European Building Construction Illustrated

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Francis DK Ching
Mark Mulville

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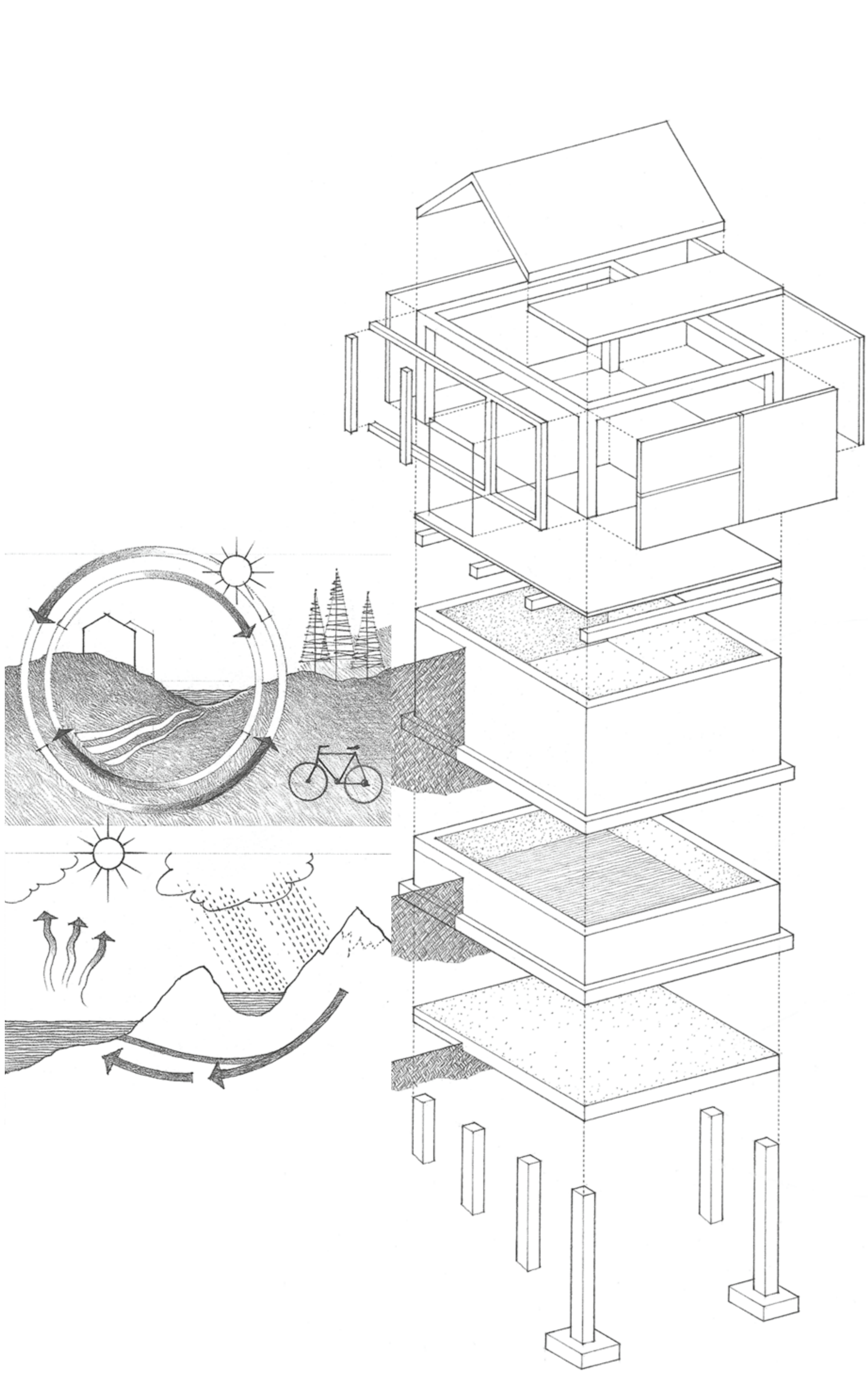


'The realisation of a design intention requires a knowledge of how building materials are assembled in construction and how the resulting construction responds to user needs, contextual fit and environmental forces.'

Francis DK Ching, 2013

First published in 1975, and now just about to go into its fifth edition, *Building Construction Illustrated* is an established classic in the US. Francis DK Ching's clear graphic signature style marks it out as the most accessible visual guide to the basics of building construction. Building on the strengths of Ching's US edition, this first edition of *European Building Construction Illustrated* aims to focus on the construction methods most commonly used in Europe. Some methods used in Europe are similar to those used in North America with simple terminological differences, while others are significantly different in form and application or indeed are governed by regulations that alter the decision-making process, due to impacts on quality, cost and time. It would not be possible to detail the wide variety of construction methods used throughout Europe – which have been heavily influenced by diverse traditions, availability of local materials and climatic conditions – in a single volume. To that end this publication gives an overview of mainstream construction methods in the region while outlining emerging construction methods as driven by the sustainability agenda.

A chapter briefly outlining construction in the Middle East, focusing on the Arab countries bordering the Persian Gulf, has been added. This is a region where the construction industry has been influenced by US and European construction methods and regulatory frameworks. The region is now at the forefront of pushing construction technology to its limits and this in turn is a key driver for innovation in the global construction industry, warranting its consideration if only somewhat succinctly in this case.

The original *Building Construction Illustrated* publications emphasised that 'buildings and sites should be planned and developed in an environmentally sensitive manner, responding to context and climate to reduce their reliance on active environmental control systems and the energy they consume'. This publication maintains this focus, describing and referring to the leading environmental assessment methods of BREEAM® and LEED® while outlining the Passive House Standard, which is of growing importance in the region, and indeed globally. The book takes a 'fabric first' approach to delivering efficient, healthy and comfortable buildings and outlines how thermally efficient and airtight buildings can be delivered.

It would be nearly impossible to cover all building materials and construction techniques, but the information presented herein should be applicable to most residential and commercial construction situations encountered today. Construction techniques continue to adjust to the development of new building materials, products and standards. What does not change are the fundamental principles that underline the approach taken to building elements and the intended function of the systems constructed. This illustrated guide focuses on these principles, which can serve as guidelines when evaluating and applying new information encountered in the planning, design and construction of a building.

Each building element, component or system is described in terms of its end use. The specific form, quality, capability and availability of an element or component will vary with manufacturer and locale. It is therefore important to always follow the manufacturer's recommendation in the use of a material or product and to pay careful attention to the building regulation requirements in effect for the use and location of a planned building. It is the user's responsibility to ascertain the appropriateness of the information contained in this handbook and to judge its fitness for any particular purpose. Seek the expert advice of a professional when needed.

Many of the drawings in this book are by Francis DK Ching and are reproduced from the US fourth edition of *Building Construction Illustrated*. Where relevant to reflect the European content of the book, the original drawings have been adapted or new graphics created, with the aim of maintaining the clarity and style of Ching's original drawing style.

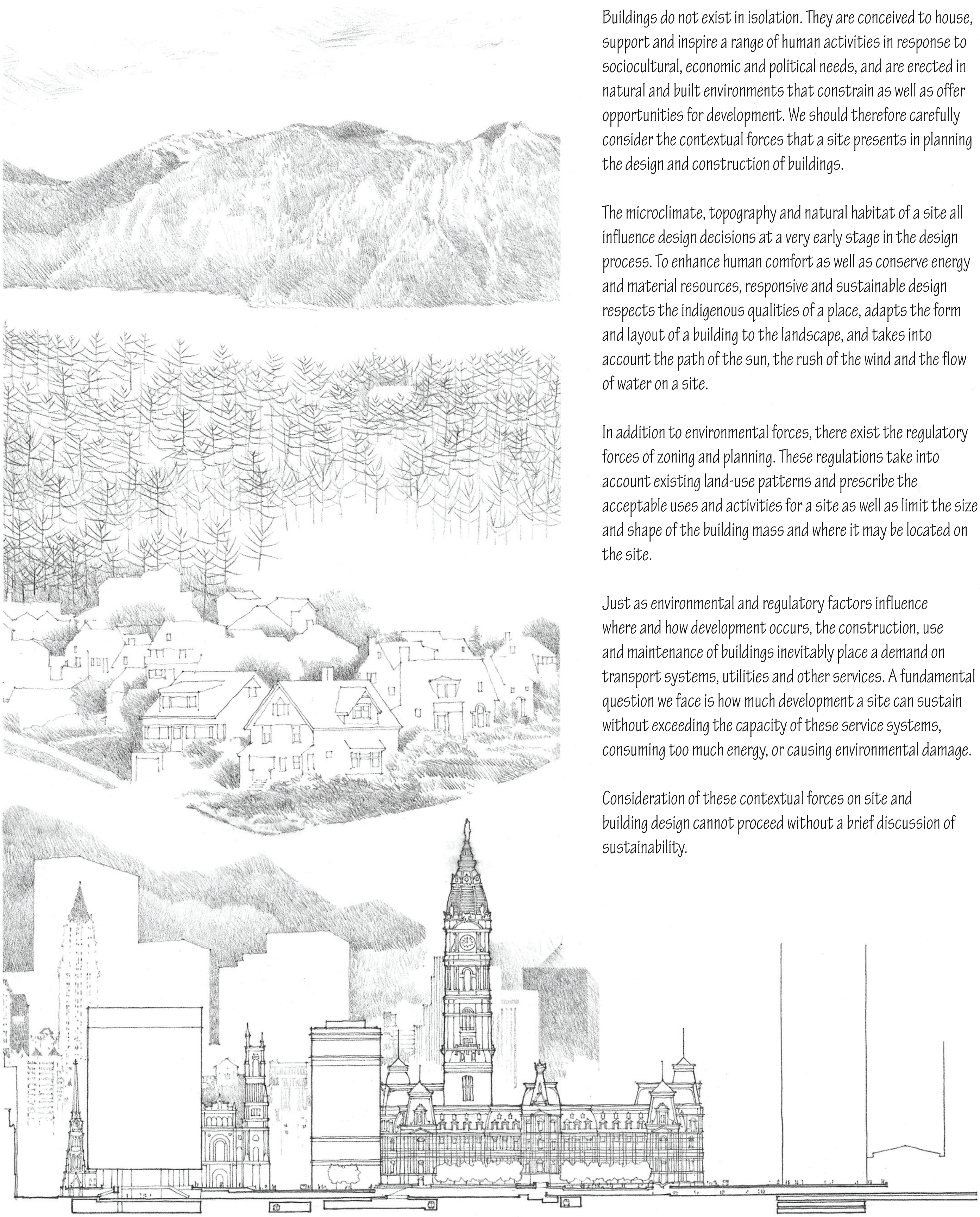
This book would not have been possible without the support, guidance and assistance of a number of people. Thanks must go to Traudel Schwarz-Funke of the University of Sharjah for her expert guidance in the development of the chapter concerning construction in the Middle East. Richard Cooper, Justine Cooper and Anthony Kelly of the University of Greenwich are also owed a debt of gratitude for their support and guidance regarding a number of technical matters throughout the book. Finally thank you to Pat, Cora, Lorna and Yulia for their unending support.

Mark Mulville, 2013

European Building Construction Illustrated
By Francis DK Ching and Mark Mulville

1

THE BUILDING SITE



Buildings do not exist in isolation. They are conceived to house, support and inspire a range of human activities in response to sociocultural, economic and political needs, and are erected in natural and built environments that constrain as well as offer opportunities for development. We should therefore carefully consider the contextual forces that a site presents in planning the design and construction of buildings.

The microclimate, topography and natural habitat of a site all influence design decisions at a very early stage in the design process. To enhance human comfort as well as conserve energy and material resources, responsive and sustainable design respects the indigenous qualities of a place, adapts the form and layout of a building to the landscape, and takes into account the path of the sun, the rush of the wind and the flow of water on a site.

In addition to environmental forces, there exist the regulatory forces of zoning and planning. These regulations take into account existing land-use patterns and prescribe the acceptable uses and activities for a site as well as limit the size and shape of the building mass and where it may be located on the site.

Just as environmental and regulatory factors influence where and how development occurs, the construction, use and maintenance of buildings inevitably place a demand on transport systems, utilities and other services. A fundamental question we face is how much development a site can sustain without exceeding the capacity of these service systems, consuming too much energy, or causing environmental damage.

Consideration of these contextual forces on site and building design cannot proceed without a brief discussion of sustainability.

In 1987, the United Nations World Commission on Environment and Development, chaired by Gro Harlem Brundtland, former Prime Minister of Norway, issued a report, *Our Common Future*. Among its findings, the report defined sustainable development as 'a form of development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

Increasing awareness of the environmental challenges presented by climate change and resource depletion has driven sustainability into becoming a significant issue shaping how the building design industry operates. Sustainability is necessarily broad in scope, affecting how we manage resources as well as build communities and the issue calls for a holistic approach that considers the social, economic and environmental impacts of development and requires the full participation of planners, architects, engineers, surveyors, developers, building owners, contractors and manufacturers, as well as governmental and non-governmental agencies.

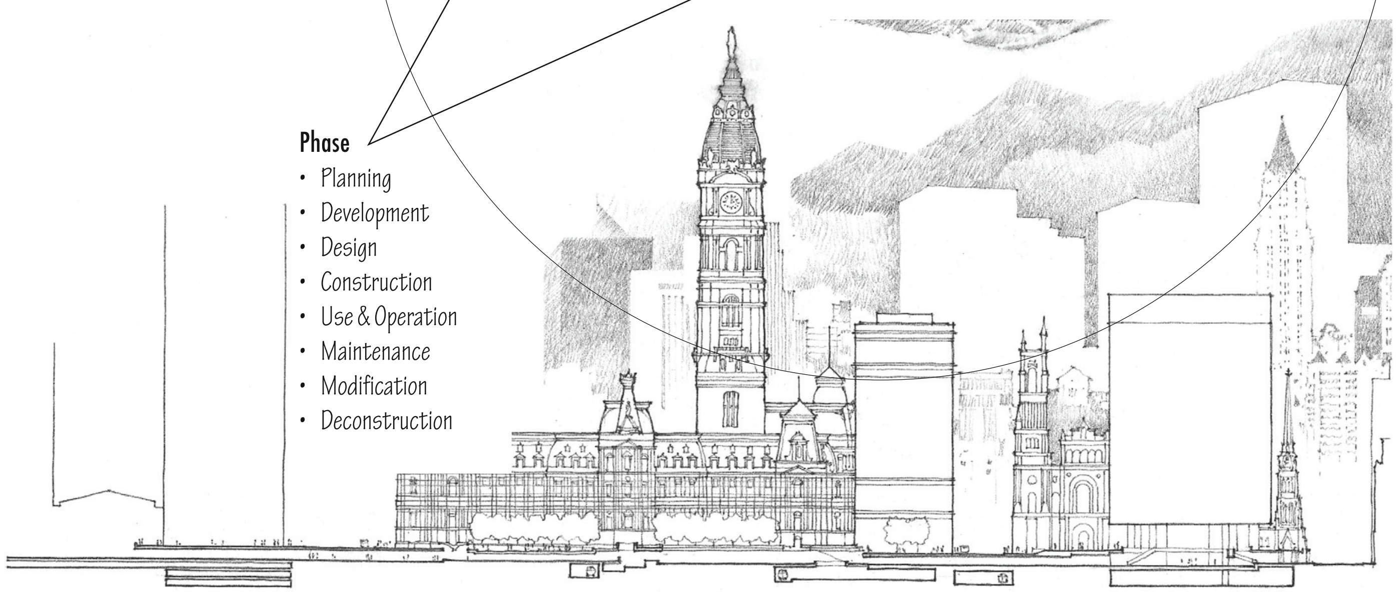
In seeking to minimise the negative environmental impact of development, sustainability emphasises efficiency and moderation in the use of materials, energy and spatial resources. Building in a sustainable manner requires paying attention to the predictable and comprehensive outcomes of decisions, actions and events throughout the life cycle of a building, from conception to the siting, design, construction, use, maintenance, deconstruction and reuse of new buildings as well as the refurbishment process for existing buildings and the reshaping of communities and cities.

Principles
- Reduce resource consumption
- Reuse resources
- Recycle resources for reuse
- Protect nature
- Eliminate toxins
- Apply life-cycle costing
- Focus on quality

Framework for Sustainable Development
In 1994 Task Group 16 of the International Council for Research and Innovation in Building and Construction proposed a three-dimensional framework for sustainable development.

Resources
- Land
- Materials
- Water
- Energy
- Ecosystems

Phase
- Planning
- Development
- Design
- Construction
- Use & Operation
- Maintenance
- Modification
- Deconstruction



1.04 GREEN BUILDING

The terms 'green building' and 'sustainable design' are often used interchangeably to describe any building designed in an environmentally sensitive manner. However, sustainability calls for a whole-systems approach to development that encompasses the notion of green building but also addresses broader social, ethical and economic issues, as well as the community context of buildings. As an essential component of sustainability, green building seeks to provide healthy environments in a resource-efficient manner using ecologically based principles.

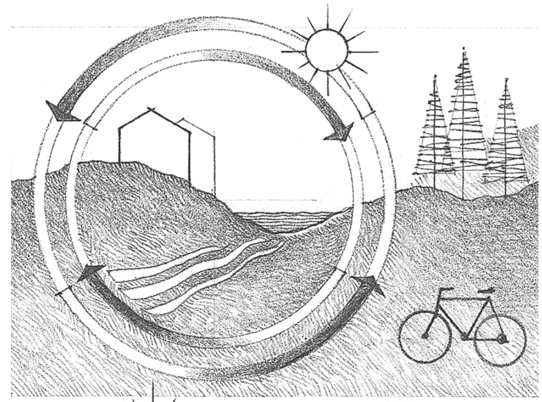
To help drive the green building agenda, the 'sustainability' of buildings is increasingly measured against standards set out within recognised environmental assessment methods. These assessment methods gauge the building's overall performance against a set of measurable criteria. Some such assessment methods or standards focus on specific aspects of sustainability such as environmental impact or energy performance, while others attempt to provide a holistic assessment of the core sustainability issues. The Building Research Establishment Environmental Assessment Method (BREEAM) is one of the longest established and most widely recognised assessment methods in the world. A wide range of similar assessment methods exist within Europe, the European Union's Committee for Standardization is working towards a set of standardised assessment methods for the region building on the European Energy Performance of Buildings Directive (EPBD). The EPBD ensures that the energy use of all domestic and non-domestic buildings within the European Union is assessed when a new building is constructed or an existing building is sold or let, thus allowing for direct comparison of the energy performance between one building and the next.

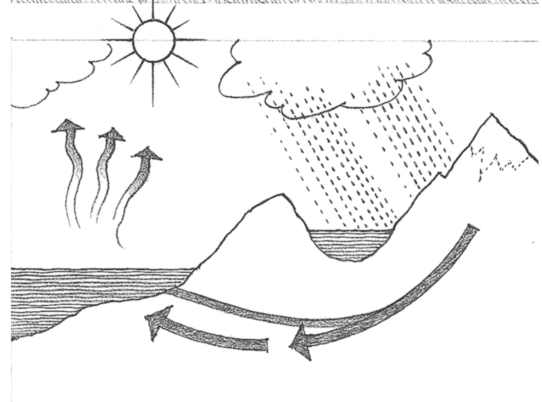
In the UK the Standard Assessment Procedure (SAP) and Simplified Building Energy Model (SBEM) are used to assess the energy performance of domestic and simple non-domestic building respectively producing Energy Performance Certificates (EPC). In accordance with the requirements of the EPBD, public buildings over 1000 m^2 must have a Display Energy Certificate (DEC), which as such is a reflection on the actual energy usage of the building. This is useful as occupant behaviour and building management which are difficult to predict can have a significant impact upon the energy use of a building.

BREEAM®: Building Research Establishment Environmental Assessment Method, first established by the Building Research Establishment (BRE) in 1990, used globally for a range of largely non-domestic buildings.

LEED®: Leadership in Energy and Environmental Design, developed by the US Green Building Council (USGBC), used globally on a wide range of new-build and refurbishment projects.

Both LEED and BREEAM attempt to assess sustainability in broad terms. They consider a wide range of potential environmental impacts associated with the life cycle of the building including materials and embodied energy, building management and waste reduction. Both methods set out a number of criteria for which credits are available. As the project progresses evidence must be gathered to demonstrate how the building complies with the criteria associated with the credits awarded. See 1.05 & 1.06.





First applied in Germany in the early 1990s, the Passive House Standard aims to achieve low energy, comfortable buildings by focusing on the delivery of a high quality, well designed building fabric and appropriate and correctly configured building systems.

This focus on the performance of the building fabric based on a sound understanding of building physics aims to deliver healthy and comfortable internal environments requiring minimum amounts of heating and/or cooling to maintain this comfort. Depending on where the building is to be located some considerations in relation to resources, climatic conditions and building regulation compliance may need to be accounted for.

The application of Passive House principles has helped to improve European construction standards. This is especially true where they have been applied in regions with milder climates where such high levels of thermal performance have not previously been considered. Care must be taken, however, to ensure that in such well insulated buildings overheating does not become an issue. The Passive House Standard does take account of this overheating risk, but some projects may apply Passive House principles without applying the full standard. See 1.08 & 1.09.

BREEAM

The BRE and relevant regional partners have developed a range of assessment methodologies covering a broad spectrum of building and project types in many locations, allowing most non-domestic building to be assessed (domestic buildings are assessed using the Code for Sustainable Homes (CfSH)):

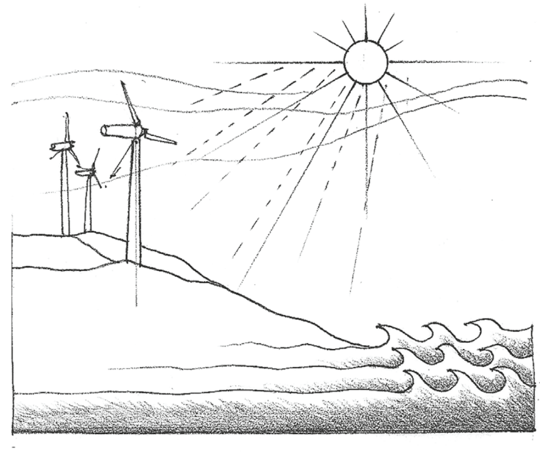
- BREEAM New Construction*
  - Shell and Core
  - Fit-Out
  - Major Refurbishment
- BREEAM Data Centres
- BREEAM Bespoke
- BREEAM Communities
- BREEAM In-Use
- BREEAM NL (The Netherlands)
- BREEAM NOR (Norway)
- BREEAM ES (Spain)
- BREEAM SE (Sweden)
- BREEAM International

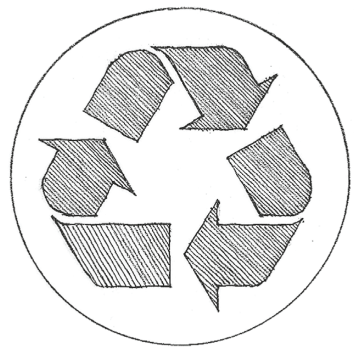
*BREEAM New Construction addresses nine major areas:

1. Management
2. Health & Wellbeing
3. Energy
4. Transport
5. Water
6. Materials
7. Waste
8. Land Use & Ecology
9. Pollution

To try and challenge the industry to deliver innovative solutions, additional credit can also be awarded for 'innovation', allowing for bespoke solutions to unique or challenging problems.

Under the BREEAM rating system each rating has a number of minimum standards that must be met regardless of the overall percentage score in order for a rating to be achieved. For example, in order to gain an 'outstanding' rating, a minimum of 10 credits must be achieved under the section considering the reduction of CO_2 emissions (ENE 01).





Each of the nine areas addressed under BREEAM receives an environmental weighting relative to its importance in delivering a sustainable building. The weighting coupled with the number of credits available for each of the criteria dictates the relative importance or impact of the criteria.

*BREEAM Environmental Weightings:

Management	12%
Health & Wellbeing	15%
Energy	19%
Transport	8%
Water	6%
Materials	12.5%
Waste	7.5%
Land Use & Ecology	10%
Pollution	10%

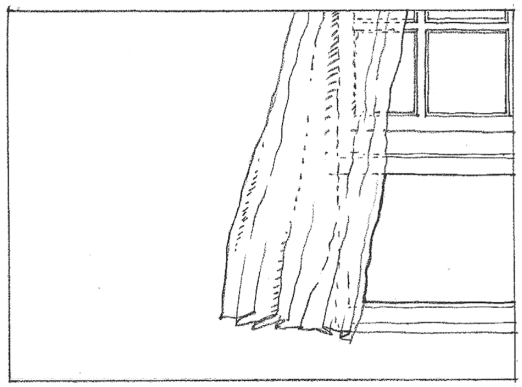
*Possible BREEAM Ratings:

Unclassified	<30%
Pass	30–44%
Good	45–54%
Very Good	55–69%
Excellent	70–84%
Outstanding	85%+

*Source: www.breeam.org

BREEAM® is the registered trademark of the Building Research Establishment Limited

1.06 LEED GREEN BUILDING RATING SYSTEM



LEED

To aid designers, builders and owners to achieve LEED certification for specific building types and phase of a building life cycle, the US Green Building Council (USGBC) has developed a number of versions of the LEED rating system:

- LEED New Construction and Major Renovations
- LEED Existing Buildings: Operations & Maintenance
- LEED Commercial Interiors
- LEED Core & Shell
- LEED Schools
- LEED Retail
- LEED Healthcare
- LEED Homes
- LEED Neighbourhood Development

The LEED rating system for new construction addresses seven major areas of development.

1. Sustainable Sites
Deals with reducing the pollution associated with construction activity, selecting sites appropriate for development, protecting environmentally sensitive areas and restoring damaged habitats, encouraging alternative modes of transport to reduce the impact of vehicle use, respecting the natural hydrology of a site, and reducing the effects of heat islands.

2. Water Efficiency
Promotes reducing the demand for potable water and the generation of wastewater by using water-conserving fixtures, capturing rainwater or recycled greywater for conveying sewage, and treating wastewater with on-site systems.

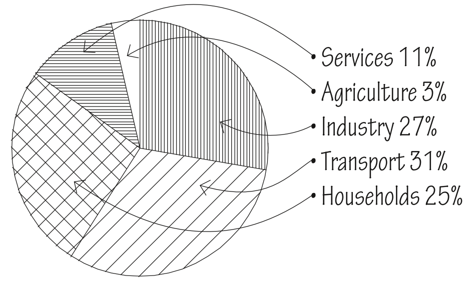
3. Energy & Atmosphere
Encourages increasing the efficiency with which buildings and their sites acquire and use energy, increasing renewable, non-polluting energy sources to reduce the environmental and economic impacts associated with fossil fuel energy use, and minimising the emissions that contribute to ozone depletion and global warming.

4. Materials & Resources
Seeks to maximise the use of locally available, rapidly renewable and recycled materials, reduce waste and the demand for virgin materials, retain cultural resources, and minimise the environmental impacts of new buildings.

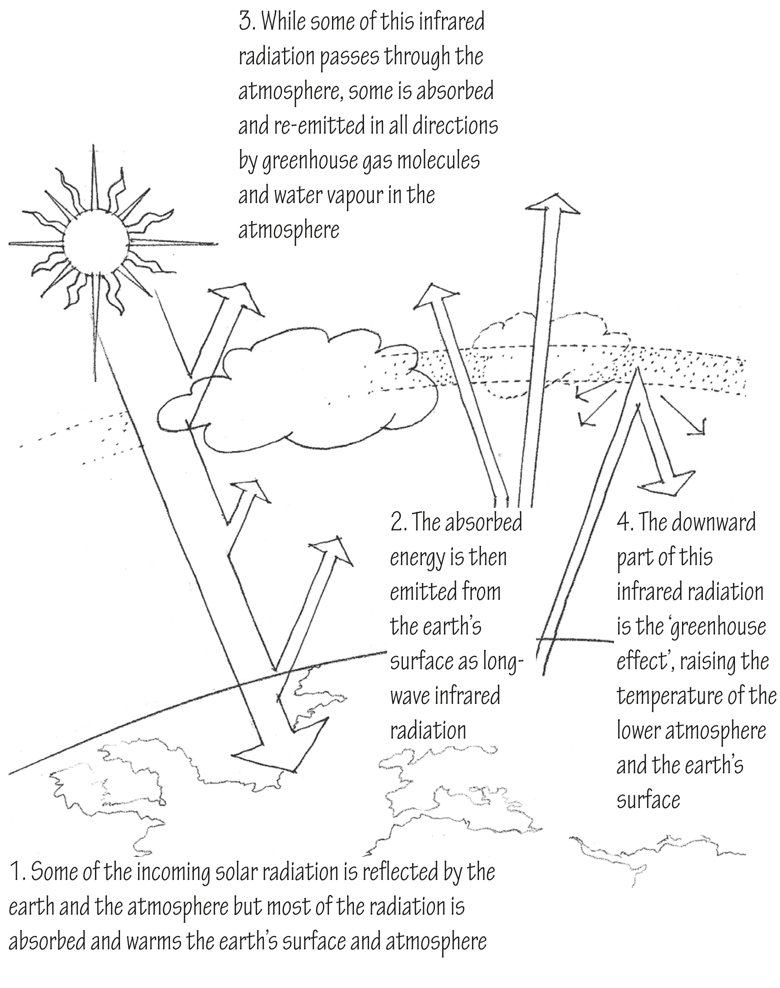
5. Indoor Environmental Quality
Promotes the enhanced comfort, productivity and wellbeing of building occupants by improving indoor air quality, maximising daylighting of interior spaces, enabling user control of lighting and thermal comfort systems to suit task needs and preferences, and minimising the exposure of building occupants to potentially hazardous particulates and chemical pollutants, such as the volatile organic compounds (VOC) contained in adhesives and coatings and the urea-formaldehyde resins in composite wood products.

