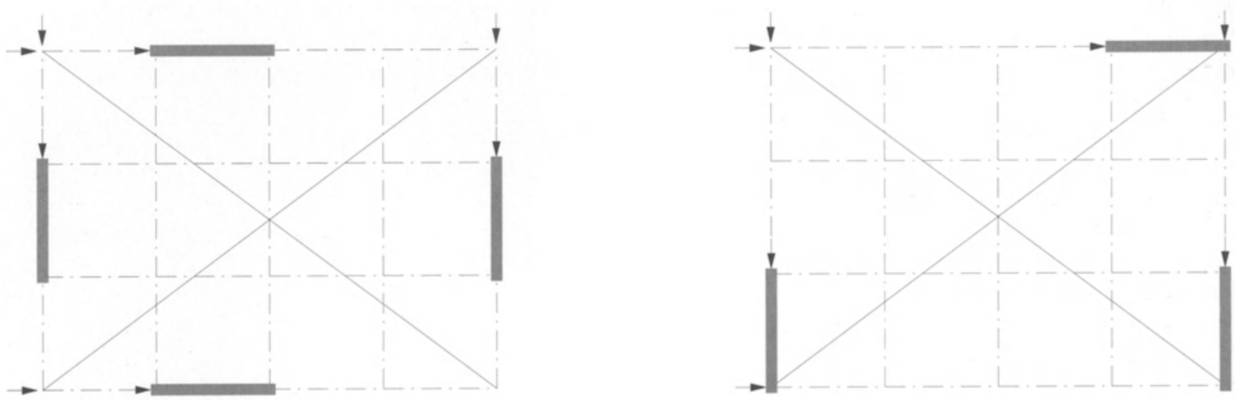

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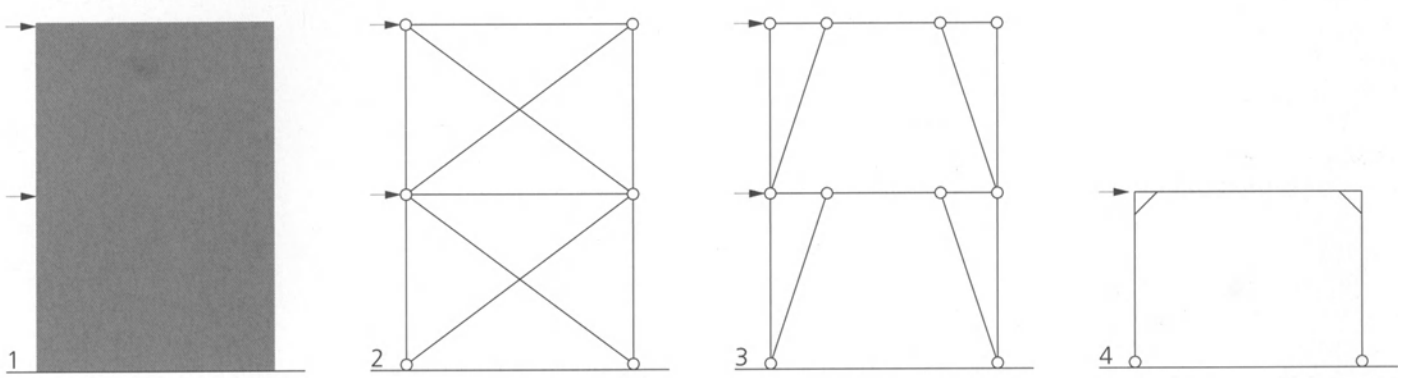


b178

b175 Stability systems
1 Walls, plates
2 Struts
3 Diagonal bracing in timber
4 Diagonal bracing in steel

b176 Stability by means of vertical plates only. Every longitudinal and transverse axis must be braced in this arrangement.

b177 Stability by means of vertical and horizontal plates. Three vertical plates (shear walls) are sufficient provided the plates do not intersect at one point on plan. To achieve adequate seismic resistance, the bracing elements must be evenly distributed (Fig. left).

b178 Provision of vertical stiffening
1 Plate (timber, masonry or concrete)
2 Wind girder
3 Trussed frame (resolved corners)
4 Rigid frame (rigid corners)

b7 60 Loadbearing structure and building envelope

Position

As the external walls do not carry any loads from the suspended floors or roof, they can basically take on any form. This means they can be positioned in front of, between, or behind the loadbearing members; Figs. b179 to b182 illustrate four possibilities. If the loadbearing framework is clad on both sides (Fig. b180) and is therefore integrated within the wall construction, regions with higher thermal conductivity (so-called thermal bridges) ensue at the columns or beam penetrations. Wall penetrations in the shape of rafters, beams, etc. are critical in timber construction because sealing these details properly is a complicated, expensive operation. The natural swelling and shrinkage behaviour of the wood is a disadvantage in this instance.
Forms of construction like those shown in Figs. b183 and b184 (horizontal sections) and Fig. b179 (sketch of principle) are advantageous. In these situations the loadbearing construction is placed on the warm side, i.e. inside the thermal insulation. It is enclosed by the inner lining, vapour barrier, airtight membrane, thermal insulation and outer cladding layers – which avoids joints and seams in those components. Consequently, there are no thermal bridges and no penetrations. Strictly speaking, these are the only forms of construction that can be recommended from the point of view of a sustainable, reliable construction.

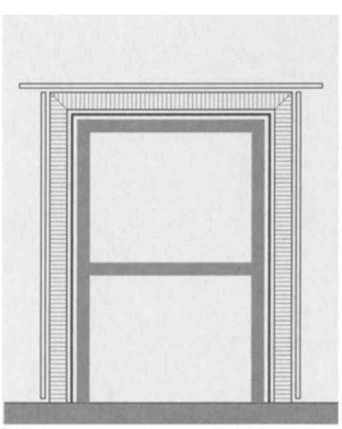
Wall construction

The wall elements can be designed according to the principles of panel construction (see chapter b6), the difference being that the walls in panel construction must generally be designed as loadbearing elements. Figs. b188 and b189 contain details of the wall construction and the junction with the facade. Forms of construction according to the systems shown in Figs. b179, b183 or b184 have been chosen deliberately. Figs. b190 and b191 show proposals for a hybrid form of construction: loadbearing columns and suspended floors in reinforced concrete, non-loadbearing external walls in the form of highly insulated timber external wall elements. This type of construction is also based on the systems shown in Figs. b179, b183 or also Fig. b184.

Multi-storey buildings in frame construction

- Generally suitable for multi-storey and larger structures
- Also advantageous in the case of heavy loads
- Early inclusion of a specialist structural engineer necessary
- Building design and type of frame construction must be harmonised at an early stage

Chapter b11 contains further information regarding multi-storey building in timber.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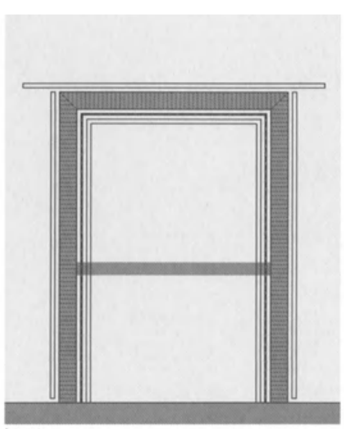
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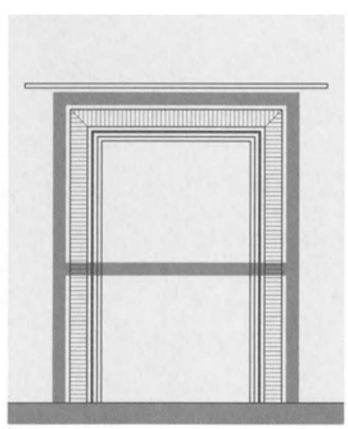
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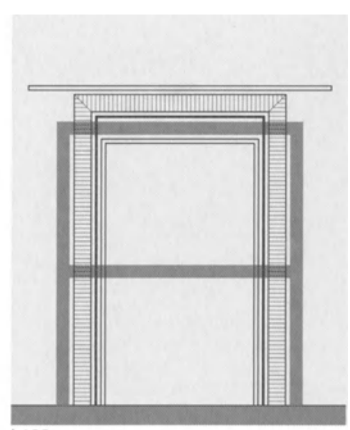
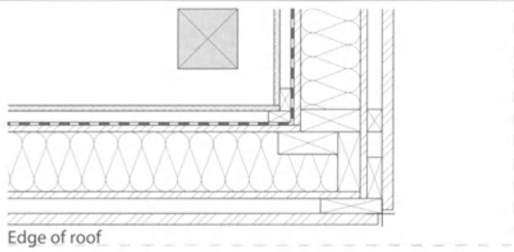

b182

b179 System with external insulation and loadbearing structure positioned on the inside. This arrangement is recommended for structural reasons and to ensure good protection from the weather (see also horizontal sections in Figs. b183 and b184).

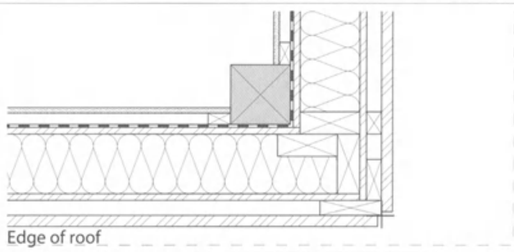
b180 System with insulation between the loadbearing members. The loadbearing structure is integrated into the wall construction (see also horizontal sections in Figs. b186 or b185).

b181 System with internal insulation and loadbearing structure positioned on the outside (see also horizontal section in Fig. b187). Not recommended owing to problems with penetration of the envelope and providing adequate protection for the timber.

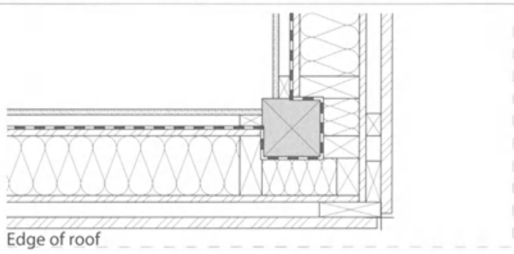
b182 Hybrid system: internal insulation for the walls (loadbearing structure positioned on the outside), external insulation for the roof (loadbearing structure positioned on the inside). Not recommended owing to problems with penetration of the envelope and providing adequate protection for the timber.



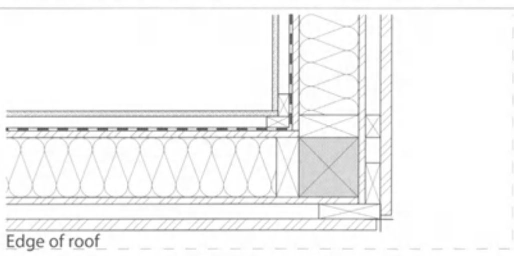
b183
Loadbearing structure on the inside (system sketch b179).
Walls are held in position with spacers.
The construction is protected against the weather and climatic influences.



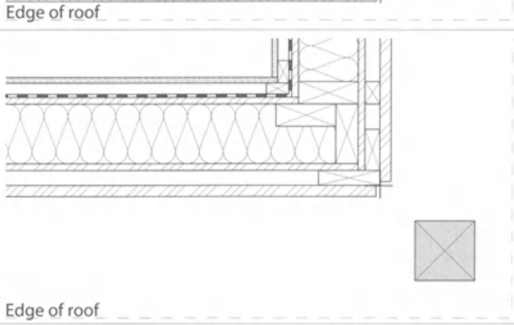
b184
Loadbearing structure on the inside (system sketch b179).
No thermal bridges or wall penetrations in this form of construction; no need for penetrations through thermal insulation, airtight membrane, or vapour barrier. The construction is protected against the weather and climatic influences.



b185
Loadbearing structure on the inner face of the construction (system sketch b180).
Airtight membrane and vapour barrier junctions must be sealed with the help of flexible sheeting.

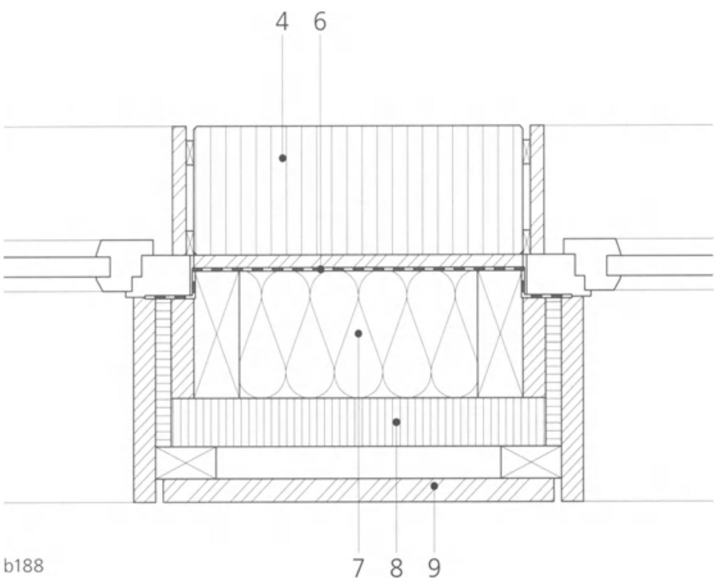


b186
Loadbearing structure within the wall construction (system sketch b180).
Wall penetrated by beams and other horizontal members, possibly even rafters.
Airtight membrane and vapour barrier junctions are awkward and expensive.



b187
Loadbearing structure on the outside (system sketches b181 and 182).
Loadbearing structure passes directly from warm side to cold side. Sealing the resulting penetrations is extremely labour-intensive and expensive. Furthermore, perfect protection against the weather is difficult to accomplish. This arrangement is not recommended.

b183 to b187 Position of the building envelope in relation to the loadbearing structure (horizontal sections). Arrangements according to system sketches b179 to b182.



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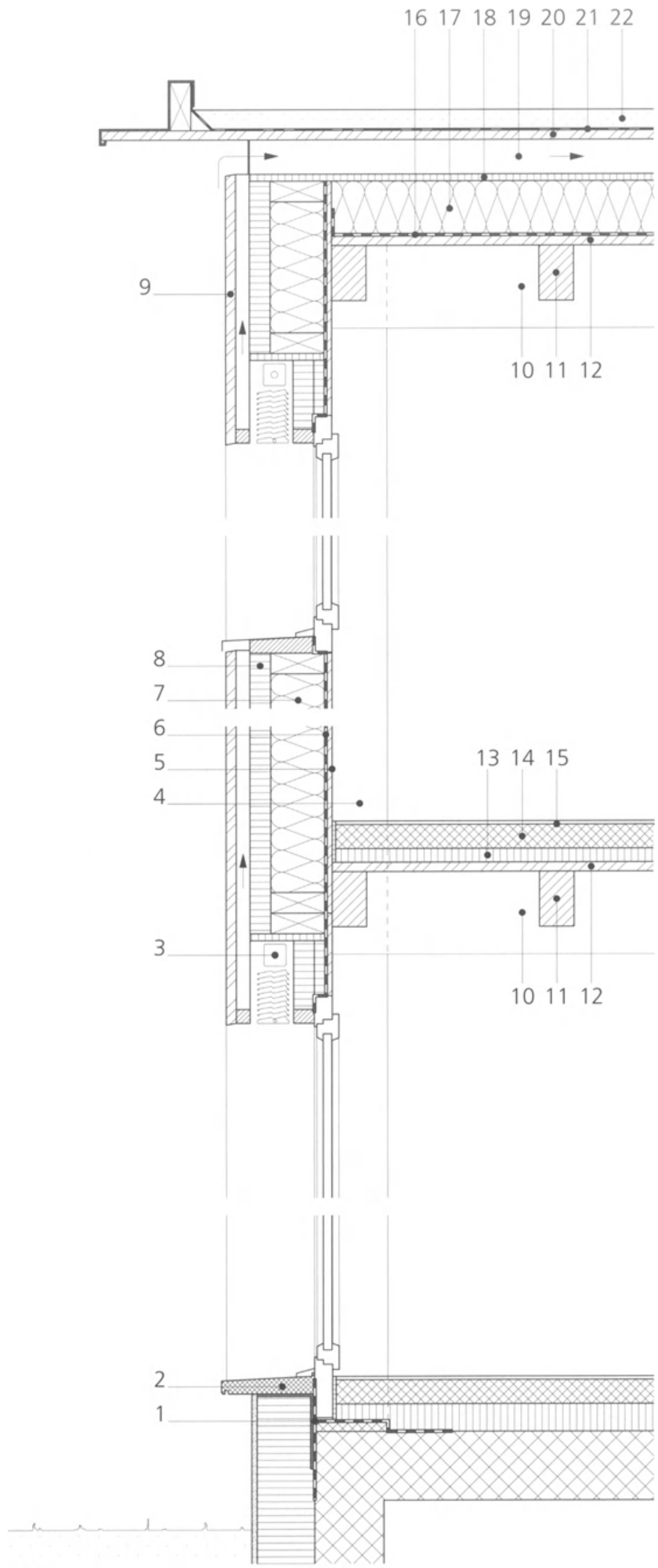
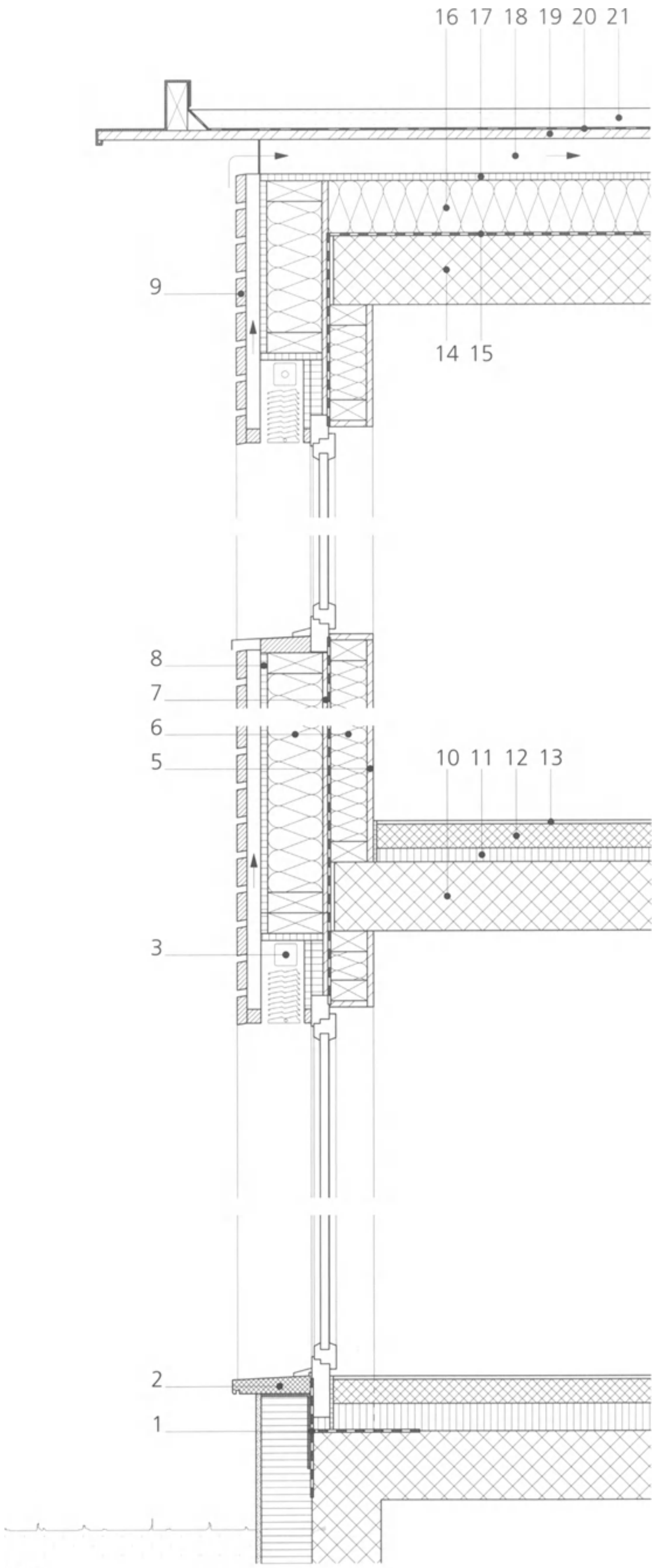


b189

1 Base plate, waterproofing, damp proof course
2 Window sill
3 Louvre blinds in storage compartment
4 Loadbearing structure
5 Internal lining
6 Airtight membrane, vapour barrier
7 Thermal insulation
8 Protection for thermal insulation, additional insulation
9 External cladding with ventilated cavity
10 Loadbearing structure
11 Secondary structure
12 Structural sheathing
13 Impact sound insulation
14 Cement screed or dry subfloor
15 Floor covering
16 Airtight membrane, vapour barrier
17 Thermal insulation
18 Secondary waterproofing layer, additional insulation
19 Ventilation space, firring pieces
20 Structural sheathing
21 Waterproofing
22 Protective layer, wearing course

b188 and b189 Sections through construction: frame construction, external wall showing window opening, junction with ground floor, suspended floor, and roof. Arrangement according to system sketches b179 and b184.

b188 Horizontal section, window jamb
b189 Vertical section



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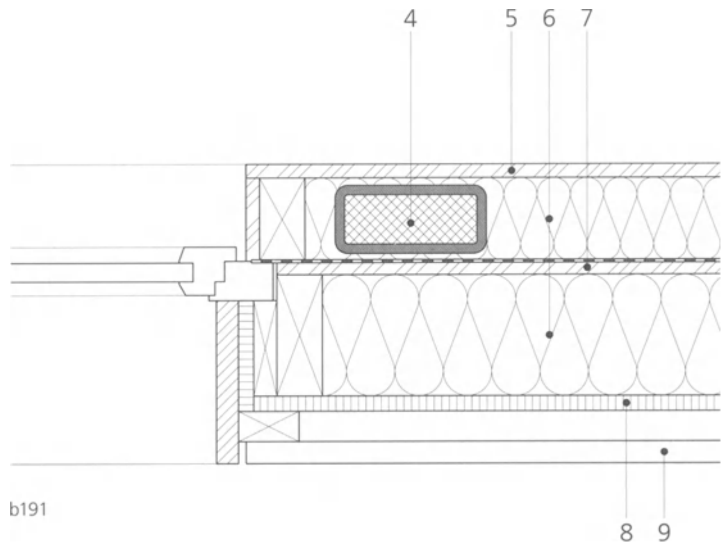


b191

1 Base plate, waterproofing, damp proof course
2 Window sill
3 Louvre blinds in storage compartment
4 Loadbearing structure (steel columns filled with concrete)
5 Internal lining
6 Thermal insulation
7 Sheathing, vapour barrier, airtight membrane
8 Protection to thermal insulation, additional insulation
9 External cladding with ventilated cavity
10 Loadbearing structure (in situ concrete)
11 Impact sound insulation
12 Cement screed or dry subfloor
13 Floor covering
14 Loadbearing structure (in situ concrete)
15 Waterproofing, airtight membrane (all joints sealed airtight)
16 Thermal insulation
17 Secondary waterproofing layer, additional insulation
18 Ventilation space, firring pieces
19 Structural sheathing
20 Waterproofing
21 Protective layer, wearing course

b190 and b191 Sections through construction: frame construction, external wall showing window opening, junction with ground floor, suspended floor, and roof. Loadbearing structure in reinforced concrete and steel, external walls in timber. Arrangement according to system sketches b179, b184, and b30 (p. 49).

190 Vertical section
191 Horizontal section, window jamb

b8 Solid timber construction

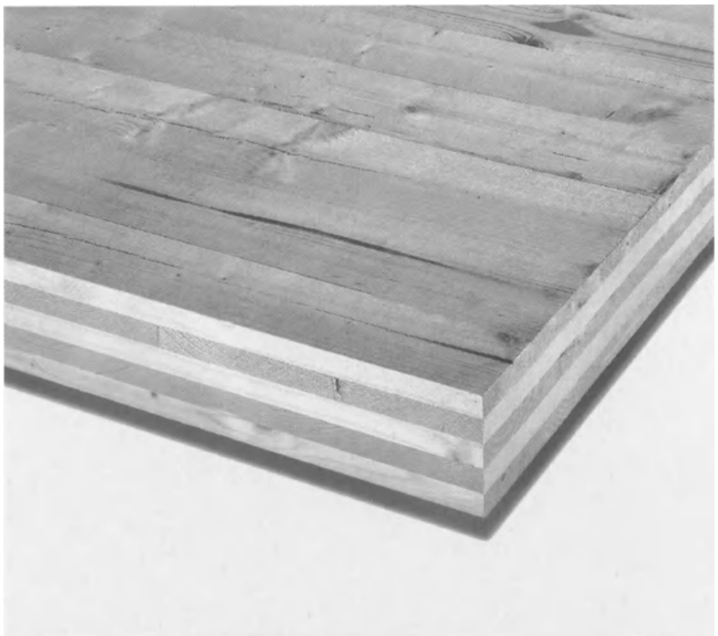
b8 10 General

The possibility of producing large-format elements on an industrial scale has led to the development and introduction of new systems in recent years. Planar elements, serving both loadbearing and enclosing functions at the same time, have opened up diverse applications for walls, suspended floors, and roofs. The components themselves are usually made from solid timber (glued, dowelled, nailed) or – but less often – wood-based products (particleboard, OSB, etc.). The heart of this concept is either a closed, often solid, board-type cross-section, or an optimised box-type element that can be assembled to form a stressed-skin structure.

The main part of the structural system always consists of a loadbearing core made from solid timber or wood-based products. They are used exclusively as two-dimensional structural systems. The loads are therefore carried via plate action (Fig. b9 in chapter b1 "Overview of systems"). One further thing that the forms of construction have in common within solid timber construction is that the thermal insulation is attached to the outside of the structure (see chapter c2 "Design and construction", also Fig. c43). The majority of the products are produced and marketed by specific companies using particular product names; there are many products on the market – exhibiting considerable differences.

b192

b192 Loadbearing structure in solid timber construction; apartment block, Zug, Switzerland



b193

Traditional log construction makes use of horizontal timber sections made from solid spruce or fir stacked to form walls and therefore this certainly belongs under the heading of "solid timber construction". It could even be called the origin of "solid timber construction". In the timber construction industry, however, the term "solid timber construction" these days refers to a new form of timber construction that makes use of factory-produced components, engineering concepts, and constructional principles, but also to a certain architectural treatment that has nothing to do with traditional log construction. In this context, we must ask ourselves the question of what proportion of a system has to be solid in order for it to be classed as solid timber construction? This question does not arise with wall systems based on a framework of linear timber sections clad with a sheathing of some description; such walls belong to panel construction. However, there are many systems that include a considerable proportion of solid timber but likewise exhibit internal voids or cavities. If these systems have a sufficiently large proportion of solid timber, act as a structural plate in principle, and the outer boundaries of the structural plane are connected by closely spaced webs (box systems), then they belong to the solid timber construction category. The prerequisite is that the solid component accounts for at least 50% of the loadbearing construction.

Solid cross-sections, compound cross-sections

The forms of construction based on solid cross-sections (section b8 20) and those based on compound cross-sections (chapter b8 30) are described separately on the following pages. Solid cross-sections without any voids are usually manufactured in the form of large-format planar elements. They are usually "elements with room or plan dimensions" (see chapter b2 20 "Building principles", Fig. b17). The compound cross-sections include enclosed voids and tend to be "elements based on a modular dimension" (Fig. b16), but can also be "small units based on a modular dimension" (Fig. b15). However, these categories certainly have no defined boundaries, and that is a fact which also applies to the format of the elements in particular, in addition to the question of their cross-sections (solid or compound). For it is certainly possible to produce components from compound cross-sections with a fabrication width of 1000 or 1250 mm in the factory or timber building company as planar elements that extend over the width of a whole room or even a whole building.

b193 Multi-ply board of solid timber

The features of solid timber construction

- Loadbearing layer consists of a solid plate whose structural action is in the plane of the plate
- Proportion of solid timber in self-contained loadbearing layer is min. 50%
- Structural system formed by large-format planar elements or small-format components acting as a plate
- Single-ply, nailed or dowelled, plus multi-ply glued or dowelled systems
- Usually storey-by-storey assembly, but continuous walls, and floors suspended between these, also possible
- High and efficient load-carrying performance
- Stability of building ensured by in-plane structural plate action
- Cross-banded glued systems exhibit excellent dimensional stability
- Fewer component layers because loadbearing, enclosing, sealing, etc. layers (depending on system) are formed solely by the solid structural elements
- Solid timber components absorb moisture from the interior air, store this, and release it again during drier periods
- The various forms of construction and systems are mostly products related to a particular manufacturer

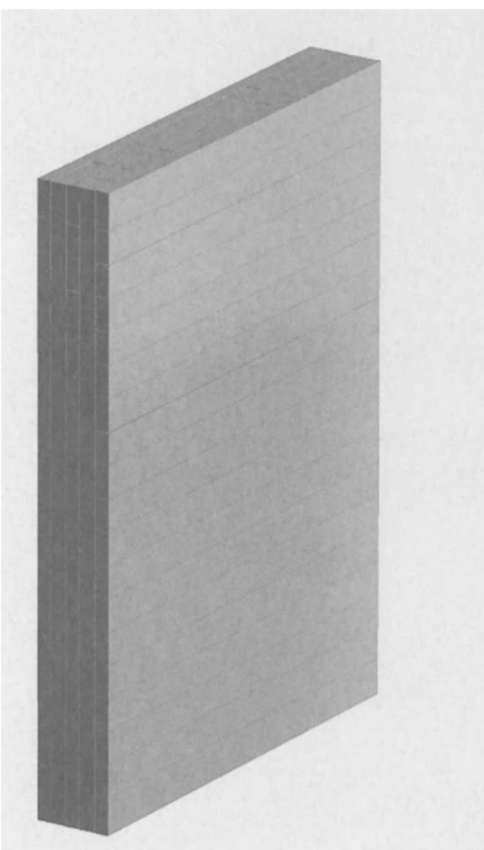
Multi-storey buildings in solid timber construction

- Well suited
- Various systems are suitable for high loads, especially cross-banded glued solid cross-sections
- Choose a structural system not susceptible to settlement
- Early involvement of specialist engineers is essential
- Building design and construction system must be harmonised at an early stage

b8 20 Solid cross-sections

b8 21 Overview of systems

Most solid cross-sections are produced in the form of large-format planar elements. Figs. b194 to b199 show the variety of the systems available, and the most common of these are described individually in section b8 26 "Examples of systems". Depending on product and manufacturer, we distinguish between single-ply or cross-banded glued, dowelled or nailed, and single- or multi-ply cross-sections. Softwood (spruce, fir) plies or laminations form the raw materials for these elements; alternatively, the large-format components can be made from wood-based products (particleboard, OSB, etc.). The elements are assembled in the factory to form walls complete with the necessary openings for doors and windows, accurate and ready for erection. Suspended floors, too, can be built using the same systems and the same methods, but different forms of construction can be combined in the same structure. The fabrication stages – described in section b2 30 – or the erection conditions can vary depending on the degree of prefabrication. On the building site, the elements are erected in a similar way to panel construction. Depending on the fitting out requirements, the loadbearing elements can be supplied ready finished.



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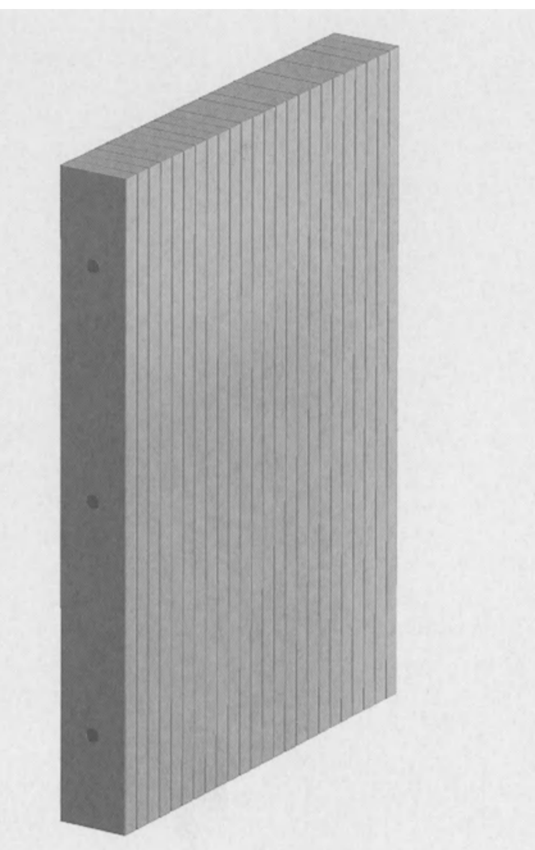

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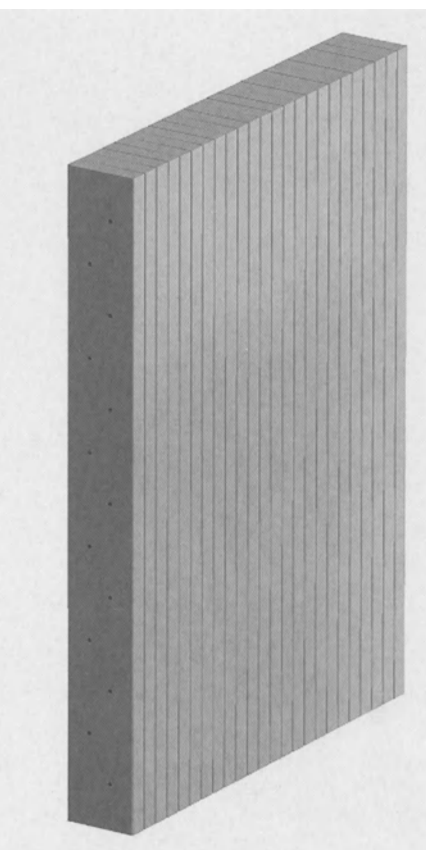
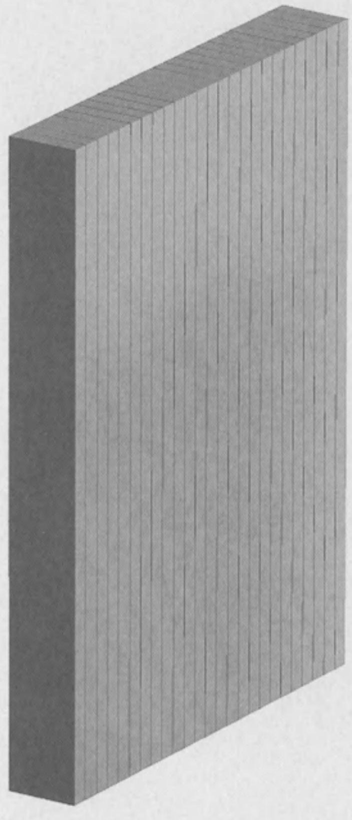


b196

b194 to b199 Overview of solid timber cross-sections, large-format planar elements; for further illustrations see section b8 26 "Examples of systems"

b194 Cross-laminated element, cross-banded glued
b195 Edge-fixed element, single-ply dowelled
b196 Edge-fixed element, single-ply nailed

b8 22 Parts of the construction and wall construction
The planar solid timber element functions as a loadbearing and enclosing element. The large panels consisting of one, three, five or even more plies can be lined on the inside of the element or left exposed. For electrical installation, it is either necessary to cut chases in the solid elements or add a framework of battens (40 to 60 mm – power sockets and junction boxes require a depth of 60 mm including lining). Like with every external wall construction, the diffusion resistance of the inner layers must be coordinated with that of the outer layers, although in the case of solid timber elements moisture can be absorbed from the interior air, stored, and then released again later. In normal situations vapour barriers made from synthetic materials are unnecessary. The requirement for a sufficiently airtight construction is achieved in different ways depending on the particular construction system used (Figs. b194 to b199), and also on the type of wall construction. Whereas the systems shown in Figs. b194 and b199 exhibit an adequate level of airtightness in themselves, depending on product and number of plies (product specifications of each manufacturer must be checked), other systems require additional airtight membranes. These can take the form of a planar, compact inner lining, a wood-based board product required for stability anyway (e.g. for the systems shown in Figs. b195 and b196), or a separate airtight membrane. Like with all building systems, the wall/plinth, wall/floor, wall/roof junctions, and also the details at penetrations such as doors, windows, chimneys, etc. must be given special



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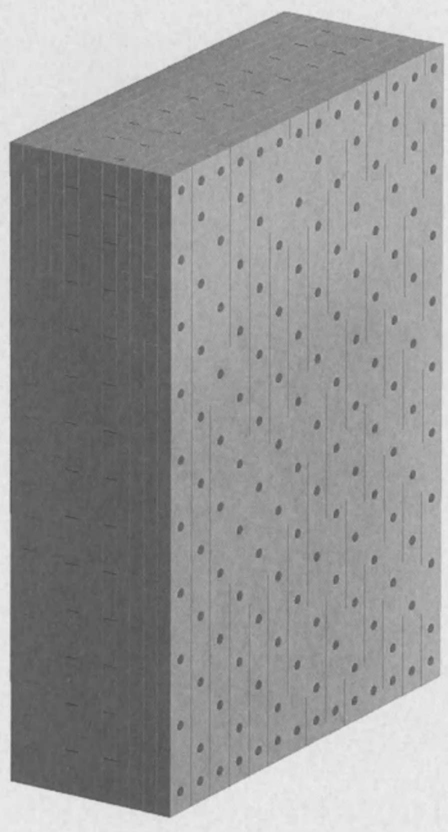

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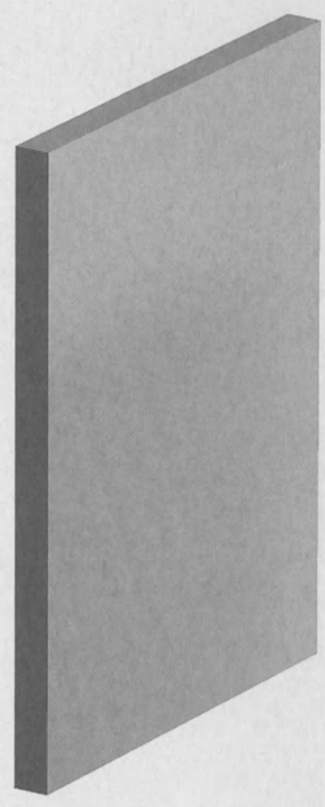


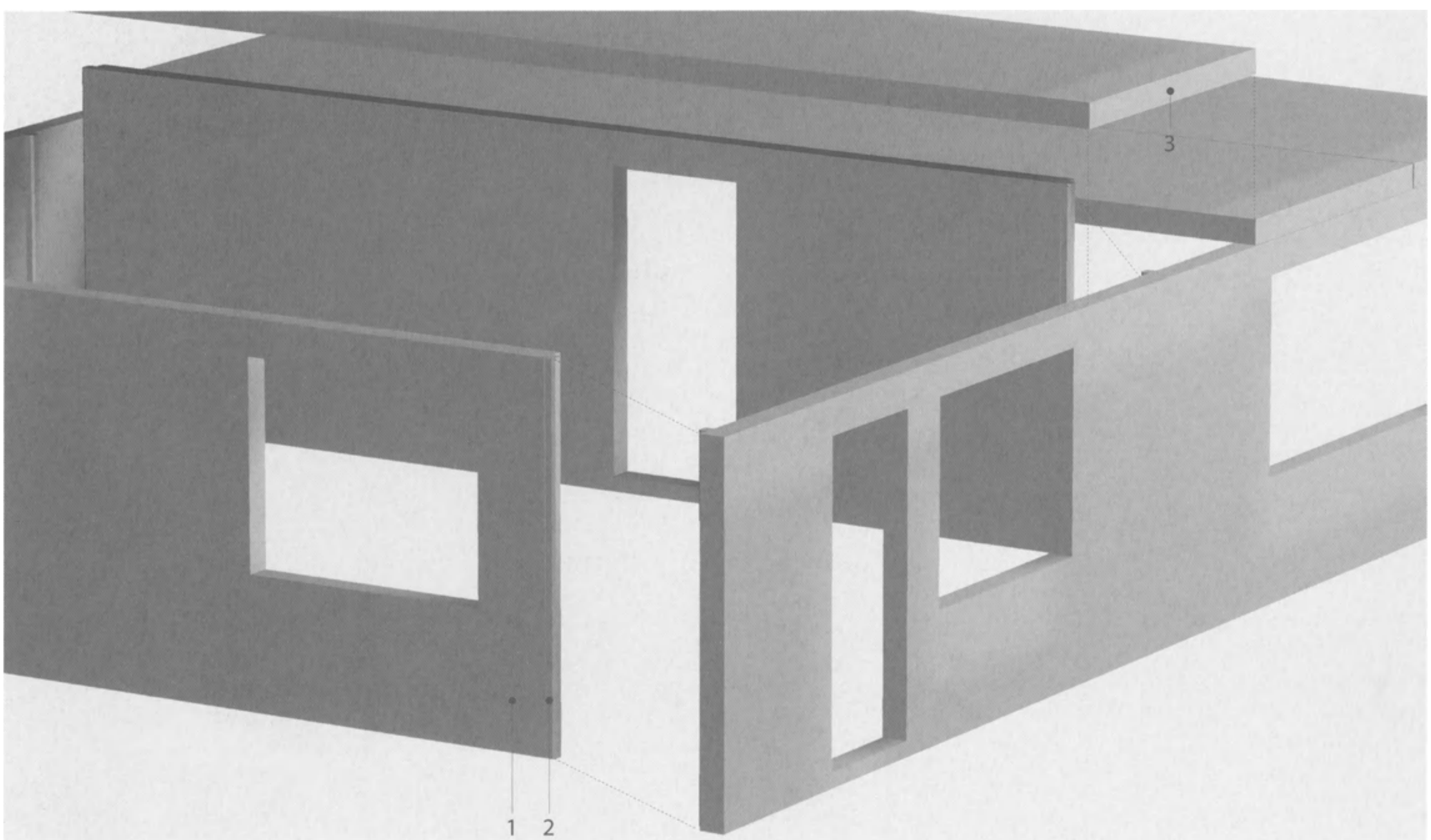
b199

b197 Glued laminated timber, single-ply glued
b198 Cross-banded dowelled
b199 Wood-based product, pressed particleboard (chipboard), flakeboard (OSB)

attention in terms of airtightness. Thermal insulation is attached to the outside of the planar solid timber elements; the thickness varies depending on thermal performance requirements. A continuous layer of thermal insulation on the outside means that the majority of thermal bridges are eliminated. The external finish can be in the form of a mineral render or some form of cladding with a ventilation cavity behind it.

b8 23 Shrinkage and swelling behaviour

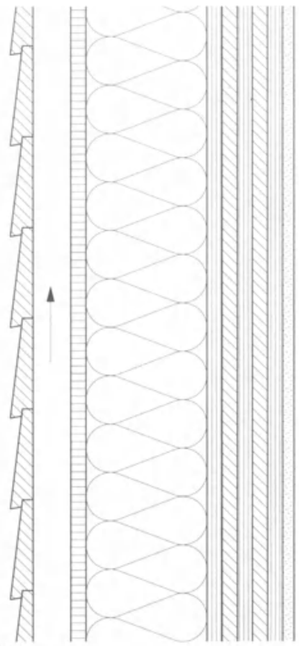
Cross-banded glued systems (e.g. those shown in Fig. b194 and Figs. b211 to b218) and also – but to a lesser extent – dowelled systems (e.g. those shown in Fig. b198 and Figs. b228 to b235) have the advantage that, thanks to the cross-wise lay-up of the raw materials, their shrinkage and swelling is limited. Their dimensional stability is therefore excellent. In the case of single-layer solid timber systems (e.g. those shown in Figs. b195, b196, and b197), however, the shrinkage and swelling behaviour must be given careful consideration. When using a non-cross-banded lay-up, possible changes to the cross-section due to the effects of moisture must be taken into account (e.g. by including expansion/contraction joints at the junctions between elements). The moisture content



b200

b200 The parts of a solid timber construction, solid cross-sections (large-format elements)

1 Wall plate, wall element (possibly with top and bottom plates, but the majority of systems do not require a base plate)
2 Assembly post, connection piece
3 Floor plate, floor element



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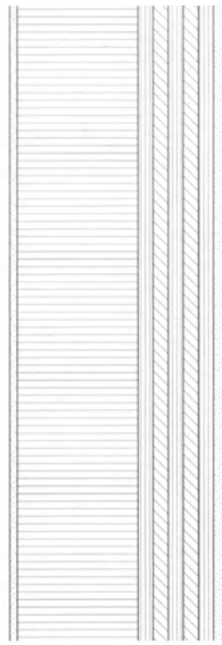


b202

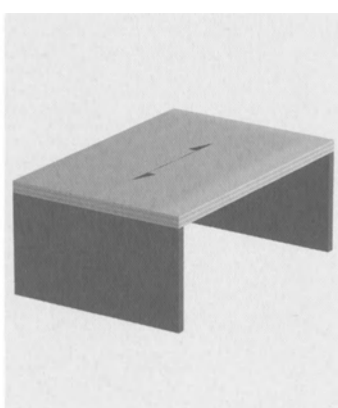
of the timber at the time of assembly should be equal to the equilibrium moisture content of the timber in the finished building. For housing, this means a moisture content of approx. 12 ± 2% during assembly, although in the case of suspended floors comprising edge-fixed elements, a marginally higher moisture content (max. 18%) is generally preferred for assembly. Individual laminations do not swell due to excess moisture during construction, but can dry out differently to the rest of the element in the course of the drying-out process. The resulting dimensional variation has an effect on the individual lamination only and no effect on the construction of the whole, provided the necessary expansion/contraction joints have been included.

b8 24 Loadbearing behaviour

Loads are carried via the plate-type elements down to the foundations. The loads to be carried and the critical buckling length determine the thickness of the elements. With a storey height of 2.4 m and a geometrical slenderness of λ=150, this means a minimum thickness of 55 mm is required. Irrespective of the critical buckling length and the loads, element thicknesses normally lie between 60 and 120 mm. Point loads, e.g. due to roof or floor beams, are carried by additional columns, depending on the particular system. Large-format, cross-banded glued elements (cross-laminated timber and a number of other boards with a cross-banded lay-up, e.g. laminated veneer lumber) can act as plates and accept horizontal loads; additional wind girders are therefore unnecessary. Thanks to the cross-banded lay-up, such elements can carry loads in both directions when used horizontally, and elements placed vertically can be used as free-standing components (compare Figs. b203 and b204). Single-ply systems such as edge-fixed elements can only carry shear forces when used in conjunction with appropriate connections or an additional sheathing. An experienced structural engineer should be brought in for the calculation and design of structures, components, and details. The manufacturer's specification must always be taken into account.

b205

b203



b204

b201 Wall construction with ventilation cavity and cladding
b202 Wall construction with thermal insulation composite system

b203 Cross-laminated timber elements, laminated veneer lumber elements, multi-ply solid timber elements and also OSB elements can carry loads in both directions, but a distinction is made between primary and secondary directions (depends on the lay-up of the plies). For further details, please consult the manufacturer.

b204 Edge-fixed elements or glued laminated timber elements can carry loads in one direction only. These systems are, however, more efficient in the load-bearing direction than those systems that can carry loads in both directions.

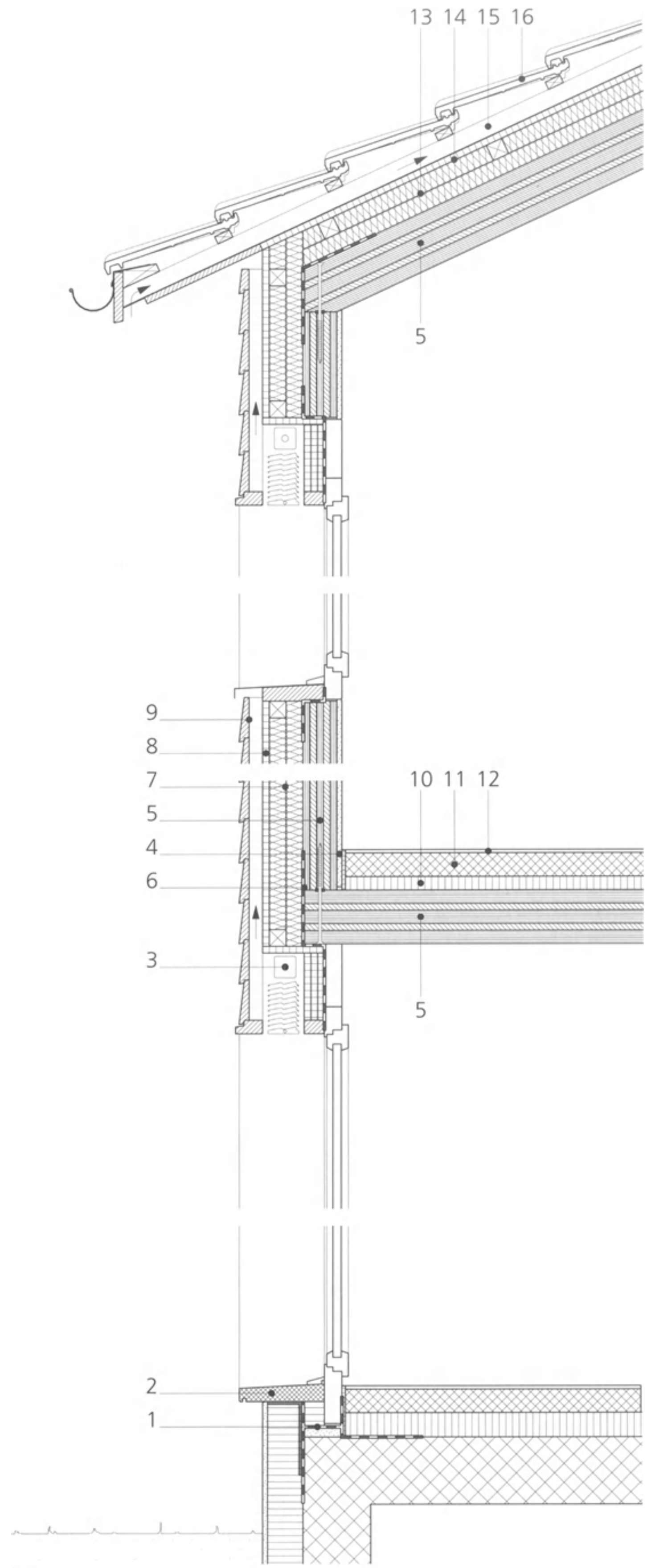
b205 Erection of solid-timber elements, large-format solid cross-sections

b8 Solid timber construction

b8 25 Applications

Buildings constructed from large-format planar elements can be built simply and efficiently. In contrast to other building systems, the number of layers can be minimised. The system is not restricted by module or grid dimensions. Different versions are used depending on the manufacturer. The most important are described on the following pages according to the main categories.
See chapter e2 for the names and addresses of manufacturers and institutes.

1 Mortar bed, waterproofing, damp proof course
2 Window sill
3 Louvre blinds in storage compartment
4 Internal lining
5 Solid timber construction (loadbearing structure)
6 Vapour barrier, airtight membrane (depending on the nature of No. 5, simply all joints sealed airtight, or laid over entire area)
7 Thermal insulation
8 Protection for thermal insulation, additional insulation
9 External cladding with ventilation cavity
10 Impact sound insulation
11 Cement screed or dry subfloor
12 Floor covering
13 Thermal insulation
14 Secondary waterproofing layer, additional insulation
15 Counter battens, ventilation space
16 Roof covering



b206 Section through construction: solid timber construction, external wall showing window opening, junction with ground floor, suspended floor, and roof.


b207


b209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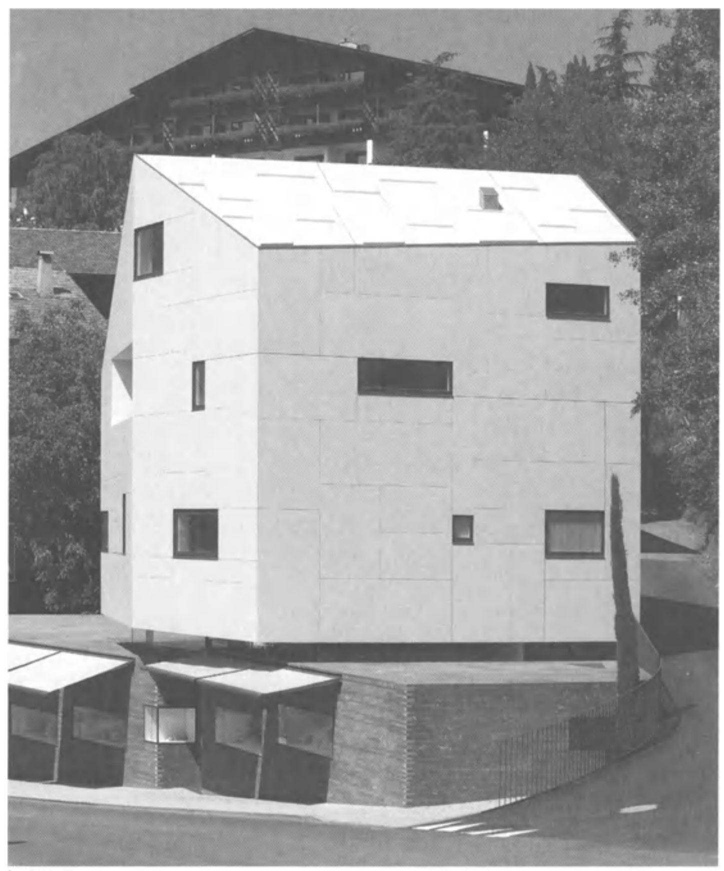
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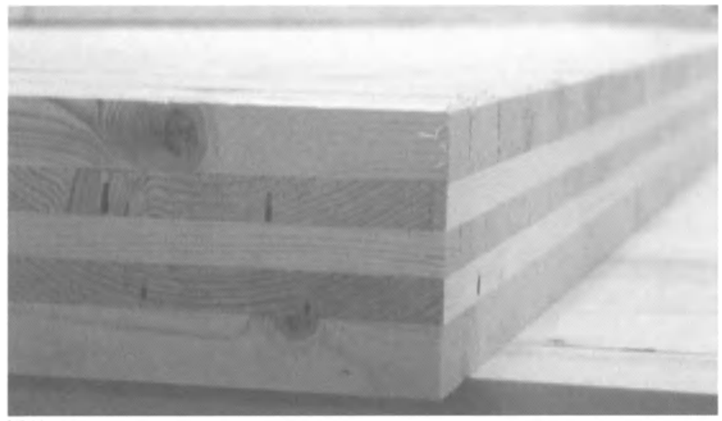
b207 and b208 Apartment block in solid timber construction, Meran, Italy

b209 Private house in solid timber construction, Au, Austria

b210 Joint residential/commercial development in solid timber construction, Schenna, Italy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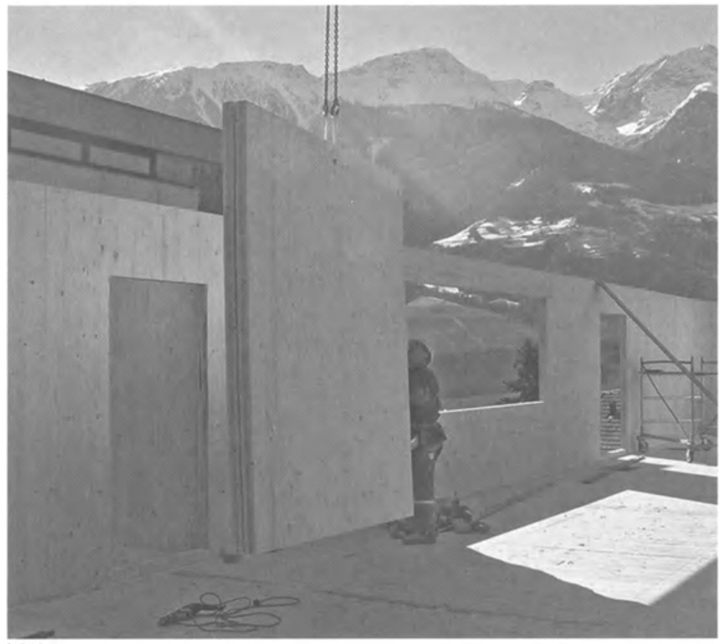
b8 26 Examples of systems
Cross-laminated timber

Cross-laminated timber consists of several plies of cross-banded glued planks. Owing to the barrier effect of the symmetrical lay-up, these elements exhibit excellent dimensional stability. The raw materials are spruce or fir planks. Assembling these as cross-banded plies produces planar loadbearing elements that can carry loads in both directions. However, we do distinguish between primary and secondary load-carrying direction.

Cross-laminated timber may be sold under various brand names but the basic form of construction, although not precisely defined, remains similar. It is not always clear whether a certain product belongs to this category! The various products must therefore be assessed individually from the engineering viewpoint and appropriately allocated to the respective building task. The thickness of cross-laminated timber elements varies from 50 to 300 mm depending on manufacturer.

See chapter e2 for the names and addresses of manufacturers and institutes.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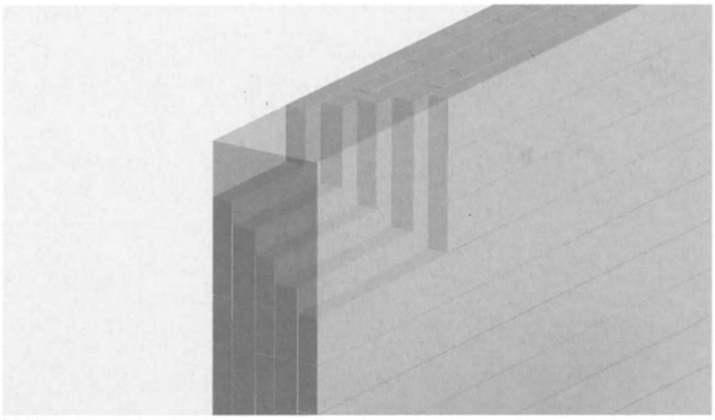
b213

b211 Large-format elements, cross-laminated timber

b212 Erection

b213 Example of application of cross-laminated timber: state-run nursery in Heilbronn, Germany



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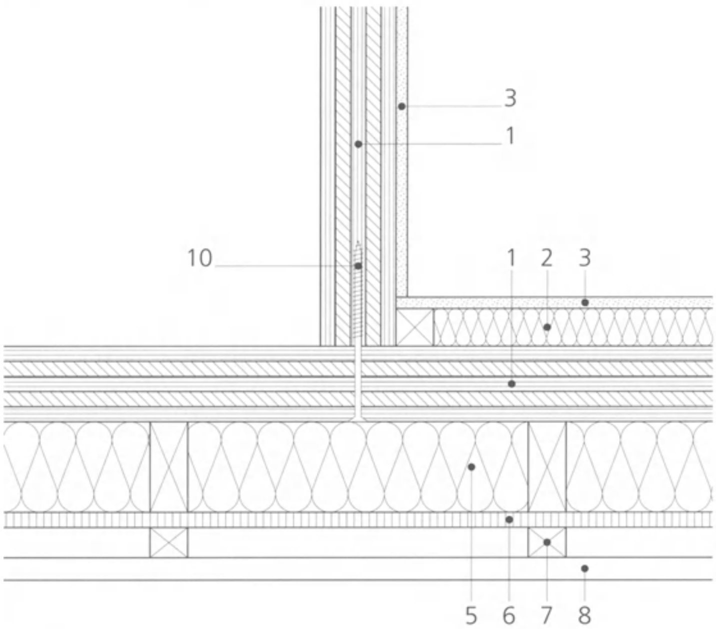

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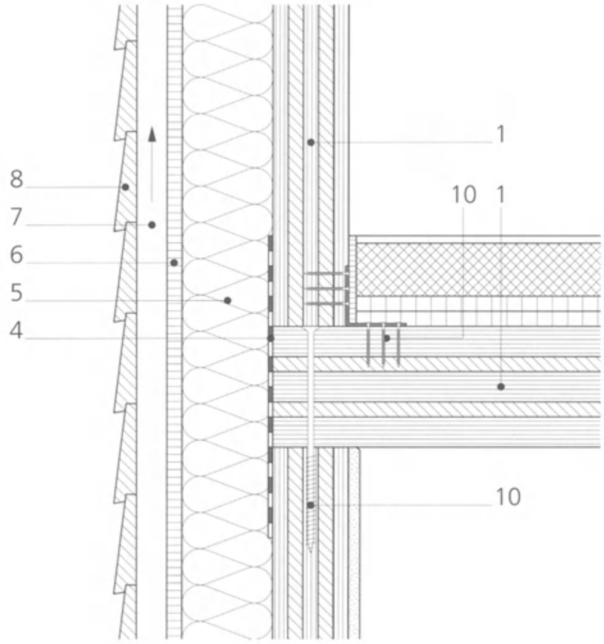

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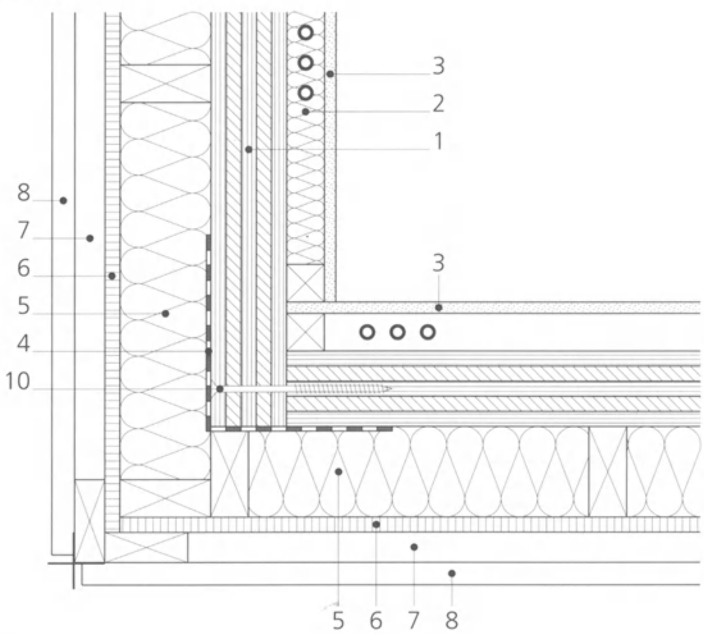

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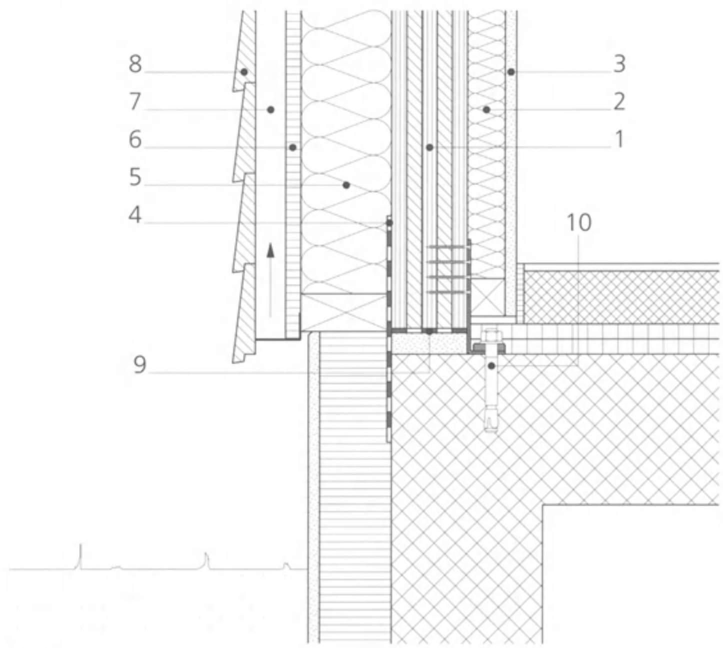
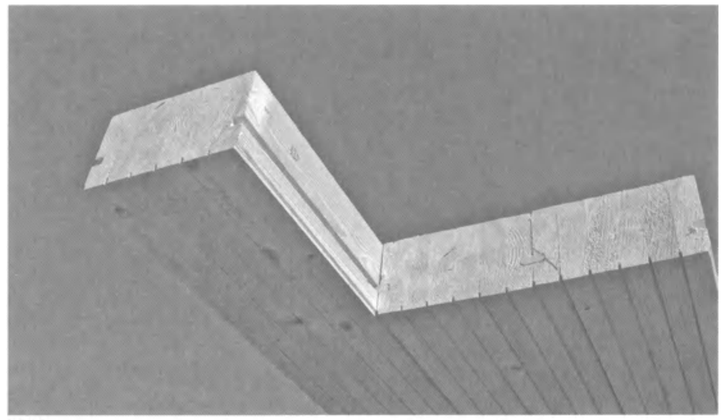


b218

b214 Sketch of principle of cross-laminated timber element
b215 to b218 Assemblies and junctions with cross-laminated timber
b215 Horizontal section, external wall/internal wall
b216 Horizontal section, external wall corner
b217 Vertical section, external wall/suspended floor
b218 Vertical section, plinth

1 Cross-laminated timber (loadbearing structure)
2 Battens, space for services
3 Internal lining
4 Airtight membrane, joints sealed airtight (depending on the nature of No. 1, may be required over entire area)
5 Thermal insulation with spacer battens
6 Protection for thermal insulation, additional insulation
7 Ventilation cavity
8 Cladding
9 Mortar bed, damp proof course
10 Anchor bolt, fastener

b8 Solid timber construction



b219

Edge-fixed timber

Edge-fixed timber elements are made up of planks (laminations) placed on edge which are normally continuous, i.e. no joints, over the full length of the element. Finger joints in the length are also possible, therefore making larger element formats possible. Laminations are normally between 20 and 50 mm thick. In order to transfer the shear forces in the transverse direction and to distribute individual loads, the laminations are interconnected with nails or hardwood dowels. This creates a homogeneous planar element. Edge-fixed timber elements are available with various surface finish qualities and profiles. The customary thicknesses of edge-fixed timber elements vary between 80 and 240 mm depending on manufacturer.

In principle, edge-fixed timber elements are not associated with certain products or manufacturers. Any timber building company with the knowledge and appropriate plant can produce such elements. In recent years, however, a number of brand-name products have become established.

See chapter e2 for the names and addresses of manufacturers and institutes.

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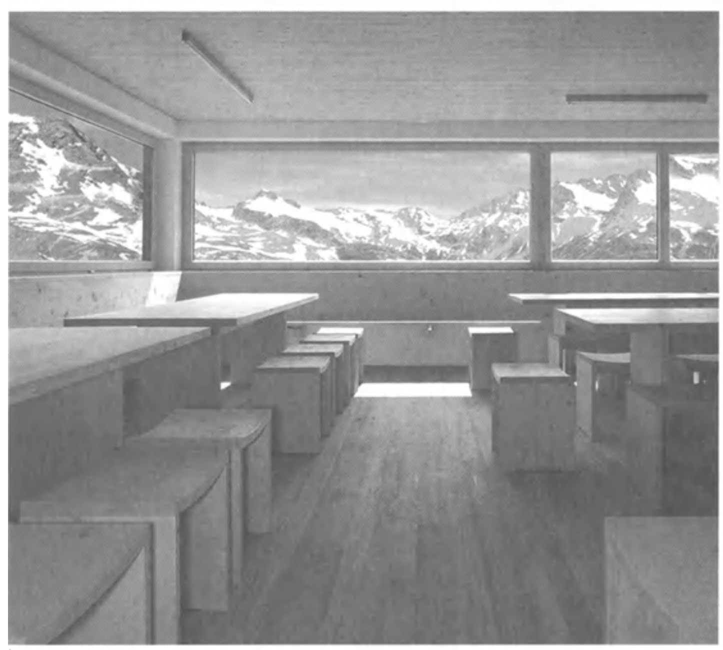
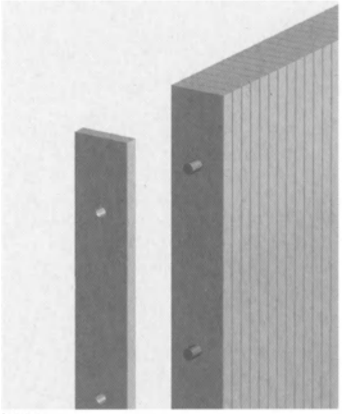


b221

b219 Edge-fixed elements

b220 Edge-fixed elements for the structural carcass

b221 Example of application of edge-fixed elements, Val Roseg, Switzerland



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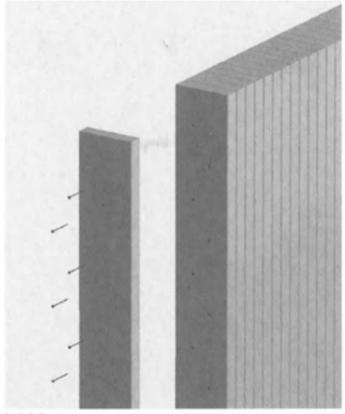

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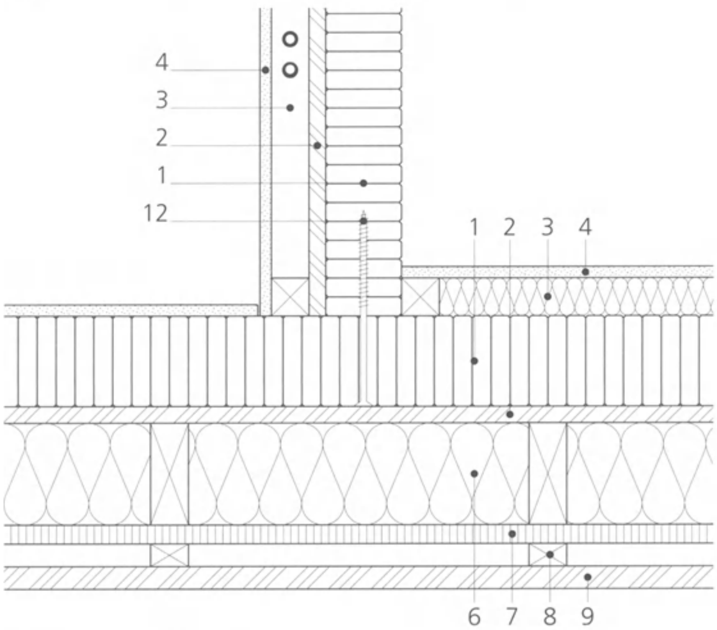

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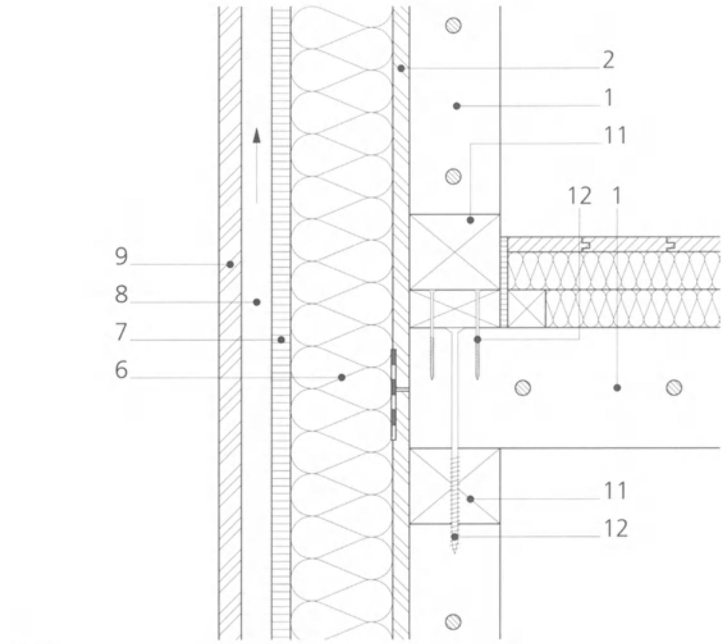

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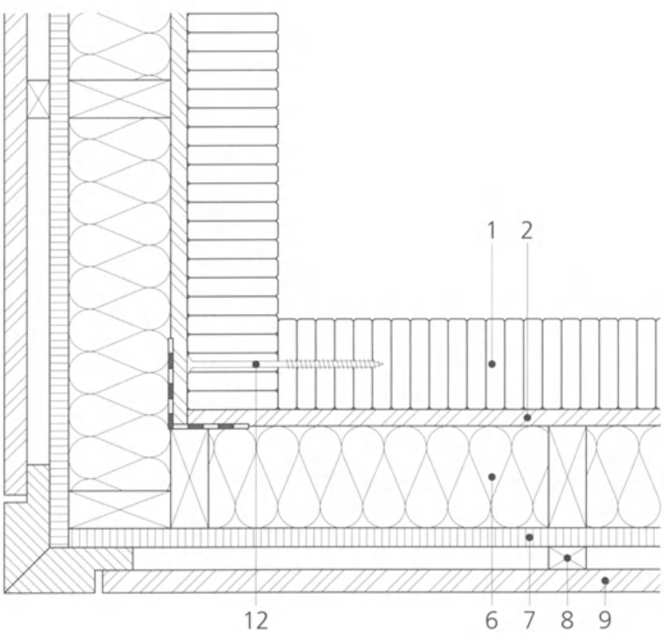

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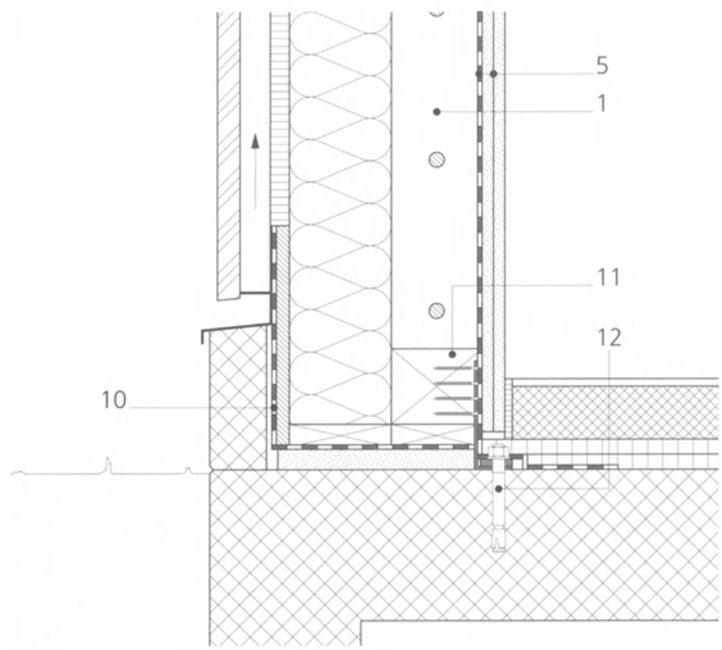

b227

b222 Sketch of principle of edge-dowelled element
b223 Sketch of principle of edge-nailed element
b224 to b227 Assemblies and junctions with edge-fixed elements
b224 Horizontal section, external wall/internal wall
b225 Horizontal section, external wall corner
b226 Vertical section, external wall/suspended floor
b227 Vertical section, plinth

1 Edge-fixed element
2 Structural sheathing, airtight membrane (joints sealed airtight), vapour barrier (e.g. OSB)
3 Battens, space for services
4 Internal lining
5 Internal lining, structural sheathing, vapour barrier, airtight membrane
6 Thermal insulation with spacer battens
7 Protection for thermal insulation, additional insulation
8 Ventilation cavity
9 Cladding
10 Mortar bed, waterproofing, damp proof course
11 Top plate, bottom plate
12 Anchor bolt, fastener

Cross-banded and dowelled

Dowelled solid timber elements consist of a 60–80 mm thick core of vertical planks to which several plies of softwood planks 20–50 mm thick are attached horizontally, vertically and diagonally on both sides by means of dowels. Owing to the cross-banded, sometimes also diagonal, arrangement of the plies, these elements can help to brace a structure against horizontal loads. Please refer to the manufacturers details in this respect.
Dowelled solid timber elements are used principally for walls. Besides the dowelled primary elements, the wall construction consists of a layer of thermal insulation on the outside covered by some form of cladding. As in this system the timber itself is called upon to provide at least part of the thermal and sound insulation, the elements are considerably thicker than those of other systems. A thickness of 150 to 400 mm for the primary timber element is typical, to which wood fibreboards are added. An alternative would be to use a primary timber element 150 or 250 mm thick, 80–160 mm wood fibreboards, 30 mm battens and 25 mm external cladding. The individual plies in the timber elements are not sufficiently airtight and therefore a separate airtight membrane is required.
On the inside, the surface of the timber element can be left exposed. Alternatively, a solid timber sheathing or a lining fixed to a framework of battens can be employed. The manufacturers of dowelled solid timber elements use no glues, metal fasteners or other man-made connectors in the fabrication of their elements, or at least try to reduce the use of these to a minimum. The materials selected for the remainder of the construction therefore tend to follow this philosophy; thermal insulation in the form of wood-fibre insulating materials and solid timber sheathing are generally used.

See chapter e2 for the names and addresses of manufacturers and institutes.


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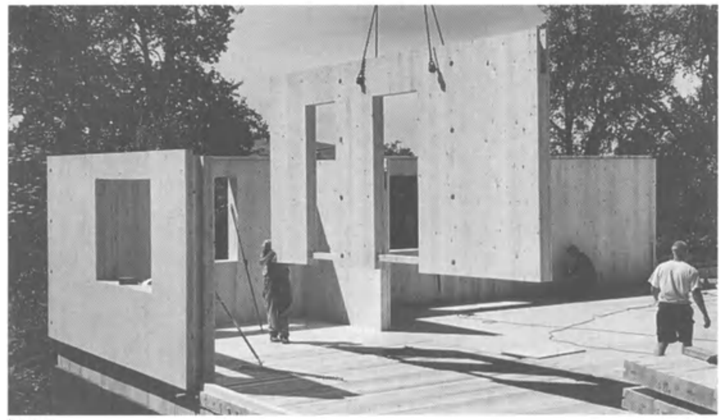
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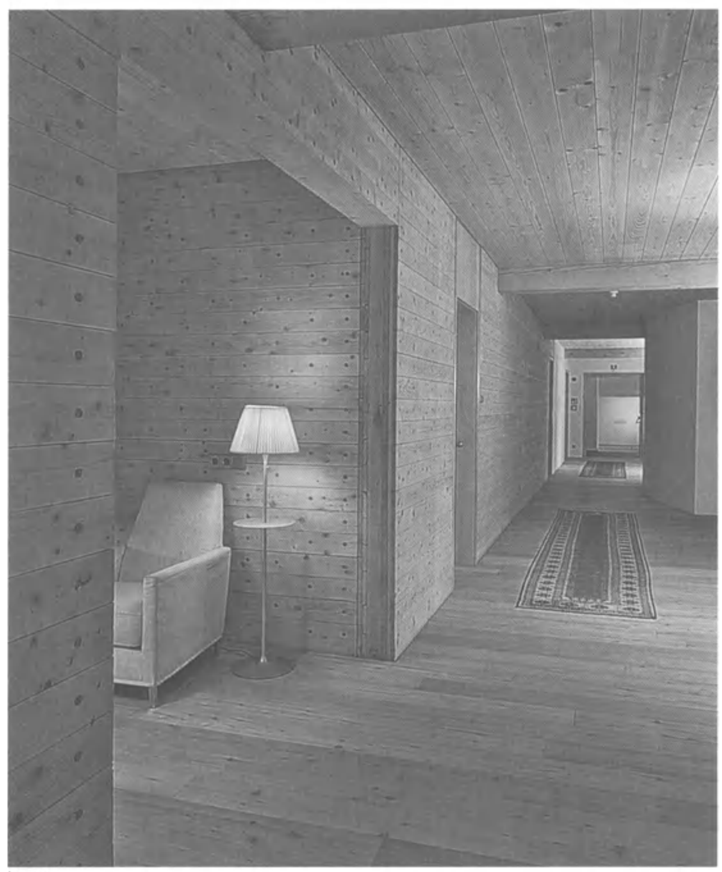
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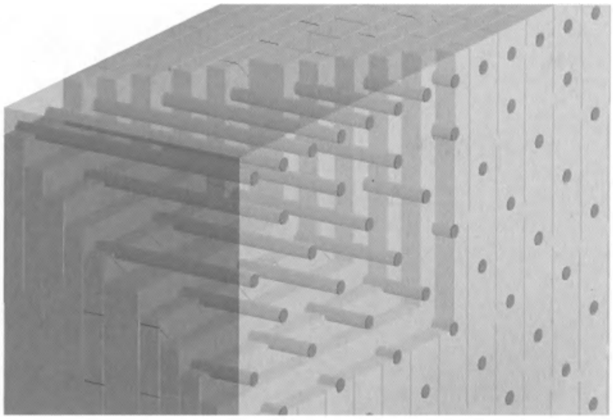
b228 Cross-banded dowelled elements (holz 100 system)

b229 Erection

b230 Example of application: the wall surfaces can be left exposed internally; Hotel Seiser Alm, Bozen, Italy



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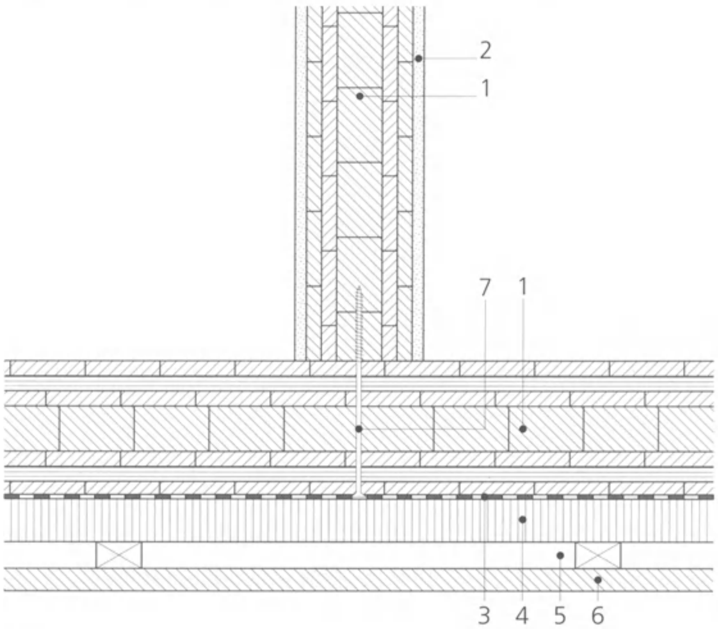

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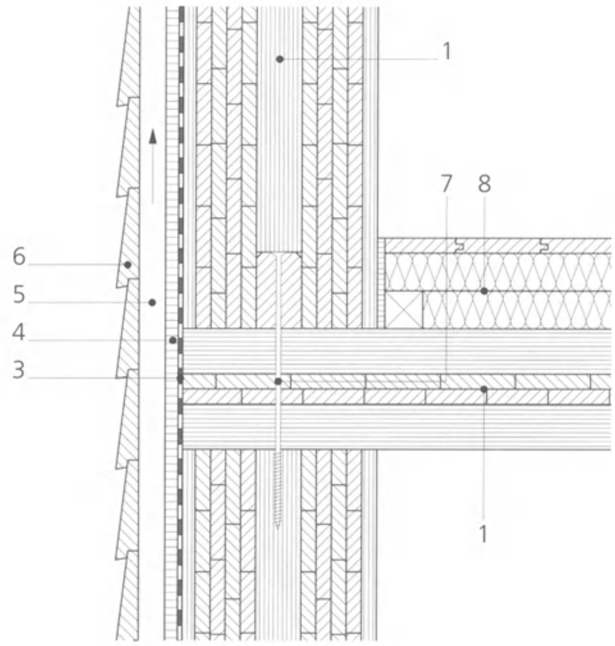

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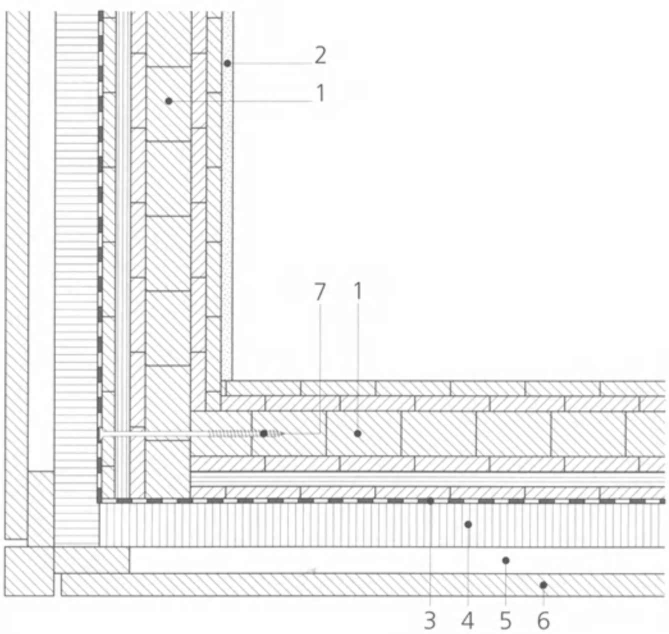

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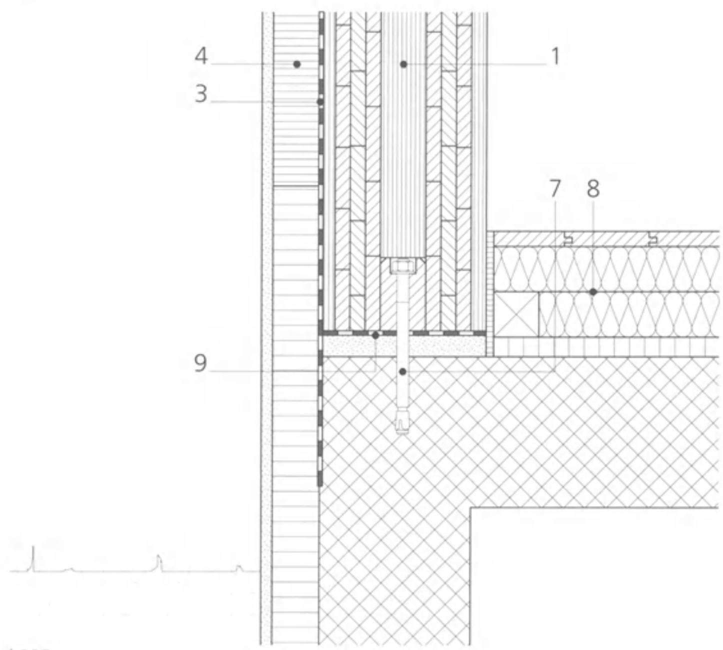

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b231 Sketch of principle of cross-banded dowelled element
b232 to b235 Assemblies and junctions with cross-banded dowelled elements
b232 Horizontal section, external wall/internal wall
b233 Horizontal section, external wall corner
b234 Vertical section, external wall/suspended floor
b235 Vertical section, plinth

1 Loadbearing construction (e.g. holz 100, Appenzellerholz)
2 Internal lining
3 Airtight membrane
4 Additional insulation
5 Ventilation cavity (may not be necessary depending on manufacturer and wall construction)
6 Cladding
7 Anchor bolt, fastener
8 Floor construction
9 Mortar bed, waterproofing, damp proof course

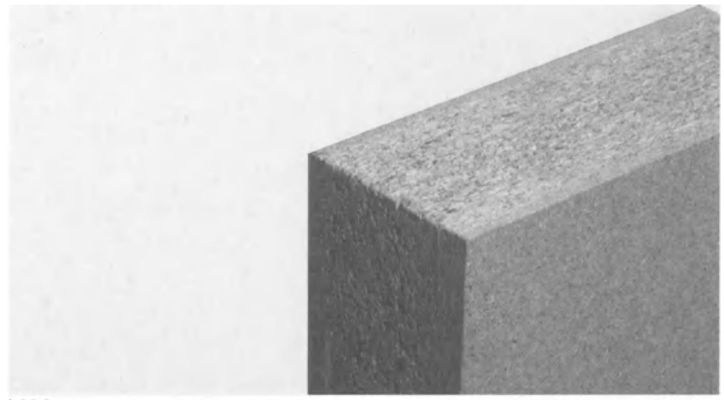
b8 Solid timber construction

Wood-based products

Loadbearing and bracing wall components can be made from single- or multi-ply glued pressed particleboards or oriented strand boards (OSB). The use of integral tongue and groove or rebated joints enables the fabrication of large, storey-height wall elements. The normal thickness for pressed particleboards (e.g. Homogen 80) is 80 mm. Individual OSB plies 25 mm thick are bonded together to form solid components with a minimum of three (= 75 mm thick) and a maximum of ten plies (= 250 mm thick).

When using either pressed particleboards, or OSB, the remainder of the wall construction, including thermal insulation and weather protection, is attached to the outside. Thermal insulation composite systems attached directly to the wall elements or cladding systems fitted to a framework of battens (to leave a ventilation cavity) can be employed. On the inside, the walls and soffits can be finished with wallpaper, paint, tiles, etc. Chases for electrical installation are cut in the elements during fabrication (not on site), or cables are laid in separate ducts.

See chapter e2 for the names and addresses of manufacturers and institutes.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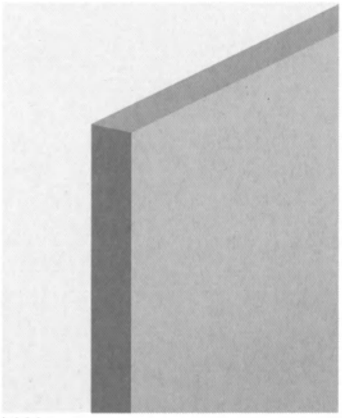
b238

b236 Wood-based product, chipboard

b237 Erection of wood-based board products

b238 Example of application for an apartment block: loadbearing construction in wood-based products, Cham, Switzerland



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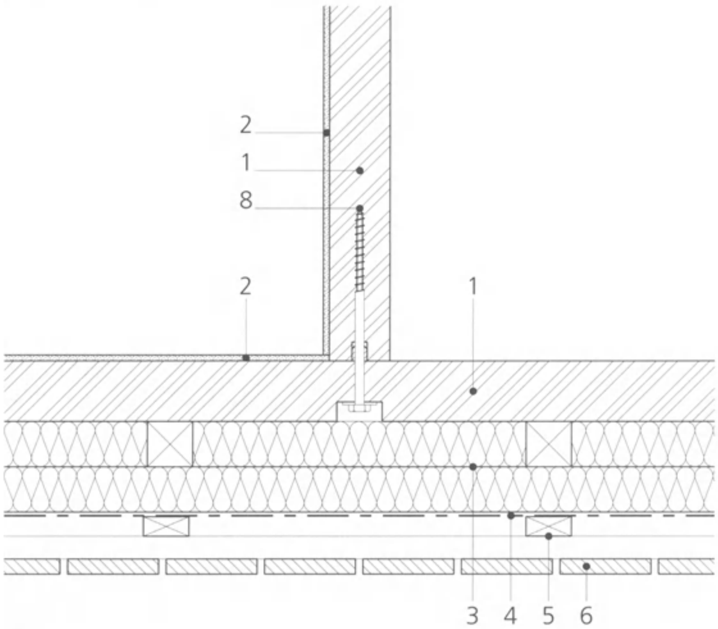

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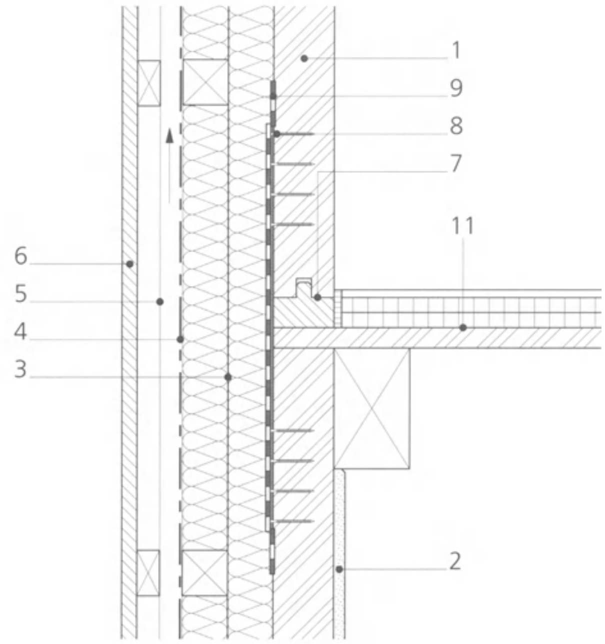

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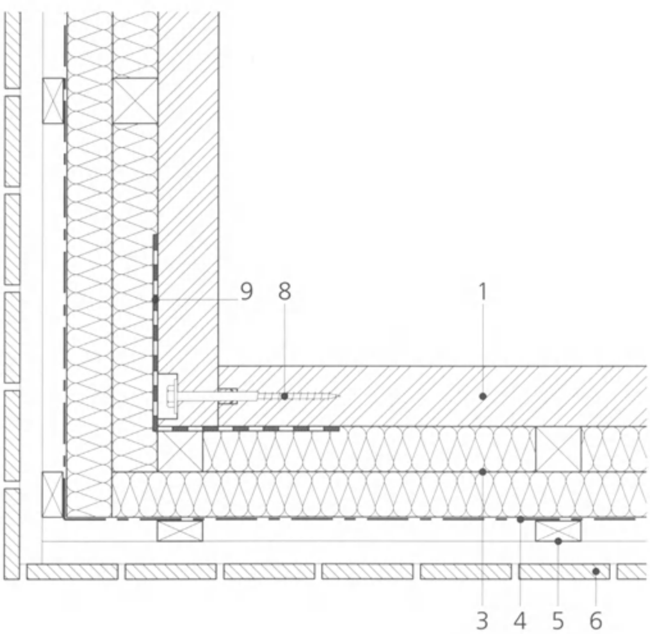

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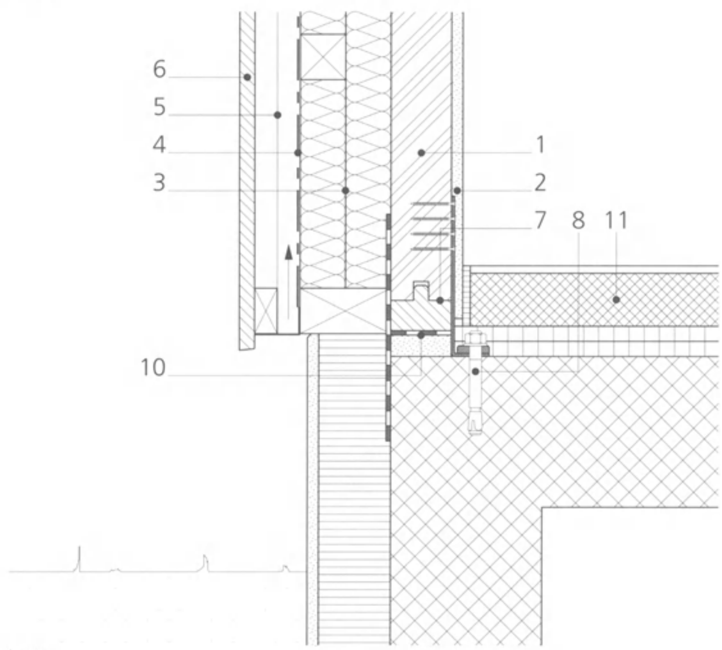


b243

b239 Sketch of principle of wood-based products, pressed particleboard (chipboard, Homogen 80), flakeboard (OSB, Magnum Board)
b240 to b243 Assemblies and junctions with wood-based products
b240 Horizontal section, external wall/internal wall
b241 Horizontal section, external wall corner
b242 Vertical section, external wall/suspended floor
b243 Vertical section, plinth

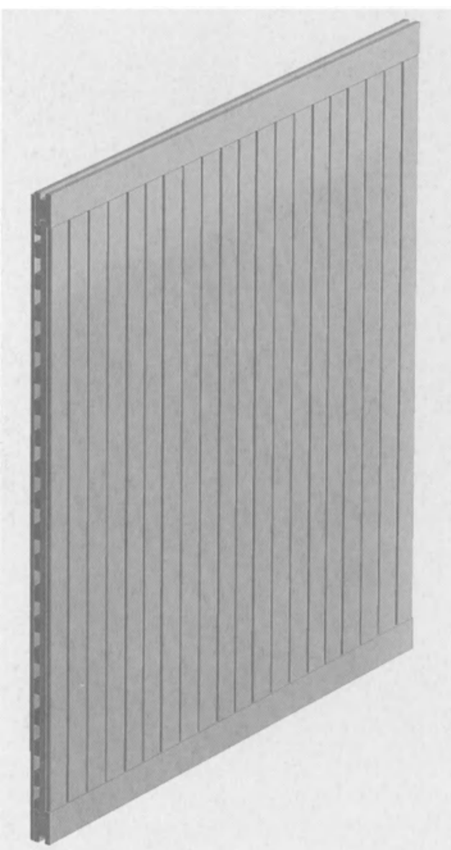
1 Loadbearing construction, e.g. Homogen 80 (chipboard), Magnum Board (OSB)
2 Internal lining
3 Thermal insulation
4 Protection for thermal insulation
5 Ventilation cavity
6 Cladding
7 Bottom plate
8 Anchor bolt, fastener
9 Airtight membrane (joints sealed airtight)
10 Mortar bed, waterproofing, damp proof course
11 Floor construction

b8 30 Compound cross-sections

b8 31 Overview of systems

The timber is placed where it can be used efficiently to meet structural or constructional requirements. This approach has led to the development of compound solid timber elements made up of boards, planks, strips, battens, or laminations. Figs. b244 to b246 show three systems, two of which are explained in detail in section b8 36.

The individual parts of the construction are subjected to different actions. Accordingly, the horizontal or vertical alignment and the dimensions vary. The individual parts are usually joined by gluing. Elements assembled in this way exhibit excellent dimensional stability and can be kept slender, although this does depend on the loads to be carried. Stability is provided by the elements themselves, but additional sheathing or stiffening ribs may be required, depending on the manufacturer. The ensuing voids in the elements can be filled with thermal insulation or used for installing services.



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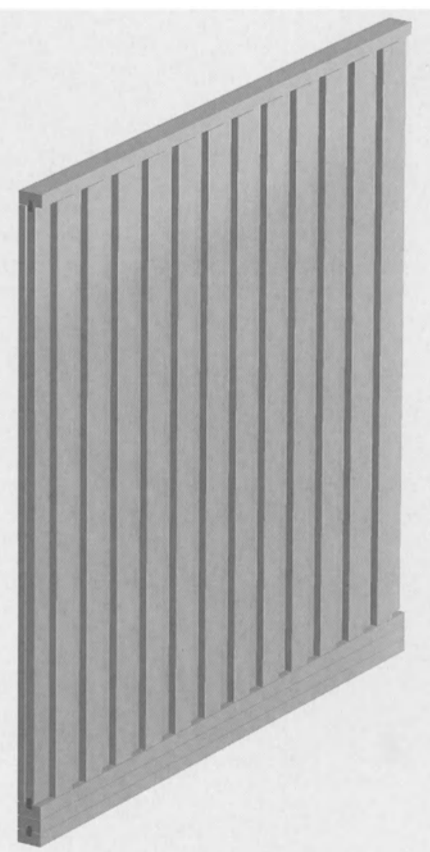

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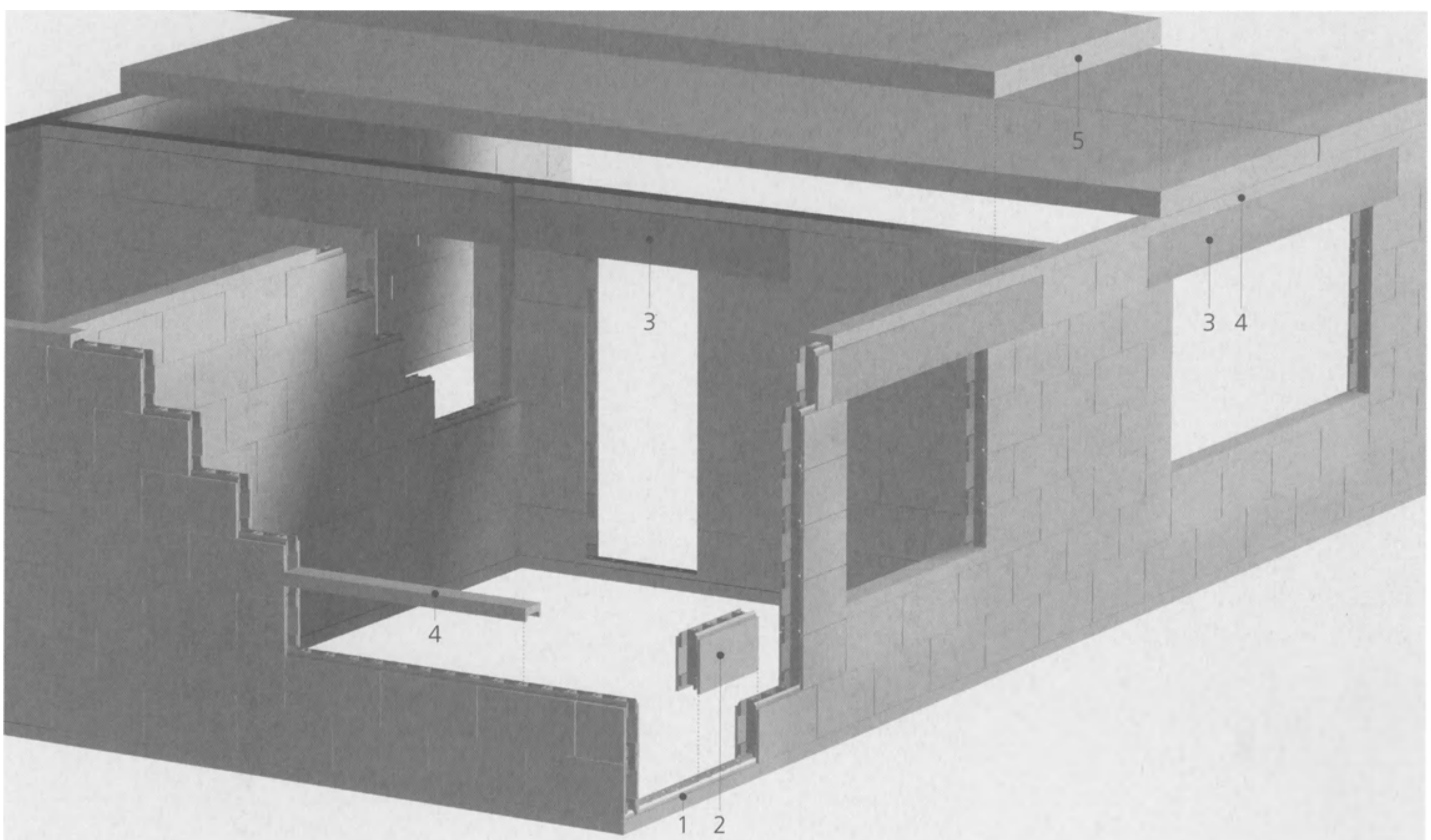
b244 to b246 Overview of compound cross-sections
b244 Cross-banded spaced plies (Lignotrend); for further illustrations see section b8 36 "Examples of systems"
b245 Modular building block system (Steko); for further illustrations see section b8 36 "Examples of systems"
b246 Tongue and groove timber planks (Ligno Swiss))

b8 32 Parts of the construction and wall construction

The solid timber component (module or element) functions as loadbearing structure and enclosing element at the same time. The inside of the element can be lined or left exposed. The voids for elements can be used for the building services, especially the electrical installation. Depending on the particular product, these voids can also be filled with insulating materials to improve the thermal or acoustic performance, which enables the thickness of the external insulation to be reduced. In other products the thermal insulation, like with systems consisting of solid cross-sections (section b8 20), is provided by the external insulation alone. The thickness of this insulation depends on the thermal performance specification. Placing the thermal insulation on the outside as a continuous layer means that most thermal bridges are eliminated. Insulation can be covered with a mineral render (thermal insulation composite system), or a cladding system fitted to a framework of battens (to leave a ventilation cavity) can be employed.