6. Innovation & Design Process
Rewards exceeding the requirements set by the LEED Green Building Rating System and/or demonstrating innovative performance in Green Building categories not specifically addressed by the LEED Green Building Rating System.

7. Regional Priority
Provides incentives for practices that address geographically specific environmental priorities.



EU–27 Energy Consumption by Sector
European Environment Agency (2012)



Climate Change & Global Warming
Greenhouse gases, such as carbon dioxide, methane and nitrous oxide, are emissions that rise into the atmosphere. CO_2 accounts for the largest share of EU greenhouse gas emissions. Fossil fuel combustion is the main source of CO_2 emissions.

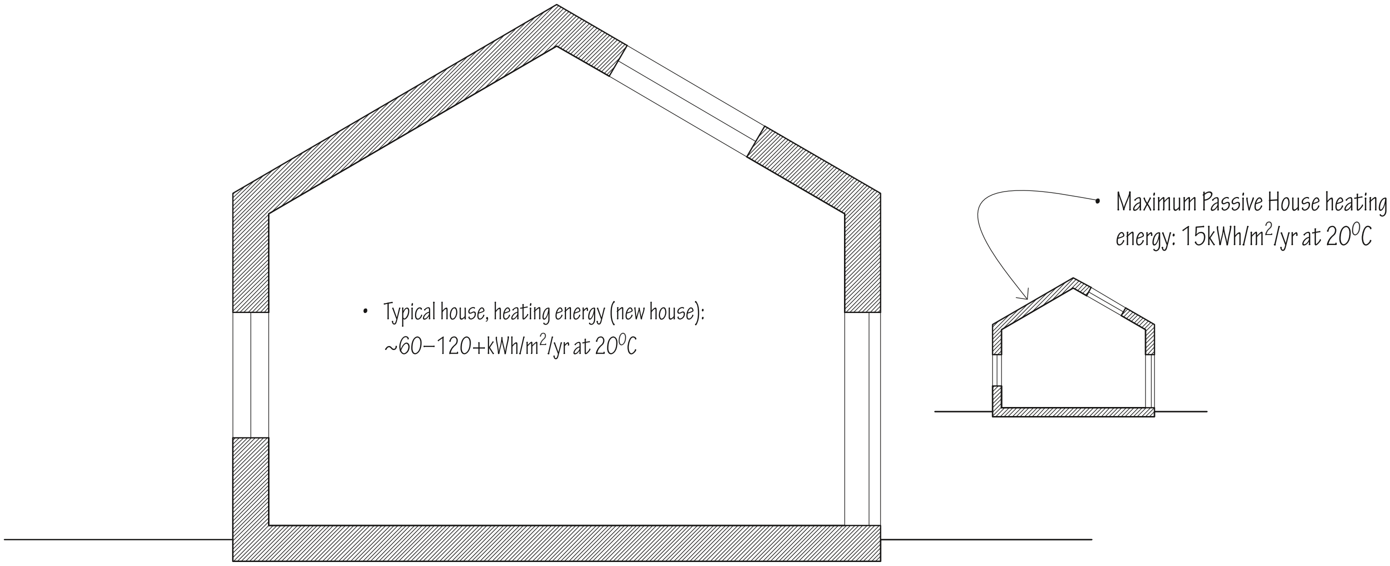
The EU has a number of strategies and targets in place with the overall aim of significantly reducing carbon emissions. As the construction and operation of our buildings is responsible for a large proportion of overall carbon emissions, the industry has the potential to contribute significantly to overall reductions. The EU 20-20-20 target calls for greenhouse gas (GHG) emissions to be reduced by 20% (over a 1990 baseline), for 20% of energy consumption to come from renewable sources and for a 20% reduction in primary energy use from efficiency measures, all by 2020.

What is relevant to any discussion of sustainable design is that most of the building sector's energy consumption is not attributable to the production of materials or the process of construction, but rather to operational processes – the heating, cooling and lighting of buildings. This means that to reduce the energy consumption and GHG emissions generated by the use and maintenance of buildings over their lifespan, it is necessary to properly design, site and shape buildings and incorporate natural heating, cooling, ventilation and daylighting strategies.

There are two approaches to reducing a building's consumption of GHG-emitting fossil fuels. The passive approach is to work with the climate in designing, siting and orienting a building and to employ passive cooling and heating techniques to reduce its overall energy requirements. The active approach is to increase the ability of a building to capture or generate its own energy from renewable or other efficient sources (solar, wind, geothermal, hydro and biomass/biogas) that are available locally and in abundance. While striking an appropriate, cost-effective balance between energy conservation and generating renewable energy is the goal, minimising energy use is a necessary first step, irrespective of the fact that the energy may come from renewable resources.

The energy hierarchy, building upon the above idea, suggests that the need for energy should first be reduced through passive measures, the remaining energy demand should be met with the most appropriate and efficient building services available (including heat recovery), and that the remaining demand should be met using low or zero carbon technologies.

1.08 THE PASSIVE HOUSE STANDARD



Passive House

Developed by Professor Wolfgang Feist and Professor Bo Adamson, the Passive House Standard aims to significantly reduce the space heating (and cooling) load of domestic and non-domestic buildings while delivering high levels of comfort and internal air quality.

This is achieved through a combination of high levels of insulation, minimal or no thermal bridges and high levels of airtightness while carefully managing heat gains to avoid overheating. To attain this, a keen understanding of building physics is required. The Passive House Planning Package (PHPP) provides designers with a tool to assist them in achieving the standard.

Considerations

Careful consideration needs to be given to glazing configuration at the design stage in order to ensure the benefits of useful heat gain and daylight from glazing are balanced against potential heat loss which will lead to an increased heating load.

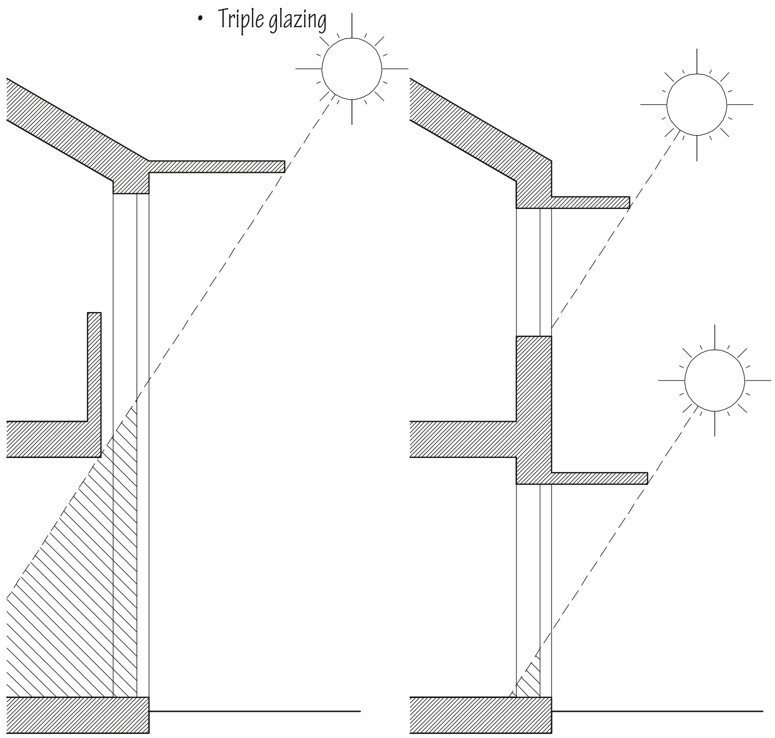
The principles underpinning the Passive House approach are based on building physics and can help to improve the overall quality of the buildings delivered.

The EnerPHit Standard has been developed to address the specific challenges presented by the refurbishment of existing buildings.

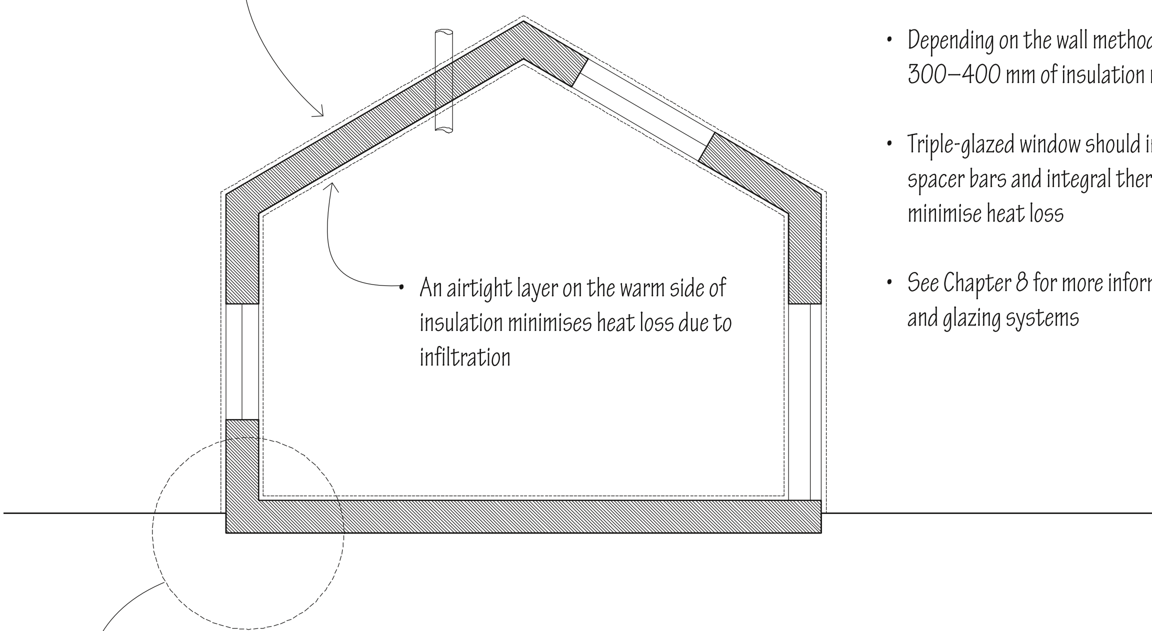
See: www.passiv.de

Achieving the Passive House Standard requires high-quality design and workmanship. Typical features of a Passive House building include:

- Average U-Values of 0.10W/m^{2}K
- Minimum airtightness of 0.6 air changes per hour (ach) @ 50pa pressure difference
- High efficiency mechanical ventilation with heat recovery (MVHR) system
- Triple glazing

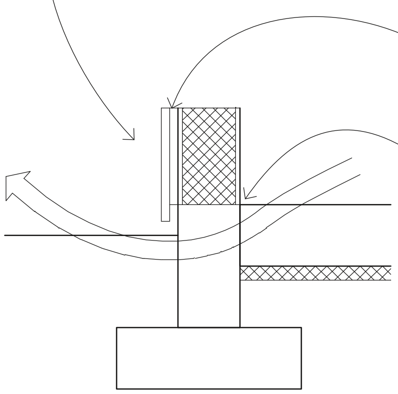


- A wind-tight layer is required to ensure that insulation does not lose heat through air circulation



- An airtight layer on the warm side of insulation minimises heat loss due to infiltration

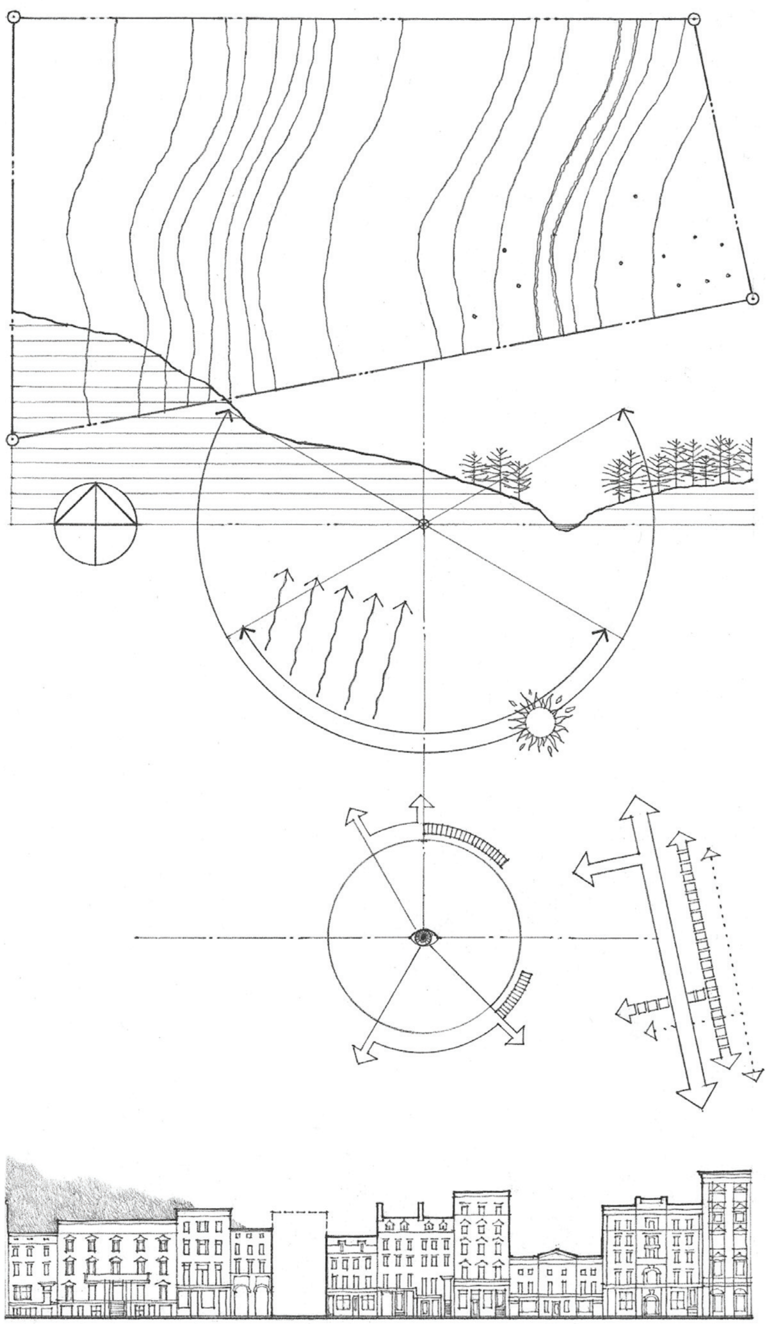
- Detailing around penetrations through the building fabric (building services, doors, windows etc) needs to be carefully designed
- Depending on the wall method used 300–400 mm of insulation may be necessary
- Triple-glazed window should include warm edge spacer bars and integral thermal breaks to minimise heat loss
- See Chapter 8 for more information on windows and glazing systems



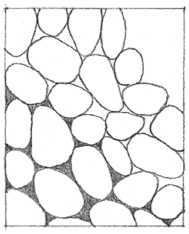
- Any fixings or penetrations required through the wind-tight, airtight and insulation layers need to be carefully considered to avoid compromising the performance of the building fabric
- Gaps in the continuity of thermal insulation lead to cold bridges which increases heat loss and can also result in mould growth
- See 7.36 for more information on cold bridging
- See 7.43 for information on how to achieve good levels of airtightness
- The Passive House Institute (PHI) provides and oversees a quality assurance mechanism for the certification of Passive House buildings

1.10 SITE ANALYSIS

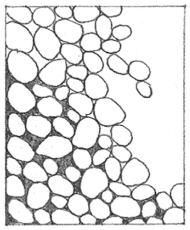
Site analysis is the process of studying the contextual forces that influence how we might situate a building, lay out and orient its spaces, shape and articulate its enclosure and establish its relationship to the landscape. Any site survey begins with the gathering of physical site data.



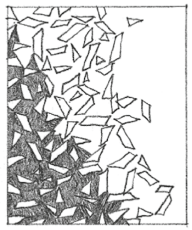
- Draw the area and shape of the site as defined by its legal boundaries
- Indicate required setbacks and rights-of-way
- Estimate the area and volume required for the building programme, site amenities and future expansion, if desired
- Analyse the ground slopes and subsoil conditions to locate the areas suitable for construction and outdoor activities
- Identify steep and moderate slopes that may be unsuitable for development
- Locate soil areas suitable for use as a drainage field, if applicable
- Map existing drainage patterns (LEED SS Credit 6.1, 6.2: Stormwater Design)
- Determine the elevation of the water table
- Identify areas subject to excessive run-off of surface water, flooding or erosion (BREEAM POL 03: Surface Water Run-Off)
- Locate existing trees and native plant materials that should be preserved and map out the corresponding root protection areas (BREEAM LE 02: Ecological Value of Site and Protection of Ecological Features)
- Chart existing water features, such as wetlands, streams, watersheds, flood plains or shorelines that should be protected (LEED SS Credit 5.1: Site Development – Protect or Restore Habitat)
- Map climatic conditions: the path of the sun, the direction of prevailing winds and the expected amount of rainfall
- Consider the impact of landforms and adjacent structures on solar access, prevailing winds and the potential for glare
- Evaluate solar radiation as a potential energy source
- Determine possible points of access from public roadways and public transit stops (BREEAM TRA 01: Public Transport Accessibility; LEED SS Credit 4.1: Alternative Transportation – Public Transportation Access)
- Study possible circulation paths for pedestrians and vehicles from these access points to building entrances
- Ascertain the availability of utilities: water mains, foul and surface water sewers, gas lines, electrical power lines, telephone and data lines and fire hydrants
- Determine access to other municipal services, such as police and fire protection
- Identify the scope of desirable views as well as objectionable views
- Cite potential sources of congestion and noise (BREEAM POL 05: Noise Attenuation)
- Evaluate the compatibility of adjacent and proposed land uses
- Map cultural and historical resources that should be preserved
- Consider how the existing scale and character of the neighbourhood or area might affect the building design
- Map the proximity to public, commercial, medical and recreational facilities (BREEAM TRA 02: Proximity to Amenities; LEED SS Credit 2: Development Density & Community Connectivity)



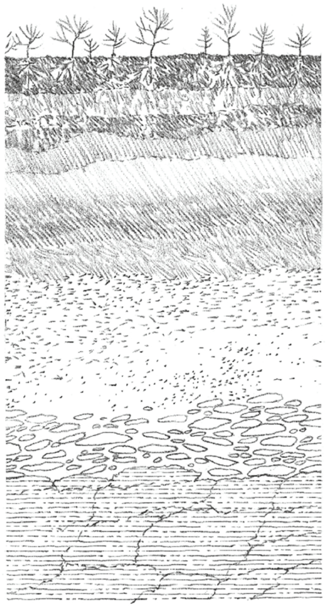
• Gravel

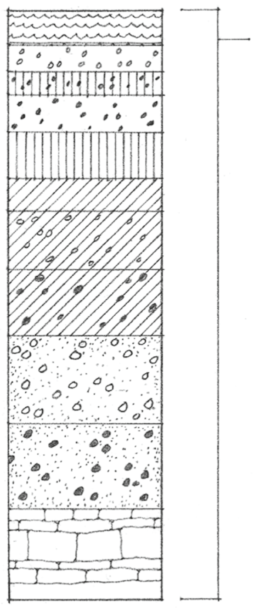


• Sand



• Clay





There are two broad classes of soils – coarse-grained non-cohesive soils and fine-grained cohesive soils. Coarse-grained soils include gravel and sand, which consist of relatively large particles visible to the naked eye; fine-grained soils, such as silt and clay, consist of much smaller particles. EN 1997 Eurocode 7 further divides gravels, sands, silts and clays into soil types based on physical composition and characteristics (see table below). Cohesive soils are more susceptible to heave and compression which has implications for foundation design.

The soil underlying a building site may actually consist of superimposed layers, each of which contains a mix of soil types, developed by weathering or deposition. To depict this succession of layers or strata called horizons, geotechnical engineers draw a soil profile, a diagram of a vertical section of soil from the ground surface to the underlying material, using information collected from a test pit or boring.

The integrity of a building structure depends ultimately on the stability and strength under loading of the soil or rock underlying the foundation. The stratification, composition and density of the soil bed, variations in particle size, and the presence or absence of groundwater are all critical factors in determining the suitability of a soil as a foundation material. When designing anything other than a single-family dwelling, it is advisable to have a geotechnical engineer undertake a subsurface investigation.

Site exploration through the digging of a trial pit or bore hole can help to determine the suitability of a site or project for a particular foundation system. A trial pit can be used to establish the ground conditions and strata for relatively shallow foundations through visual assessment or physical examination. Bore holes are suited to examine soil make-up and greater depth. In both cases it should be noted that the act of digging/drilling will in itself impact upon the properties of the soil by disturbing the area, compacting soil and potentially reducing local moisture content.

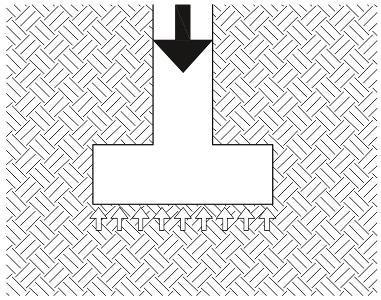
Soil Classification*	Description	Permeability & Drainage
Non-Cohesive		
Gravels	Dense Gravel	Excellent
	Medium-Dense Gravel	Excellent
	Loose Silty Gravel	Poor
Sands	Compact Sand	Excellent
	Medium Dense Sand	Excellent
	Loose Silty Sand	Fair
Cohesive		
Clays	Stiff Clay	Poor
	Firm Clay	Impervious
	Soft Clay	Impervious
Peat & Organic Soils	Organic Clay and Silt	Impervious
Highly Organic Soils	Peat	Poor

Consult a geotechnical engineer and the building regulations for allowable bearing capacities

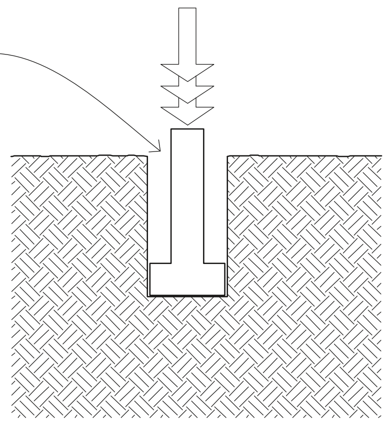
*Based on EN 1997 Eurocode 7

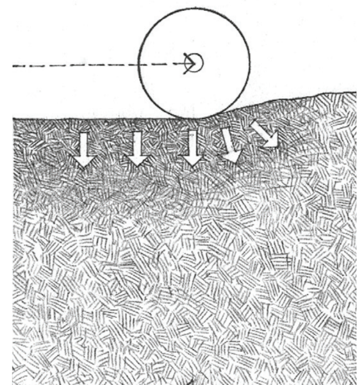
1.12 SOIL MECHANICS

The allowable bearing capacity of a soil is the maximum unit pressure a foundation is permitted to impose vertically or laterally on the soil mass. While high-bearing-capacity soils present few problems, low-bearing-capacity soils may dictate the use of a certain type of foundation and load distribution pattern, and ultimately, the form and layout of a building.



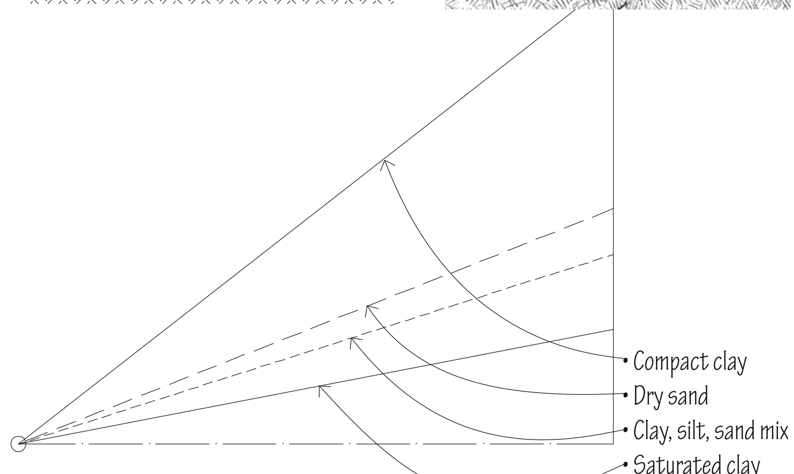
Density is a critical factor in determining the bearing capacity of granular soils. The Standard Penetration Test measures the density of granular soils and the consistency of some clays at the bottom of a bore hole, recording the number of blows required by a hammer to advance a standard soil sampler. In some cases, compaction, by means of rolling, tamping or soaking to achieve optimum moisture content, can increase the density of a soil bed. BS 1377 sets out a number of standardised tests for various soil types.





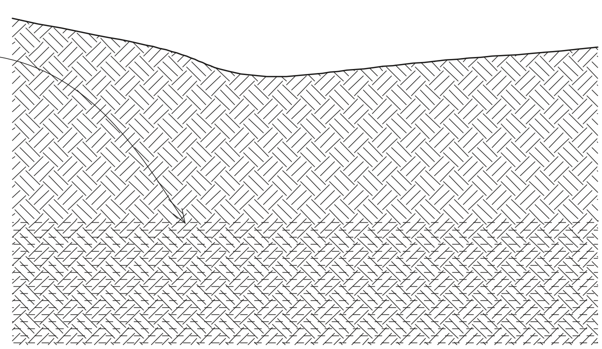
Coarse-grained soils have a relatively low percentage of void spaces and are more stable as a foundation material than silt or clay. Clay soils, in particular, tend to be unstable because they shrink and swell considerably with changes in moisture content. Unstable soils may render a site unbuildable unless an elaborately engineered and expensive foundation system is put in place.

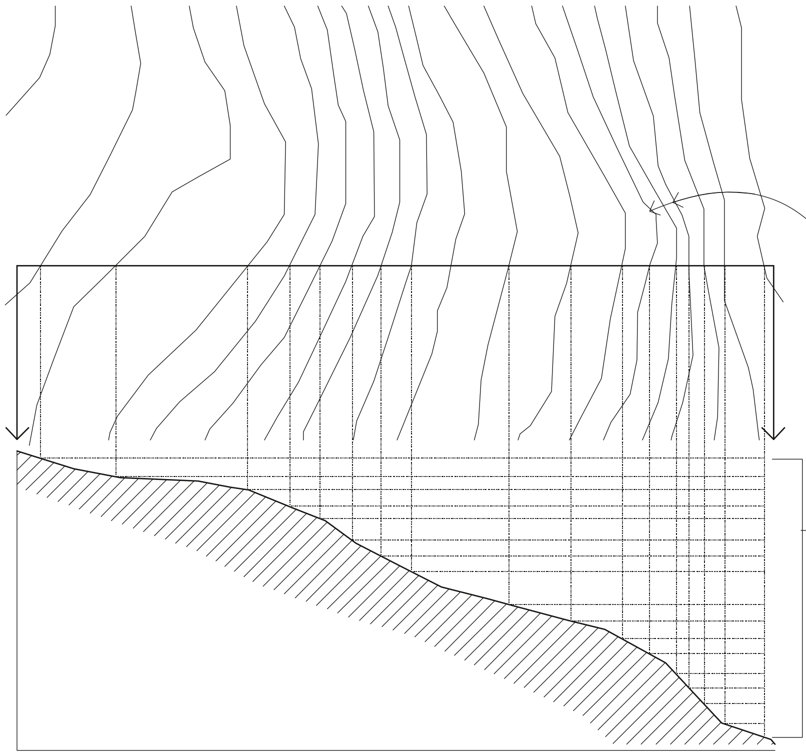
The shearing strength of a soil is a measure of its ability to resist displacement when an external force is applied, due largely to the combined effects of cohesion and internal friction. On sloping sites, as well as during the excavation of a flat site, unconfined soil has the potential to displace laterally. Cohesive soils, such as clay, retain their strength when unconfined; granular soils, such as gravel, sand or some silts, require a confining force for their shear resistance and have a relatively shallow angle of repose.