The diffusion resistance of the inner layers must be coordinated with the overall wall construction. In doing so, the solid timber elements, also in combination with insulating materials, can absorb moisture from the interior air, store this, and release it again later. Synthetic vapour barriers are normally unnecessary in solid timber construction. The requirement regarding sufficient airtightness of the construction is achieved in different ways depending on the system used and the wall construction. Whereas the configura-

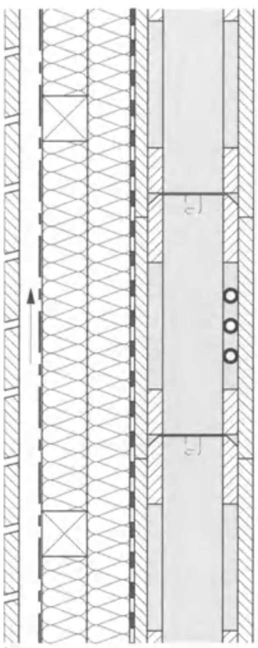


b247

b247 The parts of a solid timber construction, compound cross-sections
1 Bottom plate
2 Small-format modules or room-height elements
3 Lintel element
4 Top plate
5 Suspended floor element

b8 Solid timber construction

tion and joints of some systems are sufficiently airtight, other systems require separate airtight membranes – achieved by way of a planar, compact inner lining or external cladding, by sheathing provided for stability purposes, compact thermal insulation systems, or a separate layer of material. Like with all building systems, the wall/plinth, wall/floor, wall/roof junctions, and also the



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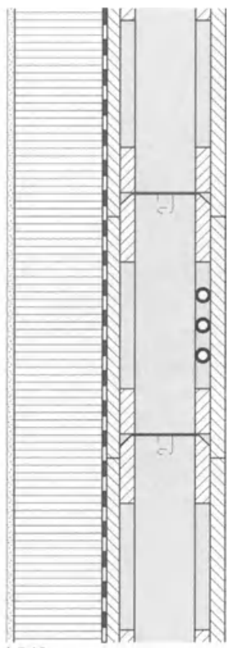

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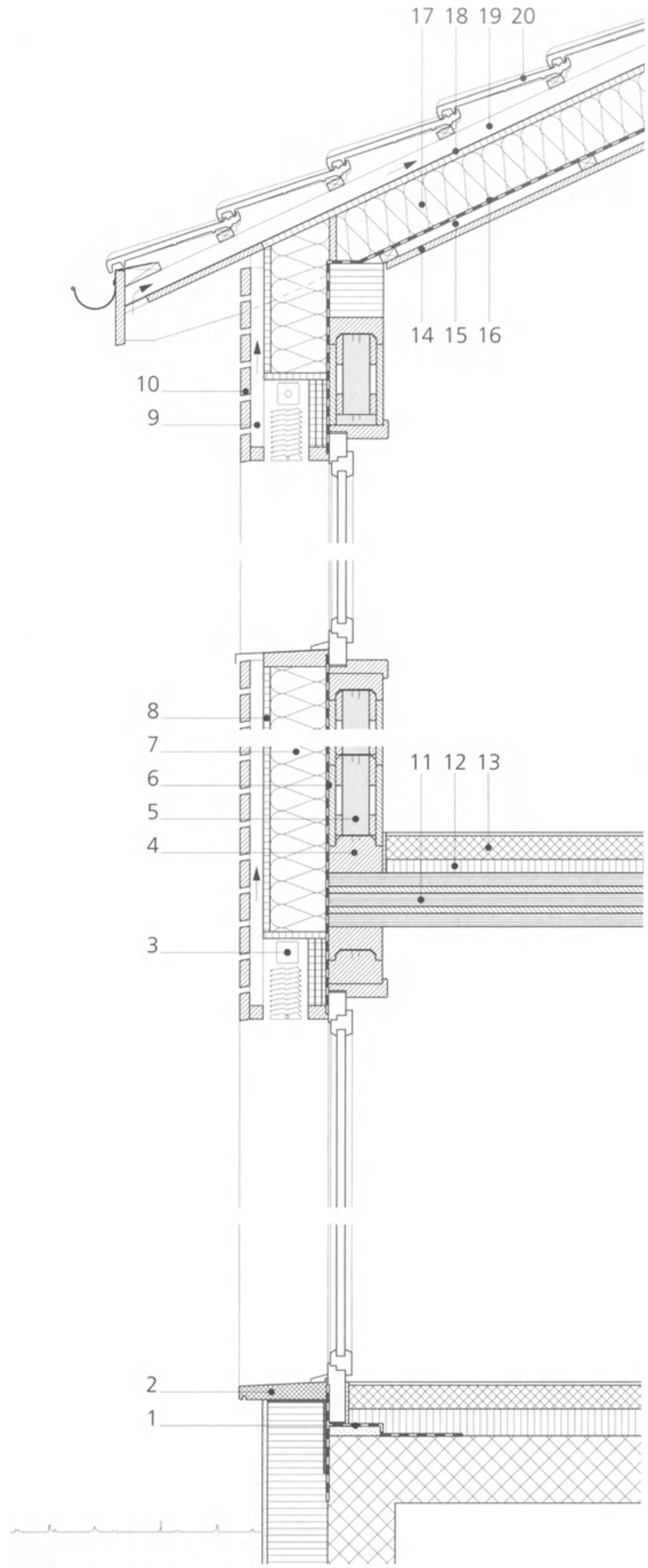


b250

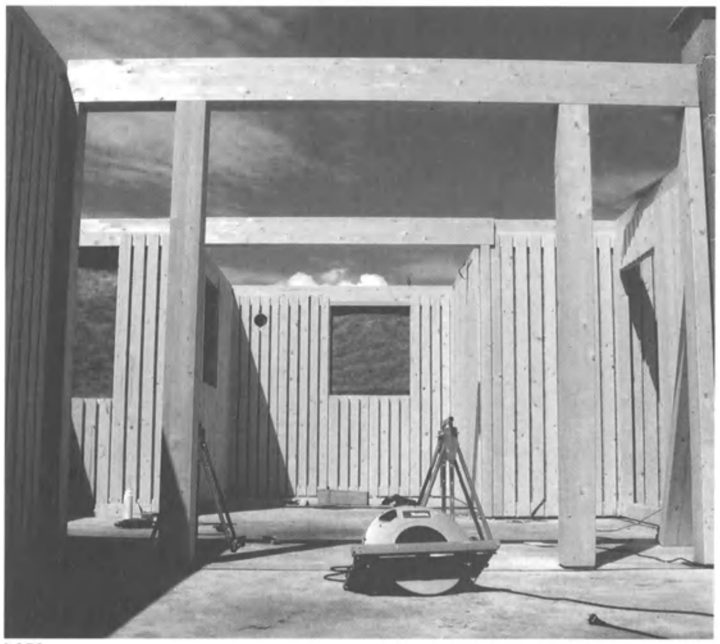
1 Mortar bed, waterproofing, damp proof course
2 Window sill
3 Louvre blinds in storage compartment
4 Bottom plate (loadbearing structure)
5 Module (insulated) (loadbearing structure)
6 Airtight membrane, vapour barrier
7 Thermal insulation
8 Protection for thermal insulation
9 Ventilation cavity
10 Cladding
11 Suspended floor structure
12 Impact sound insulation
13 Subfloor, floor covering
14 Soffit lining
15 Battens, space for services
16 Airtight membrane, vapour barrier
17 Thermal insulation
18 Secondary waterproofing layer, possibly additional insulation
19 Counter battens, ventilation space
20 Roof covering

b248 Wall construction, cladding with ventilation cavity

b249 Wall construction, thermal insulation composite system

b250 Section through construction: solid timber construction (compound cross-sections), external wall showing window opening, junction with ground floor, suspended floor, and roof.


b251


b252

details at penetrations such as doors, windows, chimneys, etc. must be given special attention in terms of airtightness. The manufacturer's specification regarding the various layers must always be taken into account.

b8 33 Shrinkage and swelling behaviour

Cross-banded glued elements exhibit excellent dimensional stability. Special precautions during transport and the on-site phase, apart from protection against the weather and dampness/precipitation, are therefore hardly necessary. In the case of non-cross-banded systems, however, changes to the cross-section can be expected due to the effects of moisture. Such deformations must be allowed for in the construction.

b251 Erection of small-format modules (Steko)

b252 Erection of wall elements (Lignotrend)

b8 34 Loadbearing behaviour

The individual elements, once joined together and to their system-related perimeter beams, form plates which can accommodate both horizontal and vertical loads. The loads are transferred via these plates down to the foundations. Buckling is prevented by stiffening measures (webs, leaves, ribs, stiffeners, etc.). High concentrated loads, e.g. from roof beams (high snow loads), are carried by additional columns, depending on the system, which can be incorporated flush with the wall elements. The elements interconnected according to the manufacturer's instructions lead to a plate effect which can resist the horizontal loads that occur. Additional bracing is not generally necessary. The components and details should be designed, calculated, and implemented with the help of a structural engineer.

b8 35 Applications

The building systems described here are all product-related systems marketed under registered trade names. They are used principally for housing – both private homes and small apartment blocks, but such products are also frequently specified for office, industrial, and commercial projects, and also for public-sector buildings. In most countries, the manufacturers of such systems require building authority approval for their products. The applications are system-based, i.e. not only the loadbearing and enclosing functions are important, but also criteria regarding insulation, airtightness, building services, and the integration of further components such as windows, doors, etc. are all met by the system. This approach guarantees a consistent concept.

See chapter e2 for the names and addresses of manufacturers and institutes.

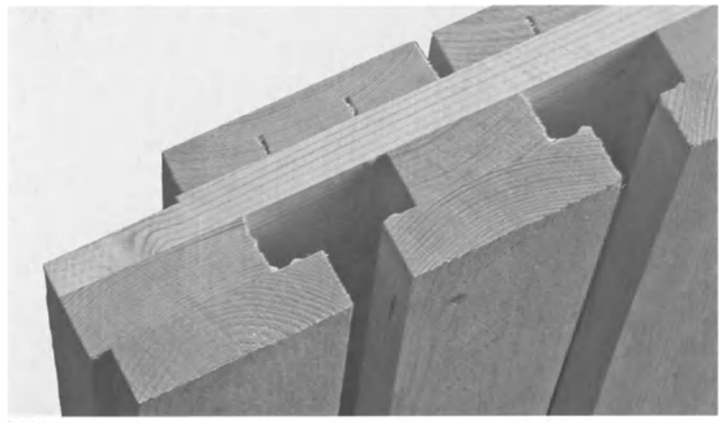
b8 Solid timber construction

b8 36 Examples of systems
Cross-banded spaced plies

The elements are made from cross-banded glued boards which are positioned at a certain pitch with gaps in between. This creates coordinated cavities which offer space for building services but also thermal and/or acoustic insulating materials. Such elements are available for walls, suspended floors, and roofs. Thanks to the cross-banded arrangement, these components exhibit excellent dimensional stability. Special system components (top and bottom plates) are required for the junctions between walls and horizontal loadbearing elements.

The inside of the elements is lined with the customary materials, but certain types of element can be left exposed. Likewise, soffits can be concealed behind ceilings or left exposed. The rest of the wall construction is placed on the outside, similar to the majority of other solid timber building systems: external insulation to suit the thermal performance specification, a ventilation cavity, and then some form of cladding. A thermal insulation composite system (insulation + render) is an alternative. An airtight layer, nevertheless open to diffusion, must be positioned between the solid timber element and the external insulation. Numerous element types and construction options are available for walls, floors, and roofs.

See chapter e2 for the names and addresses of manufacturers and institutes.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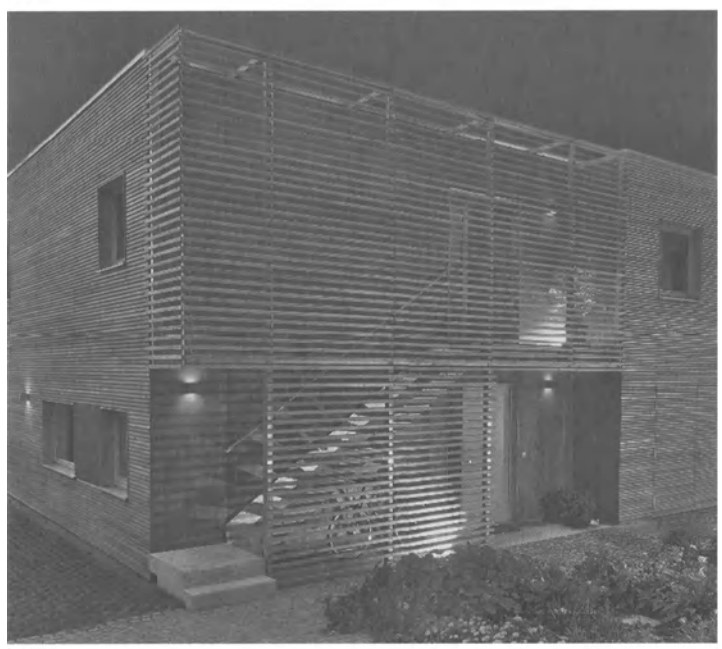
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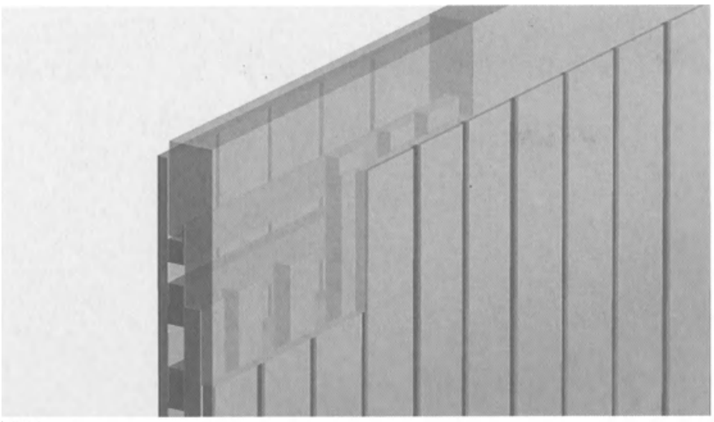
b253 Cross-banded spaced plies (Lignotrend)

b254 Erection

b255 Example of application: semi-detached houses, Munich, Germany



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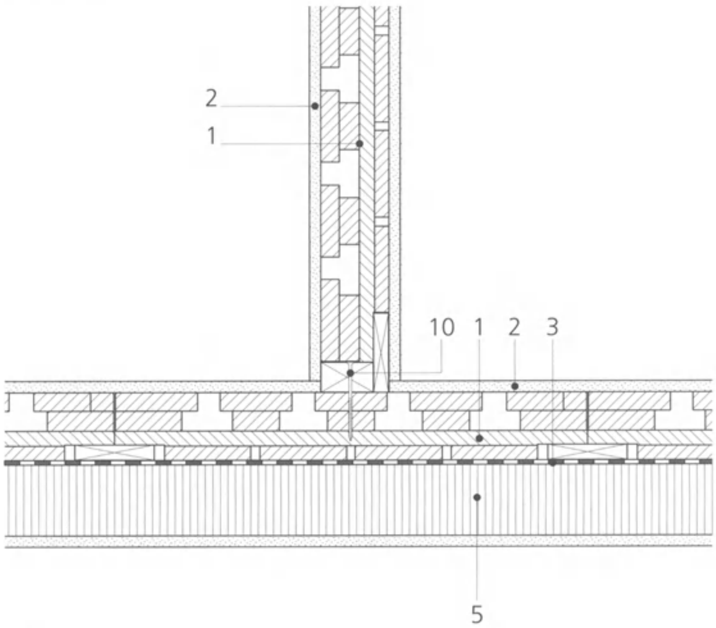

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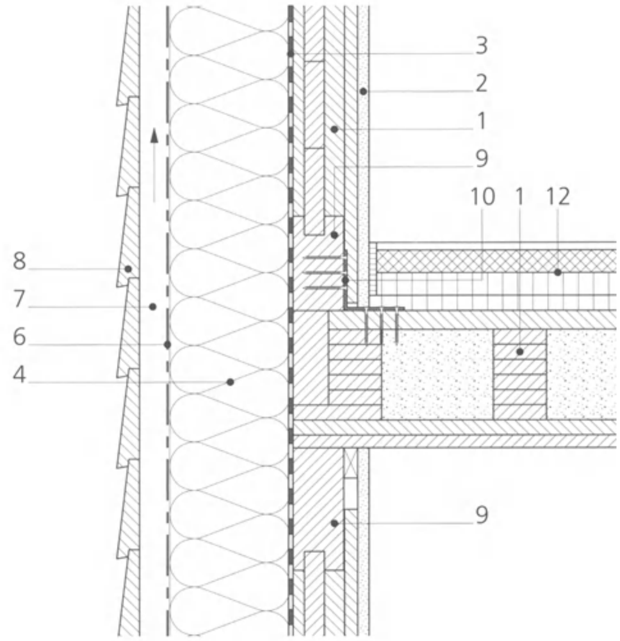

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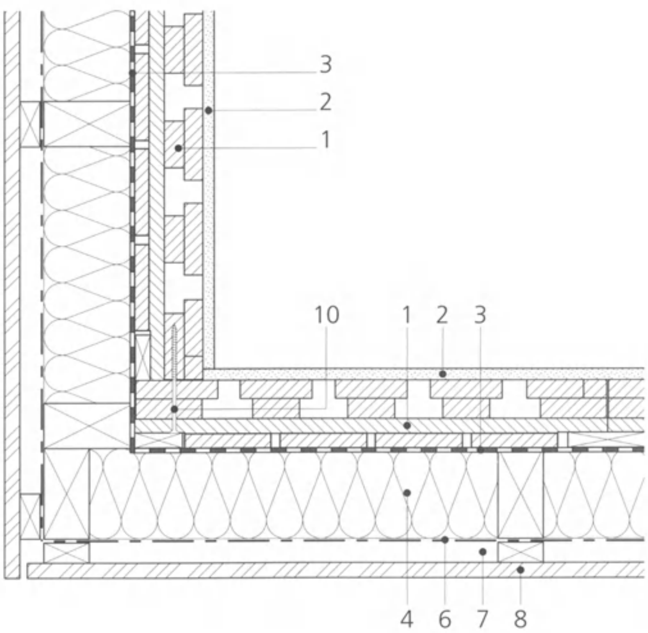

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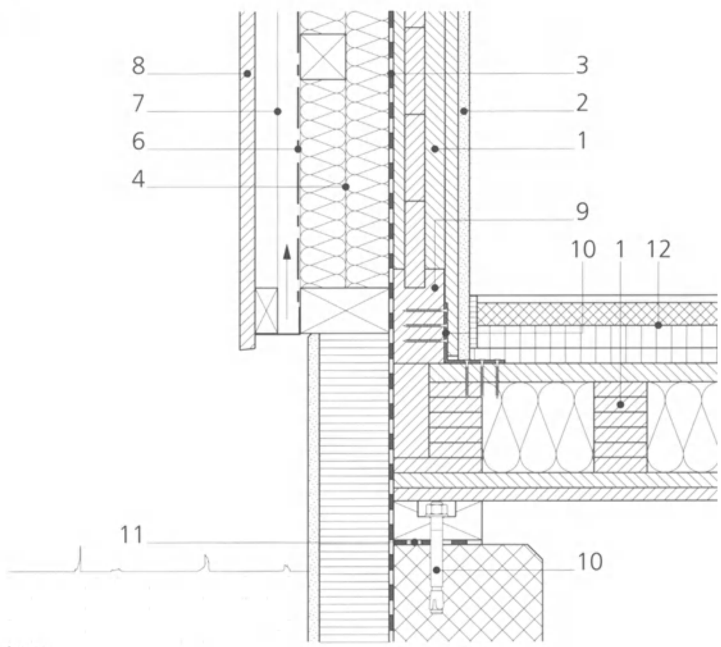

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b256 Sketch of principle of cross-banded spaced plies
b257 to b260 Assemblies and junctions with cross-banded spaced plies
b257 Horizontal section, external wall/internal wall
b258 Horizontal section, external wall corner
b259 Vertical section, external wall/suspended floor
b260 Vertical section, plinth

1 Loadbearing structure
2 Internal lining
3 Airtight membrane, vapour barrier
4 Thermal insulation
5 Thermal insulation composite system
6 Protection for thermal insulation, additional insulation (not installed)
7 Ventilation cavity
8 Cladding
9 Make-up piece
10 Anchor bolt, fastener
11 Waterproofing, damp proof course
12 Floor construction

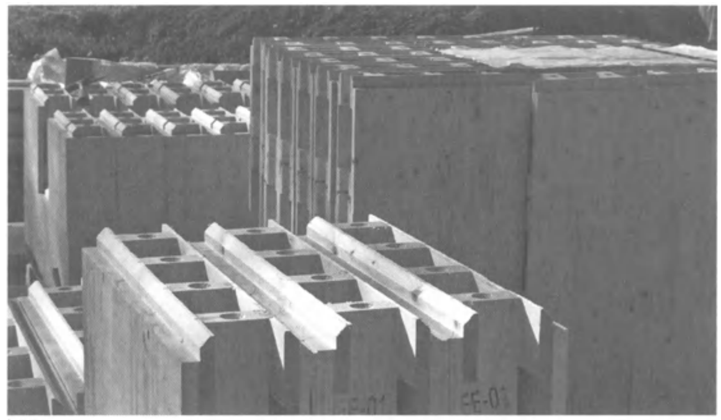
b8 Solid timber construction

Modular building block system

Small-format, factory-made modules of solid timber – basically interlocking building blocks – form the basic elements for this new type of system, which has, however, undergone considerable development and has already become quite widespread. The handy-sized modules are built up in a type of masonry bond according to the modular dimensions. This results in loadbearing internal and external walls. The standardised bottom plates, modules, top plates, and opening trimmers for standard doors and windows result in a coordinated building system.

The timber modules form the structural carcass of the building. The rest of the wall construction is carried out according to energy-related, architectural, and constructional requirements. The thickness of external insulation is chosen to achieve the U-value required for the building envelope. Cladding systems with a ventilation cavity and thermal insulation composite systems can be used to complete the outside of the wall. Internally, the walls can be left exposed or finished with customary materials such as plaster or wood-based board products. Five plies of cross-banded solid timber make up the modules themselves, which results in dimensionally stable, non-deformable units with voids. The voids are continuous in both the horizontal and vertical directions and therefore can be used as ducts for building services. Loose insulation can be blown into the voids to improve the thermal and sound insulation, which reduces the thickness of insulation required on external walls.

See chapter e2 for the names and addresses of manufacturers and institutes.



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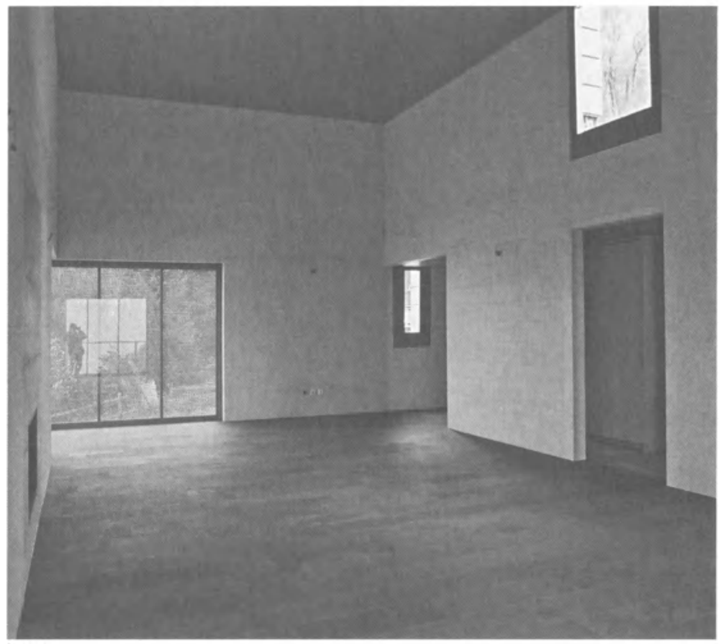

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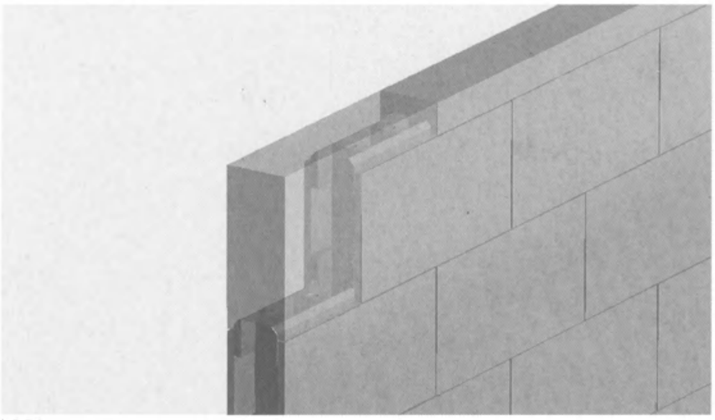
b261 Small-format modules (Steko)

b262, b263 Example of application of modular building block system. The surfaces can be left exposed internally; alternatively, they form an ideal substrate for conventional lining materials; private house in Cardada, Locarno, Switzerland



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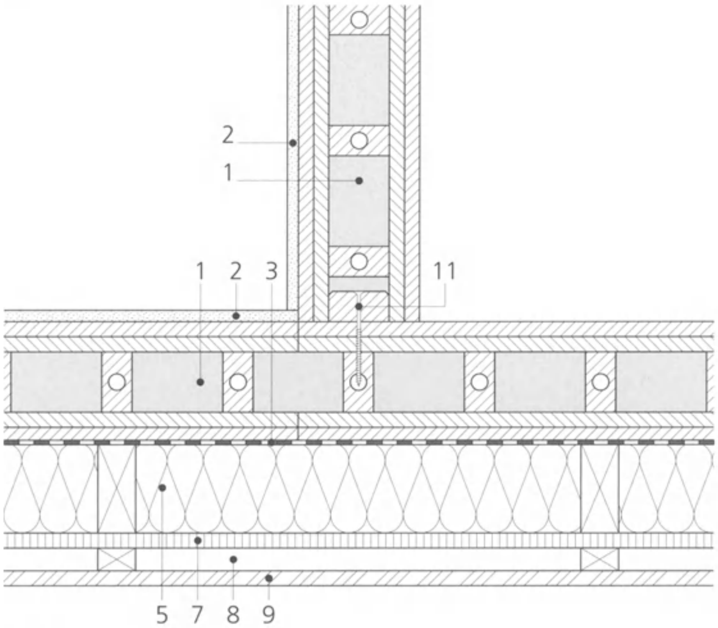

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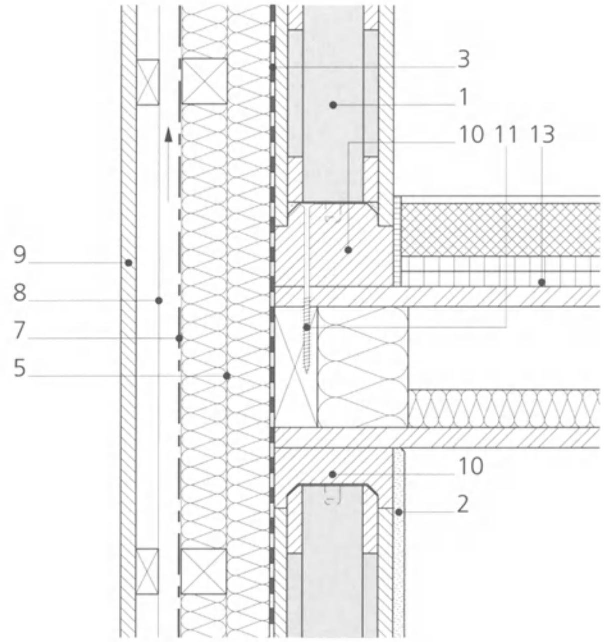

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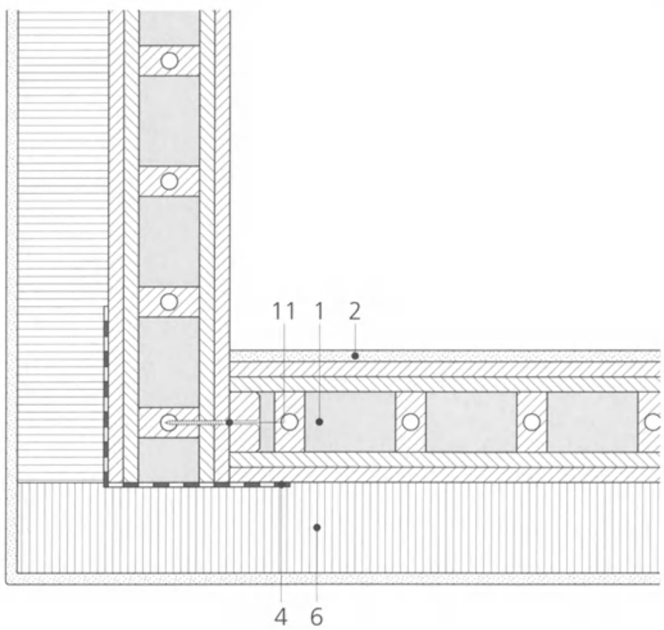

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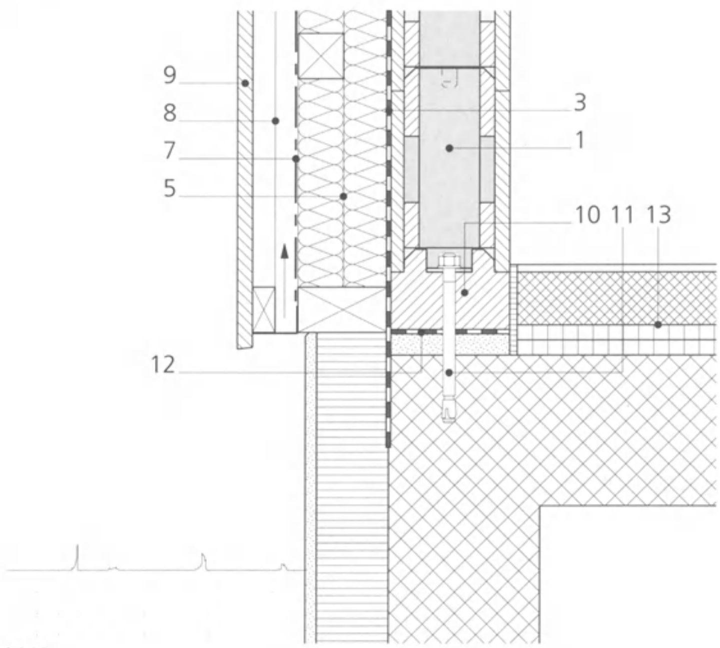


b268

b264 Sketch of principle of modular building block system
b265 to b268 Assemblies and junctions with modular building block system
b265 Horizontal section, external wall/internal wall
b266 Horizontal section, external wall corner
b267 Vertical section, external wall/suspended floor
b268 Vertical section, plinth

1 Loadbearing structure, modules, voids insulated, space for services
2 Internal lining
3 Airtight membrane
4 Airtight membrane (joints sealed airtight)
5 Thermal insulation
6 Thermal insulation composite system (open to diffusion)
7 Protection for thermal insulation
8 Ventilation cavity
9 Cladding
10 Top, bottom plate, connecting pieces
11 Anchor bolt, fastener
12 Mortar bed, waterproofing, damp proof course
13 Floor construction

b9 Roof structures

b9 10 General

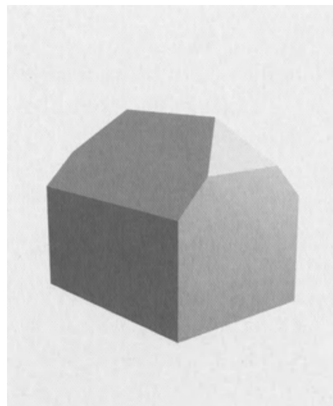
Enclosing components must satisfy thermal and acoustic performance plus fire protection requirements in addition to the constructional specification. This is especially true for the roof because its position means that it is particularly exposed to outside influences. In order that the roof can fulfil its functions without causing problems it needs an appropriate loadbearing structure, which has the task of carrying the other layers of the roof construction, the snow and wind loads, and its own weight. Section b9 21 provides an overview of roof structures, which are then subsequently described one by one. Besides the aforementioned fundamental tasks, the roof has to fulfil other functions as well, principally architectural design aspects with respect to the interior, and also the integration of the structure into the landscape or the surrounding built environment. And it is the form of the roof (section b9 11) that plays the most important role here.

b269

b269 Roof structures be left exposed internally and thus create an important architectural feature; trade fair building, Rimini, Italy

b9 11 Roof forms

The most common roof forms are:
- flat roof (Fig. b270)
- monopitch roof (Fig. b271)
- duopitch roof (Fig. b272)
- hipped roof (Fig. b273)
- hipped-gable roof (Fig. b274)
- pavilion roof (Fig. b275)
- mansard roof (Fig. b276)
- arched roof (Fig. b277)
- sawtooth roof (Fig. b278)
- flat roof with rooftop structure, garret storey (Fig. b279)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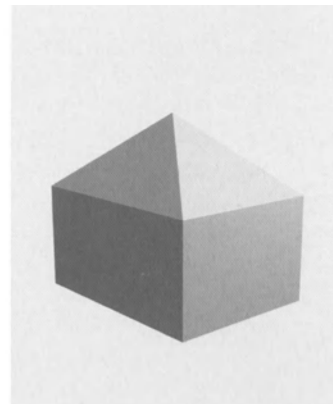
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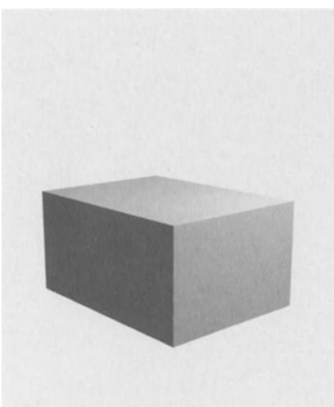
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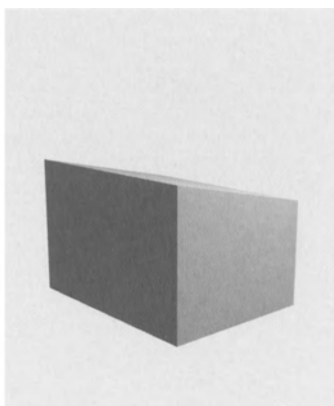
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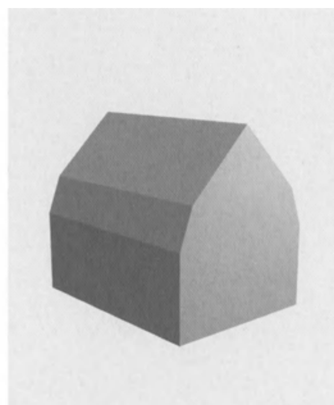
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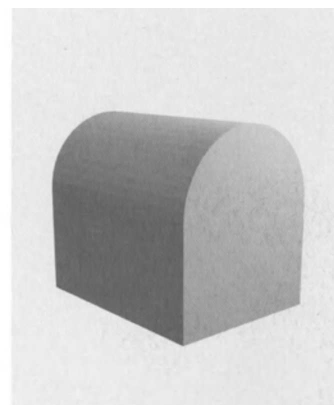
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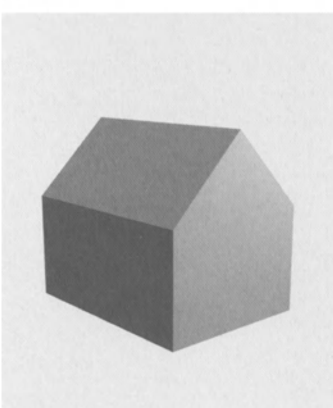
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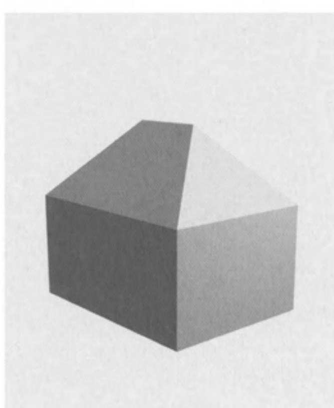
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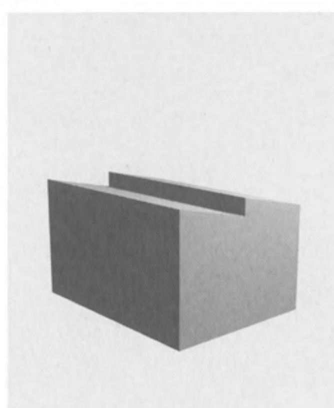
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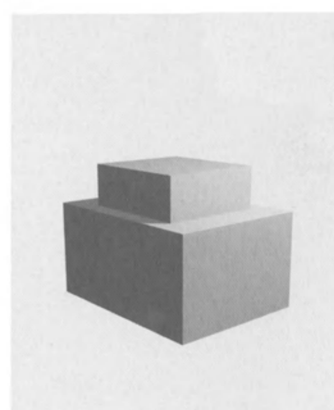

b279

b270 to b279 Overview of common roof forms

b270 Flat roof
b271 Monopitch roof
b272 Duopitch roof
b273 Hipped roof
b274 Hipped-gable roof

b275 Pavilion roof
b276 Mansard roof
b277 Arched roof
b278 Sawtooth roof
b279 Flat roof with garret storey

b9 Roof structures

b281

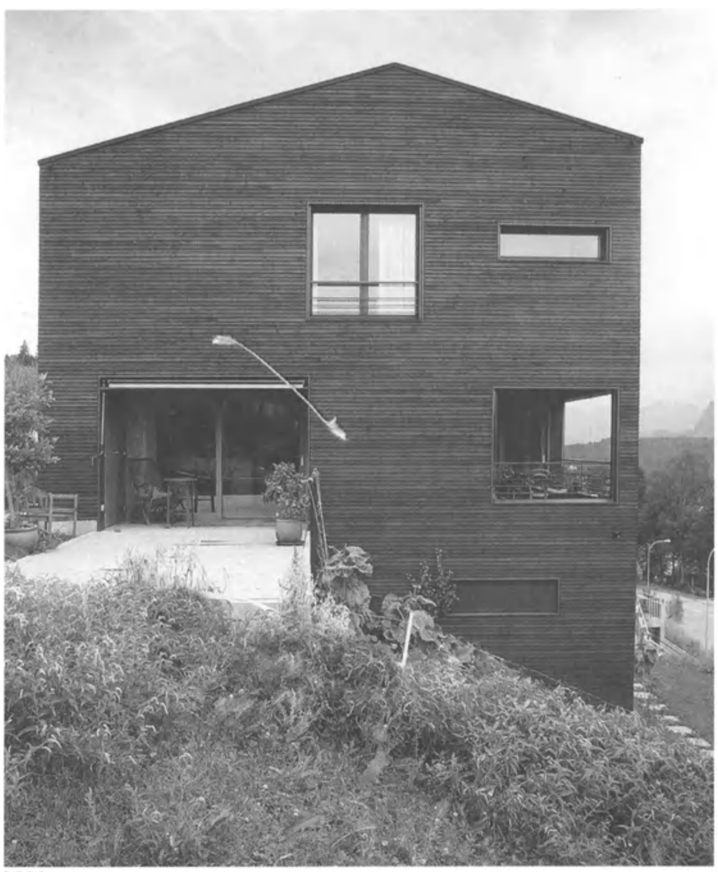
Roofs on towers or sheds can also take on different forms. Rooftop structures come in various forms, such as dormer windows in all their variations, turrets and lanterns, and cut-outs for rooftop terraces. The flat, duopitch, and monopitch roofs are, however, the forms met with most frequently in practice.

Duopitch roof

The simplest and most economic form of pitched roof is the duopitch roof (Figs. b272 and b280). In this type of roof the ridge is a horizontal line on elevation from which the roof surfaces descend to the eaves on both sides. Modifications of the duopitch roof are the hipped roof (Fig. b273) and the hipped-gable roof (Fig. b274) in which the gable ends are also in the form of sloping roof surfaces. The difference between these two latter forms is that the gable ends of the hipped roof slope from ridge to eaves, but in the hipped-gable roof part of the vertical gable wall still remains.

Mansard roof

The mansard roof (Fig. b276) is named after the French builder François Mansart (1598–1666). Mansart built duopitch roofs in which the slope on both sides changes from a steeper lower part to a shallower upper part, giving these roofs their distinctive "kink". This arrangement allows the roof space to be better utilised.



b280

b282

b280 Private house with duopitch roof

b281 Utility buildings with monopitch roofs

b282 Residential complex with unusual roof form

b283

Monopitch roof

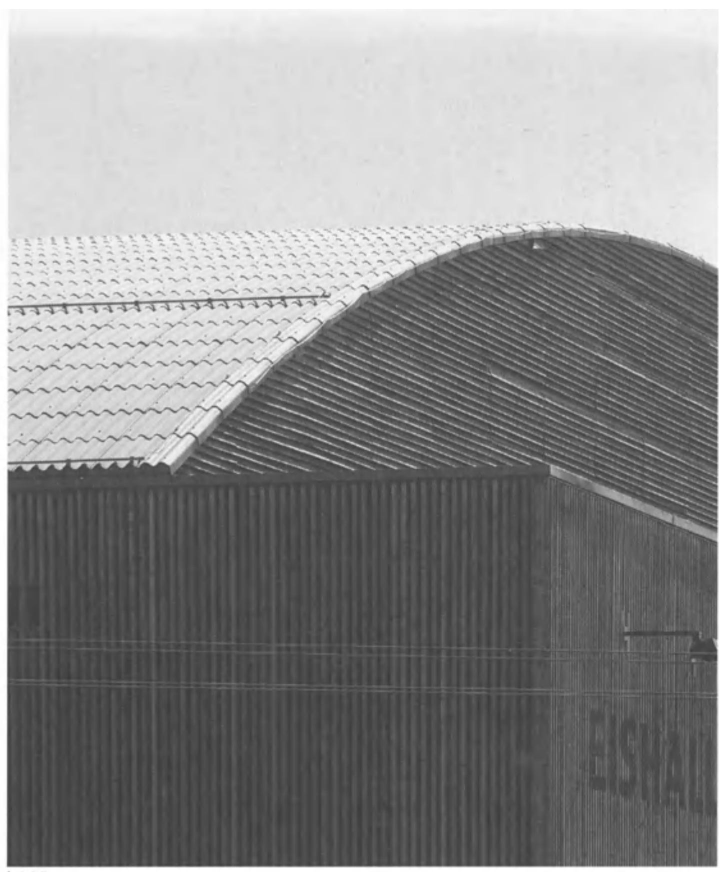
Another basic form of pitched roof is the monopitch roof (Figs. b271 and b281). This has a slope on one side of the ridge only and is therefore more suitable for narrow or stepped structures or extensions.

Flat roof

Whereas the flat roof has been widespread in certain regions, e.g. around the Mediterranean, for millennia, it was an insignificant form in central and northern Europe until fairly recently. It was not until the start of the modern age, as clear, geometrical, and simple building forms and facades appeared, that the desire for a horizontal building termination was expressed (Figs. b270 and b283). During the 18th century flat roofs were used mainly for prestigious structures only, as terraces and garden pavilions. But this changed during the industrialisation of the 19th century and flat roofs started to appear more and more on everyday buildings. Today, flat roofs are very common. Knowledge regarding choice of materials, methods of construction, and building physics has increased and so flat roofs in timber can now fully meet all aesthetic and technical demands. Optimum and durable solutions are therefore possible.

As a flat roof is that part of the building envelope subjected to the greatest loads and stresses, special requirements apply for the construction of a flat roof and the materials required.

b284



b285

b283 Apartment block with flat roof

b284 Apartment block with garret storeys

b285 Ice rink with flat and arched roofs

b9 20 Overview of structural systems

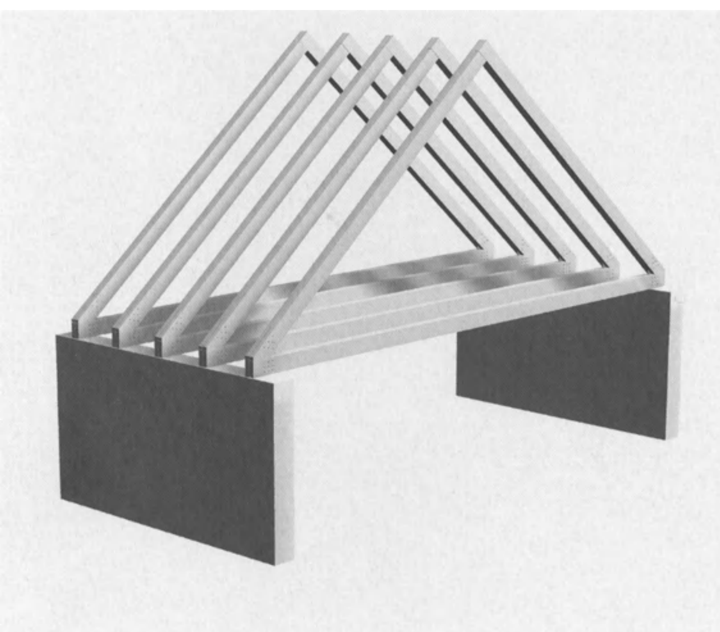
b9 21 General

The structural systems can be divided into groups. Close-couple (Fig. b286), purlin roofs (Fig. b287), trussed rafters (Fig. b289), and systems comprising primary and secondary structures (e.g. portal frame plus purlins, Fig. b290) are the most common roof structures these days. Trussed rafters are placed at close centres (approx. 0.60 to 1.25 m) and therefore support the rest of the roof construction directly. Systems with primary and secondary structures are governed by the primary structure, which is usually positioned on a large grid of 4.00 to 7.50 m or even more. The secondary structure of purlins or flat roofing elements is laid directly on the primary structure. This form of construction corresponds to frame construction, which also makes a clear distinction between primary and secondary structures. Often, the primary structure forms the principal construction for the roof and the external walls, leading to a homogeneous structural system for the entire building.

Traditional roof structures

King posts, queen posts, sling braces, and other timber roof members and structural arrangements very common in the past are still occasionally met with in modern timber construction (e.g. Fig. b288). Whereas such traditional roof structures are rare in new buildings, the situation is different in renovation, refurbishment, and repair work, and extensions to existing buildings. These forms of construction founded on traditional carpentry skills may well be justified in such projects, or can provide models for new structures designed to imitate older traditions.

In order to make a clear distinction between these and the forms of roof structure common today, traditional roof structures are designated as such and are treated separately in this book. Traditional roof structures exhibit similarities to modern systems with primary and secondary structures (Fig. b290): main frames or beams (max. spacing 4 to 5 m) and purlins form the primary structure, and rafters the secondary structure. In contrast to this, rafters are unnecessary in modern systems employing beams or frames and purlins.



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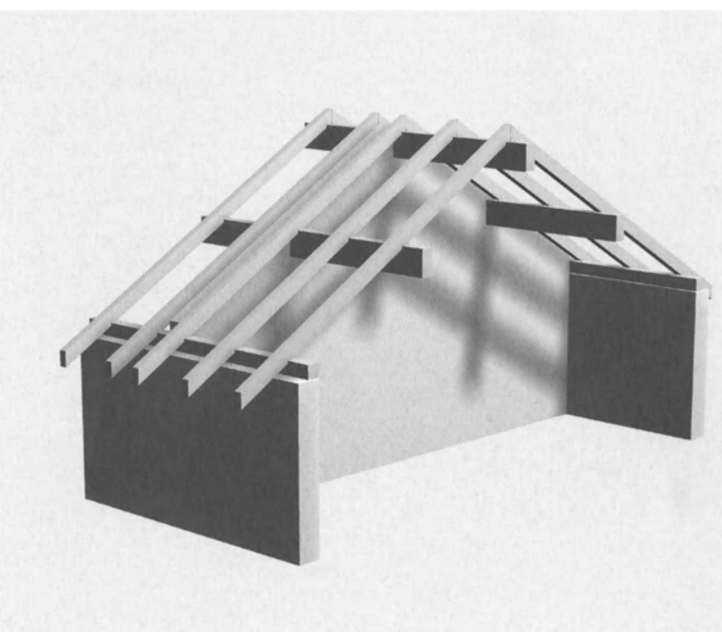
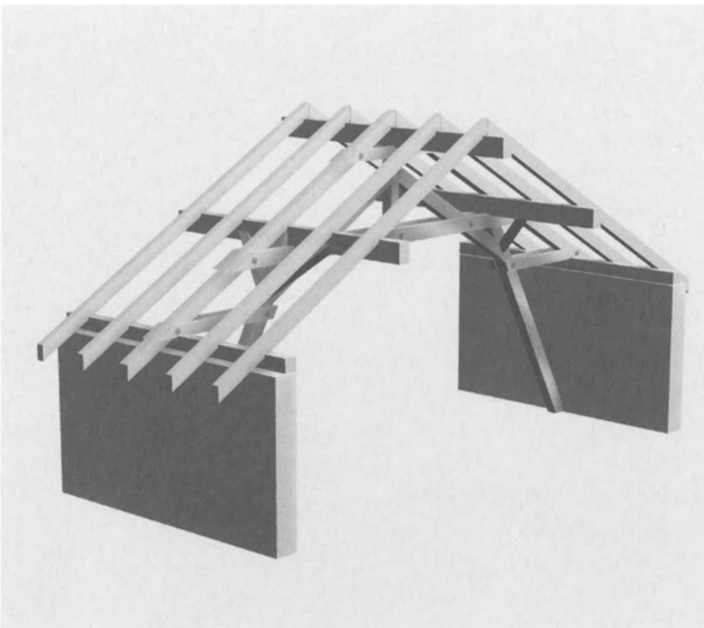


b287

b286 to b290 Overview of structural systems for roofs

b286 Close-couple roof, see b9 30 for details
b287 Purlin roof, see b9 40 for details



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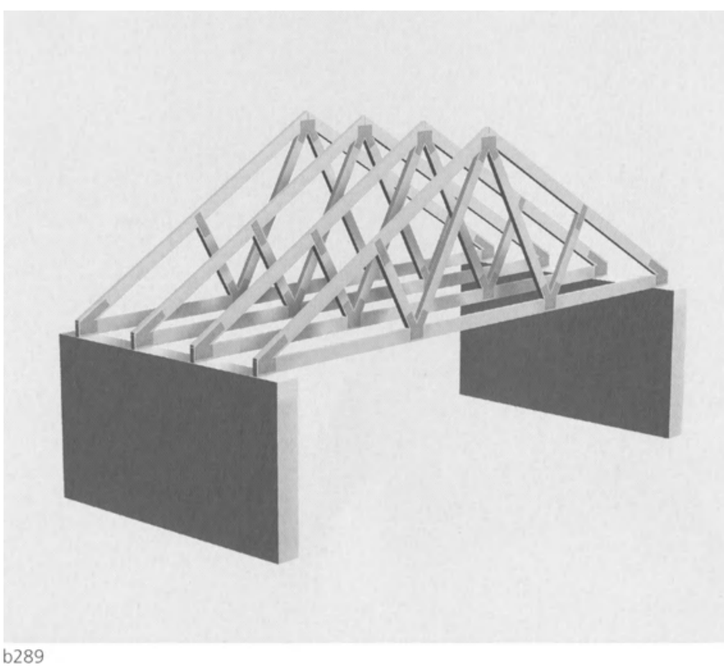
Choice of system

Close-couple roofs, purlin roofs, and trussed rafters are the structural systems met with most frequently in housing and commercial projects. For sheds, sports centres, and larger structures in general, diverse forms of roof construction based on the principle shown in Fig. b290 are popular. The choice of structural system is often prescribed by the geographical location of the building. For example, in Switzerland the purlin roof (Fig. b287) is generally preferred for pitched roofs. But in Germany, although purlin roofs are more common in the south, close-couple roofs (Fig. b286) are very widespread in the north. And in France, the UK, northern Europe, and overseas, lightweight trusses (Fig. b289) are used as the roof structures for the majority of buildings. But this hard and fast rule of the past is no longer strictly applicable; architectural and constructional criteria are now more important.

When selecting the appropriate roof structure and the timber building system, another relationship has to be taken into account: simple roof trusses are associated with panel construction, whereas frame construction is mostly found in conjunction with a purlin



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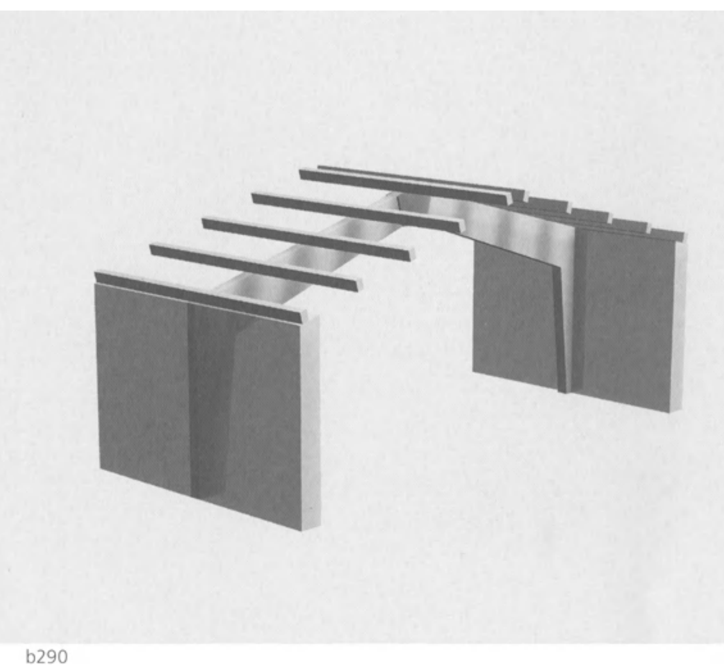

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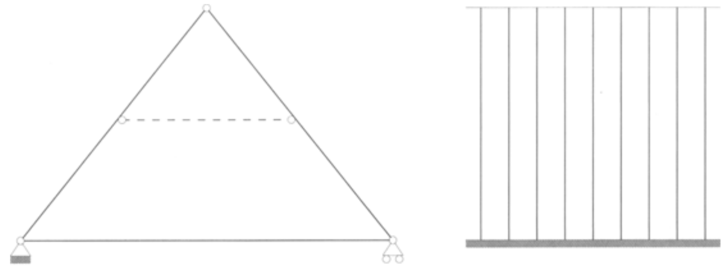
b288 Traditional roof structure with sling braces and hanger below ridge purlin, see b9 50 for details
b289 Roof trusses, trussed rafters, see b9 60 for details
b290 Primary and secondary structures, see b9 70 for details



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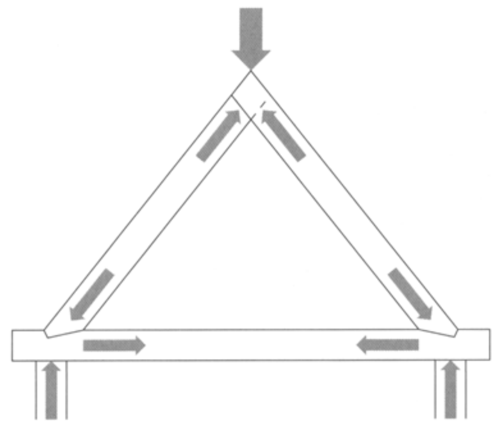


b292

roof or systems having primary and secondary structures. As a rule, purlin roofs and trussed rafters are erected with a shallower pitch (roughly 15° to 45°) than close-couple roofs (roughly 30° to 60°).

The advantages of the purlin roof over the close-couple roof are:
- No additional horizontal thrust at the base of the rafter; elaborate, expensive connections are therefore unnecessary.
- The rafters carry no high axial loads; they are loaded almost exclusively in bending.
- Dormer windows are easier to incorporate.
- Purlin roofs are easier to erect than close-couple roofs.
- Close-couple roofs often require sprocket pieces at the eaves (see Fig. b293). Modern fastener technology also enables connections that are flush at the eaves; sprocket pieces are therefore unnecessary (Figs. b295, b300, and b301).

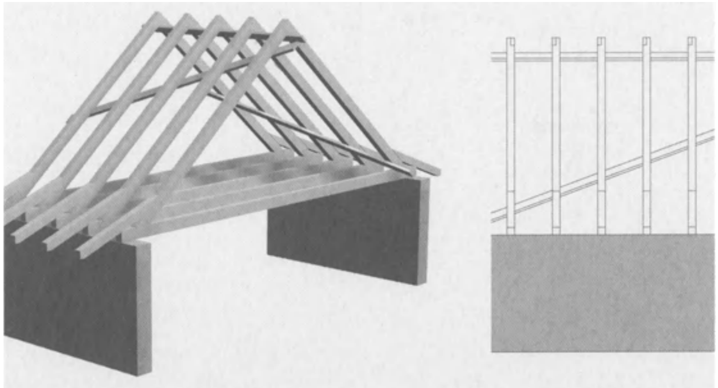
The disadvantages of the purlin roof are:
- It places loads on the gable walls, also internal walls or posts.
- In contrast to the close-couple roof, a roof space free from intervening posts or intruding purlins is not possible.

b9 30 Close-couple roof

The close-couple roof (Figs. b293 and b295) and the close-couple roof with collar (Fig. b294) are suitable for symmetrical duopitch roofs, building widths that are not too large, and roof pitches steeper than about 30°. In structural terms, each pair of rafters forms a rigid triangular frame together with the topmost floor (timber joists or concrete slab).

Fig. b291 illustrates the structural system of the close-couple roof. A collar can be included for greater building widths. In the close-couple roof the loads are split at the ridge (Fig. b292), which means that the rafters have to withstand axial compression as well as bending. At the eaves, the forces are split into a horizontal and a vertical component. Besides the vertical loads, considerable horizontal forces also occur at this point. Buildings with close-couple roofs therefore require a topmost floor whose structural members can accommodate tensile forces, unless other measures are used to guarantee that the base of the rafter is held rigidly in position. This is the case with roof structures designed to achieve a plate effect (e.g. reinforced concrete slab), or specially designed external walls of reinforced concrete, for instance.

b291 Structural system of close-couple roof (section and elevation)
b292 Flow of forces in close-couple roof



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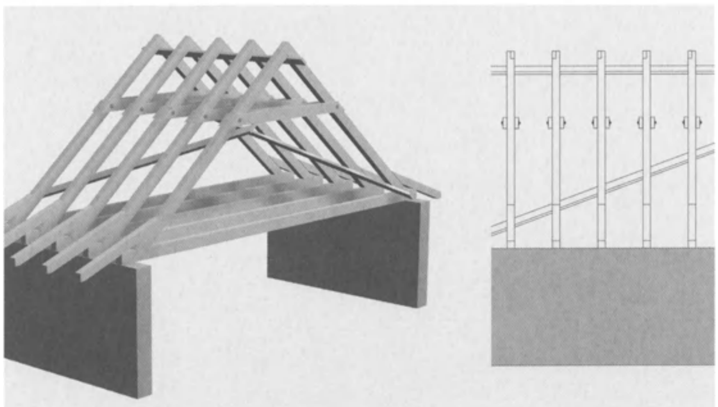

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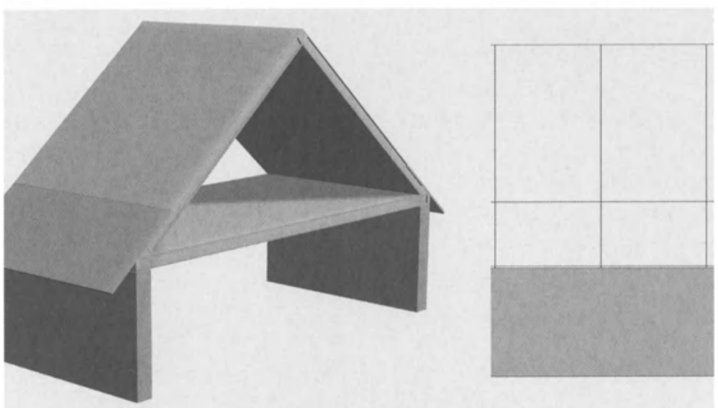


b295

Eaves detail
The connection at the eaves in a close-couple roof can be achieved with the help of one of the various kinds of oblique dado joint (e.g. see [18] p. 109). Screws or metal fishplates should be used to secure the rafters against lateral displacement and against wind loads. The connection at the base of the rafter must be accurate, as is generally prescribed for oblique dado joints. The various joints are described in the Lignum publications [16, 17] or in national standards.
In the case of high loads or a connection without projecting timber, a wood joint is difficult. Steel fasteners and connectors can be used in such instances. This results in a steel-wood connection that is accurate and can be adapted to suit the loads involved.

b293 Close-couple roof with timber joist floor and sprocket pieces
b294 Close-couple roof with collars, timber joist floor, and sprocket pieces
b295 Close-couple roof with floor and roof elements plus overhanging plate

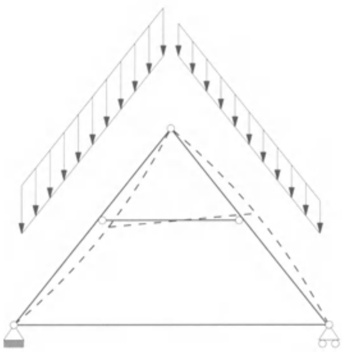
Ridge detail
At the ridge the rafters are connected via halving joints, bridle joints, metal fishplates nailed to the sides or punched metal plate fasteners. A batten to stabilise the ridge longitudinally should always be included.

Collar

Larger building widths lead to the rafters having to withstand considerable bending and buckling actions. Every pair of rafters should therefore be connected by a collar to stiffen the construction. The addition of a collar enables the construction of roofs with pitches of 30° to 50° and spans of 9 to 12 m. In terms of the fixing of the collar beam, we distinguish between two systems: close-couple roofs with non-rigid or rigid collar (Figs. b296 and b297 respectively). In a close-couple roof with non-rigid collar, the rafter/collar connection can be displaced in the case of asymmetric loading. The effect of the collar for this loading case (wind loads, asymmetric snow load) is therefore minimal.

A rigid collar can be created by forming a plate or wind girder at collar level that transfers the forces to gable and/or intermediate walls. This creates a rigid support for the rafters at the position of the collar.

Rafter/collar connection
The collar can be in the form of single member or a true double collar, which determines the connection to the rafter. In old roof structures with a one-piece collar, a dovetail joint was used. This joint is based on the recognition that a collar able to resist both tension and compression is an advantage. But the disadvantages of this connection are the severe weakening of the cross-section and the cost of such a joint. Other possibilities are oblique dado joints or mortise and tenon joints with metal fishplates (for the tension). Today's fabrication technologies and the forces ascertained with accurate structural calculations enable the use of plates let into the timber in conjunction with close-tolerance bolts. When using a true double collar, the connection can be achieved with the help of shear-plate, split-ring or toothed-plate connectors, close-tolerance bolts, or nailing (Figs. b298 and b299).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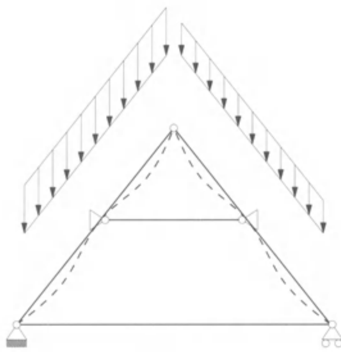
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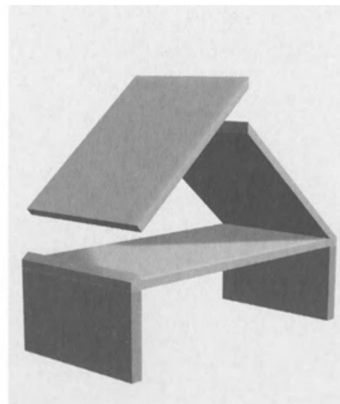
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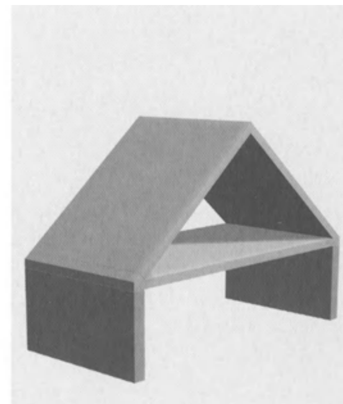
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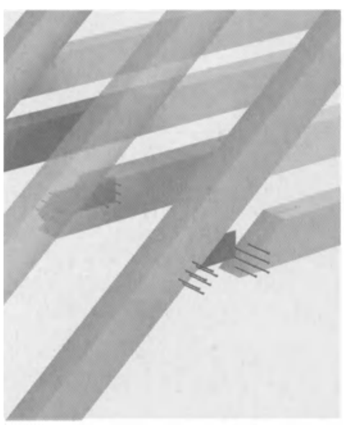
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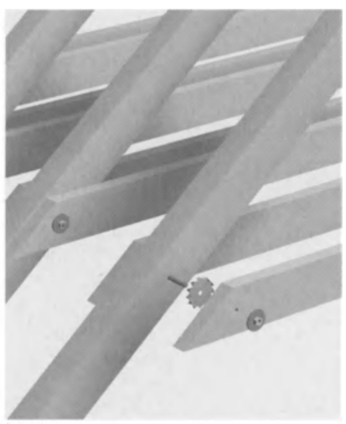
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Longitudinal bracing

Another structural requirement is the longitudinal bracing in the close-couple roof. Such a roof represents a stable structure in the transverse direction, but in the longitudinal direction the stability of the roof must be guaranteed by creating roof plates. The plate effect can be achieved by fixing planks or boards over the entire surface of the roof (in the form of an inner lining, or wood-based products attached to the outside as a secondary waterproofing layer). Diagonal bracing in the plane of the roof designed for tension and compression is also possible, or diagonal sheathing, or even sheathing parallel with the eaves in combination with diagonal bracing. Interesting from the structural point of view, however, are roof elements with structural sheathing, e.g. 3-ply core plywood or OSB (hollow-box system), which help to carry loads in the direction of the rafters but at the same time provide the necessary bracing in the longitudinal direction. Figs. b300 and b301 show this construction schematically.

Construction

Closed-couple roofs can be erected conventionally, as individual pieces – rafters, sprocket pieces, possibly collars, subsequent fixing of the individual plies and layers of the roof covering. However, closed-couple roofs are also ideally suited to factory production. The components can be prefabricated with loadbearing construction, insulation, and planar layers, also with openings for windows (even with windows already installed). All that remains to do is to transport the elements to the building site and join together the three parts – topmost floor and two roof halves (Figs. b300 and b301).

b296 Close-couple roof with non-rigid collar; deformations caused by asymmetric loading

b297 Close-couple roof with rigid collar; appropriate stiffening (wind girder or plate) in the plane of the collar provides a rigid support for the rafters at the junction with the collar.

b298 Rafter/collar connection with plates let into the timber and close-tolerance bolts

b299 Two-piece collar connected with shear-plate, split-ring or toothed-plate connectors

b300 and b301 Erection sequence for roof elements: topmost floor, two roof halves.
Prefabrication in the factory has advantages: the large-format components are fabricated as plates which provide the necessary stability in the longitudinal direction.

Extensive prefabrication off-site and the option of creating roof spaces without intervening posts and intruding purlins, plus new types of connections at the eaves, have turned the close-couple roof into a modern roof system that is making a comeback.

b302

b302 Roof space free from intervening posts and intruding purlins; roof structure in the form of a close-couple roof

b9 40 Purlin roof

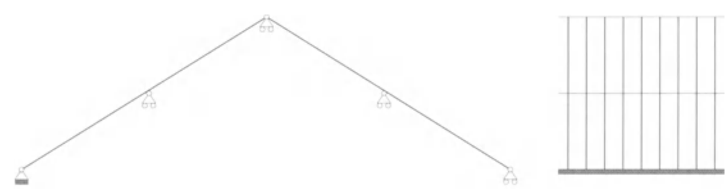
Purlin roofs are suitable for symmetrical and non-symmetrical duopitch and hipped roofs plus a number of special roof forms. The rafters are notched to accommodate the supporting purlins, which are in turn supported on posts or walls. Fig. b303 shows the structural system for the rafters of a purlin roof.

In purlin roofs the vertical loads of the purlins are transferred directly to walls (Fig. b305) or posts (Fig. b304) supported on the floor below. The purlins are interconnected by the rafters. The roof structure spanning from eaves purlin to ridge purlin in conjunction with the posts or walls and the topmost floor therefore form a rigid triangular frame which provides adequate transverse stability for shallow roof structures. Appropriate fixing of the purlins and posts and adequate connections between rafters, purlins and posts, or walls are, however, essential for stability (Figs. b306 and b307). If walls are positioned below the purlins, these can be used instead of posts, but the loadbearing behaviour remains the same. Topmost floor, rafters and walls, and the intermediate purlins must form a rigid triangular frame. A structural analysis of the forces to be transferred and the fixings and connections required is indispensable.

The horizontal load path results in an axial force in the rafters in purlin roofs, which is normally small. If, however, a joint in the length of the rafter is necessary, an adequate connection will be required.
When specifying queen-post roof structures with dwarf walls (Figs. b308 and b309), an unstable trapezium form can ensue, which must be braced. If the gable walls are sufficiently rigid, the horizontal forces can be transferred via a plate construction at the level of the collar.

Longitudinal bracing

King- or queen-post roof structures make use of kneebraces or struts or walls (shear walls, i.e. acting as vertical plates) parallel with the purlins to achieve the necessary stability in the longitudinal direction. In such arrangements, the posts must be properly anchored and the connections between kneebraces/struts and purlins/posts must be able to withstand tension and compression.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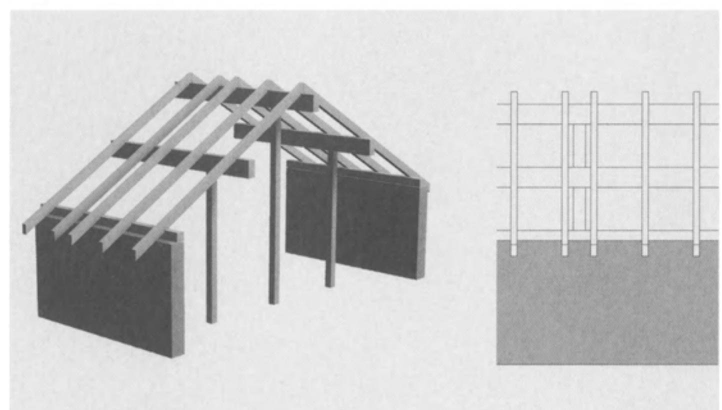
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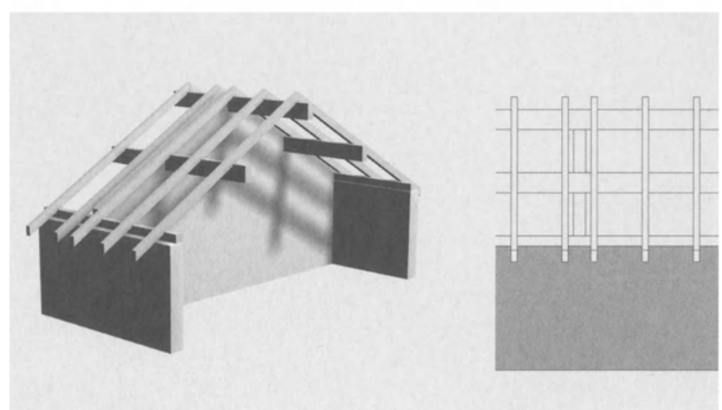
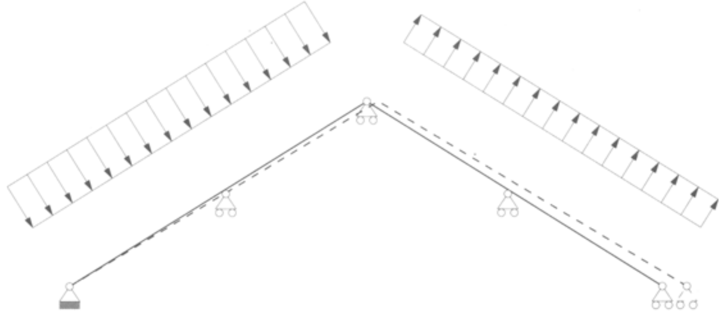

b305

b303 Structural system of purlin roof

b304 Purlin roof supported on posts

b305 Purlin roof supported on walls



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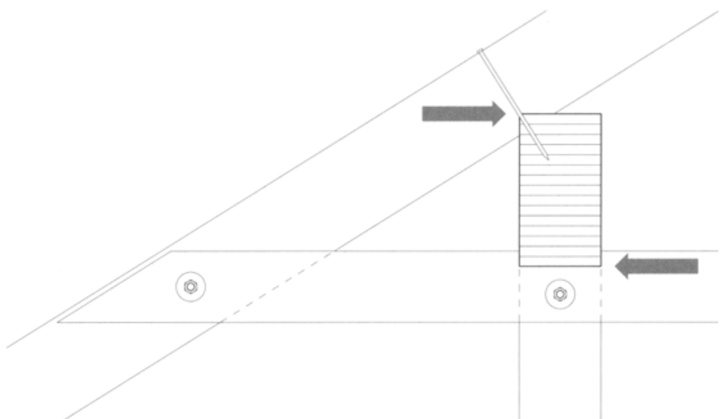

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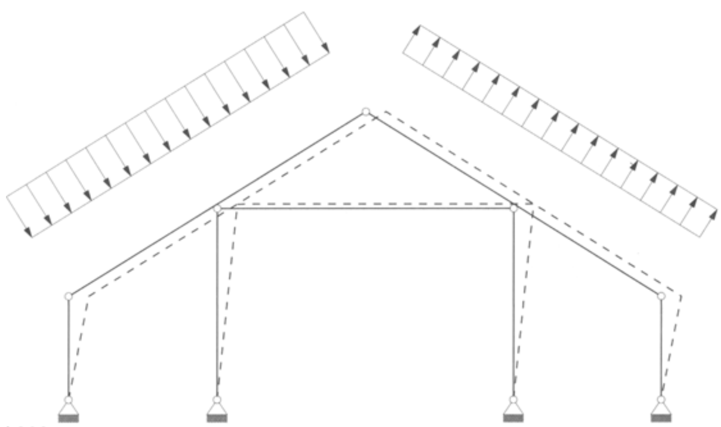

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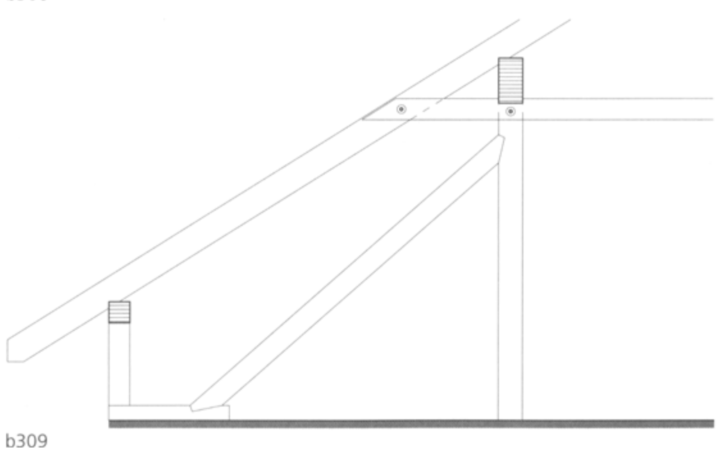


b309

b306 and b307 Transverse bracing for purlin roof.
Floor/posts, walls/rafters form a rigid triangular frame to prevent deformations. The purlin is restrained by the notched collar.

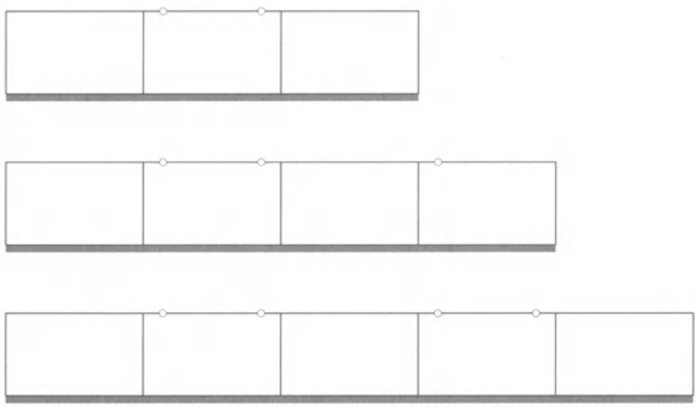
b308 and b309 Purlin roof with dwarf wall. Dwarf wall/floor/posts/rafters form a trapezium which must be braced. The bracing must be attached via tension- and compression-resistant connections.

Another option is to form plates in the plane of the rafters by using diagonal bracing, diagonal planking or wood-based board products – just like the close-couple roofs. Transverse walls cannot be used for the longitudinal stability of purlin roofs because without including appropriate measures they cannot accommodate forces perpendicular to the plane of the wall, i.e. in the longitudinal direction of the roof.

Arrangement of purlins

The rafters transfer their loads to the purlins. In doing so, the intermediate purlins must carry higher loads than the ridge and eaves purlins in the case of continuous rafters. The purlins can be designed as simply supported, continuous or balanced cantilever members. Simply supported purlins, which exhibit greater deformations than continuous purlins, are joined over every support. To ensure a good bearing on the support and a tension-resistant connection, purlins can be seated on timber bearing blocks and secured with screws and anchor bolts.
When using continuous purlins, the deformations (deflection) are smaller than those of simply supported purlins. The critical bending moments are reduced in purlins with at least three spans, but the varying loads at the supports can have disadvantages. Most continuous purlins are made from glued laminated timber, which is easier to procure than squared timber, especially when long lengths are required, and also exhibits enhanced dimensional stability.

A row of purlins each supported on two supports but with their ends cantilevering beyond the supports and simply supported purlins spanning between the cantilevering ends produces a balanced cantilever arrangement. The position of the joint between cantilevering end and simply supported section should be arranged such that the span and support moments are roughly equal. As the joint itself cannot accommodate any bending moments, it must be positioned according to the structural calculations. The number of joints is equal to the number of supports minus two, i.e. the number of joints is equal to the number of intermediate supports. Fig. b310 shows possible joint arrangements. The joint itself can be in the form of a straight or splayed scarf, but standardised sheet metal connectors or special steel components are also available these days.



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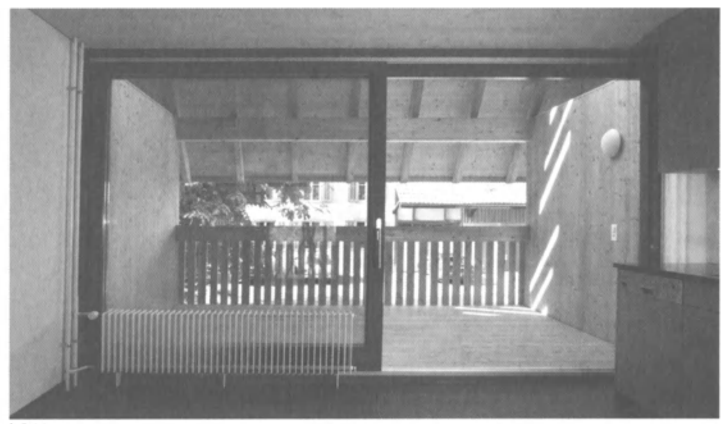


b311

Construction

Purlin roofs can be erected conventionally, in individual pieces, by first positioning the purlins and then adding the rafters. The layers of the roof covering then follow: secondary waterproofing layer, counter battens, thermal insulation, roof covering, etc. The fabrication of roof elements in the factory can be advantageous depending on the form and construction of the roof, and should be preferred to conventional erection when the fabrication options available allow this. This form of construction is becoming increasingly widespread. The rafters together with the sheet-type inner lining, thermal insulation (between rafters), vapour barrier, airtight membrane, battens and secondary waterproofing layer form one element.

The prefabrication of roof elements in the factory calls for extra work during the planning of the components and their assembly. Suitable modular dimensions matching the length and width of the elements must be chosen. Rooftop structures, roof windows, floor plan, and penetrations plus the number and arrangement of the layers of the roof construction must be included in the overall concept. Furthermore, all joints between elements, connections, and purlin supports, verge, eaves, and ridge terminations plus penetrations of the building envelope require practical solutions. These tasks involve basic principles and must also be considered in the conventional form of construction. Factory-prefabrication of roof elements calls for early, systematic planning, and leads to time-savings during on-site erection. This approach might mean additional work and costs, but is helped by careful planning and procedures, which in the end have a positive effect on the overall project.

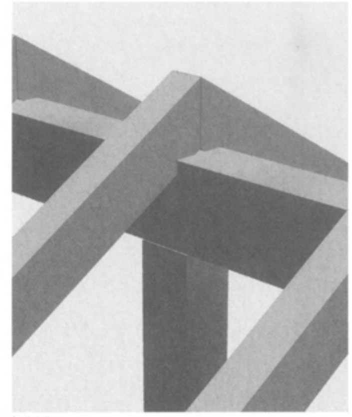
b310 Purlin as balanced cantilever: positions of joints for different numbers of supports

b311 Purlin roof application

b312

b312 Purlins at close centres (high snow loads); the roof structure constitutes a primary architectural feature

b9 Roof structures



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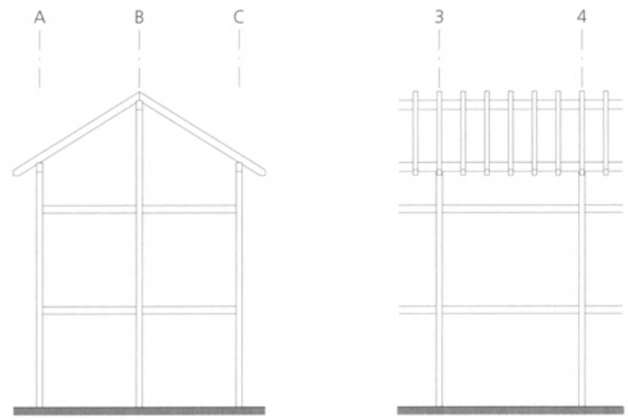
b9 50 Traditional roof structures

Pitched roof structures with king posts, queen posts, sling braces, and other timber roof members are essentially the forerunners of the modern purlin roof, indeed even the roof truss systems common today. Like with the purlin roof described in section b9 40, the loads of the rafters are transferred to the purlins which in turn transfer the loads to the supporting construction. When using king posts or queen posts, the loads are transferred to vertical posts, which form a self-contained system together with the walls and topmost floor. An alternative is to provide inclined struts (sling braces) to support the purlins, which transfer the loads to the outer walls. Figs. b313 and b317 show the differences schematically using the example of the ridge connection. Sling braces in the roof structure, which rely on a certain symmetry, a regular layout, and generously sized members, are now a rarity. Even roof structures with vertical posts based on the traditional carpentry skills of earlier times are hardly encountered in new buildings, or at best used only in a severely modified form. New types of connectors, glued beams and posts, and reliable methods of calculation render possible long-span, cost-effective, optimised loadbearing structures which have nothing to do with traditional roof structures.

Purlin roof with vertical posts

In this form of roof structure the vertical loads from the purlins are carried via posts down to the structural components below. The purlins are interconnected via the rafters.

We distinguish between roof structures with one (king post), two (queen posts) or three (king and queen posts) vertical members (Figs. b314 to b316), depending on the number of purlins. The roof space is often used for habitable rooms, and this means that walls and posts can extend as far as the underside of the roof construction, which in this case then requires rafters and purlins only. However, the requirements regarding load-carrying capacity and stability are still valid, although in this case the roof construction should be considered together with the wall construction, i.e. with the timber building system as a whole.



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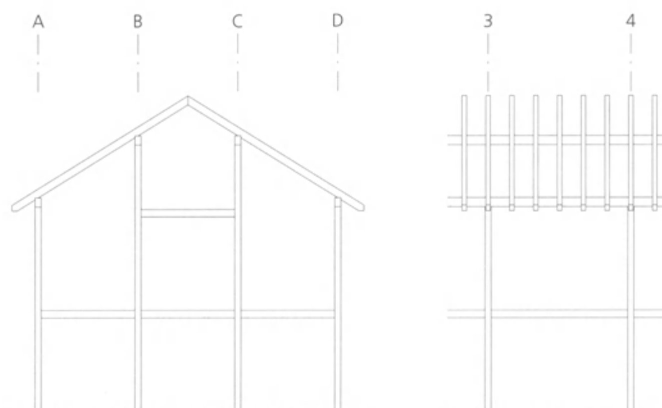

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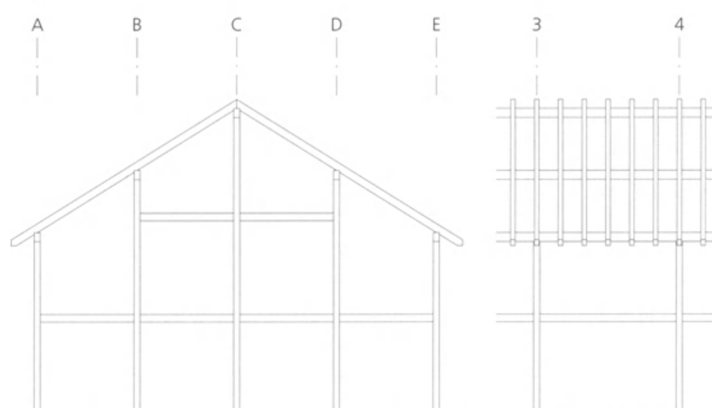


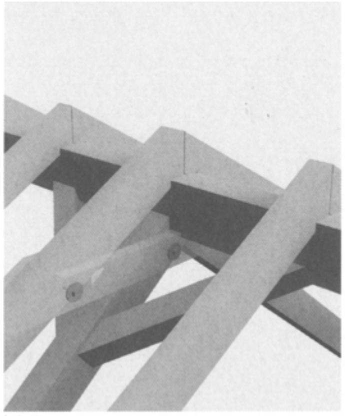
b316

b313 Ridge detail with king post

b314 Purlin roof with king post

b315 Purlin roof with queen posts

b316 Purlin roof with king and queen posts



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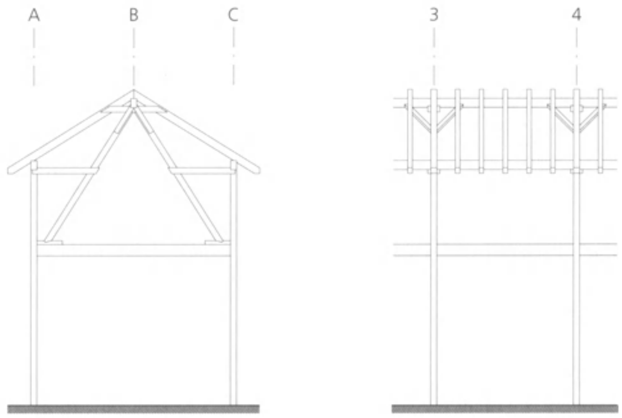

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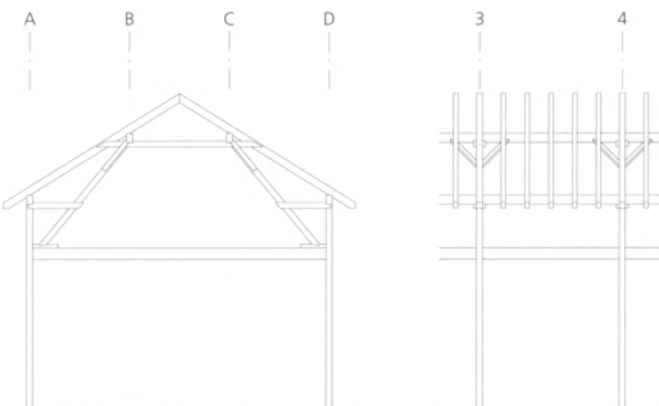

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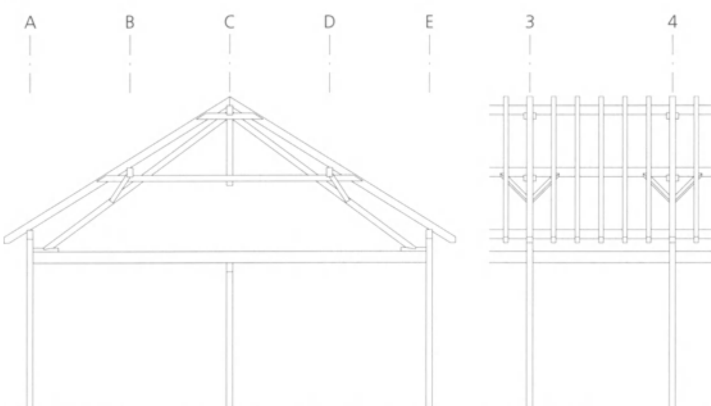


b320

Purlin roof with sling braces

In contrast to the roof structure in which forces are carried vertically via posts or walls down to the supporting construction below, this type of roof structure makes use of inclined members to support the purlins. These struts transfer the loads to the outer walls. This results in both vertical and horizontal forces at the points where the struts are supported, which must be resisted by tie beams, tie bars, or steel brackets.

A tie beam is a joist positioned between the joists at the point where the struts carrying the load from intermediate and/or ridge purlins have to be supported, i.e. where the purlins are supported on the roof structure at a certain spacing (3 to 5 m). The connection to the tie beam is by way of an oblique dado or stepped oblique dado joint, but steel components are also possible these days. The tie beam should not be subjected to bending by a load acting in the direction of the strut. This is generally guaranteed when the axis of the strut intersects with that of the tie beam at the joint. As the struts carry loads from intermediate and/or ridge purlins, they are subjected to compression and sometimes also to bending. They must be fixed properly to resist any wind loads and lateral displacement that may occur. Kneebraces can be used for the longitudinal bracing of roof structures with sling braces; but the ineffective bird's-mouth joint between kneebrace and purlin means that only low forces can be transmitted. Cross-bracing in the plane of the sling braces is often found in old roof structures, which has a considerably better bracing effect.

Like with roof structures including vertical posts, the designations of the roof structures with sling braces depends on the number of purlins (Figs. b318 to b320). Fig. b320 shows a roof structure supporting three purlins which also includes a hanger beneath the ridge purlin. The hanger carries the load from the collar and transfers this to the ridge construction.

b317 Ridge detail with sling braces

b318 Purlin roof with sling braces supporting ridge purlin

b319 Purlin roof with sling braces supporting intermediate purlins

b320 Purlin roof with sling braces supporting intermediate and ridge purlins, plus hanger beneath ridge purlin

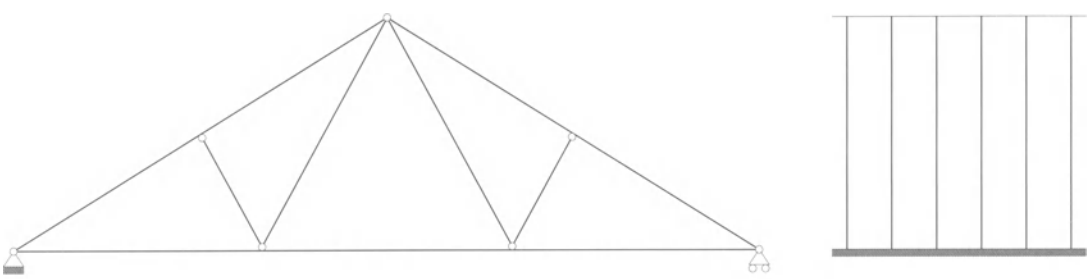
b9 60 Roof trusses, trussed rafters

Roof trusses are used for building widths up to about 20 m, mostly in triangular form for duopitch roofs, but also as lattice beams (with parallel chords) for flat and monopitch roofs. Trussed rafter is the term used for roof trusses that are positioned at a similar spacing to traditional rafters, i.e. 600 to 800 mm depending on the secondary waterproofing layer and thermal insulation. In some cases trussed rafters are used at a larger spacing, but 1250 mm is the maximum. Trussed rafters do not require a secondary structure. The roof elements can be laid directly on the trussed rafters, although it is quite usual to add counter battens to support the remainder of the roof construction.

Roof trusses and trussed rafters for duopitch or monopitch roofs are mainly used in conjunction with panel construction, i.e. when a lining is affixed to the underside of the roof structure. The roof spaces of roofs built with trussed rafters cannot be used, or at best only to a very limited extent. Roof trusses can be designed to span between the outer walls, or may be additionally supported on intermediate, loadbearing internal walls.
Fig. b321 shows the structural system of roof trusses and trussed rafters.

Construction

In recent years, trusses connected with nails or punched metal plate fasteners have proved to be the most popular solutions for



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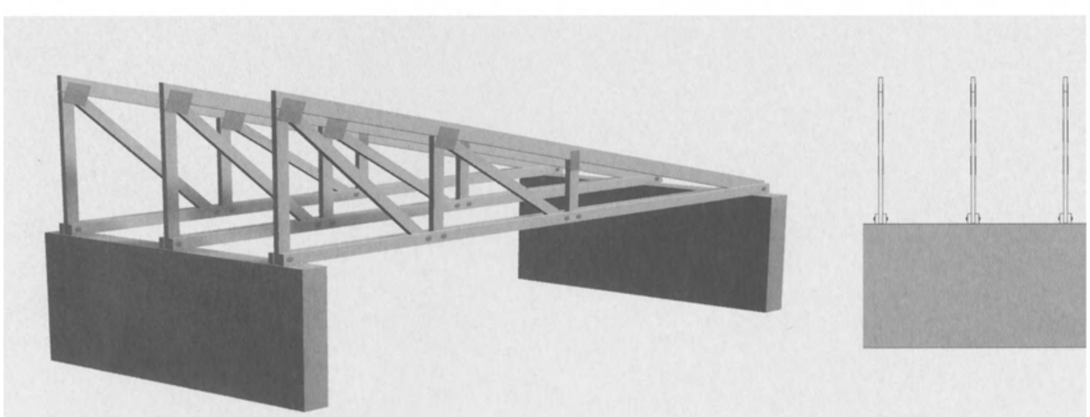
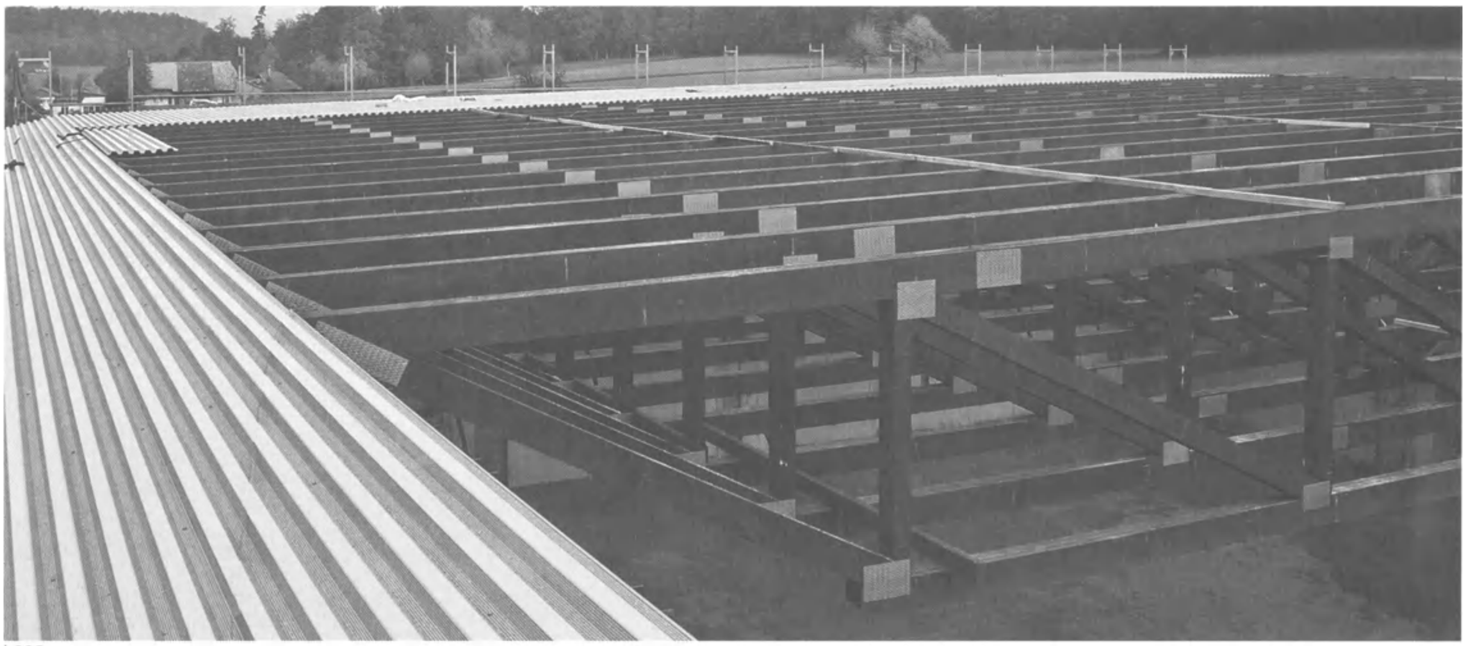


b322

b321 Structural system of roof truss: all trussed rafter

b322 Roof trusses for a monopitch roof



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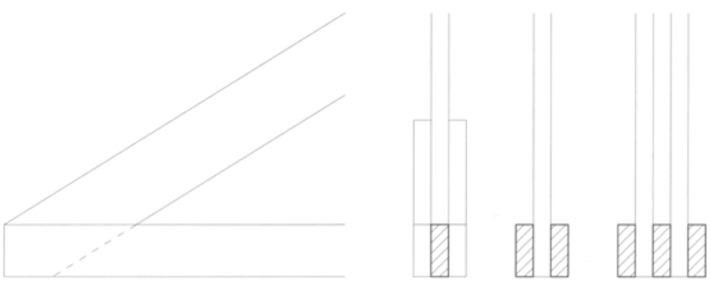

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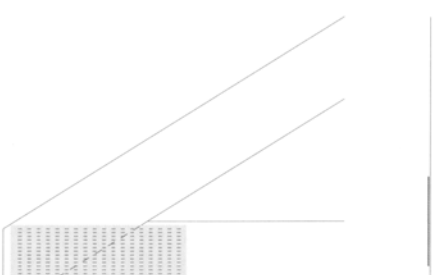

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both roof trusses and trussed rafters. There are also roof truss systems available with thin plates let into the timber members that are connected with nails or screws driven straight through the plates or through predrilled holes. Nailed trusses can be produced on the premises of any timber building company. We distinguish here between connections in single, double, and multiple shear. Trusses connected with punched metal plate fasteners, on the other hand, are particular products produced by companies with special facilities. The 1–2 mm thick punched metal plate fasteners are pressed into the timber. Also available are lattice beams, box beams, I-beams, and T-beams with glued connections, which have proved their worth in practice over many years.
See chapter e2 for the names and addresses of manufacturers and institutes.

b323 Flat roof with trusses connected using punched metal plate fasteners

b324 Nailed truss: connections in double and multiple shear

b325 Truss with punched metal plate fasteners

b9 Roof structures

b9 70 Roof systems with primary and secondary structures

The form of construction in which the primary structure is placed on a regular grid (spacing 4 to 7 m, possibly up to 10 m) is frequently used for shed structures of all kinds that involve a longer span, and it can also prove economical for residential, commercial, and office buildings. The primary structure, usually spanning across the width of the building, supports the secondary structure, which consists of solid timber or glulam purlins, or even lattice beams, depending on the spacing of the primary structure. The spacing of the purlins is 1.0 to 2.5 m depending on the type of roof construction. This secondary structure (purlins, roof elements)


b334


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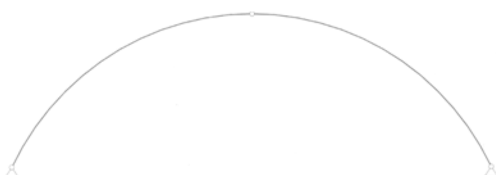
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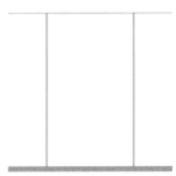
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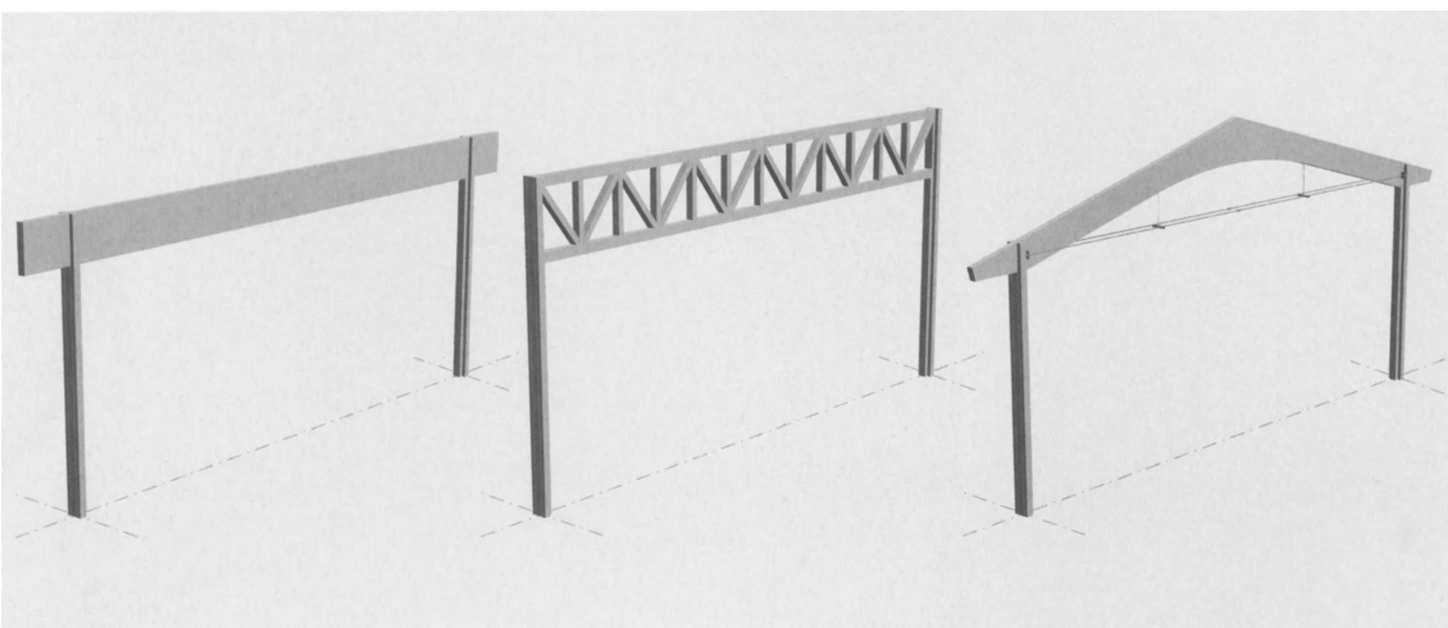
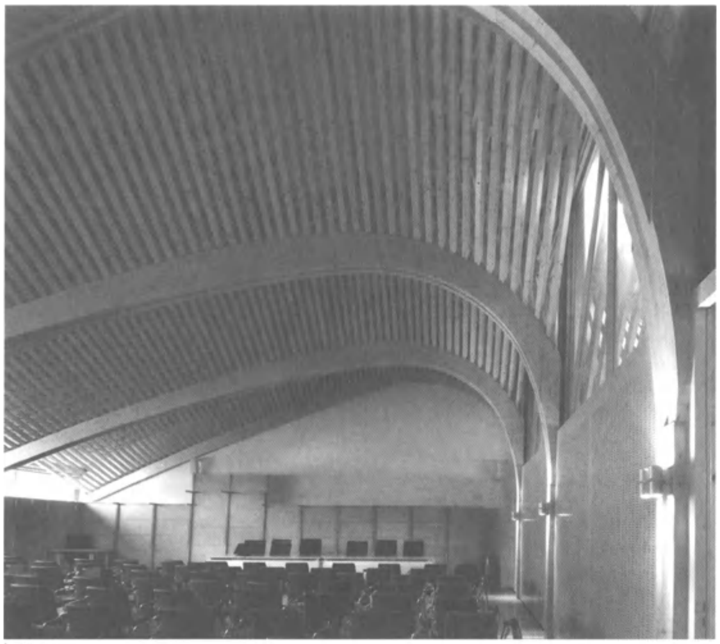

b328 b329 b330

b326 and b327 Structural system of three-pin arched roof (section and elevation), primary and secondary structures

b328 to b333 Overview of primary structures
b328 Solid-web beam
b329 Lattice beam
b330 Two-pin rafter with (or without) tie

b331 Three-pin rafter with tie
b332 Three-pin portal frame
b333 Three-pin arch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therefore runs parallel with the eaves. Architectural, constructional, and practical reasons usually dictate that both the primary and secondary structure remain visible internally. Larger areas, too, can therefore be roofed over with exposed roof structures but without intervening posts or columns. Another advantage is that the area between the primary structure members remains readily


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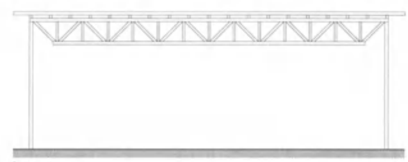
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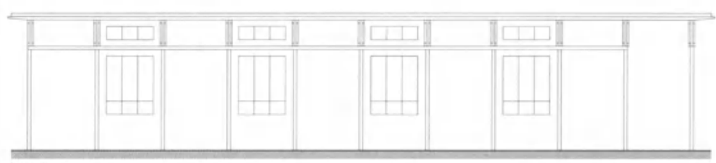
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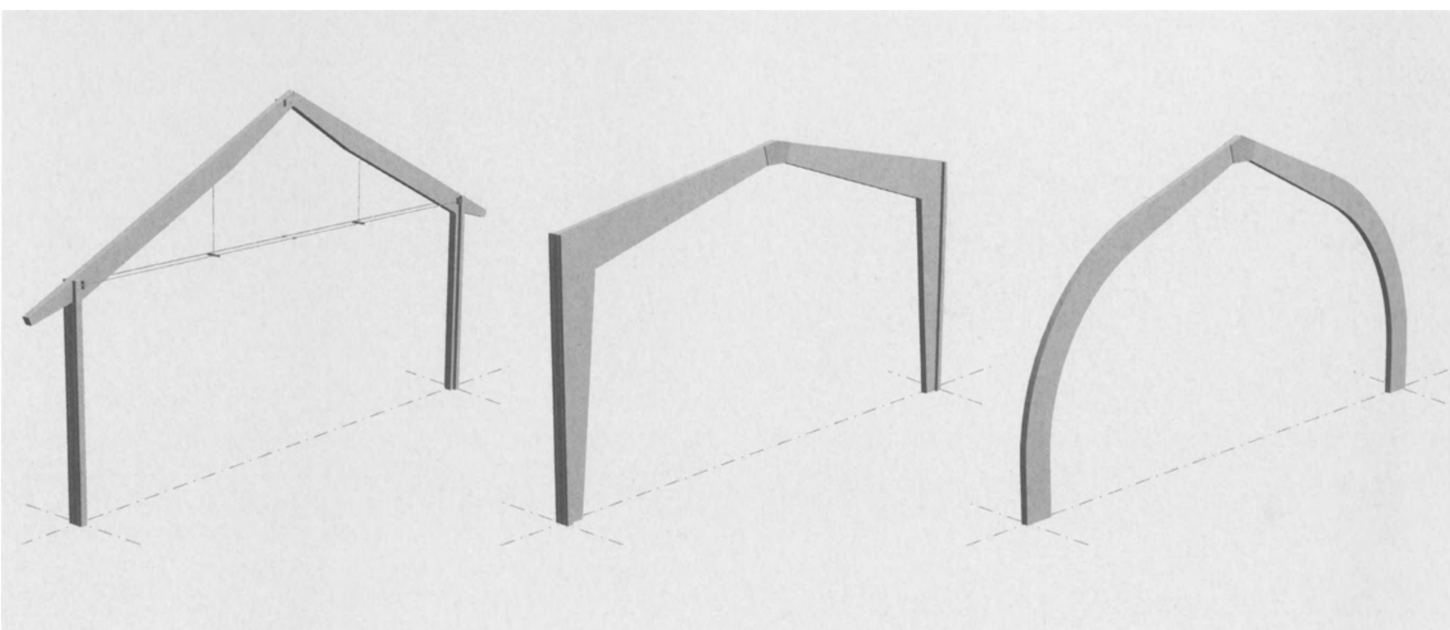
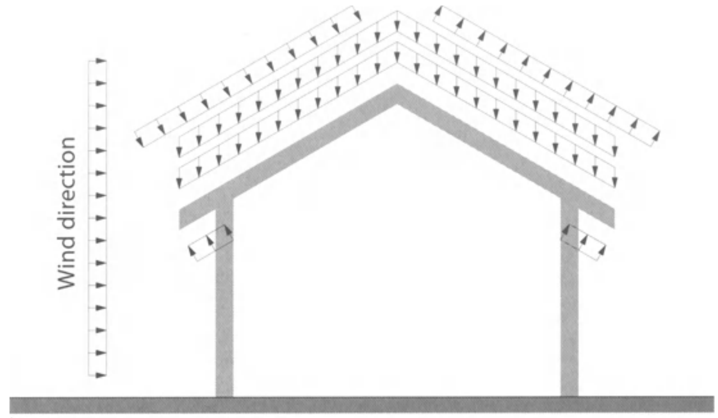

b331 b332 b333

b334 Motorway service depot with straight beams
b335 Indoor swimming pool with three-pin rafters and tie
b336 and b337 Roof structures with curved beams
b336 Assembly hall with asymmetric arched beams
b337 Assembly hall with arched beams

b338 and b339 Arrangement of lattice beams and purlins for a flat roof

b9 Roof structures



b340

accessible and therefore can be used for routing building services. Depending on the nature and the use of the building, it is also possible to attach a soffit to the underside of the roof construction.

Numerous types of construction are available for the building and structural design; Figs. b328 to b333 show a small selection. For more information, please consult the *Timber Construction Manual* [18], which deals with this theme in great detail.

b9 80 Structural engineering

b9 81 General

Like every loadbearing structure, the roof construction has to satisfy two principal requirements: ultimate load capacity and serviceability; the former requires verification of sufficient load-carrying capacity with an adequate factor of safety, the latter ensures that the construction remains usable when subjected to various actions. Criteria such as functionality, comfort, and appearance are most important for serviceability.

Simple roof structures such as purlin roofs can be designed on the basis of practical experience, by performing rough calculations, or by consulting prepared tables. If separate structural calculations are deemed unnecessary, the parties involved in the project must agree on who is responsible for structural and constructional matters. Structural calculations and proper design – coordinated with the structure as a whole – are, however, generally to be recommended.

The planning of the timber loadbearing structure is first of all a task dictated by the form of construction. The loadbearing structure is first conceived and then planned in detail. The sizes are either initially estimated or assigned preliminary dimensions obtained from tables.

Matters to be considered:
- Architectural and constructional considerations affecting the structural systems
- Availability of timber members with respect to length and cross-section
- Materials available
- Choice of structural system
- Construction considerations: off-site prefabrication of roof elements or assembly of individual pieces
- Transport and erection
- Arrangement and coordination of the functions and tasks of the building envelope
- Concepts (or at least detailed considerations) regarding the building physics: thermal performance, sound insulation, fire protection, moisture control (including weather protection), and airtightness
- Costs
- Fire protection regulations

Only after considering these planning steps is it possible to check the ultimate load capacity and the serviceability.

b9 82 Loading assumptions

Self-weight, dead loads, imposed loads, snow, and wind are in most cases the prevailing actions affecting a roof structure. Whereas the first four actions generate compressive forces, the action of the wind can lead to considerable uplift (tensile) forces. In order to avoid failure of the fixings and anchorages, appropriate design and construction is essential. Fig. b340 shows the actions affecting the roof schematically.

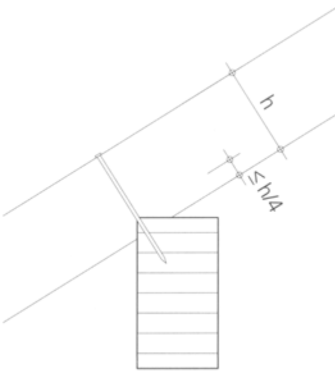
b9 83 Anchorage

Transferring forces through the roof and down to the supporting structure in small buildings is usually taken care of by the customary craftsmen-like details at junctions and connections involving distributed loads transferred via direct contact. In the case of uplift forces, however, great care is called for.
Tension-resistant connections are then required for all parts of the construction, i.e. a continuous chain of anchorage from roof covering to rafters, purlins, and posts, right down into the supporting construction. In particular, the overhangs at verge and eaves

b340 Schematic presentation of the loads to which a roof is subjected require sufficient anchorage against uplift. If roof plates or bracing in the plane of the roof are required for the stability of the building, these must be connected structurally to corresponding bracing elements in the plane of the walls independently of the anchorage.

The following types of connection can be considered for anchoring the rafters:
– nails, subjected to pull-out loads (Fig. b341)
– screws, subjected to pull-out loads (Fig. b342)
– sheet metal rafter brackets, nails subjected to shear (Fig. 343)

When using nails, square twisted or annular ringed shank nails are far superior to ordinary round wire nails because their loading capacity under the same conditions is two to three times higher. Purlins can be anchored with perforated sheet metal components, ties, steel components, or with the external sheathing materials. Rafters are notched where they are supported on the purlins. At intermediate purlins, but also in the case of longer overhangs at the eaves, such notches lead to a weakening of the cross-section in what is often the most heavily stressed zone. This is why some textbooks recommend nailing a cleat to the rafter instead of cutting a notch. This solution is, however, hardly used in practice. The reduction in work required compared with the use of a cleat more than makes up for the somewhat higher timber consumption. In addition, nailed-on cleats often disrupt the attachment of a soffit lining or its supporting framework in the roof space.



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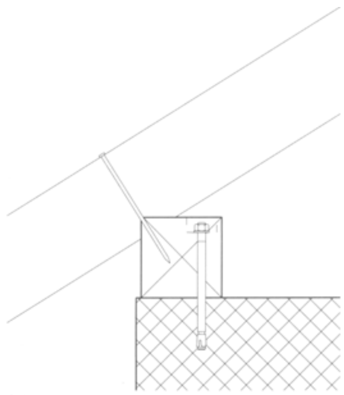
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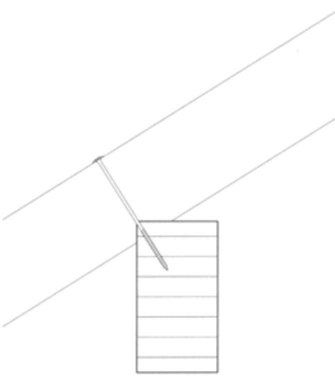
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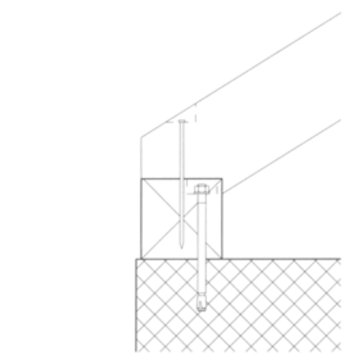
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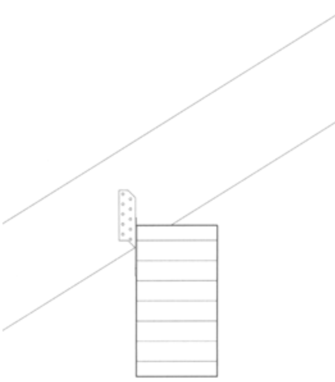
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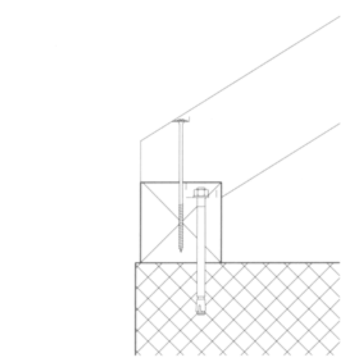
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b341 to b346 Various rafter fixings

b341 with nails
b342 with screws
b343 with sheet metal rafter brackets
b344 with nails (arrangement for continuous rafters)
b345 with nails (arrangement for non-continuous rafters, eaves constructed separately)
b346 with screws (arrangement for non-continuous rafters, eaves constructed separately)

b10 Suspended floor structures

b10 10 General, overview of systems

Suspended floors in timber, alongside those in steel and reinforced concrete, are one of the most common forms of construction used in the modern building industry. If the technical material properties of timber are exploited through proper design and construction, the advantages are obvious:
- Use of a natural building material
- Use of a sustainable building material
- Agreeable interior climate
- Diverse architectural design options
- Good ratio between self-weight and load-carrying capacity
- Fast, dry form of construction
- High off-site manufacturing depth possible
- No scaffolding or props required for erection
- Documentation available for building physics functions (fire resistance, sound insulation, thermal performance, etc.) – in the form of general information and data about specific products

We expect suspended floors to offer adequate load-carrying capacity with minimal deflection, high stiffness (little vibration), effective sound and thermal insulation properties, and the necessary fire resistance. As with the roof, several "layers" are necessary here in order to satisfy the various demands.

b347

b347 Suspended floor structures can be left exposed to create a significant architectural feature.

b348

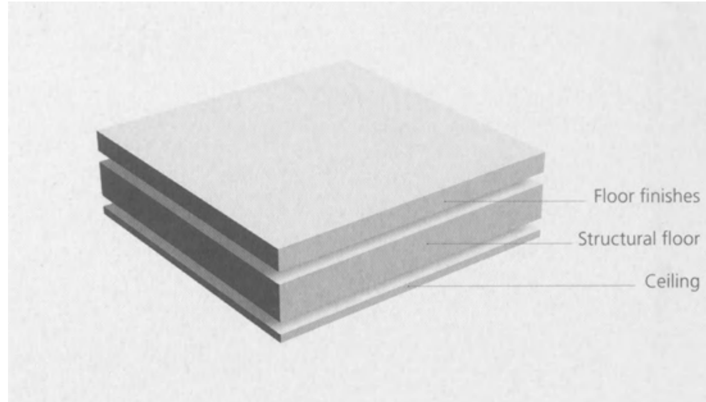
Owing to the form of construction, buildings constructed in timber above foundation level generally have timber suspended floors as well. Timber suspended floors are also frequently used in concrete or masonry buildings. The constructional and structural criteria are the same here as for timber structures, with the exception of the support and anchorage details.

b349

b348 Suspended floor structure left exposed

b349 Suspended floor structure concealed behind ceiling

b10 Suspended floor structures



b350

Overview of systems

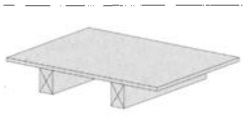
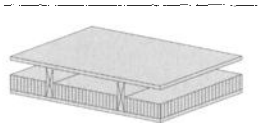
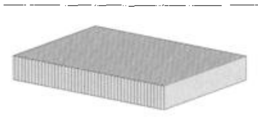
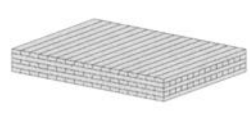
We distinguish between various types of timber suspended floor construction. In principle, suspended floors with good sound insulation properties and a good fire resistance consist of the following compatible layers: a structural floor (loadbearing construction), floor finishes (possibly including a subfloor), and a ceiling (Fig. b350). Whereas the structural floor construction is described in this chapter, the subfloor, floor finishes, and ceiling are dealt with in part c "Building envelope, walls, suspended floors", and in particular in chapter c7 "Suspended floors". Fig. b351 provides an overview of the structural floor constructions.

Structural floor constructions can be broken down into the following types (Fig. b351):
- Linear systems: timber joist floors, see b10 50 for details
- Timber composite systems: ribbed-panel and hollow-box floors, see b10 60 for details
- Solid timber systems: solid timber sections, see b10 70 for details
- Solid timber systems: board-type, glued floors, see b10 80 for details
- Timber-concrete composite floors, see b10 90 for details

b10 20 Structural engineering, loadbearing construction

As structural elements, suspended floor constructions have to accommodate various load actions. The self-weight of the floor tends to be only a minor factor here; it corresponds to the weight of the actual structural floor. Greater loads result from the dead load of the subfloor, floor finishes, and ceiling construction. In order to meet the sound and vibration requirements, heavyweight finishes are advantageous. Subfloors in the form of cement screeds or, if wet trades are undesirable, dry loose fill, dry sand, concrete flags or similar materials increase the dead loads considerably, but are useful when a high level of sound insulation is required. It is the imposed loads, however, that play the greatest role, and these can vary depending on the use of the building and even within a building. Imposed loads result from the use of the floor, persons, furniture and fittings, stored goods or materials, or even moving vehicles. In the case of housing, e.g. in accordance with Swiss standards, an imposed load of gk = 2.0 kN/m² (200 kg/m²) should be assumed. For offices this should be increased to gk = 3.0 kN/m² (300 kg/m²), and for places of assembly to gk = 4.0 kN/m². Lighter floor systems can mean a dead load of gk,a = 0.8 kN/m², but this can rise to 1.8 kN/m² for heavier systems.

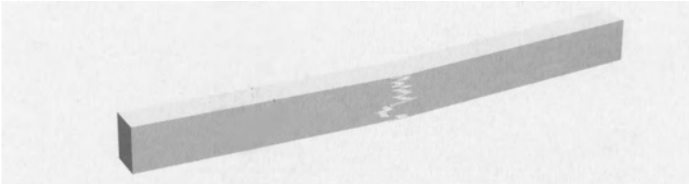
Suspended floors

Linear systems	**Timber composite systems**	**Solid timber systems**		**Timber-concrete composite systems**
joist floors beams trusses	ribbed-panel floors hollow-box floors	solid timber floors	board-type, glued floors	timber-concrete composite floors
				
exposed partly exposed clad	hollow box with/without insulation ribs	edge-fixed element glued laminated timber t. & g./loose t. solid timber joists solid timber joists	cross-laminated timber laminated veneer lumber (LVL) multi-ply boards panel elements	Composite action between: concrete & linear systems conc. & timber comp. systems conc. & solid timber systems

b351

b350 Technical make-up of suspended floor

b351 Overview of structural floors
Linear systems: timber joist floors, see b10 50 for details
Timber composite systems: ribbed-panel and hollow-box floors, see b10 60 for details
Solid timber systems: solid timber floors, see b10 70 for details
Solid timber systems: board-type, glued floors, see b10 80 for details
Timber-concrete composite floors, see b10 90 for details



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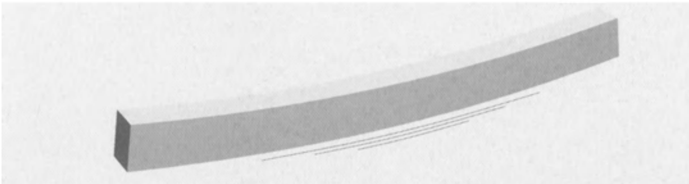


b353

In Switzerland, the actions on suspended floors are governed by SIA 261 "Actions on structures", in Germany by DIN 1055 "Actions on structures". Designs must comply with SIA 265 "Timber structures" in Switzerland, and DIN 1052 "Structural use of timber" in Germany.
Like every loadbearing structure, the suspended floor construction has to satisfy two principal requirements: ultimate load capacity and serviceability. The situations (loading cases) taken into consideration should allow for all conceivable conditions and effects that could occur during erection and use.

b10 21 Ultimate load capacity

The design should check the load-carrying capacity of the suspended floor construction loaded with all imposed loads (furniture, fittings, persons, etc.) (Fig. b352). The aim here is to prevent failure of a component or the collapse of the building.

b10 22 Serviceability

The serviceability check ensures that the construction remains usable (serviceable) when subjected to various actions. Criteria such as functionality, comfort, and appearance are critical for serviceability (Fig. b353). The design criteria for serviceability can be related to the following effects:
- Deformations (deflection) that impair the functionality, spoil the appearance or damage the interior fittings, or damage non-loadbearing components (max. permissible l/300 to l/500). For most building uses a maximum permissible deflection of l/500 (in special cases even less) is recommended.
- Vibrations that limit the functionality or impair the comfort of users or occupants. Basically, a natural frequency > 8 Hz should be aimed for.

It is recommended that these points (deformations and vibrations) be assessed together with an experienced structural engineer. Rigid loadbearing structures can be easily achieved if the right type of construction is chosen.
In addition, sealing or airtightness problems, or effects specific to the form of construction can impair the functionality, the appearance and the durability of the structure.
The serviceability should be checked for permanent and temporary usage conditions, and in certain cases for exceptional situations as well (e.g. earthquakes). We distinguish between two cases according to the possible consequences of the actions:
- action with irreversible consequences
- action with reversible consequences

The design figures for serviceability limits should be specified for every project according to SIA 260 "Basis of structural design" in Switzerland or DIN 1052 and DIN 1055-100 in Germany, generally depending on the usage requirements.

b10 23 Preliminary dimensions

Preliminary sizes for the cross-sections required for suspended floor structures can be obtained in various ways:
- with the help of rough calculations
- with the help of empirical values obtained through practice
- with the help of tables
- with the help of preliminary structural calculations

The rough calculations, empirical values, and tables mentioned below for determining sizes of sections are linked to certain conditions. They are generally only valid for uniformly distributed loads over the full length of the member (no point loads) and for structural timber of strength grade C24 or glued laminated timber grade GL24h which has achieved a stable moisture content corresponding to the type of use and is protected from the weather. The maximum permissible deflection for suspended floors in residential and office buildings is normally l/300 to l/500. As already mentioned, the deflection should be limited to $w \leq l/500$. If other requirements, heavy loads, or long spans are involved, the preliminary dimensions should be based on structural calculations.

Joist dimensions from rough calculations and empirical values

Rough calculations or empirical values can be used to establish preliminary dimensions and provide a rough check of simple joist sizes. In conventional housing, where a total load of 3.0 to 3.5 kN/m^2 is generally allowed for, the "formulas" below do not provide exact results; they must be seen merely as an approximation. These approximations can be used for uniformly distributed loads – i.e. no point loads – and are valid for joist spacings up to 700 mm. For higher loads, e.g. heavy floor finishes, or where the situation demands that deflection be minimised, structural

b352 Design for ultimate load capacity: failure is critical

b353 Design for serviceability: deformations are critical calculations will always be necessary. Vibrations are not taken into account in such rough calculations. Furthermore, these simple estimates originated at a time when deflection and stability requirements were different and may not meet today's demands or the levels of comfort we now expect. Those who want to remain well on the safe side should add 15 to 20% to the results of the calculations shown, or carry out proper structural calculations from the very start, which in the end are unavoidable anyway.

joist depth = span/20
joist width = joist depth/2
depth of support for joists = 0.7 x joist depth

Design using tables

A simple but accurate method of determining the floor member cross-sections is to use prepared tables. Once again, these tables are only valid for uniformly distributed loads, which, however, is the case for the majority of suspended floors. Timber joist floors and solid timber sections for spans between 3.00 and 6.00 m can be determined with the help of the tables in [16], which take account of different floor loads and usage categories. The manufacturers of suspended floor systems who offer semi-finished products often provide design tables for their products.

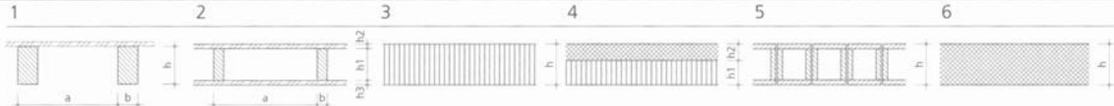
Fig. b354 (Preliminary design table for housing) shows a selection of suspended floor systems and compares the depths for different loads and spans for housing. The loads and spans for

b354 Suspended floor systems Preliminary design table for housing

Housing cat. A1 with q_k = 2.0 kN/m², light and heavy floors $g_{k,A}$, self-weight included, max. value for deflection w ≤ l/500

The table applies to simply supported beams carrying a uniformly distributed load.

Accurate analyses for ultimate load capacity and serviceability (especially vibrations) are indispensable.



Suspended floor system				1			2	3	4	5	6
	a (m) =			0.5	0.6	0.7	0.5				
Span l in m	4.0	$g_{k,A}$	0.8 kN/m²	100x 220	120x 220	120x 220	100, 27, 27	130	100, 80	140	200
		$g_{k,A}$	1.8 kN/m²	140x 220	120x 240	140x 240	120, 27, 27	150	100, 80	160	200
	5.0	$g_{k,A}$	0.8 kN/m²	140x 240	140x 260	120x 280	160, 27, 27	170	100, 80	180	200
		$g_{k,A}$	1.8 kN/m²	120x 280	160x 280	180x 280	180, 27, 27	180	100, 80	200	200
	6.0	$g_{k,A}$	0.8 kN/m²	100x 320	120x 320	140x 320	200, 27, 27	200	120, 100	220	220
		$g_{k,A}$	1.8 kN/m²	100x 360	120x 360	140x 360	240, 27, 27	220	120, 100	240	220
				Tabular values/dimensions in mm							
				1			2	3	4	5	6
	Explanations valid for tables b354 to b356			Timber joists grade C24/GL24 without a connection to upper sheathing. Possible section sizes for various joist spacings a: 0.5 m, 0.6 m, 0.7 m			Hollow-box floors with ribs of grade C24/GL24 glued to 27 mm 3-ply core plywood, rib width approx. 80 mm, rib spacing approx. 500 mm, large-format panels	Edge-fixed floor elements made from dowelled, nailed or glued sections, elements 1000 mm wide, joint details require special consideration.	Timber-concrete composite floor where the supporting timber (h1) in the form of edge-fixed floor elements is connected to the concrete topping (h2) via troughs and shear connectors. Troughs and shear connecter arrangement designed by timber engineering specialist.	Lignatur elements made from spruce/fir boards: Lignatur box elements (LKE) or Lignatur-panel elements (LFE).	Concrete floor: typical depths of concrete floors not including any pipes that may need to be laid in the floor and other specific details of reinforcement. Floors must be designed by a structural engineer.

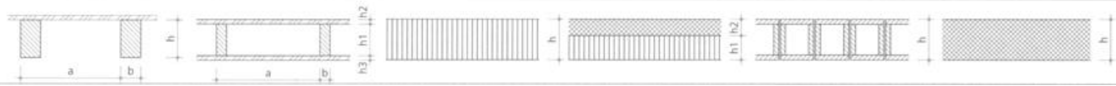
b354 Comparison of suspended floor systems (design dimensions), preliminary design table for housing, imposed load 2 kN/m²

b355 Suspended floor systems Preliminary design table for offices

Offices cat. B with q_k = 3.0 kN/m², light and heavy floors $g_{k,A}$, self-weight included, max. value for deflection w ≤ l/500

The table applies to simply supported beams carrying a uniformly distributed load.

Accurate analyses for ultimate load capacity and serviceability (especially vibrations) are indispensable



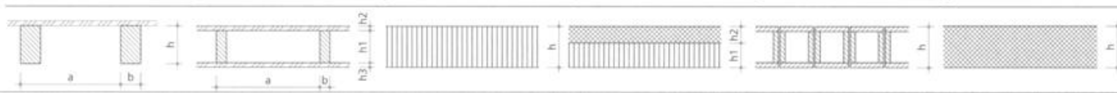
Suspended floor system			1			2	3	4	5	6
		a (m) =	0.5	0.6	0.7	0.5				
Span l in m	5.0	$g_{k,A}$ 0.8 kN/m²	140x 260	140x 280	160x 280	180, 27, 27	180	100, 80	200	200
		$g_{k,A}$ 1.8 kN/m²	160x 280	180x 280	140x 320	200, 27, 27	200	100, 80	220	200
	6.0	$g_{k,A}$ 0.8 kN/m²	200x 280	160x 320	200x 320	240, 27, 27	220	120, 100	240	220
		$g_{k,A}$ 1.8 kN/m²	180x 320	160x 360	180x 360	260, 27, 27	240	120, 100	280	250
	7.5	$g_{k,A}$ 0.8 kN/m²	180x 360	160x 400	180x 400	320, 27, 27	–	140, 140	320	250
		$g_{k,A}$ 1.8 kN/m²	160x 400	160x 440	180x 440	360, 27, 27	–	160, 140	–	250
			Tabular values/dimensions in mm							

b356 Suspended floor systems Preliminary design table for places of assembly

Places of assembly cat. C2 with q_k = 4.0 kN/m², light and heavy floors $g_{k,A}$, self-weight included, max. value for deflection w ≤ l/500

The table applies to simply supported beams carrying a uniformly distributed load.

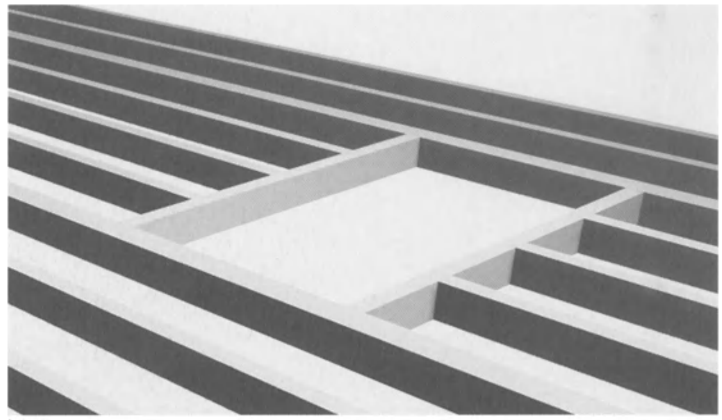
Accurate analyses for ultimate load capacity and serviceability (especially vibrations) are indispensable.



Suspended floor system			1			2	3	4	5	6
		a (m) =	0.5	0.6	0.7	0.5				
Span l in m	5.0	$g_{k,A}$ 0.8 kN/m²	160x 280	200x 280	160x 320	200, 27, 27	200	100, 80	220	200
		$g_{k,A}$ 1.8 kN/m²	200x 280	160x 320	180x 320	220, 27, 27	210	100, 80	240	200
	6.0	$g_{k,A}$ 0.8 kN/m²	200x 320	160x 360	180x 360	260, 27, 27	240	120, 100	280	220
		$g_{k,A}$ 1.8 kN/m²	160x 360	200x 360	160x 400	280, 27, 27	–	120, 100	320	250
	7.5	$g_{k,A}$ 0.8 kN/m²	180x 400	160x 440	180x 440	360, 27, 27	–	160, 140	–	250
		$g_{k,A}$ 1.8 kN/m²	160x 440	200x 440	180x 480	400, 27, 27	–	160, 140	–	250
			Tabular values/dimensions in mm							

b355 Comparison of suspended floor systems (design dimensions), preliminary design table for offices, imposed load 3 kN/m², for explanations see Fig. b354.

b356 Comparison of suspended floor systems (design dimensions), preliminary design table for places of assembly, imposed load 4 kN/m², for explanations see b354.



b357

offices and places of assembly are normally greater. The floor depths for these latter uses are given in Fig. b355 (preliminary design table for offices) and Fig. b356 (preliminary design table for places of assembly).

b10 30 Construction details

The advice given below concerns the design and construction of suspended floors in timber:
- It is advantageous to span the floors across the shorter distance.
- Floor systems continuing over two or more spans are more economical than simply supported floors.

However, the pros and cons should be weighed up in each case.

Advantages
- Reduced deflection
- Reduced timber consumption
- Faster erection
- Fewer on-site joints

Disadvantages
- The span for typical solid timber sections is about 5 to 6 m.
- Linear timber components (glued laminated timber, compound solid sections) are more readily obtainable but cost a little more than solid timber.
- Longer transport lengths, higher transport costs.
- Exposed timber joist floors with joists continuous over several rooms can be more difficult to arrange on plan.
- Continuous suspended floor constructions lead to undesirable sound and vibration transmissions from room to room.

Suspended floors can be planned according to the following scheme:
- Establish loading assumptions.
- Establish supports (downstand beams, loadbearing walls, columns).
- Select direction of span and structural system (simply supported or continuous).
- Determine requirements regarding sound insulation and fire resistance.
- Floor system exposed or concealed? Determine surface finishes and moisture content required.
- Select floor system.
- Determine perimeter details and clearance between perimeter members and walls.
- Establish layout of elements or joists.
- Determine trimming to stairs, chimney, and other floor penetrations/openings.
- Calculate floor cross-section.
- Calculate trimmers.
- Design construction details.

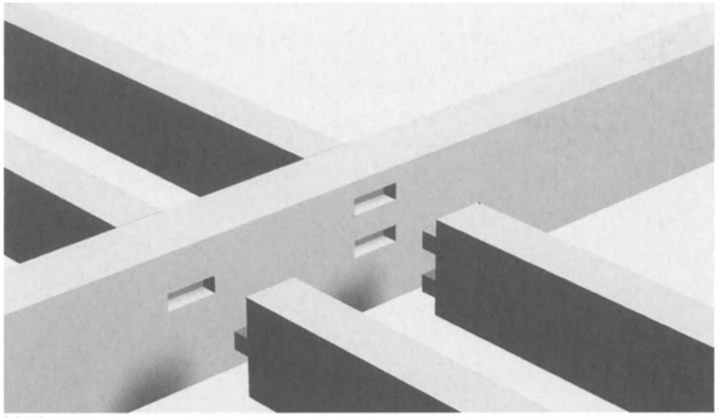
b10 31 Trimming

In most cases suspended floors covering larger areas will include penetrations or openings; stairs, chimneys, and installation ducts will need to be accommodated. When considering the trimming around such interruptions, structural considerations and fire resistance requirements will need to be taken into account as well. It should be remembered that trimmed openings and penetrations will result in higher loads for some timber components (e.g. joists). A trimmer joist transfers its loads to the next continuous joist or floor element (Fig. b357), which means that these have to carry point loads (which can be considerable depending on the particular situation) in addition to the uniformly distributed load. Such additional loads need to be considered in the structural calculations for the elements, trimmers, joists, and beams.

b10 32 Connections

Wood joints are usually sufficient for suspended floors with normal spans and normal loads. Indeed, mortise and tenon joints are still a customary way of transferring the loads in timber joist floors. However, modern suspended floors have to satisfy more stringent demands: higher loads and considerably longer spans, multi-storey forms of construction, and new fire protection regulations all contribute to wood joints being gradually replaced by mechanical fasteners in combination with sheet metal components, at all connections and junctions. This is essential for suspended floors that must satisfy fire resistance stipulations. From the structural viewpoint, cutting and notching beams and joists for wood joints weakens the cross-section – a fact that must be taken into consideration. This is another reason for choosing

b357 Trimming around a floor opening in a timber joist floor



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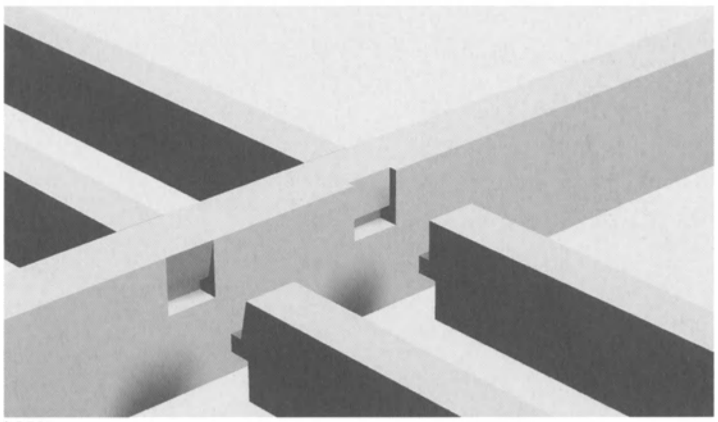

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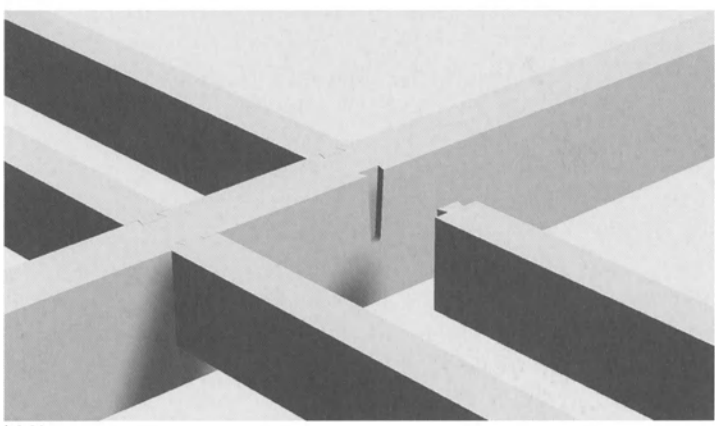

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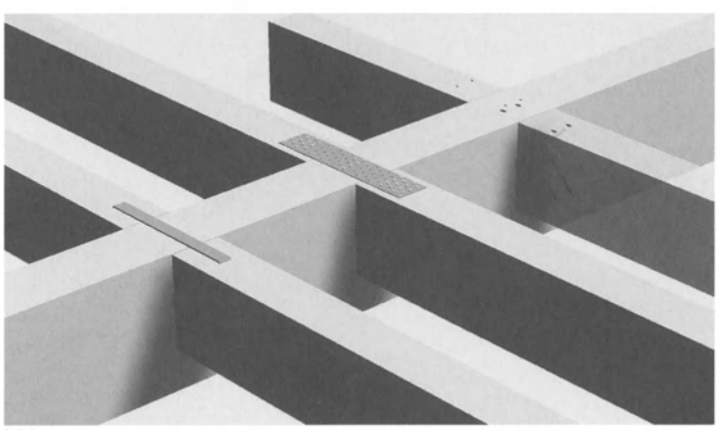


b361

b358 to b361 Wood joints
b358 Stub tenon joint, double stub tenon joint
b359 Haunched stub tenon with sloping haunch, haunched stub tenon with straight haunch
b360 Dovetail housing joint
b361 Mortise and tenon joints secured with plates let into the timber or screws

mechanical fasteners – because they generally do not result in a significant reduction in the timber cross-section.

Wood joints

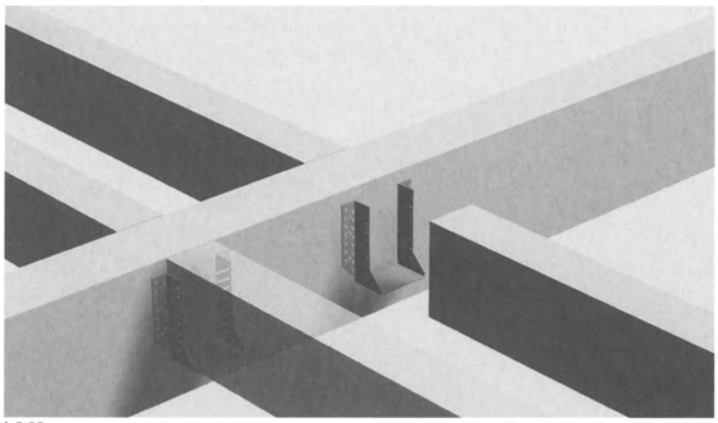
Connections between beams, joists, ribs, and trimmers carrying low loads can be achieved with mortise and tenon joints or dovetail housing joints. But when higher loads are involved, mechanical fasteners should be used.

Various types of mortise and tenon joint can be used, the most popular being the stub tenon (Fig. b358, left).

The haunched stub tenon with straight haunch (Fig. b359, right) includes a 10–20 mm deep housing above the mortise which limits the rotation of the incoming joist. The weakening of the cross-section due to this housing must be considered in the same way as for the actual mortise. The use of a haunched stub tenon with sloping haunch (Fig. b359, left) minimises the reduction in the cross-section.

Compared to the normal stub tenon, however, the haunched stub tenon does not result in any increase in the load-carrying capacity. A better load-carrying capacity can be achieved with a double stub tenon (Fig. b358, right), which is used with deep joist sections.

Mortise and tenon joints should be secured at trimmers with cramps or other steel components let into the timber (Fig. b361). If the timber is to remain exposed in the finished building, the mortises are cut 10 mm narrower so that shrinkage and swelling effects can be accommodated without the mortise becoming apparent. Since the emergence of multi-axis assembly plants, dovetail housing joints (Fig. b360) are being used more and more. The accurately cut dovetail achieves a marginally higher loadbearing capacity and enables simple assembly on site.



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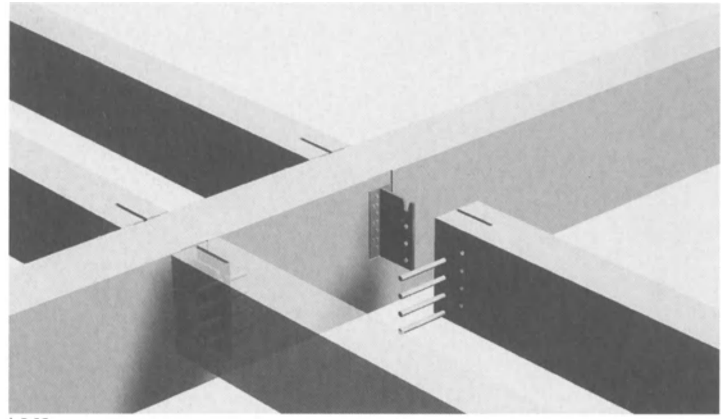

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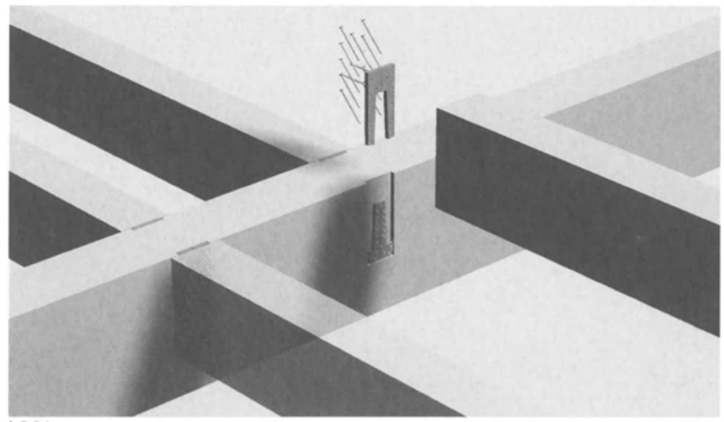

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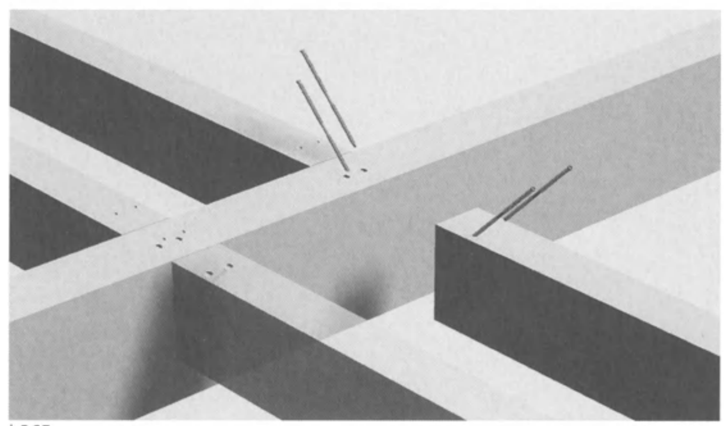

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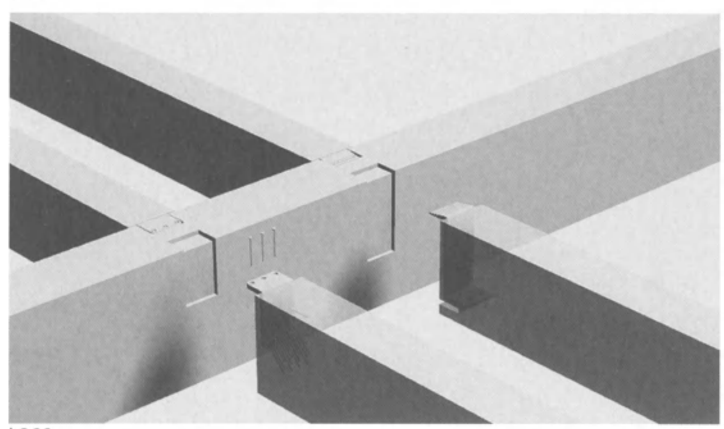


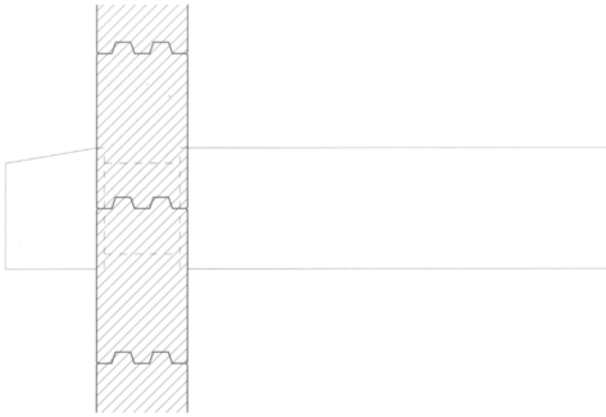
b366

Mechanical fasteners

There is usually a clear limit to the loadbearing capacity of wood joints. Mechanical fasteners can accommodate higher loads, and many different connectors are available on the market. The most common products in use are sheet metal components in the form of joist hangers, T-sections, or concealed joist hangers. Figs. b362 to b366 illustrate various options.

Many mechanical fasteners are easy to attach and do not result in a weakening of the timber cross-section. If a timber floor is to remain exposed in the finished building, the fasteners will need to be chosen accordingly, depending on the architectural demands.

b362 to b366 Mechanical fasteners
b362 Joist hanger
b363 T-section with close-tolerance pins
b364 Concealed joist hanger (e.g. ATF, BMF, ET)
b365 Special screws (e.g. SFS, WT)
b366 Special angle and Z-section hangers (e.g. Bozet, EL, Janebo, Induo).



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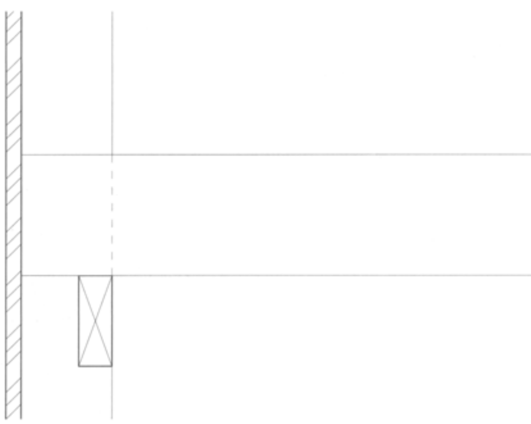

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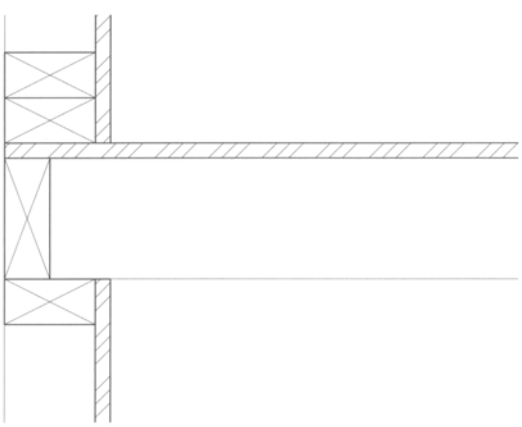

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b367 to b375 Various floor support details at external wall
b367 Log construction
b368 Timber-frame construction
b369 Balloon frame, stud construction
b370 Panel construction

b10 33 Support details

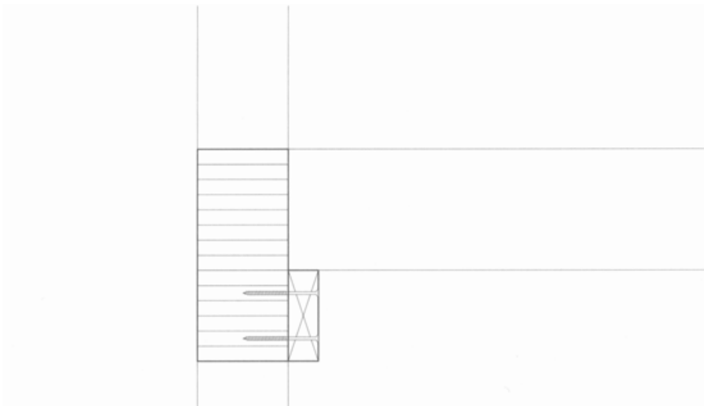
How the suspended floor is supported will depend on the timber building system because wall constructions, as well as floor constructions, are not all the same. Different support details and wall systems are described in the chapters on the building systems: b3 "Log construction", b4 "Timber-frame construction", b5 "Balloon frame, platform frame", b6 "Panel construction", b7 "Frame construction", b8 "Solid timber construction", and b11 "Multi-storey timber buildings". Fire protection requirements may result in special demands, e.g. at the junction with a fire compartment wall (fire resistance classification REI 180 or REI 90), but also if the suspended floor itself has to achieve a certain fire resistance.

In log construction (Fig. b367) the joists are notched on all sides and cantilever beyond the external wall. In timber-frame construction (Fig. b368) the joists are positioned between top and bottom plates and secured with hardwood pegs. The upper storey is anchored using steel mechanical fasteners or by using continuous external sheathing. In the balloon frame and stud construction (Fig. b369) each joist is nailed to a stud to prevent lateral buckling. The vertical load transfer is by way of direct bearing, wood on wood (i.e. perpendicular to the grain).

In panel construction (Fig. b370) the perimeter joist acts as a tension or compression flange for the whole floor plate. Here again, the vertical load transfer is by way of direct bearing, wood on wood (i.e. perpendicular to the grain). In frame construction the floor joists either bear directly on the primary structure or on ledger strips (Fig. b371), in either case secured with mechanical fasteners. And in solid timber construction the suspended floors bear directly on the walls and are provided with a shear-resistant connection (Fig. b374). The floor supports in multi-storey construction play a key role. It is important here to eliminate, or at least minimise, the influence the floors have on the settling allowance, so that there are no disadvantages. Various design principles for this are described in chapter b11. Figs. b372 and b375 illustrate two possible support details.

b10 Suspended floor structures


b373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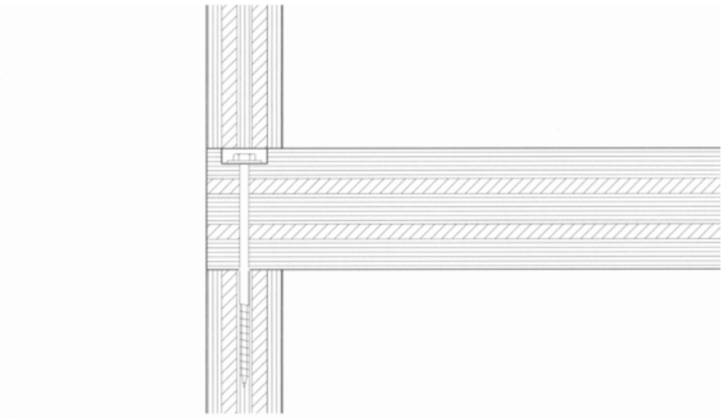
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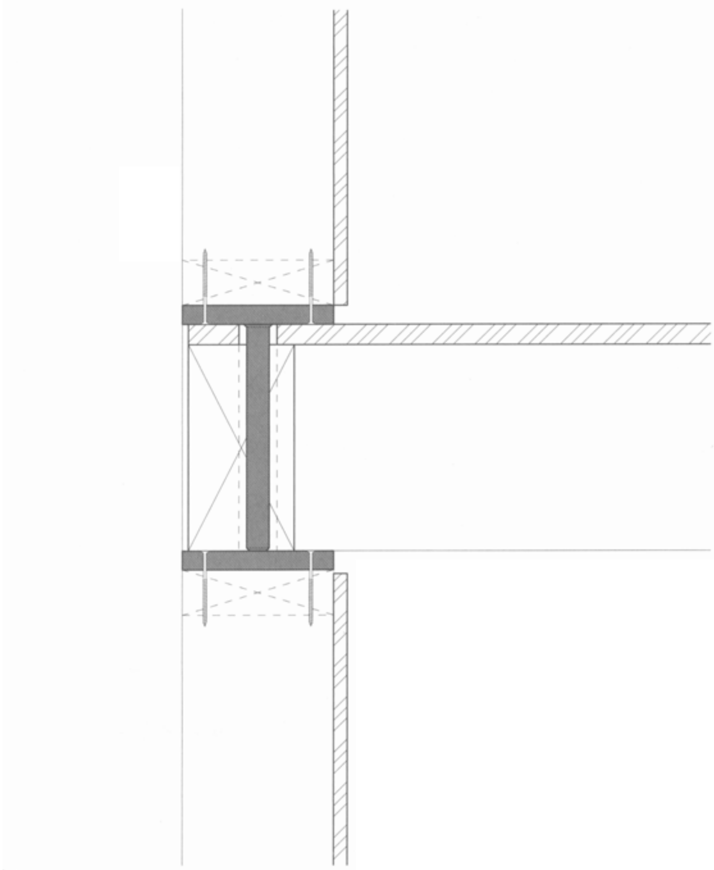
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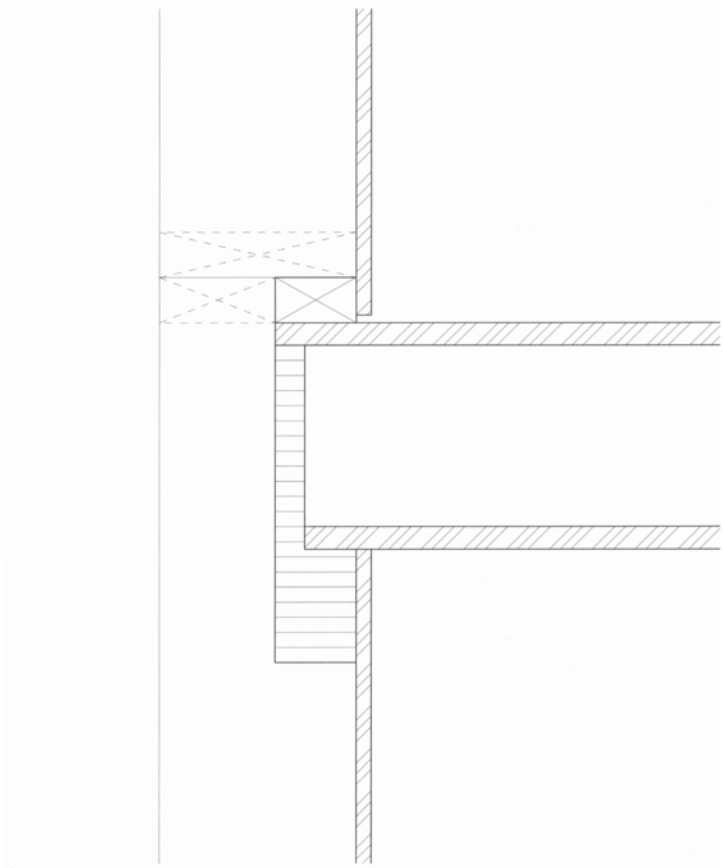
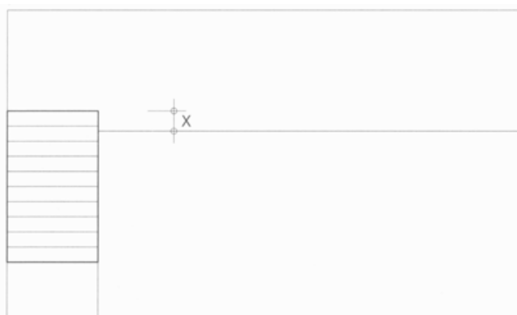

b375

b371 Frame construction
b372 and b375 Multi-storey timber structures
b373 and 374 Solid timber construction



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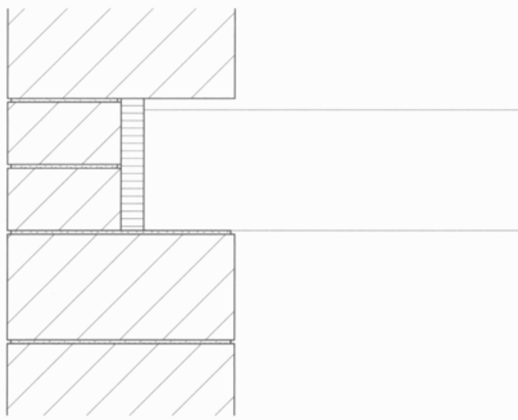

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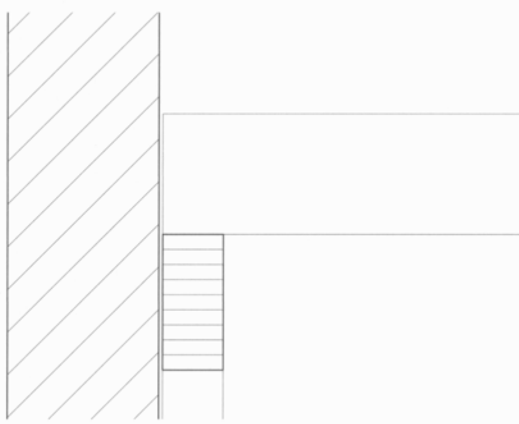

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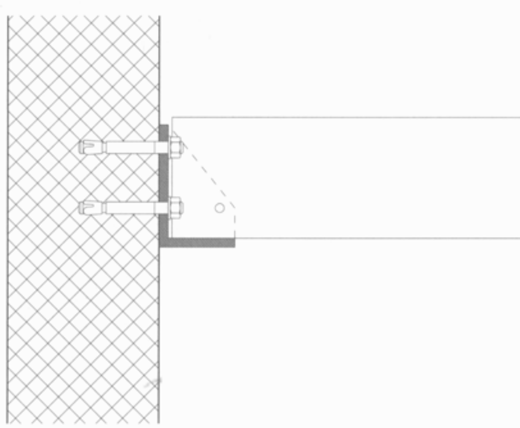


b379

When joists or beams are notched at the support, this reduces the bending capacity of the member. Such notches must be considered in the structural calculations. Constructional measures may be necessary in order to prevent splintering of the wood (Fig. b376).

When joists are supported on masonry or concrete, a damp proof course must be included to prevent rising damp. And the ends of the joists must be insulated at supports on external walls. This requirement is usually already fulfilled in the case of double-leaf masonry or masonry with external insulation. If timber is installed with a moisture content higher than the equilibrium moisture content that will ensue over time in the finished building, ventilation must be ensured so that the timber can dry out (Fig. b377).
A timber joist floor can be supported on a fire compartment wall (fire resistance classification REI 180) by using a trimmer or perimeter beam (Fig. b378), or a steel angle (Fig. b379). Figs. b381 to b383 show simple connection options at transverse beams.

Further factors to be considered:
- Different settling allowances (shrinkage).
- Shear transfer from upper to lower wall – taking account of the element fixings required if the suspended floor is required to act as a plate.
- Securing deeper joists or ribbed-panel floors against lateral buckling, also taking into account shear forces due to bracing effects.
- Structural calculations (also in case of fire) for support details involving profiled downstand beams or ledger strips.
- Compensating for a weakening of the cross-section by notches in the vicinity of the support by way of strengthening (see [18], p. 100).
- Protecting the timber against rising damp by means of a damp proof course when supported on masonry or concrete.
- Continuous layers of insulation are desirable, continuous or sealed airtight membranes are obligatory.
- Sound insulation requirements must be satisfied at the supports as well.
- Timber installed with a moisture content higher than the equilibrium moisture content that will ensue over time in the finished building will require ventilation so that it can dry out.

b376 End support for timber joist; notches (x) require special constructional measures to prevent splintering of the wood.

b377 Joists supported on masonry or concrete, with damp proof course, thermal insulation, and ventilation gap

b378 Junction with masonry or concrete wall, support in the form of a separate timber member

b379 Junction with masonry or concrete wall, support in the form of a steel shelf angle

b10 Suspended floor structures

b380

b10 40 Technical materials requirements

The principal task of a suspended floor structure is to carry the loads (dead loads, imposed loads) acting upon it. In doing so, the joists and beams are subjected to bending and shear. Strength and deformability are therefore the main criteria when selecting the materials and performing the calculations. Added to these are further factors such as durability, appearance, workability, and fire resistance.

b10 41 Moisture content

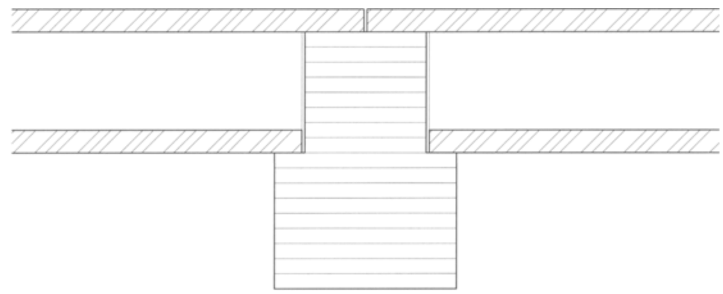
The moisture content of the timber has a considerable influence on the strength, deflection, dimensional stability, and durability of timber and wood-based products. The moisture contents for various components as specified in the standards are given in chapter d1 "Moisture content".

Here is a summary of the requirements for suspended floors:

a) In unheated interiors

The equilibrium moisture content to be expected is about 12 to 18%.

- If drying-out is guaranteed and both the anticipated deformation of the cross-sections as well as larger shrinkage fissures can be tolerated, the moisture content during installation should not exceed 25%.
- If timber is installed while damp and is loaded during the drying-out phase (e.g. floor constructions with a higher weight per unit area), greater creep deformations can be expected.
- Where structural timber has to satisfy particular deflection and dimensional stability requirements, a moisture content of 18% should be the target during installation, and should never exceed 20%.
- Changes in the moisture content (shrinkage and swelling) should be allowed for by including expansion joints.



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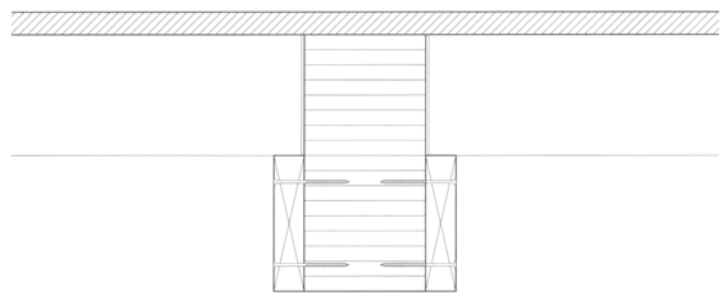

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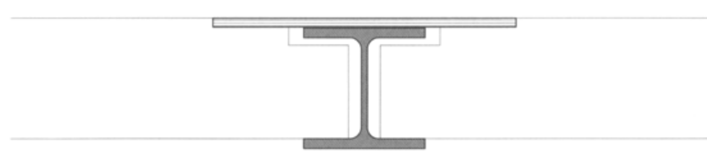


b383

b380 to b383 Support at transverse beam
b380 Supported on downstand beam
b381 Glued laminated timber beam in inverted T-form
b382 Supported on glued ledger strips (screws apply pressure during gluing only)
b383 Notched to fit steel I-beam

b) In heated interiors with the loadbearing construction clad
The equilibrium moisture content to be expected is 6 to 12%.
In addition to a), take account of the following:

- The moisture content of timber installed within the thermal insulation layer may not exceed 16% at the time of being enclosed on all sides.
- Owing to the lower equilibrium moisture content, the deformation to be expected with timber installed damp is greater than that in unheated interiors. In particular, beams that penetrate the building envelope must be sealed airtight, i.e. dry timber is essential.
- Where structural timber for joist floors is installed in dry interiors, an average moisture content of 12 to 15% should be the target during installation, and it should never exceed 17%.
- In the case of heavily loaded structures or special constructional requirements (e.g. multi-storey construction), the moisture content at the time of installation must be determined specially.

c) In heated interiors with the loadbearing construction left exposed
The equilibrium moisture content to be expected is 6 to 12%.
In addition to a) and b), take account of the following:

- With exposed timber joist floors in particular, the requirements regarding dimensional stability are high. An average moisture content of 12% is recommended for timber joist floors during installation (see chapter d1 "Moisture content").
- Further criteria such as the surface properties, surface finishes, and grading according to quality classes (appearance grading) must be considered for exposed timber joist floors (see chapter a4 "Material").

d) Planar suspended floor structures
Pre-dried timber components are essential for industrially produced suspended floor structures. On leaving the production plant, the components should have a maximum moisture content of 8 to 12%. The elements are therefore already at the level of the equilibrium moisture content for dry, heated interiors and therefore must be protected against dampness and precipitation during transport and erection. In order to accommodate any dimensional changes caused by moisture (which can range from negligible to severe depending on the particular flooring system), expansion joints are required in both the width and the length.

b10 42 Conversion

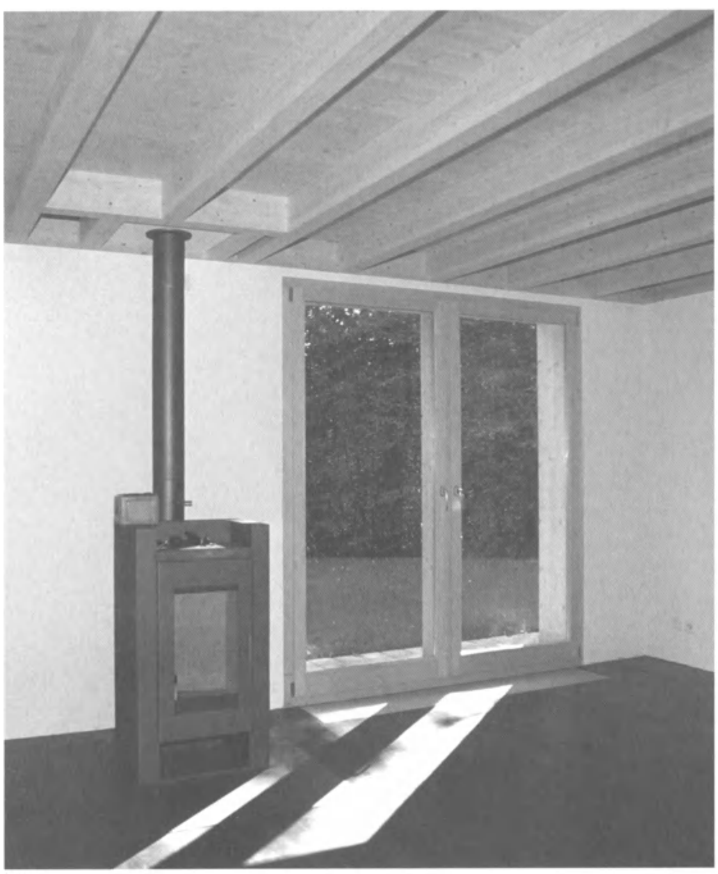
According to both SIA 265 and DIN 1052, timber of strength grade C24 or higher should be used for loadbearing components, provided drawings and specification do not specify otherwise. What this means is that pith is only allowed to a limited extent in strength grade C24. Narrow, deep sections are more economic than square sections for timber joist floors and the ribs of floor panels. In the case of solid timber containing pith, the wastage from a circular log for rectangular sections in the ratio w : h = 1 : 2 is not greater than that for square timbers. Therefore, various reasons make it preferable to use heart pieces for timber joist floors rather than boxed heart pieces. And indeed, only heart pieces can be considered for exposed constructions, in fact only non-heart timber in special circumstances.

b10 Suspended floor structures

b10 50 Timber joist floors

Timber joist floors are made up of linear components (joists) plus a structural sheathing that forms the base of the floor construction itself. The joists themselves are usually of solid timber or glued laminated timber. This traditional form of construction has proven worthwhile over the centuries and is still used for new buildings.

Advantages
- Inexpensive, well known
- Easily adapted to various levels of loading and building physics functions (fire resistance, sound insulation)
- Low self-weight
- Highly flexible in terms of fitting out and choice of materials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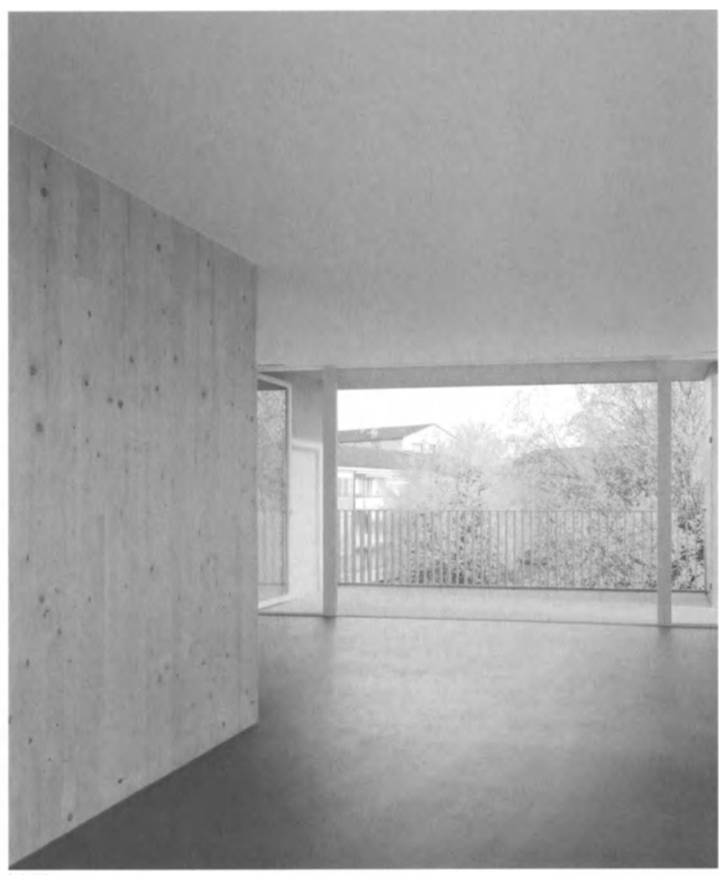
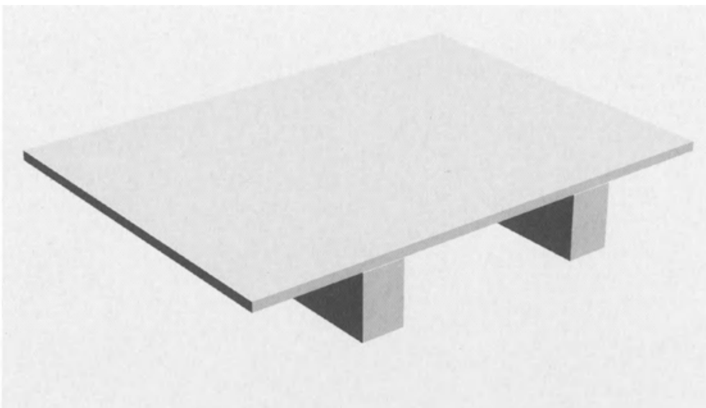

b385

b384 When a timber joist floor is to be left exposed, higher standards regarding appearance and moisture content apply. The timber is graded according to both appearance classes and strength classes.

b385 Timber joist floors not left exposed are graded according to strength classes only, and the provisions regarding timber moisture content apply accordingly.

Disadvantages
- Considerable structural depth required
- Limited range of solid timber sections available: max. depth of solid sections is 240 to 280 mm, joist sections with a depth more than 2.5 times the width must be secured against lateral buckling, glued laminated timber or some other compound section must be used for longer or larger sections.
- Lengthy erection time

Timber joist floors can be left (partly) exposed or concealed behind a ceiling. The options are shown in Figs. b386 to b388. The floor finishes and ceilings are described in chapter c7.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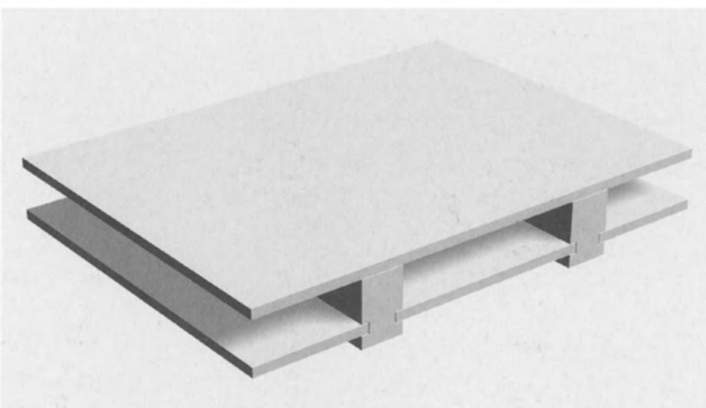
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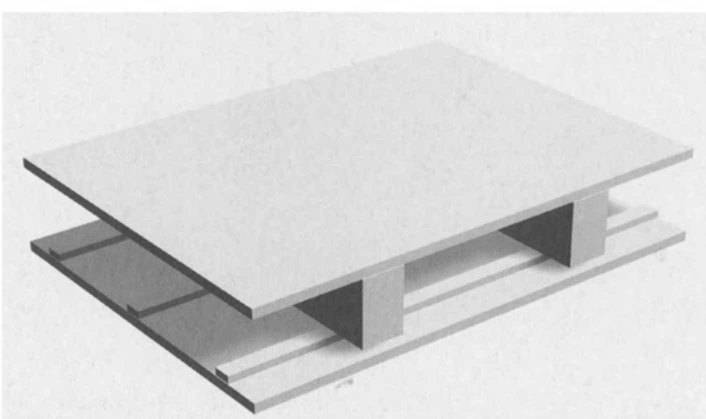

b388

b386 to b388 Overview of timber joist floors
b386 Joists exposed
b387 Joists partly exposed
b388 Joists concealed

b10 60 Ribbed-panel and hollow-box floors

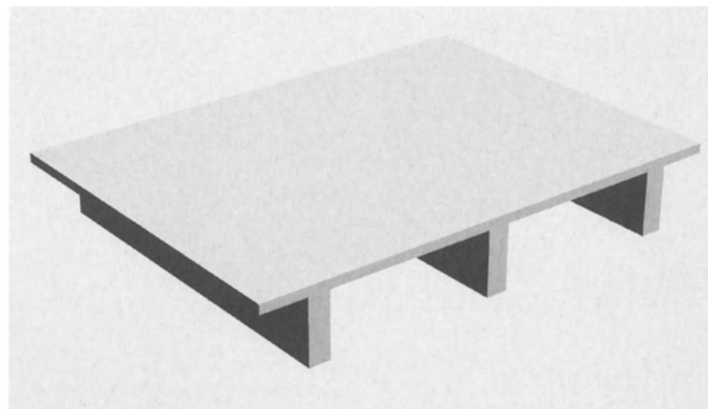
Ribbed-panel and hollow-box floors utilise the planar sheathing on one or both sides of the ribs to create a structural cross-section. To ensure a shear-resistant connection between sheathing and ribs, they are glued together in an industrial process or by using adhesive plus screws (the screws are required to apply pressure only as the adhesive sets, they are not required for structural purposes). In the case of ribbed-panel floors, the sheathing is attached only above or below the ribs, whereas hollow-box floors have sheathing on both sides. The remainder of the floor finishes are placed directly on the upper layer of sheathing (or ribs), the soffit sheathing (or ribs) can remain exposed or be concealed behind some form of soffit.

Advantages
- Low structural depth
- Interesting loadbearing behaviour because both the linear members and the planar sheathing can be taken into account in calculations
- Factory production
- Low self-weight
- Fast erection
- Bottom sheathing can be used as a soffit
- Industrially prefabricated products are available with exact details of loadbearing behaviour, fire resistance, and sound insulation.

Disadvantages
- Division into prefabricated elements can be difficult with some plan layouts
- Choice of system, fabrication, and erection must be considered in the planning, manufacturing, and erection procedures, although this should actually be regarded as an advantage

b10 61 Specific features

The ribs must be planed, straight, right-angled, and kiln-dried. Basically, compound cross-sections are desirable as solid timber sections seldom meet all these requirements. Unless specified otherwise, the strength grade must be C24 or higher. The moisture content during gluing should not exceed 12%. Sheathing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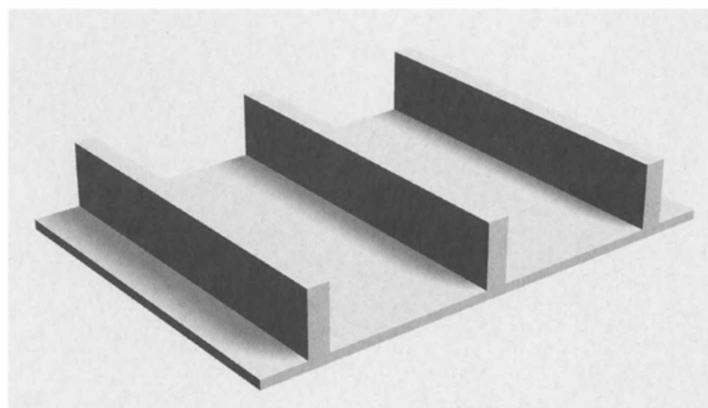
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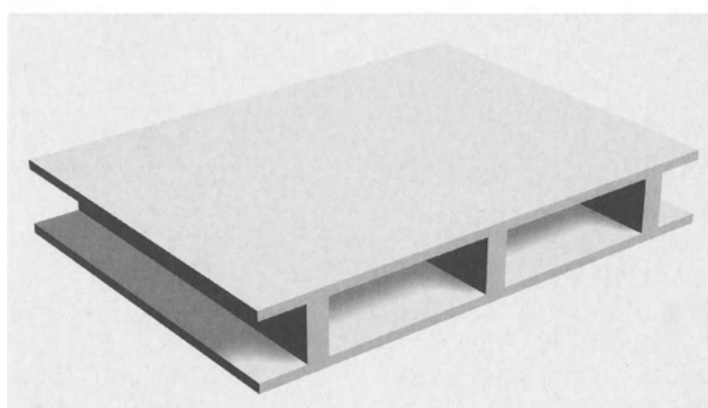
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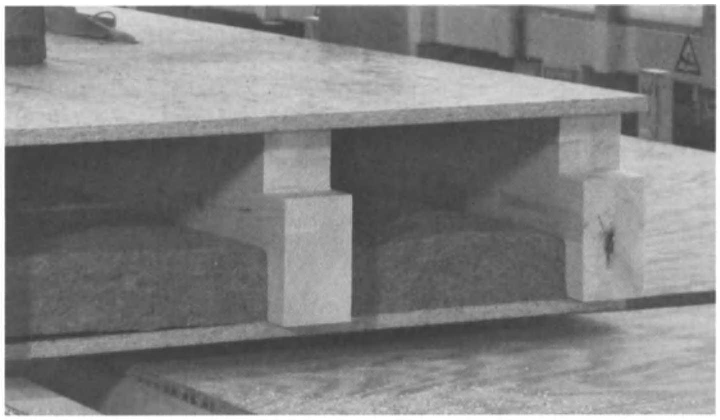
b389 to 391 and b393 Overview of ribbed-panel and hollow-box floors
b389 Ribbed-panel floor with structural sheathing fixed on top
b390 Ribbed-panel floor with structural sheathing fixed underneath
b391 Hollow-box floor



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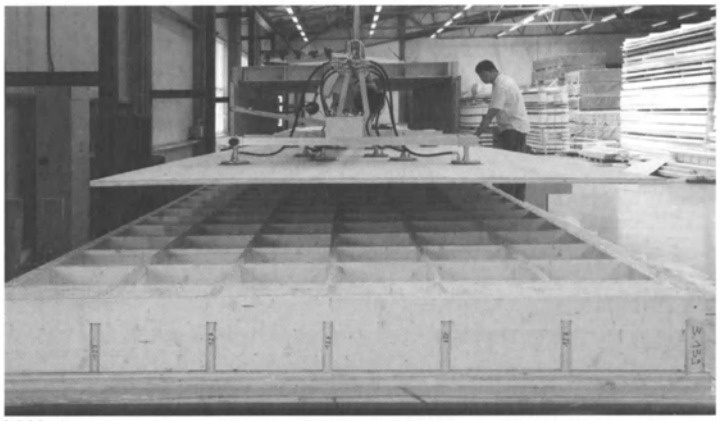

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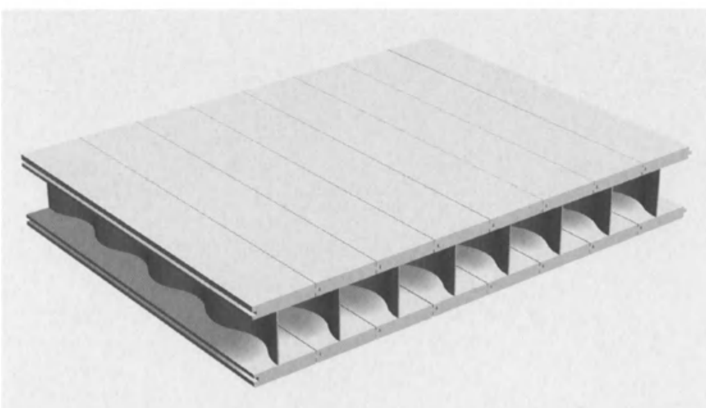


b393

materials must satisfy the same requirements. Wood-based board products such as 3-ply core plywood or laminated veneer lumber (e.g. Kerto-Q) are commonly used. Sanded flakeboard (e.g. OSB) may also be used provided the structural requirements are taken into account as such boards have a lower load-carrying capacity. During gluing, the difference in the moisture content of the different materials may not exceed 2%.

b10 62 Gluing

The adhesive bond between the sheathing (wood-based product) and the rib creates a shear-resistant connection between the two. The instructions and specification of the adhesive manufacturer must always be followed. When using nails or screws to apply pressure until the adhesive sets, the adhesive must be suitable for such applications.

The most important aspects during gluing:

- A licensed operator.
- Clean, dust-free mating faces.
- A minimum temperature of 20°C for timber, adhesive, and the ambient temperature (18° in exceptional circumstances).
- The necessary pressure during gluing must be ensured by wood screws (with shank), ordinary round wire nails, or annular ringed shank nails.
- The size, shaft length, diameter, and pitch of the screws or nails must comply with the structural requirements and the thickness of the sheathing.
- The pot-life (working time) of the adhesive must not be exceeded.
- The quantity of adhesive applied must comply with the instructions of the adhesive manufacturer.
- Production and storage free from all vibration is essential.
- The pressure and curing times as specified by the adhesive manufacturer and the supplier of the individual products must be adhered to.

b10 63 Specific systems

There is a host of highly diverse products on the market. All these products are produced by specific companies and marketed under specific product names, but they are all essentially hollow-box floors. Each manufacturer can specify certain loading capacities, sound insulation values, and fire resistances for their products. In addition, various surface profiles are available that can have a positive influence on room acoustics.

See chapter e2 for the names and addresses of manufacturers and institutes.

b392 Prefabrication of hollow-box floors
392-1 Production of Novatop Elements: hollow-box flooring system with webs in two directions
b393 Suspended floor system: Wellsteg cellular elements, various types available

b10 70 Solid timber floors made from solid timber sections

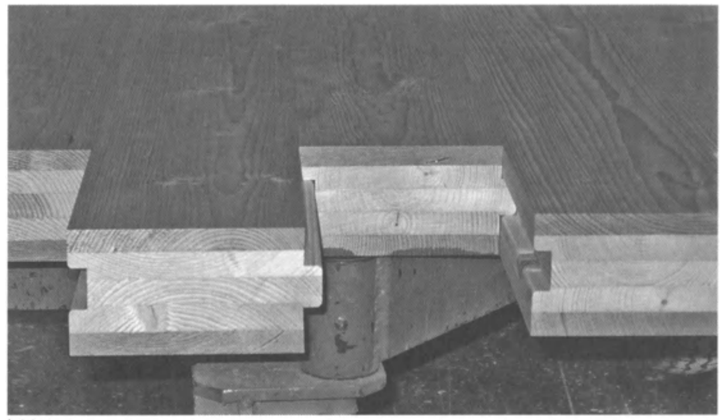
Solid timber floors can be made from solid timber sections, laminations, or glued laminated timber sections assembled to form planar components. Solid timber sections or individual glulam sections can be butt-jointed together, but are mostly fabricated with tongue and groove profiles. The pieces are delivered to the building site separately for connection piece by piece to form a solid timber floor. Edge-fixed timber floor elements are made from individual laminations placed on edge and fixed together in the factory with nails or dowels to form prefabricated elements, which are then joined together using special connectors. Glued laminated timber floors are very similar, consisting of glulam sections up to about 600 mm wide that are joined together to create a planar suspended floor.

Advantages
- Low structural depth.
- Fast erection.
- A floor construction that can be used and loaded immediately.
- Prefabrication possible.
- Underside of floor can be left exposed.
- Advantageous interior climate thanks to high proportion of timber.
- Even without further insulation, the sound insulation is higher than a timber joist floor owing to the greater weight per unit area.

Disadvantages
- High shrinkage and swelling effects must be taken into account.
- High timber consumption.
- In comparison to the high timber consumption, the load-carrying capacity is only moderate.

b10 71 Solid timber floor with tongue and groove, glulam floor

Such floors make use of profiled solid timber sections with double tongue and groove (Fig. b396) and also profiled glued laminated timber sections (Figs. b394 and b397). Many of the sections used for these floors are indeed glued compound sections in themselves. The glulam sections are wider than the solid timber sections, which means that floors can be completed faster on-site.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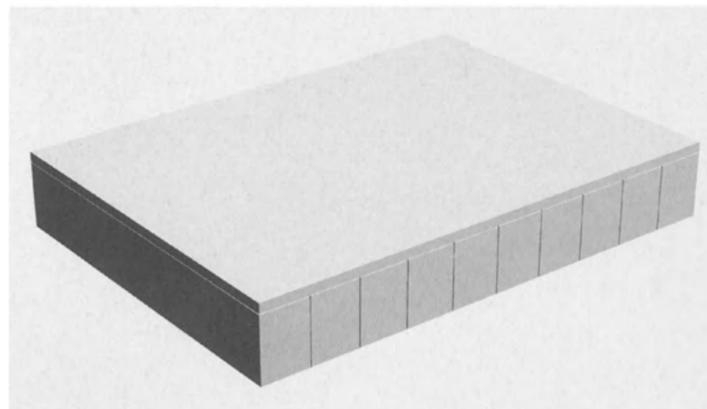
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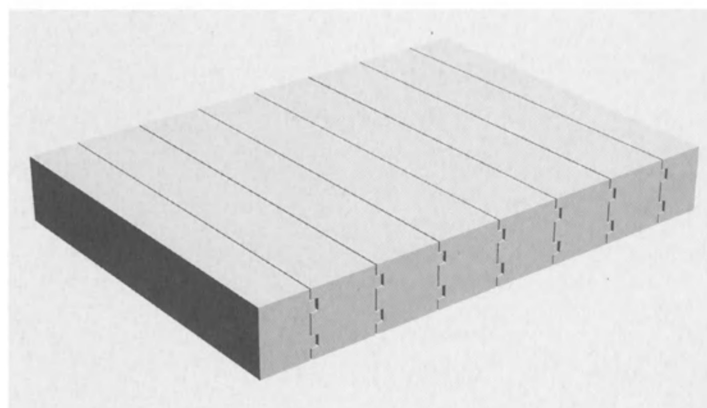
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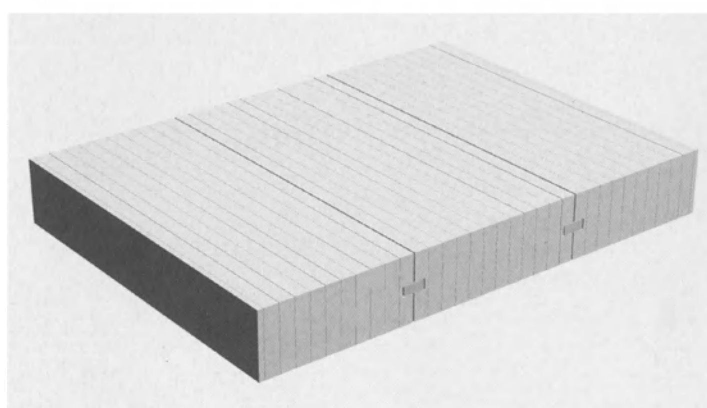
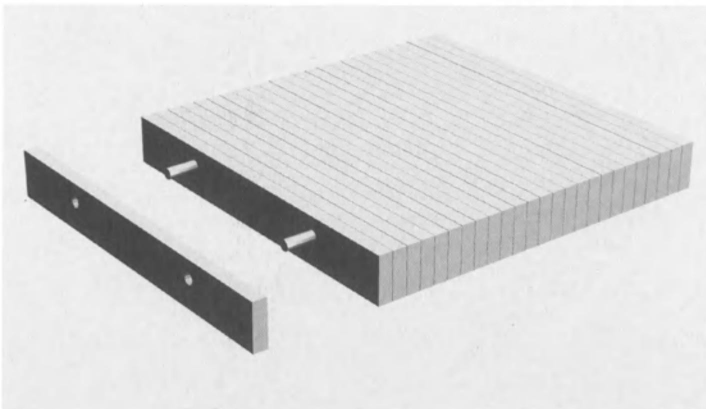

b397

b394 to b400 Overview of solid timber floors, solid timber sections
b394 Glued laminated timber sections
b395 Butt-jointed solid timber joists
b396 Solid timber joists with double tongue and groove, glued, joists laid horizontally
b397 Laminations on edge, glued, with loose tongue joint

b398



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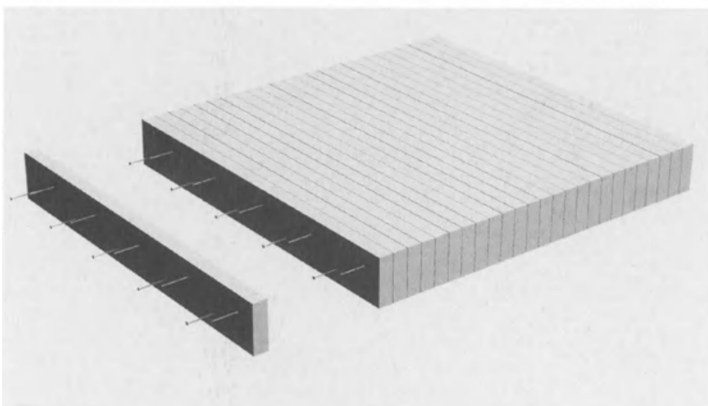


b400

b10 72 Edge-fixed floor elements

The edge-fixed elements are made from "stacks" of 20–50 mm thick timber laminations placed on edge. We distinguish between dowelled (Fig. b399) and nailed (Fig. b400) systems. The nails or dowels connecting the laminations transfer the shear forces in the transverse direction and ensure that concentrated loads are distributed. Connections between individual edge-fixed floor elements with a width of up to 3.50 m (consider transport) and a thickness of 80 to 240 mm must also be capable of transmitting shear forces. Various manufacturers produce tried-and-tested systems using various forms of construction. The edge-fixed element belongs to the solid timber construction category, which is described in chapter b8, where the reader will find further information about edge-fixed elements.

Surface finish, acoustic properties

Thanks to different surface finishes on the soffits of edge-fixed floor elements, they can satisfy many different requirements. Specific profiling can have a direct influence on the room acoustics, but can also be used as an architectural feature.

See chapter e2 for the names and addresses of manufacturers and institutes.

b10 73 Solid timber floors with transverse prestress

The Swiss Federal Institute of Technology in Zurich has developed a transverse prestressing technique using round steel bars for special applications where high point loads have to be carried, e.g. in bridges. Edge-fixed elements, solid-timber joists, and glued laminated timber joists are suitable for this treatment. The transverse prestressing enables loads to be distributed across the width of the unit, i.e. transverse to the normal loadbearing direction; this increases the effective width and hence reduces the depth of floor required.

b398 Edge-fixed floor elements, view of soffit
b399 Edge-fixed floor element, dowelled
b400 Edge-fixed floor element, nailed

b10 80 Solid timber floors made from board-type, glued elements

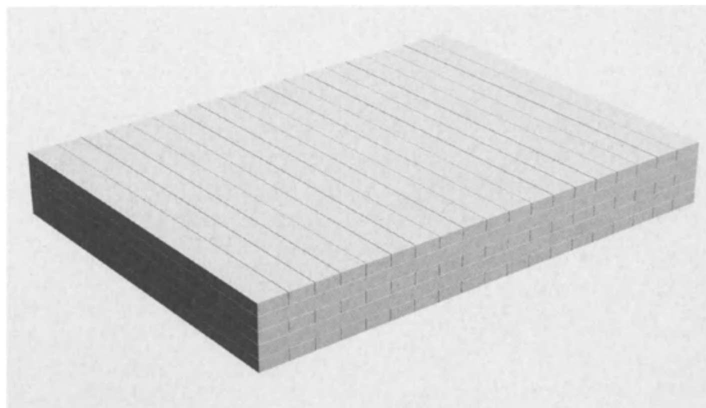
Board-type, glued floors comprise cross-banded or parallel board or veneer plies made up into floor elements.

Advantages
- Low structural depth.
- Some systems (Figs. b401 and b402) can carry loads in two directions, although we do distinguish between a primary and a secondary loadbearing direction.
- Fast erection.
- A floor construction that can be used and loaded immediately.
- The shrinkage and swelling effects in the plane of the floor are negligible in cross-banded systems.
- Prefabrication of large-format elements.
- Without further insulation, the sound insulation is higher than a timber joist floor owing to the greater weight per unit area.

Disadvantages
- Higher shrinkage and swelling effects in non-cross-banded systems must be taken into account.
- High timber consumption.
- In comparison to the high timber consumption, the load-carrying capacity of cross-banded systems is only moderate.

b10 81 Cross-laminated timber

Cross-laminated timber consists of several plies of cross-banded, glued planks with a moisture content of 10 to 12%. Thanks to the multi-ply, cross-banded lay-up, which always comprises an odd number of plies, the shrinkage and swelling effects are reduced to a minimum. Even large-format elements therefore exhibit excellent dimensional stability. The plies are 20 to 60 mm thick. Depending on the structural depth required, three, five, seven, nine or even more plies are glued together to produce a floor depth of 500 mm. Cross-laminated timber elements are generally supplied in widths of max. 2 m or max. 2.5 m, depending on the manufacturer. Wider formats are possible but the transport possibilities must be checked. Just like solid timber floors (see b10 70), cross-laminated timber elements can be supplied with surface finishes for exposed or concealed applications. Cross-laminated tim-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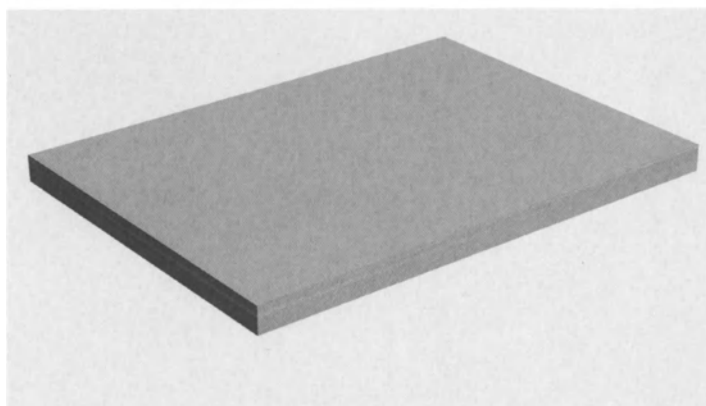
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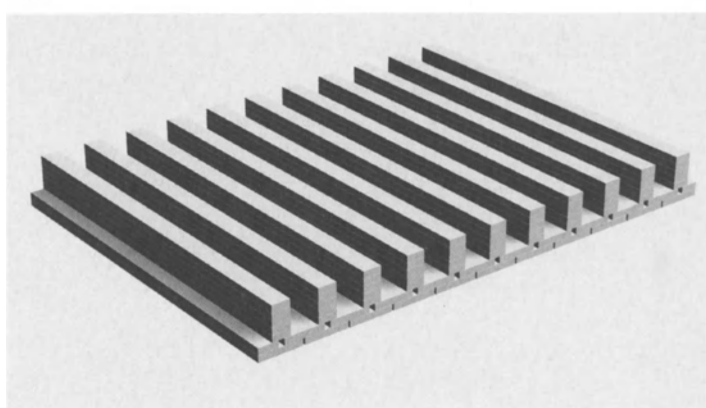
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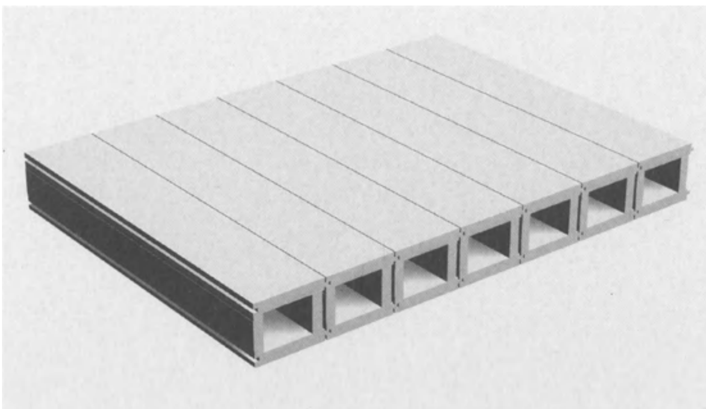
b401 to b404 Overview of solid timber floors, board-type, glued floors
b401 Cross-laminated timber
b402 Laminated veneer lumber (LVL)
b403 Suspended floor system: Lignotrend, various types available



b404

ber belongs to the solid timber construction category, which is described in chapter b8, where the reader will find further information about cross-laminated timber.

See chapter e2 for the names and addresses of manufacturers and institutes.

b10 82 Laminated veneer lumber (LVL)

In contrast to cross-laminated timber, laminated veneer lumber is made from veneer plies about 3 mm thick. These thin plies mean that many are needed and this results in a homogeneous and dimensionally stable cross-section.

Laminated veneer lumber, in contrast to the other products described here, is not actually used in the sense of a suspended floor structure. This material requires a loadbearing structure of linear members at a spacing of about 2 m transverse to the main loadbearing direction. Laminated veneer lumber is, however, ideally suited to the highly stressed flanges and laminations of hollow-box beams and for additional layers and plates requiring high tensile, compressive, and transverse tensile strength. Bracing a floor plate with laminated veneer lumber is unproblematic, even if there are high shear forces in the plane of the floor. The standard surface finish of laminated veneer lumber is unsanded spruce veneers that exhibit a dark scarf joint at regular intervals. Light-coloured, glued scarf joints are possible on request, likewise selected face veneers and boards sanded one or both sides (note delivery times).

b404 Suspended floor system: Lignatur box or panel elements, various types available

The well-known Kerto-Q product can be supplied in widths up to 2.50 m and lengths up to 23 m (although 12 m is the normal limit).

b10 83 Specific systems

Specific, plate-type, glued floor constructions are available which differ considerably from the standard forms of construction. These products are produced by certain companies and marketed under specific product names. The multi-ply glued products have a closed soffit but contain voids. Apart from their high load-carrying capacity, these elements are characterised by the ease of routing building services and their good sound insulation properties, especially when they are filled with loose ballast. Various different types of soffit finish are also available.

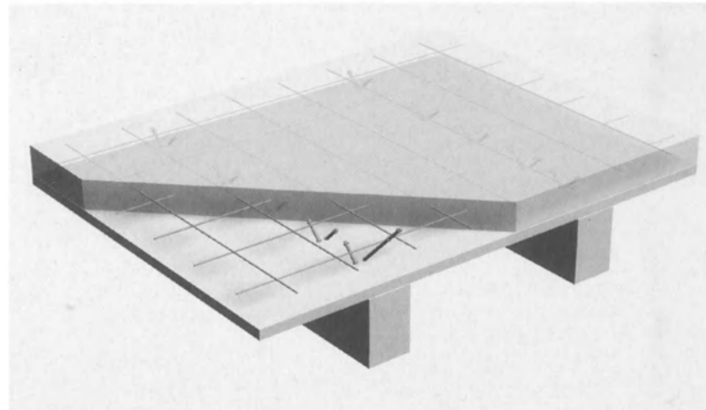
See chapter e2 for the names and addresses of manufacturers and institutes.

b10 90 Timber-concrete composite floors

For heavy loads, longer spans and wherever an especially stiff construction plus good sound insulation and high fire resistance are required, timber-concrete composite floors represent an interesting and economic alternative to pure timber or pure reinforced concrete floors. Timber-concrete composite floors consist of timber elements with a topping of reinforced concrete joined by shear connectors.
Various forms of construction can be used for the loadbearing timber construction: linear members, e.g. glued laminated timber, compound sections, solid timber sections, (Figs. b405 and b406), or planar members, e.g. edge-fixed elements (Figs. b407 and b408), and even board-type, glued products.