Angle of Repose for Bare Soil Embankments

The water table is the level beneath which the soil is saturated with groundwater. Some building sites are subject to seasonal fluctuations in the level of groundwater. Any groundwater present must be drained away from a foundation system to avoid reducing the bearing capacity of the soil and to minimise the possibility of water leaking into a basement. Coarse-grained soils are more permeable and drain better than fine-grained soils, and are less susceptible to frost action.

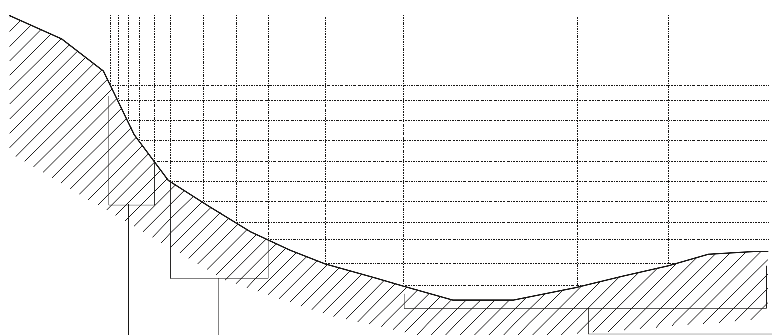




Topography refers to the configuration of surface features of a plot of land, which influences where and how to build and develop a site. To study the response of a building design to the topography of a site, we can use a series of site sections or a site plan with contour lines.

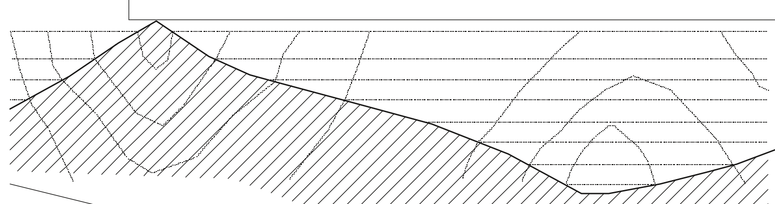
Contour lines are imaginary lines joining points of equal elevation above a datum or benchmark. The trajectory of each contour line indicates the shape of the land formation at that elevation. Note that contour lines are always continuous and never cross one another; they coincide in a plan view only when they cut across a vertical surface.

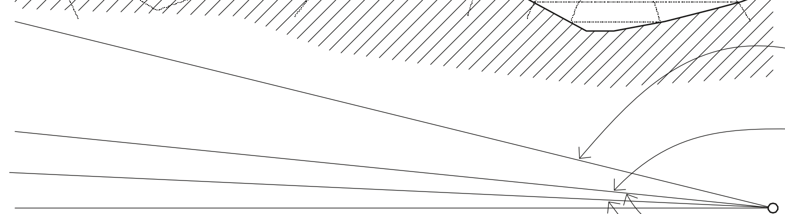
Contour interval refers to the difference in elevation represented by any two adjacent contour lines on a topographic map or site plan. The interval used is determined by the scale of a drawing, the size of the site and the nature of the topography. The larger the area and the steeper the slopes, the greater the interval between contours. For large or steeply sloping sites, 5 or 10 m contour intervals may be used. For small sites having relatively gradual slopes, 0.5 or 1.0 m contours may be necessary.



We can discern the topographical nature of a site by reading the horizontal spacing and shape of contour lines.

- Contours spaced far apart indicate a relatively flat or gently sloping surface
- Equally spaced contours denote a constant slope
- Closely spaced contours disclose a relatively steep rise in elevation
- Contour lines represent a ridge when pointing toward lower elevations; they represent a valley when pointing toward higher elevations





- Ground slopes over 25% are subject to erosion and are difficult to build on
- Ground slopes over 10% are challenging to use for outdoor activities and are more expensive to build on
- Ground slopes from 5% to 10% are suitable for informal outdoor activities and can be built on without too much difficulty
- Ground slopes up to 5% are usable for most outdoor activities and relatively easy to build on

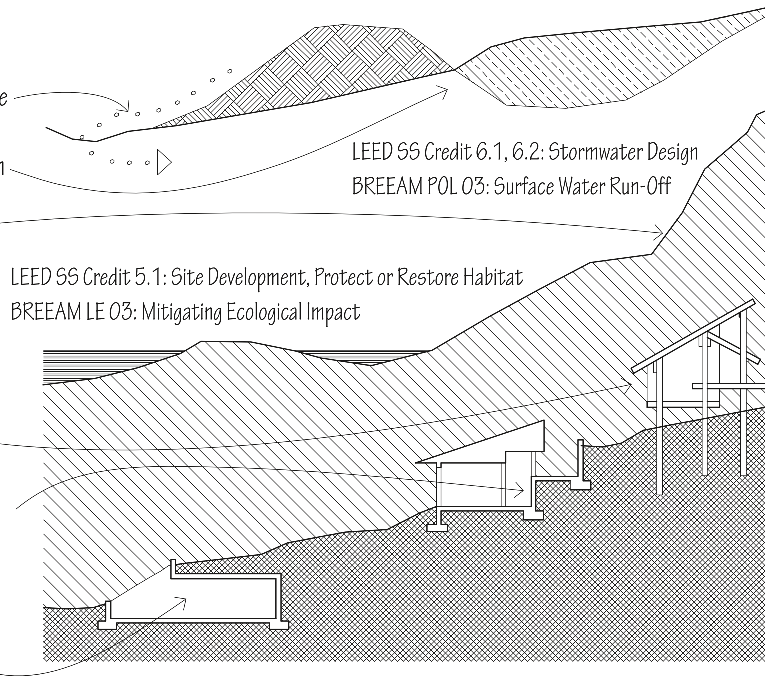
- Slope (%) = [elevation gain (v)/horizontal distance (h)] x 100

The ground slope between any two contour lines is a function of the total change in elevation and the horizontal distance between the two contours.

1.14 TOPOGRAPHY

For aesthetic and economic, as well as ecological reasons, the general intent in developing a site should be to minimise the disturbance of existing landforms and features while taking advantage of natural ground slopes and the microclimate of the site.

- Site development and construction should minimise disrupting the natural drainage patterns of the site and adjacent properties
- When modifying landforms, include provisions for the drainage of surface water and groundwater
- Attempt to equalise the amount of cut and fill required for construction of a foundation and site development
- Avoid building on steep slopes subject to erosion or slides
- Wildlife habitats may require protection and limit the buildable area of a site
- Pay particular attention to building restrictions on sites located in or near a flood plain



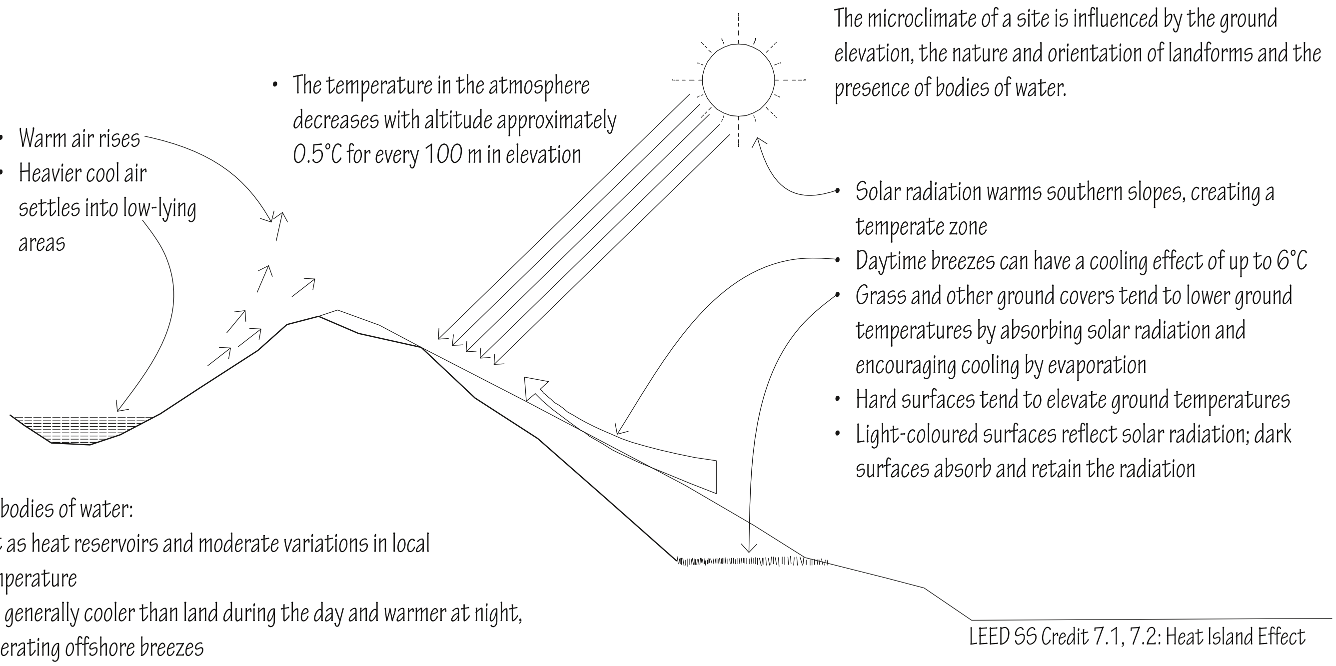
- Elevating a structure on poles or piers minimises disturbance of the natural terrain and existing vegetation
- Terracing or stepping a structure along a slope requires excavation and the use of retaining walls or bench terracing
- Cutting a structure into a slope or locating it partially underground moderates temperature extremes and minimises exposure to wind, and heat loss in cold climates

The microclimate of a site is influenced by the ground elevation, the nature and orientation of landforms and the presence of bodies of water.

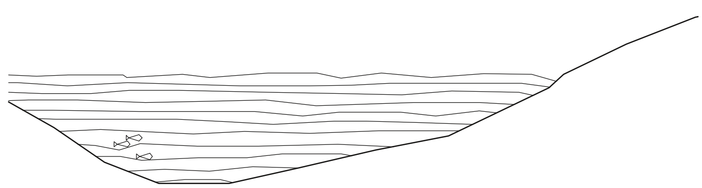
- The temperature in the atmosphere decreases with altitude approximately 0.5°C for every 100 m in elevation

- Warm air rises
- Heavier cool air settles into low-lying areas

- Solar radiation warms southern slopes, creating a temperate zone
- Daytime breezes can have a cooling effect of up to 6°C
- Grass and other ground covers tend to lower ground temperatures by absorbing solar radiation and encouraging cooling by evaporation
- Hard surfaces tend to elevate ground temperatures
- Light-coloured surfaces reflect solar radiation; dark surfaces absorb and retain the radiation

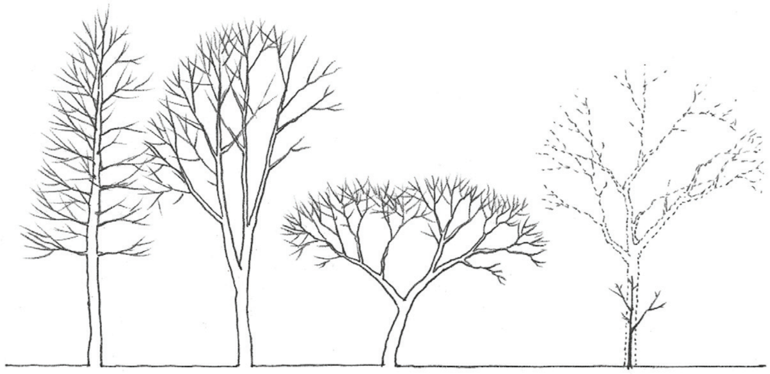


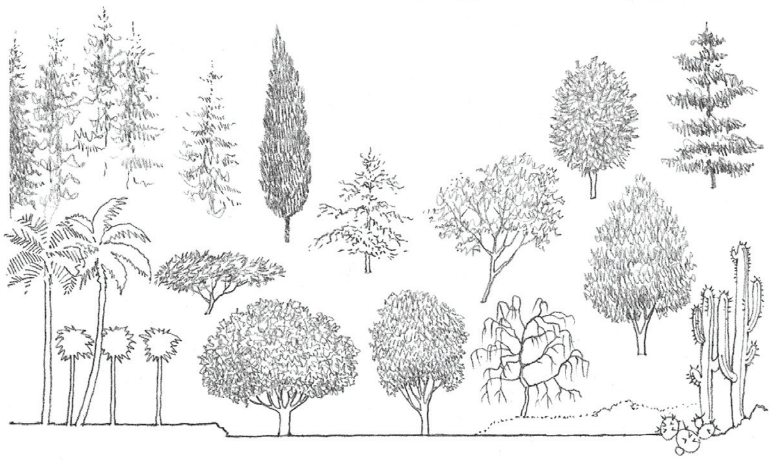
Large bodies of water:
- Act as heat reservoirs and moderate variations in local temperature
- Are generally cooler than land during the day and warmer at night, generating offshore breezes
- Are generally warmer than land in winter and cooler in summer
- In hot-dry climates, even small bodies of water are desirable, both psychologically and physically, for their evaporative cooling effect



Plant materials provide aesthetic as well as functional benefits in conserving energy, framing or screening views, moderating noise, retarding erosion and visually connecting a building to its site. Factors to consider in the selection and use of plant materials in landscaping include the:

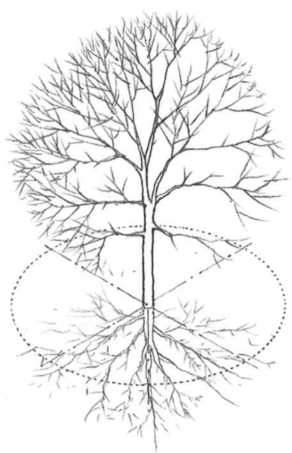
- Tree structure and shape
- Seasonal density, texture and colour of foliage
- Speed or rate of growth
- Mature height and spread of foliage
- Requirements for soil, water, sunlight and temperature range
- Depth and extent of the root structure





- Trees and other plant life adapt their forms to the climate

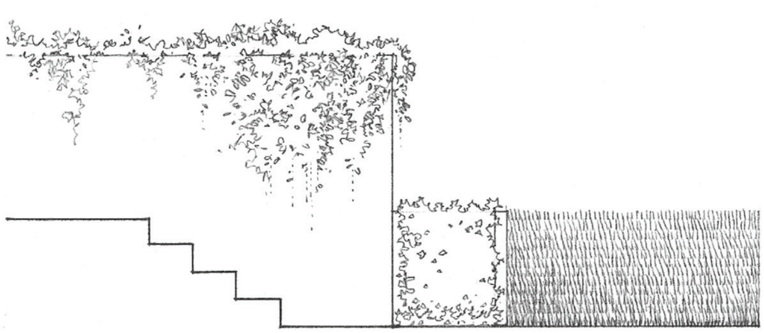
- Existing healthy trees and native plant materials should be preserved whenever possible. During construction and when regrading a site, root protection areas should be calculated to ensure existing tress are not damaged. The root systems of trees planted too close to a building may disturb the foundation system. Root structures can also interfere with underground utility lines
- To support plant life, a soil must be able to absorb moisture, supply the appropriate nutrients, be capable of aeration and be free of concentrated salts



LEED SS Credit 6.1, 6.2: Stormwater Design
LEED SS Credit 7.1: Heat Island Effect – Non-Roof
LEED WE Credit 1.2: Water Efficient Landscaping

BREEAM POL 03: Surface Water Run-Off
BREEAM LE 04: Enhancing Site Ecology

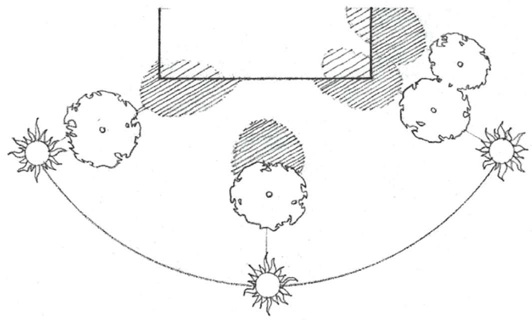
Grass and other ground covers:
- Can reduce air temperature by absorbing solar radiation and encouraging cooling by evaporation
- Aid in stabilising soil embankments and preventing erosion
- Increase the permeability of soil to air and water

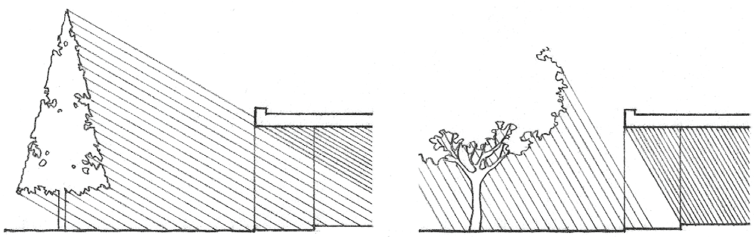


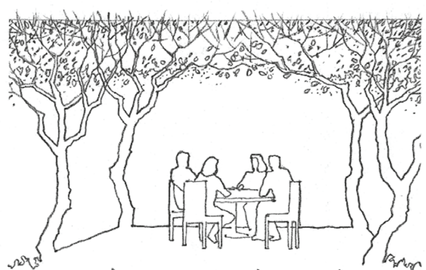
- Vines can reduce the heat transmission through a sunlit wall by providing shade and cooling the immediate environment by evaporation
- Care must be taken when planting near buildings as root systems can interfere with building foundations

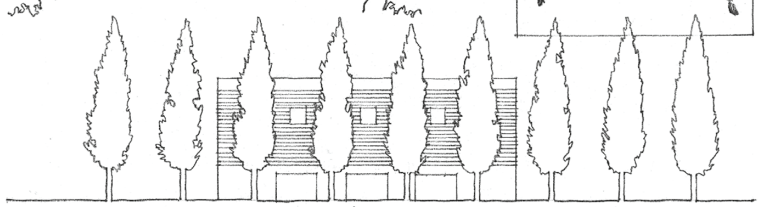
1.16 TREES

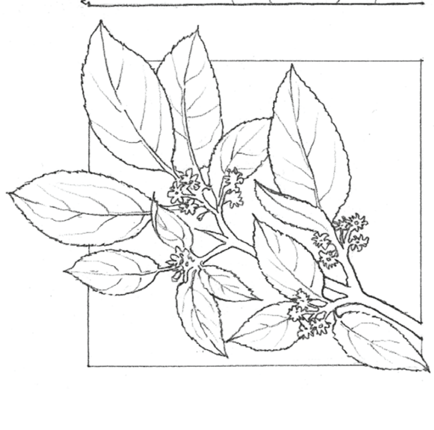
Trees affect the immediate environment of a building in the following ways:











Providing Shade

The amount of solar radiation obstructed or filtered by a tree depends on its:

- Orientation to the sun
- Proximity to a building or outdoor space
- Shape, spread and height
- Density of foliage and branch structure

- Trees shade a building or outdoor space most effectively from the south-east during the morning and the south-west during the late afternoon when the sun has a low altitude and casts long shadows
- South-facing overhangs provide more efficient shading during the midday period when the sun is high and casts short shadows
- Deciduous trees provide shade and glare protection during the summer and allow solar radiation to penetrate through their branch structures during the winter
- Evergreens provide shade throughout the year and help reduce snow glare during the winter

Serving as Windbreak

- Evergreens can form effective windbreaks and reduce heat loss from a building during the winter
- The foliage of plant materials reduces wind-blown dust

Defining Space

- Trees can shape outdoor spaces for activity and movement

Directing or Screening Views

- Trees can frame desirable views
- Trees can screen undesirable views and provide privacy for outdoor spaces

Attenuating Sound

- A combination of deciduous and evergreen trees is most effective in intercepting and attenuating airborne sound, especially when combined with earth mounds

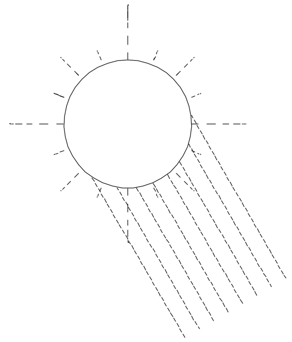
Improving Air Quality

- Trees trap particulate matter on their leaves, which is then washed to the ground during rainfall
- Leaves can also assimilate gaseous and other pollutants
- Photosynthetic process can metabolise fumes and other odours

Stabilising Soil

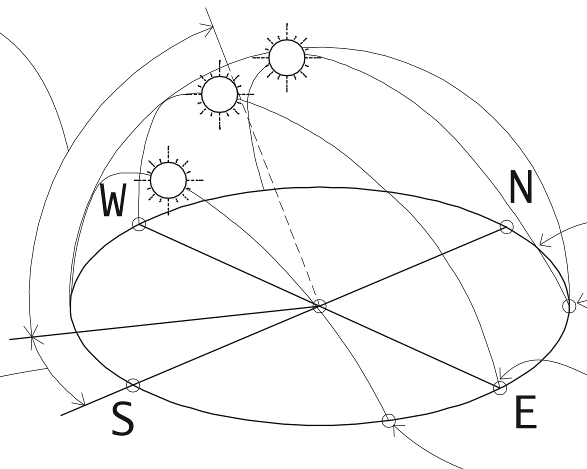
- The root structures of trees aid in stabilising soil, increasing the permeability of the soil to water and air and preventing erosion

Care must be taken when placing trees near to buildings as root systems can interfere with building foundations.

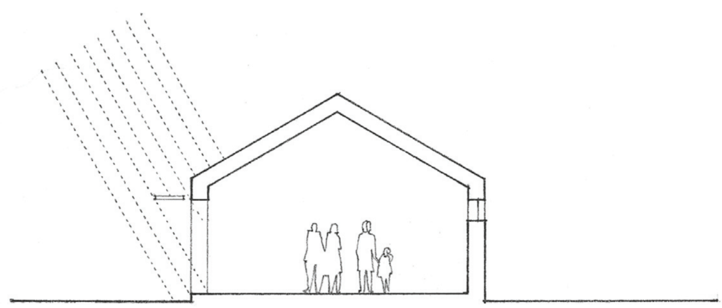


The location, form and orientation of a building and its spaces should take advantage of the thermal, hygienic and psychological benefits of sunlight. Solar radiation, however, may not always be beneficial, depending on the latitude and climate of the site. In planning the design of a building, the objective should be to maintain a balance between underheated periods when solar radiation is beneficial and overheated periods when radiation should be avoided.

The path of the sun through the sky varies with the seasons and the latitude of a building site. The range of solar angles for a specific site should be obtained from the relevant national meteorological office before calculating the potential solar heat gain and shading requirements for a building design.



Solar Path Diagram



Representative Solar Angles

North Latitude	Representative City	Altitude at Noon		Azimuth at Sunrise & Sunset	
		22 Dec	21 Mar/22 Sept	22 Dec	21 June
59°	Oslo	6°	30°	40°	143°
53°	Dublin	13°	37°	47°	133°
51°	London	15°	39°	50°	129°
43°	Nice	22°	47°	56°	122°
40°	Madrid	26°	50°	59°	123°

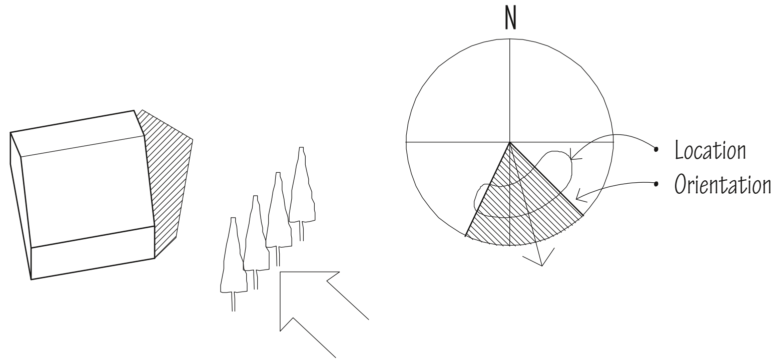
1.18 SOLAR RADIATION

The following are recommended forms and orientations for isolated buildings in different climatic regions. The information presented should be considered along with other contextual and programmatic requirements.

Cool Regions

Minimising the surface area of a building reduces exposure to low temperatures.

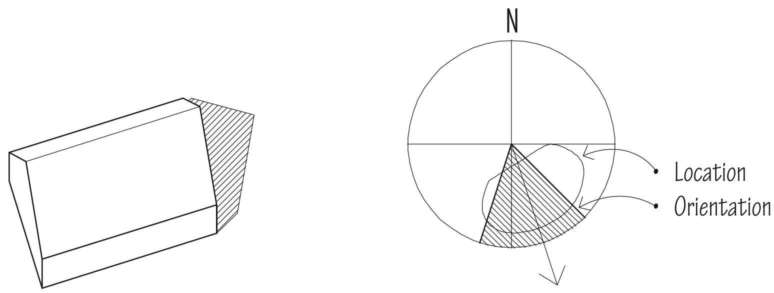
- Maximise absorption of solar radiation
- Reduce radiant, conductive and evaporative heat loss
- Provide wind protection



Temperate Regions

Elongating the form of a building along the east–west axis maximises south-facing walls.

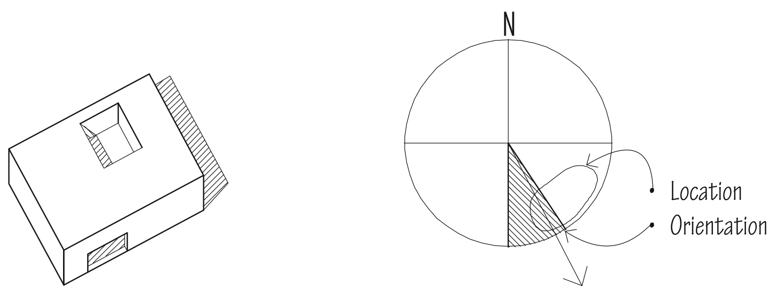
- Minimise east and west exposures, which are generally warmer in summer and cooler in winter than southern exposures
- Balance solar heat gain with shade protection on a seasonal basis
- Encourage air movement in hot weather; protect against wind in cold weather



Hot-Arid Regions

Building forms should enclose courtyard spaces.

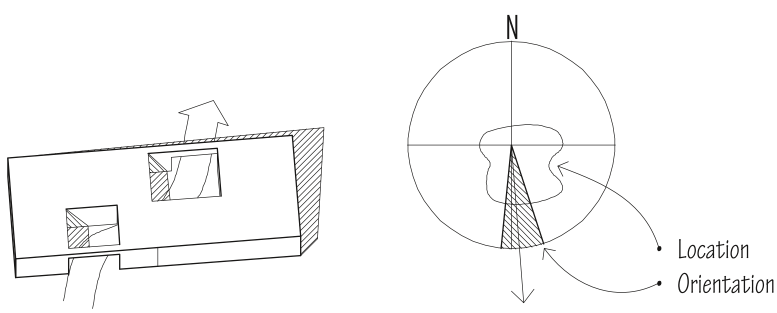
- Reduce solar and conductive heat gain
- Promote cooling by evaporation using water features and planting
- Provide solar shading for windows and outdoor spaces



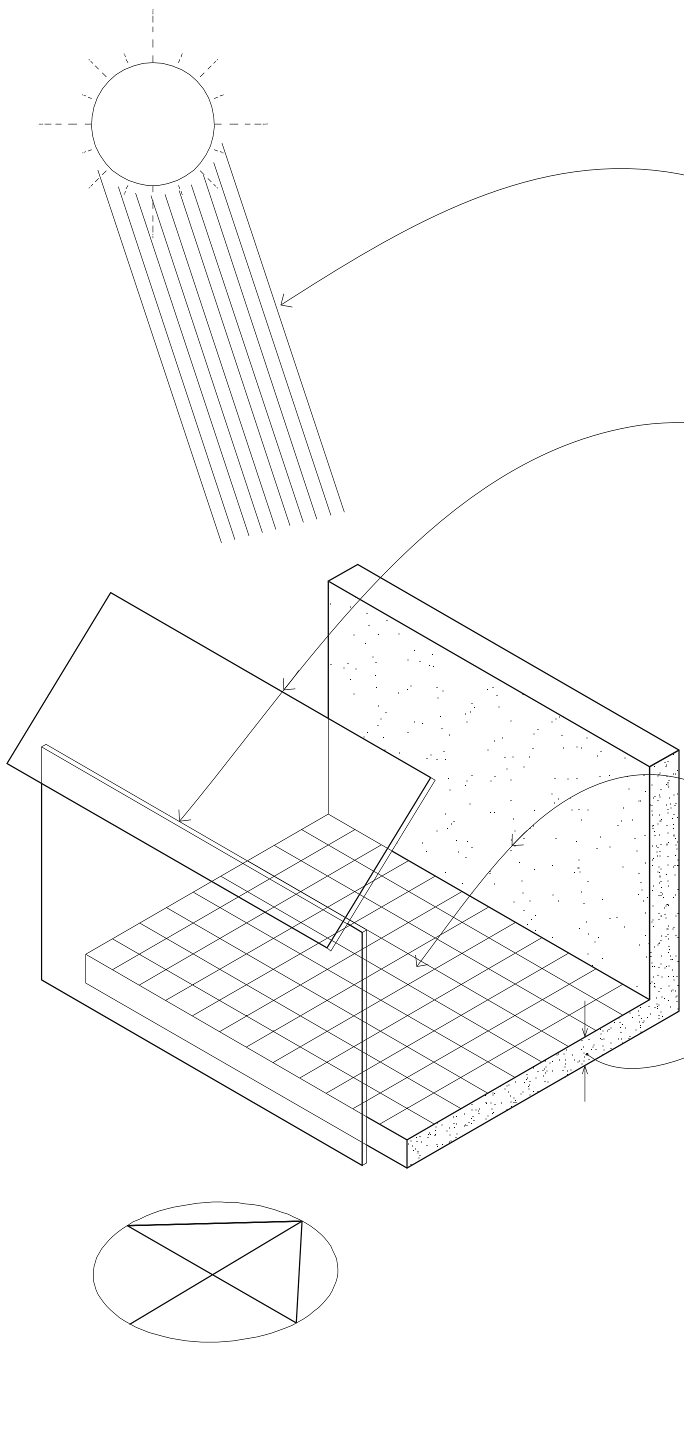
Hot-Humid Regions

Building form elongated along the east–west axis minimises east and west exposures.