Various forms of fastener can be used to create the shear-resistant connection between the timber and the concrete, e.g. screws, anchor bolts, or steel dowels. The shear transfer can also be improved with troughs and anchors or oblique dado joints. Section b10 92 "Shear connectors" describes these in detail. The concrete topping is usually 60 to 160 mm thick; this thickness depends on the compressive forces to be resisted in the total suspended floor construction, any building services that may need to be laid in the floor, and the sound insulation specification.

The supporting timber floor construction resists the tensile bending forces in the total suspended floor construction. These different structural tasks correspond to specific properties of the timber and concrete materials. The shear increases from mid-span to the supports; good shear connections in the vicinity of the supports are therefore essential.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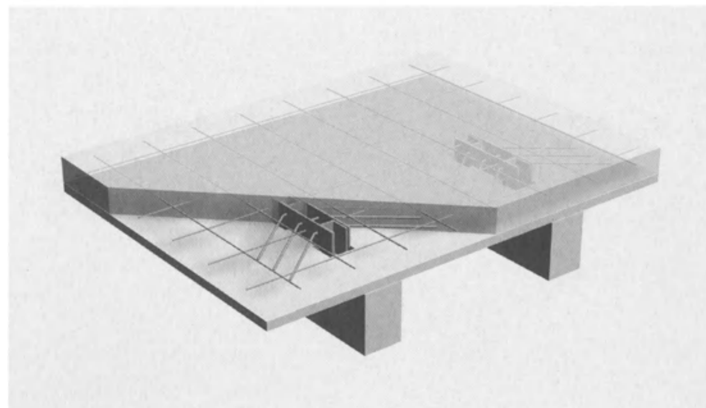
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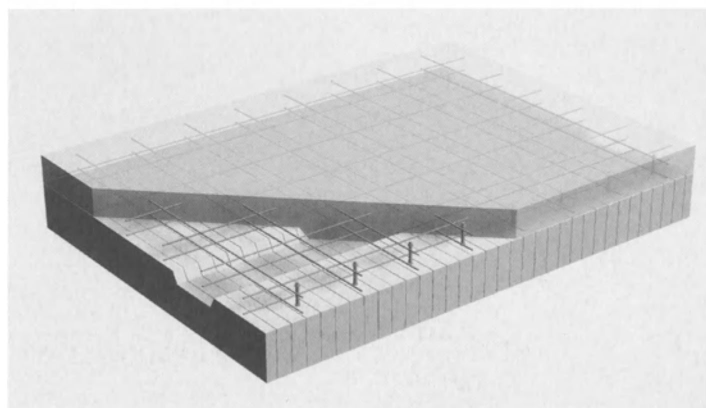
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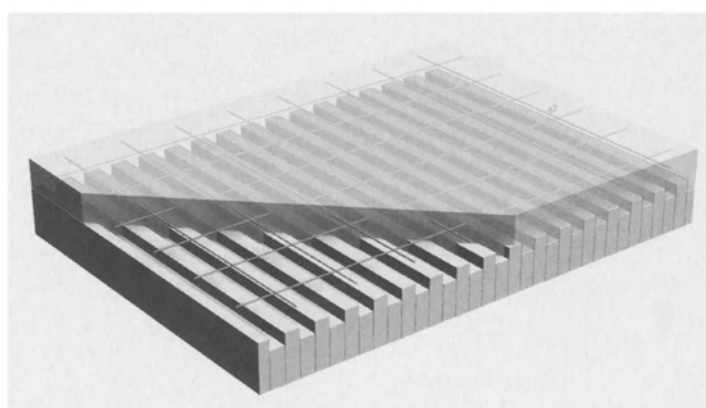
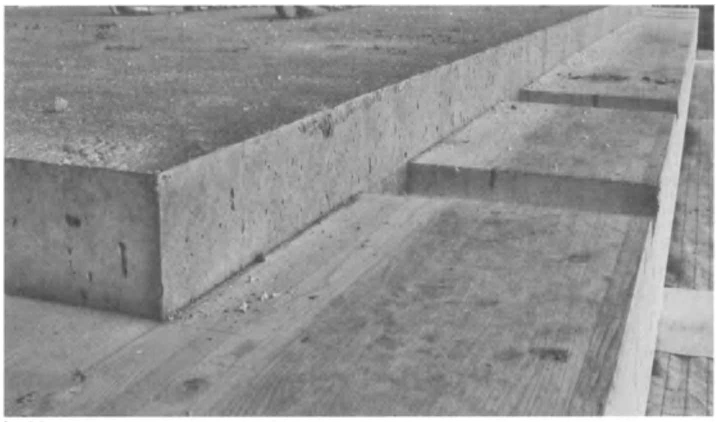

b408

b405 to b408 Overview of timber-concrete composite floors
b405 with timber joists (SFS shear connectors)
b406 with timber joists (BVD shear connectors)
b407 with edge-fixed elements (trough cut in timber)
b408 with edge-fixed elements (alternate laminations of different depths)



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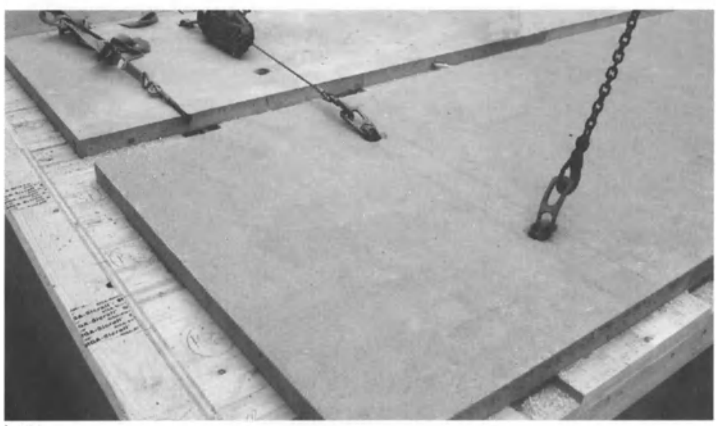

b411

On-site procedure

The supporting timber construction – comprising individual pieces or elements – is erected on site. The second step involves laying a separating layer and any building services. Depending on the system selected for the timber/concrete connection, the shear connectors should now be attached (or completed when the timber floor consists of prefabricated elements). After the shear connectors are in place, the reinforcement is laid and the concrete topping poured. Timber-concrete composite floors have now reached an advanced stage of development. Complete prefabrication off-site, including shear connectors and concrete topping, is now possible, which results in considerably faster erection. Another particular advantage of this is the dry construction on site, which once again permits further building trades to continue without delay. The high storage costs while the concrete hardens, the transport and erection costs of these heavyweight elements, and the on-site completion of the joints between elements represent the disadvantages of this system.

b10 91 Supporting timber construction

Timber-concrete composite floors can be used with various structural floor systems:

- timber joist floors, possibly ribbed-panel and hollow-box floors (Figs. b405 and b406)
- edge-fixed elements (Figs. b407 and b408)
- board-type, glued products

b10 92 Shear connection

A critical part of the timber-concrete composite floor is the shear connection between the timber and the concrete. Two types of shear connection are in use: the shear connection with a direct interlock between the timber and concrete, and the shear connection achieved by way of metal shear connectors.

Interlocking shear connection

We distinguish between two types of interlocking shear connection: the transverse trough in the vicinity of the supports, and edge-fixed elements having laminations with different depths. Both of these methods create a friction surface that transfers the shear forces between the timber and the concrete.

Use of shear connectors

Various proprietary systems are available. The SFS-VB system has become well established. It consists of special screws with a special head and intermediate washers. Other connectors available are the BVD system and the Ligno HBV system. The former consists of steel parts that are cast into pockets in combination with timber joists, and the latter forms the bond by way of expanded metal parts.

See chapter e2 for the names and addresses of manufacturers and institutes.

b409 Prefabrication of timber-concrete composite floor (edge-fixed floor elements with troughs)

b410 Erection of prefabricated timber-concrete composite floor elements

b411 Prefabricated timber-concrete composite floor elements prior to completion

b11 Multi-storey timber buildings

b11 10 General

In Central Europe, but also overseas, there is a firm tradition of timber buildings with four, five, or even more storeys. Originally, the first types of construction used for multi-storey buildings were log construction and an early form of timber-frame construction with continuous columns. These forms of construction were superseded by a form of timber-frame construction divided into storeys, i.e. each storey was built as a separate entity and placed on the loadbearing framework of the storey below. Using a similar principle, the platform frame has remained a popular form of construction in North America to the present day. These building systems dominated multi-storey timber construction until the second half of the 20th century: platform-frame construction in North America, the UK, and parts of Northern Europe, (chapter b5), and timber-frame construction in Central Europe (chapter b4).

Further developments, however, remained few and far between in Central Europe because multi-storey buildings in timber disappeared almost completely from the thinking of clients, architects, engineers, and timber building companies. Not until recently did timber manage a comeback as a serious alternative material for multi-storey buildings, indeed for large buildings as a whole. This was thanks to new applications of construction types and systems, the reformulation of fire protection regulations, and new developments in sound insulation. The reasons for this change in attitude can be found in the following new requirements and possibilities:

b412

b412 Modern multi-storey timber buildings in Zurich, Switzerland

- Ecology: the emergence of a new awareness among the general public.
- Architecture: pioneering structures by leading architects defined a new culture of timber buildings.
- Technology: new wood-based products and forms of timber construction resulted in new systems.
- Research and development: new findings in construction and structural engineering have increased the safeguards for developers and users.

Today, designers of multi-storey timber buildings can choose from frame construction, solid timber construction, and a modified form of panel construction. These three building systems have been adapted for multi-storey and large structures. Their principles have already been described in chapters b6, b7, and b8, and chapters b1 "Overview of systems" and b2 "Fabrication processes" also contain information relevant to multi-storey buildings in timber.

The features of multi-storey timber buildings

- Generous design freedoms
- Engineered approach
- Application of industrial fabrication processes
- Preferred building systems:
  - frame construction
  - panel construction (in a hybrid form with loads transferred as point loads)
  - solid timber construction (primarily cross-banded glued systems)

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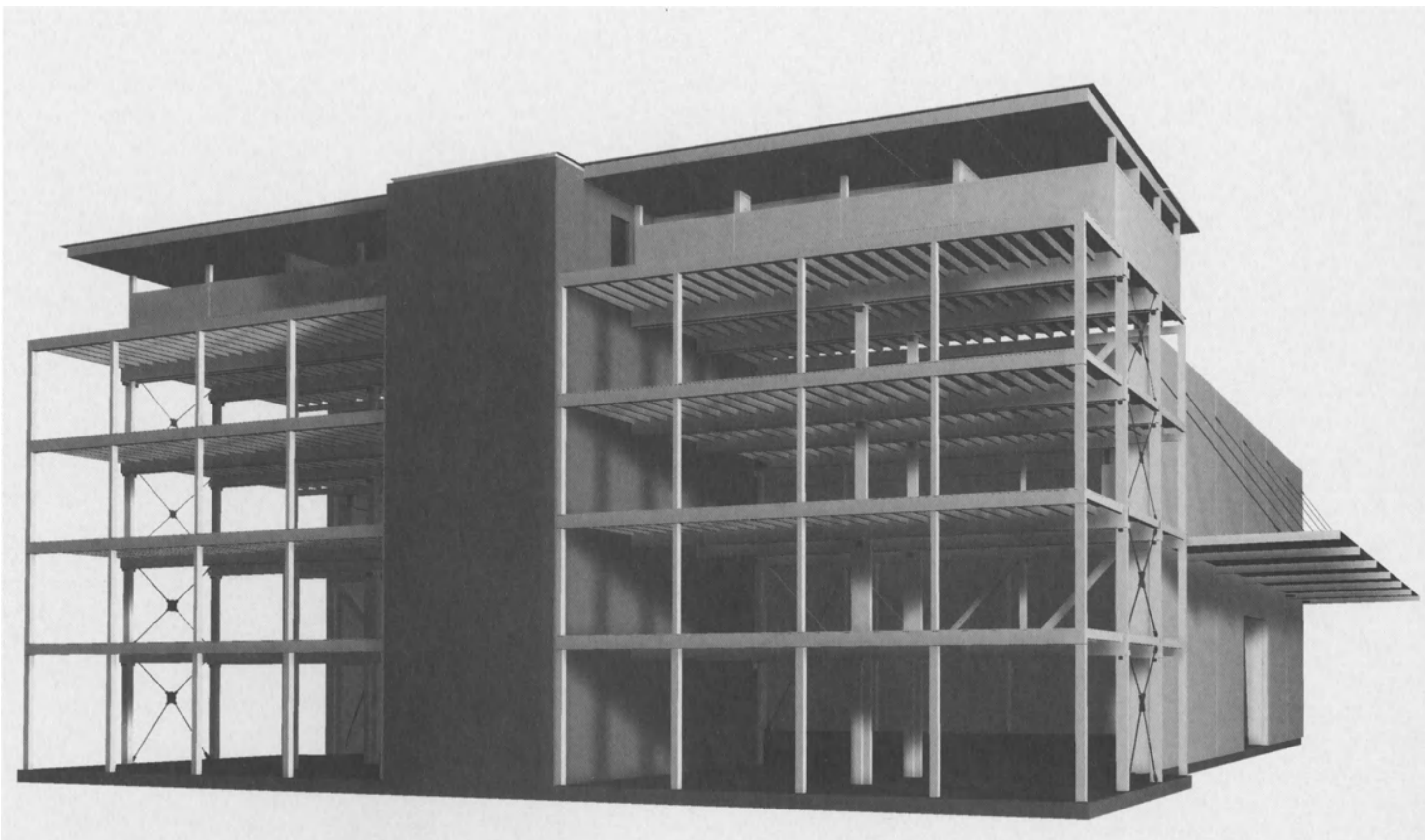
b413 Modern multi-storey timber building, school in Biel, Switzerland

b11 Multi-storey timber buildings



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b11 20 Conception and design

The relationships between conception and design have already been discussed in detail in chapter a3 "Conception and design". Additional aspects, however, must be taken into account concerning multi-storey and larger timber buildings.

Structural depth of suspended floors

Deeper suspended floor structures result in simpler and more economic constructions. Experience shows that timber suspended floors spanning more than about 5.5 m require a greater structural depth than reinforced concrete floors. Compared to concrete, a timber floor is 1 to 1.3 times deeper for spans of 5 or 6 m, indeed 1 to 1.5 times deeper in the case of heavier loads and longer spans. There are, however, timber building systems in which a smaller structural depth is possible: solid timber floors, timber-concrete composite floors, and hollow-box systems. Voids are also useful for routing pipes and cables, and for accommodating layers of insulation. Building practice shows that deeper floors – also in reinforced concrete – are ideal in every respect; sound insulation, building services, and, in particular, the economics all benefit. The structural depths of various suspended floor systems can be found in chapter b10 "Suspended floor structures" (Figs. b354 to b356).

b414 Structural design concept for a multi-storey frame construction (office building with production facilities, Figs. b415)

b415

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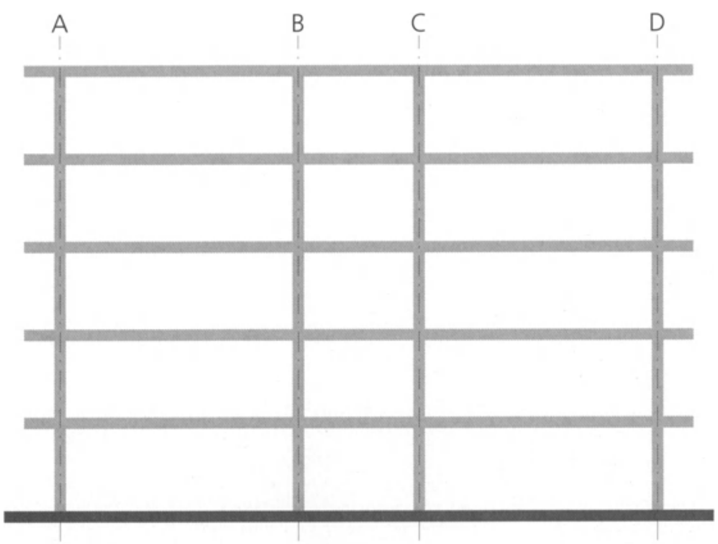

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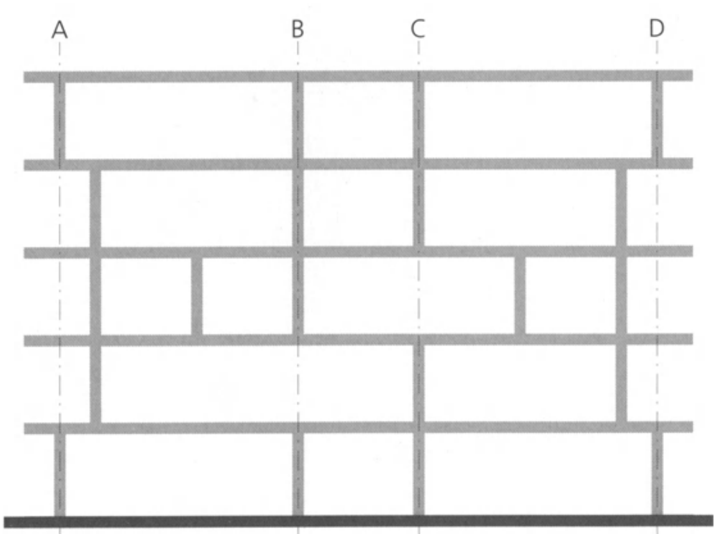


b418

b415 Multi-storey office block with adjacent production facilities (for structural design concept see Fig. b414)
b416 Multi-storey office buiding, balcony loads carried via roof structure and external walls

b417 Ideal structural concept with walls aligned in section (and on plan)
b418 Unsuitable structural concept, which complicates the vertical loading paths

Positions of walls

Another criterion is the positioning of loadbearing walls. Walls that remain in the same vertical plane on plan and on elevation in all storeys can be used to brace the building regardless of the form of construction. Likewise, columns in frame construction should be in the same position on plan in every storey (compare Figs. b417 and b418).

Planning, production, and erection processes

Multi-storey and large buildings in timber require an appropriate lead time for their planning and production. What has to be done when and by whom must be specified in a schedule of works or critical path analysis. The responsibilities of the parties involved (client, architect, engineers, specialists, contractors, and possibly municipal authorities) must be defined. A clear programme of work and clear definitions of responsibilities are regarded as the most important quality assurance measures. These measures are described in chapter a3, and Fig. a44 shows the planning sequence for larger timber construction projects.

Construction

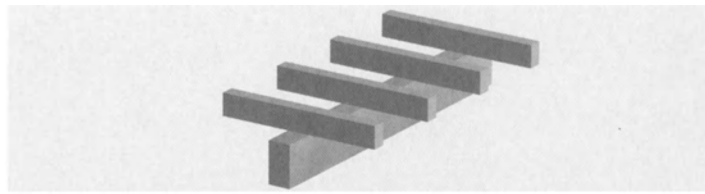
Multi-storey and large buildings in timber involve a high degree of prefabrication. This leads to advantages during construction, but calls for well-thought-out concepts and designs. The fabrication processes are described in chapter b2.

b11 30 Structural engineering

Multi-storey buildings require that all loading paths be clearly and simply arranged. It should be the aim of the designer to align all walls and columns on plan and on elevation (Figs. b417 and b418). In tall multi-storey buildings, the stability issue is crucial. Choosing a good ratio of height to plan size can result in a simple structural concept, whereas an unfavourable ratio could lead to a complex, elaborate, and hence expensive construction demanding building components capable of carrying high loads and involving awkward junctions and connections.

b11 31 Horizontal force transfer

Several construction systems are available for suspended floors, which should be chosen depending on the loads and spans, and their structural depths. Figs. b354, b355, and b356 in chapter b10 "Suspended floor structures" contain a selection of floor systems and specify the different depths required for housing, offices, and places of assembly. Depending on the plan layout and the timber building system chosen, the walls can form the supports, or the floor loads are transferred to the walls or columns via beams or lintels. Beams can be positioned below (downstand), above (upstand), or level with the floor construction (Figs. b419 to b421), whereas lintels, or the floor supports at the outer walls, are usually positioned in the same plane as the floor (Fig. b422). Suspended floors should be designed to be sufficiently rigid. Besides the ultimate load capacity, serviceability is of great importance, and a structural analysis must investigate the vibration behaviour in particular. Suspended floors that serve different uses in the same building should be avoided (Fig. b423). Rigid floor constructions are easy to achieve in timber.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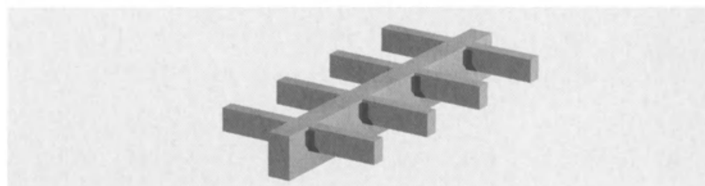
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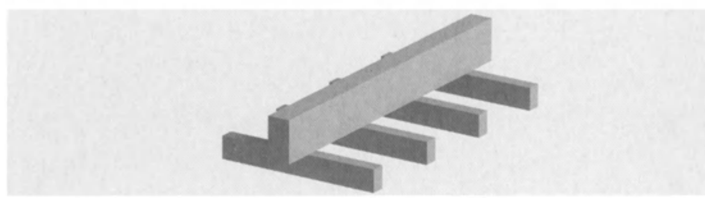
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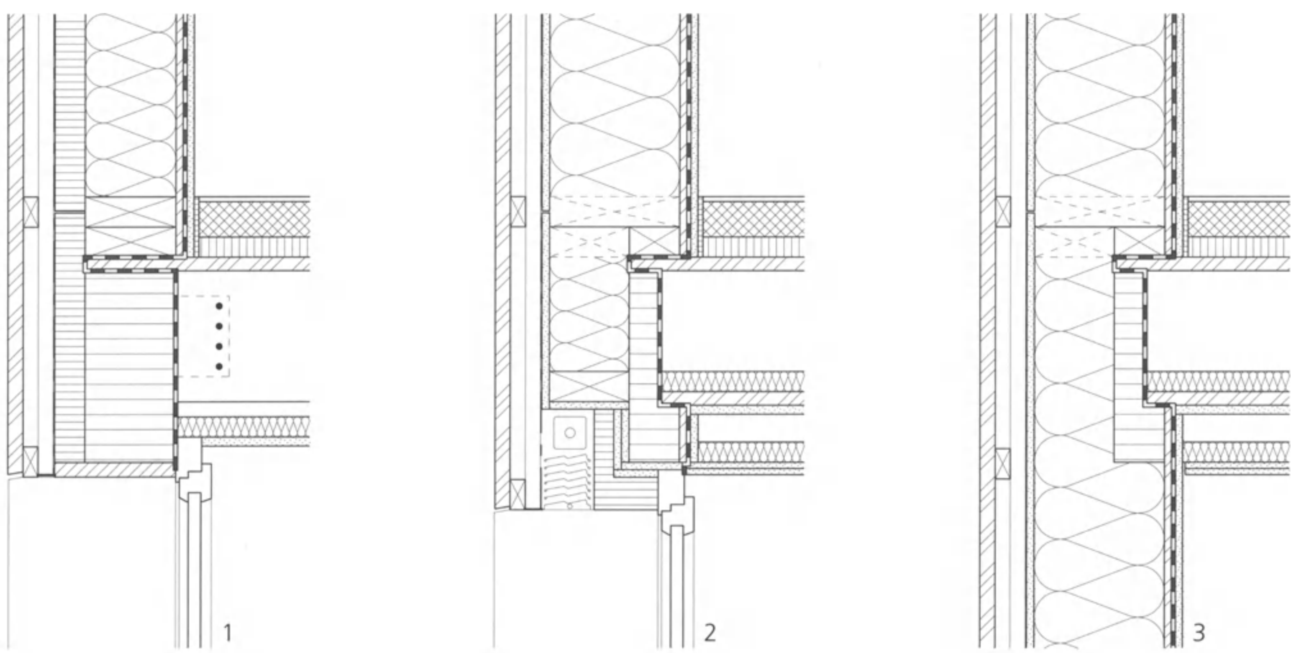
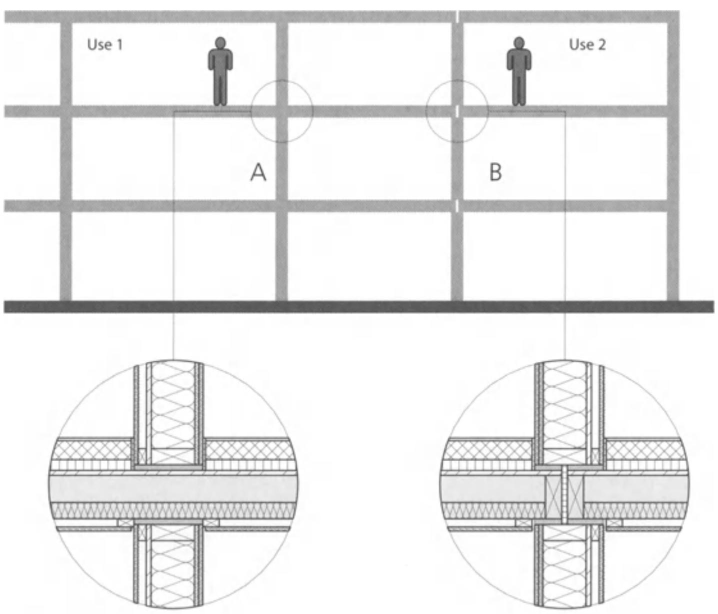


b422

b419 to b421 Possible beam positions
b419 Floor elements or joists oversailing main or downstand beam
b420 Floor elements or joists and main beam at same level
b421 Floor elements or joists suspended below main or upstand beam

b422 Possible support details at window lintels in an external wall
1 Floor element supported on glued laminated timber beam, with metal plate let into timber beam and secured with close-tolerance pins
2 Floor element supported on L-shaped glulam lintel, section through window
3 Floor element supported on L-shaped glulam lintel, section between windows

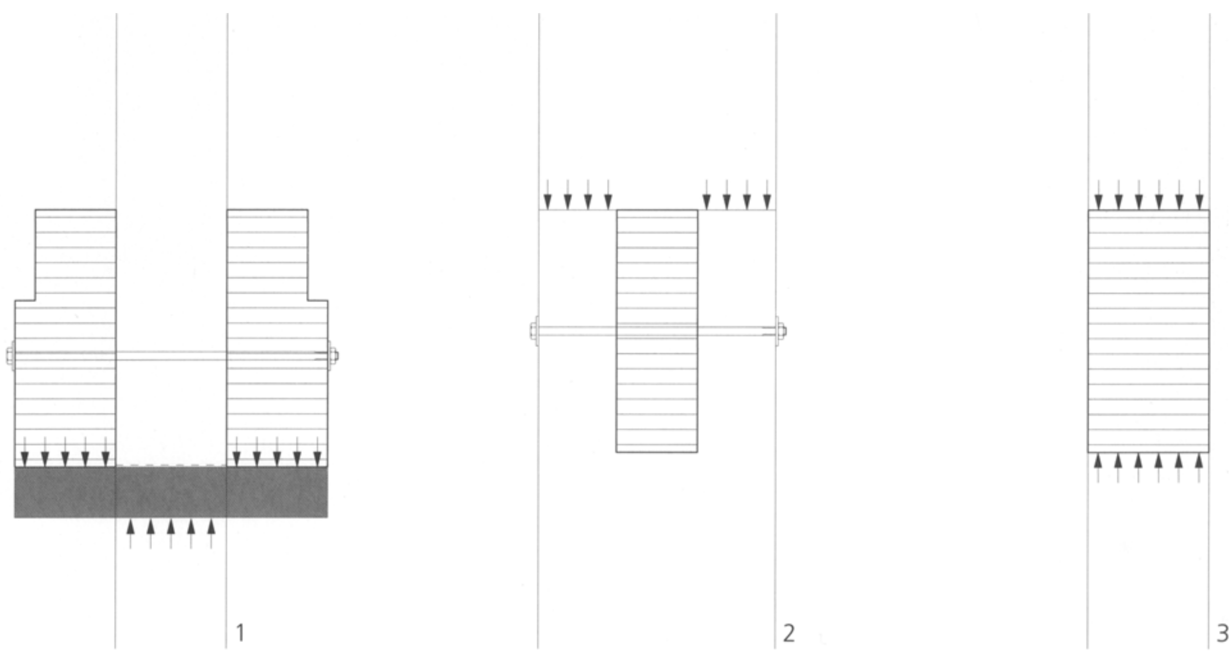


b423

An adequate structural depth should be allowed for right from the start of the planning.

b11 32 Vertical load transfer

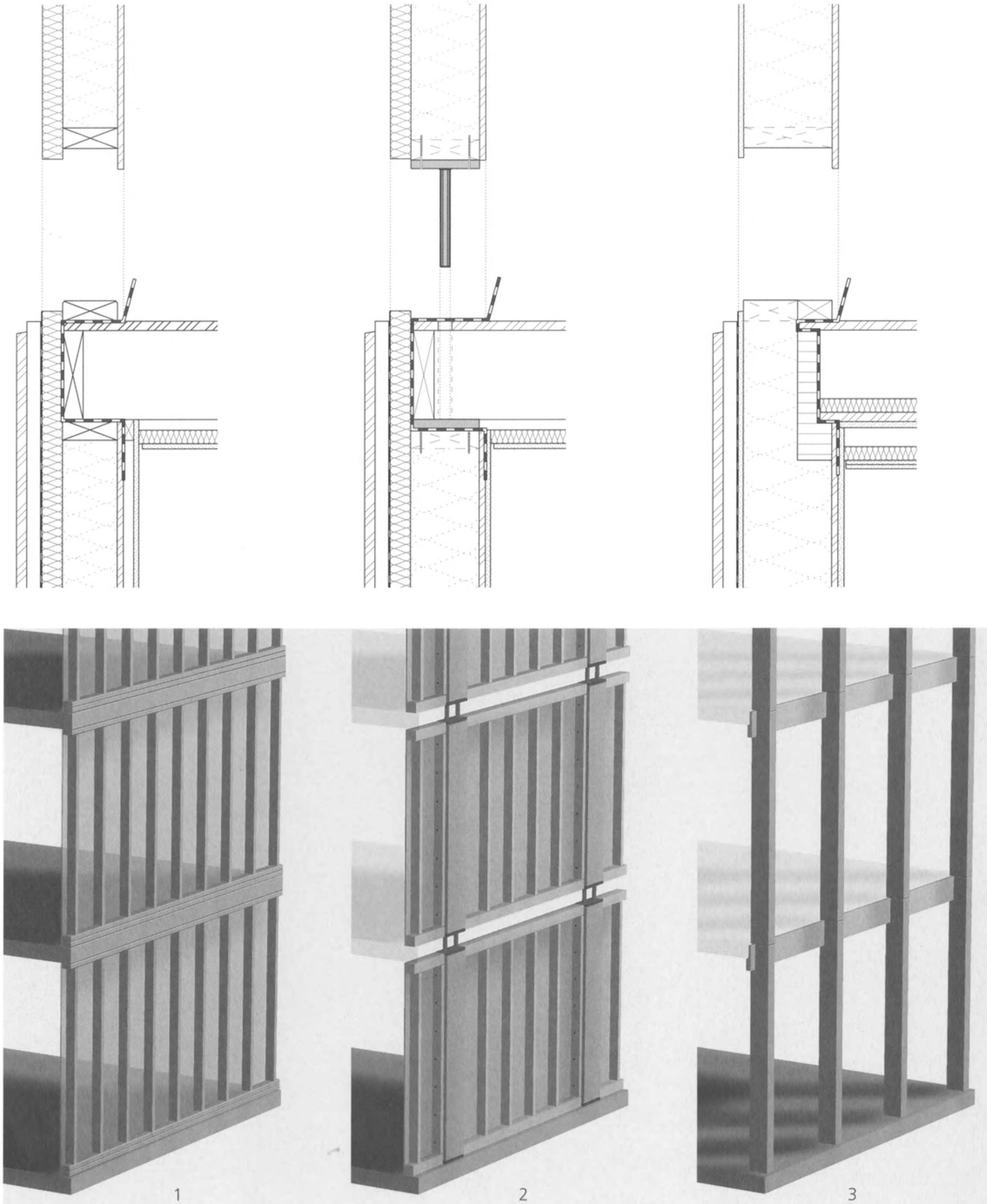
Vertical columns and posts (loads parallel to the grain) can carry about five times more load than members (e.g. top and bottom plates) installed horizontally (loads perpendicular to the grain). These properties must be considered for heavily loaded wall and column constructions in particular. Transverse timber members result in a decrease in the loads that can be carried. Very heavy loads, however, can be carried by employing longitudinal timbers over several storeys (Fig. b424). Different construction principles can be employed for carrying vertical loads depending on the particular structure. As Fig. b425 shows, the customary arrangement with floors intruding into walls (example 1) is adequate for two- and three-storey buildings.
With heavier loads, an arrangement in which the main columns are combined with non-loadbearing wall elements (examples 2 and 3) is better. And the main columns can even be integrated into the wall elements as shown in example 3. The use of steel com-



b424

b423 Floor details for different uses within one building: detail A is unsuitable between different types of use or occupancy.

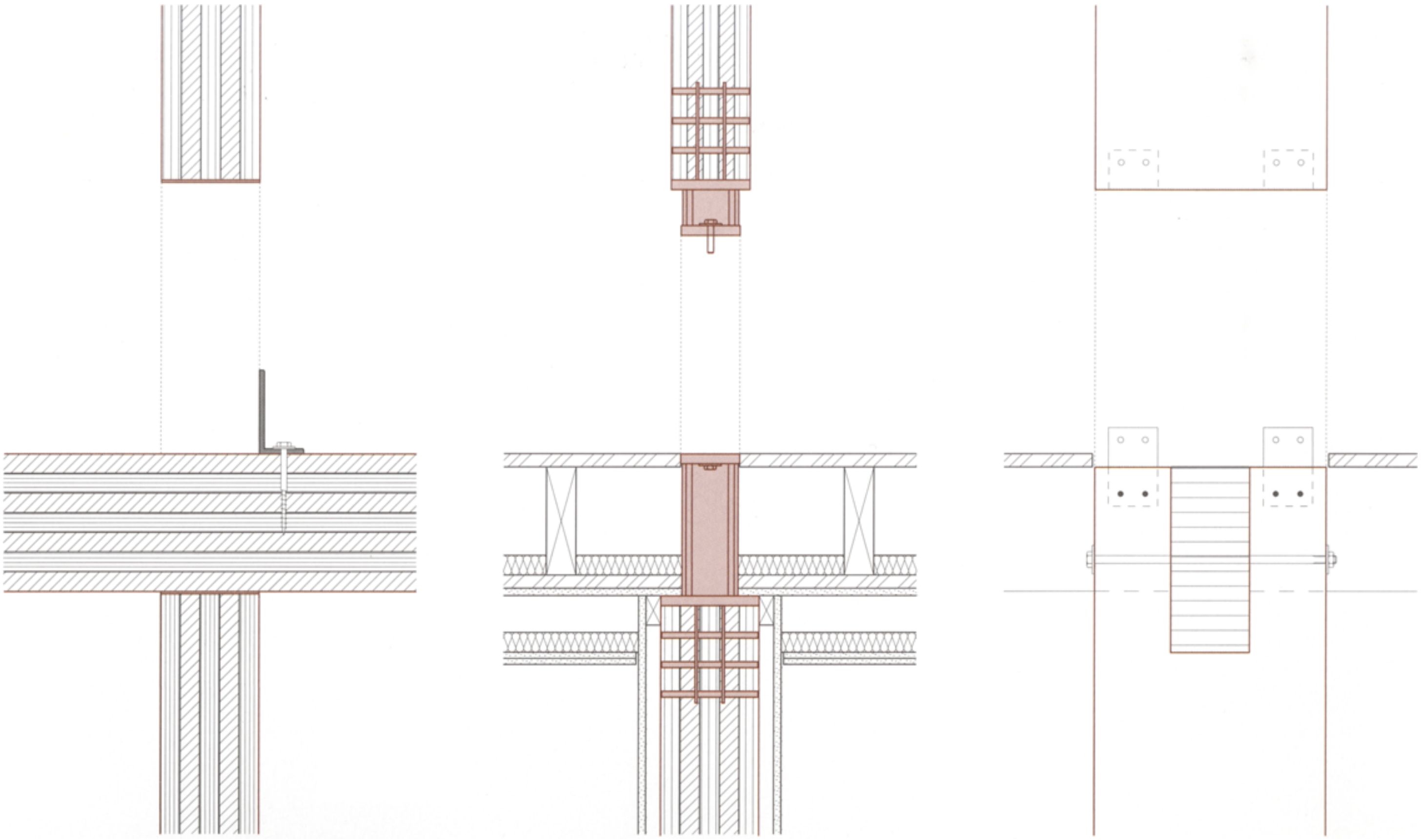
b424 Vertical load transfer, possible details at floor level:
1,2 Loads transferred via longitudinal timber members, continuous column or direct-contact joint; heavy loads can be carried and the settling is minimal. In detail 1 the loads are transferred from the beams to the continuous column via an intermediate support member (see Fig. b148, p. 97).
3 Loads transferred via horizontal timber member, i.e. stresses perpendicular to the grain; load-carrying capacity severely reduced, and the amount of settling must also be taken into account.

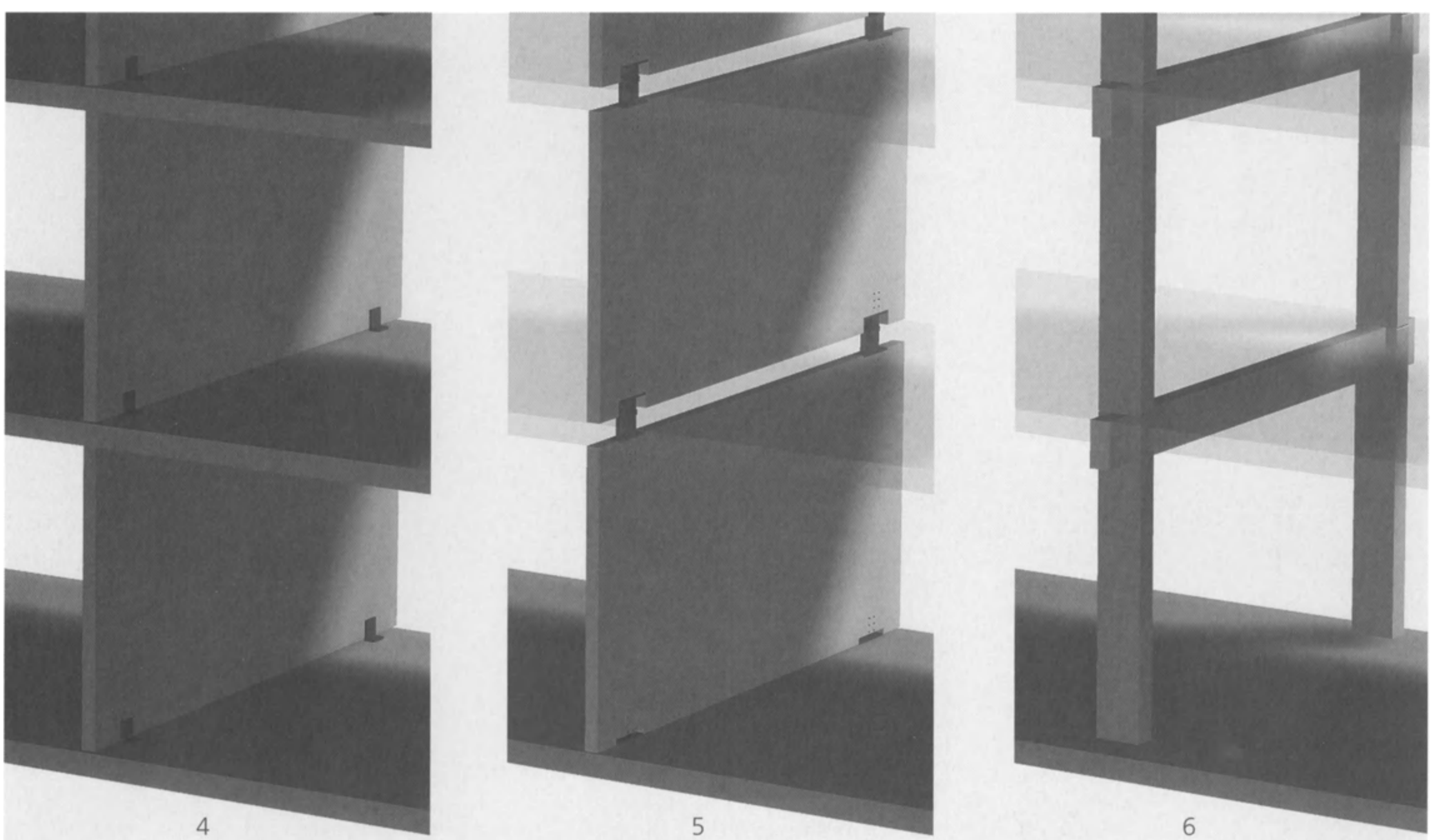


b425

b425 Vertical load transfer in multi-storey timber buildings (top: section through detail at floor level; bottom: three-dimensional view; 1–3 = external wall, 4–6 = internal wall)

1 Load transfer in panel construction via bottom plate, floor member, top plate (suitable for two- and three-storey buildings)
2 Load transfer using longitudinal timber member and steel components, floor elements supported on wall element (which transfers the loads to the main columns), wall element designed as structurally effective plate
3 Load transfer via direct-contact joint (end grain of the columns integrated in the wall element), wall element designed as structurally effective plate





4 Load transfer in solid timber construction (board-type, glued elements) by way of distributing the loads linearly (see also Fig. b9, p. 41, application for vertical forces)
5 Load transfer in solid timber construction, or rather board-type, glued elements, via steel components, application for vertical and horizontal (bracing) forces
6 Load transfer in frame construction with continuous or forked columns; forced transfer via longitudinal timber or direct-contact joint, but mostly in conjunction with mechanical fasteners let into the timber (the wall elements do not carry vertical loads)

ponents (example 5) or, as shown in example 3, the use of direct-contact joints (end grain on end grain, possibly with metal parts let into the timber), can help these main columns to carry heavy loads without the problems of transverse timber components. Example 4 shows an application in solid timber construction. Owing to the potentially simple force transfer arrangement, cross-laminated timber or multi-ply solid timber panels are well-suited to the construction of multi-storey buildings. If high horizontal forces (wind, eccentricity, earthquakes) have to be resisted, a force transfer via steel components (example 5) can prove helpful. Example 6 shows a continuous column according to the frame construction forms shown in section b7 44 "Beams and continuous columns" and b7 45 "Forked columns".

Loads should be transferred to the foundations the same way vertical loads are transferred at the supports for suspended floors. In the case of heavy loads, the forces are transferred into the foundations via direct contact or steel components.

b11 33 Stability of the structure, anchorage

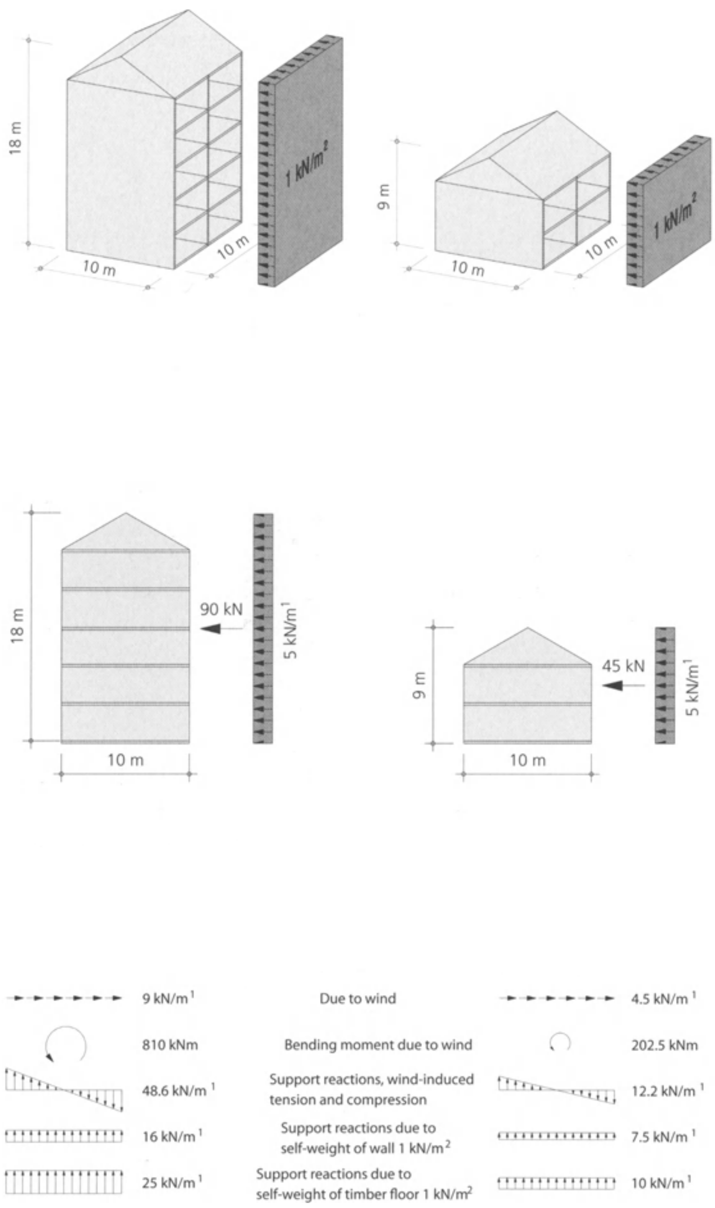
The stability of a structure with respect to horizontal loads (wind, eccentricity, earthquakes) must always be checked, and in the case of multi-storey buildings right at the start of planning. The building design governs whether a simple or a complex bracing arrangement is necessary, and the influence of the bracing measures is considerable in a multi-storey building. This becomes clear from the example illustrated in Fig. b426. The vertical support reactions due to wind increase disproportionately as the height of the building increases: doubling the height of the building results in a four-fold increase in vertical support reactions. The consequence for multi-storey buildings is high forces that have to be resisted by properly designed bracing and anchorage details. Likewise, an analysis of the effects of earthquakes is unavoidable in certain geographical regions. In particular, rules for the positioning of loadbearing elements (shear walls) must be followed. A structural engineer experienced in the design of timber structures should be appointed to carry out the calculations and design work, and to prepare the engineering and working drawings.

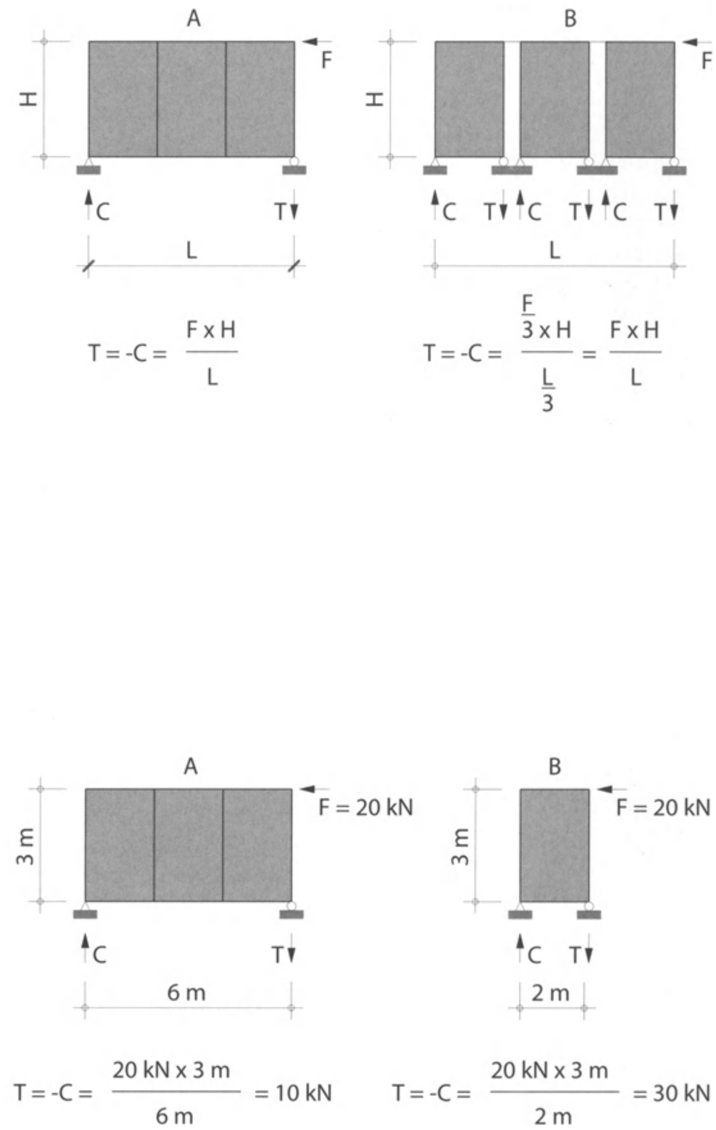
The example in Fig. b426 is based on a wall and floor self-weight of 1 kN/m^2. These values should be realistic for the structural carcass. In a two-storey building, the dead loads must be greater than the uplift due to wind. Compression and shear forces are therefore critical.

In a five-storey building, however, the reverse is true. As can be seen from the example, the dead loads cannot match the uplift forces due to wind ($16 + 25 = 41$ kN < 48.6 kN), and the building must be secured against overturning. Various anchorage details can be used in such cases.

The lengths of walls, or at least their effective lengths as shear walls, have a decisive influence on whether straightforward or more complex bracing arrangements are necessary, as is illustrated in Fig. b427. A wall of a certain length carries the forces due to wind and transfers them via a plate effect to the anchorage points. If this wall plate is now divided into three parts (e.g. interrupted by storey-high door or window openings), the force builds up due to the less favourable aspect ratios of the wall sections. Although in the example shown here the total force is the same, the one-piece shear wall requires the load to be transferred only once, the three-part wall three times.

Forces acting on the building are resisted by the floor and roof plates. These plates transfer the forces to loadbearing (bracing) wall elements or bracing elements, e.g. steel cross-bracing. These in turn transfer the forces to the storeys below, one by one until they reach, generally, the floor over the basement, the basement walls, or the foundations, where they can be anchored (Fig. b428, b429, b432, and b433). The effects of horizontal and vertical bracing can be seen in Figs. b430 and b431.



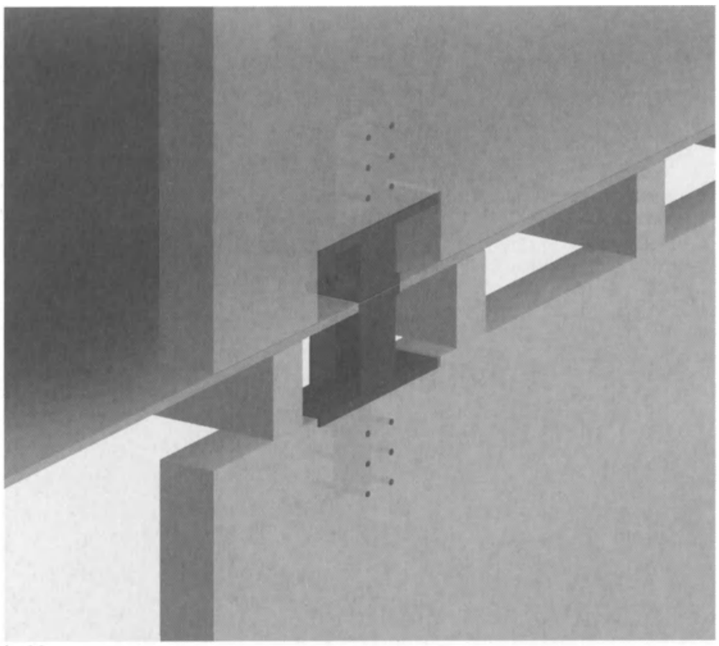


b426

b426 Stability of the building: how more storeys effect the stability using the example of the wind load on the central wall.
Doubling the number of storeys or the building height results in a four-fold increase in the uplift (tensile) and compressive forces due to wind. The bracing to the building must be given special attention.

b427

b427 Stability of the building: how the length of the plates (shear walls) affects the stability.
In version A the resultant anchorage force is T. In version B the force is identical, but occurs at three plates and must therefore be anchored three times. And in the lower example the same force T has to be resisted by a plate only one-third the size, which is therefore three times larger.



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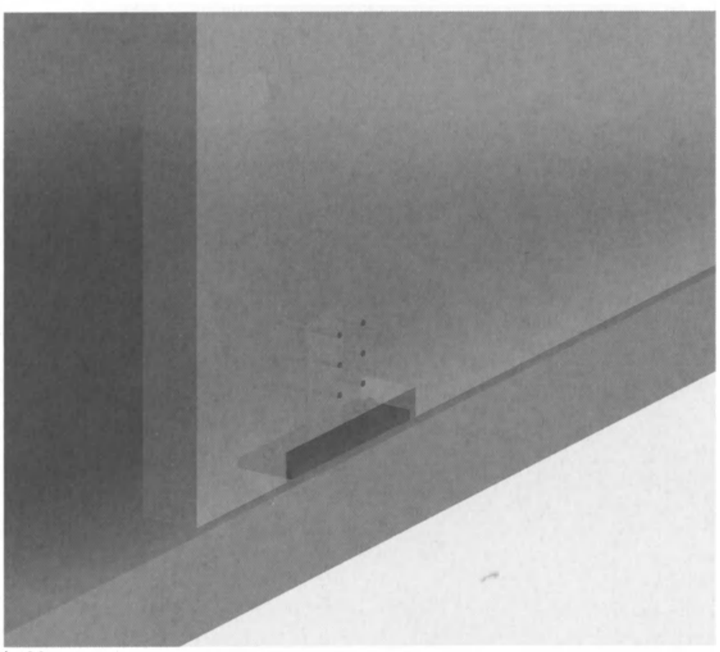

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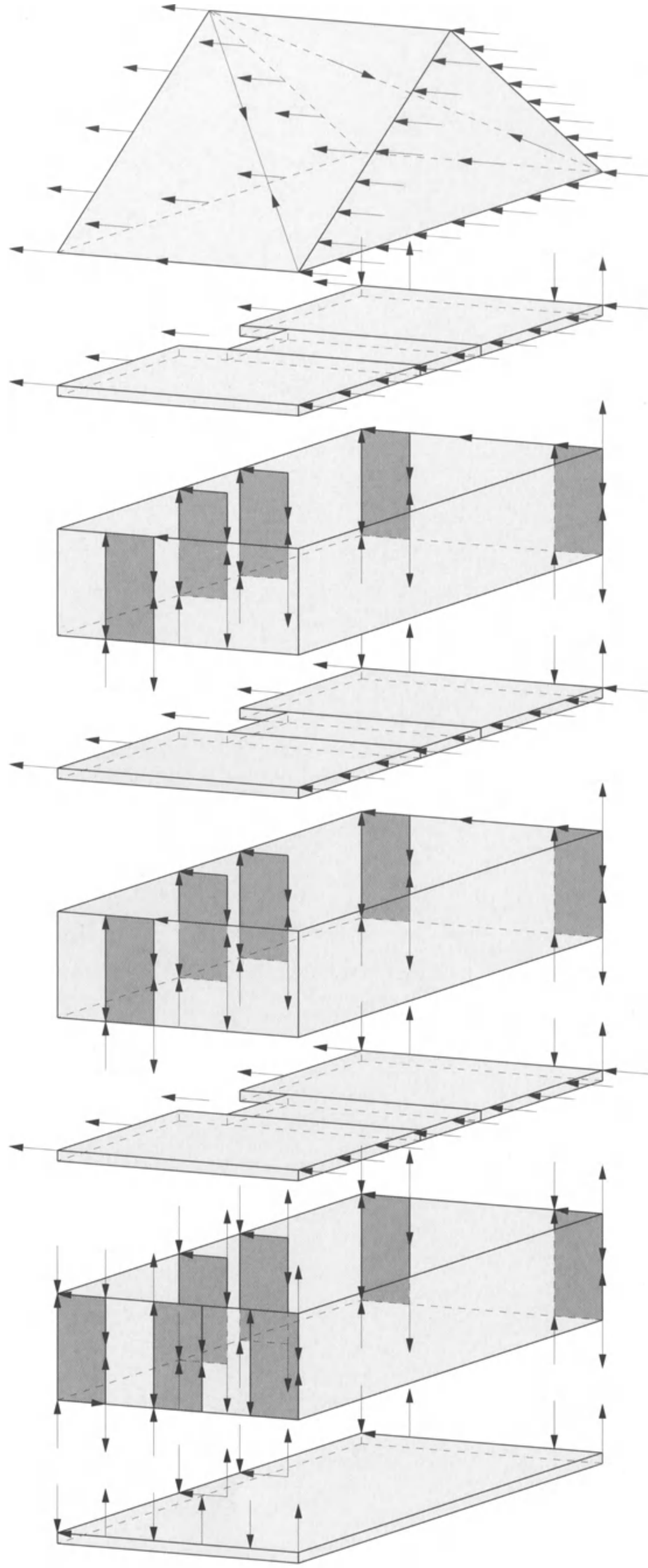
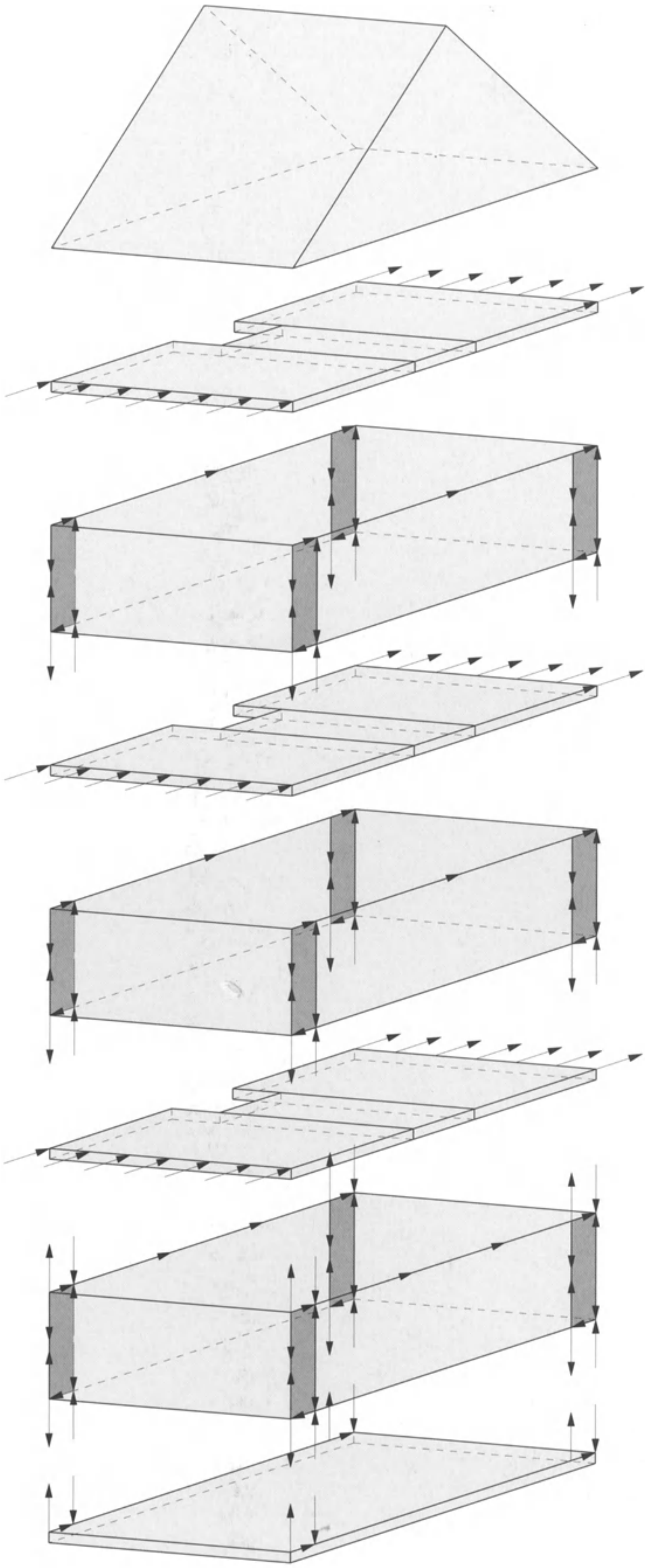


b430

b428 Anchorage at floor level

b429 Force transfer to the foundations, with plates let into timber and secured with close-tolerance pins

b430 Wind load perpendicular to the gable: the wind forces are resisted by the roof and floor plates and transferred to the wall plates



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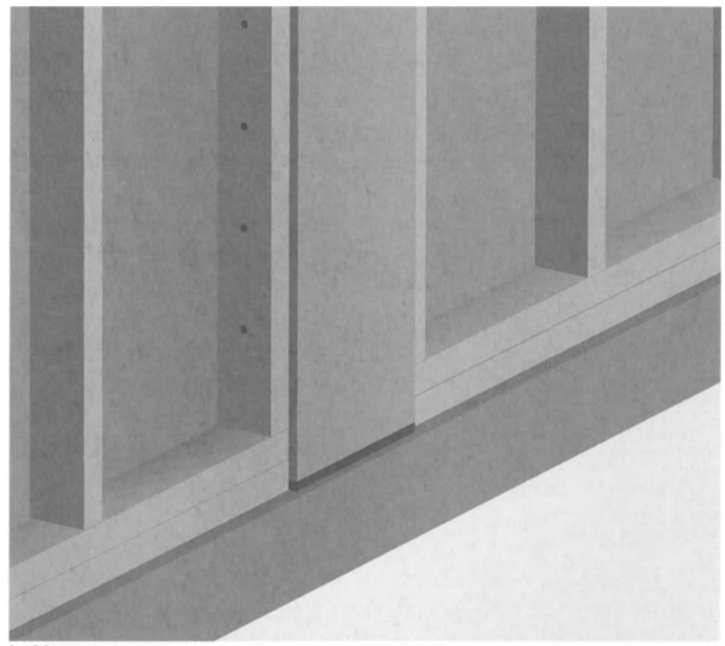

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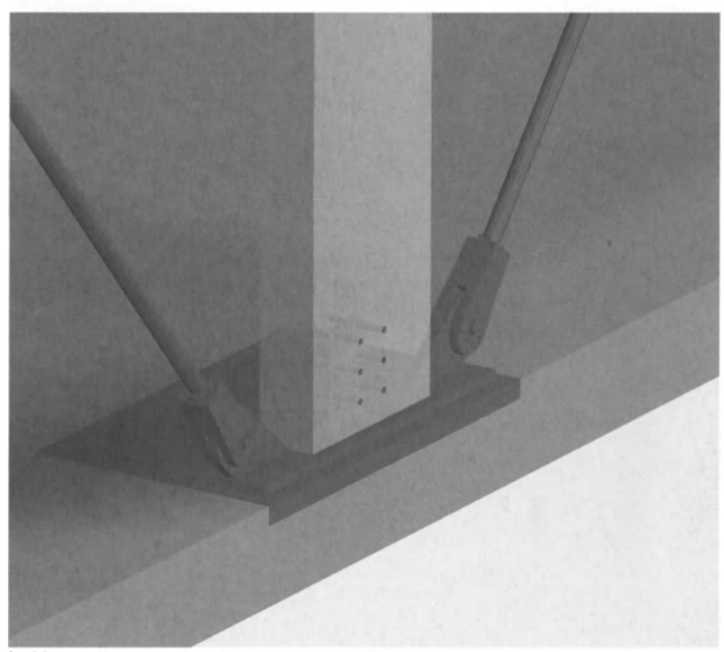


b433

b431 Wind load parallel with the gable: the wind forces are resisted by the floor plates and transferred to the wall plates.

b432 Direct force transfer into the foundations via a direct-contact joint.

b433 Transferring vertical and horizontal forces into the foundations

b436

b11 40 Settling behaviour

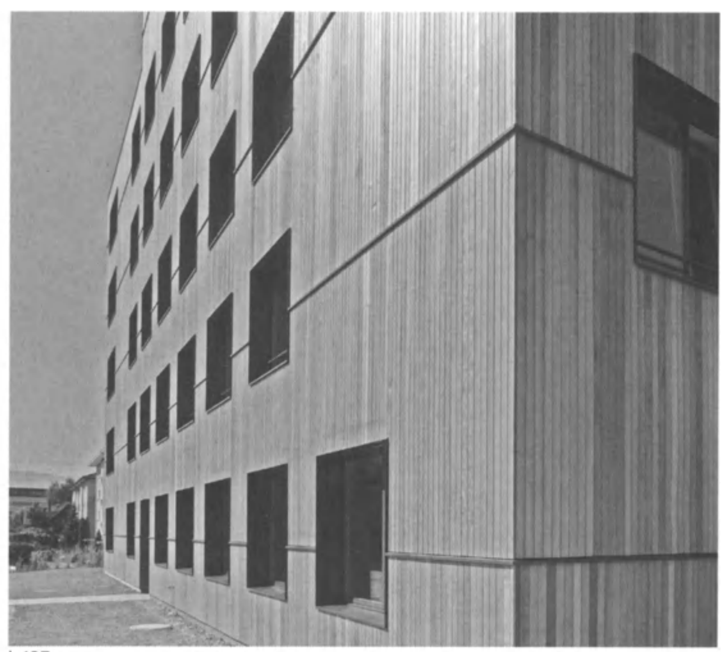
The settling behaviour of the timber construction must be paid special attention in timber buildings with three or more storeys. Firstly, because the settling effect per storey is multiplied, and secondly, because the timber is often combined with other building materials, e.g. reinforced concrete. For various reasons (fire protection, stability, and building services), it can be advisable to construct the stair shaft in masonry or reinforced concrete.

Settling behaviour and building segments in different materials

Figs. b439 to b441 show three options that take into account the different settling behaviour of the parts of a building. It should be mentioned that every building material exhibits its own specific shrinkage and swelling characteristics. However, the form of construction has an even greater influence on the settling behaviour.

b434

b435

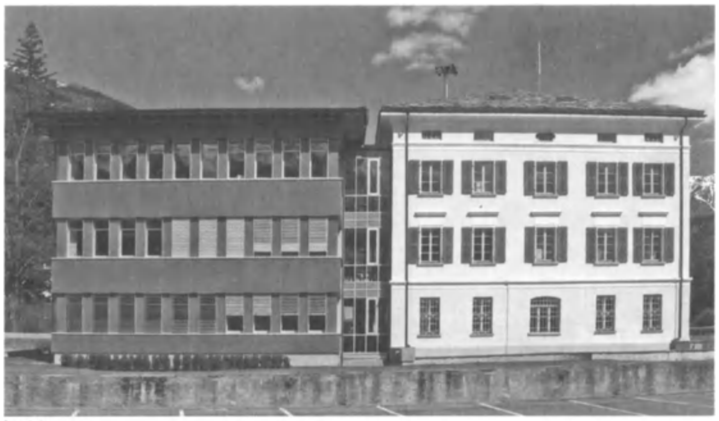


b437

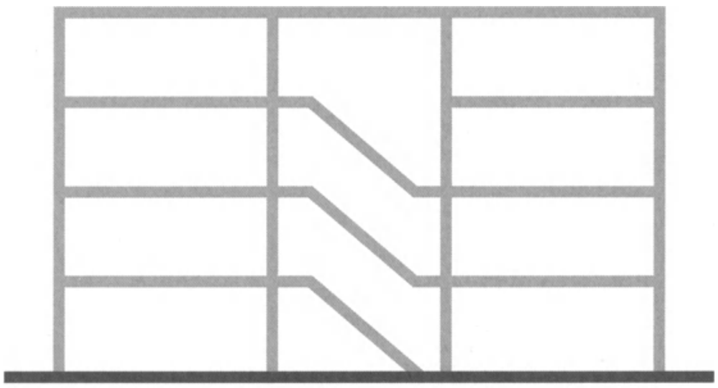
b434 Combination of reinforced concrete and timber building segments

b435 and b437 Multi-storey residential building in timber according to the concept shown in Fig. b440.

b436 Multi-storey residential building in timber, Minergie-P ECO, passive house standard, Fig. b440 shows a sketch of the principle.



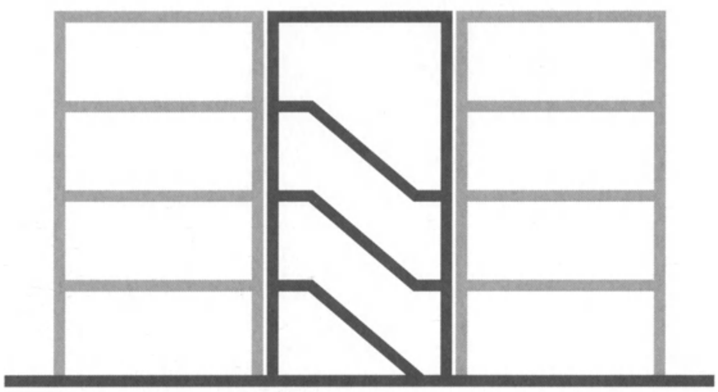
b438



b439

Complete loadbearing structure in timber

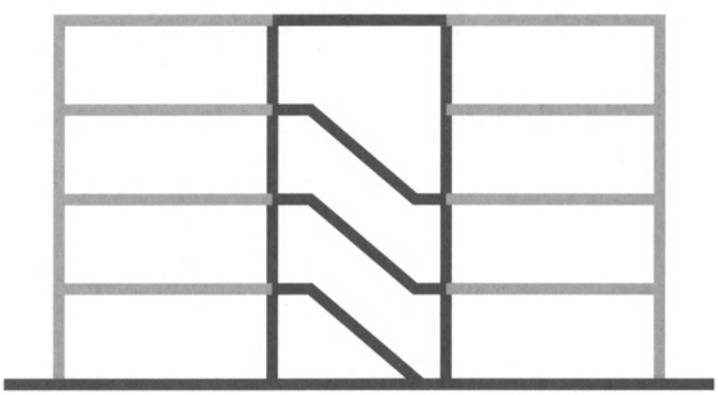
The parts of the building behave consistently. This is an ideal solution, especially for smaller multi-storey buildings.



b440

Independent loadbearing systems made from different building materials

The loadbearing systems are kept separate. The stair shaft can be built in, for example, reinforced concrete. A second, totally independent loadbearing timber structure is constructed around this stair shaft. Expansion joints between the two parts accommodate any differential structural movements.
Depending on the plan layout and the use of the building, this can represent an ideal solution. The "second leaf" around the stairs improves the sound insulation. Furthermore, the space between the stair shaft and adjacent offices, apartments, etc. can be used for routing building services.



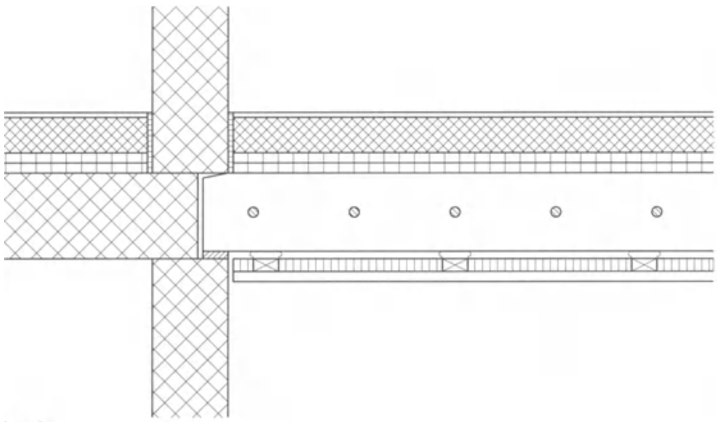
b441

Composite construction

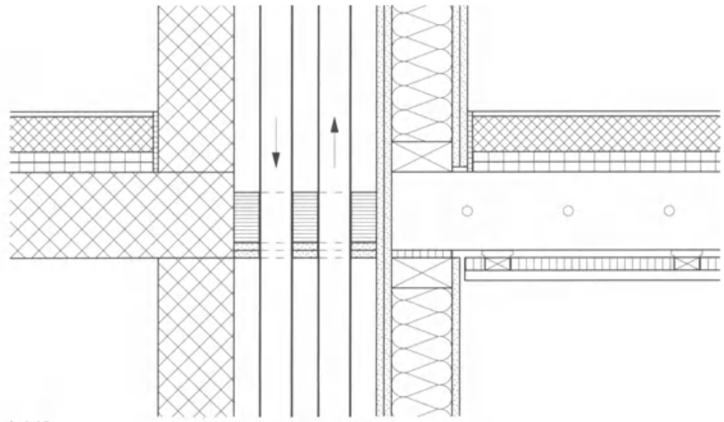
The advantage here is that no space is wasted through additional walls around the stair shaft. At the same time, the fire protection requirements are satisfied. The direct combination of different loadbearing systems must, however, be taken into account in the construction. The different deformations of the individual loadbearing systems should be minimised.

b438 Independent building segments with independent loadbearing systems: old building in masonry, new building in timber, community Centre in Poschiavo, Switzerland

b439 to b441 Concepts with different materials for different building segments
b439 Entire loadbearing structure in timber
b440 Different materials and separate segments
b441 Different materials combined



b442



b443

Support details

Fig. b442 illustrates one possible support detail for a solid timber floor at a reinforced concrete wall where the two loadbearing systems are not independent. The loads are transferred directly via the concrete floor. The concrete structure is built first and the timber floor construction, with its bevelled top edge, is fitted into this. The timber floor can deform independently of the concrete structure. Compression perpendicular to the grain at the support is less than the permissible compressive stress perpendicular to the grain. The prerequisite for the use of such a detail is that the settling allowances expected for the floor supports are equal or at least similar.

Fig. b443 illustrates one possible support detail where the loadbearing structures are kept separate. The space between the two loadbearing systems is large enough to accomodate building services, but this duct may well need fire stops depending on the use of the building and the applicable fire regulations.

Calculations for settling behaviour

The higher the building, the more the settling allowance must be reduced. This section explains how large the deformations could be, based on theoretical considerations, and what that means in terms of millimetres. The constructional measures have already been explained in the preceding sections. Besides the use of dry, generally glued timber members, it is important that the loading paths in the walls make use of longitudinal timber members. In contrast to the usual approach in timber construction, multi-storey timber buildings do not include horizontal top and bottom plates. Direct-contact joints are employed between successive vertical columns and posts.

Wood is hygroscopic, i.e. there is a constant exchange of moisture between wood and its surroundings – a valuable property of this natural building material which has a beneficial effect on the interior climate because the wood always ensures a natural moisture balance in the rooms. The absorption and release of moisture, however, results in swelling and shrinkage of the wood respectively, which must be taken into account through constructional measures. This property also varies depending on the direction of grain, i.e. the effect is anisotropic, and can be expressed by means of the amount of shrinkage in percent per 1% change in wood moisture content:

Moisture-related deformations in wood
(shrinkage and swelling amount in percent per 1% change in wood moisture content)

spruce/fir tangential	0.28....0.33	factor 20
spruce/fir radial	0.10.... 0.15	factor 10
spruce/fir longitudinal	0.01.... 0.015	factor 1

The above figures show that the change in dimension longitudinally is 20 times less than that tangentially. Structures should there-

b442 Support detail with different materials according to Fig. b441: the two loadbearing structures are not separated.
Notes:
The timber surfaces have to be protected against moisture from the concrete.
A level, horizontal bearing (mortar bed) must be provided.
The edge-fixed timber element must be fitted accurately on the relatively narrow support (60 mm) and fixed to the concrete.
Tolerances: approx. 10 mm gap at top, approx. 5 mm gap at end face

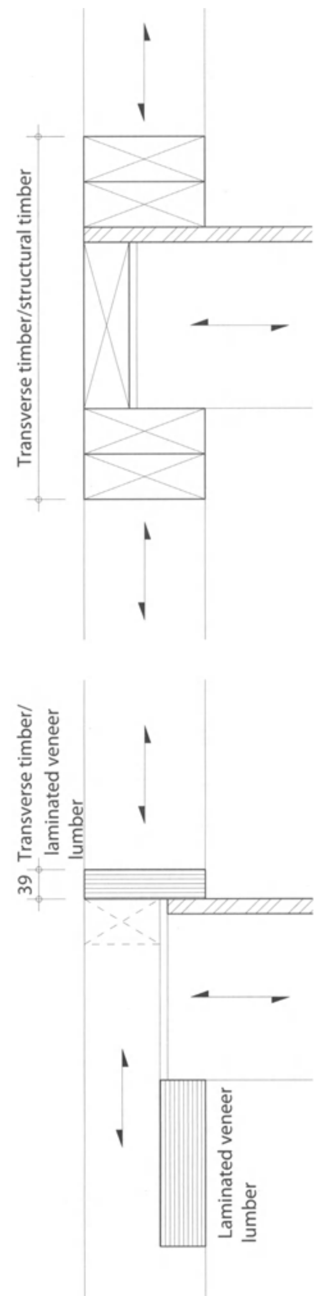
b443 Support detail with different materials according to Fig. b440: the two loadbearing structures are kept separate, and a services shaft has been incorporated between the two. The shaft includes a fire stop at every floor level for fire protection purposes.

fore be planned accordingly. According to the calculations for the details shown in Fig. b444, the total deformation due to a wood moisture content change of 5% in the external wall of this low-settling example is about 1.8 mm per storey (h = 2.66 m). If there are five storeys, a building about 14 m high, the total deformation lies in the region of 9.3 mm. This is not much – irrespective of the choice of material or form of construction. Such deformations are easily accommodated, indeed may even be neglected in some instances. But with a conventional form of timber construction, i.e. the traditional approach with top plate, suspended floor, and bottom plate, the total deformation over five storeys would be 35 to 40 mm. And with such deformations, constructional measures are vital. In addition to moisture-related deformations, load-related deformations also have to be considered. Here again, longitudinal timber members, with a strain of about 0.4‰, when the permissible critical buckling stress is fully exploited, fare much better than wood stressed perpendicular to the grain, where the strain is 7.0‰ for fully loaded transverse members.

Load-related deformations in wood
(strain with full exploitation of the permissible stresses)

spruce/fir tangential/radial	7.0 ‰	factor	17.5
spruce/fir longitudinal	0.4 ‰	factor	1.0

Further factors such as axial forces, accuracy of processing, building tolerances, etc. also have an influence on the longitudinal deformation. When exploiting the characteristic values for compression perpendicular to the grain with greater indentations, the amount of settling increases unfavourably. On the other hand, masonry and concrete structures also exhibit a certain deformation behaviour (e.g. creep), and this must be taken into account when using timber in conjunction with masonry or concrete.



b444

Calculated shrinkage:

Given
change in moisture
content of timber 5 %
transverse timber per storey 460 mm
longitudinal timber per storey 2200 mm

Shrinkage
transverse timber:
460 mm x 0.28 % x 5 % = 6.44 mm

Longitudinal timber:
2200 mm x 0.01 % x 5 % = 1.10 mm

over 5 storeys:
(6.44 mm + 1.10 mm) x 5 = 37.7 mm

Calculated shrinkage:

Given
change in moisture
content of timber 5 %
transverse timber per storey 39 mm
longitudinal timber per storey 2621 mm

Shrinkage
transverse timber:
39 mm x 0.28 % x 5 % = 0.55 mm

Longitudinal timber:
2621 mm x 0.01 % x 5 % = 1.31 mm

over 5 storeys:
(0.55 mm + 1.31 mm) x 5 = 9.30 mm

Laminated veneer lumber (LVL) can be installed already dried to the necessary equilibrium moisture content, which reduces shrinkage to a minimum

b444 Calculation of settling allowances:
form of construction with transverse timber (top)
form of construction with longitudinal timber (bottom)

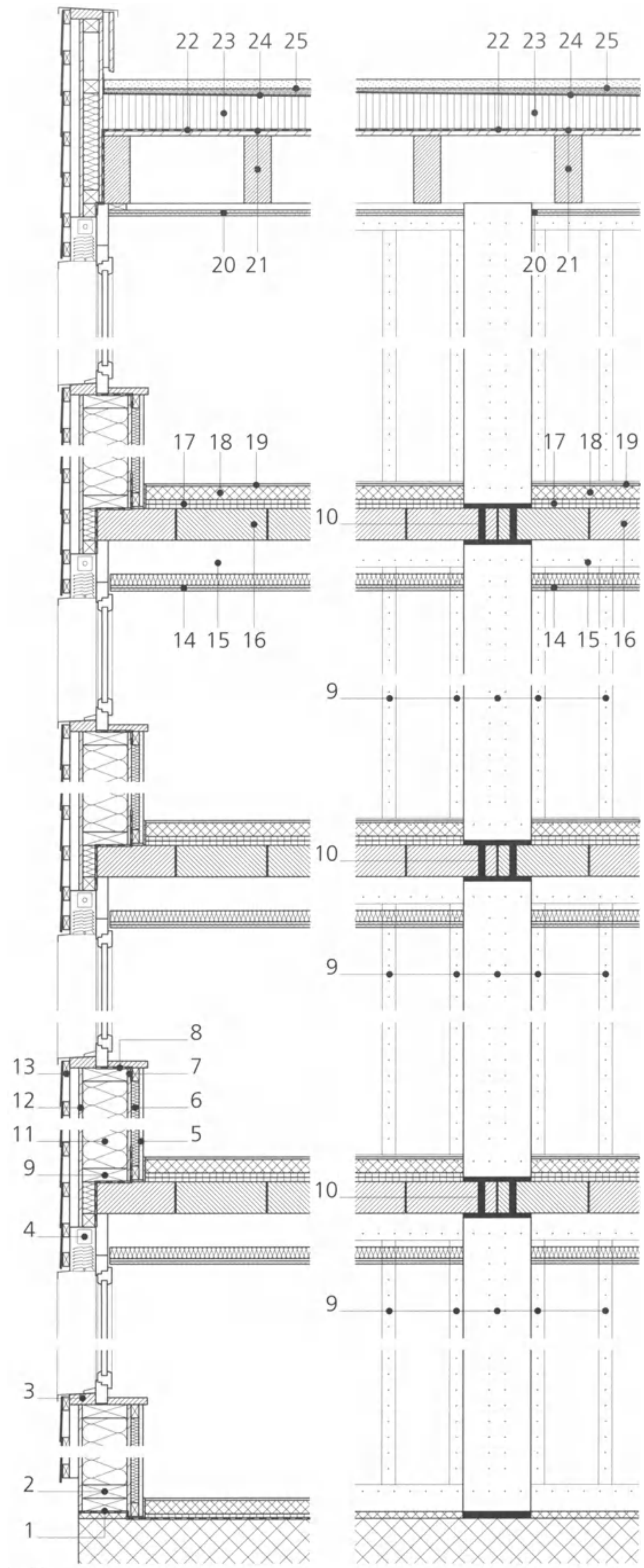
b11 Multi-storey timber buildings

b11 50 Typical sections

Figs. b446 and b447 show two typical sections through multi-storey buildings. Figs. b446 and b445 make use of the construction principle according to example 2 in Fig. b425. Figs. b447 and b448 adhere to the construction principle of example 3 in Fig. b425. In both of these buildings, the loadbearing structure of the stair shaft (in reinforced concrete) is independent of the other parts of the building.

1 Mortar bed, waterproofing, damp proof course, bearing
2 Bottom plate
3 Window sill, normally covered
4 Louvre blinds in storage compartment
5 Internal lining
6 Battens, space for services, additional insulation
7 Structurally effective sheathing, vapour barrier, airtight membrane
8 Joints sealed airtight
9 Loadbearing system with primary and secondary structures
10 Structure, steel components, load transfer in floor zone (see Fig. b425, example 2)
11 Insulation between loadbearing members
12 Protection to thermal insulation
13 External cladding with ventilation cavity
14 Suspended ceiling, non-rigid fixing, attenuated
15 Void for services
16 Floor structure (solid timber)
17 Impact sound insulation
18 Cement screed or dry subfloor
19 Floor covering
20 Ceiling
21 Roof structure (ribbed panel)
22 Waterproofing, airtight membrane, vapour barrier
23 Thermal insulation, roof falls
24 Waterproofing
25 Protective layer, wearing course

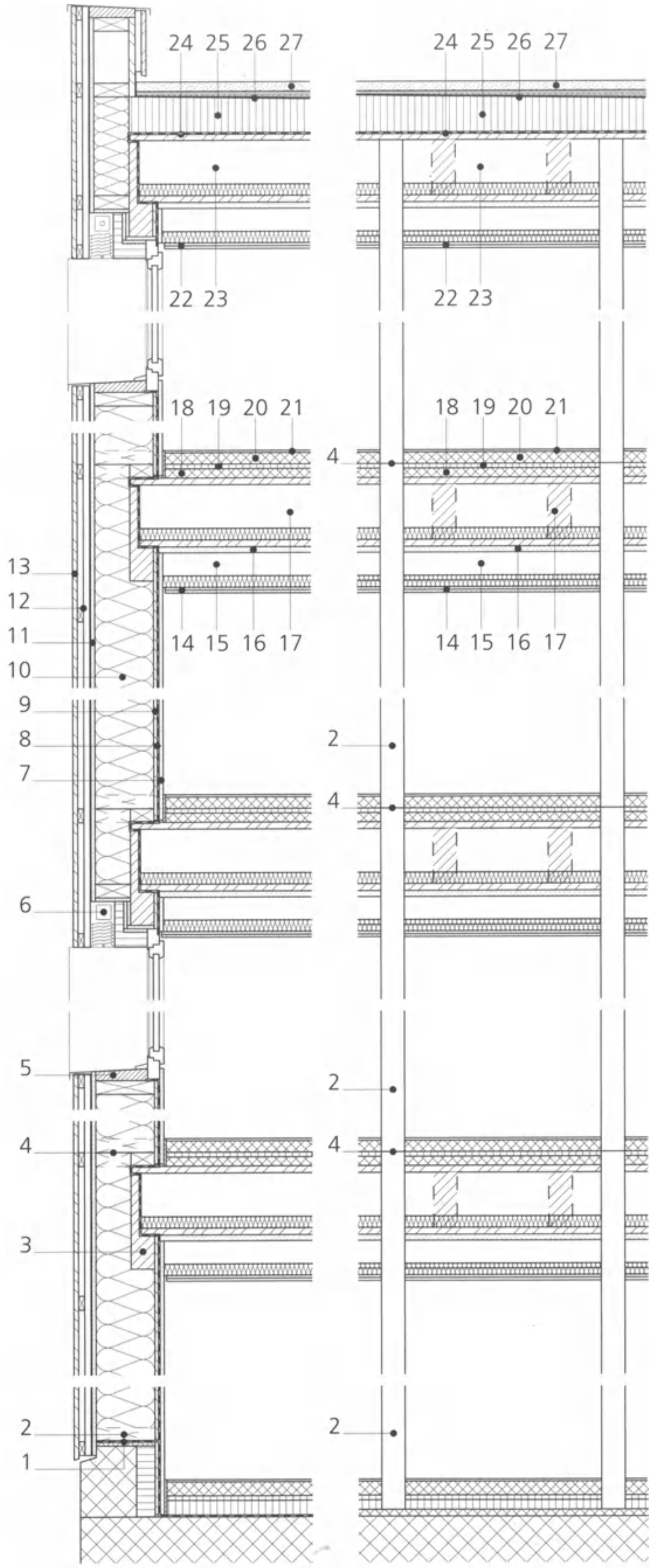
b445



b446

b445 Multi-storey timber building, some parts constructed according to Fig. b446

b446 Section through construction: external wall (non-loadbearing) left, internal wall (loadbearing) right; construction system according to example 2, Fig. b425



b447

1 Mortar bed, waterproofing, damp proof course, bearing
2 Loadbearing structure, column supported over full cross-sectional area, no horizontal timber
3 Loadbearing structure, head binder
4 Loadbearing structure, load transfer via end grain, load transfer in floor zone (see Fig. b425, example 3)
5 Window sill, normally covered
6 Louvre blinds in storage compartment
7 Internal lining
8 Vapour barrier, airtight membrane
9 Structurally effective sheathing
10 Insulation between loadbearing members
11 Sheathing, protection for thermal insulation
12 Ventilation cavity
13 External cladding
14 Suspended ceiling, non-rigid fixing, attenuated
15 Void for services
16 Fire-resistant cladding
17 Floor structure (hollow box, attenuated)
18 Ballast
19 Impact sound insulation
20 Cement screed or dry subfloor
21 Floor covering
22 Ceiling
23 Floor structure (hollow box)
24 Waterproofing, airtight membrane, vapour barrier
25 Thermal insulation, roof falls
26 Waterproofing
27 Protective layer, wearing course

b448

b447 Section through construction: external wall and loadbearing system (elevation); construction system according to 3, Fig. b425

b448 Multi-storey timber building, some parts constructed according to Fig. b447

b11 60 Building services

Building services (plumbing, electrics, heating, ventilation, and air conditioning) require suitable installation spaces. Shafts or ducts serve the primary distribution needs in the vertical direction. The secondary distribution in the horizontal direction requires voids in the floor construction itself or between that and a suspended ceiling or a raised floor. In the external walls, space for the electrical installation (conduits) is very useful. Nevertheless, many applications today make use of separate service ducts for the secondary distribution as well, which enables retrofitting or modifications at any time.

b11 70 Production

The production of prefabricated parts should be carried out in a suitable factory. Adequate accuracy of the parts of the construction must be guaranteed, as well as the use of dry, glued timber. These two latter aspects have become standard and can now be classed as normal. All components are fabricated with the help of very accurate automatic cutting plant and machining stations. When gluing together composite systems, e.g. hollow-box floors, the company must guarantee a controllable interior climate with a temperature of about 20°C. The production of multi-storey buildings involves large quantities of materials. The company must have suitable production and storage facilities at its disposal. Only companies experienced in this type of work should be awarded contracts for multi-storey timber buildings.

b11 80 Erection

The erection of large buildings should be divided into phases. Irrespective of the building form, the work should be broken down into vertical or horizontal segments. The arrangement of these erection phases must be considered during the planning work. Subdividing the building vertically is more advantageous from the point of view of providing protection from the weather. Horizontal divisions, on the other hand, enable a rational erection storey by storey. Structures covering a large plan area that are difficult to divide into vertical sections will benefit from the provision of a temporary roof.

A temporary roof can be provided in the form of a separate, temporary structure, e.g. simple beams plus a covering of corrugated sheet metal or plastic sheeting. Depending on the type of building, it may be possible to build the final roof at an early stage so that it can provide protection while other work proceeds underneath. The roof could be built first and then lifted by crane storey by storey up the building as each storey is built. A temporary roof is, however, unnecessary if the materials being used can withstand the rigours of the weather, at least during the construction phase. In addition, suspended floors can themselves provide protection during the individual construction phases. Larger timber structures have already been erected in this way, especially in Scandinavia and North America, but also in Central Europe. One critical factor here is whether the loadbearing elements are clad or left exposed in the finished structure. If the latter is the case, then it should be remembered that the structural carcass will in the end provide the finished interior. This is efficient and can be realised at reasonable cost, but requires great care be exercised during work on site, and by the following trades especially. Good protection against the weather and soiling, plus good communications between all the parties involved is also imperative.

Coordinated logistics for transport and intermediate storage on the building site and during erection are necessary when building multi-storey buildings. Building sites and the cranes used for erection require adequate working areas and schedules for their use.
Erection schedules render possible trouble-free progress. In addition, the erection conditions of parts of the construction not yet fixed and anchored are easier to specify. Safety measures may be necessary as well.
Industrial safety aspects must be given special attention. Scaffolding should be set up to match the progress of the work. Temporary guarding and covering of openings must be installed wherever necessary. A safety concept helps during the planning of such requirements.

C

Building envelope, walls, suspended floors

Functions, layers, construction

c1 Fundamentals, functions, tasks

c1 10 General

Since the late 1990s, the dwindling of resources has led to major upheavals in general economic conditions, especially with regard to our use of energy. This means that today the energy consumption, operating costs, and long-term functionality plus the maintenance of building components and buildings now requires detailed considerations, calculations, and measures. In addition, questions regarding the availability and ecological value of raw materials and the energy required for the production and use of building materials are becoming more and more important in the construction process. Added to these criteria are demands for a pleasant, healthy interior climate.

Deciding to build in timber can be likened to making a contribution to energy-savings: the building of a timber house costumes, in total, less energy than that required for houses built using other materials [19, 20]. A timber construction can accommodate thick layers of thermal insulation without the need for disproportionately thick walls that consume valuable floor space. Furthermore, it is possible to combine timber with light-permeable elements to achieve passive energy gains from solar radiation, and to use timber in conjunction with all other familiar energy media. Low-, passive- or zero-energy houses, as well as solar architecture right up to the "Minergie" standard, monitored and certified by the Swiss authorities, need not necessarily involve timber construction, but in practice there is a close relationship between timber engineering and these house types. There are good reasons why such houses are linked with the use of timber; for timber saves resources – in terms of acquiring the raw material, during the actual construction, in terms of maintenance, and, finally, upon deconstruction after the structure has served its purpose.

The themes investigated in this book cover the loadbearing structure, the building envelope, and the fitting-out of a building, taking into account the aspects of sound insulation, thermal performance, and moisture control. This fundamental information will help designers and builders understand how the loadbearing structure works, and will explain in detail how the other layers of the construction should be added to the loadbearing structure. Holistic energy concepts, however, require the assistance of a specialist.

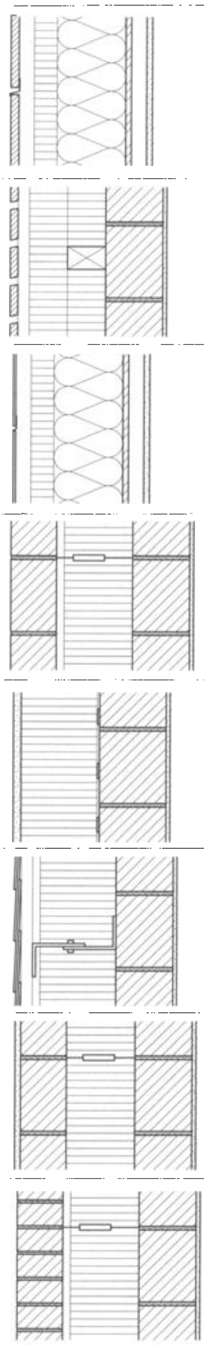
c1

c2

Overleaf:
Office building, Sursee, Switzerland

c1 Falkenweg passive houses development, Dornbirn, Austria

c2 Höcklistein passive houses development, Rapperswil, Switzerland



Wall construction	U-value	Total thickness	Embodied energy
Inner lining Space for services Timber studs with 180 mm cellulose fibre insulation 60 mm wood fibreboard 3-ply core plywood, ventilation cavity, external cladding	0.18 W/m²K	330 mm	**490** MJ/m²
Plaster 150 mm calcium-silicate masonry 200 mm rock wool external insulation Solid timber sheathing, ventilation cavity, external cladding	0.18 W/m²K	410 mm	**560** MJ/m²
Inner lining Space for services Timber studs with 180 mm cellulose fibre insulation 60 mm wood fibreboard Ventilation cavity, fibre-cement sheets	0.18 W/m²K	320 mm	**620** MJ/m²
Plaster Double-leaf (120+150 mm) calcium-silicate masonry 180 mm rock wool cavity insulation	0.19 W/m²K	480 mm	**800** MJ/m²
Plaster 175 mm clay masonry 200 mm rock wool external insulation Render	0.20 W/m²K	390 mm	**880** MJ/m²
Plaster 150 mm calcium-silicate masonry 200 mm rock wool external insulation Ventilation cavity, fibre-cement tiles	0.18 W/m²K	410 mm	**940** MJ/m²
Plaster Double-leaf (120+150 mm) clay masonry 180 mm rock wool cavity insulation Render	0.19 W/m²K	480 mm	**990** MJ/m²
Plaster 150 mm calcium-silicate masonry 180 mm rock wool cavity insulation 120 mm clay facing brickwork	0.2 W/m²K	500 mm	**1340** MJ/m²

c3

c3 Common external wall systems with good thermal insulation, with details of thermal transmittance (homogeneous U-value, without calculating the proportion of timber), overall thickness, and the embodied energy, i.e. that required for its production [19, 20]

c1 Fundamentals, functions, tasks

The most important stipulations of the standards

In Switzerland, Germany, and Austria, the requirements placed on the building envelope are embodied in regional building legislation. The regulations also state that relevant standards and recommendations (SIA, DIN, OE-NORM) must be used where applicable. This book refers mainly to the Swiss SIA standards.
The appendix contains a list of the most important Swiss (SIA) and German (DIN) standards in chapter e3 "Regulations, standards, technical information sheets, aids".

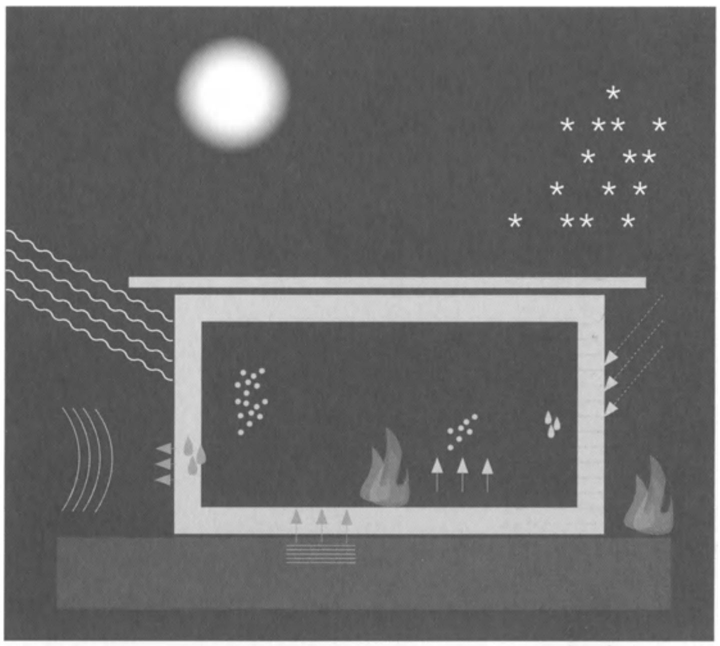
A few of the stipulations of the standards are explained below:
- The U-value (thermal transmittance) of the external walls or the roof is specified as a value between 0.2 and 0.4 W/m^{2}K in the national standards or regulations. Since 2007 a U-value of 0.25 W/m^{2}K has been specified for floors, walls, ceilings, and roofs in contact with the outside air, and 1.5 W/m^{2}K for windows and doors in Switzerland. To maintain the overall energy balance and other comfort criteria, lower U-values may be necessary. Values from 0.15 to 0.2 W/m^{2}K are generally considered to be desirable.
- Thermally insulated pitched roofs must include a secondary waterproofing/covering layer which must cover the entire roof surface and be positioned above the loadbearing structure and above the layer of thermal insulation.
- The building envelope for a heated building must be airtight. This requirement can be met by installing a sheet-type vapour barrier or airtight materials with appropriately sealed junctions, terminations, and joints.
- No unacceptable moistening or condensation formation due to vapour diffusion may occur within the construction (interstitial condensation). Vapour diffusion processes are usually regulated by the use of sheet materials that permit diffusion to a greater or lesser extent, as required. With a suitable arrangement of layers and suitable material properties, forms of construction without sheet-type vapour barriers are also possible.
- The moisture content of timber adjacent to any thermal insulating material may not exceed 16% at the time of enclosing the timber on all sides.

c1 20 Building envelope

c1 21 Building physics functions

A building envelope has to satisfy several building physics functions which are due to the various influences and actions to which the building envelope is subjected. The most important of these are:
- weather protection
- thermal performance
- moisture control
- airtightness
- sound insulation
- fire protection

Individual or a combination of several component layers can be called upon to fulfil the functions of the building envelope. The quality of a building envelope can be derived from the properties of one component layer, e.g. the thickness of the thermal insulation. But it is equally important to ensure that the individual functions are satisfied to the same extent and that they are properly coordinated with each other. Section c1 22 describes the individual component layers, and section c1 23 explains which component layers are used for which functions. Section c1 30 then describes the functions and their tasks individually, whereas chapter c2 contains information on the arrangement and sequence of the component layers in the building envelope.
Load-carrying and stabilizing functions are among those the building envelope has to provide. Depending on the building system chosen, these functions may be integrated directly into the building envelope. For example, in panel construction the external wall construction provides both loadbearing and enclosing functions, but in frame construction the external wall construction is not loadbearing because the frame provides the structural functions, i.e. loadbearing and stability. But in any case the components of the building envelope must be designed so that, in addition to their self-weight, they can deal with other forces that may act on them, e.g. wind forces, and transfer those to the main structural system. And they must do this irrespective of whether or not the primary structure is incorporated into the external wall. The loadbearing functions are described in detail in part b, arranged according to building system and form of construction.



c4

c1 22 Component layers

The individual component layers have to satisfy the tasks described in section c1 21. The building envelope is terminated on the outside by its cladding/finishes on the facade, or its roof covering/finishes. These layers constitute the primary protection against external influences and actions. Secondary waterproofing/covering layers and materials protecting the thermal insulation, in conjunction with ventilation cavities or spaces, protect against those weather effects (drifting snow, driving rain, backed-up water, etc.) that manage to penetrate the cladding or covering. The thermal performance, sound insulation, moisture control, and airtightness functions are fulfilled by further layers. On the inside, additional layers may be necessary if building services are to be installed within the building envelope. Soffit and wall linings terminate the building envelope on the inside.

The individual component layers of a roof construction are:
- roof covering/finishes
- ventilation space
- secondary waterproofing/covering
- thermal insulation
- vapour barrier
- airtight membrane
- battens, space for services
- soffit lining, internal finishes

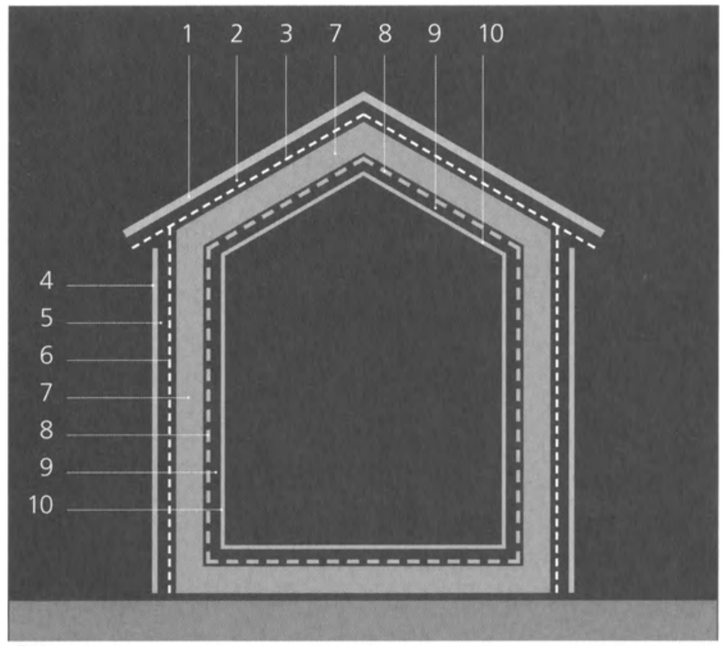
The individual component layers of an external wall construction are:
- external cladding, facade finishes
- ventilation cavity
- protection for thermal insulation
- thermal insulation
- vapour barrier
- airtight membrane
- battens, space for services
- inner lining, internal finishes

Layers such as the ventilation cavity or ventilation space, space for services, battens, protection for thermal insulation, or vapour barrier may be unnecessary in some types of construction, or may be combined with other layers. In the majority of cases, however, allocating individual functions to individual layers improves the functionality and the fault tolerance of a particular form of construction. What is important is that all the building physics functions of a building envelope should be covered by the component layers available, regardless of whether one or more layers are responsible for certain functions, or a single layer takes on several functions.