- Reduce solar heat gain
- Utilise wind to promote cooling by evaporation
- Provide solar shading for windows and outdoor spaces



LEED EA Credit 1: Optimize Energy Performance
BREEAM ENE 01: Reduction of CO_2 Emissions



Passive solar heating refers to using solar energy to heat the interior spaces of a building without relying on mechanical devices that require additional energy. Passive solar systems rely instead on the natural heat transfer processes of conduction, convection and radiation for the collection, storage, distribution and control of solar energy.

- The solar constant is the average rate at which radiant energy from the sun is received by the earth, equal to 1353 W/m^2/hr, used in calculating the effects of solar radiation on buildings

There are two essential elements in every passive solar system:

1. South-facing glass or transparent plastic for solar collection
- Area of glazing should be 30–50% of floor area in cold climates and 15–25% of floor area in temperate climates, depending on average outdoor winter temperature and projected heat loss
- Glazing material should be resistant to the degradation caused by the ultraviolet rays of the sun
- Double- or triple-glazing and insulation are required to minimise night-time heat loss

2. Thermal mass for heat collection, storage and distribution, oriented to receive maximum solar exposure
- Thermal storage materials include concrete, brick, stone, tile, rammed earth, sand and water or other liquid. Phase-change materials, such as eutectic salts and paraffins, are also feasible
- Concrete: 305–455 mm
- Brick: 255–355 mm
- Earth: 200–305 mm
- Water: 150 mm or more
- Dark-coloured surfaces absorb more solar radiation than light-coloured surfaces

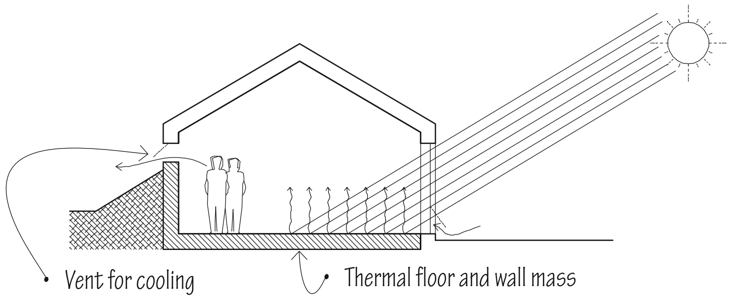
- Vents, dampers, movable insulation panels and shading devices can assist in balancing heat distribution

Based on the relationship between the sun, the interior space and the heat collection system, there are three ways in which passive solar heating can be accomplished: direct gain, indirect gain and isolated gain.

LEED EA Credit 2: On-Site Renewable Energy
LEED EA Credit 6: Green Power
BREEAM ENE 01: Reduction of CO_2 Emissions

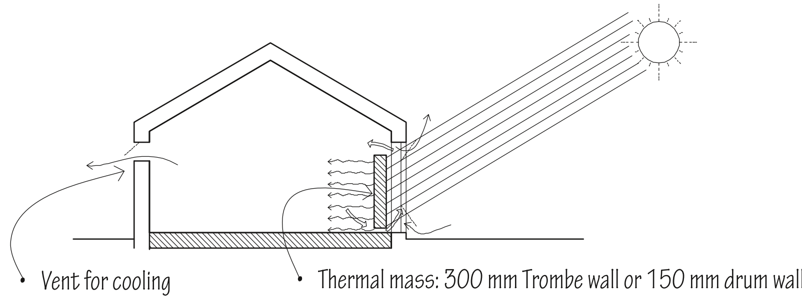
Direct Gain

Direct gain systems collect heat directly within an interior space. The surface area of the storage mass, which is incorporated into the space, should be 50–66% of the total surface area of the space. During the cooling season, operable windows and walls are used for natural or induced ventilation.



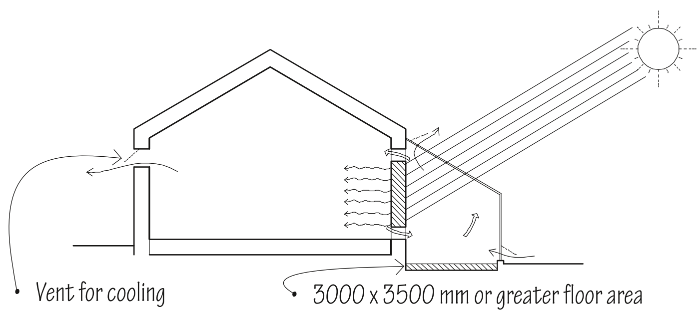
Indirect Gain

Indirect gain systems control heat gain at the exterior skin of a building. The solar radiation first strikes the thermal mass, either a concrete or masonry Trombe wall, or a drum wall of water-filled barrels or tubes, which is located between the sun and the living space. The absorbed solar energy moves through the wall by conduction and then to the space by radiation and convection.



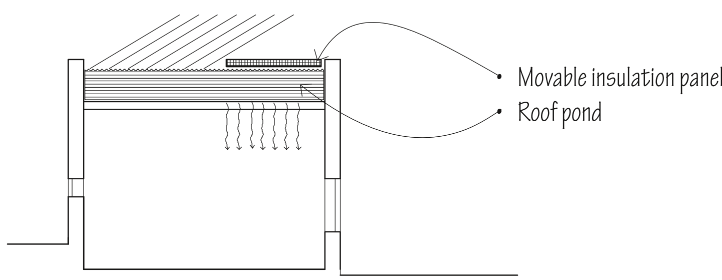
Sunspace

A sun room or solarium is another medium for indirect heat gain. The sunspace, having a floor of high thermal mass, is separated from the main living space by a thermal storage wall from which heat is drawn as needed. For cooling, the sunspace can be vented to the exterior.



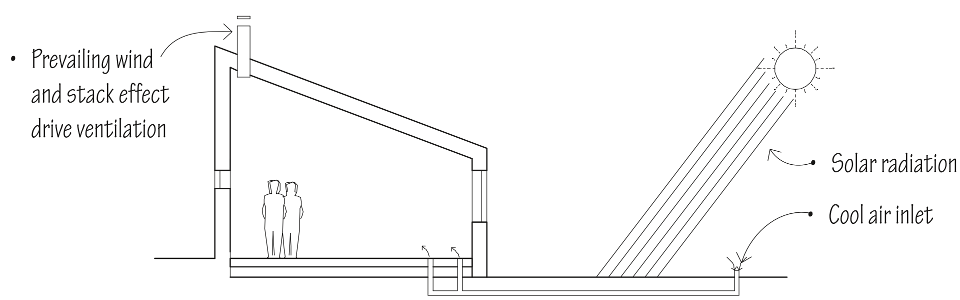
Roof Pond

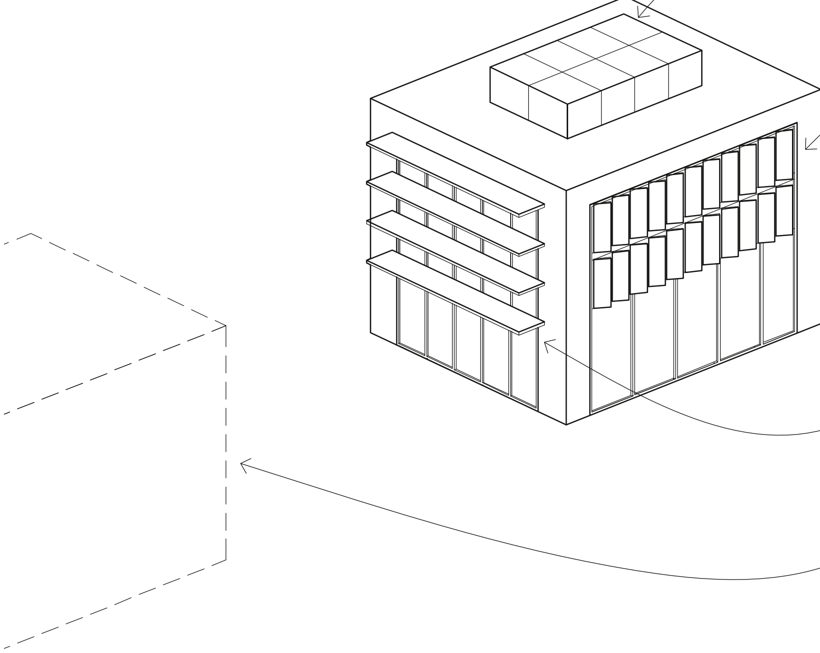
Another form of indirect gain is a roof pond that serves as a liquid mass for absorbing and storing solar energy. An insulating panel is moved over the roof pond at night, allowing the stored heat to radiate downward into the space. In summer, the process is reversed to allow internal heat absorbed during the day to radiate to the sky at night.



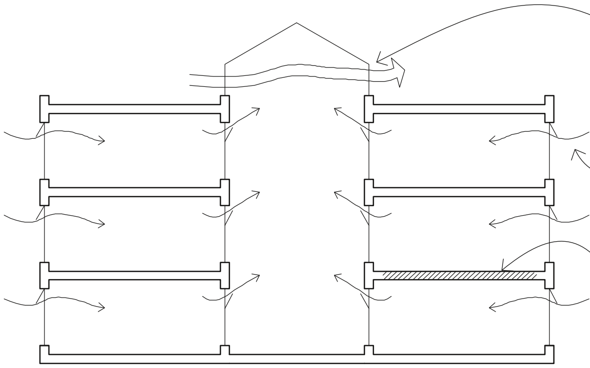
Isolated Gain

Ground tempered ventilation utilises the relatively constant warmth of the earth at depth in excess of 2 m to pre-heat ventilation air. Ventilation will need to be driven by the stack effect, a solar chimney, the prevailing winds or a combination of these measures.

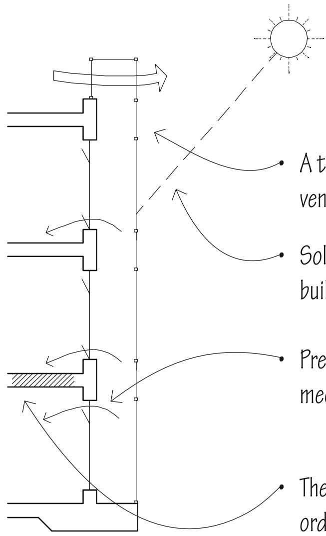




- Introducing an atrium into the centre of a deep plan building can facilitate good daylighting levels, additionally the atrium can be used as part of a natural ventilation system utilising the stack effect
- East- and west-facing glazing can be difficult to shade and may contribute to glare. West-facing glazing particularly, if unshaded can contribute to overheating
- South-facing glazing can be more easily shaded, while allowing for good levels of daylighting and utilising solar heat gains during the heating season
- When considering the daylighting and shading of a new building, the effect of nearby adjacent buildings (or planned buildings) should be taken into account



- An atrium can be used to drive a natural ventilation system using the stack effect. Care must be taken when designing an atrium space to ensure it does not contribute to overheating
- Pressure difference due to the stack effect will draw ventilation air through designed paths in the facade
- Unwanted heat gains can be stored in thermal mass and purged from the building as part of a night-time purge ventilation system, introducing coolth to the building structure
- The introduction of an atrium can increase the depth to which useful daylight can be experienced and natural ventilation used in a building by up to three times

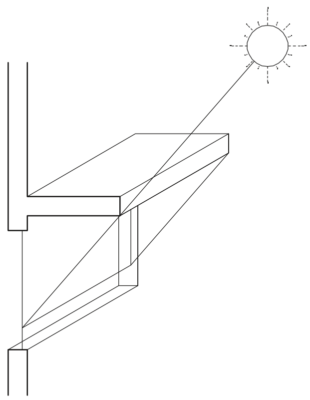


- A twin-wall system can also use the stack effect to drive natural ventilation
- Solar gains can pre-heat ventilation air before it enters the building
- Pre-heated ventilation air can be drawn into the building mechanically or as part by utilising passive means
- Thermal mass must remain coupled to the ventilation air flow in order to be useful

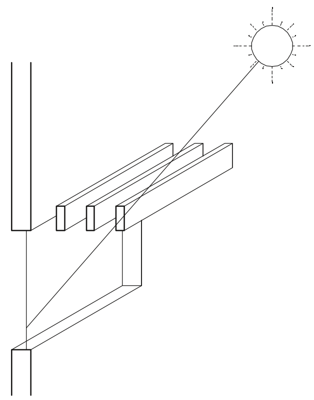
1.22 SOLAR SHADING

Shading devices shield windows and other glazed areas from direct sunlight in order to reduce glare and excessive solar heat gain in warm weather. Their effectiveness depends on their form and orientation relative to the solar altitude and azimuth for the time of day and season of the year. Exterior devices are more efficient than those located within interior spaces because they intercept solar rays before they can reach an exterior wall or window.

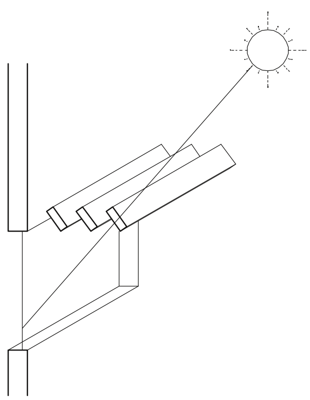
Illustrated are basic types of solar shading devices. Their form, orientation, materials and construction may vary to suit specific situations. Their visual qualities of pattern, texture and rhythm, and the shadows they cast, should be considered when designing the facades of a building.



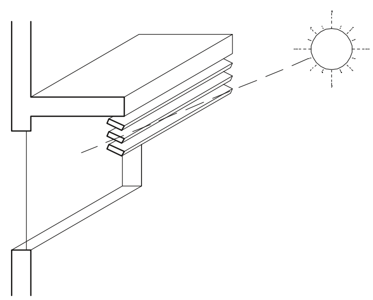
- Horizontal overhangs are most effective when they have southern orientations



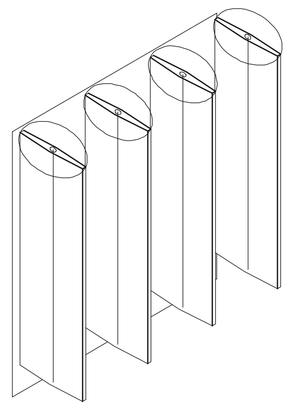
- Horizontal louvres parallel to a wall permit air circulation near the wall and reduce conductive heat gain



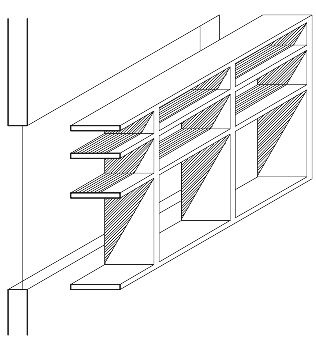
- Slanted louvres provide more protection than those parallel to a wall
- Angle varies according to the range of solar angles



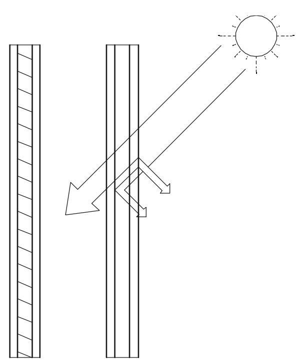
- Louvres hung from a solid overhang protect against low sun angles
- Louvres may interfere with view



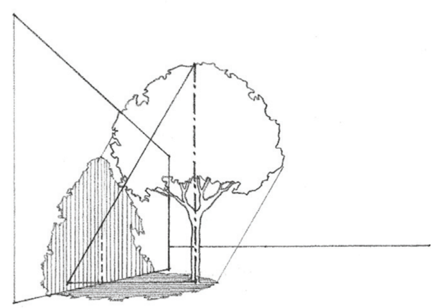
- Vertical louvres are most effective for eastern or western exposures
- Louvres may be operated manually or controlled automatically with time or photoelectric controls to adapt to solar angle
- Separation from wall reduces conductive heat gain



- Brise-soleil combine the shading characteristics of horizontal and vertical louvres and have a high shading ratio
- Brise-soleil are very efficient in hot climates

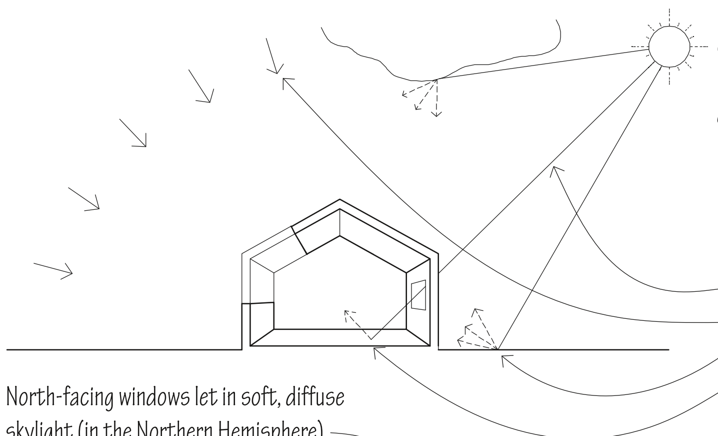


- Solar blinds and screens can provide up to a 50% reduction in solar radiation, depending on their reflectivity
- Heat-absorbing glass can absorb up to 40% of the radiation reaching its surface



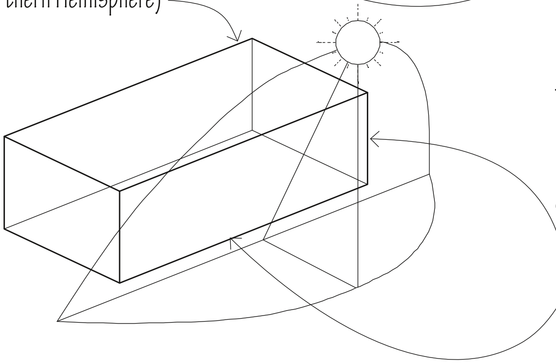
- Trees and adjacent structures may provide shade depending on their proximity, height and orientation

Solar radiation provides not only heat but also light for the interior spaces of a building. This daylight has psychological benefits as well as practical in reducing the amount of energy required for artificial lighting. While intense, direct sunlight varies with the time of day, from season to season, and from place to place, it can be diffused by cloud cover, haze and precipitation, and reflected from the ground and other surrounding surfaces.



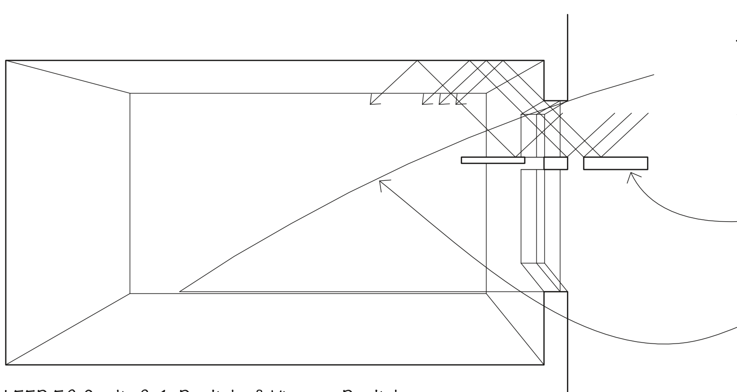
- Direct sunlight
- Skylight reflected and diffused by air molecules
- External reflectance from ground and adjacent structures
- Internal reflectance from room surfaces

- North-facing windows let in soft, diffuse skylight (in the Northern Hemisphere)



The quantity and quality of daylighting in a space are determined by the size and orientation of its window openings, transmittance of the glazing, reflectance of room surfaces and outdoor surfaces, and obstructions of overhangs and nearby trees.

- East- and west-facing windows require shading devices to avoid the bright early-morning and late-afternoon sun
- South-facing windows are ideal sources for daylight if horizontal shading devices can control excessive solar radiation and glare

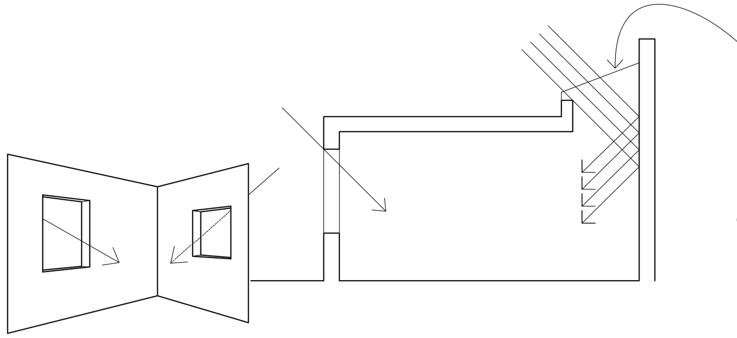


The level of illumination provided by daylight diminishes as it penetrates an interior space. Generally, the larger and higher a window is, the more daylight will enter a room; see 1.21.

- Light shelves shade glazing from direct sunlight while reflecting daylight onto the ceiling of a room. A series of parallel, opaque white louvres can also provide solar shading and reflect diffused daylight into the interior
- A useful rule of thumb is that daylighting can be effective for task illumination up to a depth of twice the height of a window
- The ceiling and back wall of a space are more effective than the side walls or the floor in the reflection and distribution of daylight; light-coloured surfaces reflect and distribute light more efficiently, but large areas of shiny surfaces can cause glare
- Skylights with translucent glazing can effectively daylight a space from above without excessive heat gain

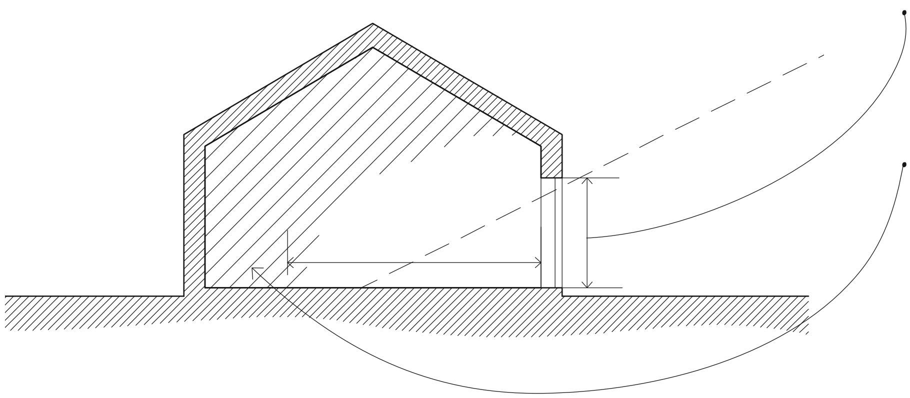
LEED EQ Credit 8.1: Daylight & Views – Daylight
BREEAM HEA 01: Visual Comfort

Excessive brightness ratios can lead to glare and impairment of visual performance. Glare can be controlled by the use of shading devices, the proper orientation of task surfaces and allowing daylight to enter a space from at least two directions.

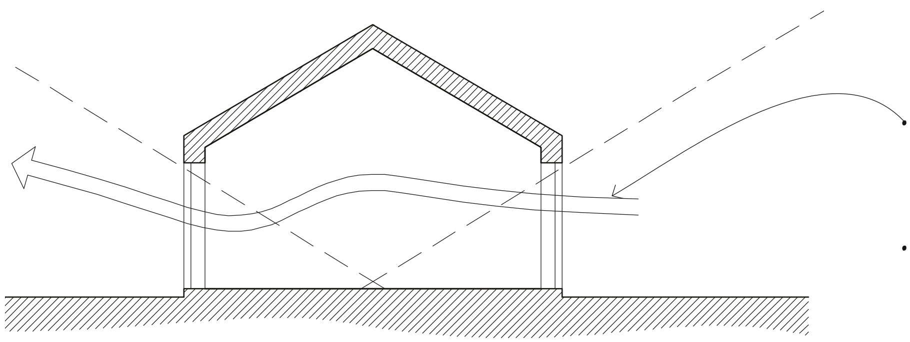


- For an even daylight distribution, allow daylight to penetrate a space from at least two directions

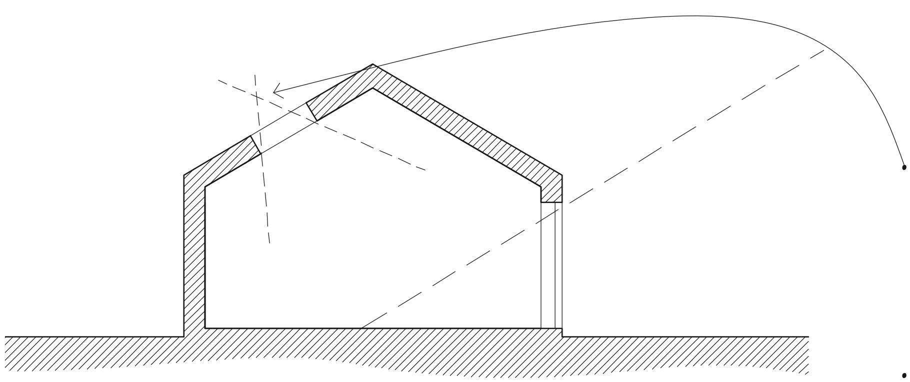
1.24 DAYLIGHTING



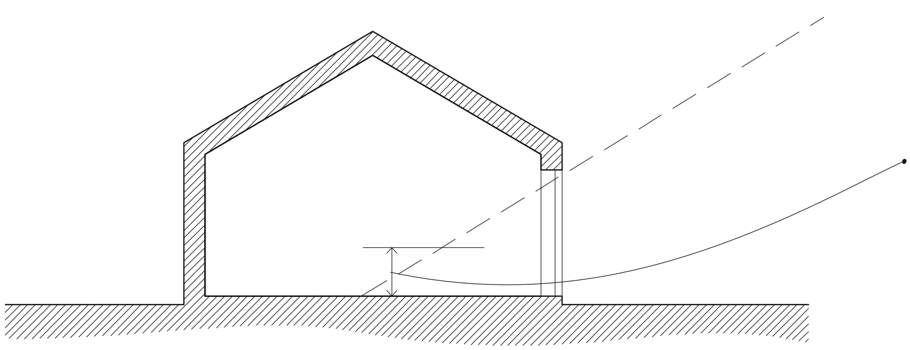
- Typically useful daylight will be experienced to a depth of up to twice the corresponding window head height
- Single-sided daylighting can lead to poor daylight uniformity. Where possible and where orientation and layout allow, daylight from at least two sides is preferable



- Daylighting from two directions can improve daylighting uniformity and also be used as part of a natural ventilation system
- The daylight factor is a measure of daylight as a percentage of the level of illumination available outside that will be experienced at a point in a corresponding inside space. To allow for natural variation the daylight factor is measured using a standard overcast sky. For daylight to be useful a minimum daylight factor of 2% is required with specific tasks such as reading requiring 4–6%

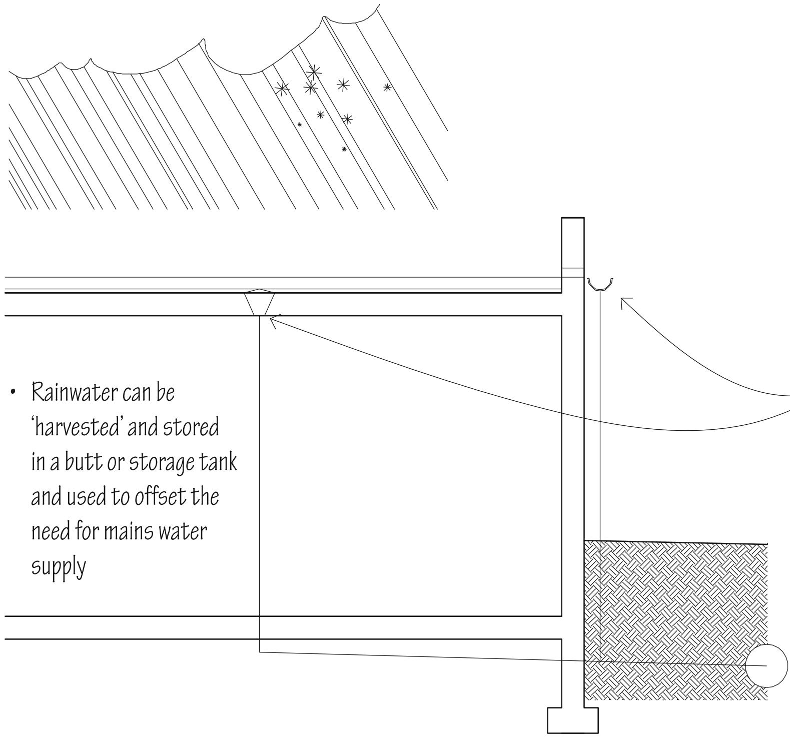


- North-facing roof lights can deliver good levels of daylighting and uniformity while avoiding the issues of glare and overheating
- Poor uniformity of daylight, or where the back of the room has a low daylight factor and the front a high daylight factor, can lead to issues of visual discomfort such as glare



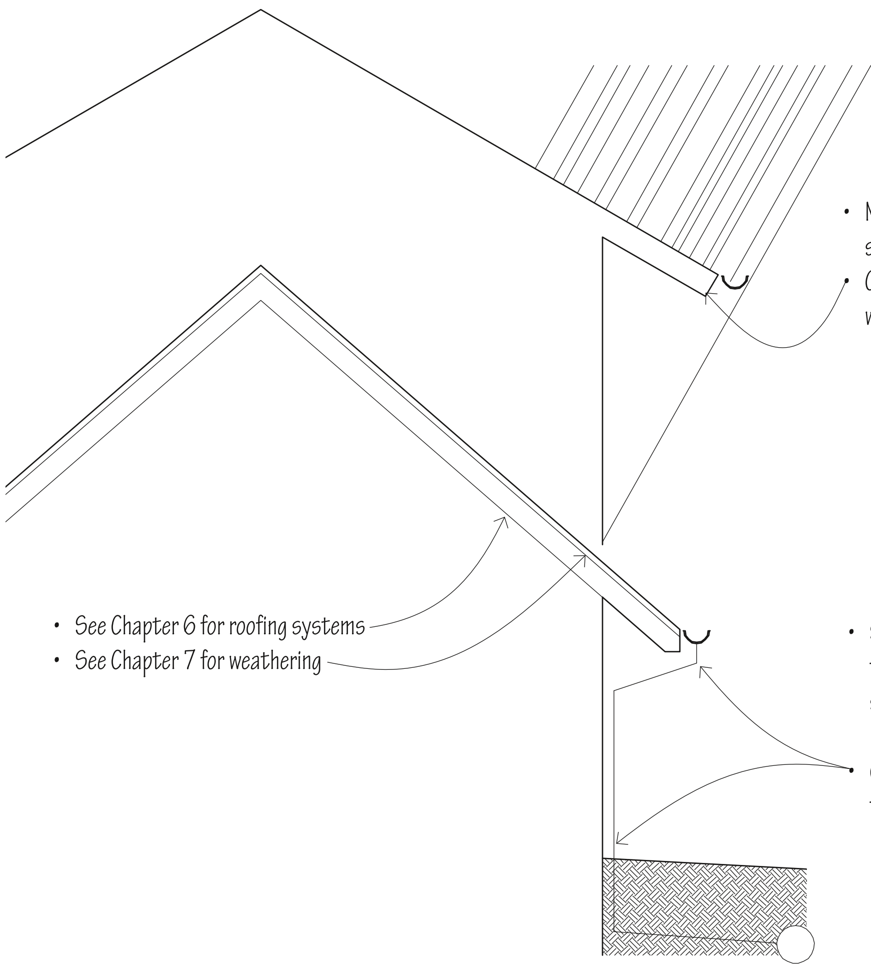
- Daylighting levels in an internal space should be measured at the working plane height (desk height) normally 700 mm above the finished floor level

The amount of annual and seasonal precipitation expected for a building site should influence the design and construction of the roof structure of a building, the choice of building materials and the detailing of its exterior wall assemblies. Furthermore, the run-off of rain and melting snow from constructed roof areas and paved surfaces increases the amount of surface water that must be drained from the site.



- Rainwater can be 'harvested' and stored in a butt or storage tank and used to offset the need for mains water supply

- Flat roofs require either interior roof drains or gutters along their perimeter for drainage
- In cold climates, flat roofs are subject to heavy snow loads. The layer of snow may serve as additional insulation



- Moderately pitched roofs easily shed rain but may retain snow
- Overhangs protect the exterior walls of a building from the weathering effects of sun and rain

- See Chapter 6 for roofing systems
- See Chapter 7 for weathering

- Steeply pitched roofs shed rainwater quickly. If the angle of the slope is greater than 60°, the roof may also be able to slough off snow

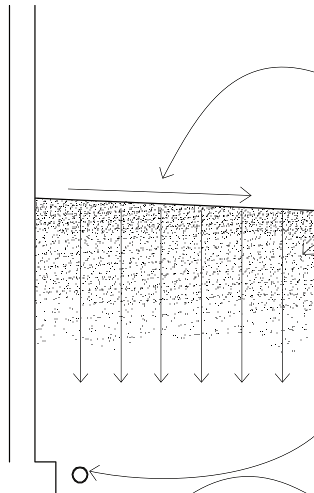
- Gutters and downspouts lead to a surface water sewer or to a natural soakaway on the site

1.26 SITE DRAINAGE

Development of a site can disrupt the existing drainage pattern and create additional water flow from constructed roof areas and paved surfaces. Limiting disruption of a site's natural hydrology and promoting infiltration by such means as pervious paving and green roofs is preferable. Site drainage is necessary to prevent erosion and the collection of excess surface water or groundwater resulting from new construction.

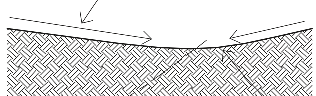
There are two basic types of site drainage: subsurface and surface drainage systems. Subsurface drainage consists of an underground network of piping for conveying groundwater to a point of disposal, as a storm sewer system or a natural outfall at a lower elevation on the site. Excess groundwater can reduce the load-carrying capacity of a foundation soil and increase the hydrostatic pressure on a building foundation. Waterproofing is required for basement structures situated close to or below the water table of a site.

Surface drainage refers to the grading and surfacing of a site in order to divert rain and other surface water into natural drainage patterns or a local authority sewer system. An attenuation pond may be necessary when the amount of surface run-off exceeds the capacity of the storm sewer system.

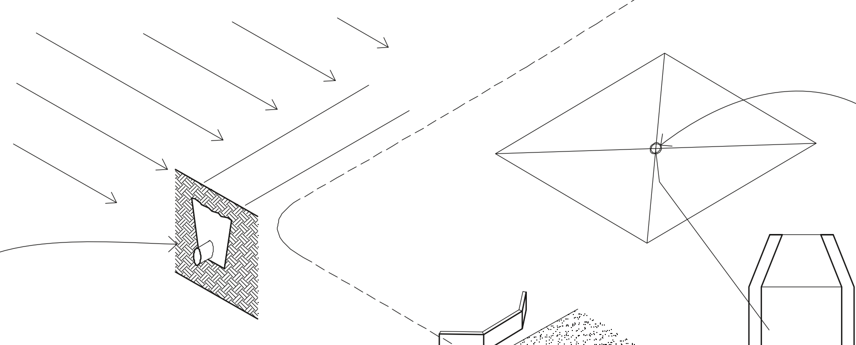


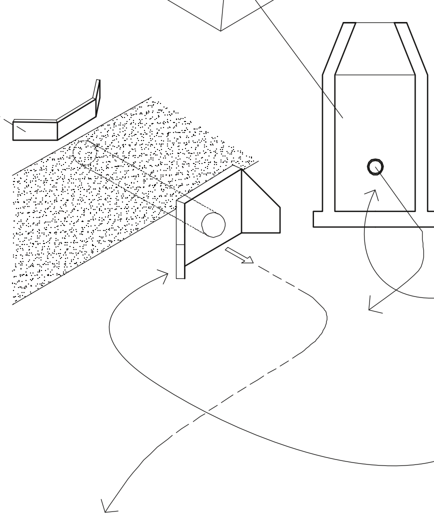
- Finish grades should be sloped to drain surface water away from a building: 5% minimum; 2% minimum for impervious surfaces
- Groundwater consists largely of surface water that has seeped down through porous soil
- Foundation drain system; see 3.14

Surface Drainage Slopes
- Grass lawns and fields: 1.5–10% recommended
- Paved parking areas: 2–3% recommended



- Swales are shallow depressions formed by the intersection of two ground slopes, designed to direct or divert the run-off of surface water. Vegetated swales can increase infiltration

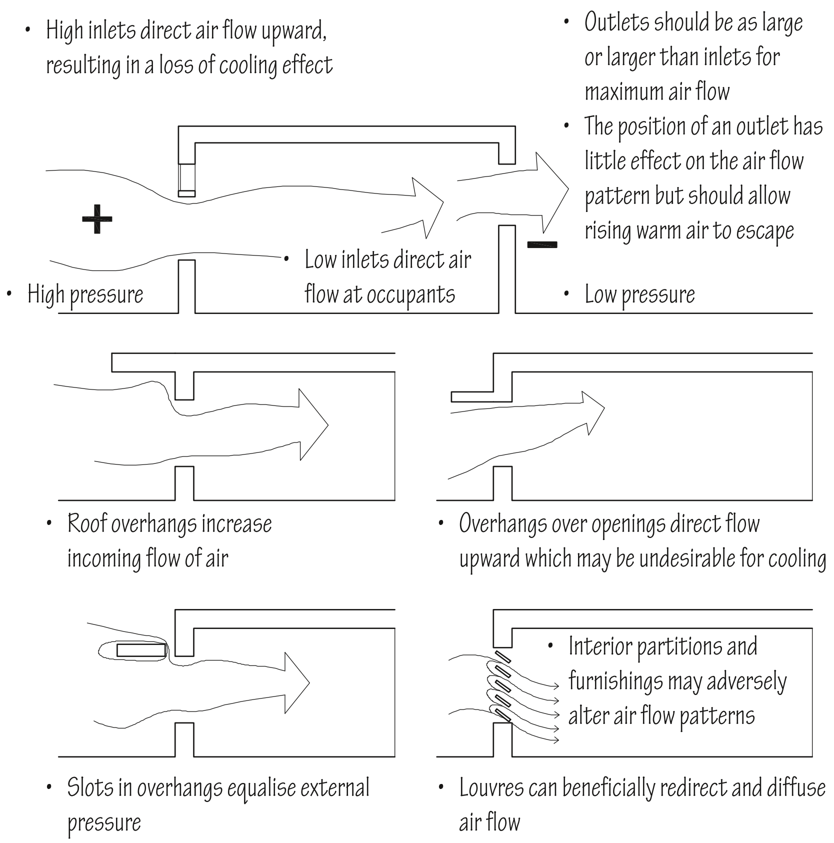


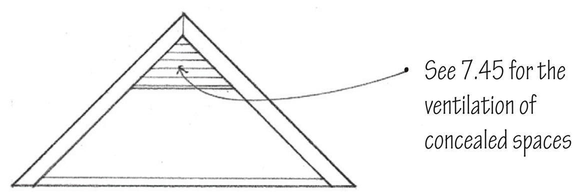


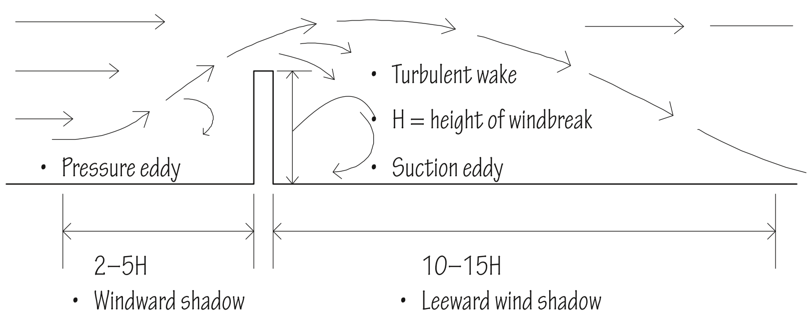
- Surface water drains collect water from a paved or impermeable area where necessary
- Soakaways are drainage pits lined with gravel or rubble to receive surface water and allow it to percolate away to absorbent earth underground
- Gullies have a basin or sump that retains heavy sediment before it can pass into underground drainage, they may also have a trap
- Culverts are drains or channels passing under a road or walkway

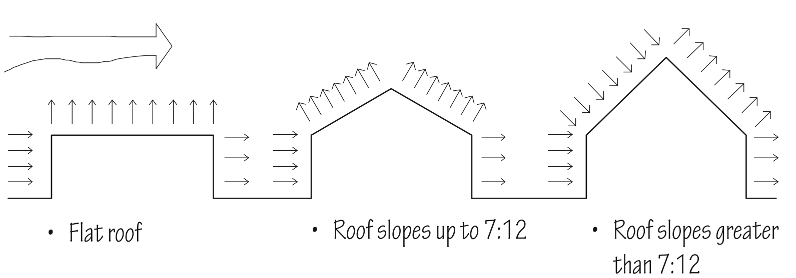
- A curtain or intercepting drain may be placed between a source of groundwater and the area to be protected
- One type of curtain drain is a French drain, which consists of a trench filled to ground level with loose stones or rock fragments

LEED SS Credit 6.1, 6.2: Stormwater Design
LEED WE Credit 2: Innovative Wastewater Technologies
BREEAM POL 03: Surface Water Run-Off









The direction and velocity of prevailing winds are important site considerations in all climatic regions. The seasonal and daily variations in wind should be carefully considered in evaluating its potential for ventilating interior spaces and outdoor courtyards in warm weather, causing heat loss in cold weather and imposing lateral loads on a building structure.

Wind-induced ventilation of interior spaces aids in the air exchange necessary for health and odour removal. In hot weather, and especially in humid climates, ventilation is beneficial for convective or evaporative cooling. Natural ventilation also reduces the energy required by mechanical fans and equipment.
(LEED IEQ Credit 2: Increased Ventilation)

The movement of air through a building is generated by differences in air pressure as well as temperature. The resulting patterns of air flow are affected more by building geometry and orientation than by air speed.

The ventilation of concealed roof spaces is required to remove moisture and control condensation. In hot weather, attic ventilation can also reduce overhead radiant heat gain.

In cold climates, a building should be buffered against chilling winds to reduce infiltration into interior spaces and lower heat loss. A windbreak may be in the form of an earth berm, a garden wall or a dense stand of trees. Windbreaks reduce wind velocity and produce an area of relative calm on their leeward side. The extent of this wind shadow depends on the height, depth and density of the windbreak, its orientation to the wind and the wind velocity.

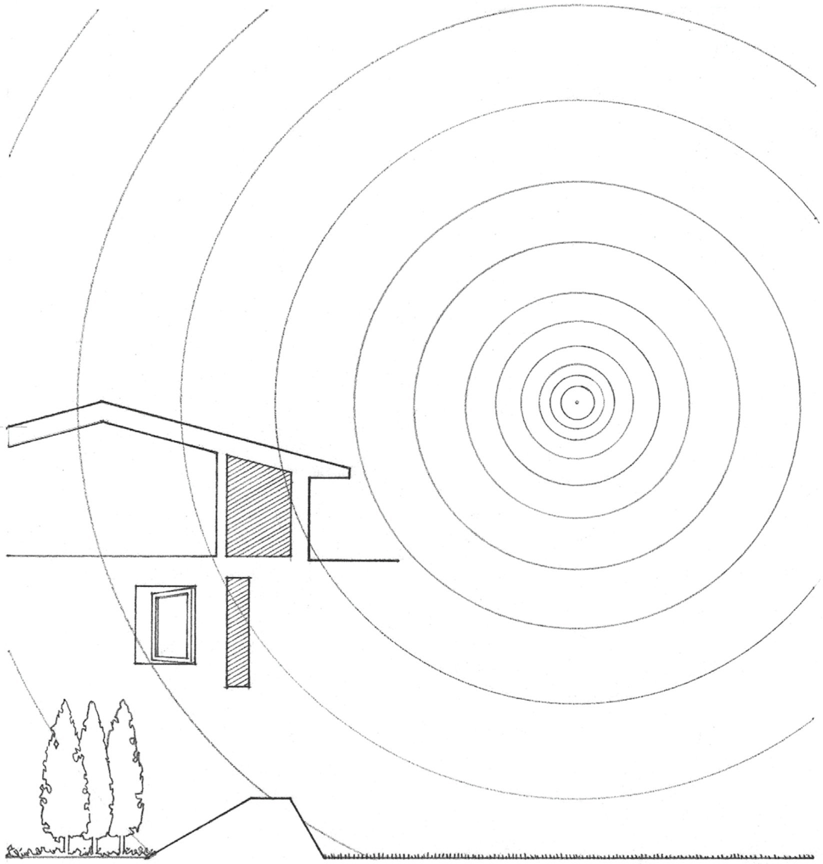
- A partially penetrable windscreen creates less pressure differential, resulting in a large wind shadow on the leeward side of the screen

The structure, components and cladding of a building must be anchored to resist wind-induced overturning, uplift and sliding. Wind exerts positive pressure on the windward surfaces of a building and on windward roof surfaces having a slope greater than 30°. Wind exerts negative pressure or suction on the sides and leeward surfaces and normal to windward roof surfaces having a slope less than 30°. See 2.09 for more information on wind forces.

SOUND & VIEWS

Sound requires a source and a path. Undesirable exterior sounds or noise may be caused by vehicular traffic, aircraft and other machinery. The sound energy they generate travels through the air outward from the source in all directions in a continuously expanding wave. This sound energy, however, lessens in intensity as it disperses over a wide area. To reduce the impact of exterior noise, therefore, the first consideration should be distance – locating a building as far from the noise source as possible. When the location or dimensions of a site do not make this possible, then the interior spaces of a building may be screened from the noise source in the following ways.

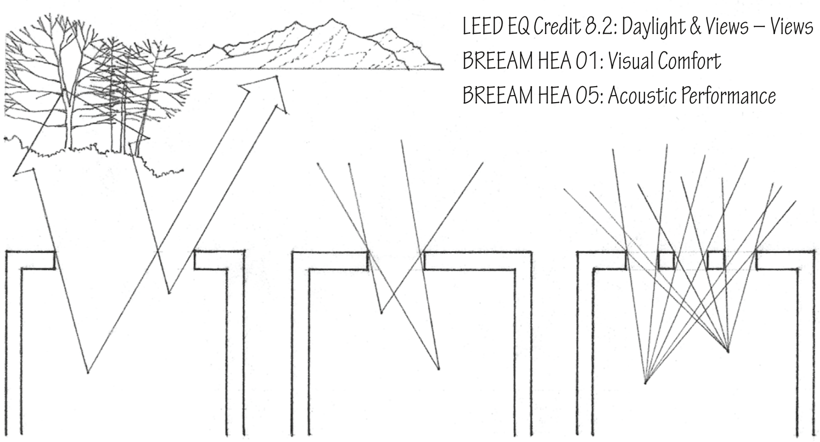
- Use building zones where noise can be tolerated, for example, mechanical, service and utility areas, as a buffer
- Employ building materials and construction assemblies designed to reduce the transmission of airborne and structure-borne sound
- Orient door and window openings away from the sources of undesirable noise
- Place physical mass, such as earth berms, between the noise source and the building
- Utilise dense planting of trees and shrubs, which can be effective in diffusing or scattering sound
- Plant grass or other ground cover, which is more absorptive than the hard, reflective surfaces of pavements



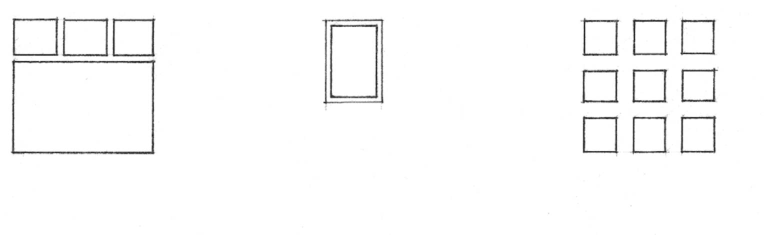
An important aspect of site planning is orienting the interior spaces of a building to the amenities and features of a site. Given the appropriate orientation, window openings in these spaces should be positioned not only to satisfy the requirements for natural light and ventilation, but also to reveal and frame desirable views. Depending on the location of the site, these views may be close or distant in nature. Even when desirable views are non-existent, a pleasant outlook can often be created within a building site through landscaping.

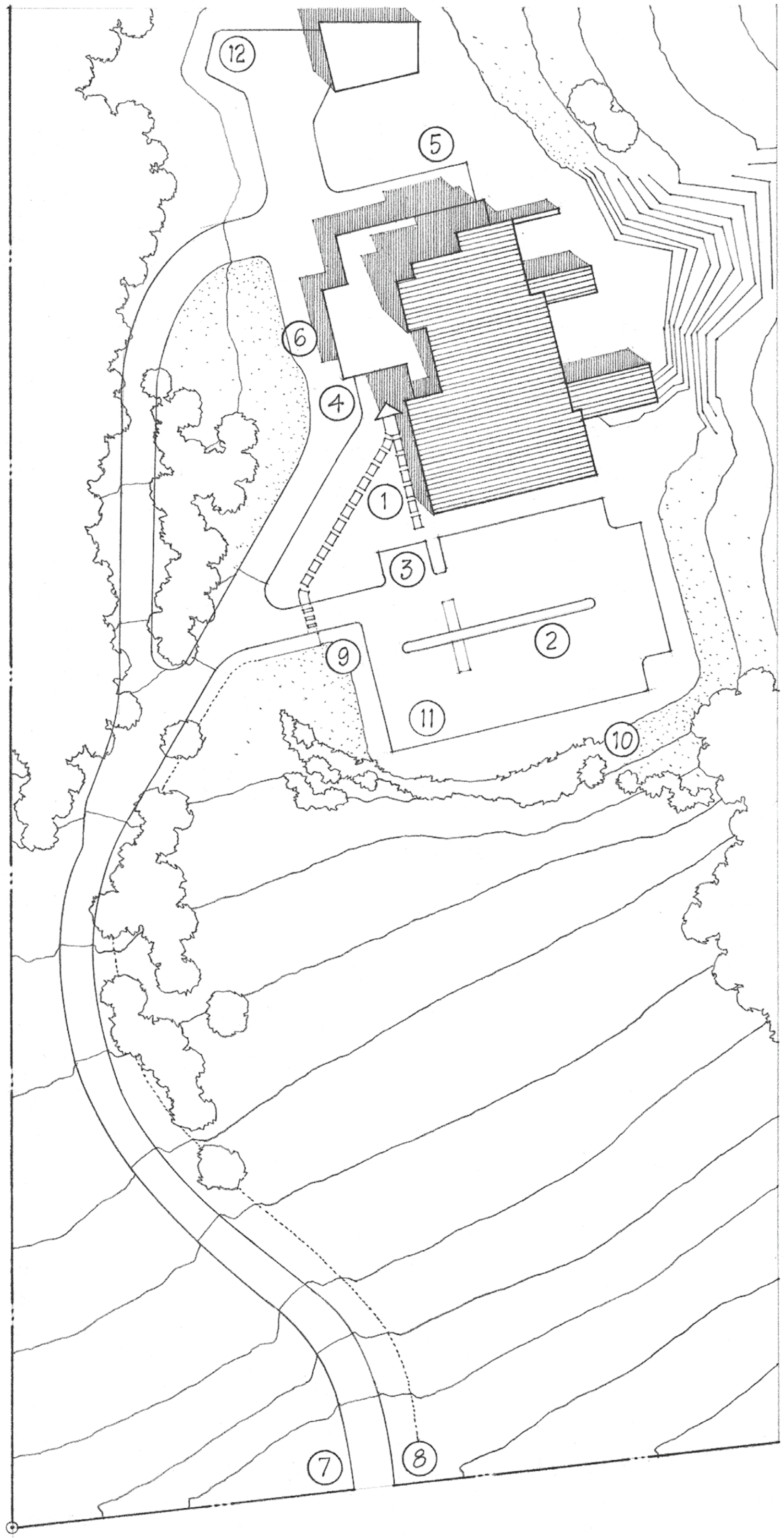
A window may be created within a wall in a number of ways, depending on the nature of the view and the way it is framed in the wall construction. It is important to note that the size and location of windows also affect the spatial quality and daylighting of a room, and the potential for heat loss or gain.

LEED EQ Credit 8.2: Daylight & Views – Views
BREEAM HEA 01: Visual Comfort
BREEAM HEA 05: Acoustic Performance



- Expansive view
- Restricted view
- Filtered view





Providing for access and circulation for pedestrians, personal vehicles and service vehicles is an important aspect of site planning, which influences both the location of a building on its site and the orientation of its entrances. Outlined here and on the following pages are fundamental criteria for estimating and laying out the space required for walkways, roadways and surface parking.