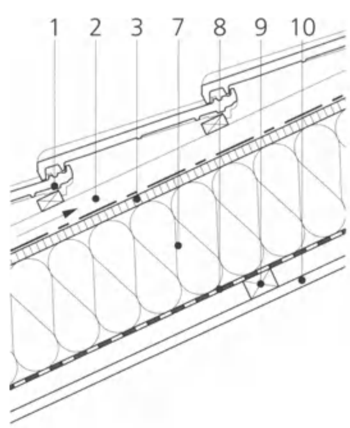
Fig. c5 shows the various component layers of a building envelope in tabular form. Figs. c6 and c7 show the layers in more detail for the roof and external wall constructions.

c4 Important influences on the building envelope

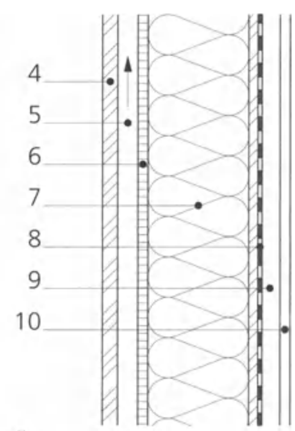
1 Roof covering: protects the underlying components against the effects of the weather (c1 31 "Weather protection", c2 21 "Roof covering, external cladding", c4 "Pitched roofs")
2 Ventilation space: ventilates the roof covering and the secondary waterproofing/covering layer; there may be one or two ventilation spaces, see Figs. c103 and c104 (c1 31 "Weather protection", c2 22 "Ventilation", c4 "Pitched roofs")
3 Secondary waterproofing/covering layer: weather protection during construction, run-off layer for moisture that has penetrated the roof covering, ice, backed-up water,, also protects against dust or drifting snow (c1 31 "Weather protection", c2 23 "Secondary waterproofing/covering layer", c4 "Pitched roofs")
4 External cladding or other finishes: weather protection and architectural design element (c3 20 "External cladding")
5 Ventilation cavity: ventilates the external cladding (c1 31 "Weather protection", c1 33 "Moisture control", c2 22 "Ventilation")
6 Protection for thermal insulation: protects the insulating material and the inner wall construction (c1 31 "Weather protection", c1 32 "Thermal performance", c2 22 "Ventilation")
7 Thermal insulation: ensures the necessary thermal performance in summer and winter, provides some sound insulation (c1 32 "Thermal performance", c2 24 "Thermal insulation")
8 Vapour barrier, airtight membrane: prevents unacceptable ingress of moisture due to convection and vapour diffusion, ensures the necessary airtightness (c1 33 "Moisture control", c2 25 "Vapour barrier", c1 34 "Airtight membrane", c2 26 "Airtight membrane")
9 Battens, space for services: supporting framework for the inner lining and at the same time space for pipes and cables (c2 27 "Space for services")
10 Soffit or wall lining: terminates the construction on the inside of the wall or roof construction (c3 30 "Inner linings")



c5



c6



c7

c5 Building envelope component layers

c6 Component layers, roof

c7 Component layers, external wall

c1 23 Allocation of the functions and tasks of the component layers

Individual component layers can be used for one or more functions. When assessing sound insulation, but also other building physics functions such as thermal performance or moisture control, it is best to include the entire wall or roof construction in the assessment. Ideal protection against the weather also entails considering the roof covering together with the secondary waterproofing/covering layer, or the external cladding in conjunction with the layer protecting the thermal insulation. Figs. c8 to c13 show the relationships between the component layers and their assignment to the various functions.

c8 Weather protection
Primary function: roof covering/finishes, external cladding/finishes. Secondary function depending on construction: secondary waterproofing/covering layer, protection to insulation.

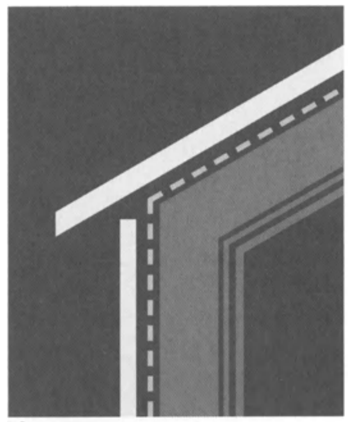
c9 Thermal performance
Primary function: thermal insulation. Secondary function depending on construction: protection for insulation, secondary waterproofing/ covering layer, inner lining.

c10 Moisture control
Primary function: vapour barrier. Secondary function depending on construction: inner lining, protection to insulation, thermal insulation.

c11 Airtightness
Primary function: airtight membrane. Secondary function depending on construction: inner lining, protection to insulation, secondary waterproofing/covering layer.

c12 Sound insulation
High sound insulation values are achieved with specific measures, usually related to the overall construction.

c13 Fire protection
High fire resistance values are achieved with specific measures, usually related to the overall construction; for the roof covering and the external cladding, special requirements such as the distance to nearby structures must be considered (see chapter d3).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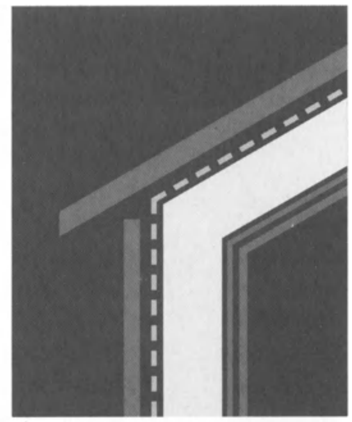
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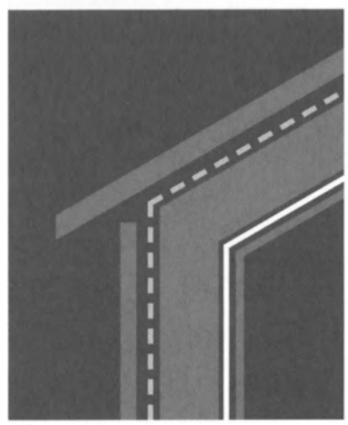
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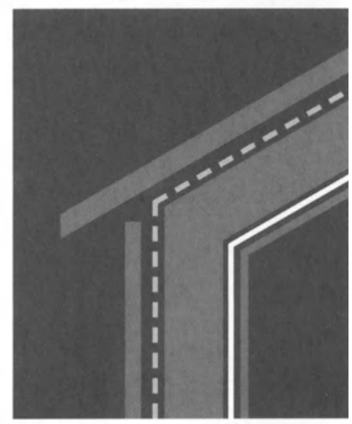
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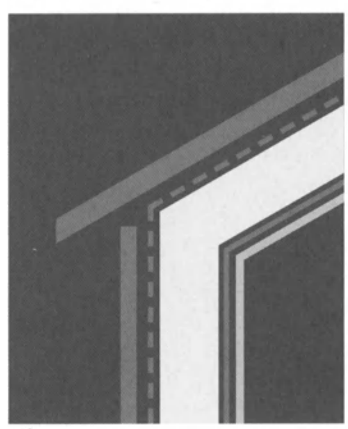
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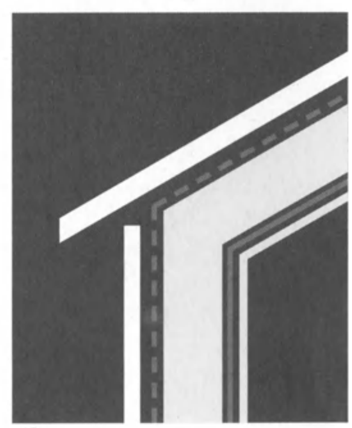
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c8 to c13 Functions and component layers

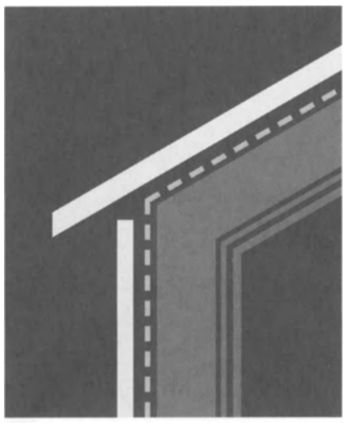
Primary function

Secondary function

Other components

c1 30 Functions, tasks, and performance

c1 31 Weather protection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Roof covering/finishes, wall cladding/finishes

The roof covering and wall cladding or other finishes protect the other components and parts of the construction against rain, snow, hail, wind, solar radiation, and mechanical damage. Adequate protection is provided when water or moisture can infiltrate the construction to a limited extent only, and then either drain away or dry out completely without having any detrimental effects. As a rule, the covering of the roof and also the cladding of the external walls should be designed with a ventilation space. The materials and systems selected must be able to withstand the aforementioned effects permanently. Defective weather protection can lead to long-term damage in the form of reduced thermal performance, mould growth, rot, and corrosion.

Ventilation

Roof and external wall assemblies with ventilation spaces have better building physics properties. The most important aspect here is the improvement to the drying-out behaviour of the overall construction, as any moisture that infiltrates can be carried away by convection. In addition, ventilation relieves the vapour pressure, and there are also certain advantages with respect to summertime thermal performance, although this does depend on the type of construction (section c1 32). Rendered facades can be built with or without a ventilation cavity – the latter in the form of a thermal insulation composite system. Moreover, there are a few types of timber facades that can be built with or without a ventilation cavity depending on the actual construction of the wall and the allocation of the functions. Many facades finished with tiles or shingles do not include a ventilation cavity because they function together with their underlay (see Fig. c92, for example). Furthermore, recent years have seen the appearance of so-called monolithic timber structures that supposedly do not require a ventilation cavity. Important for all assemblies without a ventilation space is that all the parts of the wall construction must be coordinated with respect to their vapour diffusion behaviour, and the outermost layer (cladding) should be designed so that it provides the entire weather protection.

Secondary waterproofing/covering layer (roof)

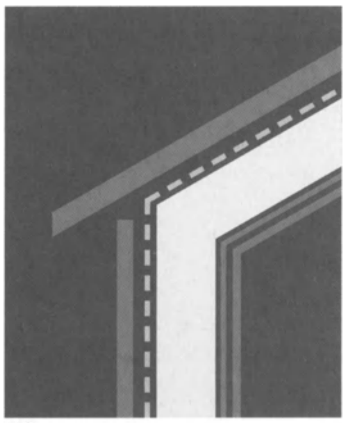
All thermally insulated roofs require a secondary waterproofing/covering layer positioned above the loadbearing structure and the thermal insulation. This layer must also provide temporary weather protection during the construction phase, up until the final roof covering is finished. In addition, it protects against moisture (e.g. drifting snow) and dust that penetrates the roof covering, either because of defects or because the roof covering itself is not perfectly sealed (e.g. roof tiles). Secondary waterproofing/covering layers are available to meet greater demands such as the infiltration of backed-up water, and the formation of ice – tasks that are especially important for buildings in exposed locations or at high altitudes. With roofs where the ventilation space is above the secondary waterproofing/covering layer (see chapter c4 "Pitched roofs"), use of a suitable material can prevent heat loss due to convection. The secondary waterproofing/covering layer is usually in the form of bitumen-impregnated wood-fibre insulating boards, cement fibreboards, or plastic or other sheeting open to diffusion.
In the case of flat roofs without a ventilation space, the secondary waterproofing/covering layer is superfluous, although the inclusion of a waterproofing layer that provides protection during construction, until the final roof covering is complete, may be advisable with certain types of construction.

Protection for thermal insulation

This layer separates the layer(s) of thermal insulation from the ventilation cavity and protects insulating materials against excessive moisture during the construction phase. Even after the building work is finished, this layer prevents any moisture that may penetrate the external cladding from reaching the thermal insulation. This layer brings further advantages with respect to thermal performance and moisture control, and also improves the fault tolerance if there are minor defects in the airtight membrane.

c14 Sketch of the principle of weather protection

c15



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c1 32 Thermal performance

Thermal insulating materials integrated into roof and wall constructions reduce heat transfer through the building envelope in both summer and winter. The high standard of building insulation required these days to save energy also helps to achieve a pleasant interior climate. The inner surfaces of the components remain free from condensation.

Thermal performance in winter

Thermal insulation layer: position, thermal bridges

Whether and to what extent energy is transported through the building components depends on the thermal insulation properties (U-values) of the suspended floor, wall, and roof constructions. The provision of insulating materials with low thermal conductivity results in a high level of thermal insulation. In timber buildings there are often voids between the loadbearing members which can be filled with insulating materials. This is a sensible arrangement because the loadbearing structure provides support and protection, therefore making slender but nevertheless well-insulated constructions are possible. One exception to this approach involves the use of solid timber components, because in the majority of solid timber building systems the form of construction dictates that thermal insulation be placed around the outside of the planar, closed loadbearing elements (see also chapter b8).
Those timber components that are installed in the plane of the thermal insulation layer must be included proportionally in the U-value calculation. In timber buildings thermal bridges due to the loadbearing timber construction do not generally present any problems with respect to surface condensation and mould growth. But as thermal insulation values gradually improve, the significance of the thermal bridges is growing from an energy viewpoint. For example, the U-value of a roof is better with narrow, deep rafters than with wide, shallow cross-sections because the former arrangement reduces the proportion of timber in the insulating layer (measured as a proportion of the area). Accordingly, the U-value increases or decreases depending on the spacing of the rafters. It is therefore advantageous to install an additional layer of insulation in roofs and walls, which is generally attached to the outside of the loadbearing layer. The influence of timber (spacer) battens that may be required is minimal, especially when these are placed transverse to the loadbearing direction of the primary structure. Requirements concerning the positioning and arrangement of the insulation according to the building system can be found in part b of this book: b6 40 (panel construction), b7 60 (frame construction), b8 20, and b8 30 (solid timber construction).

Materials

The thermal insulating materials used in timber buildings are mainly inorganic mineral-fibre materials (glass wool and rock wool), cellulose-based materials (wood fibreboards, cellulose flakes, cellulose mats), plus other materials such as cork, coconut fibres, sheep's wool, etc. Sheets of synthetic foam materials are used only very rarely. Soft, flexible materials are easier to fit around the timber components than rigid boards, and that also minimises the number of joints between the layer of insulation and the timber members. Boards made from wood fibres or mineral wool that exhibit sufficient rigidity and density can be installed over the entire area of a timber structure without the need for spacer battens.

Thermal transmittance, U-values

The thicknesses of insulating materials common today – 200 mm and more – result in timber structures with a good to very good thermal performance. Theoretically, if we ignore the timber structure and the remaining component layers, a U-value of 0.30 W/m²K can be achieved with 120 mm of insulation. If the timber components are taken into account, and that is the norm at present, in order to achieve the same U-value the thickness of insulation must be increased to 170 mm when the proportion of structural components is 15%, or 200 to 220 mm for 30%. If the insulation is installed in two layers, the overall thickness can be reduced to 160 mm for a 15% proportion of timber components, or 180 mm for 25%. Wall or roof constructions with a U-value of approx. 0.20 W/m²K can be achieved with about 200 mm of insulation

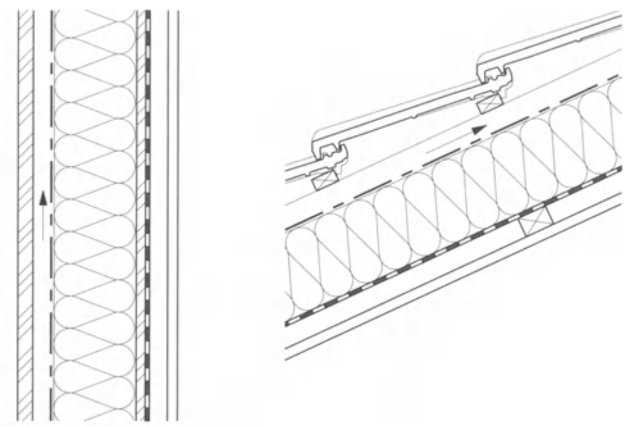
c15 Erection of highly insulated roof elements

c16 Sketch of the principle of thermal insulation (taking into account a timber proportion of 15%). If the proportion of timber is 25–30%, a layer of insulation approx. 240 mm thick will be required. To achieve these values, two layers of insulation are necessary: the first layer is in the same plane as the loadbearing elements, i.e. between the timber members, the second layer encloses the loadbearing structure on the outside.

U-values below 0.15 W/m²K can be readily achieved for passive-energy houses, but the thickness of insulation can exceed 300 mm, depending on the proportion of timber and the type of insulating material. Other important requirements are a good degree of airtightness and the elimination of thermal bridges. As the U-value decreases, thermal bridges become more and more significant. The proportion of timber over the whole cross-section should therefore be minimised because timber conducts heat approximately four times better than insulating materials. The detailing at all junctions and joints (corners, windows, doors, plinths, suspended floors, etc.) therefore requires special attention. Figs. c17 to c19 show construction examples with U-values of 0.30 W/m²K, 0.20 W/m²K, and 0.10 W/m²K. Further information regarding the U-values of wall and roof constructions can be found in chapters c3 "External walls", c4 "Pitched roofs" and c5 "Flat roofs".

Surface temperature, thermal conductivity, heat capacity
Besides an insulating material with a low thermal transmittance, minimal thermal bridges, and high airtightness, the heat storage capacity and the surface temperature characteristics of the building components have an – albeit not easily calculable – influence on the interior climate and the temperature of the interior air. Impartial investigations unrelated to any particular material are lacking in this area. But the thicknesses of insulating materials common these days makes this situation less significant, although much has been written about this and many different views prevail.

Today, timber structures also contain thicker, more solid layers in the construction in addition to thick layers of insulation. Because of their very nature, solid timber structures (see chapter b8) have advantages here over forms of construction with thin layers of sheathing. Buildings in panel construction, however, can be improved considerably by selecting the right mate-



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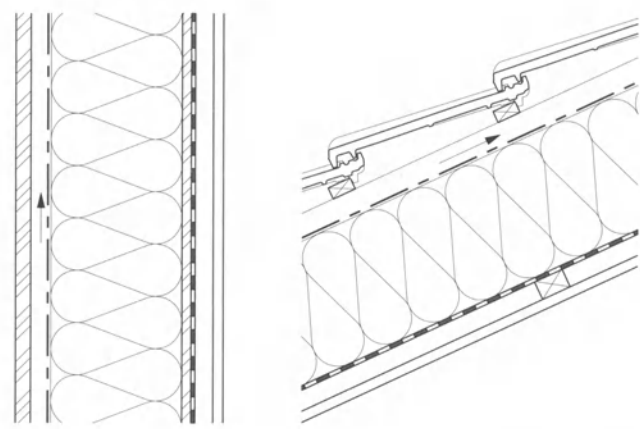

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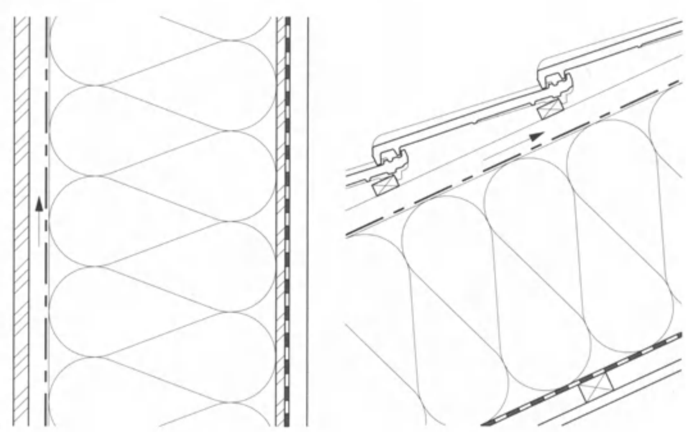
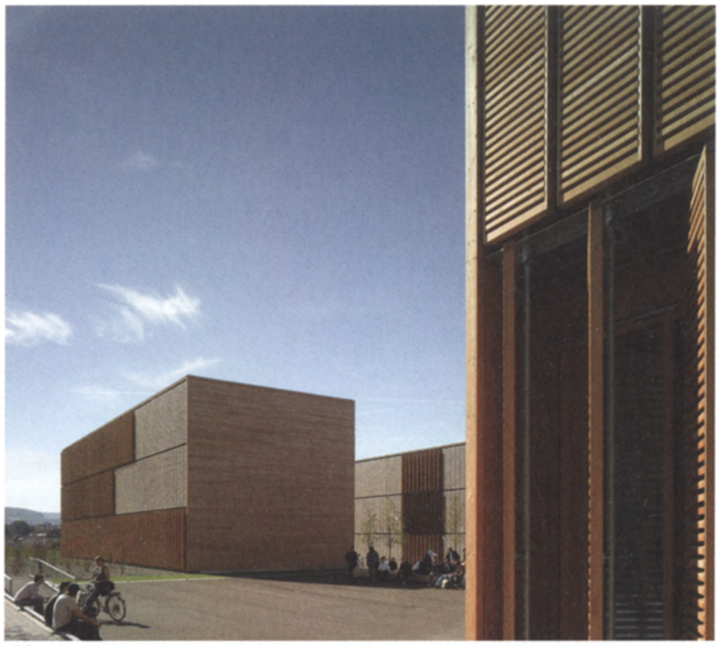


c19

c17 Wall and roof constructions with a U-value of 0.30 W/m²K
c18 Wall and roof constructions with a U-value of 0.20 W/m²K
c19 Wall and roof constructions with a U-value of 0.10 W/m²K



c20

rials (section b6 40). A good choice of materials and a carefully planned form of construction will in any case prove worthwhile: to reduce energy consumption, create pleasant interiors, and also to ensure interiors with stable, hardwearing, internal finishes to walls, floors, and soffits. Timber construction exhibits major advantages in these areas, which can be exploited through the right choice of material and construction. It should be mentioned that owing to wood's lower thermal conductance, it feels warmer to the touch than materials with a high thermal conductance, e.g. concrete or steel, with the same surface temperature. In winter interiors are therefore experienced as more agreeable although the surface temperature of the construction is identical.

Thermal performance in summer

Criteria, influences

Even during the warmer months, the prime task of the layer of thermal insulation is to guarantee the thermal comfort of the building's occupants or users. In principle, summertime thermal performance is governed by the same parameters as wintertime thermal performance. Good thermal performance with low U-values for the winter therefore corresponds to good thermal performance in summer. There are, however, a number of additional criteria that apply in summer.

The critical factors for thermal performance in summer are:

- A high total thermal resistance and a low thermal transmittance (U-value) for the external walls and the roof.
- Shading of transparent building components; this – besides the U-values of opaque components – is the most important factor and cannot be compensated for by other measures.
- Suitable options for night-time cooling, the correct behaviour of occupants and users.
- Sufficiently large, functioning ventilation spaces and cavities on both sides of the layer of thermal insulation.
- A construction (building components) with good thermodynamic behaviour, characterised by a dynamic thermal transmittance (U_{T24} value) of max. 0.20 W/m²K.
- The U_{T24} value of max. 0.20 W/m²K prescribed by SIA 180 "Thermal performance and moisture control in buildings" can be achieved in the case of lightweight components, for example, by installing a layer of thermal insulation 180 mm thick or by ensuring an adequate thermal mass when such a thickness of insulation is not possible.

Materials

Whether summertime or wintertime thermal performance is concerned, the same insulating materials are involved. Depending on the concept chosen, materials on the inside of the construction with a large mass and a large heat capacity can be important.

Effects

High outside temperatures and long exposure to sunshine can lead to excessively high internal air temperatures in occupied buildings, and especially in the roof spaces. If the external components are insulated according to the latest requirements and are also assembled with regard to the needs for summertime thermal performance, then the main cause of overheating is usually the lack of, or inadequate, sunshades over the windows, areas of glazing or other transparent components. In addition to that, it is necessary, even with very effective sunshading, to ensure good ventilation during the cooler hours of the evening, night, and early morning. In this context, the capacity of the external components to store heat is virtually insignificant.

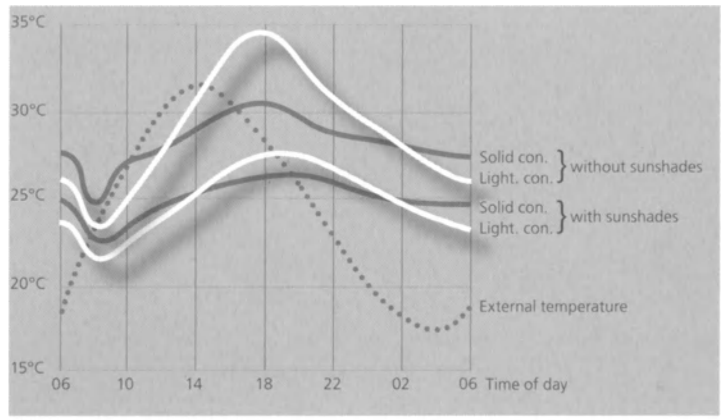
The temperature curve of a timber building over the course of a day follows the rise and fall of the outside temperature faster than that of a concrete or masonry building. The pleasant coolness of the night in summer is therefore felt more quickly, likewise the increase in temperature as the sun rises in the morning. Studies carried out back in 1978 reveal that there is no significant difference between the summertime temperature behaviour of lightweight buildings and comparable heavyweight constructions (Fig. c21). As already mentioned, sunshading measures for transparent components (e.g. windows, glazed doors) are critical – regardless of the form of construction of the building. Likewise, the

c20 To achieve good summertime thermal performance, external sunshades for transparent components are extremely important, irrespective of the type of construction.

ventilation of the roof and the external walls has an advantageous effect on a building's thermal performance in summer. The data given in Fig. c21 for comparing timber and concrete or masonry buildings was collated in 1978. At that time, the layers of insulation used were considerably thinner than today, where thicknesses of 200 mm and more are not uncommon. In addition, modern timber buildings contain heavier sections and thicker layers of sheathing than was the case in the late 1970s. These changes have resulted in major changes in the possible heat conduction through the components. These days, using external timber components insulated to current standards, it is hardly possible to register a temperature rise in the interior. With the right construction and suitable behaviour by the occupants/users (assuming night-time cooling and shading are possible), the thermal performance of timber buildings in summer is certainly comparable with that of concrete or masonry buildings.
Shading for the transparent components must be provided on the outside so that the solar radiation is reflected before it strikes the window or other transparent component. Only a small part of the solar radiation that enters a room can be reflected back out again; it heats up any internal sunshade, which then radiates the heat into the room. External sunshades are 7 to 10 times more effective than those located internally (Fig. c20).

Protection for thermal insulation

Materials designed to protect thermal insulation are placed on the outside of the insulation in order to prevent excessive cooling of lightweight, porous insulating materials and to prevent airflows behind the layer of insulation. The insulating effect of unprotected insulating materials can be impaired by infiltrating outside air. Plastic sheeting, building papers, insulating boards, and other board-type products such as plasterboard or wood-based boards – all open to diffusion – are suitable materials for protecting thermal insulation. In timber construction the thermal insulation protection function is frequently provided by thicker and stiffer boards, e.g. 40, 60, 80, or 100 mm thick, that protect the insulation and at the same time improve overall thermal performance. In this form of construction the boards enclose the loadbearing structure. Ideal products are wood fibreboards but also boards made from dense mineral wool (60 kg/m^3 or higher), which are sufficiently dense [22] and do not require any protection against excessive cooling.



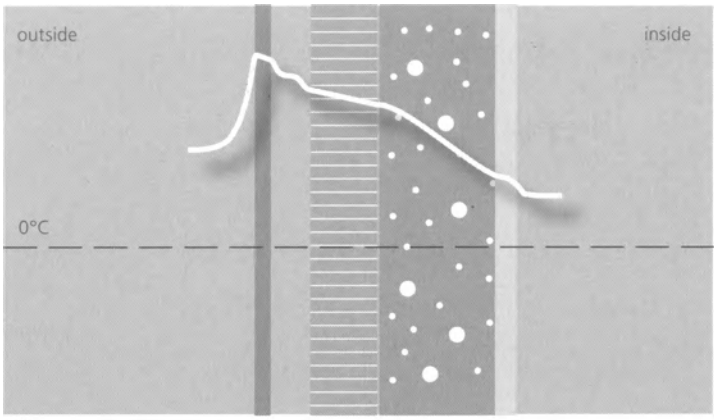
c21

Depending on the thickness of the mineral-wool boards or wood fibreboards, thermal performance in both summer and winter can be improved considerably. At the same time, such boards serve to protect the underlying layers of thermal insulation. And the use of wood fibreboards improves the sound insulation of the external wall in addition to the thermal insulation.

A layer protecting the thermal insulation also prevents damage to and saturation of it during construction, and it can also help to keep lightweight or loose insulating materials in place. In terms of its diffusion resistance, this layer must be coordinated with the overall construction; owing to its position outside the actual layer of insulation, it should exhibit a minimal diffusion resistance. As a rough guide, the outer layer must be at least 10 times more open to diffusion (s value 10 times lower) than the inner layer.

The layer protecting the insulating material is sometimes referred to as a windproof membrane. This designation is, however, deceiving because this layer is often confused with the actual airtight membrane. The layer protecting the thermal insulation cannot fulfil the function of an airtight membrane. There is a similarity with the roof construction here: a secondary waterproofing/covering layer in the roof has the same function as the thermal insulation protective layer in an external wall. Other layers are responsible for the airtightness in both the roof and the external wall, and such layers are placed on the *inside* of the thermal insulation.

c21 Temperature progression over the course of a day in the living room of a detached house depending on the form of construction (steady state) [21].
This study was carried out in 1978. In newer buildings, better thermal insulation introduced in order to save energy results in smaller differences than those shown here.



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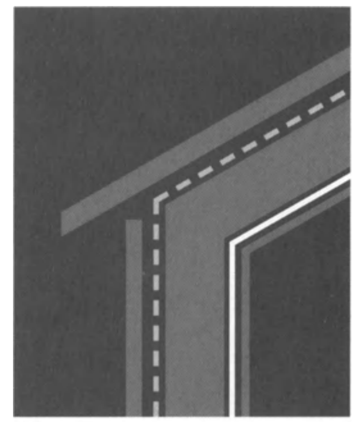
Ventilation cavities and spaces

During the warmer seasons, the external finishes (roof covering, wall cladding) are heated up by the sun and this results in surface temperatures considerably higher than those of the external air, especially in the case of dark surfaces. A ventilation space or cavity behind external finishes serves as a "radiation shield", which – depending on the cross-sectional area, the speed of the airflow, and the length of the rafters or height of the facade – can help to carry away considerable amounts of heat energy (Fig. c22). The ventilation cavity or space thus contributes to the overall thermal performance, but its influence on the interior climate is much reduced nowadays owing to forms of construction now common.

Summing up, the following criteria are important for good thermal performance:

- An insulation layer with a good total thermal resistance; typical thicknesses are 200 to 300 mm for new buildings and 180 to 220 mm for refurbishment projects.
- A low proportion of loadbearing members (thermal bridges) compared to the layer(s) of insulation; there are advantages in using two layers of insulation.
- Taking into account the proportion of timber in the insulation layer when calculating the U-value.
- Good and permanent airtightness over the whole surface and at all joints and junctions.
- A construction with a suitable diffusion behaviour.
- Good heat storage capacity and a low thermal conductivity for the innermost component layer (inner lining).

c1 33 Moisture control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The effects of moisture are characterised by diverse, superimposed interactions. These are caused by changes to the climatic and usage conditions in summer and winter, also the change from day to night, or between rain and sunshine. The aim of moisture control measures is to limit such effects so that they do not cause any damage over the entire service life of the structure. It is therefore important to assess and consider the loads, deformations, and ageing processes as realistically as possible.

Moisture comes in various forms:

- precipitation
- construction moisture
- water vapour diffusion
- convection
- surface condensation
- capillary action
- latent heat processes

The causes of and associated measures related to water vapour diffusion and convective moisture transport are explained in detail below (vapour barrier, water vapour diffusion and airtightness, convective moisture transport). The latter – alongside the effects of precipitation – is certainly the most troublesome moisture effect in timber construction. Water vapour diffusion processes are often discussed, but are actually less important in terms of sources of damage. The other moisture processes are briefly described below.

Precipitation

It is generally known that moisture coming from the outside, i.e. rain and snow, and also groundwater and run-off water, has to be drained away. Melting snow and ice formation in the form of backed-up water, etc. also needs to be considered. The measures

c22 Summertime temperature gradient in direct sunlight (sketch of principle)

c23 Sketch of the principle of moisture control necessary to deal with the effects of these forms of moisture can be allocated to "passive moisture control". Section c1 31 "Weather protection" contains the necessary information.

Construction moisture

Moisture due to wet building trades plays a role when timber components are built in with a high moisture content, i.e. higher than that recommended, or the construction is unable to dry out adequately. The correct moisture content for timber during installation are given in chapter d1 "Moisture content". Storing timber unprotected on the building site, or a high relative humidity caused by, for example, foggy conditions, but also excessive construction moisture can lead to an unacceptably high moisture content in the wood. The timber should therefore be protected against the effects of moisture during transport and on the building site.

Capillary action

Water in liquid form can be transported by means of capillary action; this is caused by the surface tension of water. The extent of this phenomenon depends on the dynamic effect of the cell walls. Capillary action in wood is considerably greater parallel to the grain than perpendicular to the grain. Timber components must be protected against becoming wet through capillary action. This affects all components in contact with the soil, splashing water, concrete or masonry components, etc.

Surface condensation

Surface condensation is rare in true timber construction. In timber loadbearing structures containing steel components, and primarily where steel beams or similar forms of construction penetrate external components, surface condensation should be ruled out with the help of isotherm calculations carried out by a building physics specialist. Even better is to avoid such forms of construction from the very outset. Discoloration due to poorly insulated windows, glazing, or support elements, or sheathing fitted with metal fasteners is not unknown. Such discoloration, which is also known as surface condensation, is usually attributable to thermal bridges: the temperature at that point on the component's surface is lower than the dew point of the surrounding air.

Latent heat processes

Water changing from its vapour to its liquid state and from its liquid to its solid state involves latent heat processes. A build-up of ice near of waterproofing and secondary waterproofing materials and the corresponding, subsequent damage as the ice melts should not be underestimated.

Vapour barrier

The migration of water vapour from inside to outside should be taken into account right from the very start by choosing appropriate forms of construction and materials. Building practice dictates that the diffusion resistance of the individual layers must decrease from inside to outside. Just how open or resistant to diffusion the regulatory vapour barrier on the inside of the thermal insulation should be essentially depends on the nature of the wall or roof construction, the ventilation, the interior climate of the adjoining rooms, and the changing climatic conditions of the surroundings. An effective vapour barrier reduces the diffusion of water vapour such that no damaging amounts of condensation build up within the construction (interstitial condensation).

Detailed requirements are laid down in the national standards; German standard DIN 4108 "Thermal insulation and energy economy in buildings" and Swiss standard SIA 180 "Thermal performance and moisture control in buildings" contain further information. For example, according to the Swiss standard the total amount of condensation in the condensation period may not exceed 3% by wt. for timber and wood-based products, or 1% by vol. for insulating materials. In unfavourable conditions the diffusion must be verified. This is mainly necessary in the case of a high relative humidity internally, external walls with no ventilation cavity, flat roofs with no ventilation space, and special applications (e.g. indoor swimming pools, etc.). The forms of construction described in SIA 180 for buildings for normal residential or working uses that do not require verification are shown in Figs. c24 to c29. The most important conditions for such forms of construction are a ventilation cavity behind the external cladding and absolute airtightness.

Forms of construction with plastic sheeting on the inside acting as a vapour barrier are well established. As the diffusion resistance

c24 to c29 In a form of construction that favours diffusion, verification of the actual diffusion behaviour is unnecessary, provided the loads are not greater than those for normal residential and working uses (SIA 180 "Thermal performance and moisture control in buildings"). In all forms of construction, a seamless airtight membrane over the entire building envelope is an important requirement. The details at junctions, joints, and penetrations require special care because a good, permanent airtight seal is essential.
1 Airtight membrane

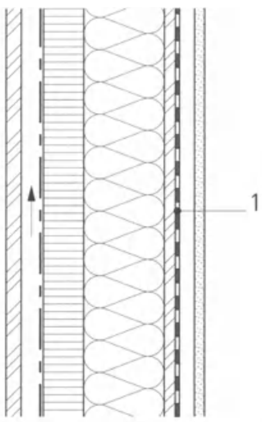
required varies according to the form of construction, different plastic sheets and building papers can be used. The vapour barrier function, however, can also be achieved with board-type materials such as OSB, multi-ply boards, plywood, etc.

External walls and roofs are increasingly being designed as open to diffusion, which means that the components are permeable to water vapour on the outside (cold side) to the extent that a separate vapour barrier is unnecessary on the inside (warm side). Such forms of construction have a vapour barrier layer on the inside (solid timber, wood-based product) and a ventilation cavity behind the external cladding, or a ventilation space beneath the roof covering.

Besides conventional vapour barriers with a constant diffusion-equivalent air layer thickness s, vapour barriers with a variable diffusion resistance have appeared on the market in recent years. Such vapour barriers with a variable diffusion resistance, or rather capillary absorption behaviour (adaptive moisture properties), promote drying and improve the moisture tolerance of troublesome forms of construction. Vapour barriers with such adaptive moisture properties should be preferred for the internal insulation layers of timber-frame or log buildings, for flat roofs and external walls with no ventilation spaces/cavities, and also for junctions between components where the position of the vapour barrier and airtight membrane changes.

Airtight membrane

The transport of moisture by convection involves the movement of the water molecules in the airflow. This becomes a problem primarily when warm, moist interior air infiltrates into the construction at joints and junctions between components and condenses on the colder layers of the construction. The significance of convective moisture transport was underestimated for a long time. In the meantime, however, it is accepted that thermally insulated timber constructions require a permanent airtight membrane on the inside (see section c1 34). Nevertheless, moisture damage caused by convection is still one of the most frequent causes of damage in timber buildings. In the majority of cases air leaks at junctions between components, at joints between elements, or around penetrations of all kinds are responsible for these problems.



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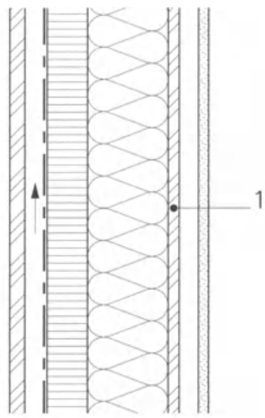

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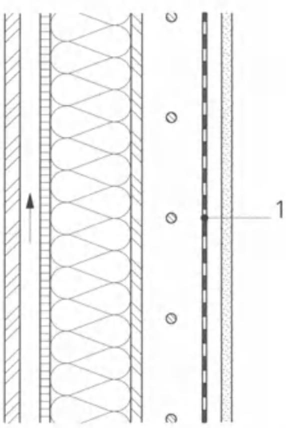

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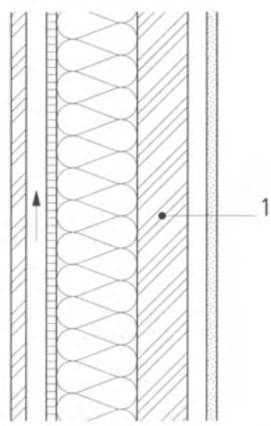

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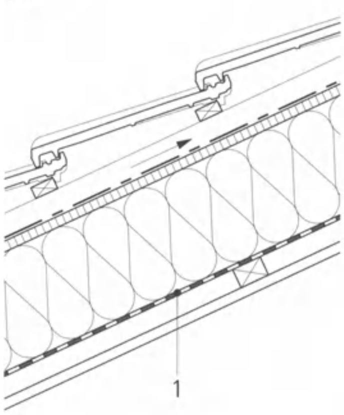

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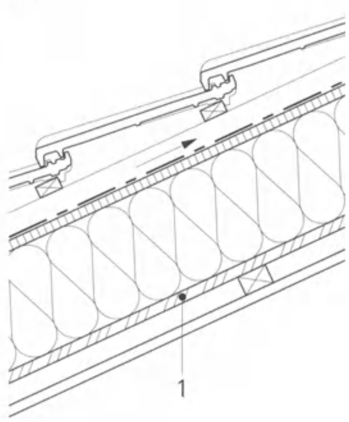


c29

c24 Wall in panel construction, with intermediate insulation and, possibly, external insulation. The airtightness is guaranteed by a separate plastic sheet.
c25 Wall in panel construction, with intermediate insulation and, possibly, external insulation. The airtightness is guaranteed by airtight sheathing.
c26 Wall in solid timber construction with external insulation. The airtightness is guaranteed by a separate plastic sheet.
c27Wall in solid timber construction with external insulation. The airtightness is guaranteed by airtight sheathing.
c28 Pitched roof construction with intermediate insulation and secondary waterproofing/covering layer and, possibly, external insulation. The airtightness is guaranteed by a separate plastic sheet.
c29 Pitched roof construction with intermediate insulation and secondary waterproofing/covering layer and, possibly, external insulation. The airtightness is guaranteed by airtight sheathing.

Ventilation cavities and spaces

The primary function of ventilation cavities and spaces is to allow the airflow to carry away any moisture present by way of convection. Whether the moisture is a result of vapour diffusion, precipitation or wet building trades is irrelevant in this case. The relevant standards provide guidance on the dimensions of ventilation cavities and spaces.

Basically, we distinguish between external walls with and without a ventilation cavity, and between roofs with one or two ventilation spaces. Ventilated constructions are regarded as favourable from a diffusion viewpoint, and do not require the diffusion behaviour to be verified by calculation, provided the moisture loads do not exceed those equivalent to normal residential and working situations. The stipulations for this are that the facade and the roof covering should be ventilated and the construction terminated on the inside of the insulation by an airtight membrane. As previously mentioned, the external wall and roof constructions illustrated in Figs. c24 to c29, with their favourable diffusion behaviour, do not require an analysis of their diffusion behaviour. In all forms of construction, a seamless airtight membrane over the entire building envelope must be ensured. Junctions, joints, and penetrations all require careful detailing.

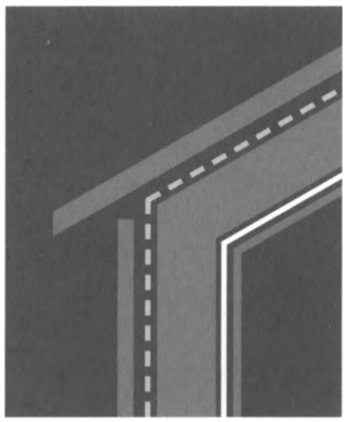
Moisture-related deformations

As the majority of timber constructions include layers that can store moisture, the risk of condensation due to vapour diffusion is low in types of construction that permit diffusion but are nevertheless airtight. On the other hand, inconsistent moisture conditions in component layers made from wood or wood-based products can lead to deformations, especially where there is no vapour barrier or the vapour barrier is very diffusion-permeable. Apart from an increase in the moisture content of the timber, dissimilar moisture content changes in the inner and outer sheathing (timber composite systems in particular) need to be given special attention. If such moisture content changes are not considered adequately in the construction, shrinkage- and swelling-related deformations can lead to widespread damage to the fabric of the building. In some flat roof constructions, such deformations and the resulting mechanical loads on the waterproofing can lead to severe problems.

Summing up, the critical points are:

- The vapour barrier must lie on the warm side of the thermal insulation and must be coordinated with the overall construction.
- The vapour barrier must be installed independently of the thermal insulation and must cover the surface of the entire building envelope.
- Penetrations, joints, and junctions with adjoining components must have an airtight seal; fewer penetrations will allow for simple, cost-effective construction.
- Pipes and cables must be laid on the warm side, i.e. inside, of the vapour barrier and should not damage this in any way.
- The vapour barrier can be combined with other component layers, generally with the airtight membrane.
- In rooms with normal building physics loads, the airtight membrane (see section c1 34) is much more important than the vapour barrier in terms of preventing damage to the fabric of the building.
- The risk of condensation due to vapour diffusion is low in timber components; on the other hand, deformations of component layers made from wood or wood-based products due to dissimilar moisture content changes (in timber composite systems) in the inner and outer sheathing cannot be ruled out.
- If the situation is unclear the necessary diffusion resistance of the vapour barrier, or the component layer acting as the vapour barrier, must be calculated.

c1 34 Airtight membrane



c30

In principle, a building envelope must be airtight when the ventilation openings are closed. The amount of external air required has to be guaranteed by opening the windows manually, other controllable ventilation openings, or suitable mechanical ventilation systems. In order to ensure the building envelope's necessary degree of airtightness, national standards now contain details about sealing the building.

When assessing the air permeability of the building envelope, the following aspects must be considered separately:

- Individual building components must exhibit the necessary airtightness according to building component standards.
- The overall air permeability of the building envelope must meet the limiting and target values of building regulations.
- Local air permeability (leaks, primarily on the inside) can lead to moisture damage because they allow moist interior air to infiltrate the construction.
- Local air permeability and associated draughts can have a detrimental effect on the thermal comfort of the occupants and can also lead to increased energy consumption.

The air permeability of the building envelope is specified by the ratio of the surface area of the building to the hourly air exchange rate for a 4 Pa pressure difference. Since 1999 the corresponding $v_{a,4}$ value has replaced the $n_{L,50}$ value used in the past (see SIA 180). A limiting value of $v_{a,4,max}$ = 0.75 m³/hm² and a target value of $v_{a,4,max}$ = 0.5 m³/hm² are specified for new buildings.

This target value must be achieved in buildings with mechanical ventilation systems. In a building with two residential units, controlled ventilation and a volume of approx. 500 m³, the corresponding air exchange rate at 4 Pa is, for example, approx. 0.4 h^{-1}. Information on the limiting and target values plus examples of the conversion of the $n_{L,50}$ values used in the past can be found in the Swiss standard SIA 180. Details for Germany are contained in [23], a publication that contains further useful information on effective building envelopes in timber construction.

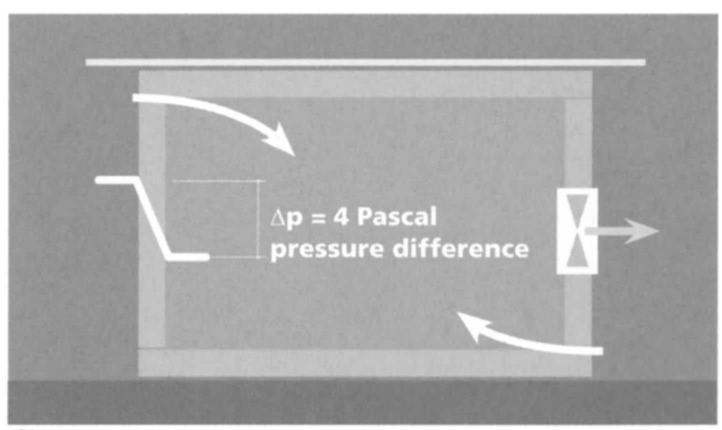
c30 Sketch of the principle of an airtight membrane

c31 Sketch of the principle of an airtightness measurement

Design and construction

In order to ensure that the building envelope has the necessary degree of airtightness, an airtight membrane is required over all parts of the construction on the warm side of the thermal insulation. Generally, the vapour barrier and airtight membrane functions are combined and provided by plastic sheeting or a board-type material (OSB, multi-ply board, plywood, gypsum fibreboard, etc.). Such materials also require fixings in the form of adhesive tape, glue, mechanical fasteners, etc., or may need to be held in place with battens. Rock wool and glass-fibre boards, wood fibreboards, wooden panelling, planking, acoustic linings, building papers, etc. cannot achieve the degree of airtightness required.

The airtight membrane must be conceived at the design stage as a "seamless" layer over the entire building envelope, planned with its practical installation in mind, and shown as a separate layer on all drawings. Good planning includes corresponding information in the tender documents and details in the working and fabrication drawings. The materials used to achieve the airtightness must be sealed airtight at junctions with adjoining components such as windows, doors, and foundations. The installation of several layers each which are only partially airtight will not result in a building with an adequate degree of sealing.



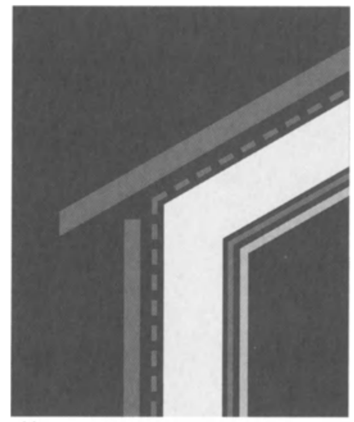
c31

In order to achieve an airtight building envelope, measures and checks during construction and after completion of the building will be necessary. If the airtight layer has been properly conceived and planned in advance, expensive blower door measurements, leak detection by means of smoke tests or IR thermography, and the cost of the associated repairs can be spared. A timber construction designed and constructed correctly will fulfil the airtightness requirements to the satisfaction of all those involved without the need for further special work, even in the case of the demanding specifications of low- and passive-energy buildings.

Summing up, the critical points are:

- A degree of airtightness is required for all thermally insulated external building components.
- The airtight membrane must be positioned on the warm side of the thermal insulation.
- The airtight membrane must be installed independently of the thermal insulation and must cover the entire area of the building envelope.
- The airtight membrane must have airtight seals at penetrations and adjoining components; fewer penetrations results in a simple, less expensive arrangement.
- Pipes and cables must be positioned on the warm side, i.e. the inside, of the airtight membrane and should not damage this in any way.
- The airtight membrane can be combined with other component layers, and indeed is often combined with the vapour barrier.
- The degree of airtightness required can also be achieved with sheathing or solid timber components provided the joints and junctions with adjoining components have permanent airtight seals.

c1 35 Sound insulation


c32

Sound insulation shields the users and occupants of the various rooms in residential accommodation, offices, schools, or other buildings against noise. The measures required for this can be divided into three groups: measures to prevent disturbing sound transmissions within a building, from one area to another (e.g. through party walls or suspended floors); measures to insulate the building envelope and the building components to such an extent that the amount of external noise is reduced to a certain level within the building; and room acoustics measures such as acoustic ceilings and other sound-attenuating measures which aim to reduce the noise level at the source itself.

We distinguish between airborne sound (sound that is transmitted in the air) and structure-borne sound (sound that is transmitted in solid materials). The human ear perceives both forms of sound transmission as airborne sound because structure-borne sound can be converted into airborne sound and vice versa.

Requirements

The relevant national standards contain requirements for sound insulation between different types of building use. This means that when analysing noise levels, in addition to the sound reduction index of each individual component, the areas of the various components (walls, windows, doors), the geometry of the rooms, and the flanking transmission paths must be taken into account. In addition, the room acoustics and reverberation time of the receiving room are important within the building. SIA 181 "Sound insulation in buildings" (2006) applies in Switzerland, and the identically named DIN 4109 (1989, currently undergoing revision) in Germany. Further information relevant to Germany can be found in section c6 40 "Suggested forms of construction". The most important stipulations of the Swiss standard SIA 181 – taken from the new 2006 edition [25] – are summarised below, but

c32 Sketch of the principle of sound insulation

c33 Classification of noise sensitivity

Noise sensitivity	Type and use of room on immissions side (receiving room)
Low	Rooms for primarily manual activities, rooms used by many persons or only briefly. Examples: workshop, handicrafts room, reception area, waiting room, open-plan office, canteen, restaurant, kitchen not intended for permanent occupation, bathroom, WC, retail space, laboratory, corridor, etc.
Moderate	Rooms for non-manual activities, living, and sleeping. Examples: living room, bedroom, artist's studio, classroom, music practice room, open-plan living/dining/kitchen, office, hotel room, hospital room without special rest function, etc.
High	Rooms for users with especially high rest needs. Examples: special rest rooms in hospitals and clinics, special therapy rooms requiring a low noise level, music room, reading room, study, etc.

c34 Minimum requirements for insulation against airborne sound from outside

	Degree of disturbance by outside noise			
Noise load	Low to moderate		Considerable to extreme	
Location of recipient area	Remote from transport routes, no disturbing operations		Close to transport routes or disturbing operations	
Assessment period	Day	Night	Day	Night
Assessment level dB(A)	$L_r \leq 60$ dB (A)	$L_r \leq 52$ dB (A)	$L_r > 60$ dB (A)	$L_r > 52$ dB (A)
Noise sensitivity	Requirement D_e			
Low	22 dB	22 dB	L_r –38 dB	L_r –30 dB
Moderate	27 dB	27 dB	L_r –33 dB	L_r –25 dB
High	32 dB	32 dB	L_r –28 dB	L_r –20 dB

knowledge of the entire standard and appropriate skills are necessary for the actual analysis and calculations.

The requirements relate to:
- External sources (external noise): airborne sound, structure-borne sound
- Internal sources (internal noise): airborne sound, impact sound, and noises from building services, structure-borne sound from industrial and commercial operations
- Room acoustics requirements for classrooms and sports gymnasiums: reverberation times

The requirements concerning internal and external sources depend on the sensitivity to noise (table c33), the noise load, and the level of sound insulation required (tables c34 to c36).

External sources (external noise)

The spectrum-adjusted, volume-corrected, graded standard sound level difference for the building envelope $D_{e,tot}$, measured in the building with windows closed, is the value for assessing the insulation against airborne noise from outside.
Table c34 lists the minimum requirements for the insulation of the building envelope (airborne sound) in decibels (D_e). The degree of disturbance caused by external noise can be measured, calculated with acknowledged methods, or classified using the figures given in table c34. The L_r value given is an indication of the infiltration of external noise according to the standards of the national Noise Abatement Act. The assessment level L_r is related to the day or night period. If enhanced requirements are necessary (obligatory for new owner-occupied apartments, terrace houses, and semi-detached houses), the values should be increased by 3 dB.

Internal sources (internal noise)

The requirements essentially concern airborne and impact sound plus noise from building services. It should be remembered here that the higher the value, the better the insulation against airborne sound. In the case of impact sound, however, the insulation improves as the value drops.

The spectrum-adjusted, volume-corrected, graded standard sound level difference $D_{i,tot}$, measured in the building, is used for assessing the insulation against airborne sound transmissions. Table c35 lists the minimum requirements for the insulation against internal noise (airborne sound) between adjacent usage units in decibels (D_i). If enhanced requirements are necessary (obligatory for new owner-occupied apartments, terrace houses, and semi-detached houses), the values should be increased by 3 dB. The spectrum-adjusted, volume-corrected, graded standard impact sound level L'_{tot} is used for assessing the insulation against impact sound transmissions. Table c36 lists the minimum requirements for the insulation against internal noise (impact sound) in decibels (L'). If enhanced

c33 The classification of noise sensitivity according to type and use of room on the immissions side (receiving room) is carried out by means of an appropriate interpretation of table c33 [25]

c34 Minimum requirements for insulation against airborne sound from outside [25]

c35 Minimum requirements for insulation against airborne sound from inside

Noise load	low	moderate	high	extreme
Examples of type and use of room on emissions side (source room)	Low-noise uses: reading room, waiting room, hospital ward, medical treatment room, archives	Normal uses: living room, bedroom, kitchen, bathroom, WC, staircase, corridor, lift shaft, office, conference room, retail space without PA system, laboratory	Noisy uses: private workshop, classroom, nursery, kindergarten, music room, place of assembly, canteen, plant room, garage, lift shaft, machine room, restaurant without PA system, retail space with PA system, and associated access spaces	Very noisy uses: commercial operations, workshop, music practice room, gymnasium, restaurant with PA system, and associated access spaces
Noise sensivity	Requirement D_i			
low	42 dB	47 dB	52 dB	57 dB
moderate	47 dB	52 dB	57 dB	62 dB
high	52 dB	57 dB	62 dB	67 dB

c36 Minimum requirements for insulation against impact sound

Noise load	Low	Moderate	High	Extreme
Examples of type and use of room on emissions side (source room)	Archives, waiting room, reading room	Living room, bedroom, kitchen, bathroom, WC, corridor, staircase, walkway, office, plant room, passage, terrace, garage	Restaurant, auditorium, classroom, nursery, kindergarten, gymnasium, workshop, music practice room, and associated access spaces	The same uses listed under "High" if the noise also occurs between 7 p.m. and 7 a.m.
Noise sensitivity	Requirement L'			
Low	63 dB	58 dB	53 dB	48 dB
Moderate	58 dB	53 dB	48 dB	43 dB
High	53 dB	48 dB	43 dB	38 dB

requirements are necessary (obligatory for new owner-occupied apartments, terrace houses, and semi-detached houses), the values should be decreased by 3 dB.

Level of sound insulation required

The minimum requirements given in tables c34 to c36 according to SIA 181 (2006) must be adhered to in all situations. The 3 dB difference applies to new terrace houses, semi-detached houses, and owner-occupied apartments (airborne sound: 3 dB increase; impact sound: 3 dB decrease). Further, special requirements must be specified for special uses or special sound insulation demands, and must be included in the contract.

Influencing factors

Important influencing factors should be considered right from the conception and planning stages in order that primary sound insulation measures can be integrated:

- Position and orientation of the building with respect to the sources of external noise.
- Plan layout, with a sensible orientation with respect to, and separation from, noise sources (bathroom, WC, kitchen) and quieter zones (living room, bedrooms)
- Sound insulation properties and positioning of windows, doors, etc.
- Construction of separating components (walls, windows, doors, suspended floors).
- Consideration of possible flanking transmission paths.
- Building services of all kinds as a source of noise (airborne sound, structure-borne sound).

The above factors indicate that good sound insulation can only be achieved with a sensible concept and suitable construction of the separating components. However, the construction systems for suspended floors, walls, and roofs resulting from these considerations always have an effect on the architectural design of a timber building.

c35 Minimum requirements for insulation against airborne sound from inside [25]

c36 Minimum requirements for insulation against impact sound [25]

Important influences during construction are:
- Care during the construction of components and the joints and junctions between components.
- Avoidance of acoustic bridges for structure-borne sound.
- Special sealing measures at openings and penetrations.
- Acoustic separation of building services.

Chapters c6 and c7 contain suggestions for party wall and party floor designs. When designing the building envelope, it is usually the sound insulation properties of the windows and the proportion of the windows in the building envelope that are critical because the sound insulation of common multi-layer external walls is in most cases much better than that of windows. In the case of higher noise loads, however, corresponding improvements are advisable, which should be conceived and calculated by a building physics or acoustics specialist.

Differences between the 1988 and 2006 editions of Swiss standard SIA 181

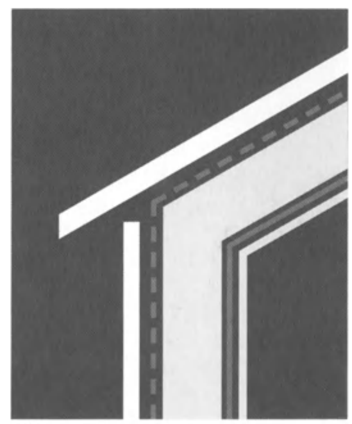
The revised SIA 181 (2006) takes into account developments in international standards and the public's demands for protection from disturbing noise.
The minimum requirements were therefore raised by 2 dB. The enhanced requirements have not been changed, but in future will be obligatory for semi-detached houses, terrace houses, and new owner-occupied apartments. One new requirement is that the spectrum adjustment values, C and C_{tr} (airborne sound) plus C_I (impact sound) must be considered in the design. The corresponding details of component constructions can be found in newer specialist publications and also in the tables in chapters c6 "Party walls, internal walls" and c7 "Suspended floors" of this book.
The same requirements and methods of assessment that apply to concrete and masonry buildings also apply to timber buildings. In the revised SIA 181 standard, however, appendix E 3.3 addresses a problem specific to timber buildings: low-frequency transmissions of, above all, impact sound noise. The recommendation is to employ alternative methods of assessment, evaluating the frequencies up to 50 Hz. Measurements in this range are, however, difficult and costly, both in situ and in the laboratory. Test setups with appropriate certification are available, but are few and far between.

c37 Sketch of the principle of fire protection

It has been shown that the use of suitable construction methods enables even timber party floors to achieve a standard of sound insulation comparable with that of concrete floors – especially for an evaluation of frequencies above 50 Hz. The extended spectrum will certainly have a positive effect on sound insulation, but comprehensive studies on sound insulation are still necessary in order to achieve optimised constructions in all areas. Such studies and investigations are in progress, but had not been completed by the time this book went to print.

c1 36 Fire protection

In the event of a fire, the loadbearing structure has to guarantee that the building or parts thereof do not collapse immediately, and the floors and walls in turn have to ensure that the building remains divided into fire compartments in order to prevent the spread of fire. The building envelope (external walls and roof) must comply with stipulations regarding the minimum distance to any neighbouring buildings and the use of combustible materials in the facade and roof. Fire protection must be given a high priority in the design and construction of the whole building, and must be considered at every stage of the draft design, detailed design, planning, and construction. As fire protection for timber buildings is a very extensive field, this subject is treated separately in chapter d3 "Fire protection".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c1 40 Building standards

General

Standards and certificates are assigned a high priority in our society, which has become very demanding and very quality-conscious. For many decades, the SIA (Swiss Engineers & Architects Association) has defined a minimum standard for building envelopes. Since 1998 the "Minergie" certificate has been available in Switzerland, and this was supplemented in 2003 by the "Minergie-P" certificate, a Swiss version of the German "passive house standard". Minergie and Minergie-P are based on the calculation principles contained in the SIA standards. A comparison with the pan-European passive house standard is not easy owing to different definitions, requirements, and reference variables.

Energy aspects with respect to the building envelope are dealt with in the standard SIA 380/1 "Thermal energy in buildings". A distinction is made between limiting and target values: limiting values are mandatory, target values are optional. On the other hand, SIA 180 (1999) "Thermal performance and moisture control in buildings" deals with the comfort of occupants/users and the avoidance of damage to the fabric of the building.

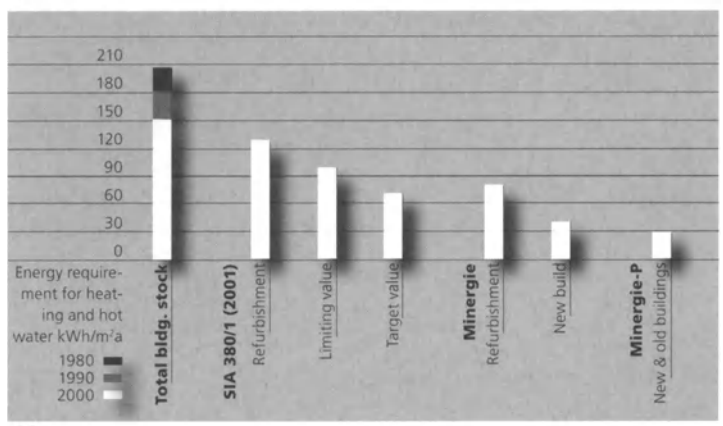
Minergie

Minergie buildings must be equipped with a mechanical ventilation system. The heating energy requirement of these buildings is some 20% lower than that of a building constructed according to standard SIA 380/1.

Minergie-P and passive house

Although the methods of calculation and the requirements are different, the Minergie-P (Switzerland) and passive house (Germany) standards are based on the same underlying principles: the highest quality of construction and insulation, an airtight building envelope, controlled ventilation with heat recovery, the use of renewable energy, efficient covering of the residual heating requirement. Table c41 shows a comparison of the three Swiss building standards and the German passive house standard. The heating requirement of a building awarded a Minergie-P certificate must be at least 80% lower than that of a conventional building. Minergie-P houses and passive houses are characterised by enormous energy-savings and enhanced comfort for their occupants. The requirements regarding the building envelope are relatively complicated and must be assessed by a specialist. Publication [24] deals in detail with the passive house theme. Chapters c3 "External walls", c4 "Pitched roofs", and c5 "Flat roofs" contain suggestions for the construction of the building envelope.

c38



c39

c38 Private house with low energy requirement

c39 Energy requirement for heating and hot water – comparison of various building standards

c40

c41 Building standards

	SIA 180, 380/1	Minergie	Minergie-P	Passive house
Reference variables				
Reference area (m²)	Energy reference area EBF (gross, ext. dimensions)	Energy reference area EBF (gross, ext. dimensions)	Energy reference area EBF (gross, ext. dimensions)	Net floor area NF
Energy source				
Renewable energy	Not required	Recommended	Recommended	
Energy parameters				
Heat distribution	Normal distribution	Normal distribution	Warm-air system possible	Warm-air system possible
Heating requirement (Q_h) (available energy)	Heating limit value depends on building envelope index (A/EBF)	$Q_h \leq 60\%$ heating limit value H_g	$Q_h \leq 40\%$ heating limit value $Q_{h,li}$ $Q_h \leq 10$ kWh/m² if A/EBF < 1.1	$Q_h \leq 15$ kWh/m²a NF calculation according to PHPP
Heating performance			$Q_{hmax} \leq 10$ W/m² EBF	
Weighted heat energy parameter (E_w), (final energy)	No requirement, only purely informative, unweighted parameters	Newly built house ≤ 38 kWh/m²a EBF flats ≤ 38 kWh/m²a EBF energy media are taken into account in the calculations	Newly built or converted house ≤ 30 kWh/m²a EBF flats ≤ 30 kWh/m²a EBF energy media are taken into account in the calculations	
Primary energy requirement				≤ 40 kWh/m²a NF (excluding household electricity), calculation according to PHPP
Household electricity		≤ 17 kWh/m²a EBF		
Equipment				
Household appliances	No requirement	EU grade A, refrigerators A+ recommended	EU grade A, refrigerators A+	No requirement, electricity consumption included in primary energy requirement
Building envelope				
Wall and roof construction	Thermal insulation 160-180 mm	Thermal insulation 220-240 mm	Thermal insulation 350-400 mm	
U-value of walls, roof	≤ 0.25 W/m²K	≤ 0.2 W/m²K	≤ 0.10 W/m²K	≤ 0.15 W/m²K
Low E glass	Double glazing	Double glazing	Triple glazing	Triple glazing
U-value of glass (U_g)	≤ 1.0 W/m²K	≤ 0.7 W/m²K	≤ 0.6 W/m²K	≤ 0.6 W/m²K
U-value of window (U_w)	≤ 1.2 or 1.5 W/m²K	≤ 1.0 W/m²K	≤ 0.8 W/m²K	≤ 0.8 W/m²K
Controlled ventilation of habitable rooms with heat recovery	Not required	Required	Required	Required
Airtightness	$v_{a,4} \leq 0.75$ m³/hm² or target value $v_{a,4} \leq 0.50$ m³/hm²	$n_{L50} \leq 1$/h	$n_{L50} \leq 0.6$/h, airtightness measurement required	$n_{L50} \leq 0.6$/h, airtightness measurement required
Miscellaneous				
Costs	No requirement	Extra costs ≤ 10% higher than comparable conventional building	Extra costs ≤ 15% higher than comparable conventional building	

A Area of building envelope (m²)
EBF Energy reference area (m²)
NF Net floor area (m²)

Q_h Heating requirement (kWh/m²a)
$Q_{h,li}$ Heating limit value
E_w Heat energy parameter (kWh/m²a)
PHPP Passive House Project Package

c40 Multi-storey office building in timber, Minergie-P ECO, passive house standard

c41 Comparison of the three Swiss building standards SIA, Minergie, and Minergie-P, plus the German passive house standard

c2 Design and construction

c2 10 General

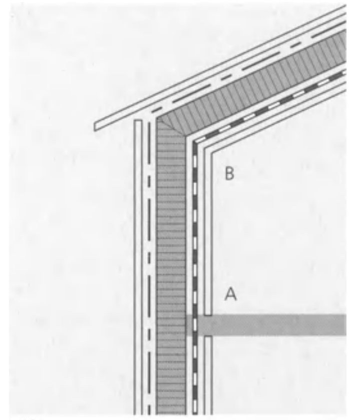
The sequence of layers from inside to outside is governed by the building physics conditions. This basic principle must be brought into line with current demands for high standards of insulation, airtight building envelopes, rational and durable joints and junctions, low- or even zero-maintenance structures, and ever more stringent economic constraints, all of which will play an even greater role in the future. These key requirements lead to new considerations with respect to the design and construction of the building envelope.

On the draft design and planning level, these requirements have an influence on conceptual considerations and decisions, which in turn have a fundamental effect on the later planning and execution of the building works. Only concepts properly selected and coordinated right from the beginning lead to optimised structures with high living standards and low energy consumption.

The fundamentals for the building envelope, the protective qualities expected of it, and the component layers required to achieve that are dealt with in chapter c1 (including the correct sequence of layers from inside to outside). This chapter describes the design of the building envelope and its individual layers with respect to the loadbearing layer, and the design of the transitions between external wall, suspended floor, and roof.

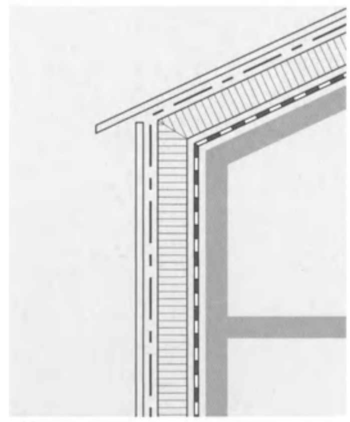
c2 11 Overview

Starting with the loadbearing structure, a decision has to be made as to whether further layers of the construction are to be placed on the inside or outside of the loadbearing members. In timber structures it is generally the case that the voids between the loadbearing members are also used for other components in the wall and roof construction. Nevertheless, it is also often worth considering positioning the other parts of the construction, especially the vapour barrier, airtight membrane, and thermal insulation, outside the loadbearing structure. This is the case when the loadbearing structure, and the space for building services, are mainly or wholly on the warm side of the construction. In this situation, further layers are then attached to the outside, enclosing the loadbearing structure without penetrations and thermal bridges caused by the



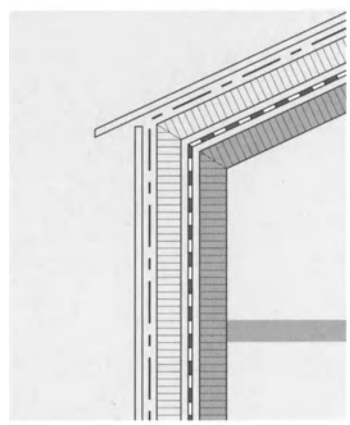
c42

Thermal insulation between structural members (see also section c2 31)
Airtight membrane and vapour barrier on the inside of the loadbearing structure, thermal insulation between the structural members.
Building envelope penetrations:
A = floor support on external wall
B = possibly purlins, beams, and collars
Uses: panel construction in particular, occasionally frame construction.



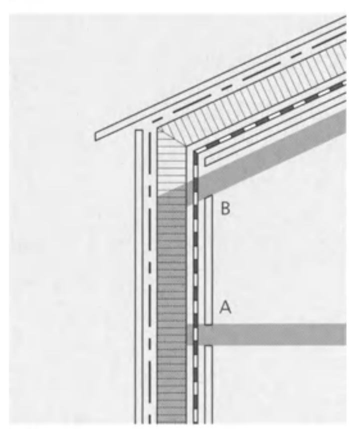
c43

External thermal insulation (see also section c2 32)
Airtight membrane, vapour barrier, and thermal insulation on the outside of the loadbearing structure.
No building envelope penetrations.
External structures such as balconies, canopies, conservatories, pergolas, etc. are built separately.
Uses: solid timber and frame construction in particular.



c44

Two-layer system (see also section c2 33)
Airtight membrane laid between the two layers of thermal insulation but outside the loadbearing structure.
No building envelope penetrations.
External structures such as balconies, canopies, conservatories, pergolas, etc. are built separately.
Uses: solid timber construction (compound cross-sections) in particular (see section b8 30).

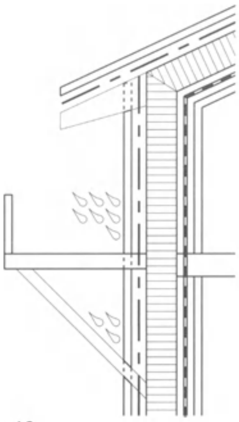


c45

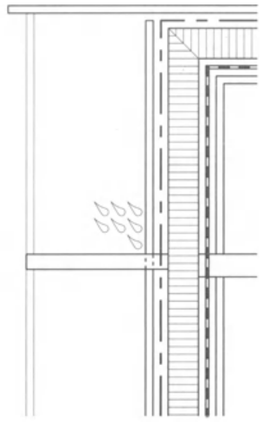
Hybrid system (see also section c2 34)
Airtight membrane and vapour barrier on inside of wall, but outside the loadbearing structure in the roof; thermal insulation between loadbearing members in the wall, but outside the loadbearing structure in the roof.
Building envelope penetrations:
A = floor support on external wall
B = primarily rafters, but possibly also purlins, beams, and collars
Note: Systems that change between external wall and roof are not to be recommended.

c42 to c45 Construction options for the building envelope
Simple systems that do not require complex, costly details at junctions are those with external insulation (c43) and the two-layer system (c44). With insulation fitted between the structural members (c42), the wall/suspended floor and wall/roof details require special care.

The hybrid system (c45) is not recommended because it is susceptible to problems.



c46



c47

loadbearing members of suspended floors or roofs, or pipes and cables. Systems have appeared in recent years in which, for example, the voids between the loadbearing members are filled with insulating material, but a further layer of thermal insulation is also added on the outside together with the airtight membrane. Figs. c42 to c45 show the basic systems.

In the system with external insulation (Fig. c43), the loadbearing structure is fully enclosed by the airtight membrane, vapour barrier, and thermal insulation layers. Here, the loadbearing structure lies on the warm side and either remains visible in the interior of the building, or is concealed behind an inner lining. This arrangement means there are no penetrations through the building envelope (see also section c2 32). Fig. c42 shows a form of construction with thermal insulation between loadbearing members; the layer of insulation is therefore interrupted again and again by structural members. Thanks to the good thermal insulation properties of wood, such interruptions are, however, acceptable; but the junctions between the airtight membrane and penetrating structural members, e.g. floor beams, are more difficult to deal with satisfactorily. Careful design is required in order to reduce these undesirable penetrations to a minimum (see also section c2 31). Another insulation arrangement is shown in Fig. c45, where the insulating materials are placed between the wall members but outside, i.e. above, the roof structure (see also section c2 34). Fig. c44 shows an ideal combination in which the thermal insulation is placed between the loadbearing members and also outside them (see also section c2 33).

c2 20 Positions of component layers

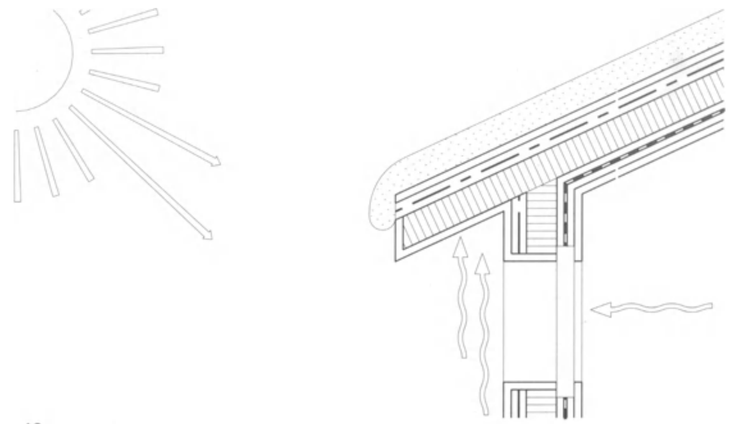
c2 21 Roof covering, external cladding

The roof covering and external cladding form the outermost component layers of a building. There are a few exceptions to this rule, and the upside-down roof, in which the thermal insulation is placed on top of the waterproofing, is perhaps the best known. In the design of the external cladding, there seems to be a growing tendency to break up the cladding at intervals, which means that the cladding no longer provides full protection from the weather. Such forms of construction are indeed possible, but always require a ventilation cavity behind the cladding plus a layer (normally the layer protecting the thermal insulation) that provides some of the functions an unbroken cladding layer would normally provide. In some instances the cladding is divided up to such an extent and has such closely spaced joints that it fulfils only an aesthetic role. In such a situation all other functions must be allocated to the next layer, which must be designed accordingly.
External cladding that is penetrated by elements from the outside must be designed in such a way that rainwater can drain away and all associated moisture can escape (Figs. c46 and c47).

c2 22 Ventilation

The ventilation space (roof) or ventilation cavity (external wall) must be positioned directly behind the weather protection layer. The width of the cavity behind the external cladding depends on the cladding system and materials used, and the spacing of air inlets and outlets; it is normally at least 30 to 40 mm. The depth of the ventilation space in a pitched roof depends on the length of the rafters, the pitch of the roof, and the altitude of the site; the minimum depth is 45 mm. The dimensions of ventilation spaces in roofs are dealt with in detail in section c4 25. The requirements for the ventilation of flat roofs are covered separately in the relevant standards.
Every ventilation space requires air inlets and outlets, the cross-section of which must be equal to at least half the required cross-sectional area of the ventilation space. If an air inlet/outlet is fitted with an insect screen, grating, etc., this must be allowed for, but the air permeability of the roof covering can be taken into consideration when sizing the air inlets and outlets. This is particularly relevant with clay tile roofs.
At higher altitudes there is a risk that snow might block the air outlets at the ridge. It must therefore be possible for the air to circulate across the slope of the roof as well. Offset barge boards (see Fig. c125, p. 252) can be used to achieve such ventilation. In addition, continuous ventilation openings at the ridge are advantageous in regions with heavy snowfall. Special ridge vents are essential in conjunction with forms of roof covering with a lower air permeability, e.g. fibre-cement slates.

c46 and c47 Unfavourable building envelope penetrations in the vicinity of the roof, and at the supports for suspended floors (from inside) and balconies (from outside). Such penetrations can be avoided by using the systems shown in Figs. c43 and c44.



c48

c2 23 Secondary waterproofing/covering layer, protection for thermal insulation

The layer protecting the thermal insulation is attached on the outside of the thermal insulating materials. Penetrations through this protective layer are usually less of a problem because a 100% seal is not necessary here. Nevertheless, the materials protecting the underlying thermal insulation should be properly and permanently fixed to the adjoining components. Any water that does penetrate the external cladding must be able to drain away without causing any problems.

On a pitched roof, a layer of material must be placed beneath the roof covering and above the loadbearing construction and thermal insulation. This secondary waterproofing/covering layer is not necessary on flat roofs with no ventilation because no water can infiltrate into the construction. However, flat roofs with a ventilation space do require a secondary waterproofing/covering layer beneath the roof finishes and above the loadbearing construction and thermal insulation. Minimal slopes enable any water – due to leaks in the waterproofing – to drain away.

c2 24 Thermal insulation

The thermal insulation can be incorporated in different ways: on the outside of (Fig. c43) or between the loadbearing members (Fig. c42). Positioning the thermal insulation between the loadbearing members is a very common method in timber buildings. Well-insulated buildings often make use of more than one layer of insulation (e.g. between and also outside the structural members, Fig. c44). Thermal insulation exclusively on the inside is hardly an option, especially with new buildings, because such internal insulation usually results in building physics problems. One exception to this rule is traditional log construction, in which the thermal insulation is attached to the inside of the loadbearing construction. The best solutions from a building physics viewpoint are the external insulation or the two-layer system (Figs. c43 and c44). In these cases the layer of thermal insulation plus the airtight membrane and the vapour barrier are on the outside of the loadbearing structure. Thermal bridges and complicated junction details are absent from this approach.

In regions with heavy snowfall it is also advantageous to include a layer of thermal insulation in the eaves overhang (Fig. c48). This arrangement limits the temperature rise and hence the melting of the layer of snow on the roof when warm air rises up the outside of the facade. Omitting the thermal insulation in the eaves allows the snow to melt unevenly, leading to meltwater, which turns to ice, on the eaves overhang.

Shading for windows and other transparent components must be positioned externally. The solar radiation must be reflected before it passes through to the inside. External louvre blinds or other shading systems are regarded as the most important measure for achieving a good summertime thermal performance.

c2 25 Vapour barrier

Building physics requirements dictate that a vapour barrier be placed on the warm side of the thermal insulation. The functions of the vapour barrier can be combined with those of the airtight membrane. If there is more than one layer of thermal insulation, it can also be placed between two layers of insulation, although in this case a building physics analysis is necessary in order to guarantee that moisture is unable to condense within the construction (interstitial condensation) and cause damage.

It is vital that the vapour barrier continue over the entire building envelope without any interruptions. Beams, rafters, pipes, cables, etc. penetrating the vapour barrier should be avoided if at all possible.

The junction between external wall and suspended floor requires special attention because the vapour barrier is interrupted by the suspended floor structure. These numerous penetrations lead to awkward details, and care should be in taken to ensure good airtightness here. If the roof structure is left exposed internally, rafters penetrating the building envelope should be avoided; it is best to curtail these at the loadbearing external wall. The members supporting the eaves should be in the form of short, separate rafters in order to avoid penetrating the vapour barrier (see arrangements in sections c2 32 or c2 33).

c48 In regions with heavy snowfall it is advantageous to include a layer of thermal insulation in the eaves overhang.

c49 Connecting building services at the junction between walls and suspended floor elements

c50 to c54 Options for installing building services (top = vertical section; bottom = horizontal section)

c50 Void for building services created by framework of battens supporting inner lining; min. 30 mm deep, but 60 mm is better.

c49

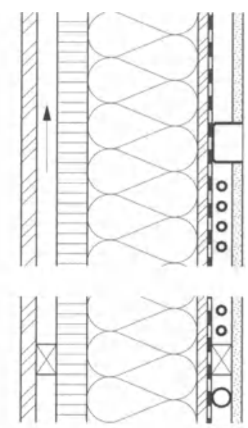
c2 26 Airtight membrane

The airtight membrane can be placed on either the inside or the outside of the loadbearing structure – but always on the inside of the thermal insulation. When there are two layers of insulation, it is also acceptable to install the airtight membrane between these. In this solution, however, even when the airtight membrane fulfils the vapour barrier functions, a building physics analysis is necessary in order to rule out interstitial condensation. Airtight membranes or vapour barriers positioned entirely on the cold side of the construction should be avoided because they can lead to condensation in cooler parts of the construction, e.g. at suspended floor junctions.

It is vital that the airtight membrane, like the vapour barrier, continue "seamlessly" around the entire building envelope. Beams, rafters, pipes, cables, etc. penetrating the airtight membrane should be avoided if at all possible. Loadbearing components or building services penetrating the airtight membrane at many points should be regarded as a flaw in the concept or planning. Figs. c50 to c54 illustrate possible solutions for routing pipes and cables without damaging the airtight membrane.

c2 27 Space for services

Building services must be positioned on the inside of the airtight membrane and the vapour barrier. The framework of battens forming this space should be at least 30 mm deep so there is enough room for electric conduits (20 mm dia.). The depth from front face of inner lining to airtight membrane and vapour barrier should be at least 60 mm, a dimension that enables power sockets and junction boxes to be incorporated in the space as well.
If the space for services plus the inner lining is intended to form an internal leaf that can vibrate independently for sound-attenuating purposes, the depth of the space for services should also be at least 60 mm.



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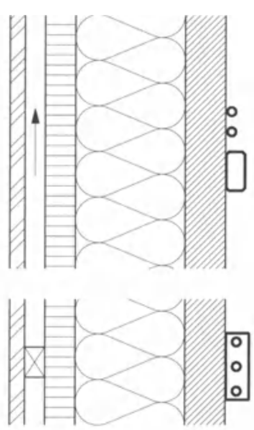

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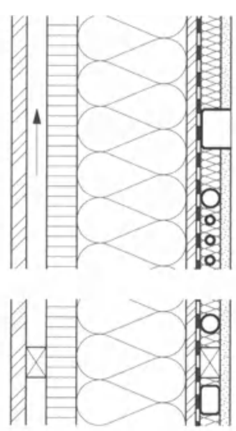

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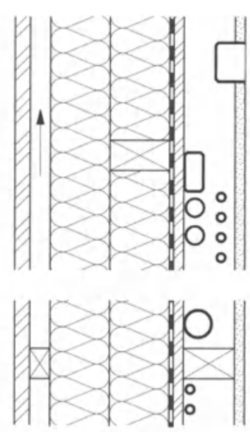

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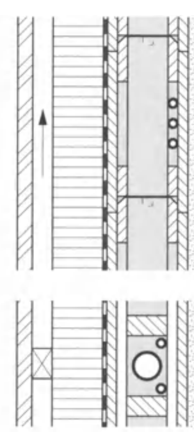


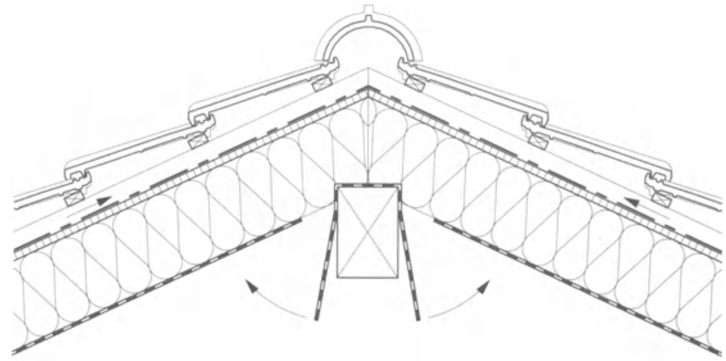
c54

c51 Surface-mounted building services, either left exposed or routed in ducts or conduits.

c52 Building services routed between framework of battens supporting an inner lining, remaining spaces filled with insulation.

c53 Building services installed in the same plane as the loadbearing structure inevitably results in a weakening of the structural cross-sections.

c54 Building services installed in the same plane as the loadbearing structure can be routed in specific vertical or horizontal voids.



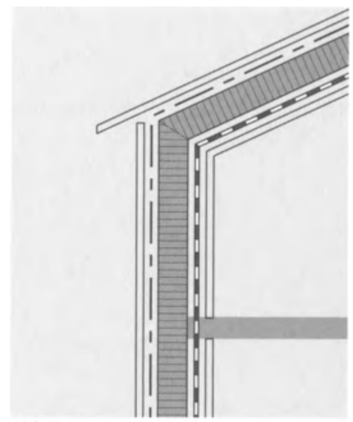
c55

c2 30 Junctions between components

The interaction of individual parts of the construction – ground floor, suspended floors, external walls, roof or walls, windows, doors, penetrations, etc. – must be assessed at each individual interface and considered in context over the entire building envelope. Starting with the overall assessment for the positions of the component layers according to chapter c1 and section c2 10, the individual layers of the components must be connected in such a way that the respective requirements to be met by those components (e.g. weather protection, thermal performance, airtightness, sound insulation, moisture control, fire protection) are not jeopardised at junctions and joints between components.

There is no difference in the sequence of layers described in c2 10, nor between the different timber construction systems; the building physics conditions remain the same. The main differences between the systems are to be found in the position of the loadbearing structure, the appearance, and the component junctions, whereas the sequence of layers – an overriding principle – remains essentially the same.

c2 31 Thermal insulation between structural members

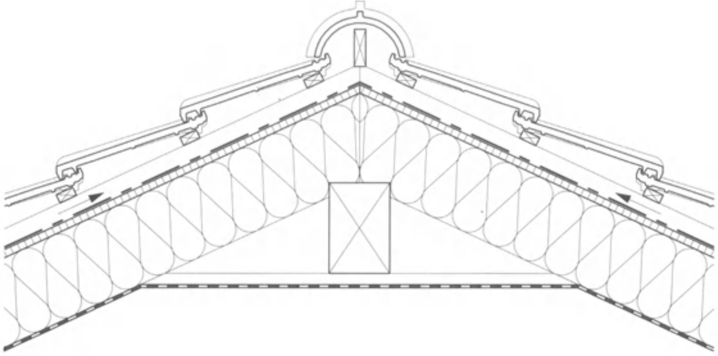


c56

The airtight membrane and the vapour barrier are positioned on the inside, the thermal insulation between the members of the loadbearing structure. Structural members of the wall and roof are covered to protect them from the weather. The rafters extend beyond the external walls to form the eaves. With this arrangement, the airtight membrane and the vapour barrier are easy to install at eaves and verges because in both components, wall and roof, the insulation is placed between the loadbearing members. The airtight membrane can therefore be laid over the entire area beneath the rafters. The airtight membrane and the vapour barrier are not penetrated at the junction between wall and roof. Exceptions to this are when the structural or architectural design requires collars, kneebraces or purlins to remain exposed externally. Such arrangements are usually unnecessary and only result in costly, problematic details because the building envelope must be penetrated. On the other hand, the airtight membrane and vapour barrier details at the junction with a suspended floor are expensive and complicated, and can cause problems in the long-term.
Systems with insulation between the structural members are particularly prevalent in panel construction. Detailed information on walls in panel construction can be found in section b6 40. These days, the thermal insulation requirements often exceed the pure structural needs, which means that deeper sections, usually > 200 mm, are specified, but in many cases the thermal performance requirements are met by adding a continuous, second layer of insulation on the outside. This form of construction, which is on the increase, often makes use of, for example, loadbearing members 160 mm deep, which means a layer of insulation 160 mm thick between the loadbearing members to which an additional layer 60, 80 or 100 mm thick, possibly even thicker, is added on the outside. This simplifies the details, especially at the junction with a suspended floor, which makes the construction more reliable and more durable.

c55 and c57 Ridge detail showing arrangement of airtight membrane
c55 Strip of airtight membrane (plastic sheeting) laid over ridge purlin in advance during erection of roof structure.
c57 Soffit board attached to underside of ridge purlin, which means the airtight membrane can be laid exclusively during the fitting-out work.

c56 Sketch of the principle of thermal insulation between structural members



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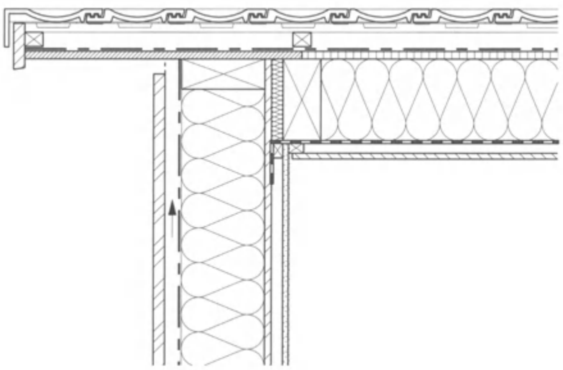

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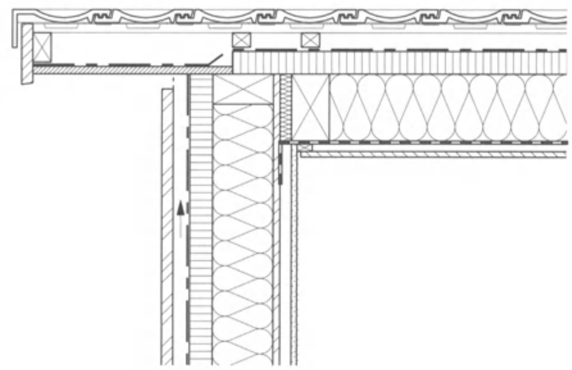

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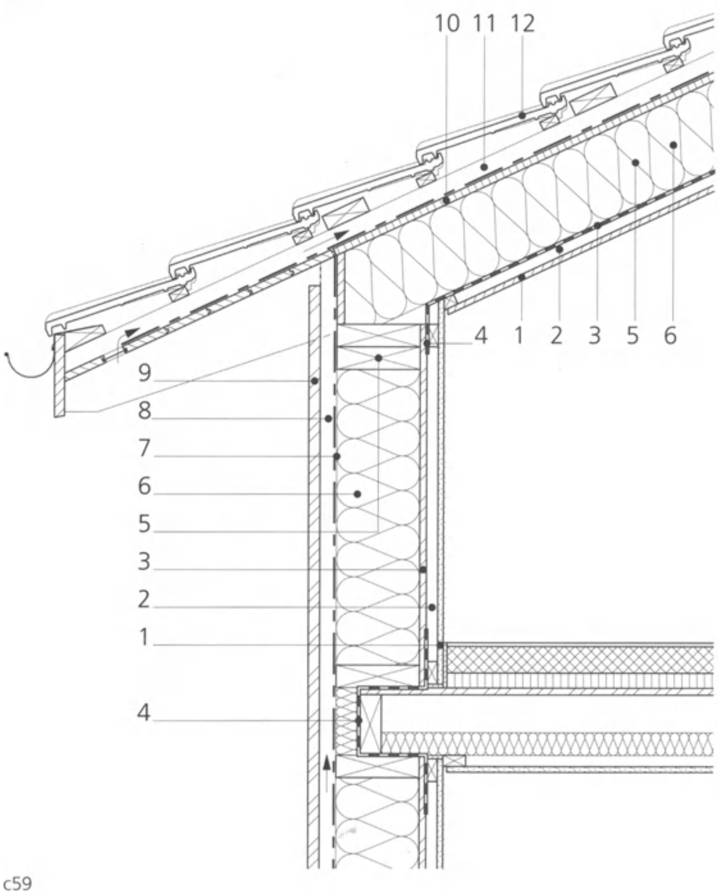

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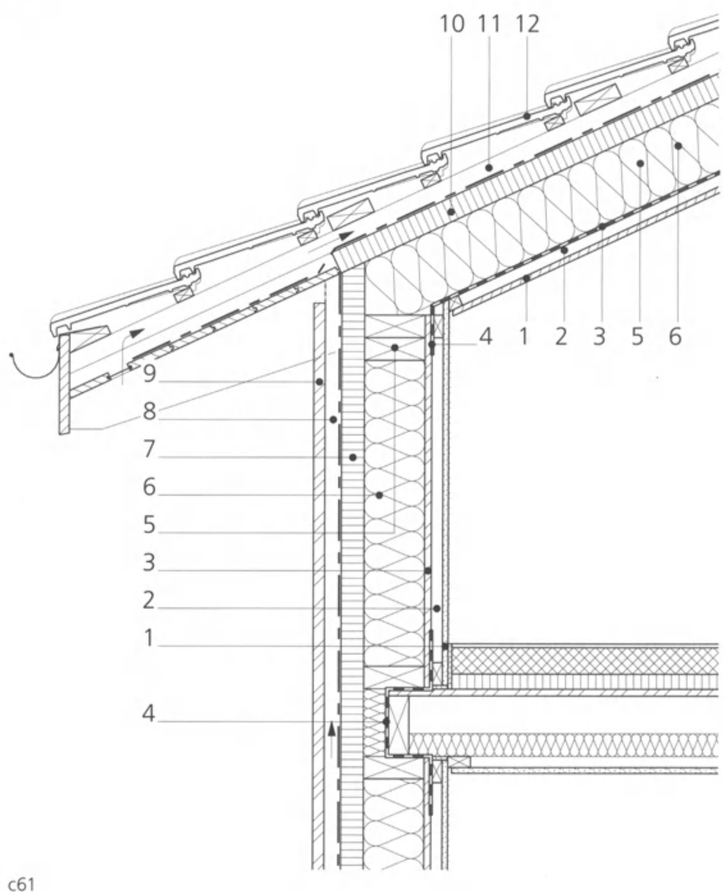


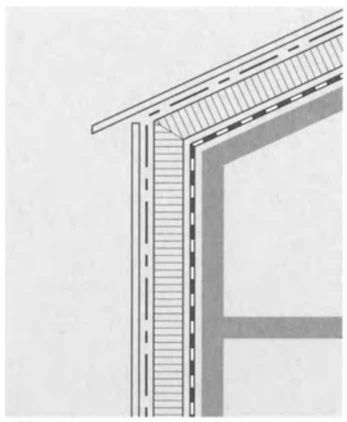
c61

c58 to c61 Junction details for thermal insulation between structural members

c 58 and c59 Panel construction with one layer of thermal insulation
c 60 and c61 Panel construction with two layers of thermal insulation

1 Inner lining, soffit lining
2 Framework of battens, space for services
3 Vapour barrier, airtight membrane, structural sheathing
4 Joints sealed airtight (plastic sheeting with variable diffusion resistance recommended)
5 Loadbearing structure
6 Thermal insulation
7 Protection for thermal insulation, possibly additional insulation
8 Framework of battens, ventilation cavity
9 External cladding
10 Secondary waterproofing/covering layer, possibly additional insulation, 3-ply core plywood at verges
11 Counter battens, ventilation space, possibly strengthening for eaves
12 Tiling battens, roof covering

c2 32 External thermal insulation


c62

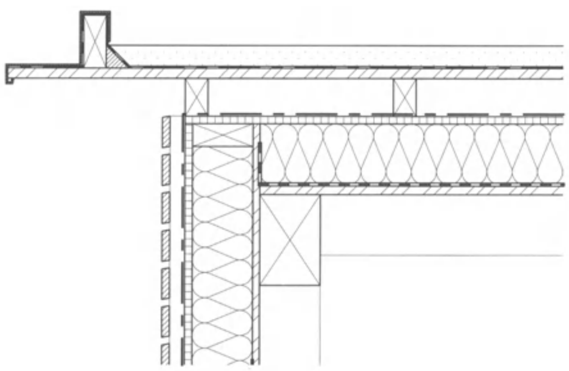
The airtight membrane, vapour barrier, and thermal insulation are placed outside the loadbearing structure, which means that the structure remains exposed internally and the rafters do not cantilever beyond the external wall. Junction details are simple because there are no penetrations, and the thickness of thermal insulation can be chosen irrespective of the loadbearing construction. Building services are routed in separate ducts or between the loadbearing members. The loadbearing structure for the eaves overhang can be in the form of battens parallel with the rafters positioned above the insulation. Longer eaves designs require separate rafters, but the full depth of the layer of insulation and the ventilation space can be used if necessary. Systems with external insulation are very popular in solid timber and frame construction.

In solid timber construction, planar, usually large-format components provide the loadbearing and enclosing functions. Pipes and cables are accommodated by cutting chases in the components or by attaching battens and an inner lining to create a cavity for the installations. Some solid timber construction systems are dense enough in themselves to provide the necessary airtightness, others require a separate airtight membrane (please refer to the manufacturer's specification in each case). The provision of a continuous layer of thermal insulation on the outside overcomes the problem of thermal bridges almost completely.

In frame construction, the loadbearing functions are independent of the enclosing functions. As the external walls do not have to carry any loads from suspended floors and roof, any type of design is, in principle, possible. The walls can therefore be positioned in front of, behind, or between the loadbearing members. It is, however, advantageous to employ a system with external thermal insulation, which places the loadbearing structure on the warm side, i.e. inside the thermal insulation. The structure is enclosed "seamlessly" by the other layers: vapour barrier, airtight membrane, thermal insulation, and external cladding or roof covering. There are therefore no thermal bridges and no penetrations.