1. Provide for safe and convenient pedestrian access and movement to building entrances from parking areas or public transit stops with minimal crossing of roadways
2. Determine the number of parking spaces required by the planning authority for the type of occupancy and total number of units or floor area of the building
3. Determine the number of accessible parking spaces as well as ramps, and paths to accessible building entrances required by building regulations
4. Provide loading zones for buses and other public transport vehicles where applicable
5. Separate service and truck loading areas from pedestrian and vehicular traffic
6. Furnish access for emergency vehicles such as fire engines and ambulances
7. Establish the required width and location of crossways and their intersection with public streets
8. Ensure clear sightlines for vehicles entering public roadways
9. Plan for control of access to parking areas where required.
10. Provide space for landscaping; screening of parking areas may be required by planning requirements
11. Slope paved walkways and parking areas for drainage
12. Provide space for snow removal equipment in cold climates

Illustration adapted from the site plan for the Maison Louis Carré House, designed by Alvar Aalto

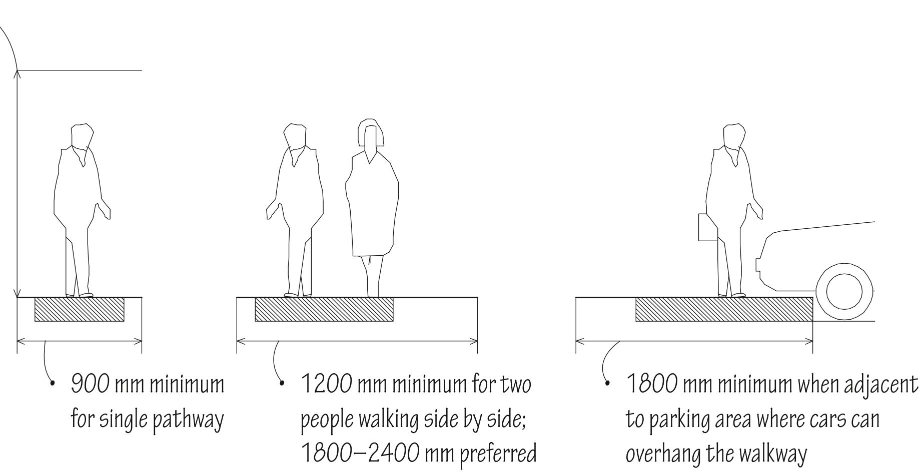
- 2400 mm minimum overhead clearance
- Minimise conflicts with roadways and parking areas
- Provide traction in areas subject to icy conditions
- 0.5% minimum slope for drainage; 1.5% preferred

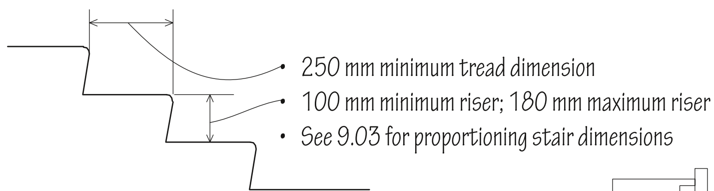
Pedestrian Walks

- Minimum of three risers per run of stairs
- Handrails are required for stairs having four or more risers, or where icy conditions exist

Exterior Stairs

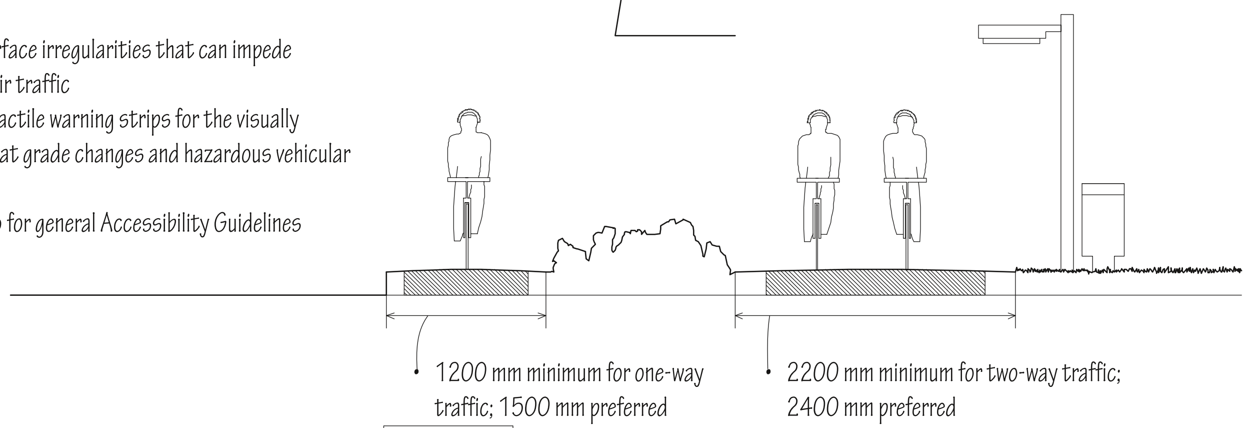
- Provide amenities, such as benches, rubbish bins and lighting

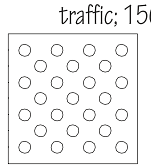




Bike Paths

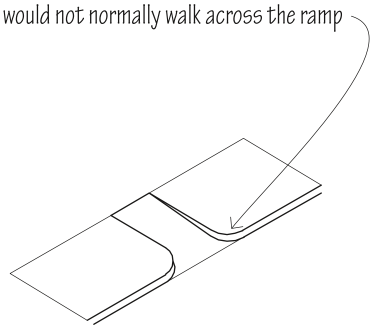
- Avoid surface irregularities that can impede wheelchair traffic
- Provide tactile warning strips for the visually impaired at grade changes and hazardous vehicular areas
- See A.03 for general Accessibility Guidelines

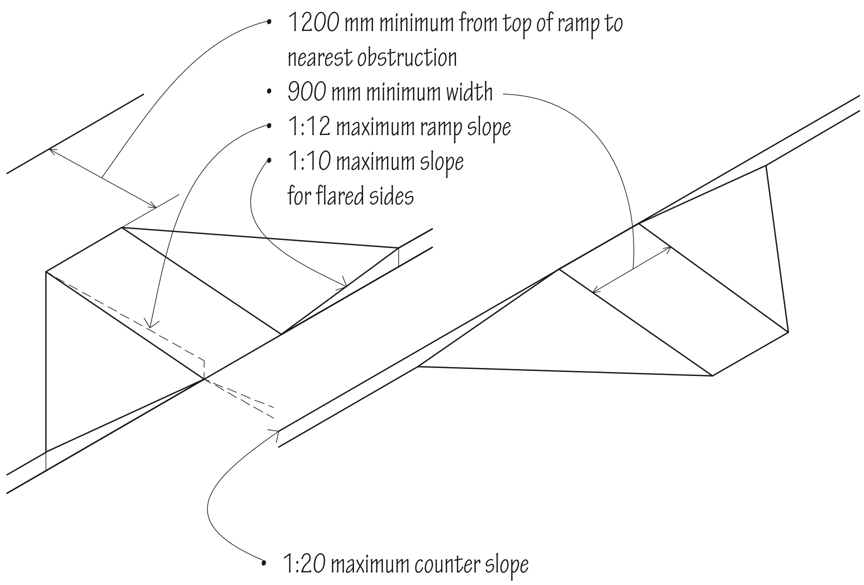




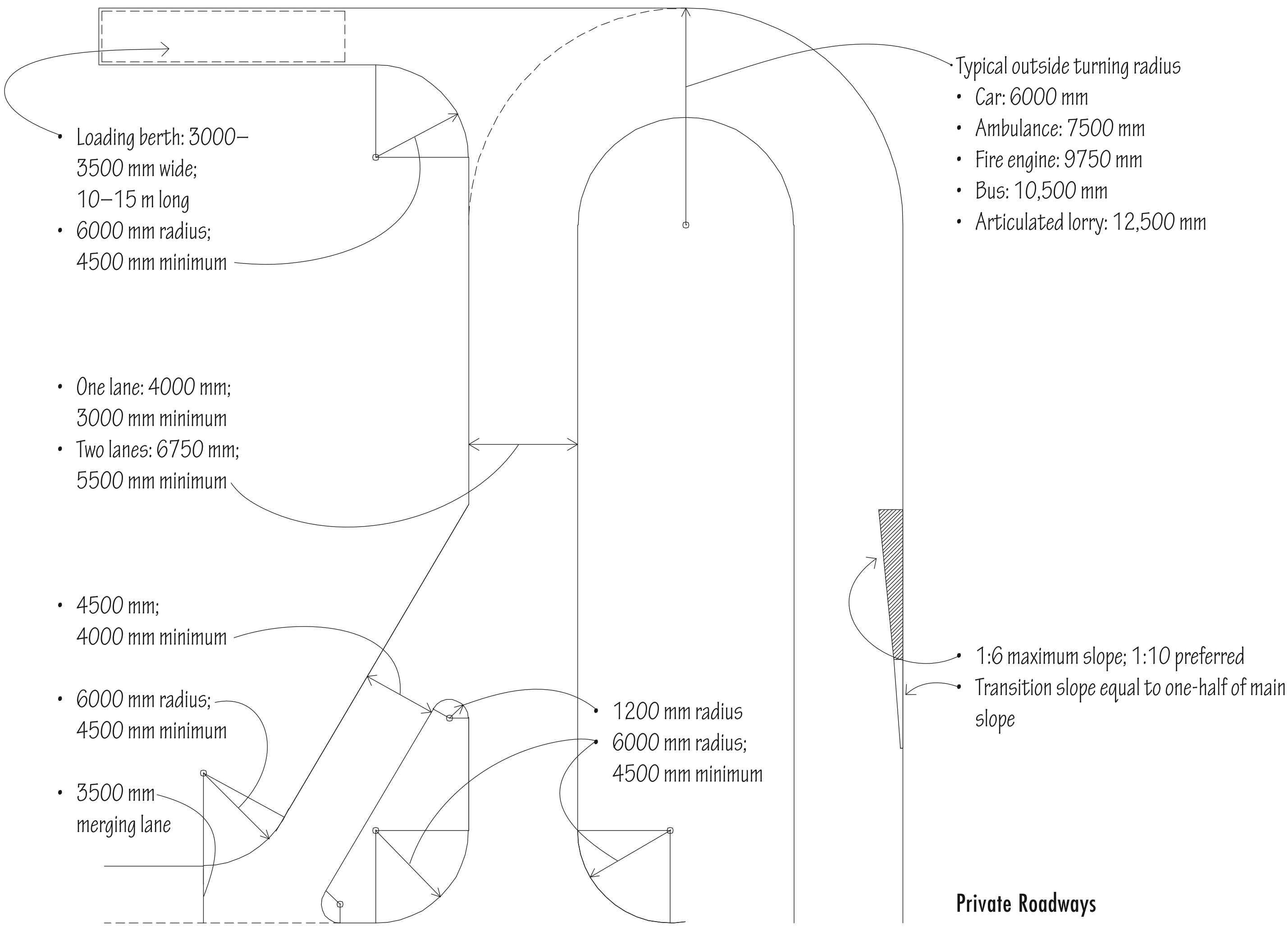
Accessibility Guidelines

- Kerb ramps are required wherever an accessible route crosses a kerb
- Surface of ramp should be stable, firm and slip-resistant
- Returned kerbs are allowable where pedestrians would not normally walk across the ramp

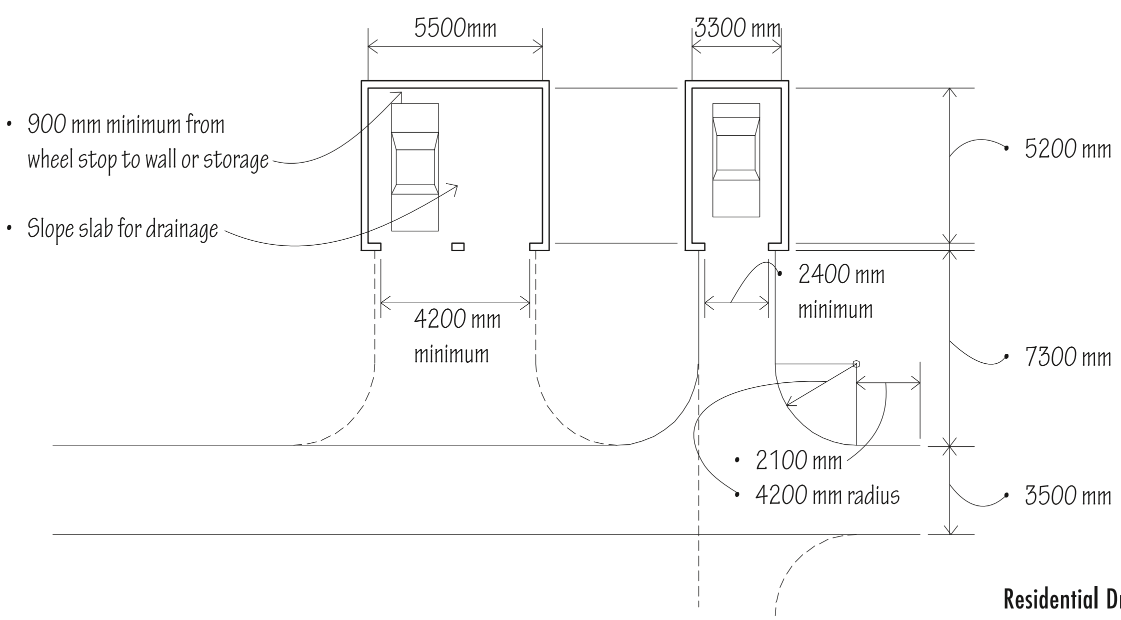




Kerb Ramps



Private Roadways



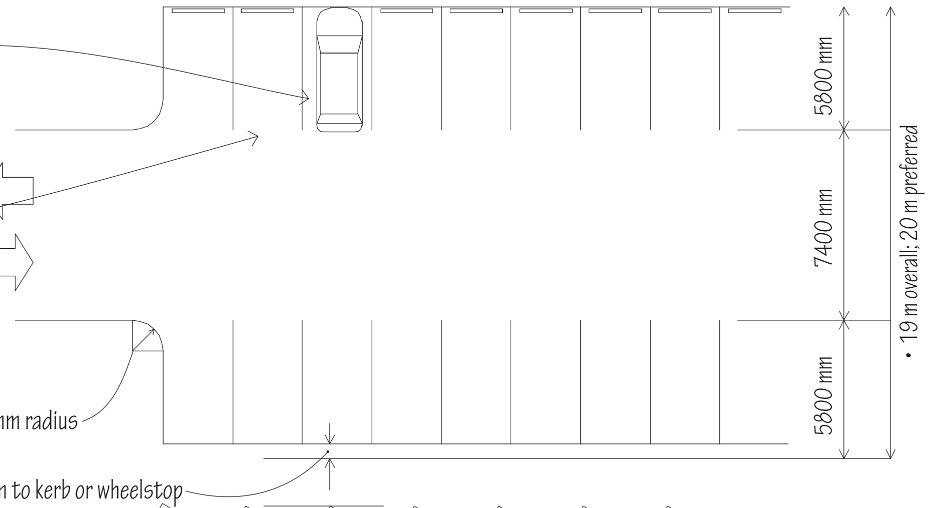
Residential Drives and Garages

Required criteria may vary from one location to another and depending on the classification of the road.

Vehicle Dimensions
- Small car: 1900 x 4000 mm
- Standard car: 1900 x 4500 mm

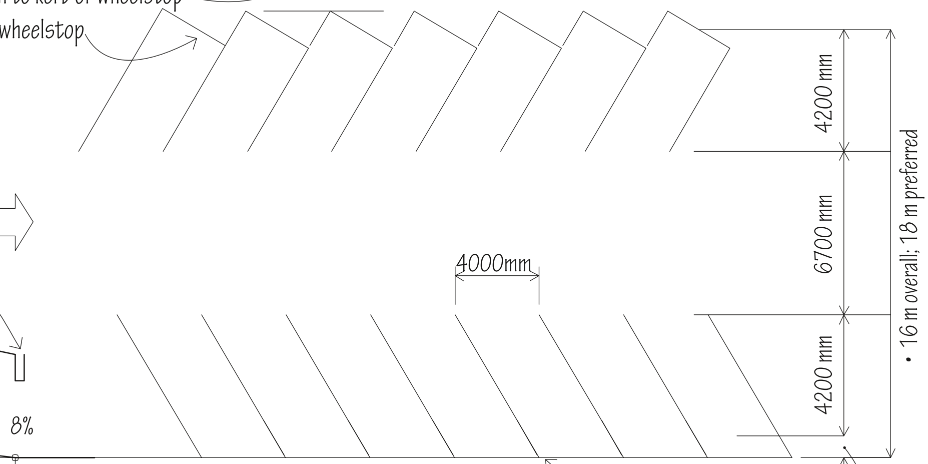
Parking Spaces
- Standard cars: 2400–2800 mm x 5800–6000mm

- Slope 1–5% for drainage; 2–3% recommended

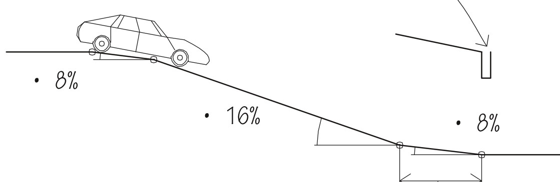


- 1200 mm radius
- 760 mm to kerb or wheelstop
- Kerb or wheelstop

Car Parks



- 2100 mm minimum overhead clearance

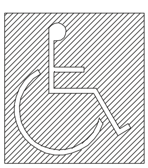


- Transition slope equal to one-half of ramp slope; 3050 mm length

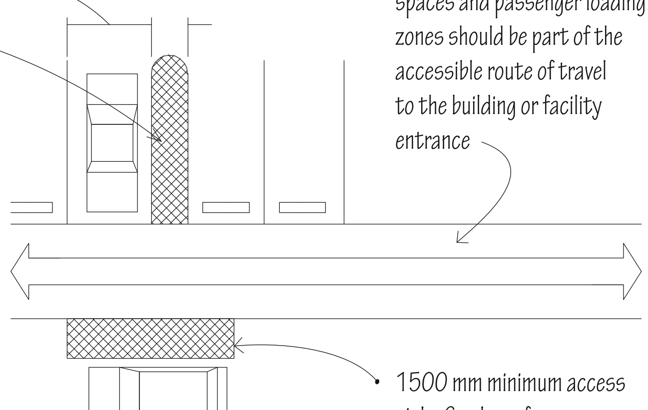
- Wall line
- 800 mm

- Access aisles for parking spaces and passenger loading zones should be part of the accessible route of travel to the building or facility entrance

Garage Ramps



- 2400 mm minimum width
- Access aisle; may be shared by two accessible parking spaces
- Identify accessible parking spaces with a sign showing the international symbol of accessibility

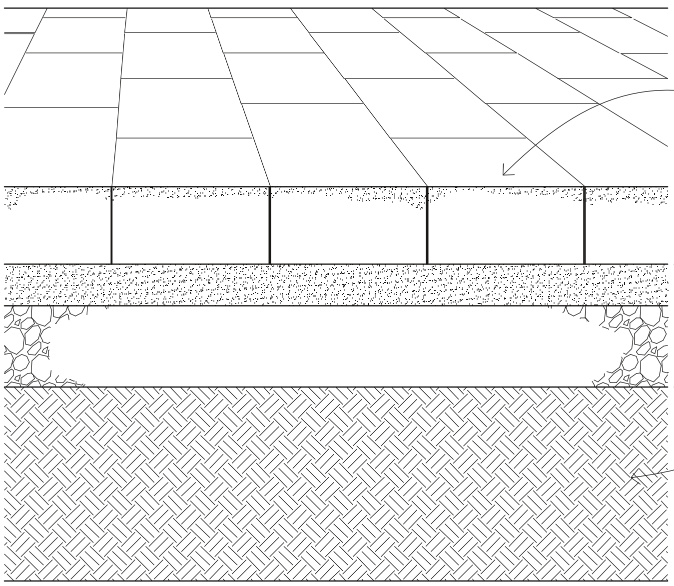


- Accessible parking spaces for vans used by persons with disabilities should have a clear height of 2500 mm and an access aisle at least 2400 mm wide

- Generally the number of accessible spaces required is regulated by local planning policy
- Locate accessible parking spaces as close as possible to building or facility entrance
- 1:50 maximum slope for spaces and access aisles

- 1500 mm minimum access aisle, 6 m long, for passenger loading zones adjacent and parallel to the vehicle pull-up space

Required criteria may vary from one location to another. In the UK *The Metric Handbook* (Littlefield, 2004) provides detailed design data.



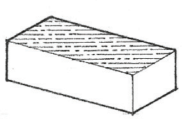
Paving provides a wearing surface for pedestrian or vehicular traffic on a site. It is a composite structure the thickness and construction of which are directly related to the type and intensity of traffic and loads to be carried, and the bearing capacity and permeability of the subgrade.

- The pavement receives the traffic wear, protects the base and transfers its load to the base structure. There are two types of pavement: flexible and rigid
- The base is a foundation of well-graded aggregate that transfers the pavement load to the subgrade. It also prevents the upward migration of capillary water. Heavy-duty loads may require an additional layer of subbase of coarser aggregate
- The subgrade, which must ultimately carry the pavement load, should be undisturbed soil or compacted fill. Because it may receive moisture from infiltration, it should be sloped to drain

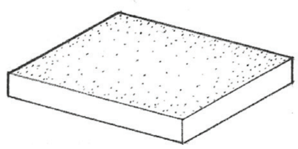
Flexible pavements, consisting of unit pavers of concrete, brick or stone laid on a sand setting bed, are somewhat resilient and distribute loads to the subgrade in a radiating manner. They require wood, steel, stone, masonry or concrete edging to restrain the horizontal movement of the paving material.

Rigid pavements, such as reinforced-concrete slabs or paving units mortared over a concrete slab, distribute their loads internally and transfer them to the subgrade over a broad area. They require reinforcement and an extension of the base material along their edges.

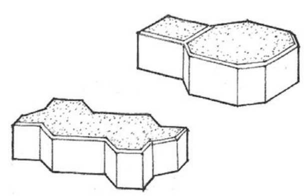
- 1% minimum slope for drainage; highly textured paving may require a steeper slope



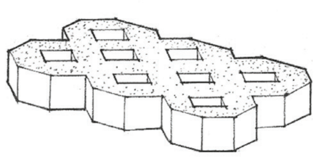
- Brick paver: 100 x 100, 205, 305; 25–60 mm thick



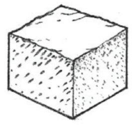
- Concrete unit paver: 305, 455, 610 mm square; 38–75 mm thick



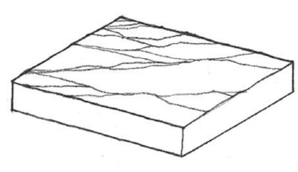
- Interlocking pavers: 64–90 mm thick



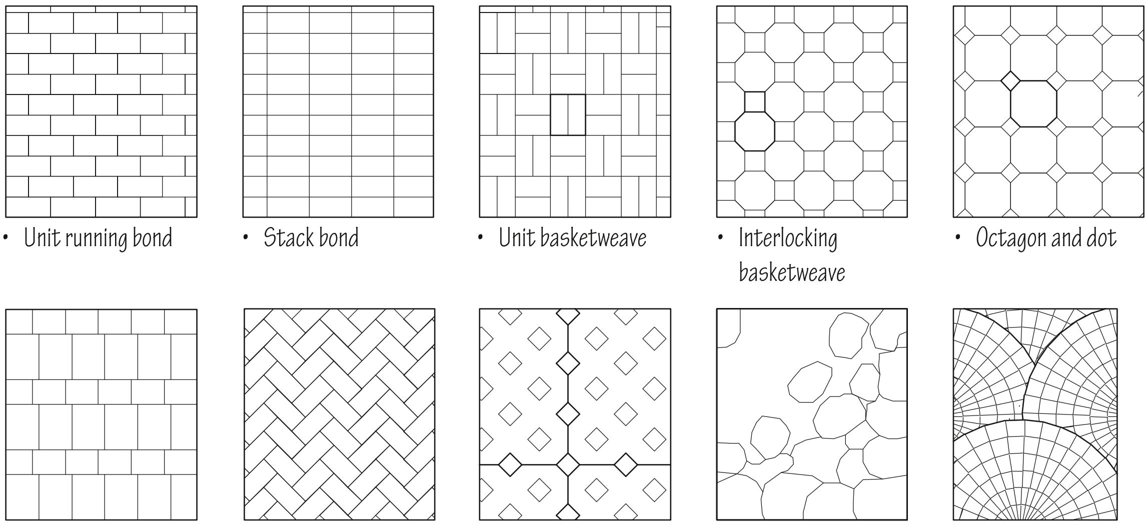
- Grid or turf block: 90 mm thick



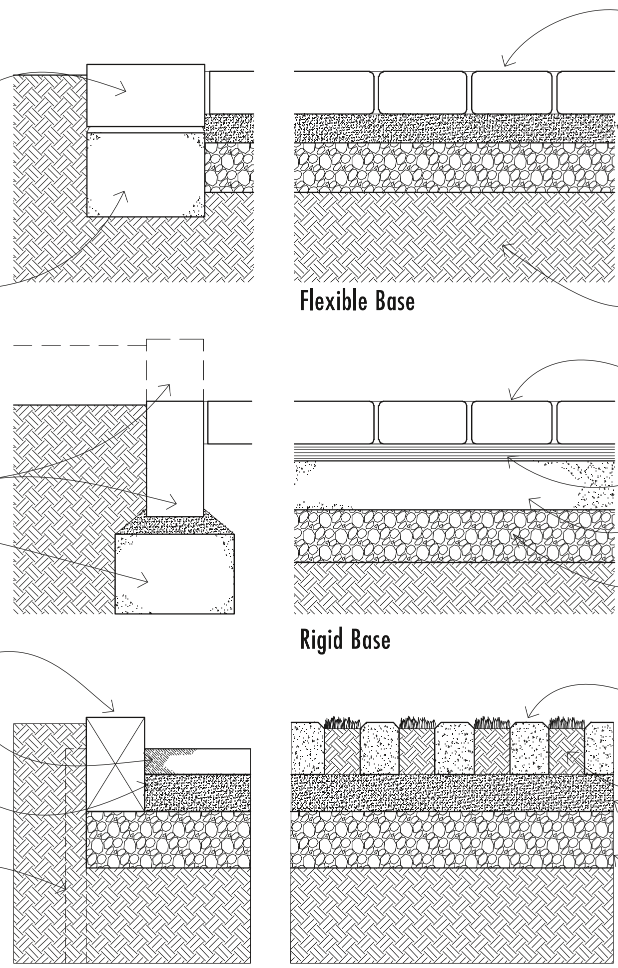
- Granite cobble: 100 or 150 mm square; 150 mm thick



- Cut stone: width and length varies; 25–50 mm thick

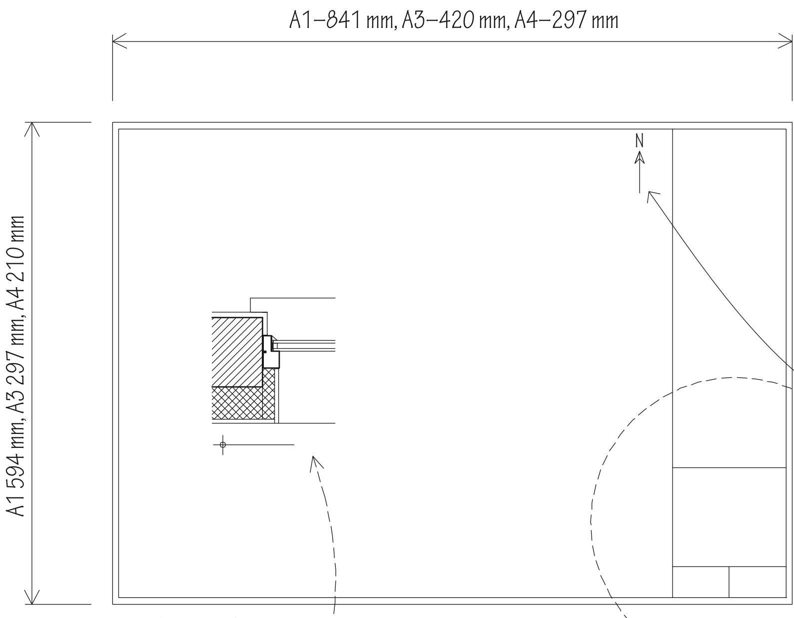


Paving Patterns



Edge Conditions

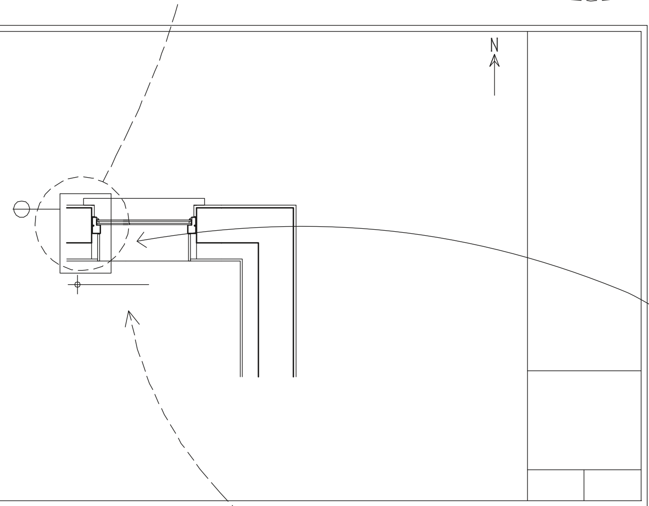
Paving Details



Detail 1:2, 1:5 or 1:10

Construction details visually explain how the various materials and elements that make up a building are joined. As buildings are composed of many materials it is important to take account of how those materials will interact with each other and with the environment around them. A well detailed building will stand the test of time, whereas a poorly detailed building may become obsolete prematurely.

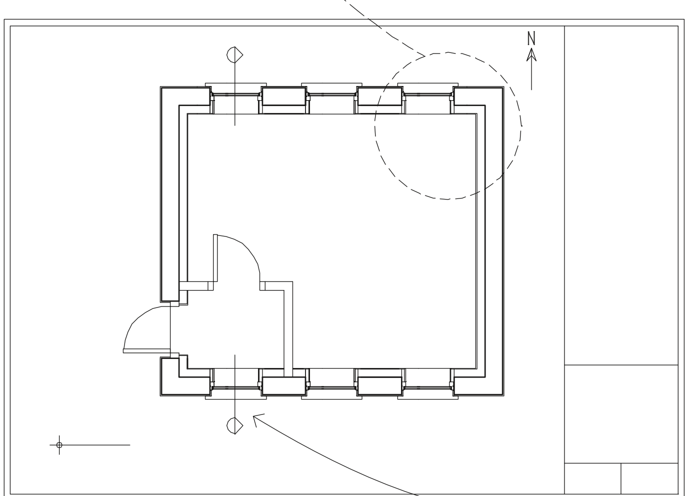
- All plan drawings should include a north-point, maps and other legal documents are oriented north to the top of the page by convention
- The title block contains important information such as drawing title, project name, scale, client and consultant details and drawing number



Detailed plan 1:20

As it may take large volumes of drawings to explain a building in sufficient detail it is important to include cross-referencing between the drawings to ensure the correct area is being considered. Cross-referencing may be between drawings, to window/door or other schedules or to specifications.

- Detailed plans include wall build-up, finishes and mechanical and electrical information
- Construction details should be identified and cross-referenced back to the relevant drawing



Floor plan 1:50 or 1:100

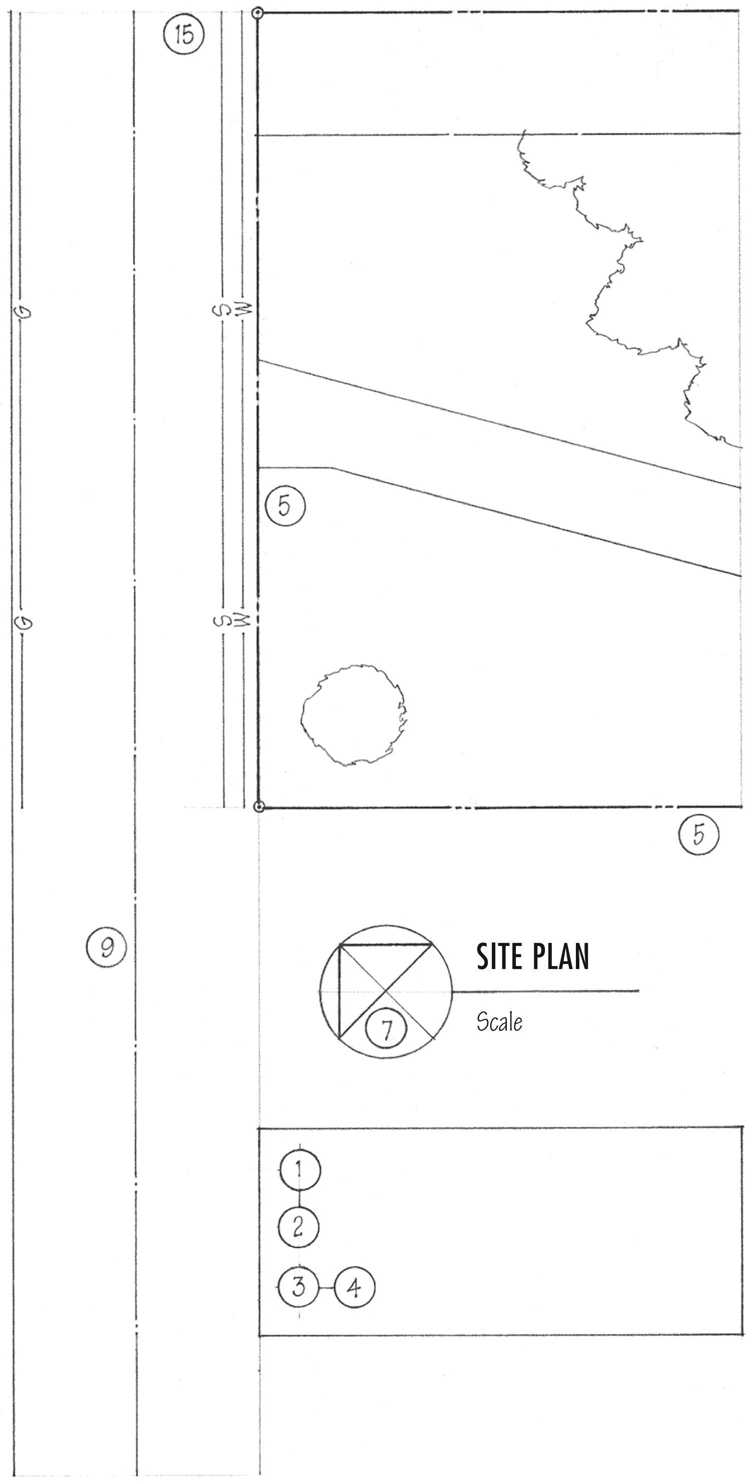
General arrangement drawings set out the location of the major elements within the building, such as openings and internal or external walls. The general arrangement drawing may contain layers of information such as the location of mechanical and electrical services, finishes, floor area and internal and external dimension of major elements. These plans should include door and window numbers (referencing to related schedules) and contain cross references to section and detail drawings.

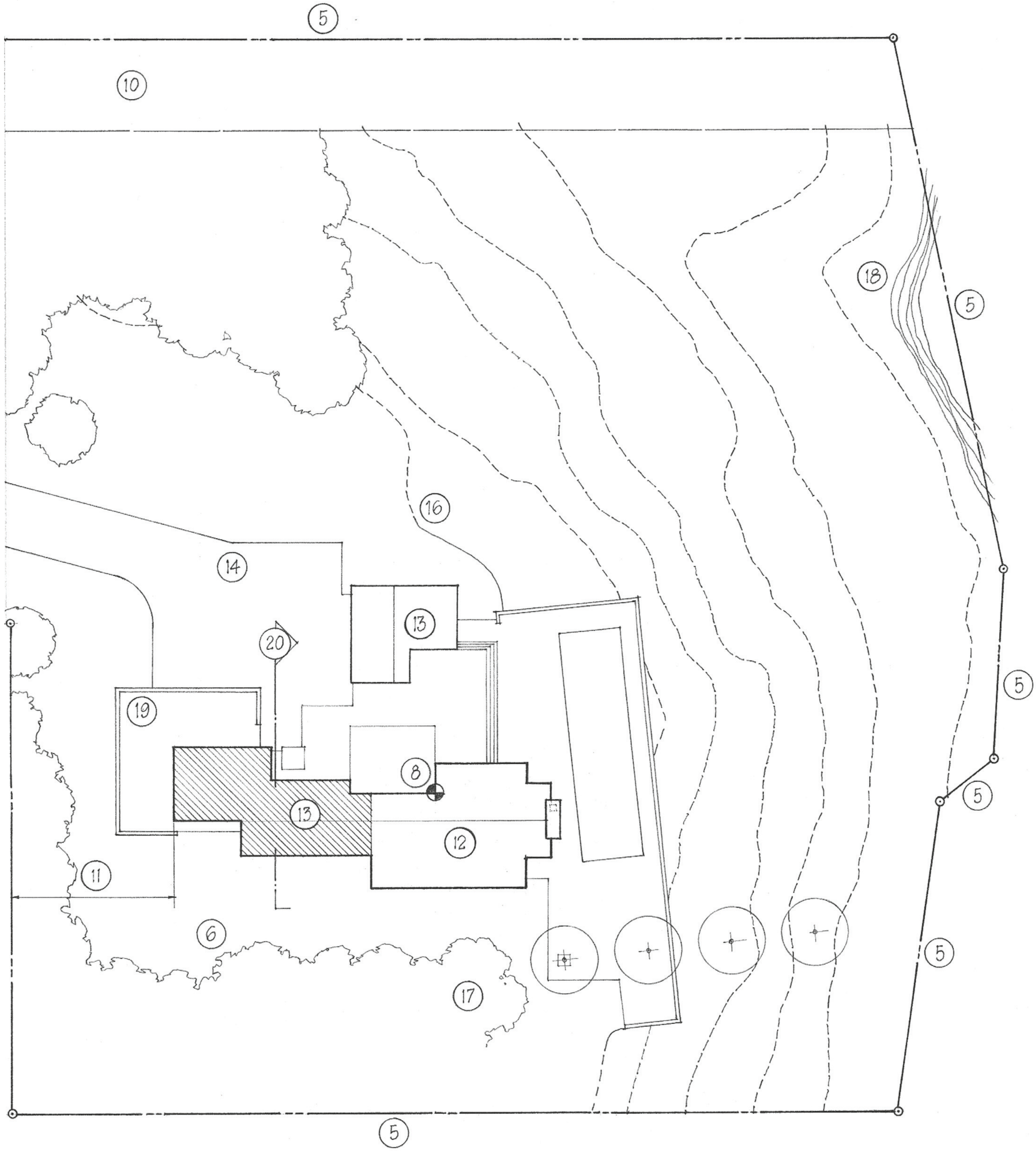
- Section lines indicate the location a section is taken and refer back to the relevant drawing number

1.36 THE SITE PLAN

The site plan illustrates the existing natural and built features of a site and describes proposed construction in relation to these existing features. The site plan is an essential piece of construction documentation. A completed site plan should include the following items:

1. Name and address of property owner
2. Address of property, if different from owner's address
3. Legal description of property
4. Source and date of land survey
5. Description of the site boundaries: dimensions of property lines, their bearing relative to north, angles of corners and radii of curves
6. Contract or project limits, if different from site boundaries
7. North point and scale of drawing
8. Location and description of benchmarks that establish the reference points for the location and elevations of new construction
9. Identification and dimensions of adjacent streets, lanes and other public rights-of-way
10. Location and dimensions of any easements or rights-of-way that cross the site
11. Dimensions of setbacks required by planning
12. Location and size of existing structures and a description of any demolition required by the new construction
13. Location, shape and size of structures proposed for construction
14. Location and dimensions of existing and proposed paved walkways, drives and parking areas
15. Location of existing utilities: water mains, sanitary and sewers, gas lines, electrical power lines, telephone, data and cable lines, fire hydrants, as well as proposed points of connections
16. Existing contour lines, new contour lines and the finish grades of drives, walks, lawns or other improved surfaces after completion of construction or grading operations
17. Existing plant materials to remain and those to be removed
18. Existing water features, such as drainage swales, flood plains, watersheds or shorelines
19. Proposed landscaping features, such as fencing, retaining walls and planting; if extensive, landscaping and other site improvements may be shown on a separate site plan
20. References to related drawings and details

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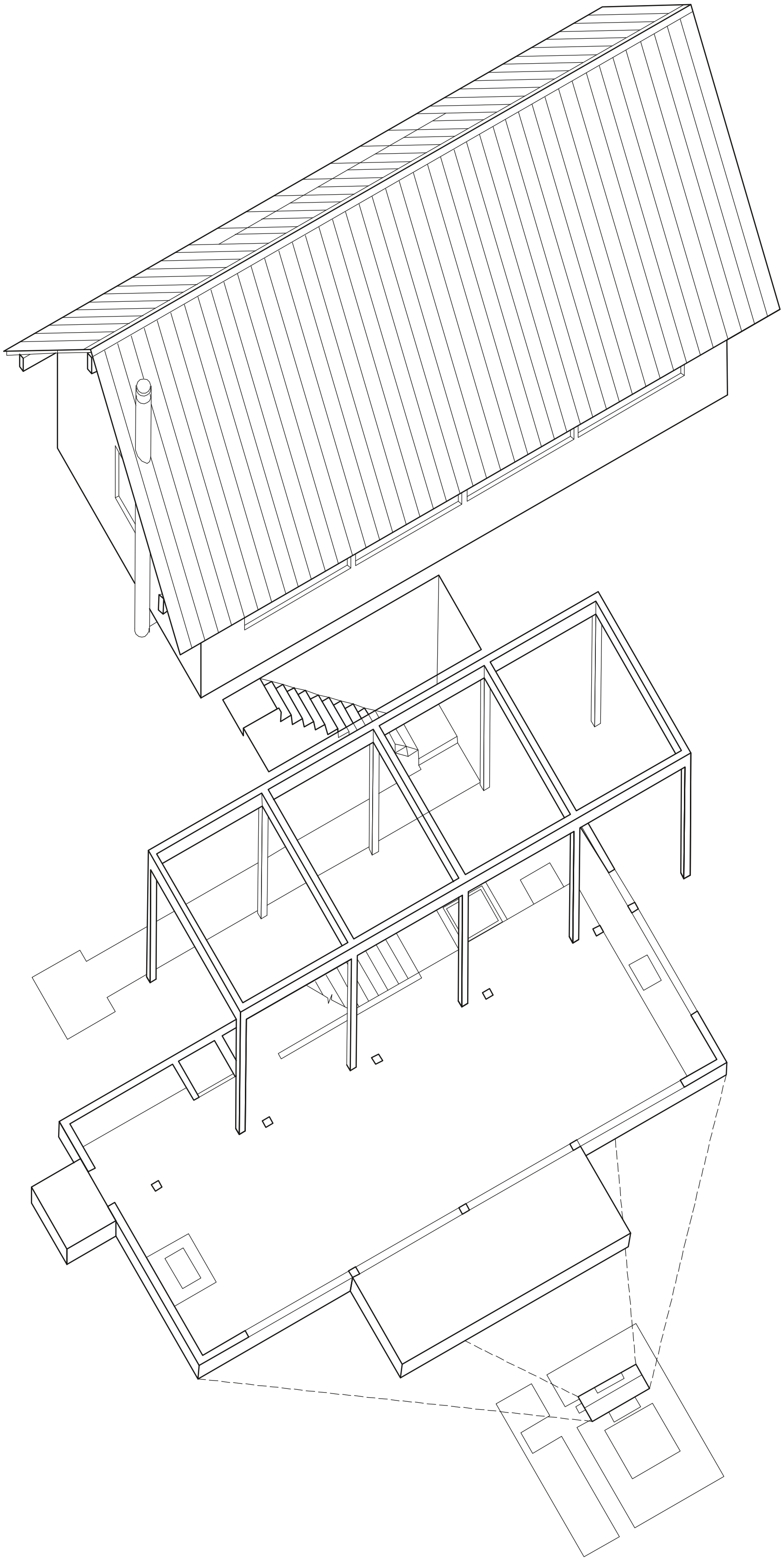
2

THE BUILDING



Architecture and building construction are not necessarily one and the same thing. An understanding of the methods for assembling various materials, elements and components is necessary during both the design and the construction of a building. This understanding, however, while it enables one to build architecture, does not guarantee it. A working knowledge of building construction is only one of several critical factors in the execution of architecture. When we speak of architecture as the art of building, we should consider the following conceptual systems of order in addition to the physical ones of construction:

- The definition, scale, proportion and organisation of the interior spaces of a building
- The ordering of human activities by their scale and dimension
- The functional zoning of the spaces of a building according to purpose and use
- Access to and the horizontal and vertical paths of movement through the interior of a building
- The sensible qualities of a building: form, space, light, colour, texture and pattern
- The building as an integrated component within the natural and built environment

Of primary interest to us in this book are the physical systems that define, organise and reinforce the perceptual and conceptual ordering of a building.

A system can be defined as an assembly of interrelated or interdependent parts forming a more complex and unified whole and serving a common purpose. A building can be understood to be the physical embodiment of a number of systems and subsystems that must necessarily be related, coordinated and integrated with each other as well as with the three-dimensional form and spatial organisation of the building as a whole.

Structural System

The structural system of a building is designed and constructed to support and transmit applied gravity and lateral loads safely to the ground without exceeding the allowable stresses in its members.

- The superstructure is the vertical extension of a building above the foundation
- Columns, beams and load-bearing walls support floor and roof structures
- The substructure is the underlying structure forming the foundation of a building

Building Envelope

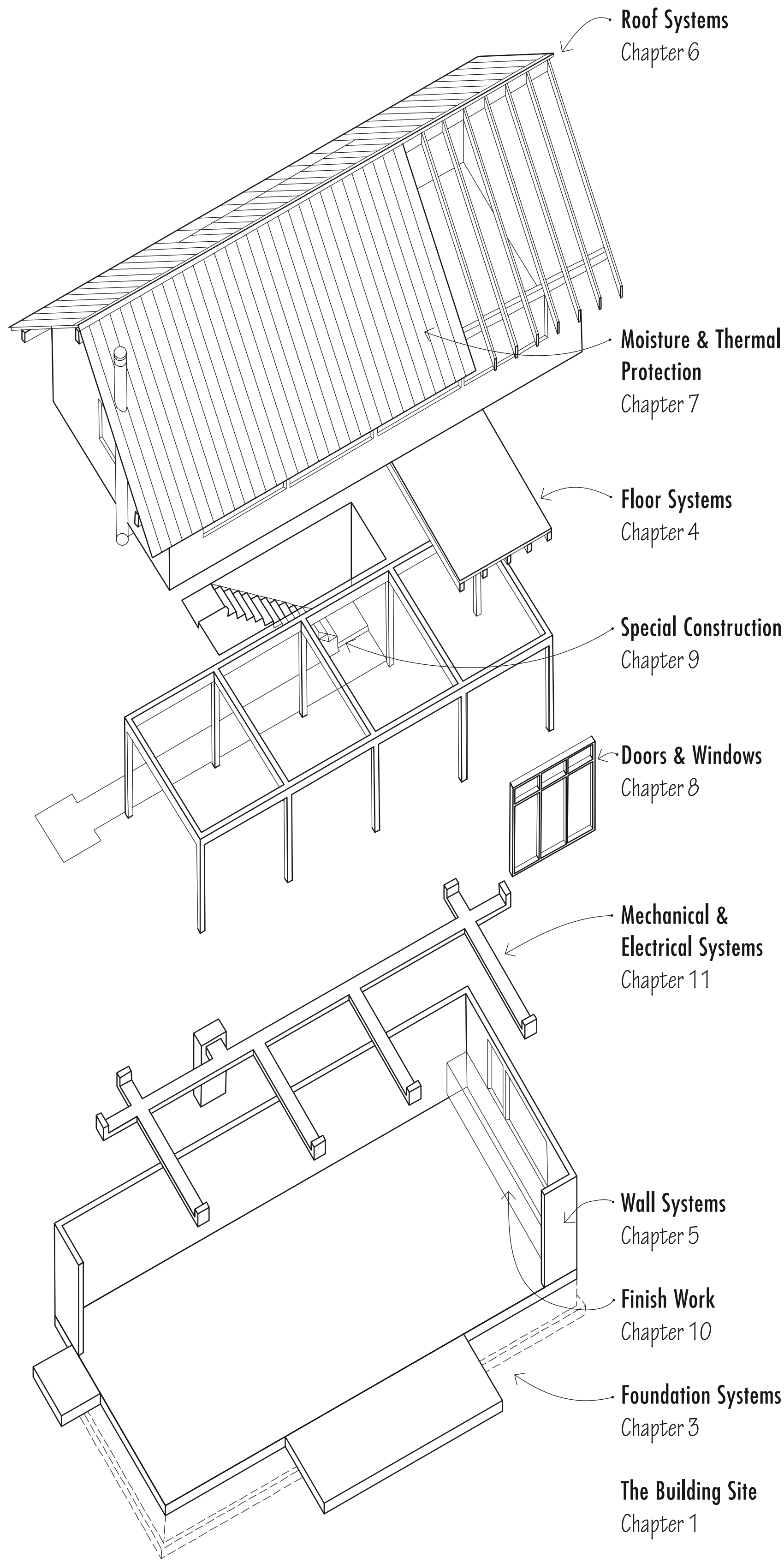
The building envelope is the shell of a building, consisting of the roof, exterior walls, windows and doors.

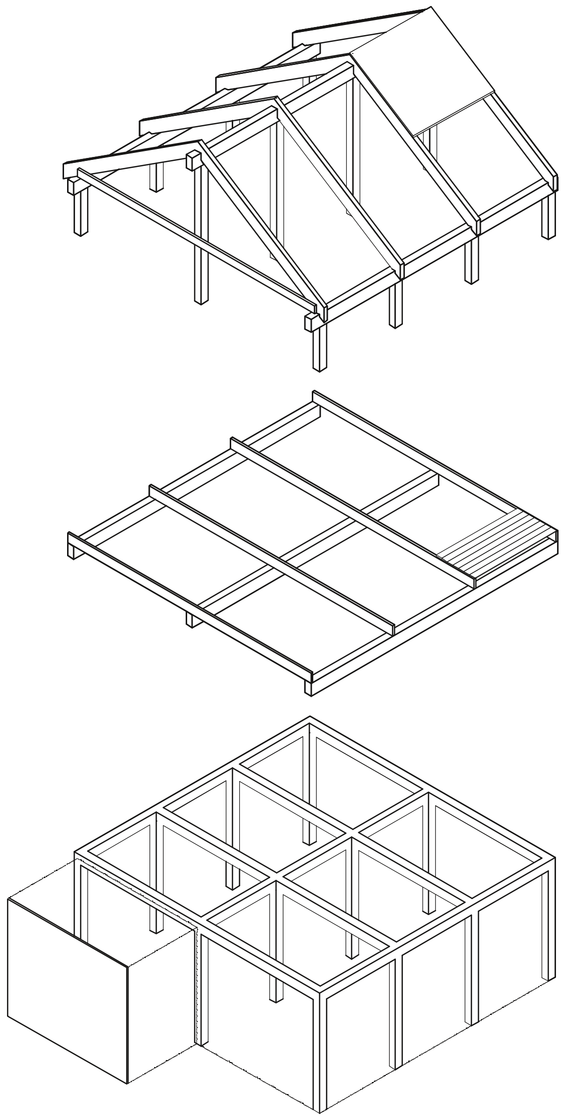
- The roof and exterior walls shelter interior spaces from inclement weather and control moisture, heat and air flow through the layering of construction assemblies, in effect acting as a filter
- Exterior walls and roofs also dampen noise and provide security and privacy for the occupants of a building
- Doors provide physical access
- Windows provide access to light, air and views
- Interior walls and partitions subdivide the interior of a building into spatial units

Mechanical Systems

The mechanical systems of a building provide essential services to a building.

- The water supply system provides potable water for human consumption and sanitation
- The sewage disposal system removes fluid waste and organic matter from a building
- Heating, ventilating and air-conditioning systems condition the interior spaces of a building for the environmental comfort of the occupants
- The electrical system controls, meters and protects the electric power supply to a building, and distributes it in a safe manner for power, lighting, security and communication systems
- Vertical transport systems carry people and goods from one level to another in medium- and high-rise buildings
- Fire-fighting systems detect and extinguish fires
- Structures may also require waste management and recycling systems





The manner in which we select, assemble and integrate the various building systems in construction should take into account the following factors:

Performance Requirements
- Structural compatibility, integration and safety
- Fire resistance, prevention and safety
- Allowable or desirable thickness of construction assemblies
- Control of heat and air flow through building assemblies
- Control of migration and condensation of water vapour
- Accommodation of building movement due to settlement, structural deflection and expansion or contraction with changes in temperature and humidity
- Noise reduction, sound isolation and acoustic privacy
- Resistance to wear, corrosion and weathering
- Finish, cleanliness and maintenance requirements
- Safety in use
- Provide a 'fit for purpose' and comfortable internal environment
- Be adaptable to future change

Aesthetic Qualities
- Desired relationship of building to its site, adjacent properties and neighbourhood
- Preferred qualities of form, massing, colour, pattern, texture and detail

Regulatory Constraints
- Compliance with planning control/zoning and building regulations

Economic Considerations
- Initial cost comprising material, transport, equipment and labour costs
- Life-cycle costs, which include not only initial cost, but also maintenance and operating costs, energy consumption, useful lifetime, demolition and replacement costs, and interest on invested money

Environmental Impact
- Conservation of energy and resources through passive measures
- Energy efficiency of mechanical systems
- Use of resource-efficient and non-toxic materials
- See 1.03–1.07

- In the UK the Health and Safety Executive (HSE) regulates the design of workplaces and sets safety standards to which a building must be constructed

Construction Practices
- Health and safety requirements
- Allowable tolerances and appropriate fit
- Conformance to industry standards and assurance
- Coordination and management of professional team, trades and subcontractors
- Budget constraints
- Construction equipment required
- Erection time required
- Provisions for inclement weather
- Buildability

Building Regulations
Building regulations are adopted and enforced by local government agencies to regulate the design, construction, alteration and repair of buildings in order to protect the public safety, health and welfare. The regulations generally establish requirements based on the type of occupancy and construction of a building, minimum standards for materials and methods of construction, and specifications for structural and fire safety. While regulations are primarily prescriptive in nature, they also contain performance criteria, stipulating how a particular component or system must function without necessarily giving the means to be employed to achieve the results. In the UK building regulations often reference standards established by the British Standards Institution (BSI). In the wider European area the European Committee for Standardization (CEN) and other technical societies and trade associations relevant to the region have established standards and guidelines relevant to the construction industry and referred to in building regulations.

In the UK, approved documents provide guidance on how compliance with building regulations can be achieved. Local authorities also have power to impose other requirements through planning conditions.

UK Approved Documents

A	Structure
B1	Fire Safety Volume 1: Dwelling Houses
B2	Fire Safety Volume 2: Non-Dwellings; see 2.06
C	Site Preparation and Resistance to Contaminants and Moisture
D	Toxic Substances
E	Resistance to the Passage of Sound
F	Ventilation
G	Sanitation, Hot Water Safety and Water Efficiency
H	Drainage and Waste Disposal
J	Combustion Appliances and Fuel Storage Systems
K	Protection from Falling, Collision and Impact
L1A	Conservation of Fuel and Power: New Dwellings
L1B	Conservation of Fuel and Power: Existing Dwellings; see 1.03
L2A	Conservation of Fuel and Power in New Buildings other than Dwellings; see 1.03
L2B	Conservation of Fuel and Power: Existing Buildings other than Dwellings; see 1.03
M	Access to and Use of Buildings
N	Glazing – Safety in Relation to Impact, Opening and Cleaning
P	Electrical Safety – Dwellings

European Building Regulations
In most European countries building regulations were established through Building Control Acts. The building regulations are supplemented by technical guidance documents offering approved methods of achieving the prescribed standards.

Regulation Outside Europe
Building regulations and enforcement procedures vary from region to region in reaction to cultural, political and local sensitivities such as earthquake zones, flood risk and drought.

US building codes are adopted and enforced by local government agencies, the codes are generally based on building type and construction method. While the codes are primarily prescriptive in nature they also contain some performance criteria.

Building codes in both Australia and New Zealand are similar in the arrangement to both the UK and US. In New Zealand, building codes are generally performance based, whereas Australian codes are prescriptive, if guidelines are followed compliance is generally achieved.

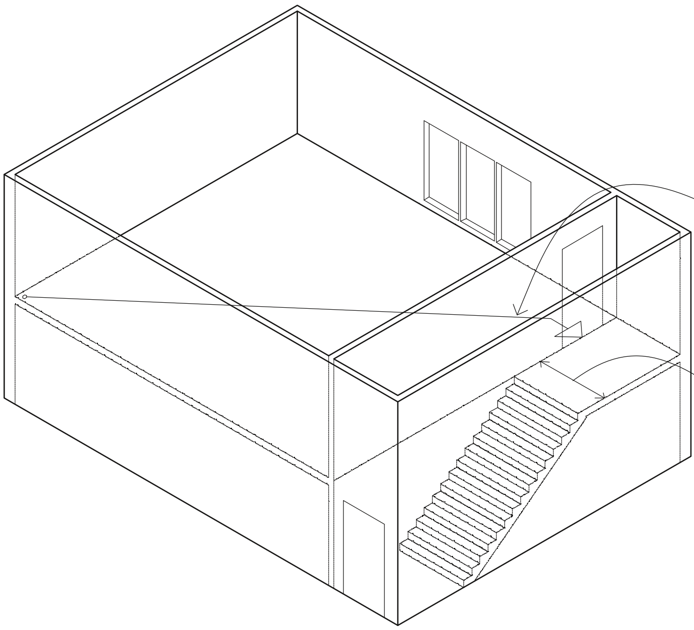
The regulatory framework in the Middle East is to some extent based on a combination of both US and UK approaches. Some nations in the region have adopted either US or UK regulations, while others have taken them as a base case and altered them according to local sensitivities.

Other Important Regulations/Guidelines
The EU Construction Products Directive (CPD) aims to provide harmonised standards for the performance of building products throughout the EU. The CPD aims to ensure the free movement of 'fit for purpose' products within the EU.

Eurocodes are a set of harmonised European Standards aiming to provide structural design guidance and to replace national standards within the EU.

The European Energy Performance of Buildings Directive (EPBD) first brought into force in 2003 aims to improve the energy performance of building within the EU by providing minimum energy performance standards, the provision of an Energy Performance Certificate when a building is constructed, sold or rented and making provision for the inspection of boilers and air-conditioning systems.

In the UK and in most European countries buildings must be constructed in line with regulations that consider the prevention of fire, means of warning and escape in the event of fire, the internal spread of fire, external spread of fire and access and facilities for fire-fighting services. As the nature, use, construction method and risk of fire varies among building types, the regulations are applied according to the 'purpose group classification' (see 2.07) of the building.