See chapter b8 for details of solid timber construction and chapter b7 for frame construction.

c62 Sketch of the principle of external thermal insulation



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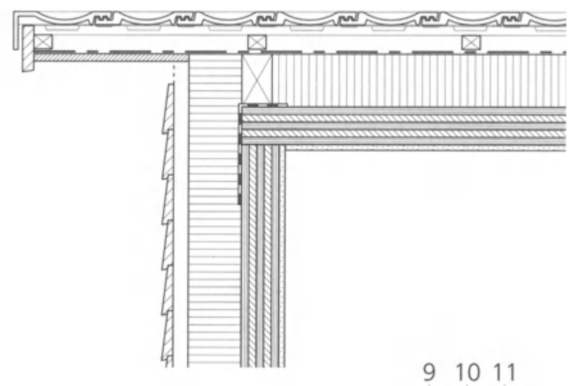

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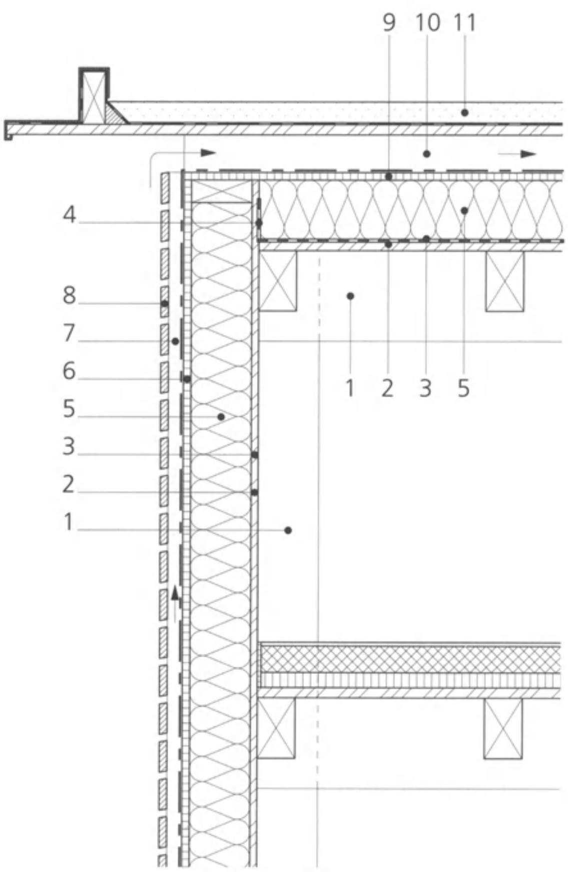

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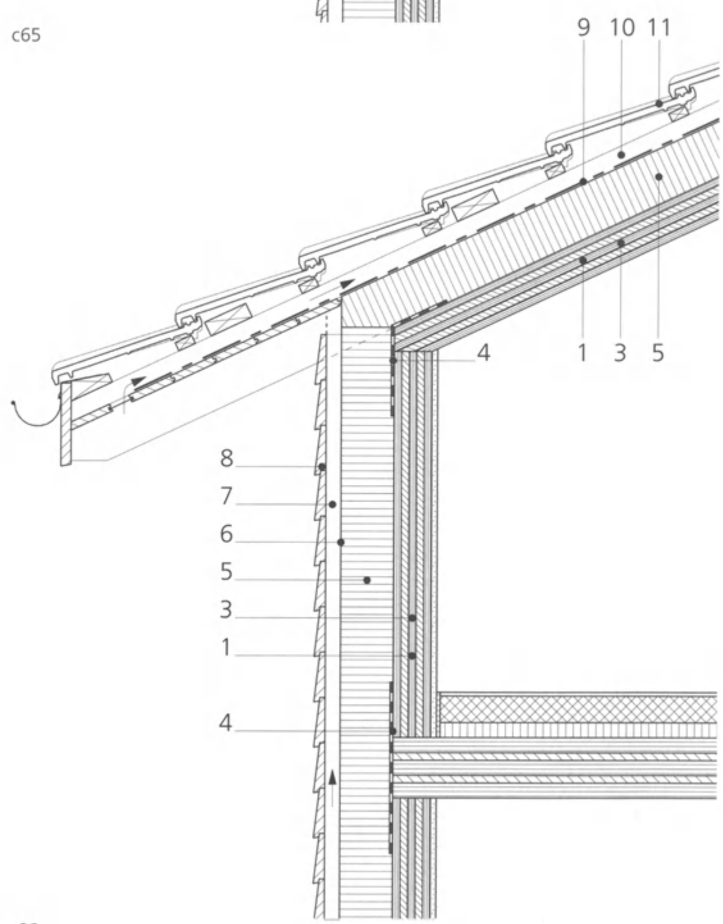


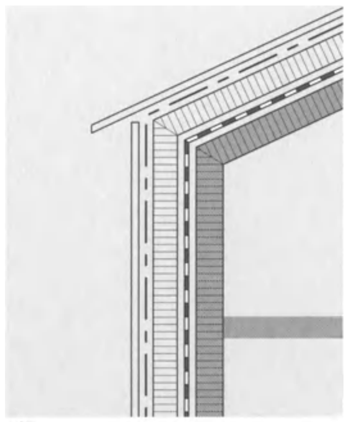
c66

c63 to c66 Junction details for external thermal insulation

c63 and c64 Frame construction
c65 and c66 Solid timber construction

1 Loadbearing structure
2 Inner lining, soffit lining
3 Vapour barrier, airtight membrane (separate layers may be necessary depending on products)
4 Joints sealed airtight (plastic sheeting with variable diffusion resistance recommended)
5 Thermal insulation, eaves rafters
6 Protection for thermal insulation, possibly additional insulation
7 Framework of battens, ventilation cavity
8 External cladding
9 Secondary waterproofing/covering layer, possibly additional insulation
10 Counter battens, ventilation space, possibly strengthening for eaves
11 Roof covering

c2 33 Two-layer system

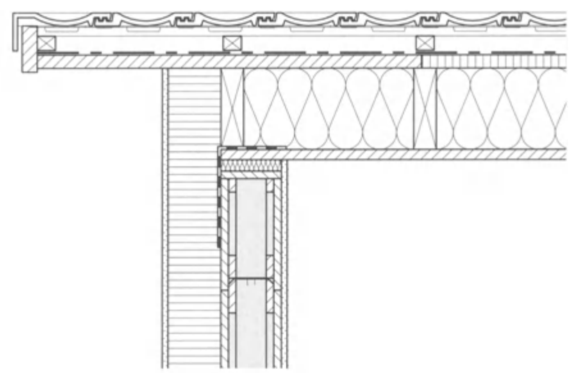


c67

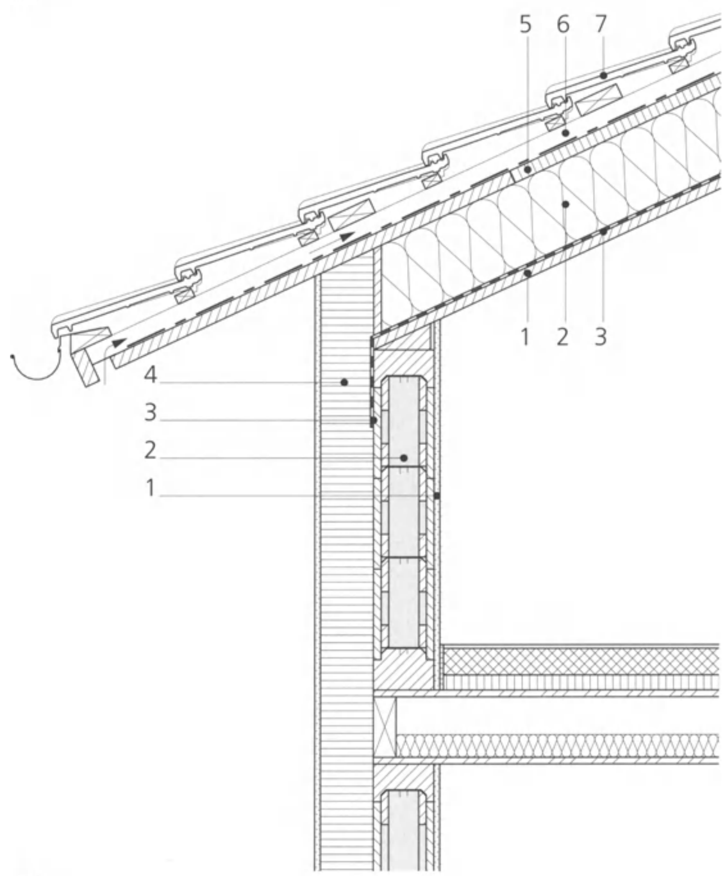
This involves two layers of thermal insulation: the first in the voids between the loadbearing members, the second attached "seamlessly" around the outside of the loadbearing structure. The airtight membrane and vapour barrier required to suit the wall construction are also attached to the outside of the loadbearing structure and therefore lie between the two layers of isulation. The independently developed systems together create a functioning system so that in most cases the vapour barrier can be omitted.

The junctions are easy to design and construct because there are no penetrations and no thermal bridges. The thickness of thermal insulation required can be chosen irrespective of the depth of the loadbearing members. Building services can be routed in separate ducts, but electric cables can also be routed directly in the voids between the loadbearing members without having to penetrate the sensitive layers of the building envelope.

Two-layer systems are particularly common in types of construction that readily permit two layers of thermal insulation. Such systems are derived from panel construction, but also from solid timber construction (see section b8 30 "Compound cross-sections").



c68



c69

c67 Sketch of the principle of a two-layer system

c68 and c69 Junction details for a two-layer system

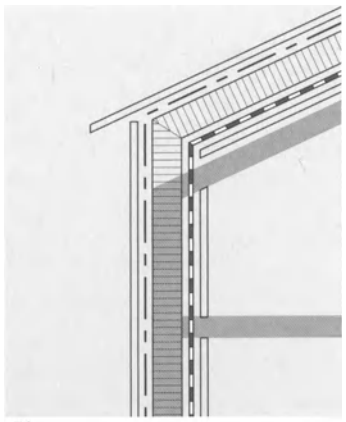
1 Soffit lining, possibly inner lining of wall
2 Loadbearing structure, thermal insulation between members
3 Vapour barrier, airtight membrane (joints sealed airtight, plastic sheeting with variable diffusion resistance recommended)
4 Thermal insulation composite system (insulation + render, open to diffusion)
5 Secondary waterproofing/covering layer, possibly additional insulation
6 Counter battens, ventilation space, possibly strengthening for eaves
7 Roof covering

c2 34 Hybrid system

The thermal insulation in the wall is positioned between the loadbearing members, that in the roof is positioned outside the structure. The airtight membrane and the vapour barrier in the wall are positioned within the clad loadbearing structure. As the roof structure is left exposed internally, both airtight membrane and vapour barrier are positioned on the outside of the roof structure. Every rafter penetrates the external wall, which leads to costly, complicated details; the airtight membrane and the vapour barrier must be sealed around every rafter. Such junctions present problems during construction, and there is also a lack of knowledge about the long-term behaviour of such systems. The plastic sheeting in the wall and in the roof must be bonded together with an acrylic or butyl sealing tape.

Figs. c71 and c72 show an improved solution. The rafters of the roof structure continue only as far as the centre of the external wall. Short, separate rafters support the eaves overhang.

Exposed timber roof structures are also popular in buildings with masonry or concrete walls. The suggested designs can be used similarly for such buildings. It should be remembered that the airtight membrane and the vapour barrier on the warm side of the thermal insulation layer must be connected to the masonry or concrete components. Generally, however, the forms of construction shown in sections c2 31 to c2 33 are to be preferred.



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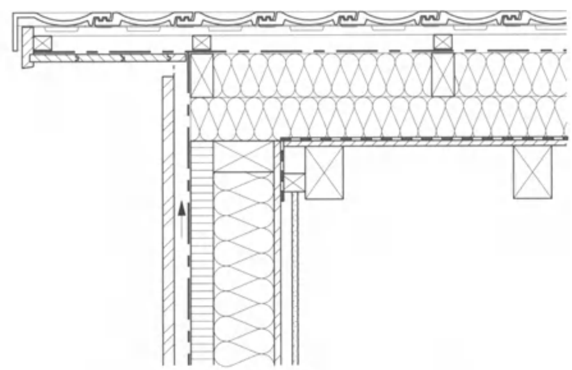

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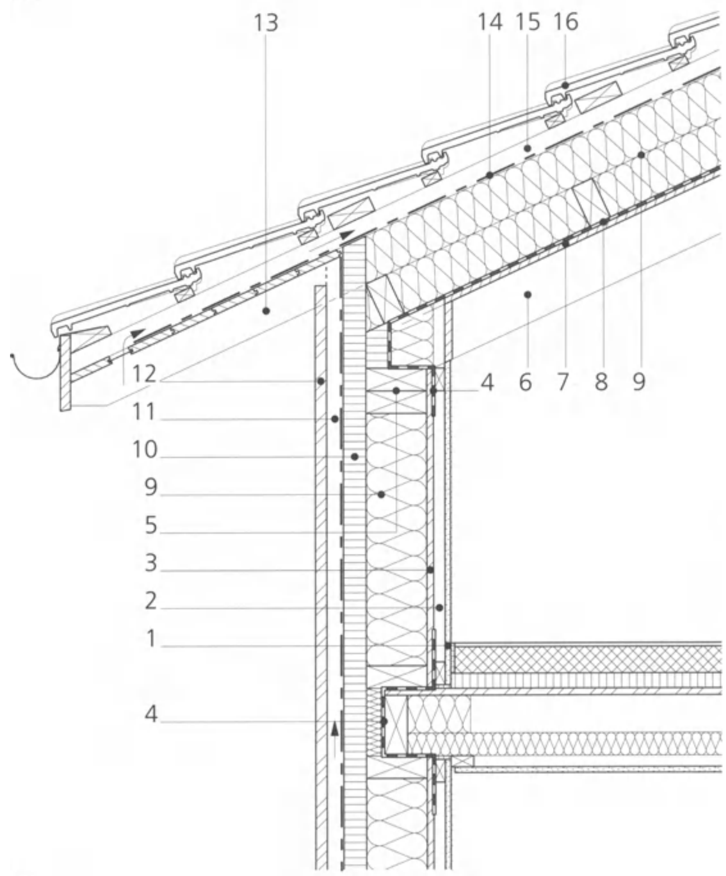


c72

c70 Sketch of the principle of hybrid system
c71 and c72 Junction details for a hybrid system (the use of continuous rafters is not recommended). Figs. c71 and c72 show an improved design with non-continuous rafters.

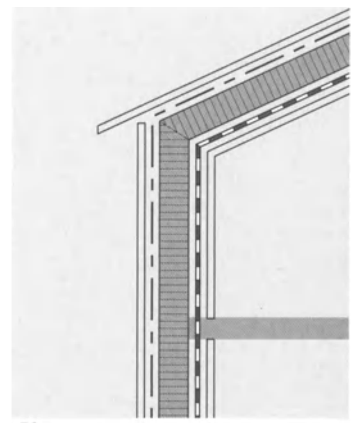
1 Inner lining
2 Framework of battens, space for services
3 Vapour barrier, airtight membrane, structural sheathing
4 Joints sealed airtight (plastic sheeting with variable diffusion resistance recommended)
5 Loadbearing structure
6 Roof structure left exposed
7 Sheathing
8 Vapour barrier, airtight membrane
9 Thermal insulation
10 Protection for thermal insulation, additional insulation
11 Framework of battens, ventilation cavity
12 External cladding
13 Eaves rafters, possibly strengthening for eaves
14 Secondary waterproofing/covering layer, possibly additional insulation, 3-ply core plywood at verges
15 Counter battens, ventilation space, possibly strengthening for eaves
16 Tiling battens, roof covering

c3 10 External wall systems

When considering the external walls, the information given below is based on the conceptual principles presented in chapter c2. We must also distinguish between external walls with external insulation, insulation between the loadbearing members, or a combination of these two basic systems (see Figs. c42 to c45 for an overview). The same considerations also apply to the component junctions discussed in section c2 30 and to the respective roof construction, and it is best when this represents a continuation of the same concept. There is no difference in the sequence of layers described in c2 10, nor between the different timber construction systems; the building physics conditions remain the same. The main differences between the systems are to be found in the position of the loadbearing structure, the appearance, and the component junctions, whereas the sequence of layers – an overriding principle – remains essentially the same. The pros and cons of the individual forms of construction depend on the timber building system (see b6 "Panel construction", b7 "Frame construction", b8 "Solid timber construction").

c3 11 Thermal insulation between structural members

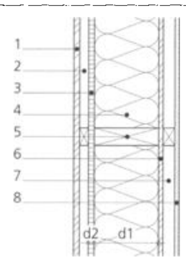
Systems with thermal insulation between the structural members are particularly prevalent in panel construction, in which the loadbearing framework is clad completely on both sides. Detailed information on walls in panel construction can be found in section b6 40. The details given here are also valid for non-loadbearing wall panels, e.g. for frame construction (exception: the enclosing components in frame construction are non-loadbearing and are therefore not designed for this function).
Tables c74 to c79 show suggested forms of construction that take into account the thermal performance and the sound insulation (if required).



c73

c74 External wall with insulation between structural members and ventilation cavity

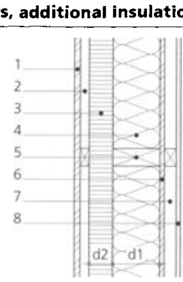
Assumption		
1 External cladding	20 mm	
2 Ventilation cavity	30 mm	R = 0.040 m²K/W
3 Wood fibreboard d2, (3), (7)	22 mm	λ = 0.047 W/mK
4 Thermal insulation d1, (1), (2), (6)	variable	λ = 0.040 W/mK
5 Loadbearing structure	variable	λ = 0.130 W/mK
6 OSB	15 mm	λ = 0.130 W/mK
7 Battens	40 mm	R = 0.160 m²K/W
8 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1, d2	Total	Insulation	Timber	Timber			
			15%	25%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (8)	mm
120,22	142	0.25	0.30	0.33	0.28	47 (–,–)	262
160,22	182	0.20	0.24	0.27	0.21	48 (–,–)	302
200,22	222	0.17	0.20	0.23	0.17	50 (–,–)	342
240,22	262	0.14	0.18	0.20	0.14	52 (–,–)	382

c75 External wall with insulation between structural members, additional insulation, and ventilation cavity

Assumption		
1 External cladding	20 mm	
2 Ventilation cavity	30 mm	R = 0.040 m²K/W
3 Wood fibreboard d2, (4), (7)	80 mm	λ = 0.042 W/mK
4 Thermal insulation d1, (1), (2), (6)	variable	λ = 0.040 W/mK
5 Loadbearing structure	variable	λ = 0.130 W/mK
6 OSB	15 mm	λ = 0.130 W/mK
7 Battens	40 mm	R = 0.160 m²K/W
8 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



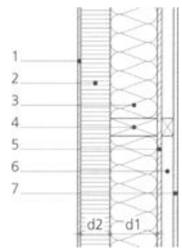
Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1, d2	Total	Insulation	Timber	Timber			
			15%	25%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (8)	mm
120,80	200	0.18	0.21	0.22	0.16	50 (–,–)	320
160,80	240	0.16	0.18	0.19	0.12	52 (–,–)	360
200,80	280	0.13	0.16	0.17	0.10	53 (–,–)	400
240,80	320	0.12	0.14	0.15	0.08	54 (–,–)	440

c73 Sketch of the principle of thermal insulation between structural members

c74 to c79 External wall construction: systems with thermal insulation between structural members

c76 External wall with insulation between structural members plus thermal insulation composite system (insulation + render)

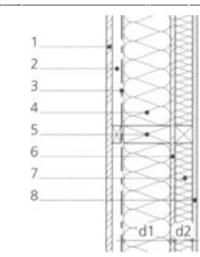
Assumption		
1 Render	10 mm	λ = 0.870 W/mK
2 Wood fibreboard d2, (5), (7)	100 mm	λ = 0.044 W/mK
3 Thermal insulation d1, (1), (2), (6)	variable	λ = 0.040 W/mK
4 Loadbearing structure	variable	λ = 0.130 W/mK
5 OSB	15 mm	λ = 0.130 W/mK
6 Battens	40 mm	R = 0.180 m²K/W
7 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1, d2	Total	Insulation	Timber	Timber			
			15%	25%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (8)	mm
120,100	220	0.17	0.19	0.20	0.11	50 (–,–)	300
160,100	260	0.15	0.17	0.18	0.08	52 (-3,–)	340
200,100	300	0.13	0.15	0.16	0.07	53 (–,–)	380
240,100	340	0.11	0.13	0.14	0.05	54 (–,–)	420

c77 External wall with insulation between structural members and additional insulation in space for services

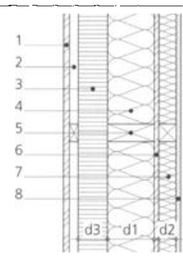
Assumption		
1 External cladding	20 mm	
2 Ventilation cavity	30 mm	R = 0.080 m²K/W
3 Protection for insulation		
4 Thermal insulation d1, (1), (6)	variable	λ = 0.040 W/mK
5 Loadbearing structure	variable	λ = 0.130 W/mK
6 OSB	15 mm	λ = 0.130 W/mK
7 Thermal insulation d2, (1), (6)	60 mm	R = 0.040 m²K/W
8 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1, d2	Total	Insulation	Timber	Timber			
			15%	25%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (8)	mm
120,60	180	0.21	0.26	0.30	0.10	50 (–,–)	260
160,60	220	0.17	0.22	0.25	0.08	52 (–,–)	300
200,60	260	0.15	0.19	0.22	0.06	53 (–,–)	340
240,60	300	0.13	0.17	0.19	0.05	54 (–,–)	380

c78 External wall with insulation between structural members plus additional insulation internally and externally

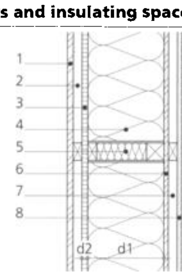
Assumption		
1 External cladding	20 mm	
2 Ventilation cavity	30 mm	R = 0.040 m²K/W
3 Wood fibreboard d3, (4), (7)	100 mm	λ = 0.042 W/mK
4 Thermal insulation d1, (1), (2), (6)	variable	λ = 0.040 W/mK
5 Loadbearing structure	variable	λ = 0.130 W/mK
6 OSB	15 mm	λ = 0.130 W/mK
7 Thermal insulation d2, (1), (6)	60 mm	R = 0.040 m²K/W
8 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1, d2, d3	Total	Insulation	Timber	Tmber			
			15%	25%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (8)	mm
120,60,100	280	0.14	0.16	0.17	0.10	50 (–,–)	360
160,60,100	320	0.12	0.14	0.15	0.08	50 (-3,-10)	400
200,60,100	360	0.11	0.13	0.14	0.07	53 (–,–)	440
240,60,100	400	0.10	0.12	0.13	0.05	54 (–,–)	480

c79 External wall with insulation between structural members and insulating spacers

Assumption		
1 External cladding	20 mm	
2 Ventilation cavity	30 mm	R = 0.080 m²K/W
3 Wood fibreboard d2, (3), (7)	22 mm	λ = 0.047 W/mK
4 Thermal insulation d1, (1), (2), (6)	variable	λ = 0.040 W/mK
5 Loadbearing structure, insul. spacers	variable	λ = 0.130 W/mK
6 OSB	15 mm	λ = 0.130 W/mK
7 Battens	40 mm	R = 0.160 m²K/W
8 Gypsum fibreboard	15 mm	λ = 0.320 W/mK

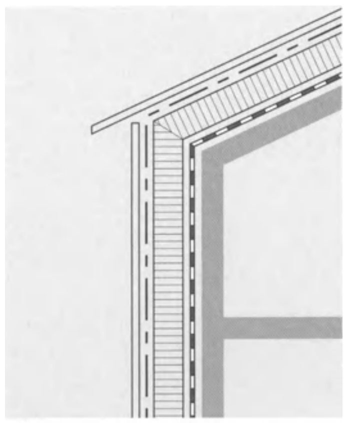


Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1, d2	Total	Insulation	Timber	Timber			
			15%	25%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (8)	mm
220,22	222	0.17	0.19	0.21	0.17	50 (–,–)	342
240,22	262	0.14	0.16	0.17	0.14	51 (-3,-10)	382
280,22	302	0.13	0.14	0.15	0.11	53 (–,–)	422
320,22	342	0.11	0.12	0.13	0.10	54 (–,–)	462
360,22	382	0.10	0.11	0.11	0.08	56 (–,–)	502
400,22	422	0.09	0.10	0.10	0.07	58 (–,–)	542

Notes to tables c74 to c79	for U-value	for U_T-value	
	Thermal conductivity	Density	Specific heat capacity (c)
(1) Mineral-fibre board	λ = 0.040 W/mK		
(2) Cellulose fibres	λ = 0.040 W/mK		
(3) Wood fibreboard, 22 mm	λ = 0.047 W/mK		
(4) Wood fibreboard, 80 mm	λ = 0.042 W/mK		
(5) Wood fibrebd., therm. insul. comp. system	λ = 0.044 W/mK		
(6) Mineral-fibre board		30 kg/m³	0.23 Wh/kgK
(7) Wood fibreboard		140 kg/m³	0.58 Wh/kgK
(8) Sound insulation: please refer to all details in section c6 40 "Suggested forms of construction"			

c3 12 External thermal insulation

Systems with external insulation are very popular in solid timber and some types of frame construction. In solid timber construction, planar, usually large-format components provide the loadbearing and enclosing functions. This loadbearing plate, usually at least 80 mm deep, functions as extra thermal insulation and also serves as a backing for the remainder of the wall construction. Chapter b8 "Solid timber construction" (b8 20 "Solid cross-sections") contains details of possible wall constructions.

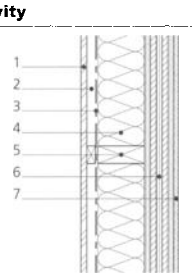


c80

Tables c81 and c82 show suggested forms of construction that take into account the thermal performance and the sound insulation (if required).

c81 External wall with external insulation and ventilation cavity

Assumption		
1 External cladding	20 mm	
2 Ventilation cavity	30 mm	R = 0.040 m²K/W
3 Protection to insulation		
4 Thermal insulation, (1), (3)	variable	λ = 0.040 W/mK
5 Spacer battens	variable	λ = 0.130 W/mK
6 Solid timber wall	100 mm	λ = 0.130 W/mK
7 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1, d2	Total	Insulation	Timber	Timber			
			10 %	15 %			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (5)	mm
120	120	0.25	0.28	0.30	0.19	50 (–,–)	285
160	160	0.20	0.23	0.24	0.14	51 (–,–)	325
100,100	200	0.17	0.19	0.20	0.11	52 (–,–)	365
120,120	240	0.14	0.16	0.17	0.09	54 (–,–)	405

c82 External wall with external insulation, as thermal insulation composite system

Assumption		
1 Render	10 mm	λ = 0.870 W/mK
2 Wood fibreboard, (2), (4)	variable	λ = 0.044 W/mK
3 Solid timber wall	100 mm	λ = 0.130 W/mK
4 Gypsum fibreboard	15 mm	λ = 0.320 W/mK

Insulation thickness	Insulation thickness	U-value	U_T-value	R'_w (C,C_{tr})	Wall thickness
d1	Total	Insulation			
mm	mm	W/m²K	W/m²K	dB (5)	mm
120	120	0.27	0.12	50 (–,–)	245
160	160	0.22	0.07	52 (–,–)	285
200	200	0.19	0.04	53 (–,–)	325

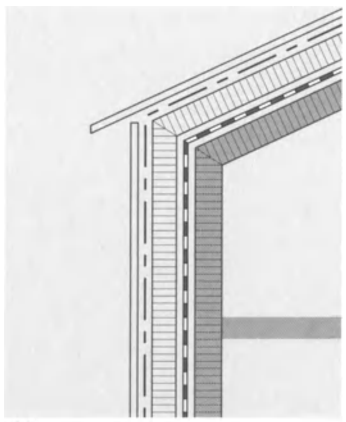
c80 Sketch of principle of external thermal insulation

c81 and c82 External wall construction: systems with external thermal insulation

Notes to tables c81 and c82	for U-value	for U_T-value	
	Thermal conductivity	Density	Specific heat capacity (c)
(1) Mineral-fibre board	λ = 0.040 W/mK		
(2) Wood fibrebd., therm. insul. comp. system	λ = 0.044 W/mK		
(3) Mineral-fibre board		30 kg/m³	0.23 Wh/kgK
(4) Wood fibreboard		140 kg/m³	0.58 Wh/kgK
(5) Sound insulation: please refer to all details in section c6 40 "Suggested forms of construction"			

c3 13 Two-layer system

This involves two layers of thermal insulation: the first in the voids between the loadbearing members, the second attached "seamlessly" around the outside of the loadbearing structure. Such two-layer systems are mainly found in brand-name timber building systems (in solid timber construction). This also means that the wall construction is governed by the respective product and is covered by a manufacturer's specification. Just like the system with insulation between the loadbearing members, the voids between the structural components offer space for the first layer of insulation, and as with the external thermal insulation system, the second layer is placed outside the loadbearing structure. The airtight membrane is positioned between these two layers.

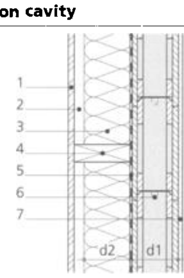


c83

Chapter b8 "Solid timber construction" (b8 30 "Compound cross-sections") contains details of possible wall constructions.
Tables c84 and c85 show suggested forms of construction that take into account the thermal performance and the sound insulation (if required).

c84 External wall with two layers of insulation and ventilation cavity

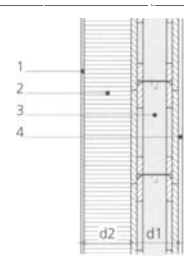
Assumption		
1 External cladding	20 mm	
2 Ventilation cavity	30 mm	R = 0.040 m²K/W
3 Thermal insulation d2, (1), (4)	variable	λ = 0.040 W/mK
4 Spacer battens	variable	λ = 0.140 W/mK
5 Airtight membrane		
6 Insulated timber module d1, (3), (6)	160 mm	λ = 0.073 W/mK
7 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C, C_{tr})	Wall thickness
d1, d2	Total	Insulation	Timber	Timber			
			10 %	15 %			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (7)	mm
(80),60	140	0.25	0.27	0.27	0.09	48 (–,–)	285
(80),100	180	0.20	0.22	0.22	0.06	49 (–,–)	325
(80),140	220	0.17	0.18	0.19	0.04	50 (–,–)	365
(80),160	240	0.16	0.17	0.18	0.04	51 (–,–)	385
(80),200	280	0.14	0.15	0.16	0.03	52 (–,–)	425
(80),120,120	320	0.12	0.13	0.14	0.03	54 (–,–)	465

c85 External wall with two layers of insulation, as thermal insulation composite system

Assumption		
1 Render	10 mm	λ = 0.870 W/mK
2 Wood fibreboard d2, (2), (5)	variable	λ = 0.044 W/mK
3 Insulated timber module d1, (3), (6)	160 mm	λ = 0.073 W/mK
4 Gypsum fibreboard	15 mm	λ = 0.320 W/mK



Insulation thickness	Insulation thickness	U-value	U_T-value	R'_w (C, C_{tr})	Wall thickness
d1, d2	Total	Insulation			
mm	mm	W/m²K	W/m²K	dB (7)	mm
(80),60	140	0.26	0.08	48 (–,–)	245
(80),80	160	0.24	0.06	49 (–,–)	265
(80),100	180	0.21	0.04	50 (–,–)	285
(80),120	200	0.19	0.03	50 (–,–)	305
(80),160	240	0.17	0.01	51 (–,–)	345
(80),200	280	0.14	0.01	51 (–,–)	385

c83 Sketch of the principle of two-layer system

c84 and c85 External wall construction: systems with two layers of thermal insulation

Notes to tables c84 and c85	for U-value	for U_T-value	
	Thermal conductivity	Density	Specific heat capacity (c)
(1) Mineral-fibre board	λ = 0.040 W/mK		
(2) Wood fibrebd., therm. insul. comp. system	λ = 0.044 W/mK		
(3) Insulated timber module	λ = 0.073 W/mK		
(4) Mineral-fibre board		30 kg/m³	0.23 Wh/kgK
(5) Wood fibreboard		140 kg/m³	0.58 Wh/kgK
(6) Insulated timber module		280 kg/m³	2.10 Wh/kgK
(7) Sound insulation: please refer to all details in section c6 40 "Suggested forms of construction"			

c3 External walls

c3 20 External cladding

It is the external cladding, the facade, the gives the building its particular external appearance. Timber in the form of solid wood or wood-based products is being used more and more in contemporary architecture, but wooden cladding has been in use for generations. Its correct use, however, presumes precise knowledge about the exposure conditions and the specific material properties.

c3 21 General design criteria

- Surroundings
- Building geometry
- Design requirements of architect and client
- Prevailing weather conditions
- Requirements regarding surface finishes and ease of maintenance
- Building regulations
- Thermal performance
- Fire protection
- Requirements regarding supporting construction

Options

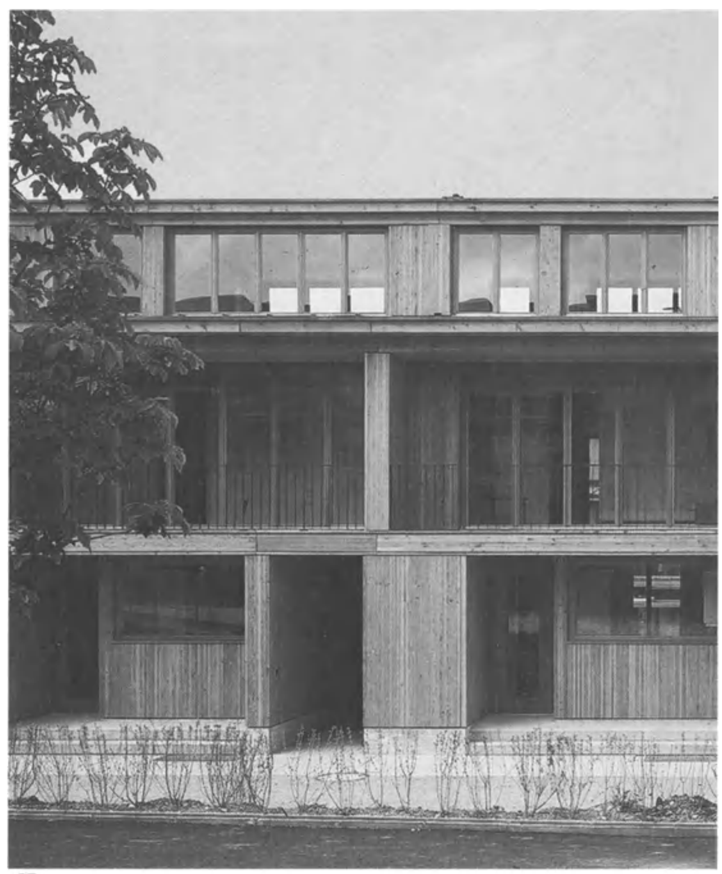
- Solid timber boards with various profiles
- Solid timber boards with cover strips
- Solid timber cladding with diverse cross-sections (strips, battens, slats, structural sections, etc.)
- Shakes and shingles
- Wood-based board products
- Cement fibreboard
- Wood cement particleboard
- Sheet metal finishes
- Facing masonry
- Mineral render on appropriate backing boards or insulating materials

c86

c3 22 External cladding in wood

Species of wood

Domestic softwoods (spruce, fir, Scots pine, larch or Douglas fir) can satisfy the requirements placed on external wall cladding in normal conditions. More resistant species such as redwood, western red cedar or oak should be used on facades exposed to more severe weather conditions. Pressure impregnation, however, improves the durability of spruce and fir to such an extent that they can also be used in exposed locations (see also section d2 30 "Surface treatments and chemical wood preservatives").



c87

c86 Timber structure
External cladding of ground floor: 8 mm fibre-cement sheets, 15 mm in some places, anthracite, with special anti-graffiti coating
External cladding of upper floor: OSB with coloured finish, spacer battens, glass-fibre panels

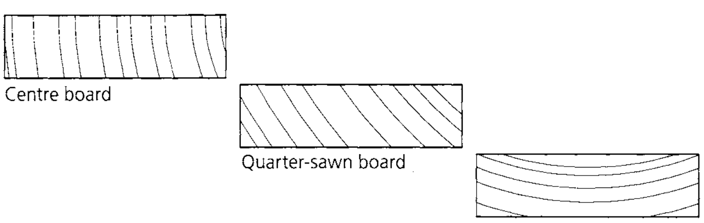
c87 Timber structure
External cladding of solid timber, Douglas fir, rough-sawn surface finish, untreated

Orientation of cladding

Planks can be attached vertically, horizontally or diagonally. Numerous profiles which guarantee good water run-off are available for both vertical and horizontal arrangements. When attaching planks diagonally, the correct design and construction of the butt joints at the ends of the planks is very important. The diagonal arrangement ensures that water drains away from the surface, but it tends to collect at the butt joints and also at corners, and junctions with doors and windows.

Orientation of annual rings

Centre and quarter-sawn boards are recommended for timber facades because the use of side boards can result in the uppermost layers of wood exposed to the weather becoming detached over the years. Furthermore, deformations can be more severe and fissures more frequent with side boards.



c88

Cross-sections

The minimum thickness of external solid timber cladding components should be 20 mm. "Relieving grooves" on the rear faces of planks can reduce their stability and, depending on the type of fixing, may aggravate cupping distortion. The maximum width of tongue and groove planks for cladding should not exceed 140 mm for planks with no or only minimal exposure to the weather, but 120 mm for planks exposed to extreme weather conditions. Generally, narrow slats (e.g. 60, 70, 80 mm) are preferable to wider (e.g. 120, 140 mm) types. Strips or slats can also be used for open types of external cladding; the spacing between the individual pieces in such designs should be at least 10 mm and the inclination of the horizontal narrow faces at least 15°. Timber components that are to be treated with preservative should have radiused corners and edges (min. 2.5 mm) in order to guarantee a sufficient thickness of the protective film.

Moisture content

Swiss standard SIA 265 "Timber structures" specifies the following values for the moisture content of timber at the time of installation (figures valid for certain areas of Switzerland):

- an average value of 15% for surfaces that absorb significant radiation, with a tolerance of ±5%
- an average value of 17% for surfaces that absorb little radiation, with a tolerance of ±4%

Guidance on this aspect is less clearly defined in Germany; DIN 1052 (2004) no longer contains any figures. The moisture content of timber used for external cladding is, however, often too high. A moisture content between 12 and 16% at the time of installation is recommended for the majority of applications.

c3 23 Cladding made from wood-based board products

Large-format panels are becoming increasingly popular for cladding in contemporary architecture. The use of products made from cement fibreboard or wood cement particleboard have become well established. By contrast, true wooden products are suitable for external applications to a limited extent only.

Weatherproof gluing of outer and inner plies is necessary when using multi-ply solid timber or laminated veneer lumber products. Plugged and filled knots and repairs in the outer plies should be avoided, likewise direct exposure to the weather of unprotected narrow edges and horizontal joints. The narrow upper edge of a board can be protected with sheet metal profiles, timber strips or by overlapping the boards. The narrow lower edge must be cut back at an angle of 15°. Vertical joints should take the form of a gap equal to the thickness of the boards, but not less than 10 mm. All narrow surfaces left uncovered should be protected by a coat of water-repellent paint. As the board materials exhibit different properties, the recommendations of the manufacturer or supplier should be followed in each case.

c88 Orientation of annual rings: centre, quarter-sawn, and side boards


c89

c90 Wood-based products as external cladding				
Type of board[1]		**Untreated**	**With surface treatment**	**Possible problems**
Solid timber boards	Single-ply [2,3,4]	less suitable	less suitable	Dimensional changes, distortion
	Cross-banded multi-ply [2,3]	sometimes suitable	sometimes suitable	Fissures, delamination
Particleboards	Synthetic resin adhesive	unsuitable	unsuitable	Durability, swelling, flaking of face particles
	Cement-bound	suitable	suitable	
	OSB [2,3]	less suitable	less suitable	Durability, swelling, flaking of face particles
	Specially compressed and processed boards	unsuitable	suitable	
Fibreboards	Highly compressed boards of impregnated fibres	unsuitable	sometimes suitable	
	Standard fibreboards	unsuitable	sometimes suitable	Water absorption, swelling, flaking of face fibres
Laminated veneer lumber	Laminated veneer lumber[2]	unsuitable	unsuitable	Dimensional changes, fissures
	Plywood	unsuitable	sometimes suitable	Closed splits in outer ply, delamination

1 Always follow the instructions of the manufacturer or supplier.
2 These boards are sometimes used in facades, but they are only suitable under certain conditions.
3 Can be used if there is a high degree of passive timber protection, e.g. a protective canopy or eaves.
4 Due to the large dimensional changes in narrow boards up to about 300 or 400 mm mm wide, pay special attention to fixings.

c3 24 Protective measures
Protective measures should be taken to ensure long-term functionality and to prevent a chain of damage with technical repercussions. The most important criteria for external cladding in wood are summarised below. Supplementary and fundamental information on protective issues can be found in chapter d2 "Protecting timber".

Constructional (passive) protective measures
- Passive timber protection forms the vital line of protection against the premature ageing of the building envelope and all the components it contains, e.g. doors, windows, etc.
- An adequate eaves overhang to provide long-term protection against moisture.
- Rainwater must be able to drain away from the surfaces unhindered and should not be able to infiltrate into seams and joints.
- Adequate distance between wooden cladding and the ground (min. 300 mm).
- Window cornices and masonry ledges should ideally be designed with a slope of 15°, and should be covered.
- Rainwater drips are advantageous in external cladding.
- Avoid condensation by including a ventilation cavity behind cladding, choosing the right wall construction, and planning and installing the airtight membrane properly.

External cladding of untreated wood
External cladding systems made from untreated wooden components can achieve a very long service life with only minimal maintenance. Buildings on which the cladding has remained intact for 40 or 50 years or even longer are not unusual. When used on external surfaces, however, untreated materials show the effects of the weather relatively quickly. In the case of wooden cladding this becomes evident mainly in the form of discoloration, which depends on the climate, the orientation, the eaves design, and the screening effect of neighbouring buildings and vegetation. The effects can even vary on the same facade surface. The surfaces of north-, east-, and south-facing elevations, also cladding protected by an eaves overhang, projecting facade elements, e.g. window sills, or horizontal joint details, exhibit a light to dark brown colouring. On the other hand, weathered timber components on west-facing

c89 Timber structure
External cladding of coloured fibre-cement sheets

c90 Wood-based products as external cladding.

c91

c92

elevations turn silver to dark grey under most climatic conditions. However, the effects of the weather and the resulting discoloration do not lead directly to the destruction of the microstructure of the wood and hence to less strength. The discoloration and minimal changes to the surface of the wood, primarily caused by UV radiation and the erosion (leaching) of photochemically decomposed constituents of the wood from the uppermost layer of cells, is a change in the surface that corresponds to the natural ageing of the wood. This alteration of the surface does not have any relevant influence on the technical durability of an untreated wooden cladding product. The changes may even be desirable for certain applications.

c91 The influence of time on the nature and intensity of the weathering and discoloration of spruce: from unexposed to 180 days of accelerated weathering on a 45° south-facing surface

c92 Timber structure
External cladding of larch shingles, laid in double-lap arrangement, 60–140 x 250 mm, 8–10 mm thick, 100 mm margin (visible part of shingle), no ventilation cavity

Surface treatment

General

- A surface treatment can change the colour of the wood. In addition, the treatment can provide protection from the weather and improve the dimensional stability.
- The prerequisite for a functioning surface treatment on wooden cladding is the selection of suitable materials and their correct application. Mistakes here cannot be made good by surface treatments or chemical preservatives.
- External cladding must be given an undercoat on all sides prior to installation.
- Edges and corners must be radiused (min. 2.5 mm) to ensure adequate coverage and the adhesion of coatings.
- Wooden surfaces with various degrees of mechanical treatment (rough-sawn, brushed, sanded, planed) are used. All surface treatment products described here can be used in conjunction with any of these mechanical pre-treatments.
- The use of rough-sawn or sanded surfaces results in much longer renovation intervals than is the case with planed surfaces (Fig. c94). The use of planed surfaces alone is not recommended; such surfaces must be slightly roughened prior to applying any coating. It is important that all parts of treated timber components be sanded, i.e. edges, corners, cover strips, narrow edges of slats or battens.
- Regular, preventive maintenance guarantees long-lasting functionality.
- Approved products are recommended for glaze coats and impregnating primers.
- Owing to better quality control, fully factory-coated wooden facade components are becoming more and more common.

Colourless, water-repellent impregnation treatments

The surface of the wood weathers like untreated wood, but slower. Impregnation can delay the saturation of the wood over time. The durability of such coatings is, however, low.

Colourless coatings, clear lacquers

Colourless glaze coats or lacquers are not suitable for external use. They offer insufficient protection against UV radiation, which limits their durability to a maximum of two years, depending on weather conditions. If the cladding is reliably protected against the direct effects of the weather, such products can delay the onset of grey discoloration.

Thin-film glaze coats

A coating material that infiltrates the wood to a certain extent. Two coats achieve a film thickness of approx. 10 to 20 µm (0.01 to 0.02 mm). The grain of the wood remains visible and is emphasized. The durability when exposed to the direct effects of the weather is about two to four years on south- and west-facing elevations. The more intense the colouring in the glaze, the higher its light- and colour-fastness. Renovation requirements are low.

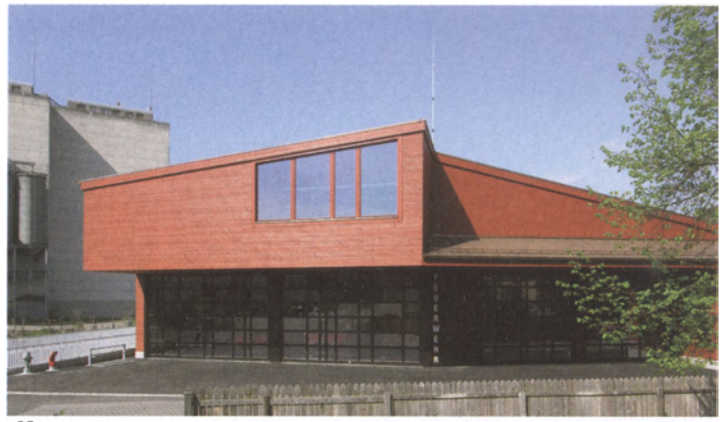
High-build glaze coats

A coating material that does not infiltrate the wood significantly. Two coats achieve a film thickness of approx. 30 to 50 µm (0.03 to 0.05 mm). The grain of the wood remains visible only as a "relief". The durability when exposed to the direct effects of the weather is about three to six years on south- and west-facing elevations. Renovation requirements are low.

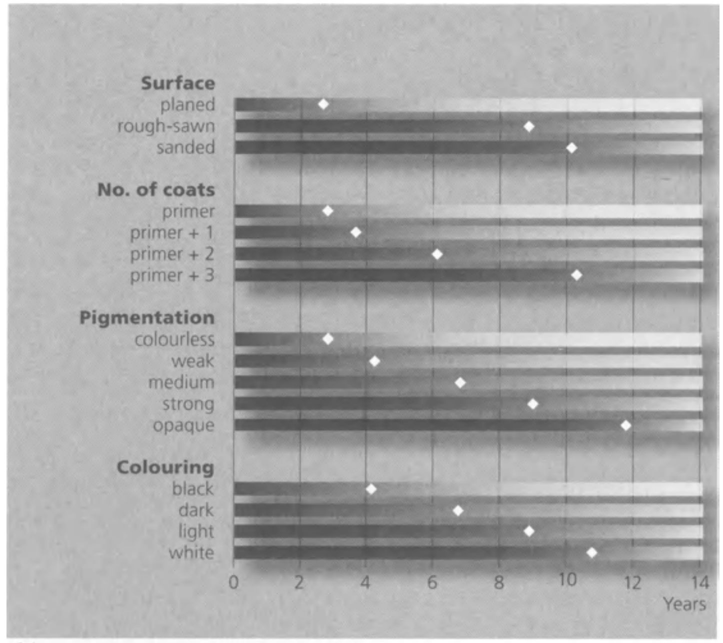
Paints, opaque coatings

Opaque coatings infiltrate the wood either to a minor degree or not at all. Two coats achieve a film thickness of approx. 80 to 120 µm (0.08 to 0.12 mm). The durability when exposed to the direct effects of the weather is about six to twelve years on south- and west-facing elevations. Renovation requirements are high.

Opaque paints produce surfaces with a uniform colour. They offer very good UV protection and therefore represent durable coatings. The thickness of the coating has a prime effect on moisture control and weathering behaviour. Dark coatings exposed to direct sunlight exhibit higher surface temperatures and hence greater deformations.



c93



c94

Pressure-impregnated wooden cladding

The preservative is forced into the timber cross-section by means of special pressure and vacuum techniques. In doing so, the depth of penetration and the quantity of preservative forced into the timber is decisive for the success of the treatment. However, the type of preservative and the species of wood also have an influence on the quality of the impregnation. Approved products subjected to constant monitoring by independent institutes are to be preferred. Pressure impregnation is carried out off-site in specialist facilities. Spruce, fir, and Scots pine are suitable for pressure-impregnated external cladding products, which are very durable and require only minimal maintenance.

Heat-treated wood

The heat treatment of wood leads to a colour change, the intensity of which depends on the species of wood and the length and intensity of the treatment, and may even reach a dark brown colour. According to studies carried out hitherto, heat-treated wood (e.g. ThermoWood®) exhibits lower water absorption and better dimensional stability, but also reduced strength and a greater

c93 Timber structure
External cladding of solid timber, horizontal overlapping slats (weatherboarding), rough-sawn with opaque paint finish

c94 Influencing factors and renovation intervals for the surfaces of timber components [26]

c95

c96

tendency towards embrittlement. Cladding made from heat-treated wood has only appeared in recent years. It is reasonable to assume that the advantageous characteristics such as lower water absorption and good dimensional stability will have a positive effect on the service life of external cladding products. It should be noted, however, that heat-treated wood is affected by UV light – it turns grey just like untreated wood. Heat-treated wood is not usually given a protective coating when used for external cladding. Spruce and fir are the species most commonly used for this treatment.

Nanotechnology

Nanotechnology could prove interesting for facade applications because the application of such a coating lends the surface of the timber a significant water-repellent characteristic. Products based on nanotechnology are already available. They prevent the infiltration of water in liquid form, but this treatment – at least with current technology – cannot prevent infiltration of water in vapour form, the main cause of shrinkage and swelling effects. Water-repellent coatings based on nanotechnology are among the new facade treatments that show great promise for the future; research and development is ongoing. For further information on pressure-impregnated cladding, heat-treated wood, and nanotechnology, please refer to chapter d2 "Protecting timber".

c95 Timber structure with rendered external wall; thermal insulation composite system, i.e. wood fibreboards as insulation plus coating of mineral render

c96 Timber structure
External cladding of solid timber, horizontal overlapping slats (weatherboarding) on single-storey structure, vertical boarding on main structure, opaque paint finish

c3 25 Fixings

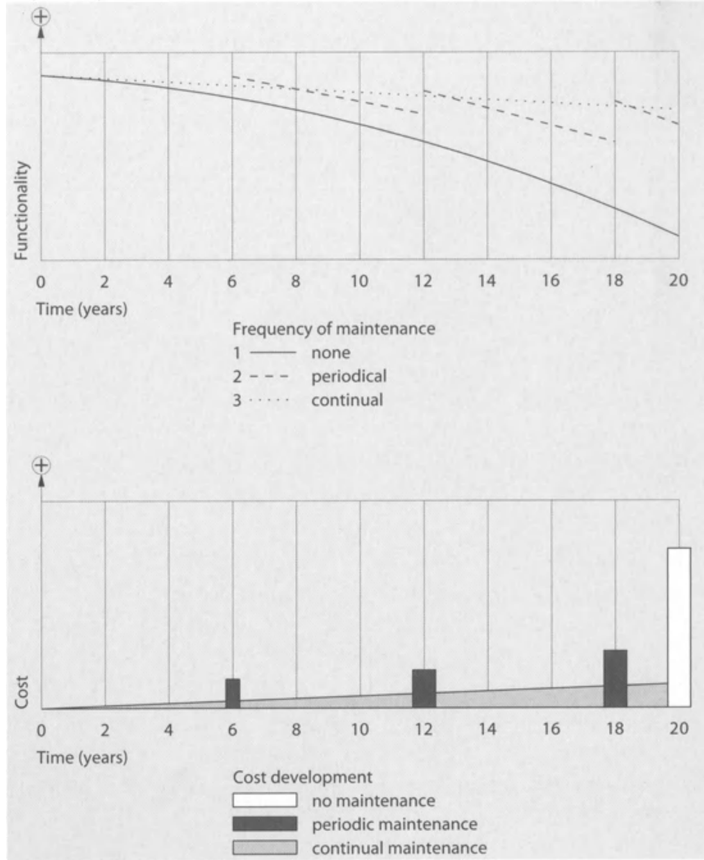
The purpose of the fixings is to secure the individual wooden cladding elements permanently. On the one hand, they should prevent individual components from deforming, on the other, they should allow dimensional changes (caused by shrinkage and swelling) to a certain extent so that fissures do not appear in the wood. Solid timber cladding elements are fixed with nails, screws or clips. In addition to such standard fixings, there are also many different patented fasteners on the market. Fixings can be fitted to the front or rear of the cladding and are either visible or concealed, depending on the type of profile and/or the overlapping arrangement of the timber components.

The primary criteria for the choice of fixings are: load-carrying capacity, durability, and weathering resistance. In the case of nails and screws, the penetration depth depends on the thickness of the cladding to be fixed. The carpenter's rule of thumb is: length of nail at least three times the thickness of the plank to be fixed. The head should neither project above the surface of the timber nor be driven deeper into the wood. Clips are recommended only for concealed fixings. It must be ensured that the fixings used do not impair the overall appearance of the cladding. So they should not cause any visible discoloration of the wood, which sometimes happens when using non-galvanised nails and screws, or when certain substances in the wood react chemically with the metal of the fasteners. Such oxidative discoloration can occur in conjunction with oak and chestnut, plus a number of exotic species. Hot-dip galvanised fasteners generally guarantee the necessary protection against corrosion. A certain caution must be exercised in the case of electrogalvanised nails, screws or clips because the zinc coating can be damaged during installation.
Wherever discoloration – caused by corrosion or chemical reactions with the substances in the wood –must be avoided at all costs, stainless steel fasteners should be used. The quality of the steel composition is decisive for avoiding discoloration.

c3 26 Inspections and maintenance

Every cladding material must be maintained if it is to reach its maximum service life. In the case of external wooden cladding, the maintenance work required depends on the realisation of the original timber protection concept. The upper diagram in Fig. c97 shows how the frequency of maintenance has a direct influence on the functionality of treated wooden cladding. No maintenance at all results in a continuous loss of functionality and rapid decay (curve 1). Refurbishment in this case involves the complete replacement of the cladding which no longer fulfils its purpose. Maintenance work can be carried out periodically (curve 2), e.g. every six years. The first time the work is carried out, much of the original quality is restored, but the loss of functionality becomes more and more obvious after successive maintenance operations. If the maintenance work is carried out continually, a little at a time (curve 3), there is still a loss in functionality, but this takes place at a much slower rate and the total service life is prolonged considerably. Such work includes, for example, an annual inspection to check for mould growth or insect attack, the cleaning of insect screens, the removal of algae growths, cutting back vegetation, etc. Whereas continual, minimal maintenance is recommended for cladding made from untreated or pressure-impregnated timber, periodic maintenance is preferred for cladding with a surface treatment.

The cost of maintaining cladding is plotted against the maintenance interval in the lower diagram in Fig. c97. A high capital outlay for the replacement of cladding must be reckoned with if maintenance is neglected. Periodic maintenance will cost more each time. And the cost of continual, minimal maintenance will certainly gradually increase over the years, but will on the whole remain low.



c97

c3 30 Inner linings

General design criteria

- Interior architecture considerations
- Use of the rooms
- Loads on and requirements to be satisfied by the surface, and maintenance
- Supporting framework, construction of internal and external walls
- Fire and acoustic requirements
- Summertime and wintertime thermal performance, moisture control requirements
- Influence on the living standards and thermal comfort
- Behaviour with respect to and control of the humidity of the interior air

Options

- Linings made from various species of wood with diverse dimensions, profiles, surface finishes, and surface treatments
- Wood-based products (LVL, veneer plywood, particleboard, OSB, hardboard, medium board, MDF, etc.), untreated, veneered, painted or pigmented
- Wood-based products, plasterboard or gypsum fibreboard as a backing for textiles, ceramics, or plastics
- Plasterboard, gypsum fibreboard, or loam building boards, with plaster finish
- Various boards such as wood cement particleboard or exfoliated vermiculite boards

c97 (top) Functionality of external cladding plotted against maintenance interval [26]
c97 (bottom) Cost of maintaining external cladding plotted against frequency of maintenance [26]

c98

Recommendations

Formaldehyde: Only materials manufactured with zero- or low-formaldehyde adhesives should be considered for indoor applications. The materials used should employ adhesives that, owing to their chemical setting behaviour, do not contain or release formaldehyde (PVAc, PUR, EPI, PMDI or hot-melt adhesives). Wood-based board products containing urea-formaldehyde resin are regarded as low-formaldehyde products, e.g. those whose potential emissions and conditions in use comply with the rules for assessing particleboards. In Switzerland such boards are marked *LIGNUM CH 6.5*, in Germany boards of emissions class E 1. Some manufacturers subject their products to checks that guarantee considerably lower emissions, guaranteed by special approvals (e.g. RAL-ZU 38 and 76, Blue Angel, Nature Plus).

It should be noted that besides the potential emissions of the boards or panels, conditions in the rooms affected must also be considered. The proportion of open cut edges or perforations also plays a role in the loads to which the interior is subjected because a great deal more formaldehyde is released via the edges than via the surfaces. Products manufactured with zero-formaldehyde adhesives are advantageous.

Interior climate: Wood-based board products suitable for use in wet areas should be used in rooms with a higher relative humidity at times (usage class 2, r.h. > 85% for a few weeks in the year), i.e. OSB to EN 300, type OSB/3 or OSB/4, particleboards to EN 312-7, type 5 or 7.

Planar materials: Wood-based products, gypsum fibreboard, and plasterboard form coherent surfaces that can shrink and swell differently than the underlying timber framework. Cracks and unsightly gaps at joints can be avoided by including expansion joints and by designing the structure accordingly.

Ceramics: In certain conditions, wood-based products and gypsum fibreboard can be used as a backing for ceramic products. The installation recommendations and instructions of the manufacturer or supplier must be followed.

c99

c100

c98 Inner lining of solid timber; such linings can remain untreated, but if treated, colourless or opaque products "free from active substances" should be used. Example shown here: local-grown fir for the soffit and walls, ash for the floor.

c99 Inner lining of plasterboard or gypsum fibreboard

c100 Wood-based board products with an improved surface finish or solid timber can be used as lining materials

c4 10 Uninsulated pitched roofs

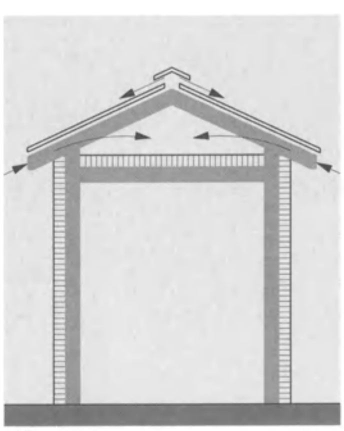
Buildings that do not need to satisfy any particular thermal performance requirements (e.g. warehouses) can be built with uninsulated pitched roofs. Another application for an uninsulated pitched roof is on a building in which the uppermost layer of thermal insulation is placed in the topmost suspended floor – which results in a cold, unheated roof space (Fig. c101). Such a ventilated roof space acts as a buffer zone in both summer and winter. During the winter, the even temperature in the roof space and on the roof surface means that snow and ice melts evenly, which prevents a build-up of ice or backed-up water along the edges of the roof. Today, however, the majority of roof spaces are used as habitable spaces, and so the following information is limited to insulated pitched roofs.

c4 20 Insulated pitched roofs

c4 21 General

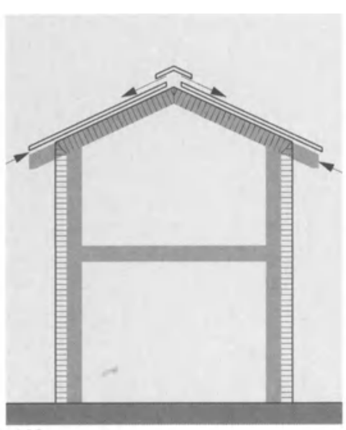
In an insulated pitched roof we find – besides the roof covering and the secondary waterproofing/covering layer – the layer of thermal insulation, the airtight membrane, the vapour barrier, and the soffit lining, all in the plane of the roof (Fig. c102). The once common attic, which formed a building physics buffer zone between the interior and exterior climates, is unusual nowadays. We distinguish between two types of insulated pitched roof:
Roofs with one ventilation space (formerly referred to as warm decks), i.e. with a ventilation space between the roof covering and the secondary waterproofing/covering layer; there is no ventilation space below the latter (Fig. c103).
Roofs with two ventilation spaces (formerly referred to as cold decks), i.e. with a ventilation space between the roof covering and the secondary waterproofing/covering layer, and another between the latter and the thermal insulation (Fig. c104).
Owing to the ever-increasing thicknesses of thermal insulation and the better use of building materials to match the vapour diffusion requirements (especially in the case of the secondary waterproofing/covering layer), roofs with two ventilation spaces (cold decks) are now much less common than in the past. A ventilation space beneath the secondary waterproofing/covering layer is therefore rare.

Like with the external wall, we also distinguish between roofs with external ventilation and roofs with insulation between the structural members. But once again, there is no difference in the sequence of layers described in c2 10, and the building physics conditions remain the same. The main differences between the systems are to be found in the position of the loadbearing structure and the appearance, whereas the sequence of layers – an overriding principle – remains essentially the same.



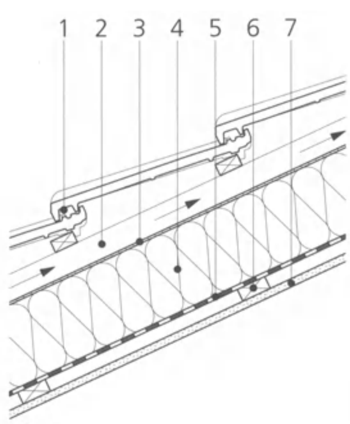
c101

c101 Building with a cold, ventilated attic; thermal insulation, airtight membrane, and vapour barrier in the topmost suspended floor.



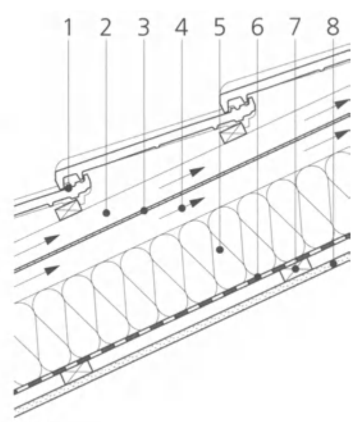
c102

c102 Roof space used for habitable rooms; thermal insulation placed in the roof structure. Today, buildings frequently include habitable rooms right up to the underside of the roof construction, which places higher building physics demands on the pitched roof construction.



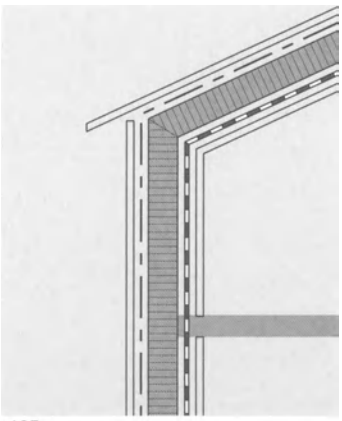
c103

c103 Roof with one ventilation space
1 Roof covering
2 Ventilation space
3 Secondary waterproofing/covering layer
4 Thermal insulation
5 Vapour barrier, airtight membrane
6 Battens, space for services
7 Soffit lining



c104

c104 Roof with two ventilation spaces
1 Roof covering
2 Ventilation space
3 Secondary waterproofing/covering layer
4 Ventilation space
5 Thermal insulation
6 Vapour barrier, airtight membrane
7 Battens, space for services
8 Soffit lining



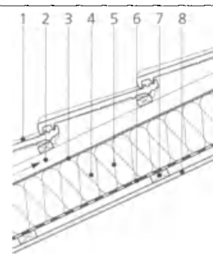
c105

c4 22 Pitched roofs with insulation between structural members

This system is well established. The overall depth of the roof construction is less than that of a system with external insulation and the design of the inner surfaces does not depend on the loadbearing structure. The thermal insulation is laid between the members of the loadbearing structure, the airtight membrane and the vapour barrier are on the inside. The details for the airtight membrane and the vapour barrier are simple at the wall/roof junction (provided the insulation in the wall is also between the structural members). But it is more difficult to accommodate components that penetrate the roof covering for architectural or structural reasons, e.g. collars, kneebraces, etc. The detailing at penetrations causes problems and therefore such penetrations should be minimised if they cannot be entirely eliminated. A ventilation space is required between the roof covering and the secondary waterproofing/covering layer, with appropriate air inlets and outlets at the eaves and ridge respectively. Tables c106 to c108 show suggested forms of construction that take into account the thermal performance and sound insulation (if required).

c106 Pitched roof with insulation between structural members

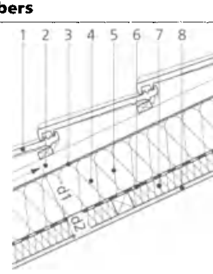
Assumption		
1 Roof covering	variable	
2 Ventilation space	50 mm	R = 0.040 m²K/W
3 Secondary layer, hardboard (3)	5 mm	λ = 0.080 W/mK
4 Thermal insulation (1), (4)	variable	λ = 0.040 W/mK
5 Loadbearing structure, rafters	variable	λ = 0.130 W/mK
6 Airtight membrane, vapour barrier		
7 Battens	30 mm	R = 0.160 m²K/W
8 Soffit lining	15 mm	λ = 0.130 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Roof thickness
d1	Total	Insulation	Timber 10%	Timber 15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (6)	mm
120	120	0.28	0.33	0.35	0.34	-- (-,-)	280
160	160	0.22	0.26	0.28	0.25	50 (-3,-9)	320
200	220	0.18	0.21	0.23	0.20	52 (-3,-10)	360
240	240	0.15	0.18	0.20	0.16	52 (-3,-10)	400
280	280	0.13	0.16	0.17	0.14	-- (-,-)	440

c107 Pitched roof with insulation between structural members

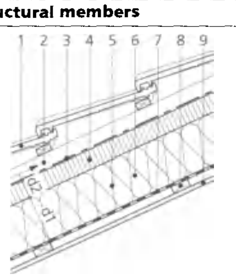
Assumption		
1 Roof covering	variable	
2 Ventilation space	50 mm	R = 0.040 m²K/W
3 Secondary layer, hardboard (3)	5 mm	λ = 0.080 W/mK
4 Thermal insulation d1 (1), (4)	variable	λ = 0.040 W/mK
5 Loadbearing structure, rafters	variable	λ = 0.130 W/mK
6 Airtight membrane, vapour barrier		
7 Thermal insulation d2	60 mm	λ = 0.040 W/mK
8 Soffit lining	15 mm	λ = 0.130 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Roof thickness
d1, d2	Total	Insulation	Timber 10%	Timber 15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (6)	mm
120,60	180	0.21	0.24	0.25	0.22	-- (-,-)	310
160,60	220	0.17	0.20	0.21	0.17	53 (-,-)	350
200,60	260	0.15	0.17	0.18	0.14	55 (-,-)	390
240,60	300	0.13	0.15	0.16	0.12	55 (-,-)	430
280,60	340	0.11	0.13	0.14	0.10	-- (-,-)	470

c108 Pitched roof with insulation between and above structural members

Assumption		
1 Roof covering	variable	
2 Ventilation space	50 mm	R = 0.040 m²K/W
3 Secondary layer, plastic sheet		
4 Thermal insulation d2 (2), (5)	80 mm	λ = 0.042 W/mK
5 Thermal insulation d1 (1), (4)	variable	λ = 0.040 W/mK
6 Loadbearing structure, rafters	variable	λ = 0.130 W/mK
7 Airtight membrane, vapour barrier		
8 Battens	30 mm	R = 0.16 m²K/W
9 Soffit lining	15 mm	λ = 0.130 W/mK

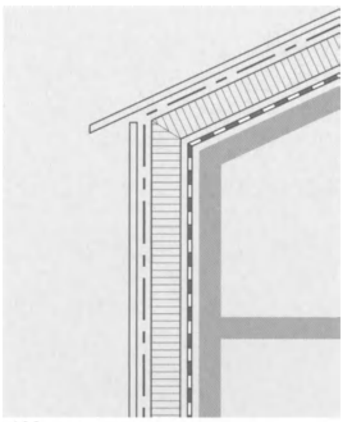


Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'_w (C,C_{tr})	Roof thickness
d1, d2	Total	Insulation	Timber 10%	Timber 15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (6)	mm
120,80	200	0.19	0.20	0.21	0.15	-- (-,-)	355
160,80	240	0.16	0.17	0.18	0.12	-- (-,-)	395
200,80	280	0.14	0.15	0.16	0.09	-- (-,-)	435
240,80	320	0.12	0.13	0.14	0.08	-- (-,-)	475
280,80	360	0.11	0.12	0.13	0.06	-- (-,-)	515

c105 Sketch of the principle of thermal insulation between structural members

c106 to c108 Pitched roof construction: thermal insulation between structural members

Notes to tables c106 to c108	for U-value	for U_T-value	
	Thermal conductivity	Density	Specific heat capacity (c)
(1) Mineral fibreboard	λ = 0.040 W/mK		
(2) Wood fibreboard, 80 mm	λ = 0.042 W/mK		
(3) Hardboard, 8 mm	λ = 0.080 W/mK		
(4) Mineral fibreboard		30 kg/m³	0.23 Wh/kgK
(5) Wood fibreboard		140 kg/m³	0.58 Wh/kgK
(6) Sound insulation: please refer to all details in section c6 40 "Suggested forms of construction"			



c109

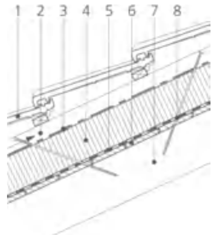
c4 23 Pitched roofs with external thermal insulation

The airtight membrane, vapour barrier, and thermal insulation are placed outside the loadbearing structure. The thickness of the insulation can therefore be chosen irrespective of the depth of the structural members. Building services are routed in separate ducts and conduits, or in the plane of the loadbearing structure, which can remain exposed internally. The eaves overhang is formed with separate members in the plane of the thermal insulation and can therefore be kept slender.

Tables c110 to c113 show suggested forms of construction that take into account the thermal performance and the sound insulation (if required).

c110 Pitched roof with external insulation and spacer screws

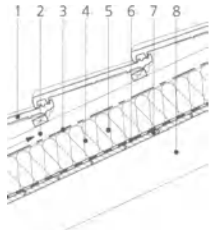
Assumption		
1 Roof covering	variable	
2 Counter battens, ventilation space	50 mm	R = 0.040 m²K/W
3 Secondary layer, plastic sheet		
4 Thermal insulation (2), (4)	variable	λ = 0.042 W/mK
5 Airtight membrane, vapour barrier		
6 Sheathing	27 mm	λ = 0.130 W/mK
7 Loadbearing structure, rafters	variable	
8 Spacer screw	variable	



Insulation thickness	Insulation thickness	U-value	U_r-value	R'_w (C,C_{tr})	Depth w/o rafters
d1	Total	Insulation			
mm	mm	W/m²K	W/m²K	dB (5)	mm
120	120	0.31	0.26	-- (-,-)	257
160	160	0.24	0.14	48 (-3,-9)	297
200	200	0.19	0.07	48 (-3,-9)	337
240	240	0.16	0.04	52 (-2,-7)	377

c111 Pitched roof with external insulation and one layer of spacer battens

Assumption		
1 Roof covering	variable	
2 Counter battens, ventilation space	50 mm	R = 0.040 m²K/W
3 Secondary layer, plastic sheet		
4 Thermal insulation (1), (3)	variable	λ = 0.040 W/mK
5 Spacer battens	variable	λ = 0.130 W/mK
6 Airtight membrane, vapour barrier		
7 Sheathing	27 mm	λ = 0.130 W/mK
8 Loadbearing structure, rafters	variable	λ = 0.130 W/mK



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_r-value	R'_w (C,C_{tr})	Depth w/o rafters
d1	Total	Insulation	Timber	Timber			
			10%	15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (5)	mm
120	120	0.29	0.34	0.37	0.32	-- (-,-)	257
160	160	0.23	0.27	0.29	0.24	-- (-,-)	297
200	200	0.19	0.22	0.24	0.19	-- (-,-)	337
240	240	0.16	0.19	0.20	0.16	-- (-,-)	377

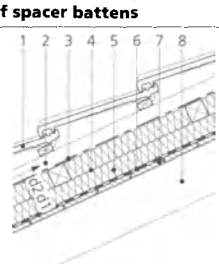
c109 Sketch of the principle of external thermal insulation

c110 to c113 Pitched roof construction: systems with external thermal insulation

c113-1

c112 Pitched roof with external insulation and two layers of spacer battens

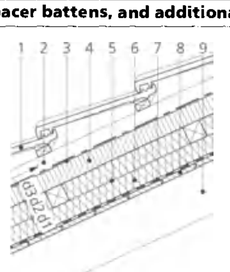
Assumption		
1 Roof covering	variable	
2 Counter battens, ventilation space	50 mm	R = 0.040 m²K/W
3 Secondary layer, plastic sheet		
4 Thermal insulation d1, d2 (1), (3)	variable	λ = 0.040 W/mK
5 Spacer battens in 2 directions	variable	λ = 0.130 W/mK
6 Airtight membrane, vapour barrier		
7 Sheathing	27 mm	λ = 0.130 W/mK
8 Loadbearing structure, rafters	variable	



Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_r-value	R'_w (C,C_{tr})	Depth w/o rafters
d1, d2	Total	Insulation	Timber	Timber			
			10%	15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (5)	mm
60,60	120	0.29	0.34	0.36	0.32	-- (-,-)	257
80,80	160	0.23	0.26	0.28	0.24	-- (-,-)	297
100,100	200	0.19	0.22	0.23	0.19	-- (-,-)	337
120,120	240	0.16	0.18	0.19	0.06	-- (-,-)	377
160,160	320	0.12	0.14	0.15	0.11	-- (-,-)	417

c113 Pitched roof with external insulation, two layers of spacer battens, and additional insulation

Assumption		
1 Roof covering	variable	
2 Counter battens, ventilation space	50 mm	R = 0.040 m²K/W
3 Secondary layer, plastic sheet		
4 Thermal insulation d3 (2), (4)	60 mm	λ = 0.042 W/mK
5 Thermal insulation d1, d2 (1), (3)	variable	λ = 0.040 W/mK
6 Spacer battens in 2 directions	variable	λ = 0.130 W/mK
7 Airtight membrane, vapour barrier		
8 Sheathing	27 mm	λ = 0.130 W/mK
9 Loadbearing structure, rafters	variable	



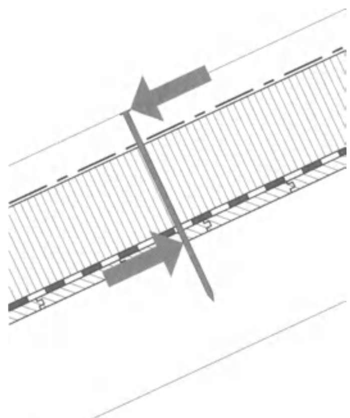
Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_r-value	R'_w (C,C_{tr})	Depth w/o rafters
d1, d2, d3	Total	Insulation	Timber	Timber			
			10%	15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB (5)	mm
60,60,60	180	0.21	0.23	0.23	0.19	-- (-,-)	317
80,80,80	240	0.17	0.19	0.20	0.15	-- (-,-)	357
100,100,60	260	0.15	0.16	0.17	0.12	-- (-,-)	397
120,120,60	300	0.13	0.14	0.15	0.10	-- (-,-)	437
160,160,60	380	0.10	0.11	0.11	0.07	-- (-,-)	517

c113-1 Pitched roof with external insulation

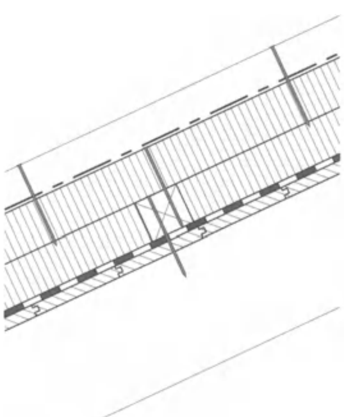
Notes to tables c110 to c113	for U-value	for U_r-value	
	Thermal conductivity	Density	Specific heat capacity (c)
(1) Mineral fibreboard	λ = 0.040 W/mK		
(2) Wood fibreboard	λ = 0.042 W/mK		
(3) Mineral fibreboard		30 kg/m³	0.23 Wh/kgK
(4) Wood fibreboard		140 kg/m³	0.58 Wh/kgK
(5) Sound insulation: please refer to all details in section c6 40 "Suggested forms of construction"			

c4 24 Fixings

If the thermal insulation is laid over the rafters (external thermal insulation system), there is no direct structural connection between the rafters and the secondary waterproofing/covering layer. The lever effect means that not inconsiderable forces act on the nails securing the counter battens (Fig. c114; forms of construction according to tables c110 to c113). In an arrangement with battens parallel with the rafters or a grid of battens in both directions (Fig. c115), an adequate connection should be possible in roofs with a pitch that is not too steep. The structural connection between the counter battens and the rafters can also be achieved using special twin-thread screws (Fig. c116), which are fitted in pairs at ±45° and driven through the counter battens and thermal insulation into the rafters. Other, special spacers can also be used for this fixing. Structural calculations are usually necessary.



c114



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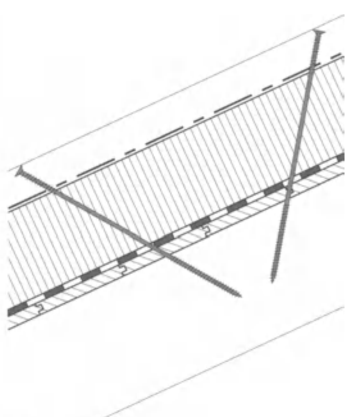


c116

c114 Fixing the counter battens without a direct structural connection between secondary waterproofing/covering layer and rafters; the arrows indicate the unfavourable couple acting on the nails.

c4 25 Ventilation spaces

Pitched roofs can have one or two ventilation spaces: just between the roof covering and the secondary waterproofing/covering layer (Fig. c103), or above and below the secondary waterproofing/covering layer (Fig. c104). Irrespective of the type of construction, insulated pitched roofs must include a ventilation space between the roof covering and the secondary waterproofing/covering layer. The ventilation spaces are primarily responsible for

- guaranteeing that any precipitation penetrating the roof covering can be reliably drained away,
- ensuring that the roof covering is properly ventilated, including the secondary waterproofing/covering layer in the case of two ventilation spaces,
- drying out any condensation in the thermal insulation,
- dissipating any water vapour that may diffuse from the inside to the outside.

Summertime thermal performance

On sunny days during the summer, the temperatures on the surface of the roof reach levels far in excess of those of the outside air; 80°C is not unusual, and even higher temperatures have been recorded under extreme conditions. The ventilation spaces help to influence the heat transfer processes within the roof construction – the same effect as in an external wall with ventilation cavity. The governing factors are the velocity of the airflows (which increase with the pitch of the roof), the cross-sectional area of the ventilation space, and the length of the rafters.

Dimensioning

Ventilation space beneath roof covering (roof with one or two ventilation spaces)

Up to about 800 m above sea level, the depth of the ventilation space between roof covering and secondary waterproofing/covering layer must be at least 45 mm. The depth should be increased to at least 60 mm at higher altitudes or in regions with heavy snowfall; 80 to 120 mm is recommended, depending on the region. For rafter lengths exceeding 10 m and for shallow-pitched roofs, a ventilation space 60 mm deep is recommended, also at lower altitudes (i.e. below 800 m above sea level).

The counter battens create the ventilation space between roof covering and secondary waterproofing/covering layer. So to com-

c115 Thermal insulation fitted between a grid of battens (two layers at 90°); the forces are transmitted through these battens.

c116 Counter battens fixed with special twin-thread screws at ±45°, which transfer the forces better than the arrangement shown in Fig. c114.

c117 Ventilation space between roof covering and secondary waterproofing/covering layer

Rafter length	Roof pitch and altitude of site above sea level							
	< 15°		15° - 20°		20° - 25°		> 25°	
	< 1000 m	> 1000 m	< 1000 m	> 1000 m	< 1000 m	> 1000 m	< 1000 m	> 1000 m
< 5 m	45 mm	60 mm	45 mm	60 mm	45 mm	45 mm	45 mm	45 mm
5 m - 10 m	60 mm	60 mm	45 mm	60 mm	45 mm	60 mm	45 mm	60 mm
10 m - 15 m	60 mm	80 mm	60 mm	80 mm	60 mm	80 mm	45 mm	60 mm
> 15 m	80 mm	100 mm	80 mm	100 mm	80 mm	80 mm	60 mm	80 mm

ply with the minimum permissible ventilation space depth, the battens must be at least 45 mm deep. The relevant standards contain further information. Tables c117 and c118 are taken from the Swiss standard SIA 232 "Pitched roofs".

Ventilation space beneath secondary waterproofing/covering layer (roof with two ventilation spaces)

The values for the ventilation space between secondary waterproofing/covering layer and thermal insulation as given in table c118 are valid for buildings up to 800 m above sea level. A deeper ventilation space (min. 60 mm) is required at higher altitudes or in regions with heavy snowfall.

Reduction in cross-section, air inlets/outlets

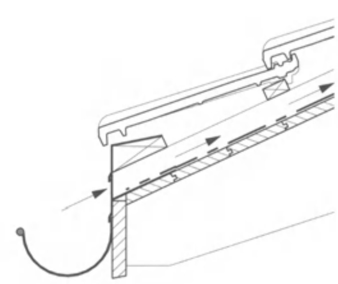
Local reductions (max. 50%) in the height or width of the ventilation space are permissible.

Ventilation spaces require air inlets and outlets at the eaves and ridge respectively, with an unobstructed aperture equal to at least half the required ventilation cross-section. The influence of an insect screen, grating, etc. on the cross-sectional area must be taken into account. A width of opening equal to the depth of the ventilation space is recommended, i.e. the minimum dimension of 45 mm applies. When sizing the air inlets/outlets, the air permeability of the roof covering can be taken into account, a factor that is particularly relevant with clay tile roofs.

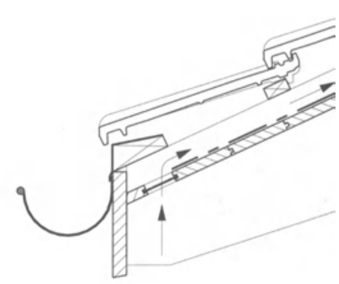
In regions with heavy snowfall, air outlets at the ridge can become blocked by snow. It is therefore essential that air can also circulate across the roof, which can be achieved by mounting the barge boards with an offset (Fig. c125). Roofs in regions with heavy snowfall also benefit from a continuous opening at the ridge. When using roof coverings with little air permeability, e.g. fibre-cement sheeting, special ridge vents must be installed.

c118 Ventilation space between secondary waterproofing/covering layer and thermal insulation

Rafter length	Roof pitch			
	< 15°	15° - 20°	20° - 25°	> 25°
< 5 m	40 mm	40 mm	40 mm	40 mm
5 m - 10 m	60 mm	40 mm	40 mm	40 mm
10 m - 15 m	60 mm	60 mm	60 mm	40 mm
> 15 m	80 mm	80 mm	60 mm	40 mm



c119



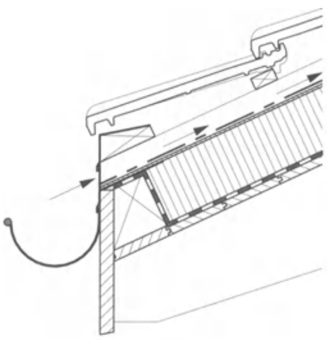
c120

c117 Minimum size of ventilation space between roof covering and secondary waterproofing/covering layer

c118 Minimum size of ventilation space between secondary waterproofing/covering layer and thermal insulation in roofs with two ventilation spaces

c119 Air inlet for ventilation space between roof covering and secondary waterproofing/covering layer; the air flows in from the "front", above the gutter, and water draining down the secondary layer drains into the gutter.

c120 Air inlet for ventilation space between roof covering and secondary waterproofing/covering layer; the air flows in from "below", behind the gutter, and water draining down the secondary layer drips off behind the gutter.



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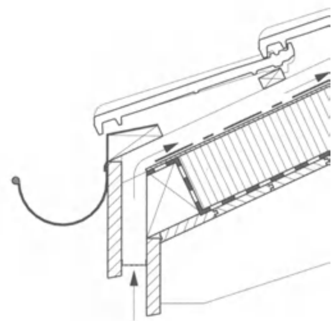
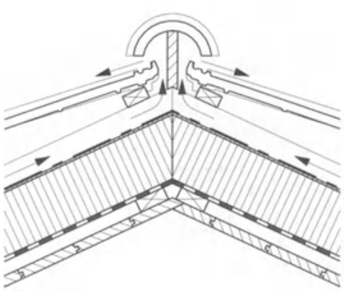
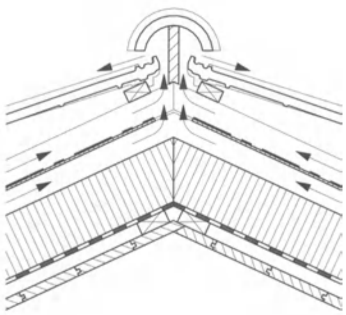


c122



c123



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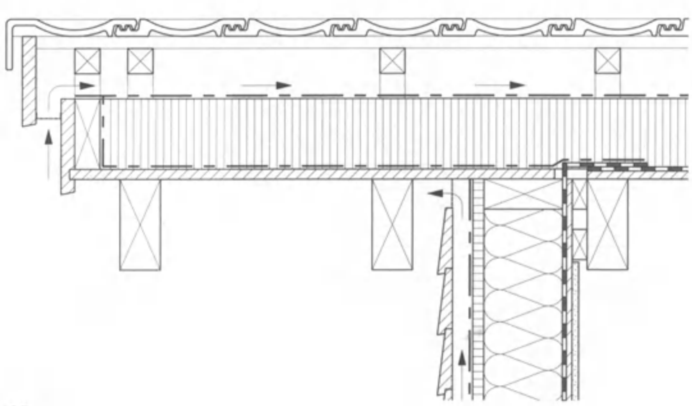


c125

c121 Air inlet for external insulation system; the air flows in from the "front", above the gutter, and water draining down the secondary layer drains into the gutter.

c122 Air inlet for external insulation system; the air flows in from "below", behind the gutter, and water draining down the secondary layer drips off behind the gutter.

c123 Air outlet at ridge for a roof with one ventilation space
c124 Air outlet at ridge for a roof with two ventilation spaces

c125 Air inlet at verge to ensure transverse roof ventilation in regions with heavy snowfall or in roofs with complicated forms. If considerable ventilation is required, the counter battens can be in two parts with gaps in the lower battens.

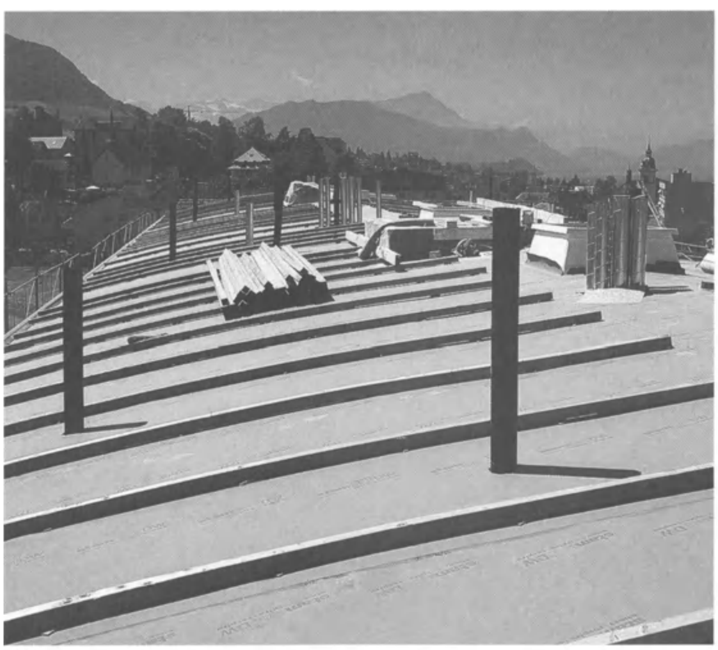
c4 26 Secondary waterproofing/covering layer

During construction, this layer must act as a temporary roof until the permanent roof covering is complete. In addition, this layer prevents any moisture that penetrates the roof covering (due to defects or severe weather conditions), including dust or drifting snow, from reaching the rest of the roof construction. Designed accordingly, it can also protect against the infiltration of backed-up water. Insulated pitched roofs should generally include a secondary waterproofing/covering layer.

We distinguish between the following:
Secondary waterproofing/covering layer for normal conditions
The material must be watertight to the extent that water can drain away reliably. Hardboard, fibre-cement sheets, and plastic sheeting are suitable in such cases. The material is simply overlapped or glued together at the joints, which, however, does not form a watertight seal against a build-up of water.

Secondary waterproofing/covering layer for extreme conditions
Extreme conditions may be present in roofs with a shallow pitch, solar collectors, internal gutters, and where there is a risk of a build-up of water (possible at altitudes in excess of 800 m above sea level, caused by the exterior climate). Only waterproof materials may be used.

"Seamless" secondary waterproofing/covering layers using reinforced flexible waterproofing materials made from bitumen, polymer-modified bitumen, and synthetic products are required in such cases (make sure that the diffusion resistance is not too high and is coordinated with the other layers). The flexible waterproofing materials are overlapped at the joints and bonded together with adhesives or by felt torching, which makes these secondary layers watertight against running water and a build-up of water. Such materials can be laid loose on the thermal insulation in the case of a single ventilation space, but can also be fixed to a rigid backing of solid timber tongue and groove planks or wood-based board products; such a backing is essential in roofs with a ventilation space below the secondary waterproofing/covering layer as well. If the secondary waterproofing/covering layer is laid directly on the thermal insulation, a rigid insulating material is required in order to prevent damage to the waterproofing/covering material and the thermal insulation when working on the roof. The secondary waterproofing/covering layer must be designed in such a way that water cannot infiltrate into the construction around chimneys, vent pipes, windows, and openings, or at the fixings for the counter battens. Water running down the secondary waterproofing/covering layer either drains into the gutter or is allowed to drip off behind the gutter. Which method is used depends on the position of air inlets for the ventilation (Figs. c119 to c122).



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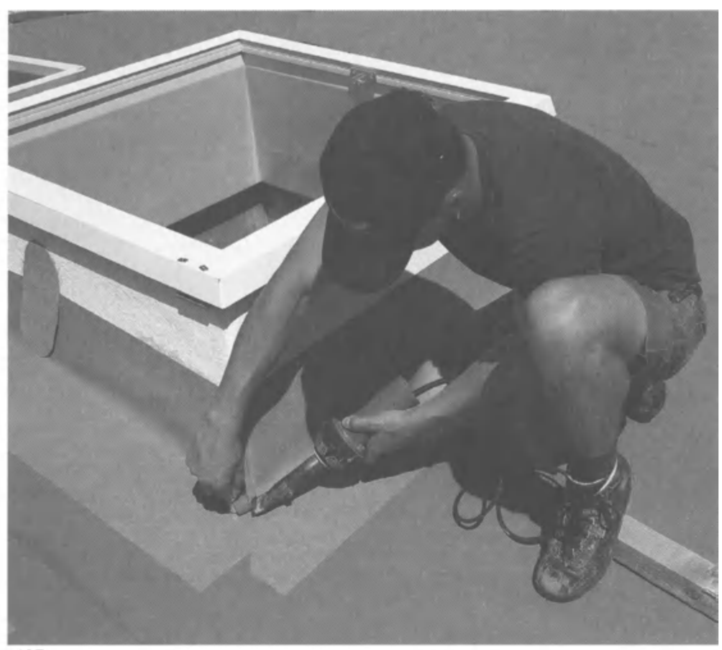


c127

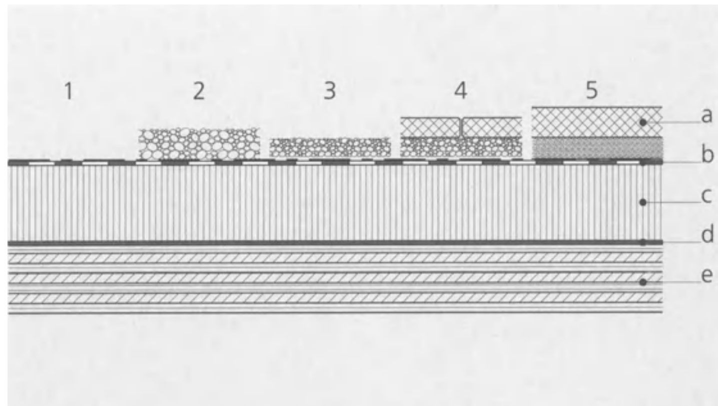
c126 Secondary waterproofing/covering layer in the form of felt-torched flexible sheeting for demanding or unusual conditions

c127 Secondary waterproofing/covering layer in the form of felt-torched flexible sheeting: "seamless" junctions around windows, openings, rooftop structures, vent pipes, flues, etc.

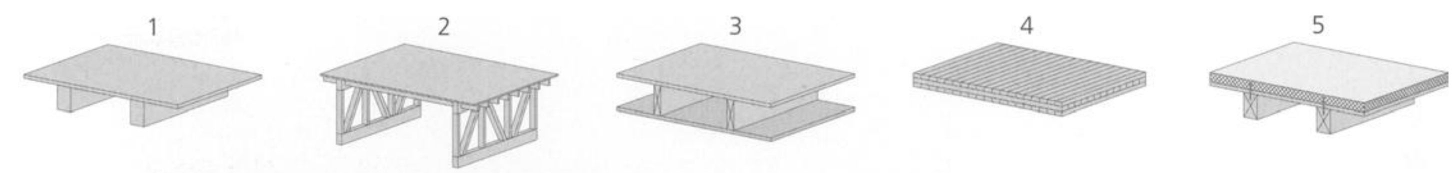
c5 Flat roofs

c5 10 Uninsulated flat roofs

An uninsulated flat roof can be used on buildings that do not need to comply with any particular thermal performance (likewise sound insulation) requirements. Flat roofs without insulation are employed for industrial buildings, warehouses, shelters, and canopies. A multitude of construction forms (Fig. c128, see also chapter b10 "Suspended floor structures") and wearing courses (Fig. c130) are available for such flat roofs.



c130



c128


c129

c128 Structural systems for flat roofs
Systems with linear members
1 Timber joists
2 Lattice beams
Systems with planar members
3 Ribbed-panel or hollow-box products
4 Solid timber or board-type, glued products
5 Timber-concrete composite construction

c129 Forestry depot with uninsulated flat roof

c130 Construction of flat roofs
Underlying construction
a Protective layer, wearing course
b Waterproofing, possibly separating layer or levelling layer
c Thermal insulation
d Waterproofing, vapour barrier, airtight membrane
e Loadbearing structure

Wearing courses
1 No wearing course
2 Gravel
3 Extensive planting (green roof)
4 Flags on chippings (trafficable roof)
5 Covering on separating layer (possibly trafficable roof)

c5 20 Insulated flat roofs

Like with the pitched roof, we have to distinguish between whether our flat roof has external insulation or insulation between the structural members, or perhaps represents a combination or hybrid version of those two basic systems (see Figs. c42 to c45, p. 224, for an overview).
The same ideas apply for the junctions between components in flat roofs as discussed for pitched roofs in section c2 30. Ideally, the same concepts should be used on both sides of the junction; roof and external wall should be based on the same principles, which makes details simple, cost-effective, and durable in the long-term.

Insulated flat roofs make use of the same loadbearing structures and wearing courses as for uninsulated systems (Figs. c128 and c130). In loadbearing systems 1 to 3 illustrated in Fig. c128, the thermal insulation can also be laid in the plane of the loadbearing structure, but in the other systems only external insulation is possible.

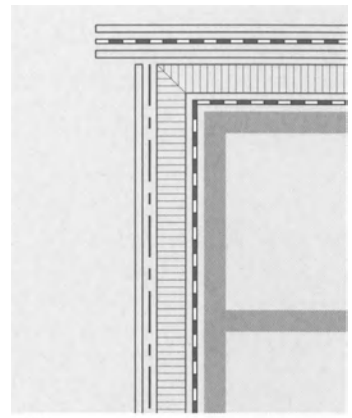

c131

c131 Thermally insulated flat roofs for housing

c132 Sketch of the principle of external thermal insulation

c5 21 Flat roofs with external thermal insulation

The loadbearing structures for flat roofs with external thermal insulation are the same as those for uninsulated flat roofs (Fig. c128). Different flat roof systems are possible, which can be divided into four groups:


c132

External thermal insulation, no ventilation space

The non-ventilated flat roof, often called a warm deck, is the most common form of construction for flat roofs. It consists of a single layer of thermal insulation onto which the waterproofing is laid directly. There is no ventilation space. The conventional wearing courses can be laid on top of the waterproofing (Fig. c133).

External thermal insulation, composite roof

In the composite roof the layers of the flat roof construction (apart from the protective layer and wearing course) are connected directly to the planar loadbearing layer. A vapour barrier can usually be omitted because the full bond of the thermal insulation (vapour-tight cellular glass boards laid in hot bitumen) with the loadbearing layer achieves the necessary vapour-tightness.
This form of construction is primarily used in the case of high imposed loads, e.g. flat roofs designed for pedestrian or vehicular traffic, or below a soil covering. The use of in situ reinforced concrete for the structure is well established. Experience has shown, however, that a timber structure is also possible, provided the boundary conditions are right and the appropriate calculations are carried out. Planar, dimensionally stable systems such as board-type, glued products or timber-concrete composite construction are recommended (Fig. c134).

External thermal insulation, upside-down roof

The layer of thermal insulation is laid on top of the waterproofing in the upside-down roof. This form of construction is mainly employed for flat roofs with limited access where gravel is used as ballast and extensive rooftop planting is employed (Fig. c135). Water draining through the thermal insulation reduces its insulating effect. This is why somewhat thicker layers of insulation are necessary on upside-down roofs (rule of thumb: 20% more). A suitable membrane in the form of a non-woven fabric that is open to diffusion but can still drain the water reliably can substantially reduce heat losses caused by running water.

According to the Swiss standard SIA 271 "Flat roofs", the loadbearing construction of an upside-down roof must have a weight of at least 300 kg/m² in order to prevent the risk of condensation caused by the cold rainwater. Lightweight timber structures are therefore out of the question! Solid timber constructions, board-type, glued products, and even timber-concrete composite constructions do not achieve the recommended weight (apart from timber-concrete composite constructions above a certain depth), but can still exhibit an adequate mass. A building physics analysis is always required in order to prove that water cannot condense.

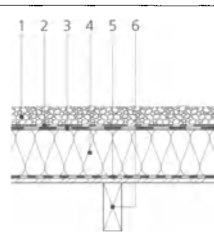
External thermal insulation, with a ventilation space

The ventilated flat roof is comparable to the pitched roof with one ventilation space. This type of flat roof (Fig. c136) consists of the loadbearing, vapour barrier, and thermal insulation layers, possibly also a secondary waterproofing/covering layer, ventilation space, waterproofing on a supporting framework plus a protective layer and wearing course. A ventilation space above the thermal insulation or secondary waterproofing/covering layer must have a cross-sectional area equal to 1/150th of the roof area, but must be at least 100 mm deep. Exceptions are possible under certain conditions – please refer to the relevant standards.

Although the flat roof with external thermal insulation and a ventilation space has advantages with respect to the dissipation of any moisture (also construction moisture) that diffuses through the construction, and with respect to the summertime thermal performance, it is not employed very often. One of the reasons for

c133 Flat roof with external thermal insulation but no ventilation space (warm deck)

Assumption		
1 Wearing course, gravel	60 mm	
2 Protective layer	2 mm	
3 Waterproofing	6 mm	
4 Thermal insulation (1), (3)	variable	λ = 0.040 W/mK
5 Airtight membrane, vapour barrier		
6 Loadbearing structure, ribbed panel	variable	λ = 0.130 W/mK

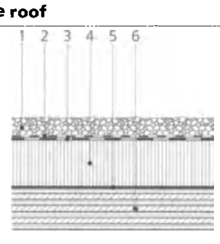


Insulation thickness	Insulation thickness	U-value	U_T-value	R'_w (C,C_{tr})	o/a depth
	Total	Insulation		Airborne sound insulation	
mm	mm	W/m²K	W/m²K	dB	mm
120	120	0.29	0.31		415
160	160	0.23	0.29	(5)	455
200	200	0.19	0.19	(5)	495
240	240	0.16	0.15	(5)	535
280	280	0.14	0.13	(5)	575
320	320	0.12	0.11	(5)	615

(5) Sound insulation: > approx. 48 dB for gravel wearing course and thermal insulation ≥ 140 mm

c134 Flat roof with external thermal insulation, composite roof

Assumption		
1 Wearing course, gravel	60 mm	
2 Protective layer	2 mm	
3 Waterproofing	6 mm	
4 Thermal insulation, cell. glass (2), (4)	variable	λ = 0.040 W/mK
5 Adhesive		
6 Loadbearing structure, solid timber	100 mm	λ = 0.130 W/mK



Insulation thickness	Insulation thickness	U-value	U_T-value	R'_w (C,C_{tr})	o/a depth
	Total	Insulation		Airborne sound insulation	
mm	mm	W/m²K	W/m²K	dB	mm
120	120	0.25	0.16		288
160	160	0.20	0.11	(5)	328
200	200	0.17	0.08	(5)	368
240	240	0.14	0.05	(5)	408
280	280	0.13	0.04	(5)	448
320	320	0.11	0.02	(5)	488

(5) Sound insulation: > approx. 50 dB for gravel wearing course and thermal insulation ≥ 140 mm; approx. 54 dB for suspended ceiling

c133 to c136 Flat roof construction: systems with external thermal insulation

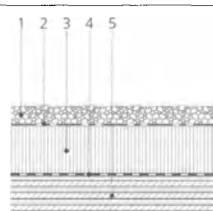
Notes to tables c133 to c136	for U-value	for U_T-value	
	Thermal conductivity	Density	Specific heat capacity (c)
(1) Mineral fibreboard	λ = 0.040 W/mK		
(2) Cellular glass	λ = 0.040 W/mK		
(3) Mineral fibreboard		30 kg/m³	0.23 Wh/kgK
(4) Cellular glass		120 kg/m³	0.23 Wh/kgK
(5) Sound insulation: please refer to all details in section c6 40 "Suggested forms of construction"			

this might be that these days there are a number of brand-name tried-and-tested flat roof construction systems available on the market that are generally based on the non-ventilated variety. On the other hand, ventilated flat roofs with external insulation represent a cost-effective and technologically ideal alternative for buildings without rooftop structures (i.e. no interruption of the ventilation space).

Tables c133 to c136 show suggested forms of construction that take into account the thermal performance and the sound insulation (if required).

c135 Flat roof with external thermal insulation, upside-down roof

Assumption		
1 Wearing course, gravel	60 mm	
2 Filter layer	8 mm	
3 Thermal insulation, cell. glass (2), (4)	variable	λ = 0.045 W/mK
4 Waterproofing, vapour barrier		
5 Loadbearing structure, solid timber	100 mm	λ = 0.130 W/mK

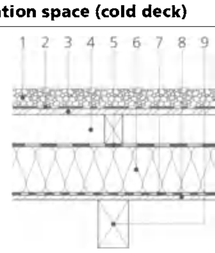


Insulation thickness	Insulation thickness	U-value	U_T-value	R'_w (C,C_{tr})	o/a depth
	Total	Insulation		Airborne sound insulation	
mm	mm	W/m²K	W/m²K	dB	mm
120	120	0.28	0.18		288
160	160	0.22	0.12	(5)	328
200	200	0.18	0.09	(5)	368
240	240	0.16	0.06	(5)	408
280	280	0.14	0.04	(5)	448
320	320	0.12	0.03	(5)	488

(5) Sound insulation: > approx. 50 dB for gravel wearing course and thermal insulation ≥ 140 mm; approx. 54 dB for suspended ceiling

c136 Flat roof with external thermal insulation and ventilation space (cold deck)

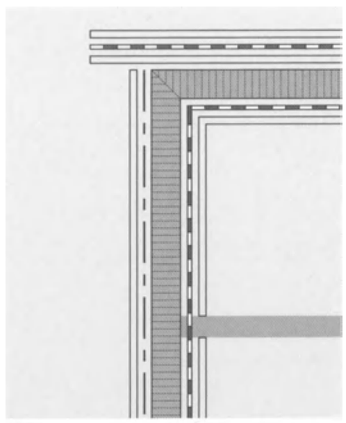
Assumption		
1 Wearing course, gravel	60 mm	
2 Waterproofing	8 mm	
3 Structural sheathing	27 mm	
4 Ventilation space	100 mm	R = 0.080 m²K/W
5 Secondary layer	100 mm	
6 Thermal insulation (1), (3)	variable	λ = 0.045 W/mK
7 Vapour barrier		
8 Soffit lining	variable	
9 Loadbearing structure, timber joists	variable	



Insulation thickness	Insulation thickness	U-value	U_T-value	R'_w (C,C_{tr})	o/a depth
	Total	Insulation		Airborne sound insulation	
mm	mm	W/m²K	W/m²K	dB	mm
120	120	0.29	0.33		542
160	160	0.23	0.24	(5)	582
200	200	0.18	0.19	(5)	622
240	240	0.16	0.16	(5)	662
280	280	0.13	0.13	(5)	702
320	320	0.12	0.11	(5)	488

(5) Sound insulation: > approx. 45 dB for gravel wearing course and thermal insulation ≥ 140 mm

c5 22 Flat roofs with insulation between structural members


c137

Structural systems that make use of linear members, e.g. timber joists, ribbed panels, hollow boxes, are suitable as the loadbearing construction for flat roofs in which the thermal insulation is placed between the structural members. Like with pitched roofs and externalwalls with insulation between the loadbearing members, the thermal insulation is in the same plane as the structure, which is clad on both sides.

Insulation between structural members, no ventilation space

In contrast to the non-ventilated flat roof with external insulation (Figs. c133 to c136), the thermal insulation in this system is placed between the loadbearing members (Figs. c138 to c140). The advantage of this is that the overall depth of the flat roof construction is less. In systems with external insulation, all the layers are placed above the plane of the structure and are therefore simple to install. But with the thermal insulation placed between the structural members, or possibly even below or on top, the joints and junctions in the vapour barrier and airtight membrane must be carried out from below.

The question to be answered when considering constructing a flat roof with insulation between the structural members is whether the roof elements could be supplied and erected as ready-made components complete with thermal insulation and sheathing top and bottom. Such forms of construction are indeed possible. But a decision will have to be made as to whether a vapour barrier is to be incorporated and, if so, which type, and whether unacceptable moisture increases within the construction and excessive moisture-related deformations of the timber construction could occur. Experience shows that conventional methods of calculation are inadequate for revealing the true moisture relationships. More comprehensive analyses are therefore necessary. Computer programs written especially for this purpose can help here. Basically, forms of construction with a ventilation space below the waterproofing or those with an exposed loadbearing structure, i.e. with an insulated flat roof construction above the loadbearing structure (external insulation system according to Figs. c133 to c136) should be preferred from a moisture control standpoint. If a non-ventilated system with insulation between the structural members is to be built, then a form of construction without any drying-out potential is inadvisable because the risk of damage to the structural timber members between the waterproofing and the airtight membrane and vapour barrier is too high. Vapour barriers with a high diffusion-equivalent air layer thickness (s value) can therefore be ruled out for a vapour barrier on the inside.

As the waterproofing represents an essentially vapour-tight layer, the airtight membrane and vapour barrier must permit diffusion to some extent in order to achieve the drying-out potential. For this reason, forms of construction without a vapour barrier (but definitely airtight!) are built with plastic sheeting open to diffusion or plastic sheeting with a variable diffusion resistance. To lower the risk of dampness during construction, moisture within the construction, and moisture-related deformations, the installation of a waterproof membrane between the loadbearing structure and the additional insulation for the duration of construction work has proved to be advantageous.

Critical for the functionality of non-ventilated flat roofs with insulation between the loadbearing members is that the moisture content changes in the timber components should not lead to damaging deformations. It is therefore important that moisture control assessments and building physics computer programs always contain reliable details of the timber moisture content to be expected. Corresponding constructional measures to protect against excessive deformations as a result of varying timber moisture content over the entire cross-section of the loadbearing construction (top and bottom sheathing) must be appraised by a structural engineer or timber engineering specialist. The situation can be relieved by simply using rafters or joists for the loadbearing construction, i.e. not ribbed panels, hollow boxes, or solid timber systems.

c137 Sketch of the principle of thermal insulation between structural members

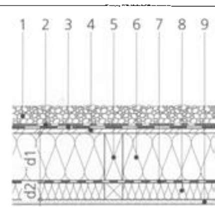
Insulation between structural members, with ventilation space

Ventilated forms of flat roof construction are also possible in conjunction with thermal insulation laid between the loadbearing members. The construction and sequence of layers are identical to the flat roof with external insulation (Fig. c136) – with the difference that the insulation here is in the voids between the structural members. Hollow-box systems are therefore ideal because the closed voids provide space and protection. Compared with the non-ventilated flat roof, the depth of the construction must be increased to accommodate the ventilation space. This ventilation space above the thermal insulation and secondary waterproofing/covering layer must have a cross-sectional area equal to 1/500th of the roof area, but must be at least 100 mm deep.

Tables c138 to c140 show suggested forms of construction that take into account the thermal performance and the sound insulation (if required).

c138 Flat roof with insulation between structural members but no ventilation space (warm deck)

Assumption		
1 Wearing course, gravel	60 mm	
2 Protective layer	2 mm	
3 Waterproofing	6 mm	
4 Structural sheathing	27 mm	
5 Loadbearing structure, timber joists	variable	λ = 0.130 W/mK
6 Thermal insulation d1 (1), (4)	variable	λ = 0.040 W/mK
7 Airtight membrane, vapour barrier		
8 Thermal insulation d2 (1), (4)	variable	λ = 0.040 W/mK
9 Gypsum fibreboard	15 mm	

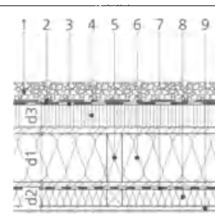


Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'$_w$	o/a depth
d1, d2	Total	Insulation	Timber	Timber			
			10%	15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB	mm
120,60	180	0.19	0.22	0.25	0.20		290
160,60	220	0.16	0.19	0.20	0.15	(6)	330
200,60	260	0.14	0.16	0.17	0.13	(6)	370
240,60	300	0.12	0.14	0.15	0.11	(6)	410

(6), Sound insulation: > approx. 50 dB for gravel wearing course and thermal insulation ≥ 140 mm

c139 Flat roof with insulation between and above structural members but no ventilation space

Assumption		
1 Wearing course, gravel	60 mm	
2 Protective layer	2 mm	
3 Waterproofing	6 mm	
4 Thermal insulation d3 (3), (5)	100 mm	λ = 0.042 W/mK
5 Loadbearing structure, hollow box	variable	λ = 0.130 W/mK
6 Thermal insulation d1 (1), (2), (4)	variable	λ = 0.040 W/mK
7 Airtight membrane, vapour barrier		
8 Thermal insulation d2 (1), (5)	60 mm	λ = 0.040 W/mK
9 Gypsum fibreboard	15 mm	

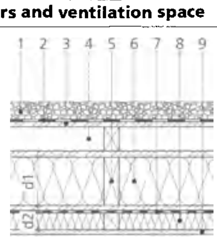


Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'$_w$	o/a depth
d1, d2, d3	Total	Insulation	Timber	Timber			
			10%	15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB	mm
120,60,100	280	0.13	0.14	0.15	0.02		417
160,60,100	320	0.12	0.13	0.13	0.01	(6)	457
200,60,100	360	0.10	0.12	0.12	0.01	(6)	497
240,60,100	400	0.09	0.11	0.11	0.01	(6)	537
280,60.100	440	0.08	0.10	0.10	0.01	(6)	577
320,60,100	480	0.08	0.09	0.09	0.01	(6)	617

(6), Sound insulation: > approx. 48 dB for gravel wearing course and thermal insulation ≥ 140 mm

c140 Flat roof with insulation between structural members and ventilation space

Assumption		
1 Wearing course, gravel	60 mm	
2 Protective layer	2 mm	
3 Structural sheathing	27 mm	
4 Ventilation space, firrings, spacers	100 mm	R = 0.080 m²K/W
5 Loadbearing structure, hollow box	variable	λ = 0.130 W/mK
6 Thermal insulation d1 (1), (2), (4)	variable	λ = 0.040 W/mK
7 Airtight membrane, vapour barrier		
8 Thermal insulation d2 (1), (4)	60 mm	λ = 0.040 W/mK
9 Gypsum fibreboard	15 mm	



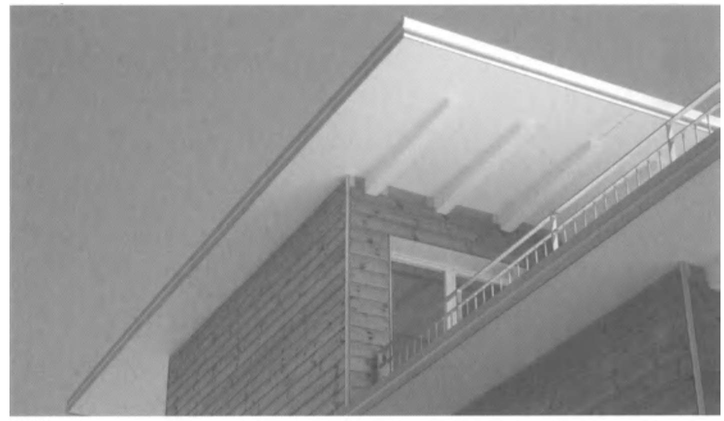
Insulation thickness	Insulation thickness	U-value	U-value	U-value	U_T-value	R'$_w$	o/a depth
d1, d2	Total	Insulation	Timber	Timber			
			10%	15%			
mm	mm	W/m²K	W/m²K	W/m²K	W/m²K	dB	mm
120,60	180	0.19	0.22	0.24	0.11		444
160,60	220	0.16	0.19	0.20	0.08	(6)	484
200,60	260	0.14	0.16	0.17	0.07	(6)	524
240,60	300	0.12	0.14	0.15	0.05	(6)	564
280,60	340	0.11	0.13	0.14	0.05	(6)	604
320,60	380	0.10	0.12	0.12	0.04	(6)	644

(6), Sound insulation: > approx. 45 dB for gravel wearing course and thermal insulation ≥ 140 mm

c138 to c140 Flat roof construction: thermal insulation between structural members
c138 Flat roof with insulation between structural members, no ventilation space, additional internal insulation
c139 Flat roof with insulation between and above structural members, no ventilation space, additional internal and external insulation
c140 Flat roof with insulation between structural members, ventilation space, additional internal insulation

Notes to tables c138 to c140	for U-value	for U_T-value	
	Thermal conductivity	Density	Specific heat capacity (c)
(1) Mineral fibreboard	λ = 0.040 W/mK		
(2) Cellulose fibres	λ = 0.040 W/mK		
(3) Wood fibreboard	λ = 0.042 W/mK		
(4) Mineral fibreboard		30 kg/m³	0.23 Wh/kgK
(5) Wood fibreboard		140 kg/m³	0.58 Wh/kgK
(6) Sound insulation: please refer to all details in section c6 40 "Suggested forms of construction"			

c5 Flat roofs



c143-1

c5 30 Design of insulated flat roofs

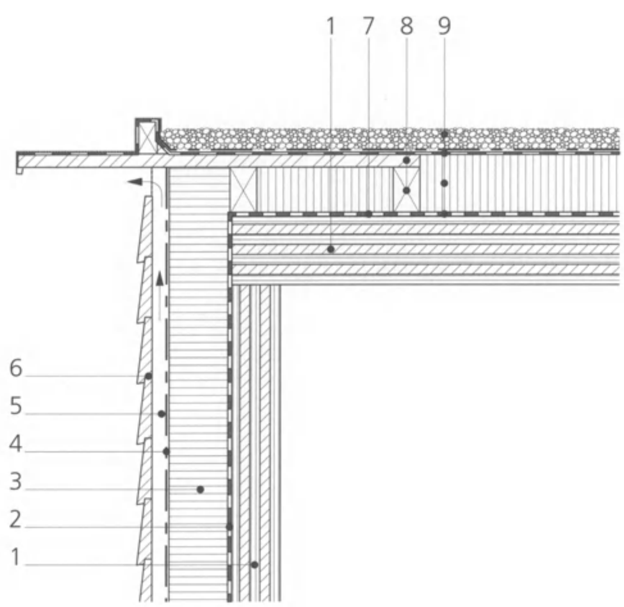
c5 31 Flat roofs with external thermal insulation

With respect to the vapour diffusion behaviour and the airtightness, roof constructions with external insulation involve the fewest problems. The construction is identical to a conventional reinforced concrete roof. The airtight membrane, vapour barrier, and thermal insulation are laid on top of the loadbearing structure. The thickness of thermal insulation required can be chosen irrespective of the depth of the loadbearing members. Building services are routed in separate ducts or conduits or in the plane of the structural members. The roof structure can remain exposed internally, or can be concealed behind a soffit lining or ceiling. The junction and joint details of the thermal insulation, airtight membrane, and vapour barrier are straightforward and durable, provided the external wall also makes use of an external thermal insulation system. An eaves overhang, if required, can be built with separate members (with a low moisture content) (Fig. c141).

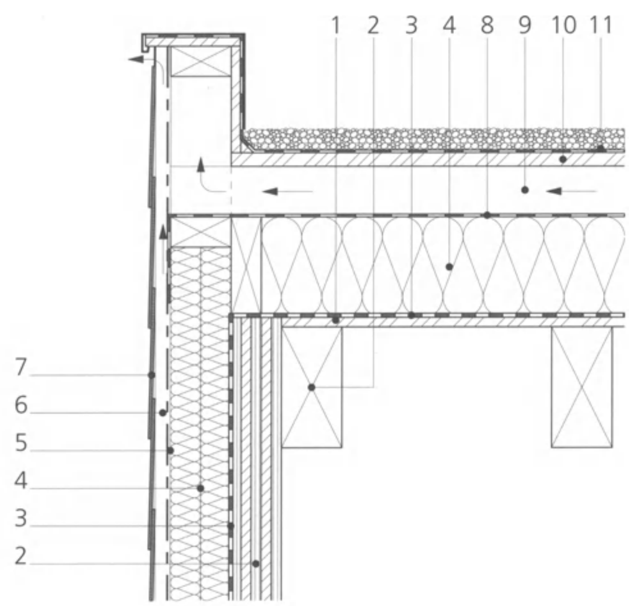
c5 32 Flat roofs with insulation between structural members

Insulation between structural members, with ventilation space

Like with the external wall, the airtight membrane and the vapour barrier are on the inside, the thermal insulation between the loadbearing members (Fig. c143). Durable flat roof/external wall junction details are easy to achieve. The details at intermediate walls and joints between elements are more complicated. In these areas the airtight membrane and vapour barrier must be installed during erection of the structure if they impinge on the building envelope. A ventilation space with appropriate air inlets and outlets is required between the flat roof finishes and the secondary waterproofing/covering layer. On roofs with rooftop structures or many penetrations, however, systems without a ventilation space are recommended because such structures and penetrations hinder the ventilation. Forms of construction with external insulation are better in such instances.



c141



c142

c141 Wall/roof junction, system with external insulation
1 Loadbearing structure
2 Airtight membrane, vapour barrier
3 Thermal insulation
4 Protection for thermal insulation, additional insulation
5 Battens, ventilation space
6 External cladding
7 Waterproofing, vapour barrier, airtight membrane
8 Eaves overhang construction, battens, wood-based board product
9 Flat roof system with thermal insulation, waterproofing, falls, protective layer, and wearing course

c142 Wall/roof junction, system with external insulation
1 Inner lining
2 Loadbearing structure
3 Airtight membrane, vapour barrier
4 Thermal insulation
5 Protection for thermal insulation, additional insulation
6 Battens, ventilation space
7 External cladding
8 Waterproofing, protection to thermal insulation
9 Ventilation space, falls
10 Structural sheathing
11 Flat roof system with waterproofing, protective layer, and wearing course

c143-1 and c143-2 Flat roofs with ventilation space

c143-2

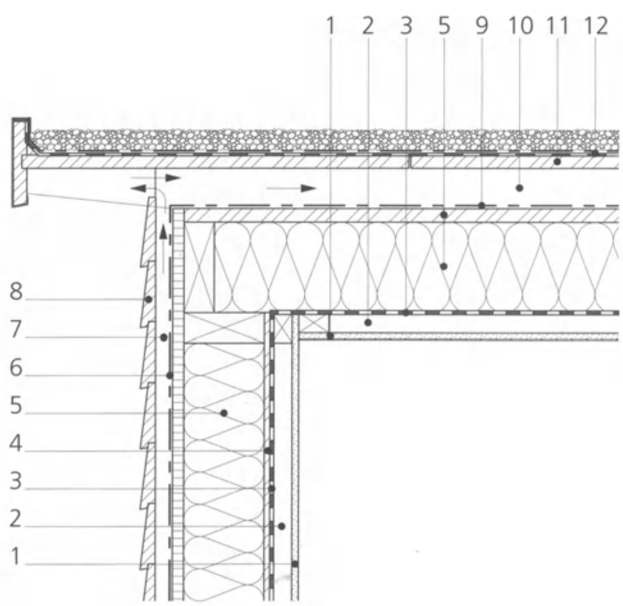
Insulation between structural members, no ventilation space

Flat roofs with insulation between the loadbearing members but no ventilation space (Figs. c138 and c139) are problematic with respect to vapour diffusion and airtightness. Long-term studies are lacking. The airtight membrane and vapour barrier are installed on the inside, the thermal insulation between the structural members. There is no ventilation space between the waterproofing and the thermal insulation and any condensation that may occur cannot be easily dissipated. Guaranteeing airtightness is generally critical, but especially so in non-ventilated forms of construction. Owing to the low fault tolerance, periodic measurements of airtightness, timber moisture content, etc. are recommended. Additional thermal insulation above the loadbearing construction and temporary waterproofing (during the construction period) is certainly worthwhile.
Summing up, it should be noted that flat roofs with insulation between the structural members but no ventilation space can certainly be used with success, but until the publication of conclusive results from practice and research should be regarded as a fringe application. Every case must be decided on its merits.

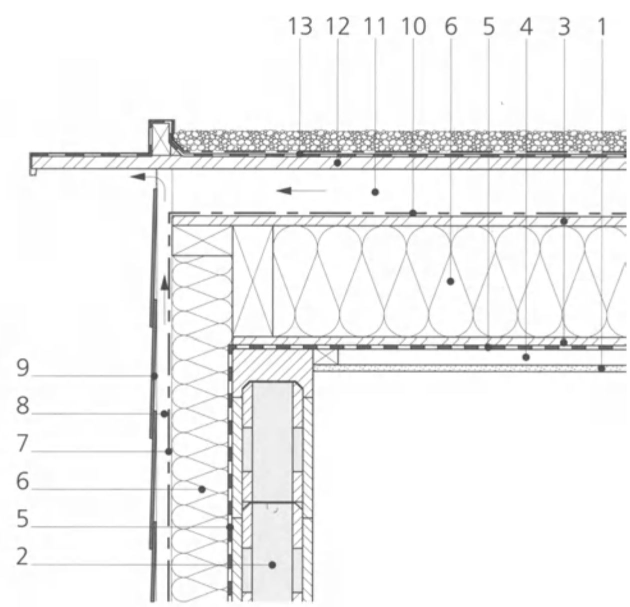
c5 40 Falls

Flat roofs are usually built to a fall (generally 1.5%). When planning the loadbearing structure, the falls and positions of rainwater outlets must be considered. Besides the option of taking the falls into account directly in the loadbearing structure, it is possible to lay firrings on a horizontal loadbearing structure. Forms of construction without falls are, however, not explicitly mentioned in the standards and can therefore be used only in specific instances, taking the particular conditions into consideration.
When designing and calculating the loadbearing structure, deflections (and necessary cambering) due to imposed loads, snow loads, etc. must be allowed for. Deformations should not be allowed to nullify the falls and lead to ponding.

Publications on the subject of flat roofs and timber engineering can be found in the bibliography [27, 28].



c143



c144

c143 Wall/roof junction, system with insulation between structural members
1 Inner lining
2 Space for services, battens
3 Airtight membrane, vapour barrier
4 Structural sheathing
5 Loadbearing structure, therm. insulation
6 Protection for thermal insulation, additional insulation
7 Battens, ventilation space
8 External cladding
9 Waterproofing, protection for thermal insulation
10 Ventilation space, falls
11 Structural sheathing
12 Flat roof system with waterproofing, protective layer, and wearing course

c144 Wall/roof junction, hybrid system
1 Inner lining
2 Loadbearing structure with insulation and voids for services
3 Loadbearing structure, hollow boxes
4 Space for services
5 Airtight membrane, vapour barrier
6 Thermal insulation
7 Protection for thermal insulation
8 Battens, ventilation space
9 External cladding
10 Waterproofing, protection for thermal insulation
11 Ventilation space, falls
12 Structural sheathing
13 Flat roof system with waterproofing, protective layer, and wearing course

c6 Party walls, internal walls

c6 10 Tasks

Party walls and internal walls separate different buildings and different rooms according to their uses. We distinguish between the following types of walls:

Party walls
The following party walls are used in timber construction in order to comply with Swiss fire protection regulations:
– Walls between houses (terrace or semi-detached houses)

Internal walls
– Permanent internal walls (loadbearing)
– Semi-permanent internal walls (non-loadbearing)
– Demountable partitions
– Movable (e.g. folding, sliding) partitions

Depending on the plan layout within a building, walls can also perform the following tasks in addition to their loadbearing and room-dividing or room-forming functions:
– Thermal performance
– Fire protection
– Sound insulation

c6 11 Thermal performance

Apart from party walls and the walls separating heated and unheated rooms, requirements with respect to thermal performance are relatively low. If the specification calls for a certain thermal performance, the construction of the wall should meet the building physics requirements of chapters c1 to c3.

c6 12 Fire protection

The creation of fire compartments to meet the fire protection requirements has a major influence on the planning, design, and construction of the building components. According to the Swiss regulations, the following parts of a building must be enclosed by suitable walls to form separate fire compartments (for the German regulations, see the publications listed at the end of this chapter or refer to chapter d3 "Fire protection"):
– adjoining buildings and those covering a large plan area
– corridors and staircases that serve as escape routes
– lift, ventilation, and service shafts
– plant rooms
– rooms with different uses and fire risks

The purpose of fire compartmentalisation is to prevent the spread of smoke and fire to neighbouring fire compartments for a specified length of time, and at the same time to permit effective fire-fighting. If walls are loadbearing, they must also remain stable for a specified length of time in the event of a fire.

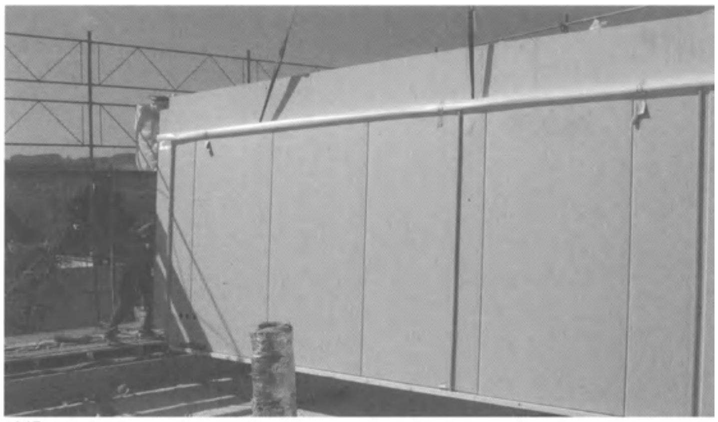
Fire walls

Fire walls are stable components that separate parts of the building with a fire resistance class of REI 180 (nbb). In residential buildings with no more than three storeys, this class can be reduced to REI 90 (nbb).
A fire resistance class of REI 90 is also adequate for party walls between semi-detached and terrace houses. Special requirements apply to the construction of REI 90 fire walls (with combustible materials).

Fire compartment walls

The walls enclosing staircases and corridors that serve as escape routes, and also those enclosing plant rooms and lift, ventilation, and service shafts, must be built as fire compartment walls. This requirement also applies to the walls between rooms with different uses and different fire risks.

The fire resistance requirements for fire compartment walls generally match those of the loadbearing structure.
According to Swiss regulations, the following fire resistance classes are required for fire compartment walls in residential, office, and school buildings:
– walls in buildings with 1 to 3 storeys: EI 30
– walls in 4-storey buildings: EI 60
– walls in 5- and 6-storey buildings: EI 60/EI 30 (nbb)
– staircase walls in buildings with up to 3 storeys: EI 60/EI 30 (nbb)
– staircase walls in buildings with 4 to 6 storeys: EI 60 (nbb)



c145

The suffix "nbb" means that the outermost layer of the wall must be made from an incombustible material offering at least 30 minutes fire resistance. If a fire compartment wall is also loadbearing, it must satisfy the R criterion (stability) as well as the E (integrity) and I (insulation) criteria.
Further information on fire protection can be found in chapter d3 and in national regulations or standards. The Lignum and DGfH publications [29, 30, 31, 32] are particularly helpful with respect to fire protection in conjunction with timber structures.

c6 13 Sound insulation

Effective sound insulation should prevent, or at least limit, acoustic disturbances from neighbouring buildings or rooms regardless of their uses. To assess this, the degree of disturbance and the noise sensitivity of the rooms must be known. The requirements of the Swiss standard SIA 181 (2006) regarding the sound transmissions between various rooms can be found in section c1 35. The corresponding requirements to be satisfied by party walls must be calculated depending on the geometric boundary conditions.

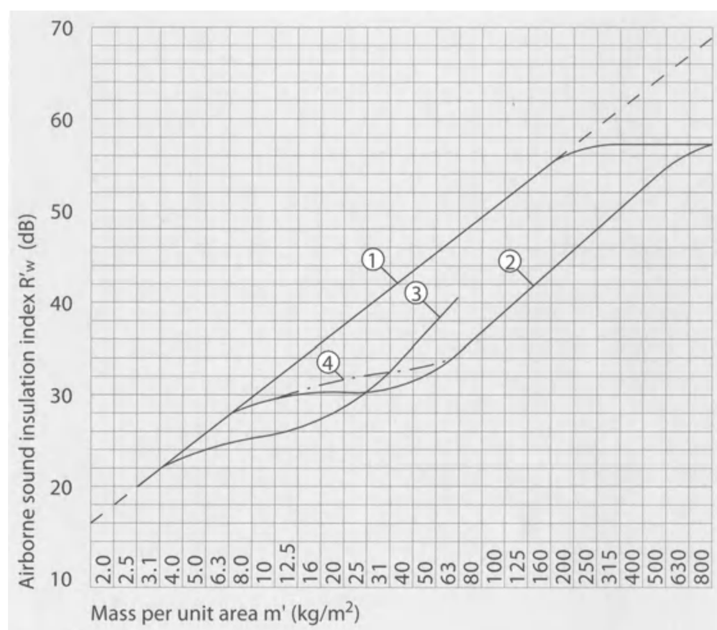
The flexural stiffness is also the reason why the sound reduction index remains practically unchanged between about 6 and 40 kg/m² for everyday building materials such as timber or wood-based products (curve 3), gypsum or masonry (curve 2). The reason for this is that as the thickness of the material increases, so the wall leaf becomes stiffer, which has a negative effect on the sound insulation.
So the aim should be to achieve maximum mass with a low flexural stiffness. Even if this requirement is satisfied, a very high mass is required if a single-leaf component is to provide good sound insulation. Double-leaf designs offer advantages here and also far more options. This means that only double-leaf designs can achieve high sound reduction indexes in timber structures.

c6 20 Sound insulation of party walls

From the acoustics viewpoint in connection with timber structures, we must distinguish between single- and double-leaf party walls. Double-leaf designs can be achieved with a one- or two-part loadbearing structure. The calculation of the acoustic properties of separating components is relatively difficult for timber buildings. Any assessment should preferably be backed up by in situ or laboratory measurements. The information given below is therefore confined to the most important features of timber components.

c6 21 Single-leaf walls

The sound insulation of single-leaf (single-layer) homogeneous walls is in the first instance dependent on their mass per unit area plus their flexural stiffness and critical frequency. Fig. c146 shows the relationship between sound insulation and mass per unit area. As can be seen, a doubling of the mass results in a theoretical increase in the sound reduction index of about 6 dB (curve 1). In practice, however, such improvements are hardly ever achieved because this approach ignores the flexural stiffness.



c146

c145 Erection of internal walls

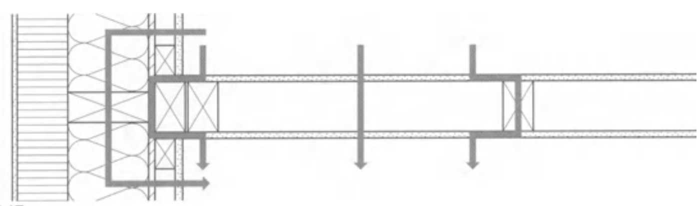
c146 The relationship between sound insulation and mass per unit area
Curve 1: Mass law, valid for ideal flexible materials such as rubber mats or thin sheet metal below their critical frequencies
Curve 2: valid for concrete, masonry, and gypsum
Curve 3: valid for timber and wood-based products
Curve 4: valid for panes of glass

c6 22 Double-leaf walls

The following points are important for the sound insulation of double-leaf walls:

- Fixing of leaves
- Construction of leaves
- Spacing of leaves
- Cavity insulation
- Spacing of studs
- Sound transmissions through the wall
- Flanking sound transmissions through adjoining components

Fig. c147 shows the possible transmission paths. Sound can be transmitted via the components (studs) connecting the leaves, the cavity, or flanking (adjoining) components.



c147

Fixing of the leaves

If the leaves are connected rigidly together by the studs, structure-borne sound transmissions are possible at these points. A point-like (articulated) connection can improve the sound insulation considerably. Fig. c148 shows the airborne sound insulation margin for two identical walls with different fixings.

Point-like (articulated) connections can be realised by inserting spacer plates, spacer screws, hardboard pads or mineral-fibre strips. Even better results can be achieved with fasteners designed to attenuate structure-borne sound transmissions, e.g. spring clips, structural members made from compound cross-sections optimised to reduce sound transmissions, or completely separate loadbearing constructions.

c147 Possible paths for sound transmissions, horizontal section through an external wall/internal wall junction

Construction of leaves

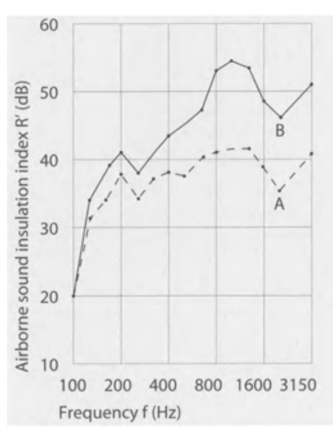
The leaves (cladding) should exhibit a maximum weight per unit area but at the same time a low flexural stiffness. Thick, rigid boards therefore result in less favourable values. Better results are obtained with two thinner boards, by doubling the number of boards, or by adding "ballast" in the form of hardboards, softboards, or heavyweight plastic sheeting.

Spacing of leaves

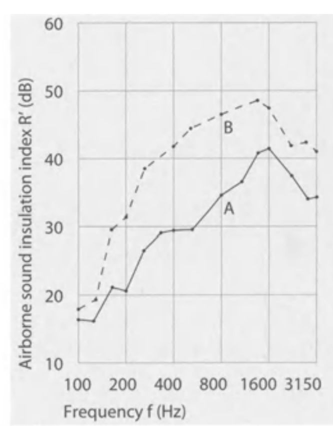
In order to achieve an acoustic advantage, the resonant frequency should be as low as possible (< 80 Hz). As the weight per unit area (kg/m^2) of the leaves and the spacing between them increases, the resonant frequency falls. The relationship between the mass and the spacing of the leaves is inversely proportional, i.e. leaves with half the mass achieve the same sound insulation at twice the spacing. The prerequisite for this is, however, adequate cavity insulation in order to prevent resonance within the cavity effectively. This principle also applies to party walls. From the fire protection point of view, the spacing of the two walls is unimportant and in practice is frequently only 20 mm. Increasing the spacing to 50 or 80 mm results in a noticeable improvement in the sound insulation properties.

Cavity insulation

Adding insulation in the cavity has a substantial influence on the acoustic properties (Fig. c149). From an acoustics viewpoint, it is sufficient when about two-thirds of the width between the leaves



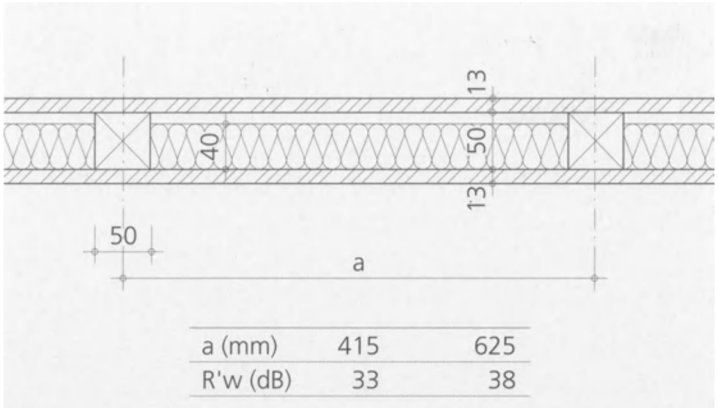
c148



c149

c148 How the fixing of the leaves affects the airborne sound insulation in a double-leaf lightweight wall construction
Curve A: Leaves rigidly connected to loadbearing structure
Curve B: Point-like (articulated) connections between leaves and loadbearing structure

c149 How cavity insulation affects the sound insulation
Kurve A: Curve A: No cavity insulation
Curve B: Mineral fibreboards in cavity



a (mm)	415	625
R'w (dB)	33	38

c150

is filled with a suitable material such as mineral fibreboards with a density of approx. 30 to 70 kg/m³. The differences in the thicknesses of the cavity insulation are not critical for the sound insulation properties. When using boards with a high density, it should be ensured that they are not too rigid and thus contribute to structure-borne sound transmissions. Rigid materials (e.g. expanded foam boards) are not suitable for cavity insulation.

Spacing of studs

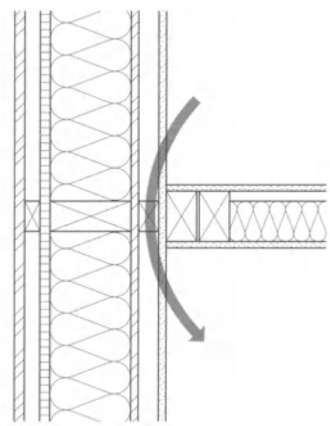
The sound insulation properties of a party wall worsen when the studs are too close together. Fig. c150 shows the relationship between the stud spacing and the airborne sound insulation index of a party wall without flanking transmissions. In principle, the spacing of the studs should not be less than 600 mm.

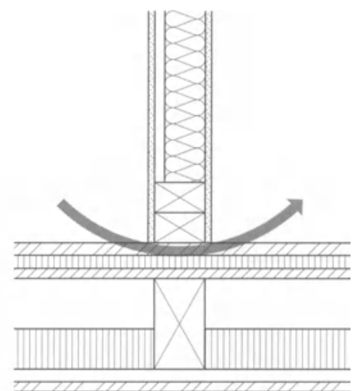
Party walls

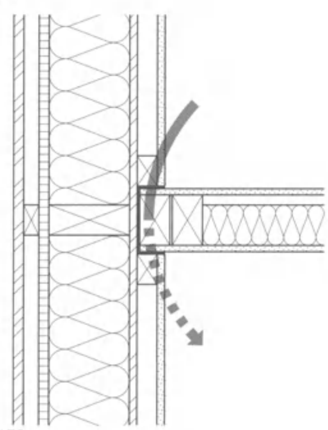
The walls described here for separating residential accommodation are governed by both sound insulation and fire protection requirements. As a rule, such walls comprise two independent walls with their own loadbearing structures, layers of insulation, and cladding.
An REI 90 fire wall must be constructed on the boundary of each plot for a terrace house. In the event of a fire in one house, the stability of the fire-resistant walls of the neighbouring houses must be guaranteed for a duration of 90 minutes. The structures of the houses are therefore designed and built separately.
This concept of two independent walls required for fire protection purposes also benefits the sound insulation. In addition, walls with a fire resistance of 90 minutes call for stable and heavyweight layers. However, walls tested and approved as a whole for their fire resistance are based on systems and are hence optimised for fire protection. From an acoustics viewpoint, there are differences in the design and construction that must be taken into account (Fig. c160).

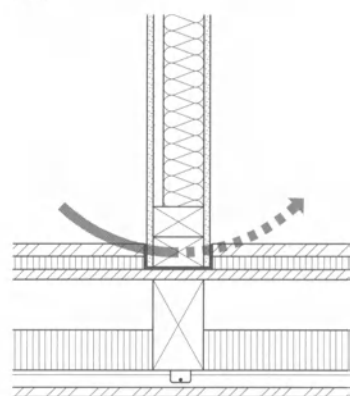
c6 30 Flanking transmissions

The measures described achieve the desired effects only when the flanking transmissions are kept to a minimum; for the sound is transmitted not only directly through the party wall itself, but also via adjoining components such as floors, ceilings, walls, poorly detailed joints and junctions, and building services. The higher the sound reduction index of a party wall, the greater the significance of the flanking transmissions. Their influence increases in party walls with a high sound reduction index and can become critical. Figs. c151 and c152 show poor details, Figs. c153 and c154 better alternatives.


c151


c152

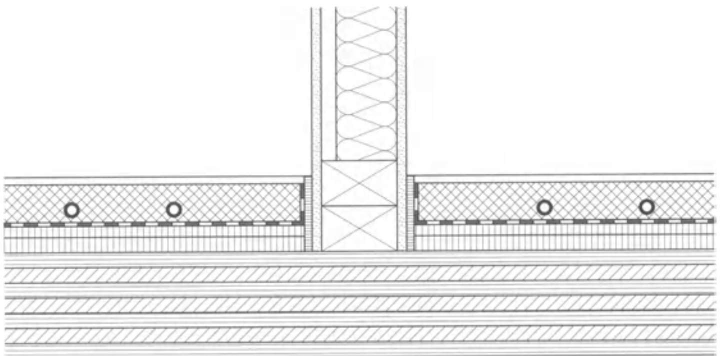

c153


c154

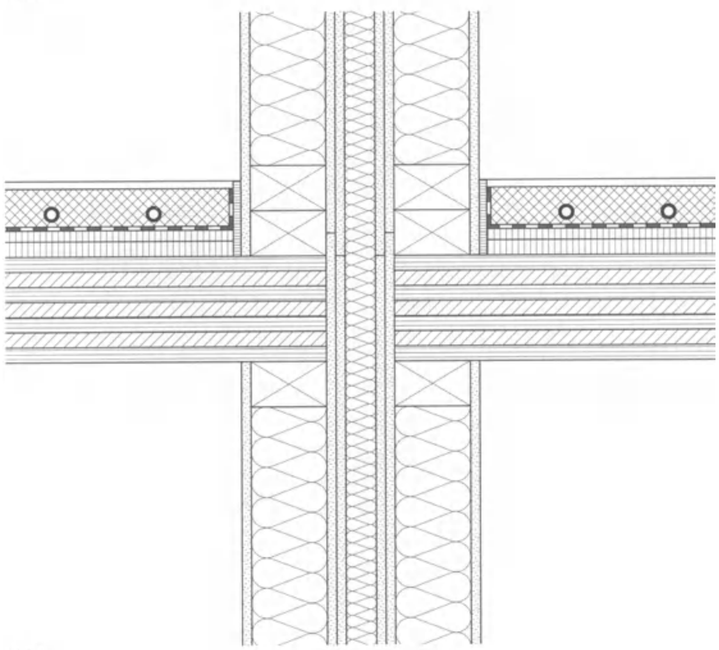
c150 How the spacing of the studs affects the sound transmissions

c151 and c152 Junctions with severe flanking transmissions
c151 Internal wall/external wall (horizontal section)
c152 Internal wall/suspended floor (vertical section)

c153 and c154 Junctions with suppressed flanking transmissions
c153 Internal wall/external wall (horizontal section)
c154 Internal wall/suspended floor (vertical section)



c155



c156

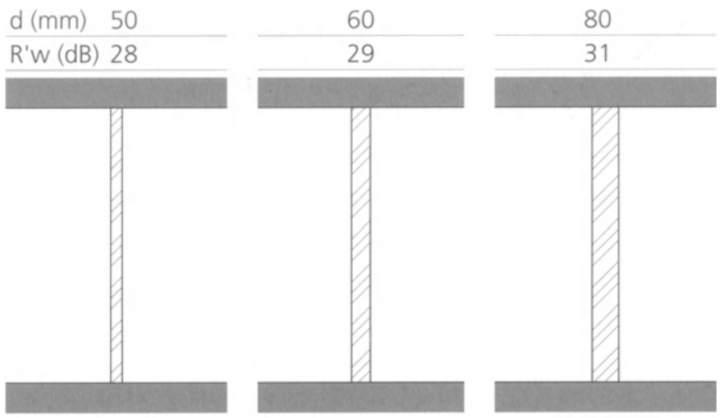
c6 40 Suggested forms of construction

Tables c158 to c160 show examples of party walls plus their sound reduction indexes. The values given have either been calculated or taken or derived from the tests of manufacturers or suppliers. A few of the examples shown were also measured in situ in finished buildings or have been estimated to enable a comparison between the different types of construction. All values should be taken as a guide only and in each case for the airborne sound with R'_w values (airborne sound reduction index in dB, determined with realistic flanking transmissions). The sound reduction indexes are specified as R'_w values and not as R_w values (laboratory measurements without flanking transmissions). The reasons for this are that only R'_w values are available for many types of construction and the measurements in the laboratory can only be measured reliably up to about 60 dB without flanking transmissions. By comparison, R'_w values should be classed as more conservative than R_w values for identical adjoining components and suppression of flanking transmissions. They tend to be on the safe side when appraising a form of construction.

The exact product specification, in situ situation, adjoining components, building services, and quality of workmanship have a decisive influence on the quality of walls that must meet certain sound insulation standards. Very careful planning and calculations must therefore be carried out specifically for every project. Manufacturers' specifications and approvals for their individual products must be taken into account.
Unfortunately, it is not easy to compile a systematic overview of reliable, proven forms of construction that is not based on specific products. Furthermore, the generalised spectrum adjustment values are missing in many cases.
- Ctr for airborne sound, outside noise
- C for airborne sound, inside noise
- CI for impact sound

which are defined in ISO 717-1 and 717-2 and in the meantime have been incorporated into the latest national standards of many countries and are hence mandatory (e.g. in Switzerland SIA 181 "Sound insulation in buildings", valid since mid-2006).

c155 and c156 Junctions with suppressed flanking transmissions
c155 Internal wall/suspended floor (vertical section)
c156 Party wall/suspended floor (vertical section)



c157

Where these values are known and seem plausible, the correction values necessary for the analysis have been included in the following tables.

The tables have been set up in such a way that they enable an overview according to constructional, general aspects (i.e. not only sound insulation). Where no reliable sound insulation data was available, the values have been omitted. As already mentioned above, calculating the acoustic properties of party walls in timber construction is comparatively difficult, especially the C and C_{tr} values. An assessment should therefore be backed up by laboratory or in situ measurements. What this means in practice is that reference is made to products and forms of construction with dependable figures, or forms of construction with an adequate margin of reliability. In this respect, the figures and forms of construction given in the tables can serve only as a guide or for the purposes of comparison.

Timber or wood-based board products are suitable for the sound insulation of single-leaf party walls to a limited extent only. The otherwise beneficial characteristics, e.g. high load-carrying capacity coupled with a low self-weight, tend to be disadvantageous here and do not result in satisfactory sound insulation.

Double-leaf party walls, however, can be built simply and rationally. For optimised fabrication it is advantageous when frame and covering materials are rigidly connected. If the elements also have to provide structural functions (bracing, loadbearing), rigid connection of the leaves is frequently unavoidable. A compromise between the structural and acoustic requirements is necessary here. The use of heavyweight components or two layers of sheathing can reduce substantially the acoustic disadvantages of the rigid connection. Forms of construction with compound cross-sections or resilient bars are also available and these overcome fully the disadvantages of the rigid connection. Two-part, completely independent walls are recommended for party walls between apartments, for staircase walls, and walls between different uses generally. Party walls should certainly be built in two parts, not only for sound insulation reasons. And the use of two independent walls means that forms of timber construction can be used that meet the high demands of sound insulation.

c157 Sound insulation of single-leaf party walls using the example of particleboards of different thicknesses (ignoring joints and junctions)

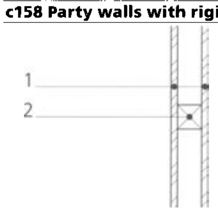
Sound insulation in timber buildings according to DIN 4109

The situation in Germany is somewhat different and this is reflected in the main standard for sound insulation in Germany, DIN 4109. Although this standard is also being revised to take account of European standards, the publications widely available concerning sound insulation in timber buildings according to the DIN standards are much better than the information available in the SIA standards valid in Switzerland. The reason for this is that comprehensive test series and evaluations of sound insulation in timber buildings and associated flanking transmissions have been undertaken in Germany in recent years. The corresponding assessments can be found in a DGfH publication [35]. Referring to this document will help achieve reliable sound insulation in timber buildings. As mentioned, the current DIN concept is being revised and adapted to conform with the European standards. But to do this, like in Switzerland, the entire acoustic analysis process to ensure adequate sound insulation must be revised in Germany.

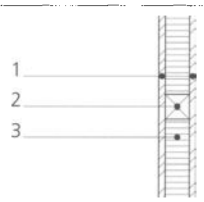
Publications on sound insulation in timber buildings can be found in the bibliography [33, 34, 35, 36, 37].

c6 Party walls, internal walls

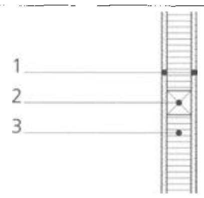
c158 Party walls with rigidly connected leaves



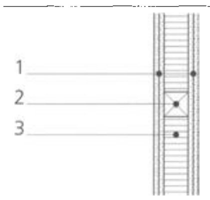
1 Particleboard, screwed		16 mm
2 Studs, a = min. 600 mm		60 x 60 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
92	33	(–.–)



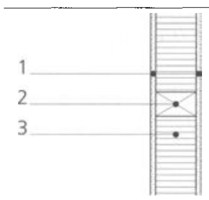
1 Particleboard, screwed		16 mm
2 Studs, a = min. 600 mm		60 x 60 mm
3 Mineral fibreboard, 40-70 kg/m³		60 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
92	35	(-2,-6)



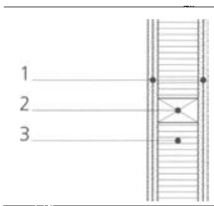
1 Gypsum fibreboard		12.5 mm
2 Studs, a = min. 600 mm		60 x 60 mm
3 Mineral fibreboard, 40-70 kg/m³		60 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
85	42	(-3.-6)



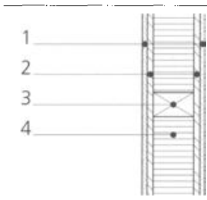
1 2 No. gypsum fibreboard		25 mm
2 Studs, a = min. 600 mm		60 x 60 mm
3 Mineral fibreboard, 40-70 kg/m³		60 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
110	47	(-2,-5)



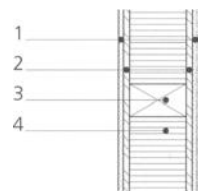
1 Gypsum fibreboard		12.5 mm
2 Studs, a = min. 600 mm		60 x 100 mm
3 Mineral fibreboard, 40-70 kg/m³		100 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
125	44	(-2,-4)



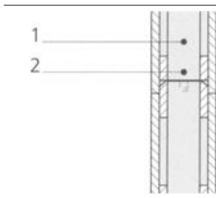
1 2 No. gypsum fibreboard		25 mm
2 Studs, a = min. 600 mm		60 x 100 mm
3 Mineral fibreboard, 40-70 kg/m³		100 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
150	50	(-2,-9)



1 Gypsum fibreboard		12.5 mm
2 OSB		15 mm
3 Studs, a = min. 600 mm		60 x 100 mm
4 Mineral fibreboard, 40-70 kg/m³		100 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
155	49	(-2.-9)



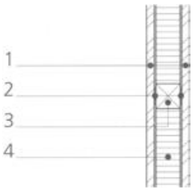
1 Gypsum fibreboard		12.5 mm
2 OSB		15 mm
3 Studs, a = min. 600 mm		80 x 140 mm
4 Mineral fibreboard, 40-70 kg/m³		140 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
195	51	(-2,-9)



1 Steko timber building system (visible quality)		160 mm
2 Voids filled with quartz sand		120 mm
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
160	48	(-1,-3)

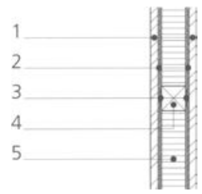
c158 Examples of forms of construction:
Party walls with rigidly connected leaves

c159 Party walls with hinged leaf connections, or made from compound sections



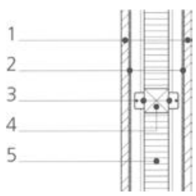
1 Particleboard, screwed	19 mm
2 Hardwood pads, 40 x 40mm,- a = min. 400 mm	4 mm
3 Studs, a = min. 600 mm	60 x 60 mm
4 Mineral fibreboard, 40-70 kg/m^3	60 mm

Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
106	40	(–,–)



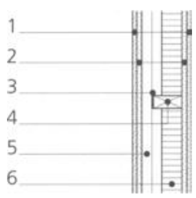
1 Particleboard, screwed	19 mm
2 Wood fibreboard nailed or clipped to rear of particleboard, a = 150-200 mm	4 mm
3 Hardwood pads, 40 x 40mm, a = min. 400 mm	4 mm
4 Studs, a = min. 600 mm	60 x 60 mm
5 Mineral fibreboard, 40-70 kg/m^3	60 mm

Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
114	45	(–,–)



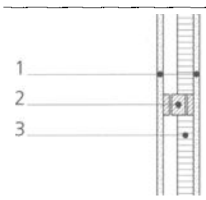
1 Particleboard, screwed	19 mm
2 Wood fibreboard nailed or clipped to rear of particleboard, a = 150-200 mm	4 mm
3 Battens attached with spring clips	30 mm
4 Studs, a = min. 600 mm	60 x 60 mm
5 Mineral fibreboard, 40-70 kg/m^3	60 mm

Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
174	50	(–,–)



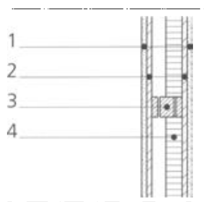
1 Gypsum fibreboard	10 mm
2 Gypsum fibreboard	12.5 mm
3 with felt underlay (1) without felt underlay (2)	
4 Studs, a = min. 600 mm	50 x 70 mm
5 Horizontal battens	30 x 50 mm
6 Mineral fibreboard, 40-70 kg/m^3	40 mm

Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
144	57 (1)	(–,–)
	54 (2)	



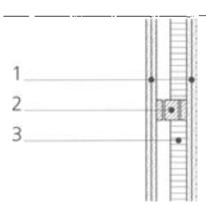
1 Gypsum fibreboard	12.5 mm
2 "timbatec" section	75 mm
3 Mineral fibreboard, 40-70 kg/m^3	40 mm

Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
105	46	(-5,-11)



1 Gypsum fibreboard	12.5 mm
2 OSB	12 mm
3 "timbatec" section	75 mm
4 Mineral fibreboard, 40-70 kg/m^3	40 mm

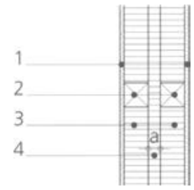
Wall thickness	Airborne sound	
	R'_w	$C,C_{tr})$
mm	dB	dB
124	54	(–,–)



1 2 No. gypsum fibreboard	25 mm
2 "timbatec" section	75 mm
3 Mineral fibreboard, 40-70 kg/m^3	40 mm

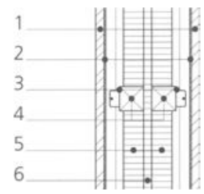
Wall thickness	Airborne sound	
	R'_w	(C,C_{tr})
mm	dB	dB
125	58	(–,–)

c160 Two-part party walls



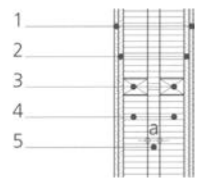
1 Gypsum fibreboard (1)	12.5 mm
2 No. gypsum fibreboard (2)	25 mm
2 Studs, a = min. 600 mm	60 x 60 mm
3 Mineral fibreboard, 40-70 kg/m^3	60 mm
4 Mineral fibreboard, 40-70 kg/m^3	30 mm

	Wall thickness	Airborne sound	
a		R'_w	(C,C_{tr})
mm	mm	dB	dB
30	215	50 (1)	(–,–)
30	245	59 (2)	(–,–)



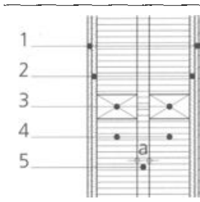
1 Particleboard, screwed	22 mm
2 Wood fibreboard nailed or clipped to rear of particleboard, a = 150-200 mm	4 mm
3 Battens attached with spring clips	30 mm
4 Studs, a = min. 600 mm	60 x 60 mm
5 Mineral fibreboard, 40-70 kg/m^3	50 mm
6 Mineral fibreboard, 40-70 kg/m^3	variable (a)

	Wall thickness	Airborne sound	
		R'_w	(C,C_{tr})
	mm	dB	dB
	258	57	(–,–)



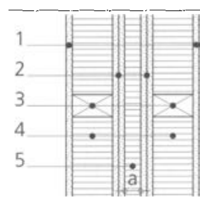
1 Gypsum fibreboard	10 mm
2 Gypsum fibreboard	12.5 mm
3 Studs, a = min. 600 mm	40 x 70 mm
4 Mineral fibreboard, 40-70 kg/m^3	70 mm
5 Mineral fibreboard, 40-70 kg/m^3	30 mm

	Wall thickness	Airborne sound	
a		R'_w	(C,C_{tr})
mm	mm	dB	dB
30	215	60	(-3,-7)



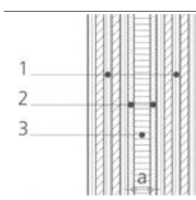
1 Gypsum fibreboard	10 mm
2 Gypsum fibreboard	12.5 mm
3 Studs, a = min. 600 mm	60 x 100 mm
4 Mineral fibreboard, 40-70 kg/m^3	100 mm
5 Mineral fibreboard, 40-70 kg/m^3	30 mm

	Wall thickness	Airborne sound	
a		R'_w	(C,C_{tr})
mm	mm	dB	dB
30	275	62	(–,–)



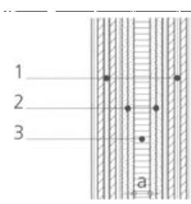
1 Gypsum fibreboard	15 mm
2 2 No. gypsum fibreboard	30 mm
3 Studs, a = min. 600 mm	60 x 100 mm
4 Mineral fibreboard, 40-70 kg/m^3	100 mm
5 Mineral fibreboard, 40-70 kg/m^3	variable (a)

	Wall thickness	Airborne sound	
a		R'_w	(C,C_{tr})
mm	mm	dB	dB
40	330	57	(–,–)
60	350	60	(–,–)



1 Solid timber wall	100 mm
2 Gypsum fibreboard	15 mm
3 Mineral fibreboard, 40-70 kg/m^3	variable (a)

	Wall thickness	Airborne sound	
a		R'_w	(C,C_{tr})
mm	mm	dB	dB
40	270	57	(–,–)
80	310	60	(–,–)



1 Solid timber wall	80 mm
2 Gypsum fibreboard	15 mm
3 Mineral fibreboard, 40-70 kg/m^3	variable (a)

	Wall thickness	Airborne sound	
a		R'_w	(C,C_{tr})
mm	mm	dB	dB
40	270	55	(–,–)
80	310	58	(–,–)

c159 Examples of forms of construction: Party walls with hinged leaf connections, or made from compound sections

c160 Examples of forms of construction: Two-part party walls

c7 Suspended floors

c7 10 Tasks

Depending on the location of a suspended floor, it may also have to comply with requirements concerning
- thermal performance
- fire protection
- sound insulation

in addition to satisfying the ultimate load and serviceability requirements.

c7 11 Thermal performance

Apart from suspended floors between heated and unheated rooms, and floors over basements or crawl spaces, the requirements regarding thermal performance are relatively low. If there are thermal performance requirements to be met, the construction of the floor must satisfy the building physics conditions.

c7 12 Fire protection

In terms of fire engineering, every storey is regarded as a separate fire compartment (except in a detached house). Consequently, every suspended floor has to be designed as a fire floor, i.e. with a certain fire resistance. The purpose of compartmentalisation is to prevent smoke and fire spreading to neighbouring storeys for a specified length of time and at the same time to permit effective fire-fighting. In addition, suspended floors, as loadbearing elements, must also remain stable for the specified length of time in the event of a fire.

According to Swiss fire regulations, detached houses do not normally have to satisfy any particular requirements. The following fire resistance classes are required for fire floors in residential, office, and school buildings:

– suspended floors in detached houses:	no requirement
– suspended floors in 2- and 3-storey buildings:	REI 30
– suspended floors in 4-storey buildings:	REI 60
– suspended floors in 5-/6-storey buildings:	REI 60/EI 30 (nbb)

The suffix "nbb" means that the outermost layers of the floor must be made from non-combustible materials offering at least 30 minutes fire resistance.

Further information on fire protection can be found in chapter d3 and in national regulations or standards. The Lignum and DGfH publications [29, 30, 31, 32] are particularly helpful with respect to fire protection in conjunction with timber structures.

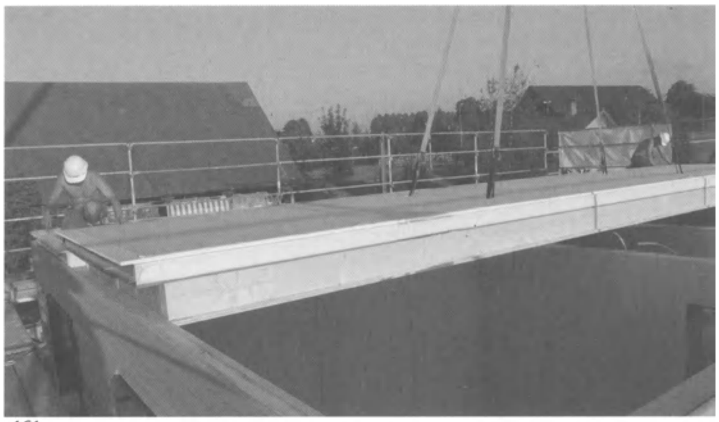
c7 13 Sound insulation

Sound insulation is another very important issue with suspended floors. And on trafficable floors, impact sound insulation must be considered as well as airborne sound insulation. The requirements regarding impact sound insulation are stipulated in the relevant standards (see also section c1 35). It should be noted that in contrast to airborne sound insulation, insulation for impact sound improves as the values decrease. Airborne sound measurement involves differential measurements; the better the separating component between the two areas (noisy and quiet) needs to be, the higher the decibel value should be. But the measurement of impact sound involves absolute measurements; the lower the value measured in the receiving room, the better the sound insulation.

As with airborne sound, the requirements for impact sound are not related to a single building component. The geometrical relationships should therefore also be considered when calculating the required sound reduction index. The calculation of the acoustic properties of separating components is relatively difficult for timber buildings. Any assessment should preferably be backed up by in situ or laboratory measurements. The information given below is therefore confined to the most important features of timber components.

c7 20 Sound insulation of suspended timber floors

For a long time, the mass per unit area (kg/m^2) was considered to be the sole governing criterion when designing for high standards of sound insulation. In the case of single-layer, solid components, this assumption is correct for airborne sound – in the majority of situations. Timber joist floors, however, always involve more than one layer, which means that further criteria play a role and enable suspended timber floors to achieve good to very good sound insulation values.



c161

Primarily owing to their low weight per unit area, the low stiffness of the loadbearing construction and significant sealing and connection problems, timber floors have inherent disadvantages when it comes to sound insulation, unless they have been specifically designed to satisfy acoustic requirements. And in terms of impact sound insulation, it is the low frequencies that are especially problematic (muffled vibrations). There is a certain relationship between impact sound and airborne sound insulation. This explains the guiding principle that if the impact sound insulation of a suspended timber floor is adequate, the airborne sound insulation will generally be adequate too. Both airborne sound insulation and impact sound insulation are affected by flanking transmissions common in buildings.

The sound reduction index of a timber joist floor can be influenced by the following factors:

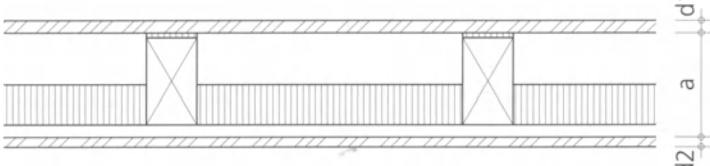
- Ceiling fixings
- Nature and weight of ceiling
- Distance between floor finishes or structural floor and ceiling. Intermediate layers, e.g. isolated ceilings, reduce the distance and have a detrimental effect (Fig. c162)
- Attenuating materials in voids between joists
- Floating subfloors, e.g. particleboards, dry subfloors, or screeds
- Ballast materials such as sand fill or heavyweight flags
- Nature of floor coverings, e.g. soft carpets or synthetic floor coverings, wood-block flooring with resilient intermediate layers or underlays

c7 21 Ceilings

The underside of a suspended timber floor can be left exposed or it can be concealed behind a ceiling. From the acoustics viewpoint, however, the latter solution is to be preferred. The construction of a ceiling produces a further layer that together with the layers on top of the loadbearing joists forms an effective acoustic assembly.
A comparison of the sound reduction indexes of three basic types of timber joist floor (loadbearing joists left exposed, loadbearing joists partly exposed, loadbearing joists concealed) clearly reveals the positive effect of the multi-layer approach. Starting with a basic floor (exposed joists plus planar floor material; construction type 1, table c165, p. 277), a ceiling attached with resilient fixings plus insulating material in the void between the joists improves the airborne sound insulation by about 15 to 16 dB. At the same time, the standard impact sound level is lowered by some 18 to 20 dB.

a) Ceiling fixings

If the ceiling is rigidly connected to the joists, the sound is transmitted directly. Suspended floors that have to satisfy acoustic requirements should therefore be built with separate layers. A separate ceiling is advantageous and easy to build (Fig. c164). Alternatively, direct connections to the joists by way of spring clips or resilient bars (Fig. c163) can achieve similar, good results and avoid the need for a totally separate construction.



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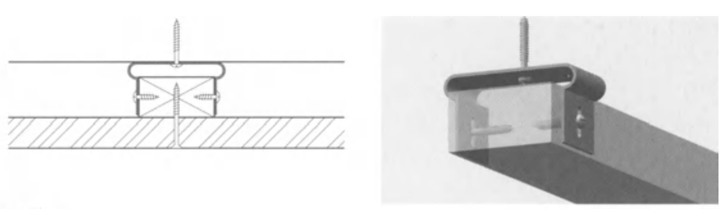


c163

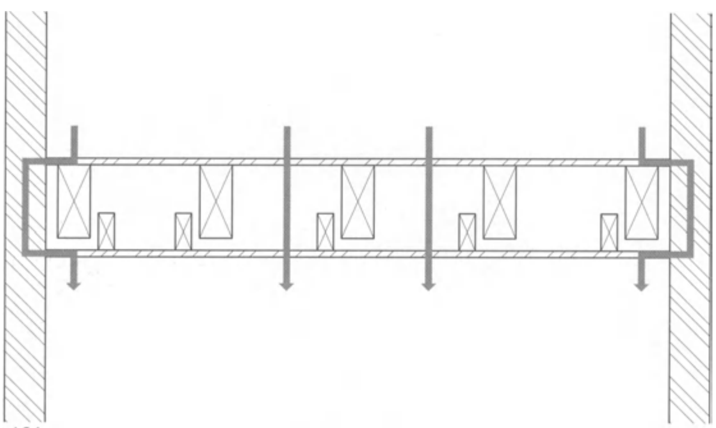
c161 Erecting a suspended timber floor

c162 Double-layer construction with good acoustic properties
- large spacing (a)
- separated layers
- attenuating material (mineral fibre board) in voids between layers
- thin, heavyweight, and non-rigid layers, or asymmetric construction (d1/d2 = approx. 2)

c163 Battens fixed with spring clips or resilient bars

b) Nature and weight of the ceiling

The basic principle is that the ceiling (acoustically effective lower layer) should have a maximum mass per unit area and a low flexural stiffness. Thick, single-layer ceilings therefore produce worse figures than several thin components. Good values are achieved by doubling the number of (thinner) boards or by adding "ballast" in the form of hardboard or heavyweight plastic sheeting. Wooden panelling should be attached to a "coherent" backing of, for example, particleboard, hardboard, plasterboard, or gypsum fibreboard because such panelling has a high number of joints which means that it hardly functions as a coherent layer, if at all. In order to be able to assess the ceiling better, different ceilings were attached to the first four forms of construction in table c171 (p. 280). Although the aforementioned principle (mass per unit


c164

area + flexural stiffness) still applies, the results lie closer together than might be expected. With respect to airborne sound, the results obtained all lie within just 2 dB of each other, and the impact sound results are only spread over a range of 6 dB. It should be noted that the forms of construction shown in table c171 should all be classed as very good in terms of sound insulation. Other, less well-insulated forms of construction can be improved by doubling the layers and adding weight to the ceiling. Whether it is economically viable to add weight or further layers to the ceiling in such forms of construction must be decided in each individual situation.

Summing up, we can say that adding ceilings of standard particleboard, hardboard, or plasterboard products generally improves the standard of sound insulation. Further improvements involve adding weight to the ceiling or another layer of the same material (e.g. 2 No. 12.5 mm plasterboards or gypsum fibreboards or 2 No. 16 mm particleboards). If non-rigid board types such as particleboard, hardboard, or plasterboard with a maximum thickness of 16 mm are used for the ceiling, the choice of material is of only secondary importance.

c) Ceiling fitted between the joists

If exposed joists are preferred for interior architecture reasons, a ceiling can be fitted between the joists (tables c168 and c169, p. 279). Compared with suspended floor constructions in which the loadbearing joists are left fully exposed, this approach does allow some improvement in the sound insulation. Using the trial assemblies described in the tables, such a ceiling including mineral fibreboard in the ensuing voids achieved an average (modest) 4 dB improvement in the airborne sound insulation values. Such forms of construction, however, have a greater effect on the impact sound insulation, achieving, on average, an 11 dB improvement, with minor differences between the various forms of floor construction. In order to achieve the values shown, however, the ceilings or their supporting frameworks must be installed with no gaps.

c7 22 Attenuating materials between the joists

Adding a ceiling to a timber joist floor, either below or between the joists, creates voids. In order to increase the sound insulation noticeably, these joists can be filled with materials that will attenuate the sound.

The density of the filling material to be used is almost irrelevant, as has been shown by theoretical calculations and practical experience. In addition, the voids do not need to be filled completely. For example, mineral fibreboard (30-70 kg/m³, 80 mm thick, possibly 100 mm if the joists are deep enough) is a suitable material.

Placing an attenuating material in the voids is worthwhile when the joists are closely spaced (min. 600 mm joist spacing) and when sound cannot be transmitted via a rigid connection (ceiling). Measurements of hollow-box solid timber floors (see construction type 3 in table c165, p. 277) with and without a mineral-wool filling in the voids showed that the filling did not bring about any improve-

c164 Sound transmissions via adjoining walls (flanking transmissions) in an otherwise well-insulated suspended timber floor ment in the airborne and impact sound insulation values. The reason for this is that the top and bottom members of such hollow boxes are connected by closely spaced, rigid webs which transmit sound regardless of whether or not the voids are filled with an attenuating material.

Timber joist floors, but also hollow-box floors with more widely spaced webs, need an attenuating material in the voids for sound insulation reasons. This is especially the case when the ceiling is not fixed rigidly.

c7 23 Floor finishes

There are limits to what can be achieved in terms of sound insulation with the measures mentioned above. If the floor is laid directly on the joists, the impact sound can be transmitted into the walls via the joist supports (flanking transmissions). The same is true for timber joist floors in which the full depth of the joists is left exposed. Neither a resiliently fixed ceiling nor attenuating materials are available to improve the sound insulation. In such cases, if a better degree of sound insulation is required, an effective acoustic construction can be achieved by adding materials above the floor structure. This form of construction – also known as a floating floor – is made up of an intermediate insulating layer, flooring-grade boards as a backing for the floor covering, and the floor covering itself. Additional measures involve adding weight to the loadbearing construction, possibly also the flooring-grade boards.

a) Floating particleboard floor

The sound insulation effect of a floating particleboard floor is essentially based on two facts: firstly, it adds a certain amount of weight and, secondly, the "resilient" bedding interrupts the direct sound transmission between floor covering and loadbearing joists. This "resilient" bedding is achieved by including an intermediate insulating layer that separates the floor covering, or rather the flooring-grade boards, from the loadbearing structure. When employing this form of construction, it must be ensured that the insulating material used is neither too soft nor too hard. The so-called dynamic stiffness is critical for impact sound insulation, and this should be as low as possible, although the serviceability and resilience under load must always be taken into account.

In order to achieve good sound insulation, mineral-fibre impact sound insulating boards with a density of about 80 to 110 kg/m³ or highly porous wood-fibre impact sound insulating boards are suitable.
Table c172 (pp. 281-82) contains values to enable a comparison. The density and thickness of mineral fibreboards depend on the particular product and purpose. Boards that are too soft can have disadvantages because their settlement under higher loads is excessive. Please refer to the information provided by manufacturers and suppliers.

The floating floor construction must be carefully separated from the perimeter walls with the help of strips of insulating material in order to prevent transmission of structure-borne sound. In addition, with hard floor coverings, a permanently resilient putty joint must be installed between the floor covering and the skirting boards in order to prevent transmission of structure-borne sound. With soft carpeting, however, the skirting board can be in direct contact with the carpet.

b) Floating screeds

Floating screeds, e.g. made with an anhydrite or cement binder, are frequently used to improve the acoustic properties of suspended floors – a good and cost-effective solution. The requirements regarding laying and thickness are specified in national standards, e.g. SIA 251/1 "Floating screeds". One disadvantage of thin anhydrite screeds is the low-frequency resonant frequencies that can occur. Another disadvantage is how the additional moisture introduced by this wet construction affects the drying-out behaviour of the building.

c) Influence of "ballast"

Considerable improvements can be achieved by adding weight in the form of resilient materials, e.g. loose sand fill, small-format flags or ballasting systems (e.g. Fermacell honeycomb subfloor). Important here is that the ballast lies directly on the structural floor and that the flexural stiffness of the floor material is not increased. When using concrete, for example, this should be in the form of separate, small-format flags or blocks. The joints between these prevent a detrimental stiffening of the suspended timber floor. The simplest solution is to lay the flags on a felt underlay, glue them to the structural floor, or lay them in a sand bedding in order to achieve adequate contact with the floor structure. The material the flags are made of is of secondary importance – the mass per unit area is critical.

When using a loose sand fill between the joists, possible sound transmissions via the joists themselves must not be forgotten. Only adequate separation will bring satisfactory results. Like with all loose fill solutions, attention must be given to ensuring that the loose material cannot escape through joints and gaps, or through holes cut later for building services, or drilled for fixings. A sand fill must be placed in compartments measuring approx. 600 x 600 mm because otherwise the loose sand can shift over time from heavily trafficked zones to lightly trafficked zones as a result of vibrations. Loadbearing structures with ballast are shown in tables c167, c169, c171, and c176; there are also some examples in tables c172 and c175.

d) Influence of floor coverings

Floor coverings such as carpeting or other materials with a soft backing help considerably to reduce impact sound in the middle and high frequencies. Hard floor coverings such as ceramic tiles, wood-block flooring (without a soft backing), and hard synthetic materials have hardly any effect on impact sound and should be laid on a floating subfloor (e.g. particleboard) in order to achieve a higher standard of sound insulation. The floor covering does not have a significant effect on the airborne sound insulation of a suspended timber floor.

The effect of carpeting and wood-block flooring with a soft backing has been investigated for a number of types of construction. In the case of carpeting ($\Delta L'_{w}$, impact sound insulation improvement index on concrete slab = 25 dB), an average improvement of $\Delta L'_{n,w}$ = 10 dB can be achieved; with wood-block flooring (laid floating on a separating fleece), the improvement is $\Delta L'_{n,w}$ = 4 dB. The airborne sound insulation is not affected by floor coverings. In forms of construction in which the influence of the carpeting and the wood-block flooring is known, the values are marked with T (carpet), P (wood-block flooring) or L (laminated flooring on separating layer).

However, carpeting products with a soft foam backing exhibit a very wide range of reactions. Some products laid on suspended timber floors cause low-frequency rumbling noises when they are walked on. Practical in situ tests with pieces measuring 1 m² and a tapping machine (to simulate footsteps) are recommended.

If floorboards are required as a floor covering, the individual boards should be laid on a grid of timber battens if possible. A floating floor construction is therefore difficult. One possible solution is to use the Pavatherm-NK Floor system (or a similar systém), 40 mm or 60 mm thick, installed with NK joint fillers on the structural floor (table c175).

c7 24 Absorber elements

The idea behind the absorber solution is to take measures for reducing vibrations from bridge-building and use them for sound insulation. This technology attenuates vibrations in the low-frequency range and thus reduces the transmission of footfall noise. Mass in the shape of calcium silicate bricks is introduced into the voids of hollow-box elements. These heavyweight elements are placed on resilient pads so that they function as absorbers. The use of absorbers in Lignatur hollow-box floors [38] considerably improves the sound insulation qualities, and especially the impact sound insulation qualities in the low-frequency range. Table c176 shows forms of construction with absorbers.

c7 25 Sound insulation of solid timber floors

Compared with loadbearing structures employing linear members, the planar solid timber floors (made from solid timber or board-type, glued products, see Fig. b351, p. 160) exhibit a higher weight per unit area. The basic acoustic property of such a suspended floor is therefore somewhat better.

Planar suspended timber floors made from solid timber, hollow-box elements with closely spaced webs, or cross-laminated timber all act as plates. Their soffits usually remain exposed (for details of the loadbearing construction, see chapter b10 "Suspended floor structures"). The stiffness of these plates is relatively high and the self-weight of, for example, a 100 mm deep solid timber floor is about 45 kg/m². The sound insulation values of the floor structures, provided they are known, can be found in table c165. These less than favourable values can be substantially improved by adding certain components, including the same forms of construction described for timber joist floors. As the soffits of solid timber floors usually remain exposed, the information given in section c7 23 "Floor finishes" is particularly relevant, likewise the details regarding floor coverings.

c7 30 Flanking transmissions

Sound transmissions between two rooms can take place via various transmission paths. Through different approaches to planning and design, an element separating two rooms can have different acoustic properties. The airborne sound transmission paths shown in Fig. c164 (p. 272) can be prevented or at least reduced. Sound transmissions through the suspended floor itself can be more or less eliminated by using a floating floor construction in the form of boards, subfloors, or screeds, and also the use of separate or elastically supported suspended ceilings. The flanking transmissions and pipes or cables or service ducts, however, influence the sound insulation of a suspended floor considerably. The higher the sound reduction index, the more significant the flanking transmissions, i.e. their influence increases with the sound reduction index and can become critical for a suspended floor.
Details of the junctions between suspended floors and walls can be found in the relevant publications [33, 34, 35, 36, 37]. The suggestions for suppressing flanking transmission paths at junctions with walls as shown in Figs. c153 to c156 (pp. 265–66) apply, in principle, to suspended floors as well.

Flanking transmissions through unsealed joints and junctions in the timber construction (e.g. wood panelling) should be overcome by using large-format covering materials or supporting structures, or the gaps should be sealed.
To achieve sound insulation values exceeding 60 dB, disproportionately costly and elaborate measures are required when it comes to flanking transmissions. Such measures include non-rigid facing leaves of hardboard, particleboard or plasterboard (on the flanking walls), and resilient supports.

c7 40 Suggested forms of construction

The sound insulation figures given in tables c165 to c176 were for the most part tested on a test rig belonging to the EMPA (Swiss National Materials-testing Institute), which complies with international ISO standards. The test rig and hence the surface area of the suspended floors tested measured 19 m². The tests were carried out in 1988 [33], the spectrum adjustment values C, C_{tr} and c_i were recalculated in 2006 based on the test reports and published [36]. The other values were either calculated or taken or derived from the tests of system suppliers. A few forms of construction were actually measured in buildings or were estimated to enable a comparison between the different types of construction. All the values should be taken as a guide only and in each case for the airborne sound with R'_w values (airborne sound reduction index in dB, determined with realistic flanking transmissions in dB), and in the case of impact sound with $L'_{n,w}$ values (weighted standard impact sound level in dB, determined with realistic flanking transmissions in dB). A few forms of construction, however, are specified with R_w or $L_{n,w}$ values (written in italics) (airborne sound insulation index measured in the laboratory).

The exact product specification, in situ situation, adjoining components, building services, and quality of workmanship have a decisive influence on the quality of suspended floors that must meet certain sound insulation standards. Very careful planning and calculations must therefore be carried out specifically for every project. Manufacturers' specifications and approvals for their individual products must be taken into account.
The information regarding the values in the tables described in section c6 40 for party walls and internal walls also applies here, but is adjusted to suit suspended floors. Also relevant here is the information on sound insulation in timber buildings according to DIN 4109, also included in section c6 40.

Tables c172 to c176 contain details of planar solid cross-sections and hollow-box cross-sections (with closely spaced webs). The forms of construction relate to either a solid cross-section or a hollow-box cross-section. The question of whether the given values, or rather the forms of construction, may be interchanged should be addressed as follows: in the case of the floor structures, the values for airborne sound deviate by 2 dB; in the case of impact sound they are identical. Further comparative measurements were carried out for the various forms of construction. The deviations were either minimal or negligible. As a result, it is not necessary to distinguish between the values for solid cross-sections and hollow-box cross-sections for planar solid timber floor structures. The values for airborne and impact sound insulation are therefore valid for both systems.

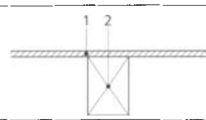
The differences between various intermediate insulation layers (table c172) and flooring-grade boards (table c173) have also been calculated for the solid cross-sections. Accordingly, the differential values for various products can be used for the timber joist floors. The prerequisite for this is, however, that the sound insulation values of the overall construction are roughly in the same order of magnitude. In order to achieve the values given in the tables, flanking transmissions must be avoided. As mentioned in section c7 30, this is particularly true for forms of construction with good sound insulation behaviour.

Publications on sound insulation in timber buildings can be found in the bibliography [33, 34, 35, 36, 37].

c165 Floor structures

Timber joist floor, joists exposed

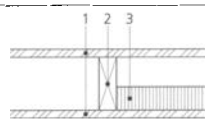
1 Timber sheathing	21 mm
2 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
29	221	26	(-1,-4)	90	(-5)

Hollow-box floor

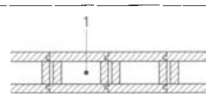
1 3-ply core plywood	27 mm
2 Rib	60 x 180 mm
3 Mineral fibreboard, 40-70 kg/m³	80 mm
3 Attenuating material (w/o mineral fibreboard)	



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
36	234	36	–	86	–
33	234	34	–	88	–

Hollow-box floor system

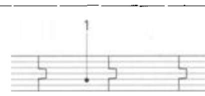
1 Hollow-box element	



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
43	140	35	(-1,-3)	88	(-4)

Solid timber floor

1 Glued laminated timber, solid tongue + groove joists	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
54	120	37	(-1,-3)	88	(-6)

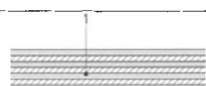
Solid timber floor

1 Edge-fixed timber	160 mm

Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
72	160	36	–	82	–

Solid timber floor board-type

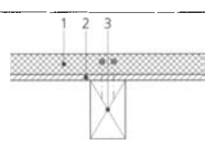
1 Cross-laminated timber	160 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
72	160	40	–	88	–

Timber-concrete composite floor

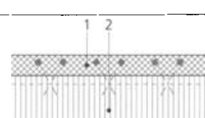
1 Concrete topping with shear connectors	70 mm
2 Timber sheathing	21 mm
3 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
204	273	42	–	88	–

Timber-concrete composite floor

1 Concrete topping with shear connectors	70 mm
2 Edge-fixed timber	160 mm



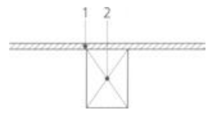
Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
247	230	44	–	85	–

c165 Floor structures

c166 Timber joist floors, structure exposed

1

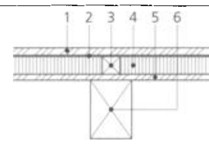
1 Timber sheathing	21 mm
2 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
29	221	26	(-1,-4)	90	(-5)
				69 T	(1)
				82 P	(-2)

2

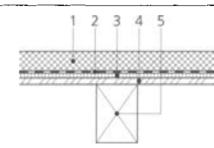
1 Particleboard, laid floating	25 mm
2 Impact sound insulation fleece	3 mm
3 Battens, fixed	60 x 60 mm
4 Mineral fibreboard, 40-70 kg/m³	60 mm
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
52	309	47	(-3,-10)	70	(0)
				60 T	(1)
				67 P	(0)

3

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-100 kg/m³	15 mm
4 Timber sheathing	21 mm
5 Timber joists	140x200 mm

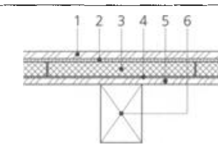


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
150	296	46	(-2,-6)	72	(-1)
				57 T	(0)
				69 P	(0)

c167 Timber joist floors, structure exposed, with ballast

1

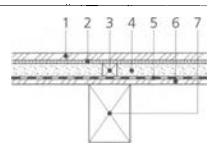
1 Particleboard, laid floating	25 mm
2 Mineral fibreboard 80-110 kg/m³	10 mm
3 Concrete flags, laid dry, 120 kg/m²	50 mm
4 Impact sound insulation fleece	3 mm
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
168	309	48	(-3,-8)	66	(-1)
				54 T	(1)
				61 P	(0)

2

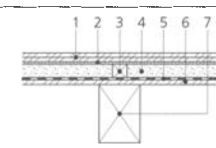
1 Particleboard, laid floating	25 mm
2 Impact sound insulation fleece	3 mm
3 Battens, fixed	50 x 50 mm
4 Dry sand, 1500 kg/m³	50 mm
5 Sheet to prevent loss of sand	
6 Timber sheathing	21 mm
7 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
127	306	53	(-4,-11)	64	(-1)
				50 T	(3)
				57 P	(0)

3

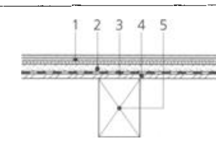
1 2 No. wood fibreboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Battens, fixed	50 x 50 mm
4 Dry sand, 1500 kg/m³	50 mm
5 Sheet to prevent loss of sand	
6 Timber sheathing	21 mm
7 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
126	306	54	(-3,-9)	65	(0)
				52 T	–
				61 P	–

4

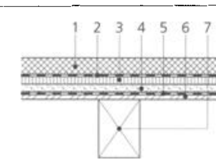
1 Fermacell honeycomb subfloor	30 mm
2 Fermacell honeycomb fill	30 mm
3 Sheet to prevent loss of loose fill	
4 Timber sheathing	21 mm
5 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
99	306	49	(-5,-13)	63	(-1)

5

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-110 kg/m³	30 mm
4 Dry sand, 1500 kg/m³	30 mm
5 Sheet to prevent loss of sand	
6 Flooring-grade boards	21 mm
7 Timber joists	140x200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_t)
kg/m²	mm	dB	dB	dB	dB
203	372	56	(-2,-6)	56	(-2)

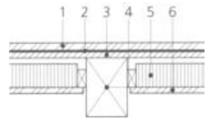
c166 Timber joist floors, structure exposed
T= value includes carpeting
P= value includes wood-block flooring

c167 Timber joist floors, structure exposed, with ballast
T= value includes carpeting
P= value includes wood-block flooring

c168 Timber joist floors, structure partly exposed

1

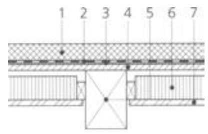
1 Particleboard, laid floating	25 mm
2 2 No. impact sound insulation fleece	6 mm
3 Timber sheathing	21 mm
4 Timber joists	140x200 mm
5 Mineral fibreboard, 30-70 kg/m³	80 mm
6 Particleboard	16 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
62	252	46	(-2,-7)	67	(-1)
				58 T	(2)
				61 P	(1)

2

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-110 kg/m³	15 mm
4 Timber sheathing	21 mm
5 Timber joists	140x200 mm
6 Mineral fibreboard, 30-70 kg/m³	80 mm
7 Particleboard	16 mm

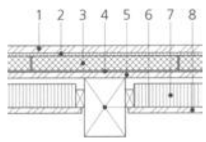


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
155	296	50	(-2,-6)	60	(-2)
				49 T	(1)
				56 P	(1)

c169 Timber joist floors, structure partly exposed, with ballast

1

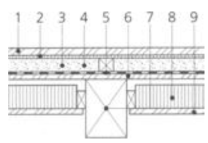
1 Particleboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Concrete flags, laid dry, 120 kg/m²	50 mm
4 Impact sound insulation fleece	3 mm
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm
7 Mineral fibreboard, 30-70 kg/m³	80 mm
8 Particleboard	16 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
197	309	55	(-4,-11)	55	(0)
				47 T	(1)
				52 P	–

2

1 Particleboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Battens, fixed	50 x 50 mm
4 Dry sand, 1500 kg/m³	50 mm
5 Sheet to prevent loss of sand	
6 Timber sheathing	21 mm
7 Timber joists	140x200 mm
8 Mineral fibreboard, 30-70 kg/m³	80 mm
9 Particleboard	16 mm

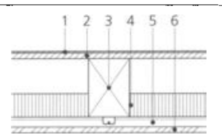


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
144	306	55	(-4,-10)	51	(1)
				45 T	–
				49 P	(2)

c170 Timber joist floor, structure concealed

1

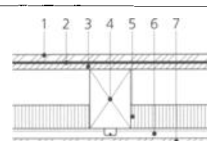
1 Sanded medium board	5.4 mm
2 Timber sheathing	21 mm
3 Timber joists	140x200 mm
4 Mineral fibreboard, 30-70 kg/m³	80 mm
5 Battens fixed with spring clips	30 mm
6 Particleboard	16 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
59	273	51	(-2,-8)	59	(1)
				52 T	–
				57 P	–

2

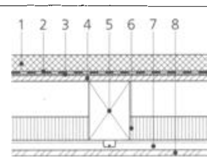
1 Particleboard, laid floating	25 mm
2 2 No. impact sound insulation fleece	6 mm
3 Timber sheathing	21 mm
4 Timber joists	140x200 mm
5 Mineral fibreboard, 30-70 kg/m³	80 mm
6 Battens fixed with spring clips	30 mm
7 Particleboard	16 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
72	298	56	(-3,-10)	57	(2)
				50 T	(4)
				54 P	(2)

3

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-110 kg/m³	15 mm
4 Timber sheathing	21 mm
5 Timber joists	140x200 mm
6 Mineral fibreboard, 30-70 kg/m³	80 mm
7 Battens fixed with spring clips	30 mm
8 Particleboard	16 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
174	342	60	(-2,-8)	52	(1)
				49 T	(3)
				50 P	–

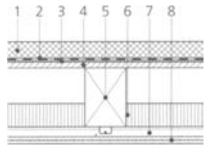
c168 Timber joist floors, structure partly exposed
T= value includes carpeting
P= value includes wood-block flooring

c169 Timber joist floors, structure partly exposed, with ballast
T= value includes carpeting
P= value includes wood-block flooring

c170 Timber joist floor, structure concealed
T= value includes carpeting
P= value includes wood-block flooring

4

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard 80-110 kg/m³	15 mm
4 Timber sheathing	21 mm
5 Timber joists	140x200 mm
6 Mineral fibreboard, 30-70 kg/m³	80 mm
7 Battens fixed with spring clips	30 mm
8 2 No. gypsum fibreboard	25 mm

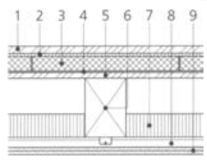


Weight	Depth of construction	Airborne sound		Impact sound	
		R'w	(C, Ctr)	L'n,w	(Ct)
kg/m²	mm	dB	dB	dB	dB
183	350	63		47	(1)
				41 T	–
				45 P	–

c171 Timber joist floor, structure concealed, with ballast, various ceilings

1

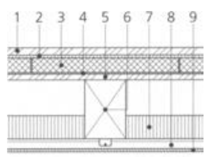
1 Particleboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Concrete flags, laid dry, 120 kg/m², 500 x 500 mm	50 mm
4 Impact sound insulation fleece	3 mm
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm
7 Mineral fibreboard, 30-70 kg/m³	80 mm
8 Battens fixed with spring clips	30 mm
9 2 No. gypsum fibreboard	25 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'w	(C, Ctr)	L'n,w	(Ct)
kg/m²	mm	dB	dB	dB	dB
197	363	64	(-2,-7)	44	(3)
				39 T	(4)
				43 P	(4)

2

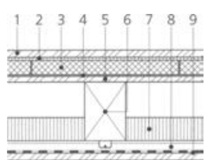
1 Particleboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Concrete flags, laid dry, 120 kg/m², 500 x 500 mm	50 mm
4 Impact sound insulation fleece	3 mm
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm
7 Mineral fibreboard, 30-70 kg/m³	80 mm
8 Battens fixed with spring clips	30 mm
9 Glued laminated hardboard	10 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'w	(C, Ctr)	L'n,w	(Ct)
kg/m²	mm	dB	dB	dB	dB
182	348	62	(-3,-10)	49	–
				45 T	–
				49 P	–

3

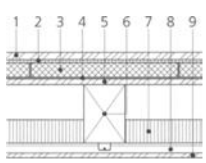
1 Particleboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Concrete flags, laid dry, 120 kg/m², 500 x 500 mm	50 mm
4 Impact sound insulation fleece	3 mm
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm
7 Mineral fibreboard, 30-70 kg/m³	80 mm
8 Battens fixed with spring clips	30 mm
9 Heavyweight plastic sheeting and particleboard	25 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'w	(C, Ctr)	L'n,w	(Ct)
kg/m²	mm	dB	dB	dB	dB
198	363	63	(-2,-8)	43	–
				39 T	–
				42 P	–

4

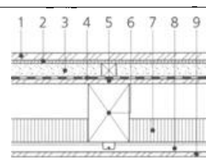
1 Particleboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Concrete flags, laid dry, 120 kg/m², 500 x 500 mm	50 mm
4 Impact sound insulation fleece	3 mm
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm
7 Mineral fibreboard, 30-70 kg/m³	80 mm
8 Battens fixed with spring clips	30 mm
9 Particleboard	16 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'w	(C, Ctr)	L'n,w	(Ct)
kg/m²	mm	dB	dB	dB	dB
184	355	62	(-3,-9)	48	(4)
				46 T	–
				48 P	–

5

1 Particleboard, laid floating	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Dry sand, 1500 kg/m³	50 mm
4 Sheet to prevent loss of sand	
5 Timber sheathing	21 mm
6 Timber joists	140x200 mm
7 Mineral fibreboard, 30-70 kg/m³	80 mm
8 Battens fixed with spring clips	30 mm
9 Particleboard	16 mm

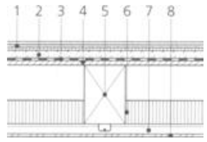


Weight	Depth of construction	Airborne sound		Impact sound	
		R'w	(C, Ctr)	L'n,w	(Ct)
kg/m²	mm	dB	dB	dB	dB
144	352	63	(-3,-10)	45	(4)
				43 P	(5)

c171 Timber joist floor, structure concealed, with ballast, various ceilings
T= value includes carpeting
P= value includes wood-block flooring

6

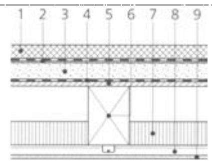
1 Fermacell honeycomb subfloor	30 mm
2 Fermacell honeycomb fill	30 mm
3 Sheet to prevent loss of loose fill	
4 Timber sheathing	21 mm
5 Timber joists	140x200 mm
6 Mineral fibreboard, 30-70 kg/m³	89 mm
7 Battens fixed with spring clips	30 mm
8 Fermacell HD board	10 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
62	321	62	(-1,-7)	47	(3)
				41 T	–
				45 P	–

7

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane, min. fibrebd, 80-110 kg/m³	30 mm
3 Dry sand, 1500 kg/m³	60 mm
4 Sheet to prevent loss of sand	
5 Flooring-grade boards	22 mm
6 Timber joists	140x200 mm
7 Mineral fibreboard, 30-70 kg/m³	100 mm
8 Battens fixed with spring clips	30 mm
9 Gypsum fibreboard	12.5 mm

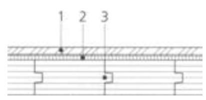


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
267	424	65	–	40	(0)

c172 Solid timber floor, various intermediate insulating materials

1

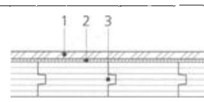
1 Particleboard	25 mm
2 Highly porous wood-fibre impact sound insul. bd	16 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
74	161	49	(-3,-8)	71	–

2

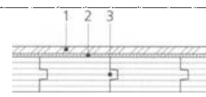
1 Particleboard	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
72	155	49	(-3,-8)	67	–

3

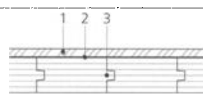
1 Particleboard	25 mm
2 Homogeneous cork board	10 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
73	155	44	(-1,-6)	73	–

4

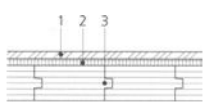
1 Particleboard	25 mm
2 Impact sound insulation fleece	5 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
72	150	46	(-2,-7)	68	–

5

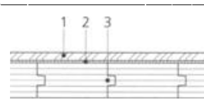
1 Particleboard	25 mm
2 Polyester impact sound insulation board, elasticated	20 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
73	165	47	(-3,-8)	68	–

6

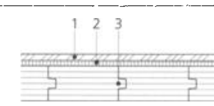
1 Particleboard	25 mm
2 Cork granulate	8 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
73	153	45	(-2,-6)	72	–

7

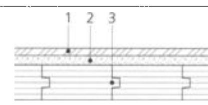
1 Particleboard	25 mm
2 Cork granulate	16 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
76	161	45	–	69	–

8

1 Particleboard	25 mm
2 Dry loose fill	30 mm
3 Solid timber floor, glued laminated timber	120 mm

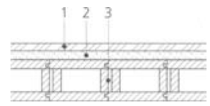


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
76	175	49	(-1,-6)	70	–

c172 Solid timber floor, various intermediate insulating materials
T= value includes carpeting
P= value includes wood-block flooring

9

1 Particleboard	25 mm
2 Cellulose fibreboard	20 mm
3 Hollow-box floor system	140 mm

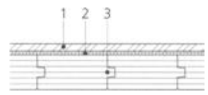


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
71	185	45	(-1,-5)	71	–
				57 T	–

c173 Solid timber floor, various subfloors

1

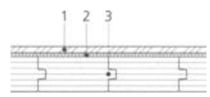
1 Particleboard	25 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
72	155	49	(-3,-8)	67	–

2

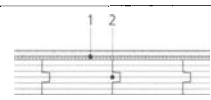
1 Glued laminated hardboard	22 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
75	152	51	(-3,-9)	66	(2)

3

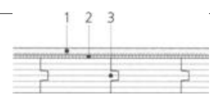
1 20 mm gypsum fibreboard bonded to 10 mm mineral fibreboard, 80-110 kg/m³	30 mm
2 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
79	150	47	(-3,-9)	68	–

4

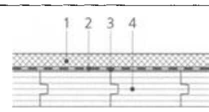
1 Gypsum fibreboard	22 mm
2 Mineral fibreboard, 80-110 kg/m³	10 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
81	152	49	(-3,-10)	65	(1)

5

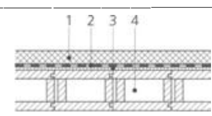
1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 30-110 kg/m³	10 mm
4 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
164	180	53	(-2,-9)	64	(-1)

6

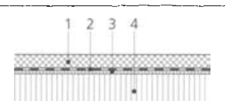
1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-110 kg/m³	15 mm
4 Hollow-box floor system	140 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
153	203	52	(-2,-7)	59	(-2)
				53 T	(4)
				57 P	(1)

7

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-110 kg/m³	30 mm
4 Edge-nailed or edge-dowelled timber	120 mm

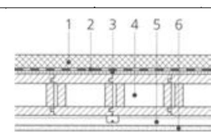


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
176	200	53	(-2,-7)	57	(-3)

c174 Solid timber floor with ceiling

1

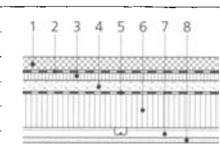
1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-110 kg/m³	15 mm
4 Hollow-box floor system	140 mm
5 Battens fixed with spring clips	30 mm
6 Gypsum fibreboard	18 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
172	256	59	(-3,-9)	52	(2)
				49 T	(3)
				51 P	(3)

2

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral fibreboard, 80-110 kg/m³	30 mm
4 Dry sand, 1500 kg/m³	40 mm
5 Sheet to prevent loss of sand	
6 Edge-nailed or edge-dowelled timber	120 mm
7 Battens fixed with spring clips	30 mm
8 Gypsum fibreboard	12.5 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
253	283	62	(-4,-10)	47	(2)

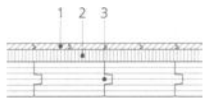
c173 Solid timber floor, various subfloors
T= value includes carpeting
P= value includes wood-block flooring

c174 Solid timber floor with ceiling
T= value includes carpeting
P= value includes wood-block flooring

c175 Solid timber floor, floor finishes with floorboards

1

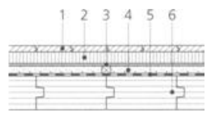
1 Floorboards	21 mm
2 Pavatherm, type NK, together with battens, or similar system	40 mm
3 Solid timber floor, glued laminated timber	120 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
73	182	49	(-2,-8)	67	

2

1 Floorboards	21 mm
2 Pavatherm, type NK, together with battens, or similar system	40 mm
3 Highly porous wood fibreboard between battens	8 mm
4 Dry sand, 1500 kg/m³, between fixed battens	30 mm
5 Sheet to prevent loss of sand	
6 Solid timber floor, glued laminated timber	30 mm

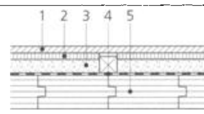


Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
125	220	53	(-4,-10)	60	(1)

c176 Solid timber floor, with ballast or absorber elements

1

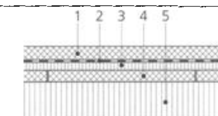
1 Pavaflor NK, "decor"	23 mm
2 Pavapor	20 mm
3 Dry sand, 1500 kg/m³, between fixed battens	50 mm
4 Sheet to prevent loss of sand	
5 Solid timber floor, glued laminated timber	140 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
165	215	55	–	58	–
				53 T	

2

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral-fibre insulating board, 80-110 kg/m³	30 mm
4 Concrete flags, laid dry, 100 kg/m²	40 mm
5 Edge-nailed timber	140 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
285	260	61	0	46	(-1)

3

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral-fibre insulating board, 80-110 kg/m³	30 mm
4 Dry sand, 1500 kg/m³	40 mm
5 Sheet to prevent loss of sand	
6 Edge-nailed timber	120 mm

Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
237	240	61	(-3,-10)	46	(-1)

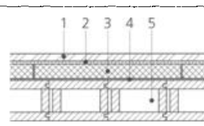
4

1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral-fibre insulating board, 80-110 kg/m³	30 mm
4 Dry sand, 1500 kg/m³	80 mm
5 Sheet to prevent loss of sand	
6 Edge-nailed timber	140 mm

Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
305	300	64	(-4,-10)	44	(-1)

5

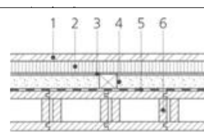
1 Particleboard, laid floating	25 mm
2 Mineral-fibre insulating board, 80-110 kg/m³	10 mm
3 Concrete flags, laid dry, 120 kg/m²	50 mm
4 Impact sound insulation fleece	3 mm
5 Hollow-box floor system	140 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
182	228	54	(-2,-8)	58	(1)
				52 T	(2)
				57 P	(2)

6

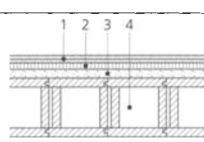
1 Particleboard, laid floating	25 mm
2 Pavatherm, type NK, screwed to battens	40 mm
3 Highly porous wood fibreboard between battens	8 mm
4 Dry sand, 1500 kg/m³	50 mm
5 Sheet to prevent loss of sand	
6 Hollow-box floor system	140 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
152	263	58	(-2,-8)	60	(0)
				48 T	(3)

7

1 2 No. gypsum fibreboard	25 mm
2 Mineral-fibre insulating board, 80-110 kg/m³	20 mm
3 Fermacell Honeycomb fill	30 mm
4 Hollow-box floor system	200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R'_w	(C, C_{tr})	$L'_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
125	275	54	(-2,–)	53	(0)

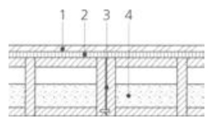
c175 Solid timber floor, floor finishes with floorboards
T= value includes carpeting
P= value includes wood-block flooring

c176 Solid timber floor, with ballast or absorber elements
T= value includes carpeting
P= value includes wood-block flooring
L= value includes laminated flooring

c7 Suspended floors

8

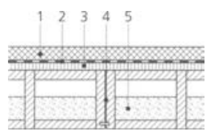
1 Particleboard, laid floating	22 mm
2 Mineral-fibre insulating board, 80-110 kg/m³	30 mm
3 Floor system	200 mm
4 Loose fill, 80 kg/m²	



Weight	Depth of construction	Airborne sound		Impact sound	
		R_w	(C, C_{tr})	$L_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
134	245	*61*	(-2,–)	*56*	(2)
				47 L	(6)

9

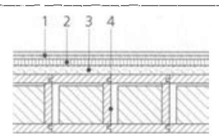
1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral-fibre insulating board, 80-110 kg/m³	30 mm
4 Floor system	200 mm
5 Loose fill, 80 kg/m²	



Weight	Depth of construction	Airborne sound		Impact sound	
		R_w	(C, C_{tr})	$L_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
239	280	*71*	(-2,–)	*58*	(-9)
				43 L	(1)

10

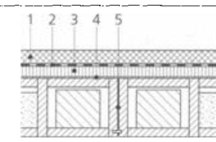
1 Fermacell honeycomb subfloor	25 mm
2 Mineral-fibre insulating board, 80-110 kg/m³	22 mm
3 Fermacell honeycomb fill	30 mm
4 Lignatur "silence" hollow-box element [38]	200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R_w	(C, C_{tr})	$L_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
205	277	*65*	(-2,–)	*51*	(-1)
				40 T	(2)
				48 P	(1)

11

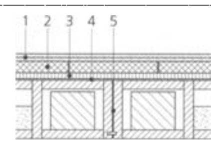
1 Cement screed, 120 kg/m²	50, 60 mm
2 Damp-proof membrane	
3 Mineral-fibre insulating board, 80-110 kg/m³	40 mm
4 Hardboard	5 mm
5 Lignatur "silence" floor element [38]	200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R_w	(C, C_{tr})	$L_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
295	295	*73*	(-2,–)	*50*	(-5)

12

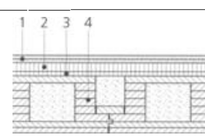
1 Fermacell subfloor	25 mm
2 Concrete flags, laid dry, 100 kg/m², 300 x 300 mm	40 mm
3 Mineral-fibre insulating board, 80-110 kg/m³	22 mm
4 Hardboard	5 mm
5 Lignatur "silence" floor element [38]	200 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R_w	(C, C_{tr})	$L_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
258	287	*68*	(-2,–)	*50*	(-2)
				45 P	(-1)

13

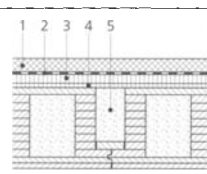
1 Dry subfloor element	30 mm
2 Wood-fibre impact sound insulation board	32/30 mm
3 Wood-fibre insulation board to spread the load	15 mm
4 Lignotrend cross-laminated timber floor element LIGNO floor Q3-196 with facing quality wooden soffit and filling of chippings, approx. 120 kg/m²	196 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R_w	(C, C_{tr})	$L_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
209	271	*67*	(-6,-15)	*49*	(1)

14

1 Cement screed, 120 kg/m²	50 mm
2 Damp-proof membrane	
3 Mineral-fibre insulating board s'=5 MN/m³	40/35 mm
4 Wood-fibre insulation board to spread the load	15 mm
5 Lignotrend cross-laminated timber floor element LIGNO floor Q3-262 with facing quality wooden soffit and filling of chippings, approx. 196 kg/m²	262 mm



Weight	Depth of construction	Airborne sound		Impact sound	
		R_w	(C, C_{tr})	$L_{n,w}$	(C_I)
kg/m²	mm	dB	dB	dB	dB
376	362	*78*	(-3,-9)	*37*	(0)

d

Boundary conditions

Moisture content, protecting timber, fire protection

d1 Moisture content


d2

d1 10 General

As a hygroscopic material, timber has the ability to release or absorb moisture depending on its immediate environment. This means that a certain moisture content in equilibrium with the immediate environment becomes established in the wood (equilibrium moisture content). This property is beneficial for a balanced interior climate, but in terms of the dimensional stability and the drying process of the timber it also involves disadvantages, which, however, can be eliminated through constructional measures.
Owing to timber's hygroscopic behaviour every change in the immediate environment leads to a change in the moisture content of the wood. A changing moisture content less than the fibre saturation point (from that point onwards when the porous cell walls are no longer full with water) in turn means a change in the dimensions of the cross-section. Such changes also depend on the internal structure of the wood, and the orientation and arrangement of the cells. Owing to its microstructure, wood exhibits different shrinkage and swelling characteristics in its radial, tangential, and longitudinal directions; it is anisotropic. The dimensional changes in the tangential direction are largest, those in the radial direction are only about half this amount, and in the longitudinal direction they are negligible. Section b11 40 contains calculations showing the anisotropic behaviour of wood and the effects it can have on the construction.

d1 20 Requirements

In order to guarantee dimensional stability, strength, and durability, the installation moisture content of the timber must match the service moisture content as given in table d1.
Summarising table d1 results in the following equilibrium moisture content values:
– heated rooms: 6 to 12%
– unheated roof spaces: 12 to 18%
– outdoor components, but under cover: 12 to 22%

There are many constructional requirements, some of them prescribed in standards, a few of which will be highlighted here:

Position of component	**Average moisture content of cross-section**	
	mean value	range of fluctuation
Components protected from the weather		
in well-ventilated rooms, well-heated in winter	9 %	± 3 %
in well-ventilated rooms, poorly heated in winter	12 %	± 3 %
in well-ventilated but unheated rooms	15 %	± 3 %
Components partly protected from the weather		
in open and covered structures	17 %	± 5 %
small cross-sections (e.g. facade panelling with or without surface treatment)		
significant radiation absorption	15 %	± 5 %
little radiation absorption	17 %	± 4 %
average cross-sections (e.g. balcony components under cover)		
significant radiation absorption	13 %	± 4 %
little radiation absorption	16 %	± 4 %
Components directly exposed to the weather		
large cross-sections (e.g. structural timber without sealing surface treatment)		
average	18 %	± 6 %
outer zone of cross-section	20 %	± 8 %
Components in damp conditions		
in damp, insufficiently ventilated rooms	24% to more than fibre saturation	
Components in water (freshwater)	via fibre saturation	

d1

Overleaf:
External cladding in solid larch, bevelled, untreated horizontal slats, with ventilation cavity, supplied as prefabricated elements, fixings concealed.

d1 Average moisture content (equilibrium moisture content) according to position of component, Swiss standard SIA 265 "Timber structures".

d2 Timber used primarily as a load-bearing material: components protected from the weather, in well-ventilated rooms, well-heated in winter, average moisture content 9%, range of fluctuation ± 3%, according to table d1.


d3


d4

- Timber that is moist or has not finished drying at the time of installation, but is loaded during the drying-out period, will very likely exhibit higher creep deformations.
- The moisture content of timber installed within the thermal insulation layer may not exceed 16% at the time of being enclosed on all sides.
- Building envelope penetrations must be sealed tightly, which is only possible with timber members that satisfy the requirements regarding dimensional stability, and therefore only dry timber may be used.

d1 30 The right installation moisture content

The right installation moisture content of the timber can be derived from the details given in section d1 20. What this means for various applications is summarised below:

Timber used primarily as a covering material

(cladding, supporting framework, boards and planks)
The moisture content at the time of installation should be equal to the equilibrium moisture content that will ensue in service. See table d1 for the values.
Wooden cladding materials are generally supplied dry. A check should be carried out to establish whether the moisture content of the products as delivered corresponds with the desired installation moisture content. Please note that it is important that the timber be protected against moisture during transport, erection, and subsequent work on site.

Timber used primarily as a loadbearing material

(structural timber)
Structural timber must also exhibit a certain installation moisture content that matches the service moisture content required later, in most cases 8 to 12%. These days, the majority of structural timber members are glued products, and this implies that they are supplied dry, i.e. the requirement regarding the right moisture content (see table d1) has been satisfied by the time of installation. In the meantime, even the small-format sections used in panel construction are available in the form of glued cross-sections, and are in fact becoming very widespread. Dried, glued timber guarantees the necessary dimensional stability and accuracy of fit. In addition, dried and planed timber is very unlikely to be attacked by insects.
It is significantly more difficult and more costly to dry solid timber products (see Fig. a54, p. 34, for details of types and sizes) than small-format boards or laminations – the raw materials for glued cross-sections. It is therefore inadvisable to specify installation moisture contents of, for example, 8 to 12% for solid timber, and, indeed, hardly possible from the technical viewpoint [39].

The most important installation moisture content is specified below according to type of product:
- The moisture content of small-format, glued or non-glued cross-sections for use in heated residential buildings, e.g. for use in panel construction, may not exceed 12%.
- Glued laminated timber members, and other glued cross-sections, should be produced from laminations with an average moisture content of 10%; the glued timber products therefore leave the works with a moisture content of 8 to 12%.
- Owing to difficulties experienced during drying, solid timber for heated interiors should have an average installation moisture content of 15%, and the maximum value should not exceed 17%. A moisture content of max. 20% is permissible for the interior of the timber (central zone of joist, depth of cross-section > w/4) in cross-sections with finished sizes up to 120 mm. In the case of unheated rooms, an average installation moisture content of 18% and a maximum value of 20% should be specified [39].
- Non-dried structural timber can be installed with a moisture content of max. 25% provided subsequent drying-out is guaranteed and the deformations to be expected do not result in any disadvantages.
- Impregnating coatings with water-repellent and mould-resistant properties are well established means of protection. Such coatings are also available in colourless, transparent varieties.
- Please note that it is important to protect the timber against moisture during transport, erection, and subsequent work on site (construction moisture in particular).

d3 Timber used primarily as a covering material: components partly protected from the weather, small cross-sections, facade cladding, average moisture content 17%, range of fluctuation ± 4% (little radiation absorption), according to table d1.

d4 Timber used primarily as a covering material: components protected from the weather, in well-ventilated rooms, well-heated in winter, average moisture content 9%, range of fluctuation ± 3%, according to table d1.
An installation moisture content of 6–10% is recommended for inner linings.

d2 Protecting timber

In order to ensure that timber components continue to function as intended over the long-term, the initial focus should be on constructional, material, and processing measures. Where necessary, these measures should be backed up by suitable surface treatments or pressure impregnation. In heated interiors, however, such chemical preservation measures are unnecessary, provided the building physics requirements are satisfied but chemical preservation treatments cannot compensate for any shortcomings here. And in other situations as well, the need for chemical preservatives must be checked on a case-by-case basis. They are mostly needed for components installed in the open air and therefore exposed to the rigours of the weather, or for timber members in contact with the ground. Other factors to be considered are the geographical location of the site and the local climate. In dry areas, e.g. elevated regions with an Alpine climate, moisture affects the outside of a building much less than in regions where foggy and misty conditions prevail. Generally speaking, as constructional, passive protection options (design, details) decrease, so the problems and hence the risks increase. The less protection a component has, the more important are measures such as choice of material or type of conversion. Wherever constructional measures are inadequate, surface treatments or chemical preservatives will be unavoidable.

d2 10 Risks

The moisture content is the most significant influence with respect to the physical and biological properties of timber components and hence the most significant influence with respect to their long-term functionality. Changes in the moisture content lead to shrinking and swelling of the wood. The consequences are dimensional variations and often distortion in the form of curvature, twisting, etc. Rapid moisture changes, which occur primarily in conjunction with intense temperature fluctuations, promote fissures. Fissures, open joints, etc. lead to saturation of the wood and provide ideal places for insects to lay their eggs. A constantly high moisture content, caused by the effects of precipitation, condensation or moisture in the soil, can lead to discoloration of the wood and destruction by fungi. The direct effects of the weather (solar radiation, precipitation) have an especially intensive effect on wood, which leads to the aforementioned moisture physics processes, weathering of the surface, and discoloration of the timber. (See chapter c3 20 "External cladding" for further information.)
The use of dry wood is the best protection against fungi and in most cases also against insect attack. In new buildings, the use of dry wood obviates the need for chemical preservatives inside the building, with the possible exception of showers or bathrooms, but this does depend on the type of construction and the particular effects.

d5

d2 11 Fungi

The risk of fungal attack depends in the first place on the moisture content of the wood and how that changes over time. For timber installed in a building, a moisture content that exceeds 25% for a long time (i.e. weeks) is regarded as critical.
When the moisture content exceeds 20%, fungi can cause discoloration of the surface and thus lead to an aesthetic problem. They do not have any influence on the strength of the timber because they do not destroy the cell walls or cause any rotting of the wood. Among the "indigenous" species, Scots pine is most at risk, whereas spruce, fir, and larch suffer less.
External components exposed to the full effects of the weather, e.g. pergolas, non-covered bridges, and components on facades without a significant eaves overhang, can be subjected to a severely fluctuating moisture content. This leads to fissures in the surface of the timber which make it easy for water to penetrate deep into

d5 Chemical wood preservatives are not necessary in heated interiors, provided the building physics conditions are satisfied.

d6

the wood. Long-term saturation and, consequently, fungal attack cannot be ruled out, especially in large-format components. Such effects call for chemical protection measures in most instances. A surface treatment only works when a suitable system is applied with thick coats and careful maintenance because such systems can only be recommended when the timber is not in contact with the soil. In such cases, industrial pressure impregnation of the timber is the only answer. An adequate depth of penetration and fixing of the active substances must be ensured.

d2 12 Insects

The risk of insect attack depends on the species of wood and its nutrients content, and also on the age of the wood and its moisture content. The larvae of insects that attack the essentially dry timber in buildings, e.g. house longhorn beetle, common furniture beetle, etc., prefer slightly moist to dry timber rich in nutrients. The larvae of the house longhorn beetle live primarily in the sapwood zones of softwood. The heartwood of Scots pine and larch is not attacked by insects, and at moisture contents below about 9%, the house longhorn beetle and common furniture beetle cannot survive.

An average timber moisture content of about 9% can be expected in centrally heated, thermally insulated buildings. No measures to protect against insect attack are necessary at such a low moisture content. Possible options are physical protection and coloured finishes not classed as chemical preservatives. If appropriate, inaccessible timber members built into external walls and roofs can be treated to protect against insects, possibly also fungi. Structural timber members in prefabricated wall, suspended floor, and roof systems are usually installed with a moisture content between 9 and 12% and are covered on all sides with further component layers, which means that it is not usually possible for insects to subsequently lay their eggs in these members, and therefore further measures to protect against insect attack are unnecessary.

Structural timber members thicker than about 30 mm in external elements, e.g. pergolas, balconies, and exposed rails, can be treated to protect against the minimal residual risk of insect attack. On the whole, though, the risk of attack in many parts of Central Europe can be regarded as low.

d2 13 Other effects

Compared to other building materials, timber is remarkably resistant to other effects such as chemicals (salts, acids, light bases, and lyes).

d2 20 Constructional (passive) protection

Constructional protection of the timber forms the basis of measures to prevent moisture penetration in the form of water and to prevent fungal attack. It is also an important prerequisite for protection against insect attack, although constructional measures are only partially effective in the battle against wood-destroying insects.

The constructional measures include:

- Protecting the building itself by avoiding overexposed sites and by choosing the best orientation.
- Considering the prevailing direction of the weather when choosing the form of construction and the design of the building.
- Protecting the facade by means of eaves overhangs and projecting elements.
- Employing specific protective measures for sensitive components (e.g. windows) on facades exposed to the worst weather.
- Avoiding direct contact with wet building components and the ground (including splashing water).

(See chapter c3 20 "External cladding" for further information.)

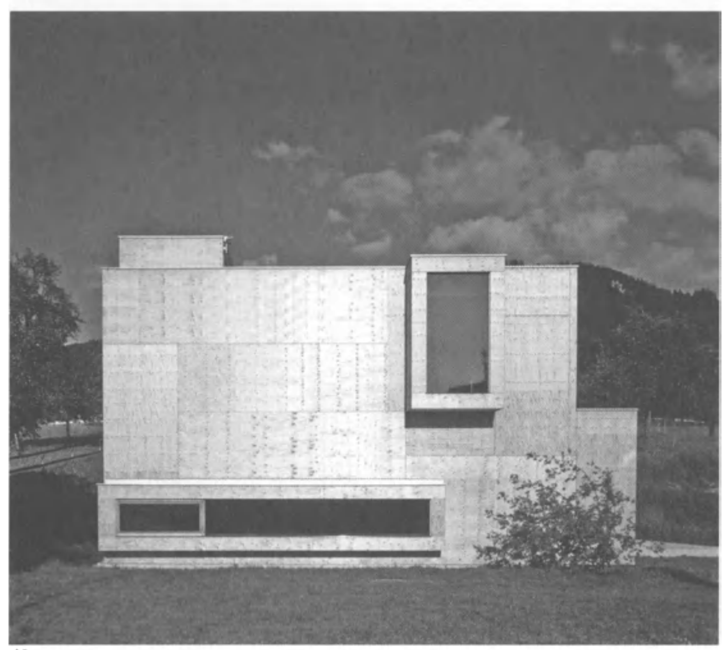
d6 The durability of wooden cladding exposed to the weather can be considerably improved by selecting the right species of wood and form of construction, or by using a pressure-impregnated preservative.

d2 Protecting timber

The most important design-, materials-, and construction-related measures are:

- The choice of the right species of wood, taking into account the timber grading criteria according to relevant standards.
- The use of additional materials to suit the circumstances.
- Guaranteeing an appropriate moisture content during processing and installation.
- Preventing subsequent wetting of the timber by:
- Designing the facade so that precipitation can drain away immediately.
- Preventing water from infiltrating joints and the end grain.
- Avoiding water traps at corners, junctions, recesses, and joints.
- Including a ventilation cavity behind timber members exposed to moisture.
- Preventing meltwater and a build-up of water in and on the roof.
- Ensuring that roofs are properly drained.
- Protecting timber components in contact with other components which have a high moisture content (install damp-proof membranes, especially where rising damp could be a problem).
- Avoiding horizontal components exposed to the weather.
- Taking into account that wood-based products are more vulnerable to moisture.
- Protecting materials during transport and construction (the required protective effects and the measures to be provided must be clearly specified).
- Arranging the building envelope layers in the correct building physics order.
- Providing seals around penetrations and at junctions between different components.
- Performing systematic inspections to ensure good workmanship, especially for those components that are inaccessible in the finished building (insulation, seals).

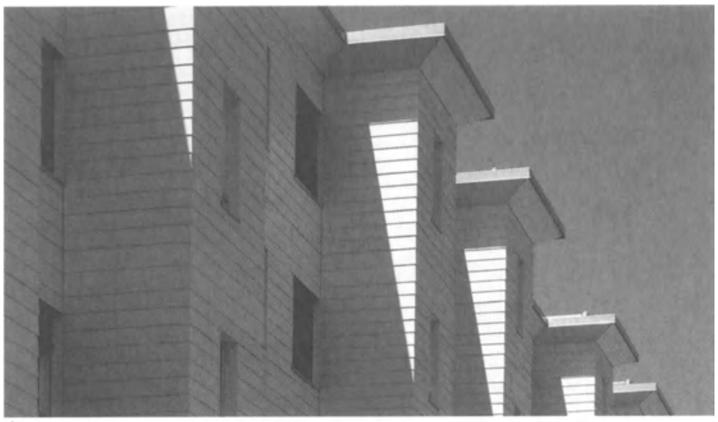
d7



d8

d7 The durability of external wooden cladding is considerably prolonged with good constructional measures.

d8 Constructional protection measures for external wooden cladding become more significant as the degree of exposure to the weather increases.



d9

d2 30 Surface treatments and chemical wood preservatives

d2 31 Preventive chemical protection

If despite design-, materials-, and construction-related measures fungi or insect attack cannot be ruled out, a chemical wood preservative should be employed. This protective treatment includes the surface treatments with wood preservatives described in section d2 32 or the pressure impregnation options also described. Preventive chemical protection is applied according to the degree of the problem or the suspected risks.

Products

Chemical products for protecting timber are based on organic solvents and emulsions, water-soluble protective salts or creosote preparations. As the water solubility and weathering resistance of these products varies depending on their active constituents and formulations, the resulting effects on the wood must be considered. A treatment with boron salt alone, for example, is not rainproof and will be washed out over time. By contrast, an emulsion, depending on its composition, will remain effective even after a period of rain during construction. The prerequisite for this is, however, that the emulsion be completely dry before the timber becomes wet. If the timber is pressure-impregnated properly with salt compounds, creosote or weather-resistant active substances in organic solvents, it will remain protected for a long time, even in the open air.

Safety and health aspects must always be taken into account when using chemical wood preservatives. There may be restrictions on types of application and because of the toxicological effects. Preservatives offering effective protection against insects or fungi contain toxic substances. Measures to protect users as well as plants, animals, and watercourses must be applied when working with such products. If pressure-impregnated timber has been used, correct disposal is essential – in a waste incineration plant with an exhaust-gas scrubber. In principle, chemical products should be used only when such protection is absolutely necessary.

Types of protection

Various types of protective products can be used for preventive chemical protection. The most important are listed below according to the Lignum quality mark [42]:

- B = protects against blue stain
- Iv = protects against wood-destroying insects
- P = protects against wood-destroying fungi that cause brown rot
- W = suitable for wood permanently exposed to the weather, but not permanently in contact with soil or water

Application

Means of protection can be introduced into the timber using various surface treatment or pressure methods. The main differences between the methods are the quantities of material used and the depth of penetration. Critical for the choice of method are the conditions to which the respective timber component are subjected when in use and the degree of protection required.

Surface treatment

On external components, a surface treatment protects the surface of the component against the effects of the weather (precipitation, solar radiation) and against excessive changes in the moisture content due to fluctuations in the climate (temperature and humidity of the air, radiated heat).

The most important types of surface treatment are:

- Impregnations, colourless or lightly pigmented, usually with some form of quality mark depending on the protection against fungi and blue stain (Lignum quality mark P, B), often also as an impregnating primer (B).
- Thin-film glaze coats, lightly to heavily pigmented, usually with some form of quality mark (Lignum quality mark B), film thickness (two coats) approx. 10 to 30 μm (0.01 to 0.03 mm).
- High-build glaze coats, medium to heavily pigmented, total film thickness depends on product and number of coats, usually 40 to 80 μm (0.04 to 0.08 mm).
- Opaque coatings (oil- and water-based paints), total film thickness depends on product, usually 80 to 120 μm (0.08 to 0.12 mm).

d9 The overhanging flat roof protects the external wall.

In order to achieve proper protection of the timber, the quantities specified by the manufacturer must be applied. Perfect compatibility with the subsequent coats is also important. The number of coats (primer, undercoats, finishing coats) depends on the type of coating, the exposure conditions, and the degree of protection required, and is usually between two and four. In most cases a coordinated system using the products of a certain supplier is the preferred approach.
Primer plus first and possibly also further undercoats should be applied in the factory, with the first coat being applied to all sides. Before applying any treatments, all surfaces that will be exposed to the weather later must be sanded, possibly brushed or rough-sawn (fine-cut). The edges and corners of all timber components (boards, slats, sheathing) and additional parts (corner mouldings, cover strips, edge trim, etc.) must be radiused (min. 2.5 mm), and the surfaces must be sanded so that consistent application and good adhesion of the subsequent coats is possible. Treated external cladding systems are now available from specialist suppliers who give guarantees of up to 10 years for their carefully processed and treated products with intact coatings.

Further information on surface treatments for facades can be found in chapter c3 "External walls", in particular section c3 20 "External cladding".

Pressure impregnation
Components exposed to severe weather conditions or those in contact with the ground can be protected against biogenic damage by using pressure impregnation treatments. This method is suitable for components in the open air, e.g. telephone poles, components in contact with the ground, possibly also the structural members of bridges, playground equipment, pergolas, exposed cladding, etc. The advantage of pressure impregnation is that the preservative is applied under pressure in specially built, properly controlled vessels and thus achieves good, long-lasting protection when used properly.

Quality marks

The use of products subject to independent and neutral quality monitoring are recommended for impregntion products, primers, and glaze coats for the surface treatment and pressure impregna-

d10

d11

d10 Chemical wood preservatives are not required when using resistant species of wood (chestnut in this case). Among the indigenous softwoods, those suitable for external cladding are spruce, fur, Scots pine, larch, and Douglas fir.

More resistant species such as redwood, western red cedar, oak or chestnut can be employed on facades exposed to severe weather conditions.

d11 Glaze coat finish, low to medium pigmentation

tion of timber. The types of protection and products with quality marks are described here in sections d2 31 and d2 32.
Quality marks and wood preservative directories are handled differently in different countries. In Switzerland it is primarily the information given in the EMPA/LIGNUM directive [42] that governs. In Germany DIN 68 800 "Protection of timber used in buildings" (parts 1 to 4 are undergoing a major revision) covers both constructional and preventive chemical protection measures, also the risk classes and the quality markings required. This information is summarised in a German publication [40].
A manufacturer applies to have his products tested at the EMPA (a Swiss national materials-testing institute). Suitable products are awarded the LIGNUM approval mark [42]. Both the Swiss Federal Office of Public Health (FOPH) and the Swiss Federal Office for the Environment (FOEN) become involved in testing the toxicological and environmental effects. In Germany the building authority concerned must be provided with proof of a product's effectiveness. Products that satisfy the requirements are awarded a general building authority approval certificate by the German Building Technology Institute (DIBt).

d2 32 Surface treatments with chemical wood preservatives

In principle it is good constructional protection and the right design of details that increase the durability of any surface treatment and hence reduce the need for maintenance. A surface treatment protects the surface of the component against the effects of the weather (precipitation, solar radiation) and against significant moisture content variations (vapour diffusion). This protective task becomes more important as the component becomes more massive. Facade cladding systems are less sensitive in this 'respect, depending on the system of treatment. Window frames, on the other hand, need a high-quality surface treatment because the dimensional stability requirements are much higher. Surface treatments are also the best way of protecting dry structural timber and glued laminated timber against soiling and the effects of moisture.


d12


d13

d12 Glaze coat finish, medium to high pigmentation

d13 Opaque coating, oil- and water-based paints

Glaze coats and impregnating materials

The following overview contains glaze coats and impregnating materials which have a LIGNUM quality mark or CE marking, arranged according to position and risks:

- Coats with active substances are not required for structural timber members in the interior nor for accessible structural timber members in roofs and basements. A coating material without any active substances may be applied to protect dry wood against moisture and soiling during construction if necessary.
  > Lignum quality mark: preservative type O

- Inaccessible structural timber members in roofs and basements.
  > Lignum quality mark: preservative type Iv
  > CE marking: 1, H

- Timber components in bathrooms, kitchens, indoor swimming pools with poor ventilation, covered assemblies.
  > Lignum quality mark: preservative type B, plus possibly P or F
  > CE marking: possibly 2, B

- Undersides of roofs and cladding protected from the weather, and if a surface treatment is applied, then a coating material with resistance to blue stain is recommended.
  > Lignum quality mark: preservative type B

- Balcony components beneath the eaves overhang, structural timber members in open sheds, protected windows, structural timber members in roofs.
  > Lignum quality mark: preservative type B, Iv
  > CE marking: possibly 2, B, H

- Loadbearing structures, suspended floors, floors in damp basements.
  > Lignum quality mark: preservative type P, Iv
  > CE marking: 2, H

- Unprotected wooden facade panelling, thin balcony components, and fence laths (small cross-sections), provided a surface treatment is desirable.
  > Lignum quality mark: preservative type B, W

- Structural timber members outdoors, e.g. pergolas (not in contact with the ground).
  > Lignum quality mark: preservative type P, W
  > CE marking: 3

- For balconies, bridge beams, glued laminated timber constructions, noise and privacy screens without constructional protection, a surface treatment is only adequate in conjunction with careful maintenance, otherwise immersion (windows) or pressure impregnation must be used.
  > Lignum quality mark: preservative type P, B, Iv, W
  > CE marking: 3, B, H

Lignum quality mark: used in Switzerland in particular according to the EMPA/LIGNUM directive [42], see also section d2 31.
CE product marking to draft standard EN 599: Durability of wood and wood-based products:
1–4 = risk classes; class 2 and higher always includes protection against wood-destroying fungi
B = blue stain; H = house longhorn beetle; F = product tested in field trials

d2 33 "Biological" surface treatments

In discussions surrounding chemical wood preservatives and protective paints, the terms "natural", "biological", and "alternative" crop up again and again in connection with products. If such products are indeed suitable (and there certainly are some!), these "biological" wood preservatives can represent alternatives to conventional products. Terms like "natural" or "biological" are, however, decidedly non-specific and can also be misleading. These products include, for example, wood tar, wood vinegar (toxicity class 3!), beeswax, borax solutions, and even ethereal oils. It cannot be denied that protecting wood effectively against biotic pests, i.e. against living organisms, always requires the use of some form of poison. And this can also be the case with natural products.
No assessments or recommendations regarding the use or handling of "biological" wood preservatives can be given at this point because neither their effectiveness nor their compatibility with humans, plants, and animals has been adequately clarified to date.

The use of more resistant species of wood as well as proven constructional measures can be regarded as a "natural" way of protecting wood. The glaze coats and opaque paints include products based on natural materials which have been available on the market for many decades and have proved their worth.

d2 40 New developments in protecting timber

Wooden facades are used increasingly in the refurbishment of the existing building stock, and for new buildings as well. If these facades remain untreated, and provided the criteria of constructional protection have been properly applied, they represent a form of cladding that needs little maintenance and will last for many years. If, however, these facades are coated for aesthetic reasons, the maintenance interval is shortened and the total cost increases. It is therefore in everybody's interest to lengthen markedly the comparatively short maintenance intervals for wooden facades. More research and development work is already underway to improve substantially the properties profile, especially the durability of timber elements exposed to the weather. Some potential solutions are already available.

d2 41 Nanotechnology

Nanotechnology involves using very small parts from physics, chemistry, and biology, and has a wide range of applications. A length of one nanometer (nm), one-billionth of a metre, is difficult to grasp; if we imagine 1 m stretched to 100 km, then 1 nm at that scale is roughly equal to the thickness of a pencil line. Tiny parts, which can also be individual atoms, form the foundation of nanotechnology.

Nanotechnology can also be relevant for protecting materials. Products based on nanotechnology are already available in the field of weather protection for timber; they lend the surface of the wood a hydrophobic (water-repellent) characteristic. However, the technology has not yet been fully developed. There are many unknown factors and too little research has been carried out so far – also into the risks, including the health risks [44].

The following are known nanotechnology possibilities for facades as of 2006:

- Hydrophobic timber appears as if untreated and has open pores.
- Timber that has already turned grey with age can still be treated and then rainwater simply runs off the surface in globules; grey surfaces do not then turn black in the rain.
- The hydrophobic, water-repellent effect remains effective for a few years (only) when exposed to the weather, but can be easily recoated with the same product.
- The weather-induced discoloration of wood, particularly the greying with age, is not prevented by this water-repellent impregnation, but is noticeably delayed.

The following issues still need to be researched:

- During intense sunshine, drops of water on horizontal surfaces can act like magnifying lenses and cause blemishes on the wood.
- A hydrophobic coating is on its own insufficient for treating dimensionally stable components because it does not provide a barrier to diffusion (vapour check).
- The effects of renovation work compared to conventional treatments.

Owing to the good experience gained so far, hydrophobic coatings based on nanotechnology can be counted among the promising developments for facade treatments. Better penetration and the combining of a hydrophobic coating with compatible, film-building systems in order to achieve a durable, zero-maintenance coating for timber are the objects of current research studies [45].

d2 42 Heat-treated timber

The heat treatment of timber using various methods has been around for some ten years ThermoWood® is one of the trade names by which this product is known. The annual production capacities for heat-treated timber in Europe now exceed 50,000 m^3. In Switzerland, Austria, and Germany, corresponding products, primarily for timber constructions exposed to the weather, are now being manufactured and marketed.
The heat treatment to improve the quality of the wood involves raising the temperature in several stages up to a maximum of 250°C while excluding oxygen. This treatment, sometimes intensified by adding moisture and increasing the pressure, leads to a chemical change, mainly in those constituents in the wood that attract or bond moisture [45].

Heat treatment has the following positive effects:
- A reduction in the hygroscopic absorption of moisture from the surrounding air (by up to 50%).
- A considerable reduction in shrinkage and swelling movements, and an improvement in the dimensional stability, especially in species of wood that normally exhibit a naturally unfavourable dimensional stability.
- A very much reduced absorption of liquid water through capillary action.
- Improved resistance to organisms (fungi) that destroy or discolour wood.
- Heat treatment represents a technological upgrade for less dimensionally stable hardwoods such as beech.

But heat treatment alters certain features of timber, which could be counted as disadvantages:
- The strength of the timber is lowered, but the stiffness tends to increase; the timber becomes more brittle.
- The splitting resistance and tensile strength perpendicular to the grain decrease; nails need pre-drilled holes, and pull-out failures and splintering are more frequent when working with the wood.
- Acidic, corrosive decomposition products form; corrosion-resistant fasteners must be used in applications where moisture is present.
- The unmistakable smell of burnt wood.
- Depending on the intensity of the thermal degradation, the surface of the wood can turn a medium to dark brown colour; this may be desirable, but does represent a restriction if a lighter colour is preferred.

More recent studies (at EMPA and ETH Zurich) concerning the weathering properties and the behaviour compared to surface treatments can be summarised as follows:
- Weathering phenomena such as greying, erosion of the surface, and fissures occur with heat-treated wood just like with untreated samples, but the onset is less rapid with heat-treated wood.
- Infestation by grey or black mould varieties (e.g. cladosporium) is delayed compared to untreated samples, but cannot be entirely prevented.
- The durability of conventional surface treatments has to be assessed depending on the particular system and product. Owing to the low initial moisture content, application problems can occur, especially with water-based systems. One positive effect is that owing to reduced shrinkage and swelling movements, the coatings are subjected to lower mechanical stresses.

The bibliography includes further publications on the subject of protecting timber [40, 41, 42, 43, 44, 45].

d14

d15

d14 Surface treatment with glaze coat by means of "ASS-Nano-Technologie"

d15 External cladding of heat-treated timber

d3 Fire protection

As a naturally growing material, wood consists mainly of organic carbon compounds and is therefore combustible. In most cases this is a useful property – wood can be burned in a controlled fashion in order to generate energy, heat or light. But if fire gets out of control, it can present a danger to persons and property. According to statistics, every building is affected by a fire once every 100 years on average.
Fire protection regulations specify mandatory rules for the constructions, building components, and building materials used in structures. The regulations reflect different building traditions and legal frameworks but also the insurance technicalities of their respective countries; and in Germany and Austria there are also differences between the individual federal states. In Switzerland in 2004, a national body declared one standard containing 18 fire protection directives to be the obligatory standard for the whole of Switzerland, and this came into force on 1 January 2005.

d3 10 Fire protection in the planning process

The fire protection requirements laid down in laws, standards, and specifications must be taken into account without exception at all stages of design and planning, but also during production, erection, and use. Fig. d16 lists the most important steps during the planning phase and includes brief details of how these fire protection measures can be implemented. The majority of these tasks are inherent to every construction project anyway, regardless of the fire protection requirements. The more complex a building project, the better it is to contact the fire authorities and fire protection specialists at an early stage.

d3 20 Fundamental terms

In structural fire protection we distinguish between two fundamental terms: behaviour during a fire and fire resistance. Behaviour during a fire relates to the building materials, fire resistance to the components or constructions.

Phase	Tasks
Start	
Definition of targets	Description of project Definition of interior layout Definition of use(s)
Contract for project planning client – planner	Definition of tasks Definition of responsibilities Usage agreement
Preliminary project	Specification of volumes, distances to neighbouring buildings, number of storeys, materials
Inquiry/clarification	Clarification of fire protection requirements, preliminary inquiries at the fire protection authority in the case of complex structures
Project	Detailing of the project Drawing up the fire protection concept
Building application	Submission of building application documents and fire protection concept
Checking the building application	Check by the authorities to ensure completeness and conformity with standards
Detailed design	Materials Details (Fire protection) analyses

d16

d3 21 Behaviour during a fire

The behaviour during a fire specifies how a building material reacts in the event of fire, in particular whether it ignites and, if it does, how it burns, and also with respect to the quantity of smoke and fumes it may produce.
Various methods are used to test and classify building materials (Figs. d17 and d18). In Switzerland the deciding factor is the BKZ number (Fig. d17). This number describes the degree of combustibility (1 to 6) and the degree of smoke development (1 to 3) for a building material. Spruce, for example, has a BKZ of 4.3, which is made up of a degree of combustibility 4 (flammable) and a degree of smoke development 3 (low). Besides the Swiss system with its BKZ numbers, there are other classification systems, e.g. according to the German DIN standards [46] or the European EN standards [47] (Fig. d18).

d16 Fire protection in the planning process

Degree of combustibility		Degree of smoke development	
3	highly flammable	1	high
4	flammable	2	moderate
5	not readily flammable	3	low
6q	virtually inflammable		
6	inflammable		

The fire classes (BKZ number) of some building materials	
Timber (spruce, fir)	BKZ 4.3
Wood-based products such as OSB, particleboard, plywood	BKZ 4.3
Rigid expanded polystyrene*	BKZ 5.1
Hardwood (oak)	BKZ 5.3
Wood-block flooring (beech, oak, ash)*	BKZ 5.3
Plasterboard, gypsum fibreboard*	BKZ 6q.3
Mineral wool*	BKZ 6q.3
Steel, concrete, clay bricks, glass	BKZ 6.3

* Products included in the Swiss fire protection register

d17

Behaviour during a fire	
A1, A2	no contribution to fire
B	very limited contribution to fire
C	limited contribution to fire
D	acceptable contribution to fire
E	acceptable behaviour during a fire
F	not approved as building material

Smoke development (s - smoke)		Flaming droplets (d - dropping)	
s1	low	d0	none
s2	moderate	d1	for a limited time only
s3	high	d2	continuous

d18

The EN standards, for example, divide building materials into six different classes for the purpose of behaviour during a fire; added to these are further subdivisions regarding smoke development and flaming droplets/particles. This results in 39 different European classes for classifying building materials. Marginally different criteria apply to floor coverings. The majority of wood-based products and also softwoods fall under European classification D-s2, d0 (acceptable contribution to fire, moderate smoke development, no flaming droplets/particles; Fig. d18).

d17 Classification of building materials according to the Swiss system

d18 Classification of building materials according to EN 13501 [47]

As the test methods and the performance criteria of the individual classification systems cannot be compared with each other, classifications cannot be converted from one system to another. Only the incombustible building materials can be compared: European class A1 is comparable with Swiss class BKZ 6.3, and European class A2-s1, d0 essentially corresponds to Swiss class BKZ 6q.3.
It is to be expected that the European classification will supersede the various national classification systems over the coming years.

d3 22 Fire resistance
Fire resistance criteria

Building components have to provide a certain amount of fire resistance depending on their function and position. Fire resistance is based on one or more fire resistance criteria in order that the required duration of fire resistance is achieved. The components can be made of one or more building materials.
The relevant fire resistance criteria are:

R stability
E integrity
I insulation

The criteria E and I together are relevant for the creation of a fire compartment. The codes therefore have the following meanings:

R loadbearing, no creation of fire compartment (exposed to fire on more than one side)
EI non-loadbearing, creation of fire compartment (exposed to fire on one side)
REI loadbearing, creation of fire compartment (exposed to fire on one side)

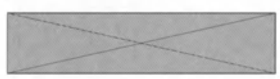
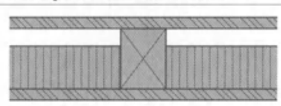
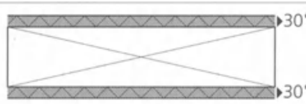
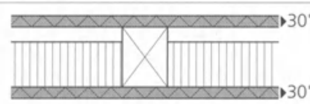
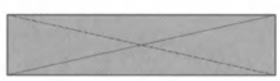
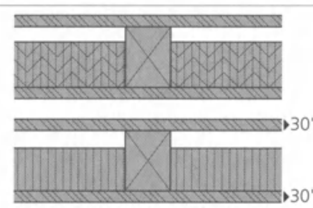
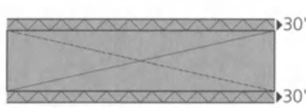
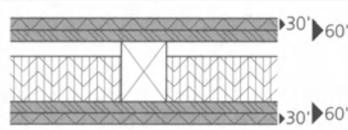
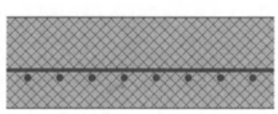
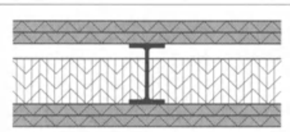
Fire resistance classification

Just as the classification of building materials according to their behaviour in fire differs in different countries, so the classification of building components according to their fire resistance also varies on a national basis to some extent. There are, however, European standards which guarantee that at least the testing of building components is carried out to the same standard throughout Europe.
Behaviour during a fire is totally irrelevant for the fire resistance classification. According to the Swiss fire protection regulations [48], however, the use of combustible building materials is restricted in components required to exhibit fire resistance, which is indicated

by the abbreviation "nbb". In the latest edition of the fire protection regulations, the use of timber is primarily interesting for the 30- and 60-minute fire resistance classes. Fig. d19 shows how such fire resistance specifications can be met with timber.
The German classification according to the DIN standards [46] refers to the type of component, with F standing for loadbearing walls, suspended floors, columns, etc. that form fire compartments, T for doors, G for glazed elements, etc. This designation is then complemented by the building materials class (A, B, or a combination of these) to be used, which also enables the use of combustible materials in fire-resistant components to be restricted. For example, an F 90-A loadbearing fire wall may not contain any combustible constituents.

Progress in research and development has now made it possible to calculate the fire resistance in an increasing number of situations. This results in cost-savings over actual fire tests. EN 1995-1-2 [49] contains a method of calculation to determine fire resistance with respect to the loadbearing capacity and the fire compartmentalisation when using timber components.

The use of timber in the various fire resistance classes

Fire resistance class	Solid cross-section	Compound cross-section	Remarks
R 30 EI 30 REI 30			
R 30 (nbb) EI 30 (nbb) REI 30 (nbb)			Incombustible covering on both sides with 30 minutes fire resistance
R 60 EI 60 REI 60			Combustible insulation covered by material with 30 minutes fire resistance
R 60 / EI 30 (nbb) EI 60 / EI 30 (nbb) REI 60 / EI 30 (nbb)			Incombustible covering on both sides with 30 minutes fire resistance, voids closed off with two layers of covering material with 60 minutes fire resistance Insulating material with BKZ No. 6q.3 at least
R 60 (nbb) EI 60 (nbb) REI 60 (nbb)			No combustible materials

d19

Solid timber
Combustible building material
Incombustible building material
Concrete
Combustible insulating material
Incombustible insulating material
Effective for fire engineering purposes

d19 The use of timber in the various fire resistance classes according to the Swiss Fire Protection Regulations [48]

d3 30 Requirements

Even though European harmonisation of the testing and classification standards for building materials and building components is on the horizon, the use of classified products will remain different in individual countries. This is because the formulation of the requirements for fire protection always depends on the respective legislation and regional circumstances, e.g. access to a certain region, building traditions, or the organisation and availability of local fire brigades. In Germany, fire protection requirements are specified in the building codes of the individual federal states, which usually adopt the provisions of the model building code (MBO) [50]. The MBO allows the use of timber construction up to building class 4, i.e. in buildings in which the level of the topmost floor is a max. 13 m above the surrounding ground level and the size of the individual usage units is max. 400 m^2. The model timber construction directive (M-HFHHolzR) [51] describes the design of timber structures which satisfy the fire protection requirements of building class 4. The directive specifies that building components must exhibit a fire resistance of at least 60 minutes and may not ignite during those 60 minutes.
Deviations are possible if compensatory measures are specified within a fire protection concept. The German publication [52] describes the options here.
Since 1 January 2005, one set of fire protection regulations has been valid throughout Switzerland (VKF 2003). The most important fire protection requirements of these regulations that need to be considered with timber structures are listed in Fig. d20. These may deviate – for the reasons given above – from the provisions in other countries. The following specific detailed requirements are therefore valid in Switzerland only, but the methods and the points to be considered can still be transferred to neighbouring countries.
When using timber in buildings, fire protection requirements regarding the loadbearing structure, the fire compartments, the distances to neighbouring buildings, and the use of combustible building materials must be given particular attention. There are also requirements that apply in the vicinity of building services. What certainly apply in every case, irrespective of the form of construction, are the requirements regarding escape routes.

Loadbearing structure d3 31	Loadbearing capacity in the event of a fire (fire resistance criterion R)
	– loadbearing floors and walls – loadbearing linear components – bracing components – connections
Fire compartments d3 31	Fire resistance of components forming fire compartments (fire resistance criterion EI)
	– floors, walls – doors, barriers – fire stops
Distances to neighbouring buildings d3 32	Safety clearances to nearby structures
Use of combustible materials d3 33	Behaviour in fire of surfaces, insulating materials, and intermediate layers in:
	– external walls – internal walls, suspended and ground floors – roofs – pipes and their insulation
Building services d3 34	Safety clearances and fire resistance in the vicinity of:
	– heating systems – chimneys – flues – ventilation ducts
	Building services installations
	– electrics – plumbing
Escape routes d3 35	Dimensions and layouts of:
	– lengths of escape routes – widths of escape routes – corridors – staircases

d20

d20 An overview of structural fire protection criteria that are most significant for timber engineering and the ensuing requirements: loadbearing structure and fire compartments (d3 31); distances to neighbouring buildings (d3 32); use of combustible materials (d3 33); building services (d3 34); escape routes (d3 35)

d3 31 Loadbearing structure and fire compartments

In terms of fire protection, the loadbearing structure is understood to be all those building components that are required to carry loads, transfer loads, and brace the structure. In timber engineering those can be linear or planar building components plus their associated connections. Loadbearing structures should therefore be designed so that they remain stable in a fire for a certain length of time. This duration of fire resistance, which varies depending on the fire protection concept chosen, is included in fire protection regulations and therefore depends on the number of storeys and the use of the building.

The aim of compartmentalisation is to restrict the spread of fire, to facilitate fire-fighting measures, and to limit damage.
The following should be designed as separate fire compartments:
- each individual storey
- different uses
- adjoining and extensive buildings and complexes
- corridors and staircases that provide a means of escape
- vertical links extending over several storeys (e.g. lift shafts, service shafts)
- plant rooms

Fire compartments are usually separated by fire walls or fire floors. Openings in such compartment-enclosing elements must be closed off with fire-resistant materials and penetrations sealed with fire stops. The fire resistance of the fire wall or fire floor depends on the fire protection concept chosen; it is specified in the fire protection regulations and depends on the number of storeys and the use of the building.

According to the Swiss Fire Protection Regulations [48], the protection targets regarding the loadbearing structure and the fire compartments can be achieved with various concepts:
Standard concepts
- standard constructional concept
- standard sprinkler concept

Project-related concept (exception)

Standard concepts

In the normal case, protection targets are achieved via standard concepts prescribed in the regulations. These are expressed in the form of fire resistance requirements for the loadbearing structure and the fire compartments. The Swiss fire protection regulations [48] specify two different standard concepts – a constructional concept and a sprinkler concept.

Standard constructional concept
The constructional concept allows for the construction of loadbearing structures and compartment-enclosing elements in timber in residential, office, and school buildings with up to six storeys. Buildings with up to three storeys usually require class REI 30 fire resistance, four-storey buildings class REI 60. Sixty minutes is also adequate for the components of five- and six-storey buildings, but in such buildings the coverings to such components must be incombustible and exhibit a fire resistance of at least 30 minutes – fire resistance class REI 60/EI 30 (nbb). Stricter requirements apply to certain uses, e.g. industrial and commercial buildings with a high fire load, hospitals, hotels, and retail premises.
Standard sprinkler concept
In the standard sprinkler concept, sprinklers – provided they are not already required because of the use of the building – may be taken into consideration when specifying the fire resistance of the loadbearing structure and fire compartment components. The reduction in fire resistance compared to the standard constructional concept can be up to 30 minutes, or the incombustible covering of the timber components may be omitted. This approach results in alternatives to the constructional fire protection concept which are also interesting from an economic viewpoint.

Detached houses		
Structure, fire compartments, staircase:	no requirements	Timber construction
Exception: Fire walls between terrace houses	REI 90	Timber construction

d21

d21 to d27 Requirements regarding loadbearing structure and fire compartments according to the Swiss Fire Protection Regulations [48]:
d21 Detached houses
d22 Structures with up to 3 storeys – standard constructional concept for housing, offices, schools
d23 Structures with 4 storeys – standard constructional concept for housing, offices, schools
d24 Structures with 4 storeys – standard sprinkler concept for housing, offices, schools

Structures with up to 3 storeys

Standard constructional concept for housing, offices, schools:

Structure	R 30	Timber construction
Fire compartments	EI 30	Timber construction
Staircase	REI 60 / EI 30 (nbb)	Timber with incombustible covering

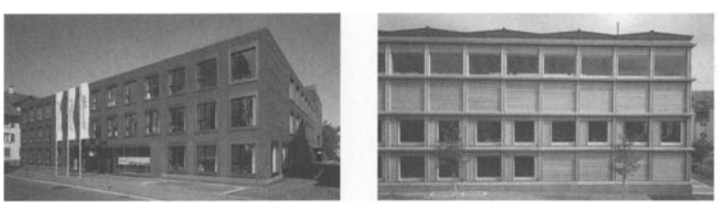
d22

Structures with 4 storeys

Standard constructional concept for housing, offices, schools:

Structure	R 60	Timber construction
Fire compartments	EI 60	Timber construction
Staircase	REI 60 (nbb)	No timber construction

d23



Structures with 4 storeys

Standard sprinkler concept for housing, offices, schools:

Structure	R 30	Timber construction
Fire compartments	EI 30	Timber construction
Staircase	REI 60 (nbb)	No timber construction

d24

Structures with 5 and 6 storeys

Standard constructional concept for housing, offices, schools:

Structure	R 60 / EI 30 (nbb)	Timber with incombustible covering
Fire compartments	EI 60 / EI 30 (nbb)	Timber with incombustible covering
Staircase	REI 60 (nbb)	No timber construction

Specialist engineer, fire protection concept, and quality assurance system required

d25

Structures with 5 and 6 storeys

Standard sprinkler concept for housing, offices, schools:

Structure	R 60	Timber construction
Fire compartments	EI 60	Timber construction
Staircase	REI 60 (nbb)	No timber construction

Specialist engineer, fire protection concept, and quality assurance system required

d26

Structures with project-related concepts

Project-related concept (exception), e.g. for sheltered housing with particular care facilities
Framework conditions in fire protection regulations:

- Alternative measures may be used instead of the measures according to the standard concepts.
- The protection aims must be equivalent.
- The equivalence with the protection aims in the standard concepts must be verified.

d27

d25 Structures with 5 and 6 storeys – standard constructional concept for housing, offices, schools
d26 Structures with 5 and 6 storeys – standard sprinkler concept for housing, offices, schools
d27 Structures with project-related concepts

Project-related concepts

Project-related concepts contain coordinated measures to replace the standard requirements described. Such project-related fire protection concepts enable the constructional, technical, and organisational fire protection measures to be ideally adapted to the boundary conditions and usage requirements of a specific structure. The measures must be equivalent to the standard requirements and must be submitted to the authorities for approval. It is advisable to consult specialists when drawing up project-related fire protection concepts and to specify the framework conditions in good time with fire protection authorities.
Figs. d21 to d27 show examples of buildings classified according to use, concept, and requirements.

d3 32 Distances to neighbouring buildings

Besides the distances to boundaries required by construction law, the fire protection regulations also specify distances to neighbouring buildings to help prevent the spread of fire (Fig. d28). If these distances cannot be maintained, then the walls of the buildings (possibly corners and eaves overhangs as well) will have to satisfy additional requirements. Such additional requirements could be, for example, a fire-resistant construction for the external wall facing the other building, also measures to prevent the spread of fire to combustible surfaces, and the use of fire-resistant materials for windows or doors. The measures to be taken in the case of insufficient safety clearances must always be discussed with the fire protection authorities.

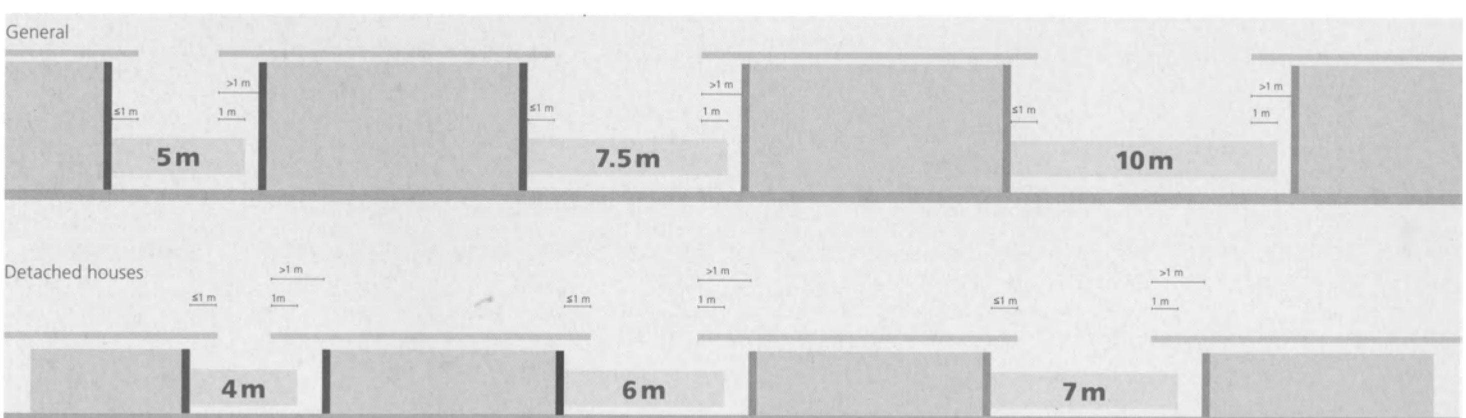
d3 33 Use of combustible building materials

The Swiss Fire Protection Regulations allow the use of combustible building materials only when they do not lead to an unacceptable increase in the fire hazard. Critical for their use is the classification of building materials according to their behaviour in fire (BKZ number or European class, Figs. d17 and d18).
Which requirements regarding behaviour in fire apply to which layer of a building component are specified in the Swiss Fire Protection Regulations [48]. The requirements depend mainly on the use of the building, the number of storeys, and the number of occupants/users. During the design and construction of timber buildings, requirements regarding the behaviour during a fire are primarily relevant for the following building components layers:

- covering materials to floors and walls
- external cladding
- floor coverings
- insulation layers

Apart from escape routes (corridors and staircases), it is generally possible to use timber and wood-based products in the above layers for low- and medium-rise residential, office, and school buildings. The most important exceptions here are:

- Only incombustible insulating materials may be used in buildings with four or more storeys having timber loadbearing structures.
- The use of wooden external cladding on buildings with four or more storeys requires the express approval of the fire protection authorities. Such cladding must not promote the spread of



d28

d28 Distances to neighbouring buildings for fire protection purposes according to the Swiss Fire Protection Regulations [48]

Incombustible external cladding
Combustible external cladding

d29

fire over several storeys, and it will require appropriate constructional measures, e.g. fire stops in the ventilation cavity, aprons to subdivide the facade, or fire-resistant external walls (see Fig. d29 for an example).

d3 34 Building services

Building services installations such as heating systems and chimneys plus any associated flues require special consideration during design and construction.

For example, flues must be inherently fire-resistant or installed in fire-resistant shafts (Fig. d32). In detached houses the requirement for the fire resistance of a flue or its shaft is EI 30 (nbb); in multi-occupancy buildings it is EI 60 (nbb).

One essential point is the maintenance of minimum clearances (safety clearances) between combustible building materials and heating plant or flues. These are specified in the approval documents for the respective installations. Requirements with respect to fire-resistant construction and clearances to combustible materials also apply to ventilation ducts.

d3 35 Escape routes

In the event of a fire, an escape route must provide building occupants/users with a safe path from any point within the building to a place where they can leave the building safely. They also serve to provide access for fire-fighting and rescue services. They must be kept clear at all times and there should be no furniture or other items in such escape routes that could ignite or otherwise hinder the escape of persons.

The number, maximum lengths, and required widths of escape routes are specified in the fire protection regulations. Only incombustible materials may be used for the linings of walls and soffits in escape routes. Combustible materials may in some cases be used for floor coverings but this depends on the use of the building and the number of storeys.

Corridors and staircases forming part of an escape route must be built as separate fire compartments. The walls and the floors above and below a corridor in a timber building may be built from combustible materials, but they must be clad in an incombustible material on the corridor side. The staircase shaft in a timber building with up to three storeys may be built in timber, but in this case it must exhibit a fire resistance of REI 60/EI 30 (nbb). This means that the components of the staircase must have an incombustible covering on both sides and may not contain any combustible insulating materials. Buildings with more than three storeys require a staircase made from incombustible materials.

d29 Multi-storey building with wooden cladding divided into storey heights to prevent the spread of fire

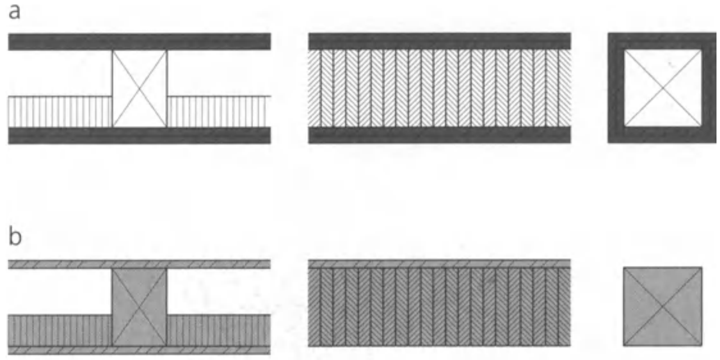
d3 40 Design

d3 41 Components

In principle, two different methods are available for designing building components to satisfy fire resistance requirements, and these are shown in Fig. d30. The fire resistance required can be achieved by using covering materials with a fire protection function (designation according to Swiss Fire Protection Regulations: EI xx; designation according to European standards: K xx). The advantage of this approach is that the inner layers, e.g. insulating materials, loadbearing columns, beams, and ribs, cannot ignite and therefore do not have to satisfy any further fire resistance requirements. Instead of using covering materials with a fire protection function, the fire resistance can be achieved by the construction of the component as a whole. The inner layers therefore also contribute to fire resistance. They must satisfy certain requirements with respect to their thickness and material properties. Such forms of construction are frequently more economic than those in which the fire resistance is provided by the covering materials alone. Fire-resistant components made from timber are described in various publications, e.g. [29]. The fire resistance can also be calculated theoretically by using acknowledged methods of calculation.

d3 42 Junctions

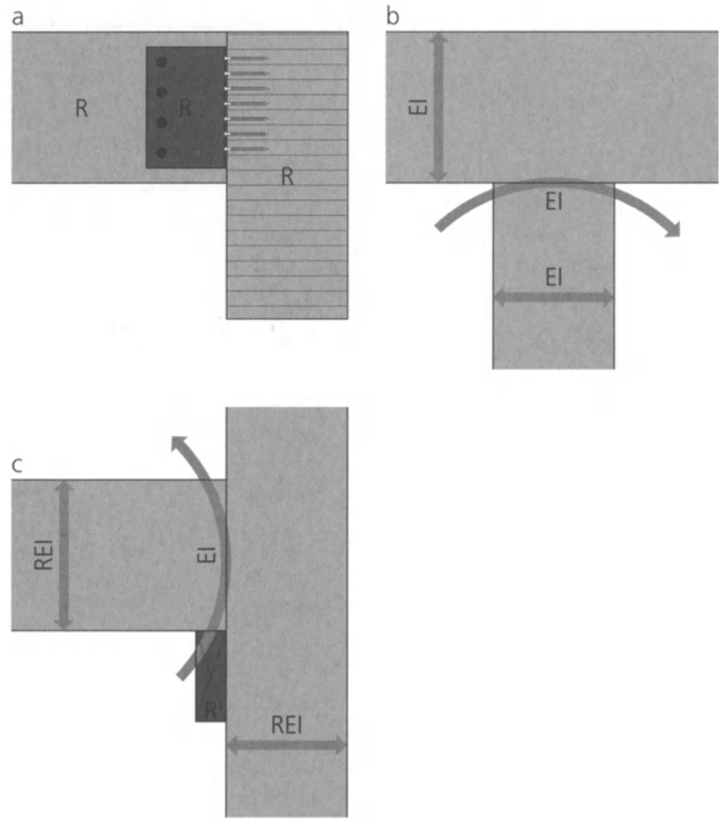
It is the designer's responsibility to ensure that junctions, e.g. supports for fire floors, a junction between a fire wall and the underside of roof, are designed to suit fire protection requirements. Junctions between components have to satisfy the same criteria as the components themselves: loadbearing capacity (R) and compartmentalisation (EI). Suitable measures should be employed to guarantee that the fire cannot spread to another compartment for the specified duration and that the loadbearing capacity of supports remains intact. A selection of junctions is shown schematically in Fig. d31.



d30

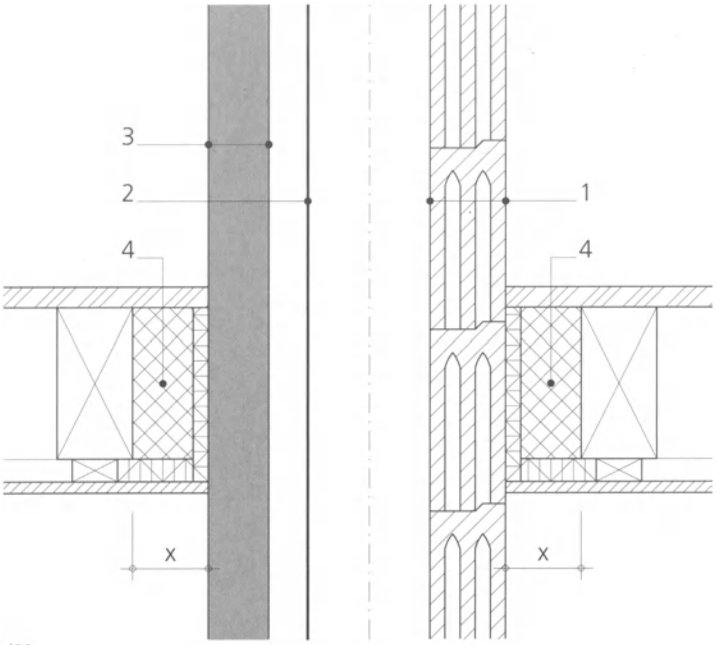
d30 Construction of timber components to suit fire protection requirements; schematic diagrams of:
a) fire resistance provided by fire-resistant covering materials
b) fire resistance provided by component as a whole

- Fire-resistant covering material
- Component layer not contributing to fire resistance
- Component layer contributing to fire resistance



d31

d31 When designing junctions, the criteria R (stability) and EI (integrity and insulation) have to be considered (selection, schematic diagrams)
a R junction, secondary beam/primary beam (loadbearing capacity)
b EI junction (creation of fire compartment)
c REI junction, suspended floor support at external wall (loadbearing capacity and creation of fire compartment)



d32

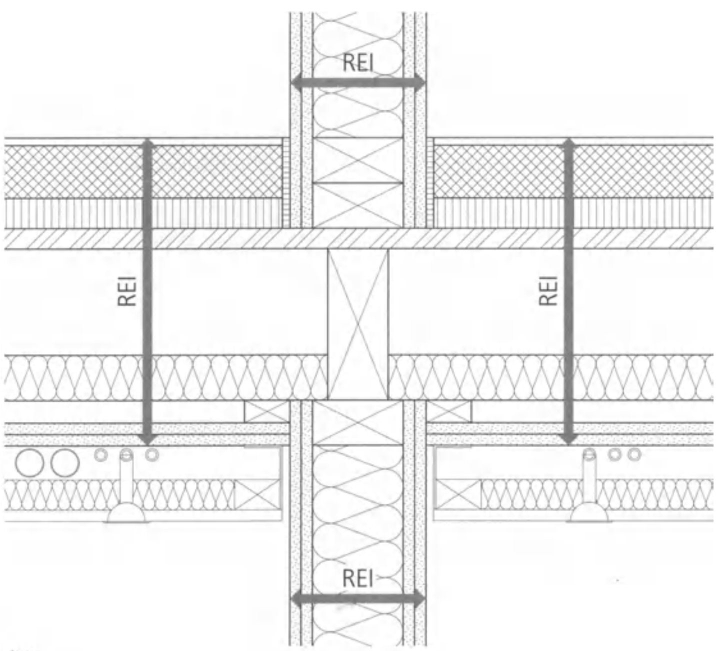
d3 43 Building services

Multi-storey buildings in particular place high demands on the design, fabrication, and installation of building services. The vertical routing of building services over several storeys is achieved by way of ducts and shafts which must be designed as separate fire compartments. When it comes to the horizontal routing, pipes and cables within fire floors and fire walls should be avoided. Good concepts make use of services laid behind wall linings or above suspended ceilings that are ignored in the fire protection concept (Fig. d33). These aspects must be clarified in conjunction with the building services engineers in order to develop an advantageous concept.

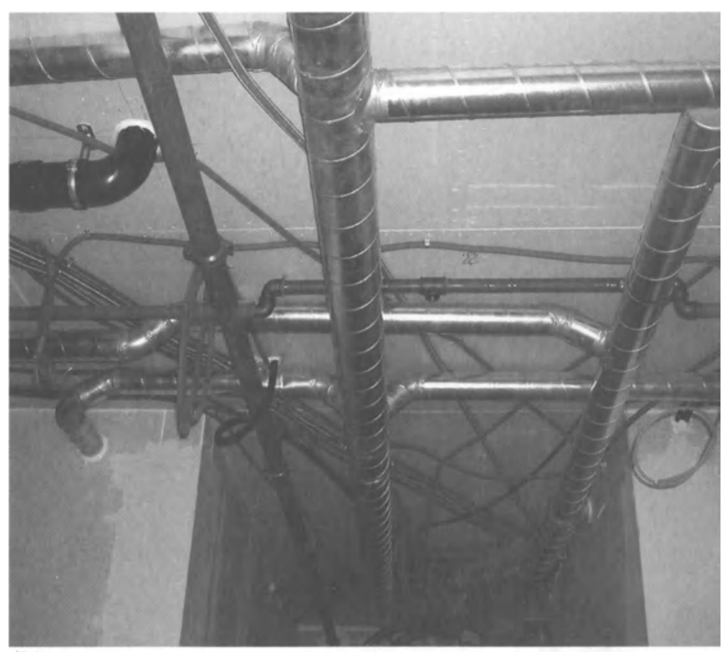
d3 44 Quality assurance

Thanks to technological advances and intensive efforts in research and development, most of the countries in Europe have adapted their current fire protection legislation to suit the opportunities presented by timber construction. For instance, multi-storey, large-volume timber structures with a high level of fire protection have now become possible for many uses. Training programmes offered by the timber industry and the fire protection authorities plus aids in the form of informative, design, and calculation documents for authorities, designers, and users now enable the quality of timber structures to be appraised reliably. There are also many publications available covering the sequence and checking of the various processes in design, manufacture, and use. These are described in section a3 40 "Quality assurance" and in publication [12].

Further information on the subject of fire protection in conjunction with timber construction can be found in the bibliography [12, 29, 30, 31, 32, 46, 47, 48, 49, 50, 51, 52].



d33


d34

d32 Safety clearances (a selection) that have to be considered during design and construction: flue in shaft (left) and fire-resistant flue (right)
1 Fire-resistant flue
2 Non-fire-resistant flue
3 Masonry enclosure or shaft, EI 30 (nbb) or EI 60 (nbb)
4 Fire stop

x = Safety clearance for flues – requirements according to Swiss Fire Protection Regulations [48]: If the required distance to combustible materials according to the approval documents of the flue is 50 mm or less, ceilings, floor finishes, and skirting board may be fitted directly to the flue or shaft.

d33 Horizontal distribution of building services in the void between a suspended floor complying with fire protection requirements and a suspended ceiling not considered as providing any fire protection

d34 Typical application (prior to erecting a suspended ceiling according to Fig. d33)

The new timber engineering

As long ago as the 1930s, Konrad Wachsmann opened his, at that time pioneering, book *Building the Wooden House: Technique and Design* [53] with the following words: "Today, the wooden house is produced by machines in factories, not by the craftsman in his shop. A traditional, highly developed craft has evolved into a modern machine technology; new applications and new forms are being developed."

Wachsmann's words were based on activities that at that time were extremely progressive. He was the architect of Albert Einstein's country home in Caputh near Potsdam, which still stands today. Among his projects were a large children's convalescent home near Spremberg, the building for the Earth Sciences Institute in Ratibor, and offices for the Berlin Public Transport Authority. All these structures were in timber, but in contrast to the customary, rustic forms of construction, Wachsmann realised a form of timber architecture that was based on the principles of the Bauhaus movement. Parallel with his search for new building forms, he did not forget to retain the proven principles of durable timber engineering: overhanging eaves, adequately sized plinths, opaque coatings on particularly exposed and sensitive components such as windows, doors or window shutters. And Wachsmann was not the only one to pursue new paths for timber engineering in those days; Bauhaus founder Walter Gropius and, in Switzerland, the architect and publisher Paul Artaria were both active in this field. Wachsmann, however, was an early and very faithful pioneer of prefabrication and industrialisation in building. His buildings appear fresh and exemplary even today.

In contrast to the general feeling during the 1980s, timber engineering today is once again taking on a leading role, and is regarded more than ever before as a contemporary, forward-looking form of construction. As part of this trend, the modern means of expression for forms, use of materials, and also surface finishes play a role which gives modern timber house-building its striking, independent image. The rational planning and fabrication methods that Wachsmann swore by, combined with the standardisation of details, have become reality, bringing cost-savings and quality benefits with them.

The foundations of modern timber engineering can be attributed to three essential elements:

- Research and development systematically geared to practical uses.
- Companies (and their suppliers) in the timber industry who are receptive to new developments.
- Clients and architects who readily accept new ideas; the architects in turn assisted by specialist timber engineers, timber building companies, and other well-trained specialists.

In addition to these technical accomplishments there is the knowledge that wood is an ideal way of realising an ecological and sustainable cradle-to-grave economy. The basis for every use of wood is the forest. The forest is the starting point for a process that stretches from sustainable forestry to harvesting the raw material to processing and using the forest's products and to returning them to a life cycle which is unique and exemplary. All the stages in this process are inseparably linked with the conditions of sustainable development, linked with ecology, economy and social values, also with the conservation of values. After the end of their useful lives, the materials of timber building components can be recycled. This form of cascade usage should be continued until re-use of the materials is no longer viable. Only then is it justified to use the wood for energy-generation purposes. The CO_2 released during this final process is once again absorbed by the growing forest and the life cycle begins anew.

The wood life cycle has five stages: forest, timber, building, usage, recycling. This book has shown the interfaces between timber, building, and usage, and how timber can be used successfully in contemporary construction. Timber can therefore be a fascinating companion for everybody in the building industry and especially for the occupants and users of timber buildings. In the end it is they and the environment who should benefit from the gratifying developments in timber engineering and the preservation of the value of our forests. Today timber engineering is one of the most efficient forms of building and one that has recaptured its proper place in the modern construction industry – a place that it will hopefully not only retain in the future, but improve upon.

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Appendix

Disclaimer, notes, references

e Disclaimer, notes, references

Disclaimer, notes

The themes in this book relate to the loadbearing structure, the building envelope, and the fitting-out of buildings while taking into account functional and building physics issues. The principles outlined here will help designers and contractors gain a better understanding of how timber loadbearing structures work. There is also specific advice on how to add the other layers of the construction to the loadbearing structure.

Building with timber must be carried out in compliance with laws, regulations, and standards; these are taken into account in this book and in some cases are referred to directly. In principle, the aim is to present the generally applicable state of the art and corresponding forms of construction. This appendix contains the most important German and Swiss standards relevant to timber engineering. The written advice and information, also the drawings, figures, and tables, all relate to specific systems and do not refer to individual projects or structures.
The information given here cannot replace the advice, calculations and analyses of qualified persons that are required for every single construction project. These must therefore be carried out for the respective objects, situation and material by appropriate specialists taking into account the statutory instruments, regulations, standards, etc. applicable in each individual case.

It is the responsibility of the user to interpret and apply the data properly. The publishers, editorial team, and author shall not be liable for any damages that might ensue as a result of using this publication.

Overleaf: Private house in timber panel construction, vertical loadbearing plates in solid timber

e1 References, institutions

1 Winter, W., TU Vienna

2 Steurer, A.: Developments in Timber Engineering. The Swiss Contribution, Birkhäuser, Basel/Boston/Berlin, 2006

3 ETH Zurich, Institute for Building Physics & Building Design: Entwicklung von einem modulartigen Holzbausystem

4 Rauch-Schwegler T. (ed.): Nachhaltig handeln, h.e.p. Verlag AG, Bern, 2005

5 Informationsdienst Holz: Holz Rohstoff der Zukunft, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 2001

6 Informationsdienst Holz: Ökobilanzen Holz, Deutsche Gesellschaft für Holzforschung e.V., Munich, 1997

7 Swiss Federal Office for the Environment: National Forests Inventory, Bern, 1999

8 pro Holz Austria, Vienna

9 TU Vienna

10 Swiss Federal Office for the Environment: Umwelt-Materialien 131, Bern, 2001

11 Lignum: Lignatec, Vernetztes Planen im Holzbau, 1998

12 Lignum: Lignum-Dokumentation Brandschutz, Bauen mit Holz – Qualitätssicherung und Brandschutz, 2005

13 Kolb, J.: Systembau mit Holz (4th ed.), Lignum, Baufachverlag AG, Zurich, 1988

14 German Association of Master Carpenters: Holzrahmenbau, Bruderverlag, Karlsruhe, 2006

15 Swiss Federal Office for Economic Affairs: Holzrahmenbau, Bern, 1985

16 Lignum: Holzbau-Tabellen 1, 2005

17 Lignum: Dokumentation Holz (vol. 2) Bemessungsgrundlagen, Verbindungen und Verbindungsmittel, 1988

18 Herzog, T., Natterer, J., Schweitzer, R.: Timber Construction Manual, Birkhäuser, Basel/Boston/Berlin, 2004

19 SIA D 0122, Hochbaukonstruktionen nach ökologischen Gesichtspunkten, 1995, and SIA D 0122, Ökologische Aspekte des Bauens – Versuch einer gesamtheitlichen Betrachtung, Zurich, 1995

20 Swiss Federal Office for the Environment: Graue Energie von Baustoffen, Bern, 1999

21 Hauser, G., Schulze, H.: Das sommerliche Temperaturverhalten von Einfamilienhäusern (offprint from Ges.-Ing.), 1978

22 EMPA, Building Physics Department: Wärmebrücken von hinterlüfteten Fassaden, EMPA Final Report 158 740, 1995

23 Informationsdienst Holz: Funktionsschichten und Anschlüsse für den Holzbau, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 2004

24 Informationsdienst Holz, : Das Passivhaus – Energie-Effizientes-Bauen, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 2002

25 SIA 181 Sound insulation in buildings, 2006

26 Bösch, H.: Aussenwandverkleidungen aus Holz, SAH Conference Proceedings, 1997

27 Lignum: Lignatec, Flachdachkonstruktionen im Holzbau, 2003

28 Informationsdienst Holz: Flachdächer, Deutsche Gesellschaft für Holzforschung e.V., Munich, 1972

29 Lignum: Brandschutz im Holzbau, laufende Erneuerungen in den Jahren 2006 bis 2010 (current publications can be obtained from www.lignum.ch)

30 Kordina K., Meyers-Ottens C.: Holz Brandschutzbuch, Deutsche Gesellschaft für Holzforschung e.V., Munich, 1994 (revision in progress)

31 Informationsdienst Holz: Grundlagen des Brandschutzes, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 1996

32 Informationsdienst Holz: Brandschutz im Holzbau – gebaute Beispiele, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 2001

33 Swiss Federal Office for Economic Affairs: Impulsprogramm Holz, Schallschutz im Holzbau, Bern, 1988

34 Informationsdienst Holz: Grundlagen des Schallschutzes, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 1998

35 Informationsdienst Holz: Schallschutz, Wände und Dächer, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 2004

36 SIA D 0189: Bauteildokumentation Schallschutz im Hochbau Zusammenstellung gemessener Bauteile, Zurich, 2005

37 Scholl, W., Bietz, H.: Überarbeitung der DIN 4109 mit Hinblick auf den Holz-/ Leichtbau, in: wksb, 54/2005

38 Lignatur AG: Influence of absorber elements, Swiss patent No. 695 318 (2006), Lignatur AG, Waldstadt

39 EMPA, SHIV, SIA, Lignum: Trocknung von Konstruktionsholz, technical information sheet, 1989

40 Informationsdienst Holz: Baulicher Holzschutz, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn / German Association of Master Carpenters, Berlin, 1997

41 Informationsdienst Holz: Konstruktive Vollholzprodukte, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 2000

42 Lignatec 1: Holzschutz im Bauwesen – Empa/Lignum Guideline, Lignum, Zurich, 1995

43 Lignatec 13: Oberflächenschutz von Holzfassaden, Lignum, Zurich, 2005

44 Hett, A.: Nanotechnology: Small Matter, Many Unknowns, Swiss Re, 2004

45 Richter, K.: Neue Materialien und Beschichtungen für den Oberflächenschutz, Schweizer Holzbau 2005/07

46 DIN 4102 Fire behaviour of building materials and building components, Beuth Verlag, Berlin

47 EN 13501 Fire classification of construction products and building elements, CEN, Brussels

48 Vereinigung Kantonaler Feuerversicherungen VKF: Swiss Fire Protection Regulations, Bern, 2003

49 EN 1995-1-2, 2004; Eurocode 5: Design of timber structures; part 1-2: General rules – Structural fire design, CEN, Brussels

50 German Model Building Code (MBO), 2002 edition, IS-Argebau, Conference of Building Ministers (www.is-argebau.de)

51 M-HFHHolzR (model guideline on technical fire protection requirements for highly fire-resistant timber building components), 2004 edition, IS-Argebau, Conference of Building Ministers (www.is-argebau.de)

52 Informationsdienst Holz: Brandschutzkonzepte für mehrgeschossige Gebäude und Aufstockungen in Holzbauweise, Deutsche Gesellschaft für Holzforschung e.V., Munich / Holzabsatzfonds, Bonn, 2005

53 Wachsmann, K.: Building the Wooden House: Technique and Design, reprint of the original 1930 edition, Birkhäuser, Basel/Boston/Berlin, 1995

e Disclaimer, notes, references

e2 Information, databases of manufacturers

General information, databases of manufacturers
Switzerland: Lignum, Zurich, www.lignum.ch
Germany: DGfH, Munich, www.dgfh.de
Austria: proHolz Austria, Vienna, www.proholz.at
UK: TRADA, High Wycombe, www.trada.co.uk
France: CNDB, Paris, www.cndb.org
Netherlands: Centrum Hout, Almere, www.centrum-hout.nl
Denmark: Træbranchens Oplysningsråd, Lyngby, www.top.dk
Norway: Trefokus AS, Oslo, www.trefokus.no
Sweden: Skogsindustrierna, Stockholm, www.skogsindustrierna.org
Finland: Puuinfo Oy, Helsinki, www.puuinfo.fi
USA: APA, Tacoma, www.apawood.org
Canada: Canadian Wood Council, Ottawa, www.cwc.ca
Australia: Forest & Wood Products Australia, Melbourne, www.timber.org.au

Further advice and information
www.woodforgood.com
www.beconstructive.com
www.informationsdienst-holz.de
www.infoholz.de
www.dataholz.com/en

Product information
See also "Products for timber engineering", pp. 318–322
Kaufmann Holz GmbH: www.kaufmann-holz.at
Kronospan Schweiz AG: www.kronospan.ch
Lignatur AG: www.lignatur.ch
Lignotrend Produktions GmbH: www.lignotrend.com
Sägerei Sidler AG: www.sidler-holz.ch
Pavatex SA: www.pavatex.com
Purbond AG: www.purpond.com
Schilliger Holz AG: www.schilliger.ch
SFS intec AG: www.sfsintec.biz
Stora Enso Timber: www.storaenso.com/timber

Information, databases of manufacturers, updates
Josef Kolb AG: www.kolbag.ch, www.holzbaumitsystem.ch,
www.timbersystems.info

e3 Regulations, standards, technical information sheets, aids

e3 10 Switzerland

SIA standards
(Swiss Engineers & Architects Association, Zurich)
SIA 118, 1977, 1991: General conditions for building works
SIA 118/265, 2004: General conditions for timber building works

SIA 180, 1999: Thermal performance and moisture control in buildings
SIA 181, 2006: Sound insulation in buildings

SIA 232, 2000: Pitched roofs
SIA 233, 2000: External walls with cladding

SIA 260, 2003: Basis of structural design
SIA 261, 2003: Actions on structures
SIA 261/1, 2003: Actions on structures – Supplementary specifications
SIA 265, 2003: Timber structures
SIA 265/1, 2003: Timber structures – Supplementary specifications
(revision in progress)

SIA 380/1, 2001, 2007: Thermal energy in buildings

SIA D 0185, 2003: Holzbau – Einführung in die Norm SIA 265
SIA D 0189, 2005: Schallschutz im Hochbau – Zusammenstellung gemessener Bauteile

VKF
(Association of Cantonal Fire Insurers, Bern)
Swiss Fire Protection Regulations VKF, 2003, with fire protection standard and fire protection guidelines
Swiss Fire Protection Register, VKF, published annually

Lignum
(Lignum, Zurich)
Lignum fire protection publications, Lignum, Zurich:
- Lignatec, Bauten in Holz – Brandschutz-Anforderungen, 2005
- Bauen mit Holz – Qualitätssicherung und Brandschutz, 2005
- Bauteile in Holz – Decken, Wände und Bekleidungen mit Feuerwiderstand, 2007
- Bauteile in Holz – Konstruktion REI 90 für REFH, 2007
- Haustechnik und Abschottungen – Brandschutzlösungen, 2008
- Aussenwände – Konstruktion und Bekleidung, 2008
- Abschlüsse – Tür- und Trennwandsysteme, 2008
- Abschlüsse – Brandschutzfenster EI30, 2007
- SIA/Lignum-Dokumentation 83: Brandschutz im Holzbau, Lignum, Zurich, 1997

Lignatec, technical information publications, Lignum, Zurich:
- Holzschutz im Bauwesen, EMPA/Lignum-Richtlinie, 1995
- Holz, ein ökologischer Rohstoff, 1996
- Vernetztes Planen im Holzbau, 1998
- Fassadenverkleidungen aus unbehandeltem Holz, 1999
- Holzfaser-Produkte, 2000
- Oberflächenschutz von Holzfassaden, 2001
- Fachdachkonstruktionen im Holzbau, 2003
- Minergie und Holzbau, 2003
- Innenbekleidungen, 2006
- Massivholzbau, 2007

Holzbautabellen, HBT 1 Handbuch für die Bemessung, 2005

e3 20 Germany

DIN standards
(Deutsches Institut für Normung e.V., Berlin, and Beuth Verlag, Berlin)
DIN 1052, 2004: Structural use of timber
DIN 4102-4, 1994: Fire behaviour of building materials and building components; Synopsis and application of classified building materials, components and special components
DIN 4102-4/A1, 2004: ditto, Amendment A1
DIN 4108, 1982-2006: Thermal insulation in buildings (various parts, supplements, amendments, and corrigenda); 2006: various parts available as drafts or new editions
DIN 4109, 1989: Sound insulation in buildings (various parts, supplements, amendments, and corrigenda); 2006: various parts available as drafts
DIN 68800-2, 1996: Protection of timber; preventive constructional measures in buildings
DIN 68800-3, 1990: Protection of timber; preventive chemical protection (DIN 68800 parts 1 to 4 are currently undergoing revision, specific proposals discussed in 2006)

Informationsdienst Holz
(DGfH, Deutsche Gesellschaft für Holzforschung – German Society of Wood Research, Munich, and Holzabsatzfonds, Bonn)
1996: Grundlagen des Brandschutzes
1997: Baulicher Holzschutz
1997: Ökobilanzen Holz, Fakten lesen, verstehen und Handeln
1998: Grundlagen des Schallschutzes
1998: Holzskelettbau
1998: Holzrahmenbau
1999: Holz-Glas-Fassaden
2000: Holzbau und die Energiesparverordnung
2000: Konstruktive Vollholzprodukte
2001: Holz, Rohstoff der Zukunft, nachhaltig verfügbar und umweltgerecht
2001: Brandschutz im Holzbau – gebaute Beispiele
2001: Modernisierung von Altbauten
2002: Das Passivhaus – Energie-Effizientes-Bauen
2002: Innovative Haustechnik im Holzbau
2002: Holzhäuser, Werthaltigkeit und Lebensdauer
2004: Funktionsschichten und Anschlüsse für den Holzhausbau
2004: Schallschutz, Wände und Dächer
2004: Erneuerung von Fachwerkbauten
2004: Wärmebrückenkatalog – Holzbaudetails (CD)
2005: Fassadenelemente für den Gebäudebestand
2005: Brandschutzkonzepte für mehrgeschossige Gebäude und Aufstockungen in Holzbauweise
2005: Erläuterungen zur DIN 1052: 2004, Entwurf, Berechnung und Bemessung von Holzbauwerken
2006: Trittschallprognose - Software (CD)

Colling, F.: Lernen aus Schäden im Holzbau – Ursachen, Vermeidung, Beispiele, 2000
Kordina K., Scheer, C.: Holz-Brandschutz-Handbuch, 2008

e3 30 European building materials and products standards

EN 302, 2004: Adhesives for loadbearing timber structures
EN 338, 2003: Timber structures – Strength classes
EN 350-2, 1994: Durability of wood and wood based products – Natural durability of solid wood
EN 351-2, 1995: Durability of wood and wood-based products – Preservative-treated solid wood
EN 13501, 2002: Fire classification of construction products and building elements

e4 Further reading

Affentranger, C.: New Wood Architecture in Scandinavia, Birkhäuser, Basel/Boston/Berlin, 1997

Ambrozy, H., Giertlova, Z.: Planungshandbuch, Holzwerkstoffe, Springer, Vienna/New York, 2005

Colling, F.: Lernen aus Schäden im Holzbau – Ursachen, Vermeidung, Beispiele, DGfH, Munich, 2000

Friedrich-Schoenberger, M.: Holzarchitektur im Detail, Deutsche Verlags-Anstalt, Stuttgart/Munich, 2003

Gauzin-Müller, D.: Wood Houses. Spaces for Contemporary Living and Working, Birkhäuser, Basel/Boston/Berlin, 2004

Indergand, J-N., Vitacco, S., Sell, J.: Holzhausbau, Qualität + Detail, EMPA, Dübendorf, Lignum, Zurich, Baufachverlag, Zurich, 1998

Krämer, F.: Grundwissen des Zimmerers, Bruderverlag, Karlsruhe, 1998

Meier, U.: Moderne Holzhäuser, Bruderverlag, Karlsruhe, 2004

Meili, M., Peter, M., Vogel, Z.: Schweizerische Hochschule für die Holzwirtschaft, Biel, Niggli AG, Sulgen/Zurich, 2000

Milner, M. W., Bainbridge, R. J.: New Opportunities for Timber Engineering, in: The Structural Engineer, 16/1997

Müller, J. (ed.): Holzschutz im Hochbau, Fraunhofer IRB Verlag, Stuttgart, 2005

Ozelton, E. C.: Timber Designers' Manual (3rd ed.), Oxford, 2002

Pierer, H.: Holzbau in der Steiermark, proholz, Steiermark, 2002

Reiners, H.: Bauen mit Holz – Die besten Einfamilienhäuser, Callwey, Munich, 2001

Ruske, W.: Timber Construction for Trade, Industry, Administration, Birkhäuser, Basel/Boston/Berlin, 2004

SAH (Swiss timber research study group): Brandschutz im Holzbau – Grundlagen, Forschung und Umsetzung, proceedings of 37th training conference, 2005

SAH (Swiss timber research study group): Gebäudehüllen in Holz: Holzfassaden – Aussenwände, proceedings of 36th training conference, 2004

SAH (Swiss timber research study group): Holzbau mit System, proceedings of 29th training conference, 1997

SAH (Swiss timber research study group): Mehrgeschossiger Holzbau, proceedings of 33rd training conference, 2001

SAH (Swiss timber research study group): Spezielle Bemessungsituation im mehrgeschossigen Holzbau, proceedings of 35th training conference, 2003

Scheer, C., Radovic, B., Peter, M.: Holzbau-Taschenbuch, 10th ed., Ernst & Sohn, Berlin, 2006

Slavid, R.: Holzarchitektur international, Deutsche Verlags-Anstalt, Stuttgart/Munich, 2005

Staufer, A., Hasler, T.: Kantonsschule Wil – ein Holzbauwerk, Niggli AG, Sulgen/Zurich, 2004

Steurer, A.: Developments in Timber Engineering. The Swiss Contribution, Birkhäuser, Basel/Boston/Berlin, 2006

various authors: Mehrgeschossiger Holzbau in Österreich, proholz, Vienna, 1999

von Büren, C.: Prix Lignum, Baufachverlag, Zurich, Lignum, Zurich, 2000

Winter, W., Schöber. H., Bednar, T.: Holzbauweisen im verdichteten Wohnungsbau, Fraunhofer Verlag, Stuttgart, 2005

e5 Picture credits

Aerni, G., Zurich, Switzerland, b413, b434
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Makiol + Widerkehr, Beinwil, Switzerland, b410, d34
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Meier, B., Studio f. Werbefotografie, Sursee, Switzerland, b76
Metron Architektur AG, Brugg, Switzerland, b29
Meyer, D., Lucerne, Switzerland, b280
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Roos Architekten GmbH, Rapperswil, Switzerland, c2
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Seiser Alm Hotel, Urthaler, Italy, b230
Sidler Sägerei AG, Oberlunkhofen, Switzerland, b219, b220, b398, b411
Simonetti, F., Brunate, Italy, b221
Sprenger, L., Dresden, Germany, b205
Stamoid AG, Eglisau, Switzerland, c126, c127
Staufer & Hasler, Frauenfeld, Switzerland, b172
Steko Holz-Bausysteme AG, Uttwil, Switzerland, b19, b251
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Thoma Holz GmbH, Goldegg, Austria, b228, b229, b373
Tschopp Holzbau AG, Hochdorf, Switzerland, c145
Vial SA, Le Mouret, Switzerland, b150
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Winkelmann Architekturbüro, Murten, Switzerland, b323
Wodego AG, St. Gallen, Switzerland, b24
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Zimmermann, R., Zurich, Switzerland, b238
Zumbühl, R., Arlesheim, Switzerland, b42

e6 Construction projects featured in photographs

p. 9, a26 Palais de l'Equilibre, Expo 2002, Neuenburg, Switzerland; Arch.: Groupe H, Meyrin, Switzerland

a2, a7 Private house, Lude-Hopf, Stuttgart, Germany; Arch.: Hartwig N. Schneider, Stuttgart, Germany

a4, b31 School building and multipurpose facility, St. Peter, Switzerland; Arch.: Conradin Clavuot, Chur, Switzerland

a5 ViTa, University Hospital, Tübingen, Germany; Arch.: MGF Architekten, Stuttgart, Germany

a6 Boat-house, Minneapolis Rowing Club, USA; Arch.: VJA Architects, Minneapolis, USA

a9 Representation offices of the Federal State of North Rhine-Westfalia in Berlin, Germany; Arch.: Petzinka Pink Technologische Architektur, Düsseldorf, Germany

a10 School building, Mirecourt, France; Arch.: Architecture-Studio, Paris, and Olivier Paré, France

a11 "EXPODACH" (roof structure), Hannover, Germany; Arch.: Herzog + Partner, Munich, Germany

a12 Industrial building for Trisa AG, Triengen, Switzerland; Arch.: S+P Architekten AG, Reiden & Triengen, Switzerland

a13, d27-1 "Pfrundhaus" sheltered housing, Glarus, Switzerland; Arch.: Herbert Oberholzer, Rapperswil, Switzerland

a14, c87 "Obere Widen" housing estate, Arlesheim, Switzerland; Arch.: Proplaning AG, Basel, Switzerland

a15 Production building for Sirch, Böhen, Germany; Arch.: Baumschlager & Eberle, Lochau, Austria

a16, p. 201, d14, d24-1 "Renggli" mixed residential/commercial development, Sursee, Switzerland; Arch.: Scheitlin – Syfrig + Partner, Lucerne, Switzerland

a17 Room "GA 200", UNO Headquarters, New York, USA; Arch.: mlzd Architekten, Biel & Bucher Bründler, Basel, Switzerland

a18 Fitting-out of library, Zurich University, Switzerland; Arch.: Calatrava Valls, Zurich, Switzerland

a19, a34, a35, a36, p. 37, b125, b127, b172, b347, d24-2 School building, Wil, Switzerland; Arch.: Staufer & Hasler, Frauenfeld, Switzerland

a20, b335 Indoor swimming pool, Bassins, Switzerland; Arch.: Fournier-Maccagnan, Bex, Switzerland

a28 "Vinikus" restaurant, Davos, Switzerland; Arch.: Gigon/Guyer, Zurich, Switzerland

a55 "Winter Garden", Sheffield, UK; Arch.: Pringle Richards Sharratt Architects, London, UK

a56 Offices for Kaufmann, Schwarzach, Austria; Arch.: Hermann Kaufmann, Schwarzach, Austria

a57 Offices for DIE DREI, Dornbirn, Austria; Arch.: Hermann Kaufmann, Schwarzach, Austria

e Disclaimer, notes, references

b27, b251, b302, c96, c99 Private house, Kesswil, Switzerland; Arch.: Ueli Rhiner, Sax, Switzerland

b28 "Le Pommier" residential development, Grand-Saconnex, Switzerland; Arch.: Mecol Architectes, Carouge, and Metron Architektur AG, Brugg, Switzerland

b29 "Bachmatt" housing estate, Schwyz, Switzerland; Arch.: Metron Architektur AG, Brugg, Switzerland

b32, b39 Private house, Gasser Stokar, Rumein, Switzerland; Arch.: Gion A. Caminada, Vrin, Switzerland

b33 Funeral parlour, Vrin, Switzerland; Arch.: Gion A. Caminada, Vrin, Switzerland

b40 Private house, Walpen, Blatten, Switzerland; Arch.: Gion A. Caminada, Vrin, Switzerland

b42 Timber-frame buildings, Thayngen, Switzerland

b59 13 "Cube Houses", Karlsruhe, Germany; Arch.: evaplan, Dagmar Zschocke, Karlsruhe / Gilbert + Holzapfel, Karlsruhe, Germany

b63 FME student accommodation, Lausanne, Switzerland; Arch.: Christian J. Golay, Lausanne, Switzerland

b64 Scout troop accommodation, Baregg, Switzerland; Arch.: Meier Rolf & Leder Martin Architekten, Baden, Switzerland

b76 UNICA concept house, Baldegg, Switzerland; Arch.: Renggli AG, Sursee, Switzerland

b108 Private house, Tschudi, Nussbaumen, Switzerland; Arch.: BEM-Architekten, Baden, Switzerland

b109 Semi-detached houses, Küsnacht, Switzerland; Arch.: Burkhalter Sumi, Zurich, Switzerland

b116, b384 Private house, Schweizer, Rüschlikon, Switzerland; Arch.: Künzli Holz AG, Davos, Switzerland

b120 "Im Raiser" residential development, Stuttgart-Zuffenhausen, Germany; Arch.: Kohlmayer Oberst Architekten, Stuttgart, Germany

b121 Private house, Maurer, Langenthal, Switzerland; Arch.: Thomas Maurer, Langenthal, Switzerland

b126 Private house, Simmen, Brugg, Switzerland; Arch.: Architektengemeinschaft 4, Aarau, Switzerland

b144, b147, b150 School of Forestry, Lyss, Switzerland; Arch.: Itten + Brechbühl AG, Bern, Switzerland

b154 Sports Centre, Haag, Switzerland; Arch.: Schlegel + Hofer, Architekten AG, Trübbach, Switzerland

b158, b161, p. 285 Industrial building for Interpars AG, Schönenberg, Switzerland; Arch.: Forster & Burgemer, Kreuzlingen, Switzerland

b164 School media library, Küsnacht, Switzerland; Arch.: Betrix & Consolascio Architekten AG, Erlenbach, Switzerland

b192 Private house, Seiz, Zug, Switzerland; Arch.: plan.b, Roland Burkard, Zug, Switzerland

b205 Hellerau studios building, Dresden, Germany; Arch.: Haller, Morgenstern, Quincke, Dresden University, Germany

b207, b208 "Wolkenstein" housing development, Meran, Italy; Arch.: Holzbox Tirol, Innsbruck, Austria

b209 Private house, Kopf, Au, Austria; Arch.: Hermann Kaufmann, Schwarzach, Austria

b210 Mixed residential and commercial development, Schenna, Italy; Arch.: Höller & Klotzner, Meran, Italy

b213 State-run nursery, Heilbronn, Germany; Arch.: Bernd Zimmermann, Heilbronn, Germany

b221 Camanna da Tschierva, Val Roseg, Switzerland; Arch.: Hans-Jörg Ruch, St. Moritz, Switzerland

b230 "Seiser Alm" Hotel, Urthaler, Italy; Arch.: Tacus & Didoné, Bozen, Italy

b238 Private house, Rigistrasse, Cham, Switzerland; Arch.: HWP Architekten AG, Hünenberg, Switzerland

b255 Semi-detached houses, Munich, Germany; Arch.: Borkner Feinweber Tellmann, Munich, Germany

b262, b263 Houses, Cardada, Locarno, Switzerland; Arch.: Mario Botta, Lugano, Switzerland

b269 Trade fair building, Nuova Fiera, Rimini, Italy; Arch.: gmp – von Gerkan, Marg + Partner, Hamburg, Germany

b280 "Oberhusrain" apartment blocks, Kriens, Switzerland; Arch.: Lengacher + Emmenegger, Lucerne, Switzerland

b281 Outbuildings (abattoir building and two cowsheds), Vrin, Switzerland; Arch.: Gion A. Caminada, Vrin, Switzerland

b282 Residential development, Trondheim, Norway; Arch.: Brendeland & Kristoffersen Arkitekter AS, Trondheim, Norway

b283 Residential development, Hofsteigstrasse, Wolfurt, Austria; Arch.: Hermann Kaufmann, Schwarzach, Austria

b284 Industrial building partly converted into residential accommodation, Aarau, Switzerland; Arch.: bkf architektur ag, Zurich, Switzerland

b285 Ice rink, Winterthur, Switzerland; Arch.: Ulrich Isler, Winterthur, Switzerland

b311 Private house, Dorfstrasse, Dättwil, Switzerland; Arch.: BEM-Architekten, Baden, Switzerland

b312 Farmhouse, Bever, Switzerland; Arch.: Jachen Könz, Ludovica Molo, Lugano, Switzerland

b323 Sports Centre, Gurmels, Switzerland; Arch.: Grobéty Consortium, Freiburg / Bächler & Fidanza, Freiburg / Winkelmann, Murten, Switzerland

b334 Motorway service depot, Bursins, Switzerland; Arch.: Atelier nivo, Lausanne, Switzerland

b336 Assembly hall, Nyon, Switzerland; Arch.: François Z'Graggen, Nyon, Switzerland b337 Assembly hall, Aubonne, Switzerland; Arch.: Hélium, Penthalaz, Switzerland

b348 Holiday home, Wisconsin, USA; Arch.: VJA Architects, Minneapolis, USA

b349, c86 Public transport information office, St. Gallen, Switzerland; Arch.: Peter Lüchinger, St. Gallen, Switzerland

b380 Two passive-energy houses, Petzberg, Germany; Arch.: Ingo Bucher-Beholz, Gaienhofen, Germany

b385, c95, d22-1 Apartment block, Maienzugstrasse, Aarau, Switzerland; Arch.: Zimmermann, Aarau, Switzerland

b412, d25-1 Residential development, Hegianwandweg, Zurich, Switzerland; Arch.: EM2N Architekten, Zurich, Switzerland

b413, b434 Timber Industry College, Biel, Switzerland; Arch.: Meili & Peter, Zurich, Switzerland

b415, d26-2 Production facility for Peterhans Schibli, Fislisbach, Switzerland; Arch.: Peterhans Schibli, Fislisbach, Switzerland

b416, c40 Office building, Kemptthal, Switzerland; Arch.: Beat Kämpfen, Zurich, Switzerland

b435, b437, b448, d25-2 Private house, Zugerstrasse, Steinhausen, Switzerland; Arch.: Scheitlin – Syfrig + Partner, Lucerne, Switzerland

b436 Apartment block with three residential units, Liebefeld, Switzerland; Arch.: Halle 58 Architekten, Bern, Switzerland

b438 Extension of community centre, Poschiavo, Switzerland; Arch.: Gervasi + Wyss, Poschiavo, Switzerland

b445, d27-2 "Hof" sheltered housing, Speicher, Switzerland; Arch.: Affolter + Kempter, St. Gallen, Switzerland

c1 Passive-house development, Falkenweg, Dornbirn, Austria; Arch.: Johannes Kaufmann, Dornbirn, Austria

c2 "Höcklistein" residential development, Rapperswil, Switzerland; Arch.: Roos Architekten GmbH, Rapperswil, Switzerland

c20, d3 Aalen University, Germany; Arch.: MGF Architekten GmbH, Stuttgart, Germany

c20, d5, d7 Community centre, Ludesch, Austria; Arch.: Hermann Kaufmann, Schwarzach, Austria

c38 Private house, Burgdorf, Switzerland; Arch.: Renggli AG

c89 Temporary hospital wards, Winterthur, Switzerland; Arch.: Heinrich Irion, Winterthur, Switzerland

c92 Private house, Bearth-Candinas, Sumvitg, Switzerland; Arch.: Bearth & Deplazes, Chur, Switzerland

c93 Fire station, Bürglen, Switzerland; Arch.: Keller-Schulthess, Amriswil, Switzerland

c98 "Wartau" sheltered housing, Azmoos, Switzerland; Arch.: Hubert Bischoff, Wolfhalden, Switzerland

c100 Combined fire station and arts centre, Hittisau, Austria; Arch.: Cukrowicz Nachbaur Architekten, Bregenz, Austria

c129 "Bärenhölzli" forestry depot, Kreuzlingen, Canton Building Department, Frauenfeld, Switzerland; Arch.: Imhof + Roth, Kreuzlingen, Switzerland

c131 Terrace houses, Heckenweg, Zollikofen, Switzerland; Arch.: D. Luginbühl and G. Luginbühl, Bern, Switzerland

c143-1, c143-2, d15 Terrace houses, Schönenwerd, Switzerland; Arch.: Sandro Imbimbo, Gretzenbach, Switzerland

d2, d4 Weihenstephan Polytechnic, Freising, Germany; Arch.: Florian Nagler, Munich, Germany

d5, d7 Community Centre, Ludesch, Austria; Arch.: Hermann Kaufmann, Schwarzach, Austria

d6 "Sunny Woods" passive-energy house, Zurich, Switzerland; Arch.: Beat Kämpfen, Zurich, Switzerland

d8 Music society premises, Zwischenwasser, Austria; Arch.: Marte Marte Architekten, Weiler, Austria

d9, d26-1 "Chemin Vert" housing association development, Carouge, Switzerland; Arch.: Favre & Guth SA, Chêne-Bougeries, Switzerland

d10 Private house, Marron, Arlesheim, Switzerland; Arch.: Dorenbach AG Architekten, Basel, Switzerland

d11 "Flüeler" apartment block, Stansstad, Switzerland; Arch.: Scheitlin – Syfrig + Partner, Lucerne, Switzerland

d12 Boarding school, Immensee, Switzerland; Arch.: Herbert Oberholzer, Rapperswil, Switzerland

d13 Kessel nursery, Schaffhausen, Switzerland; Arch.: Reich & Bächtold, Schaffhausen, Switzerland

d21-1 Private house, Pittet-Tardin, Lausanne, Switzerland; Arch.: J. Pittet and B. Tardin, Lausanne, Switzerland

d21-2 "Laubiboden" terrace houses, Liestal, Switzerland; Arch.: Peter Baeriswyl, Basel, Switzerland

d22-2 Offices for Bioforce AG, Roggwil, Switzerland; Arch.: Inauen & Partner, St. Gallen, Switzerland

d23-1 Private house, Lorenzstrasse, Lucerne, Switzerland; Arch.: Hegi Koch Kolb, Zug, Switzerland

d23-2 Private house, Künzli Holz AG, Davos, Switzerland

d29 "Herti 6" residential development, Zug, Switzerland; Arch.: KC/ASTOC Architects & Planners, Cologne, Germany

p. 309 Private house, Lake Zurich, Switzerland; Arch.: Wild Bär, Zurich, Switzerland