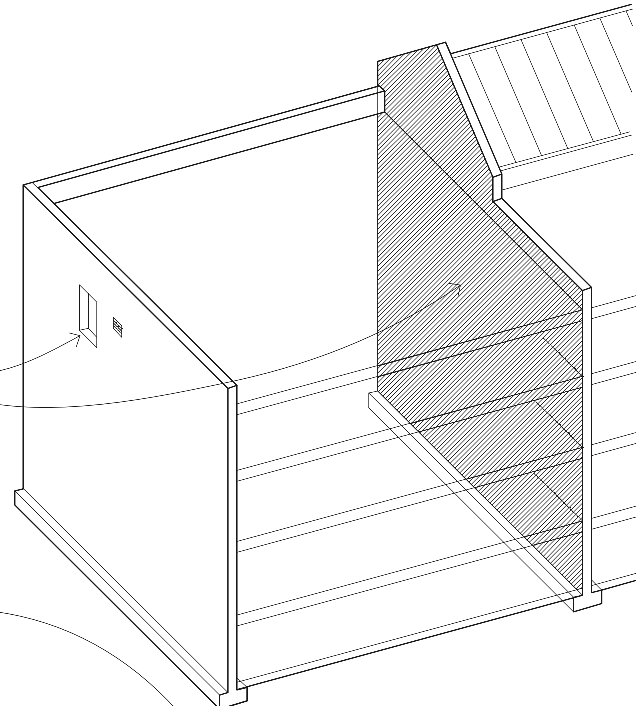
- Construction materials are classified according to their performance in reaction to fire and ultimate resistance. Classifications are A1, A2, B, C, D, E & F. Class A1 offer the highest performance and F the lowest. This European classification system is used to determine, through building regulations, allowable materials to be used in structures, external walls and linings (see EN 13501-1 as referred to in Eurocode 1: Actions on Structures)
- Travel distance is the distance that needs to be travelled from any point in a room to a place of safety. Building regulations set out maximum travel distances based on the number of escape routes and the purpose group classification
- The widths of vertical and horizontal escape routes are required to have a direct relationship to the maximum number of people needing to use the escape route. This will be influenced by the escape strategy (phased or continuous) and the occupant capacity of the space being served
- The table below outlines the required minimum period of fire resistance according to European classification in relation to load-bearing capacity (R), integrity (E) and insulation (I)

Minimum Period of Fire Resistance (in minutes)

	R	E	I
Structural frame	30–120	–	–
Glazing in protected shaft	–	30	–
Fire-fighting shaft	120	120	120
Floor construction	30	30	30
Roof construction	30	30	30
Compartment walls	60	60	60

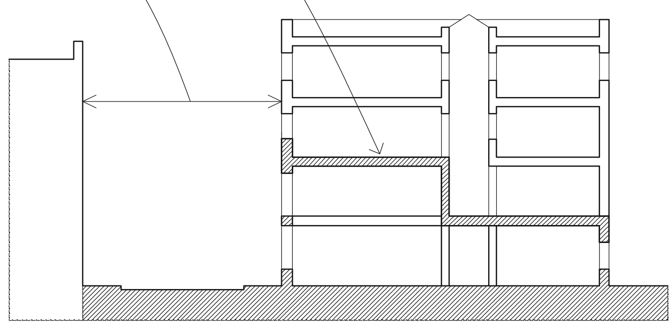
Based on Department of Communities and Local Government (2007a). Approved Document B1 – Dwelling Houses, table A1

In the UK and most European countries, building regulations limit the maximum height of a building that does not include an automated fire suppression system (sprinklers). Generally any building with a top floor 30 m or more above ground level will require automated fire suppression in order to comply with building regulations.



The maximum allowable occupancy per metre squared for a room, floor or building is directly related to the purpose group or type of accommodation, demonstrating the relationship between the size of the building and the nature of its occupancy. The larger a building, the greater the number of occupants and the more hazardous the occupancy, the more fire-resistant the facility should be. The intent is to protect a building from fire and to contain a fire long enough for the safe evacuation of occupants and for a fire-fighting response to occur.

- Compartmentation refers to floors, ceilings and walls which form a protected compartment within a building. Compartments are required at junctions with separate buildings or where differing occupancies or uses occur within a building. In larger buildings, depending on the building purpose group classification, maximum allowable floor areas are set beyond which compartmentation must be included
- Space separation distance refers to the minimum separation distance required between a building face and the relevant boundary or nearby building. It is influenced by the extent of unprotected area in an external wall, that is the area of wall which does not meet minimum fire resistance standards for external walls (glazing, openings or section containing combustible materials)



Example of Purpose Group Classifications

Based on Department of Communities and Local Government (2007b). Approved Document B2 – Buildings Other Than Dwellings, table D1.

1 Residential (Dwellings)
Flats, apartments, dwelling houses

2 Residential (Institutional)
Residential care homes, hostels, hotels

3 Office
Premises used for office or administration purposes

4 Factories
Fabricating, assembling or manufacturing facilities

5 Shop and Commercial
Retail premises and other shops or businesses such as bookstore or auctioneers

5 Assembly and Recreation
Places of assembly, recreation or entertainment

6 Industrial
Factories, manufacturing and processing plants

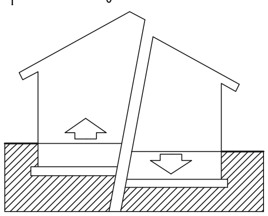
7 Storage and other Non-Residential
Storage of materials, goods, cars or any building not covered under the other classifications

In enclosing a space for habitation, the structural system of a building must be able to support two types of loads: static and dynamic.

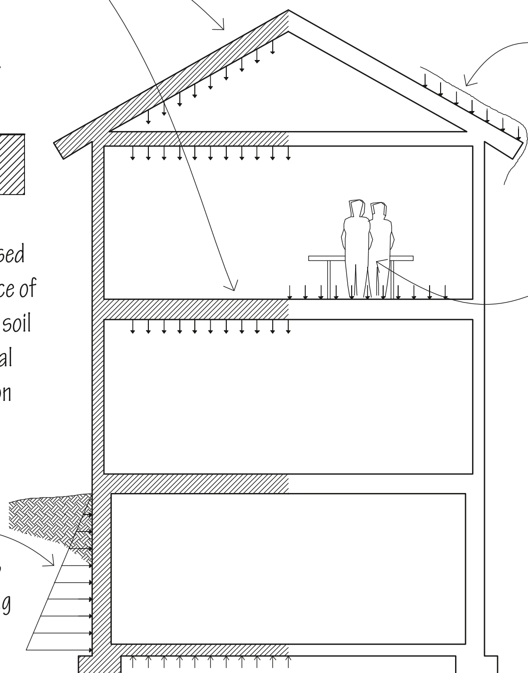
Static Loads

Static loads are assumed to be applied slowly to a structure until it reaches its peak value without fluctuating rapidly in magnitude or position. Under a static load, a structure responds slowly and its deformation reaches a peak when the static force is maximum.

- Dead loads are static loads acting vertically downward on a structure, comprising the self-weight of the structure and the weight of building elements, fixtures and equipment permanently attached to it

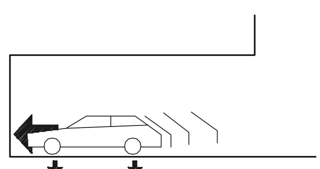


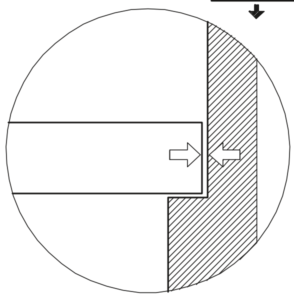
- Settlement loads are imposed on a structure by subsidence of a portion of the supporting soil and the resulting differential settlement of its foundation



- Ground pressure is the horizontal force a soil mass exerts on a vertical retaining structure
- Water pressure is the hydraulic force groundwater exerts on a foundation system
- Thermal stresses are the compressive or tensile stresses developed in a material constrained against thermal expansion or contraction

- Dead loads are the loads due to the weight of the walls, floors, roof and all permanent parts of the structure including building services
- Snow loads are created by the weight of snow accumulating on a roof. Snow loads vary with geographic location, site exposure, wind conditions and roof geometry
- Imposed or live loads comprise any moving or movable loads on a structure resulting from occupancy, collected snow and water, or moving equipment. A live load typically acts vertically downward but may act horizontally as well to reflect the dynamic nature of a moving load
- Imposed occupancy loads result from the weight of people, furniture, stored material and other similar items in a building. Building regulations specify a minimum uniformly distributed unit load and concentrated load for various uses and occupancies
- Rain loads result from the accumulation of water on a roof because of its form, deflection or the clogging of its drainage system
- Impact loads are kinetic loads of short duration due to moving vehicles, equipment and machinery



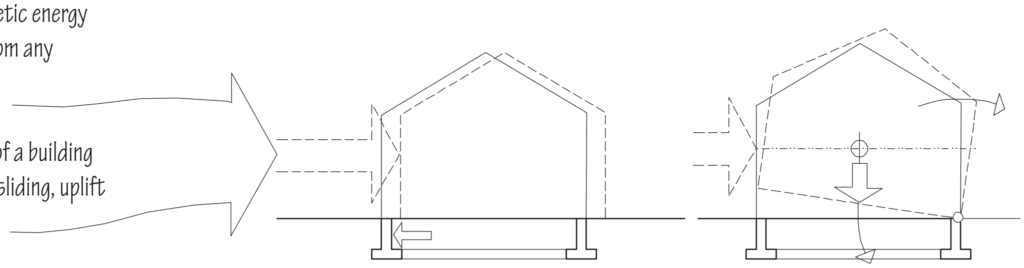


Dynamic Loads

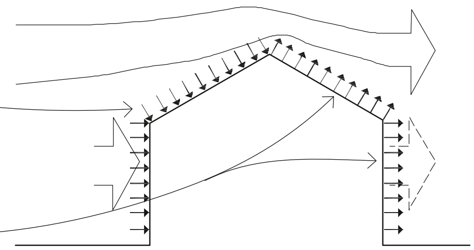
Dynamic loads are applied suddenly to a structure, often with rapid changes in magnitude and point of application. Under a dynamic load, a structure develops inertial forces in relation to its mass, and its maximum deformation does not necessarily correspond to the maximum magnitude of the applied force. The two major types of dynamic loads are wind loads and earthquake loads. In geographical zones subject to seismic activity, guidelines for earthquake loads are given in building regulations.

Wind loads are the forces exerted by the kinetic energy of a moving mass of air, assumed to come from any horizontal direction.

- The structure, components and cladding of a building must be designed to resist wind-induced sliding, uplift or overturning

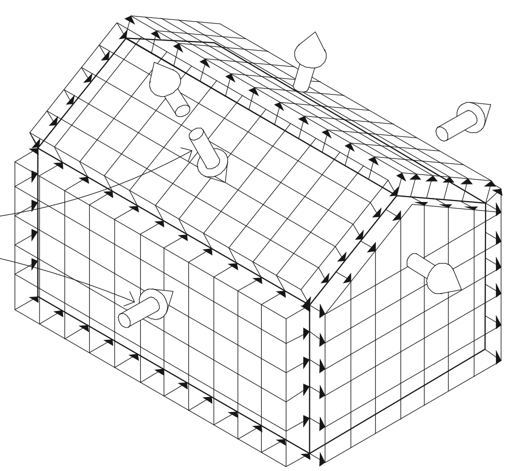


- Wind exerts positive pressure horizontally on the windward vertical surfaces of a building and normal to windward roof surfaces having a slope greater than 30°
- Wind exerts negative pressure or suction on the sides and leeward surfaces and normal to windward roof surfaces having a slope less than 30°

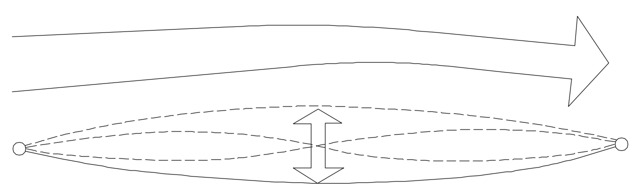


BS 6399-2 provides two methods of assessing the impact of wind loads on buildings, the standard method and the non-standard directional method.

- The standard method provides a static pressure equivalent to the wind load on the exterior surfaces of a structure resulting from a critical wind velocity, equal to a reference wind pressure measured at a height of 10 m, modified by a number of coefficients to account for the effects of exposure condition, topography, building height, wind gusts and the geometry and orientation of the structure to the impinging air flow
- The non-standard directional method gives more accurate estimates of the effect of wind speeds in urban locations and for sites affected by topography

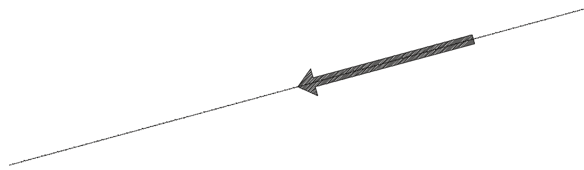


- Flutter refers to the rapid oscillations of a flexible cable or membrane structure caused by the aerodynamic effects of wind
- Tall, slender buildings, structures with unusual or complex shapes, and lightweight, flexible structures subject to flutter require wind tunnel testing or computer modelling to investigate how they respond to the distribution of wind pressure

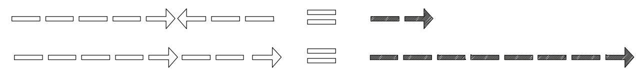


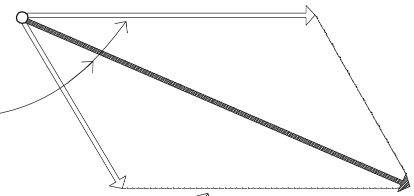
2.10 STRUCTURAL FORCES

A force is any influence that produces a change in the shape or movement of a body. It is considered to be a vector quantity possessing both magnitude and direction, represented by an arrow whose length is proportional to the magnitude and whose orientation in space represents the direction. A single force acting on a rigid body may be regarded as acting anywhere along its line of action without altering the external effect of the force. Two or more forces may be related in the following ways:



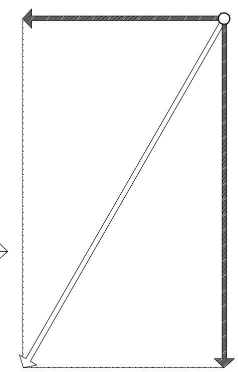
- Collinear forces occur along a straight line, the vector sum of which is the algebraic sum of the magnitudes of the forces, acting along the same line of action



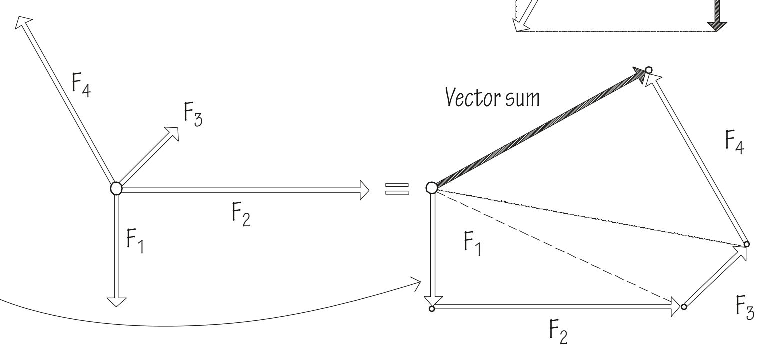


- Concurrent forces have lines of action intersecting at a common point, the vector sum of which is equivalent to and produces the same effect on a rigid body as the application of the vectors of the several forces
- The parallelogram law states that the vector sum or resultant of two concurrent forces can be described by the diagonal of a parallelogram having adjacent sides that represent the two force vectors being added

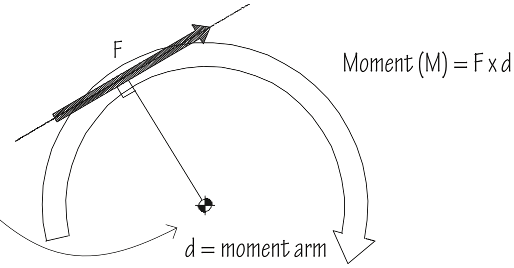
- In a similar manner, any single force can be resolved into two or more concurrent forces having a net effect on a rigid body equivalent to that of the initial force. For convenience in structural analysis, these are usually the rectangular or Cartesian components of the initial force



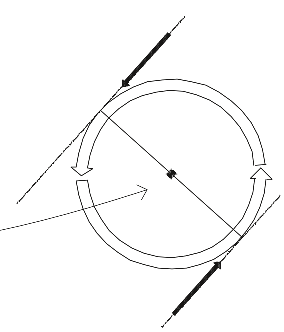
- The polygon method is a graphic technique for finding the vector sum of a coplanar system of several concurrent forces by drawing to scale each force vector in succession, with the tail of each at the head of the one preceding it, and completing the polygon with a vector that represents the resultant force, extending from the tail of the first to the head of the last vector

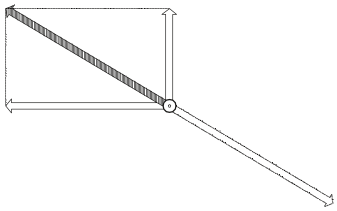


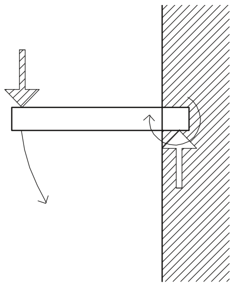
- Non-concurrent forces have lines of action that do not intersect at a common point, the vector sum of which is a single force that would cause the same translation and rotation of a body as the set of original forces
- A moment is the tendency of a force to produce rotation of a body about a point or line, equal in magnitude to the product of the force and the moment arm and acting in a clockwise or counterclockwise direction



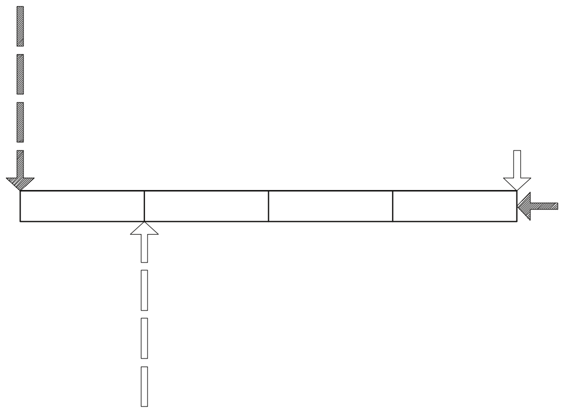
- A couple is a force system of two equal, parallel forces acting in opposite directions and tending to produce rotation but not translation. The moment of a couple is equal in magnitude to the product of one of the forces and the perpendicular distance between the two forces



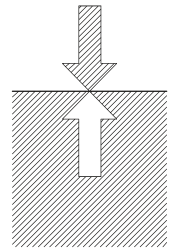




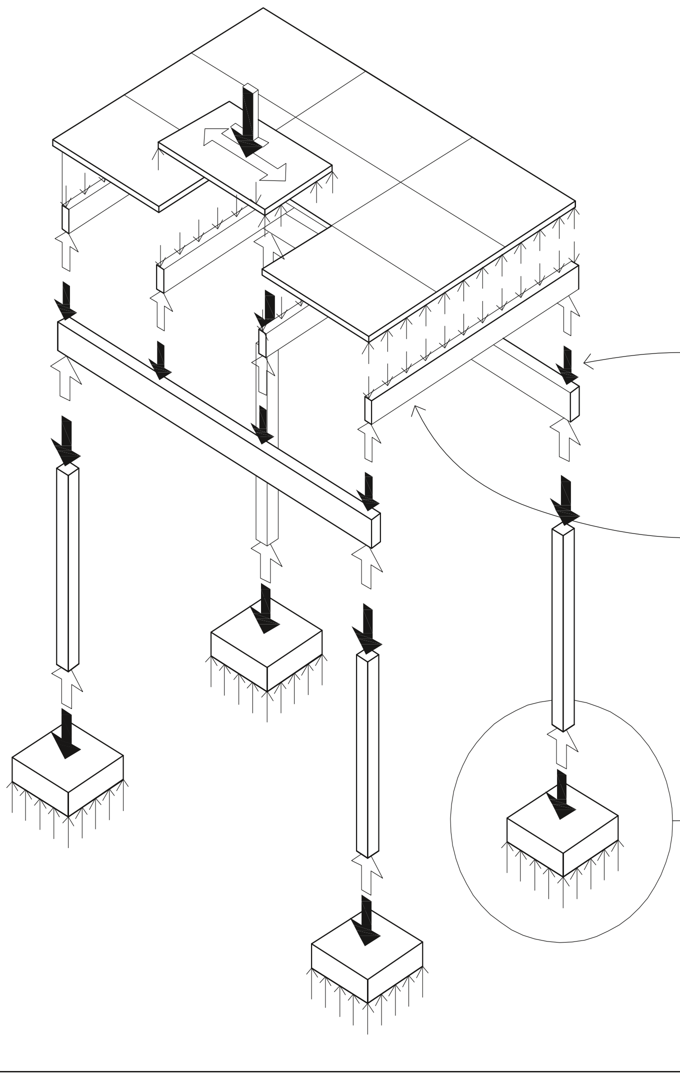
In both structural design and analysis, we are concerned first with the magnitude, direction and point of application of forces, and their resolution to produce a state of equilibrium. Equilibrium is a state of balance or rest resulting from the equal action of opposing forces. In other words, as each structural element is loaded, its supporting elements must react with equal but opposite forces. For a rigid body to be in equilibrium, two conditions are necessary.



- First, the vector sum of all forces acting on it must equal zero, ensuring translational equilibrium: $\Sigma F_x = 0; \Sigma F_y = 0; \Sigma F_z = 0$
- Second, the algebraic sum of all moments of the forces about any point or line must equal zero, ensuring rotational equilibrium: $\Sigma M = 0$



- Newton's third law of motion, the law of action and reaction, states that for every force acting on a body, the body exerts a force having equal magnitude and the opposite direction along the same line of action as the original force

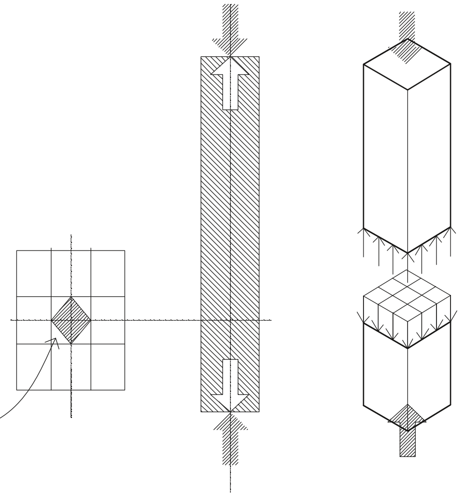


- A concentrated load acts on a very small area or particular point of a supporting structural element, as when a beam bears on a post or a column bears on its footing
- A uniformly distributed load is a load of uniform magnitude extending over the length or area of the supporting structural element, as in the case of the live load on a floor deck or joist, or a wind load on a wall

- A load path diagram is a graphic representation of the complete system of applied and reactive forces acting on a body or an isolated part of a structure. Every elementary part of a structural system has reactions that are necessary for the equilibrium of the part, just as the larger system has reactions at its supports that serve to maintain the equilibrium of the whole

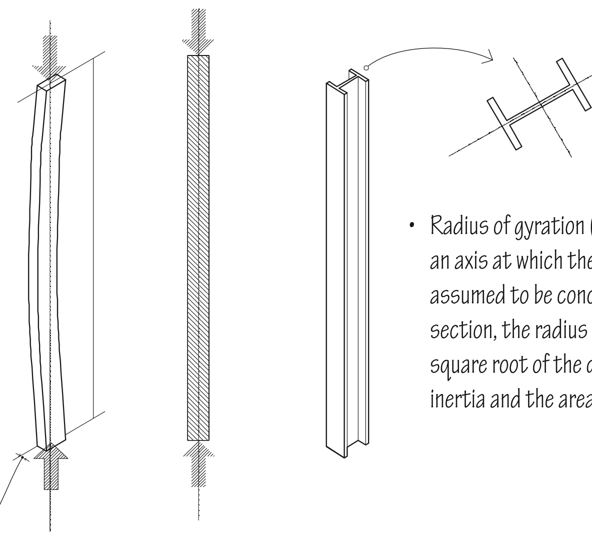
2.12 COLUMNS

Columns are rigid, relatively slender structural members designed primarily to support axial compressive loads applied to the ends of the members. Relatively short, thick columns are subject to failure by crushing rather than by buckling. Failure occurs when the direct stress from an axial load exceeds the compressive strength of the material available in the cross section. An eccentric load, however, can produce bending and result in an uneven stress distribution in the section.

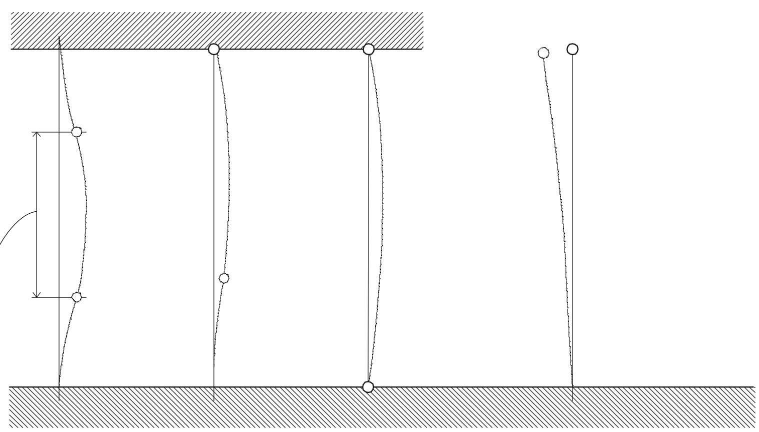


- Kern area is the central area of any horizontal section of a column or wall within which the resultant of all compressive loads must pass if only compressive stresses are to be present in the section. A compressive load applied beyond this area will cause tensile stresses to develop in the section
- External forces create internal stresses within structural elements

Long, slender columns are subject to failure by buckling rather than by crushing. Buckling is the sudden lateral or torsional instability of a slender structural member induced by the action of an axial load before the yield stress of the material is reached. Under a buckling load, a column begins to deflect laterally and cannot generate the internal forces necessary to restore its original linear condition. Any additional loading would cause the column to deflect further until collapse occurs in bending. The higher the slenderness ratio of a column, the lower is the critical stress that will cause it to buckle. A primary objective in the design of a column is to reduce its slenderness ratio by shortening its effective length or maximising the radius of gyration of its cross section.

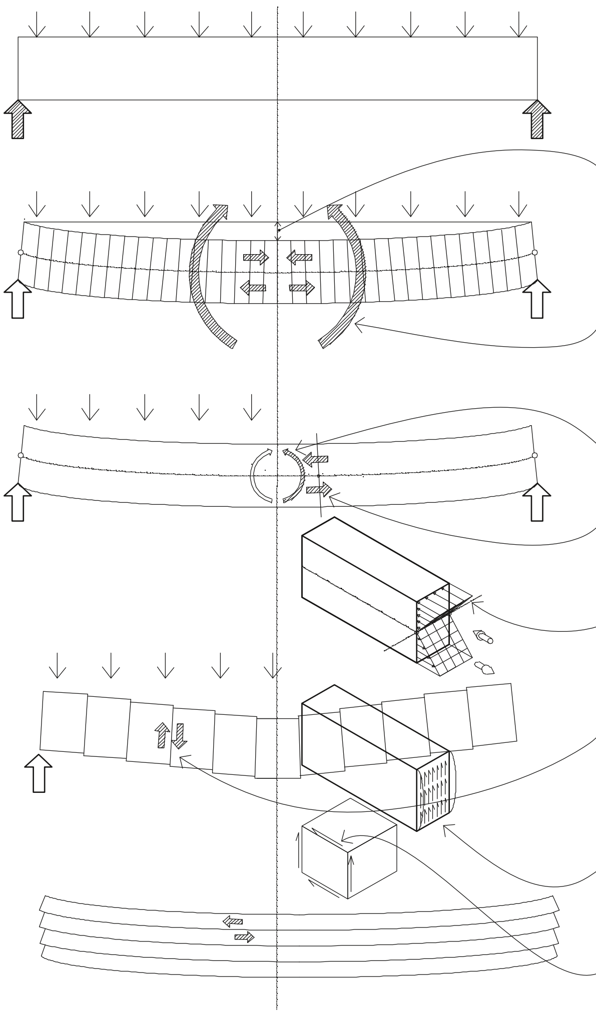


- Radius of gyration (r) is the distance from an axis at which the mass of a body may be assumed to be concentrated. For a column section, the radius of gyration is equal to the square root of the quotient of the moment of inertia and the area
- The slenderness ratio of a column is the ratio of its effective length (L) to its smallest radius of gyration (r). For asymmetrical column sections, therefore, buckling will tend to occur about the weaker axis or in the direction of the smallest dimension



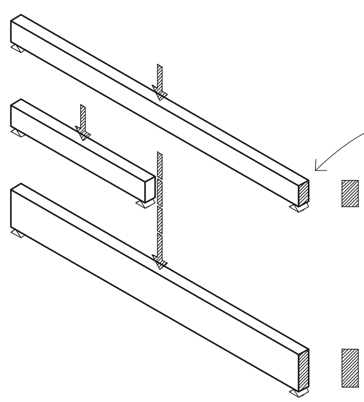
- Both ends fixed; k = 0.5
- One end pinned, one end fixed; k = 0.7
- Both ends pinned; k = 1.0
- One end free, one end fixed; k = 2.0

- Effective length is the distance between inflection points in a column subject to buckling. When this portion of a column buckles, the entire column fails
- The effective length factor (k) is a coefficient for modifying the actual length of a column according to its end conditions in order to determine its effective length. For example, fixing both ends of a long column reduces its effective length by half and increases its load-bearing capacity by a factor of 4



Beams are rigid structural members designed to carry and transfer transverse loads across space to supporting elements. The non-concurrent pattern of forces subjects a beam to bending and deflection, which must be resisted by the internal strength of the material.

- Deflection is the perpendicular distance a spanning member deviates from a true course under transverse loading, increasing with load and span, and decreasing with an increase in the moment of inertia of the section or the modulus of elasticity of the material
- Bending moment is an external moment tending to cause part of a structure to rotate or bend, equal to the algebraic sum of the moments about the neutral axis of the section under consideration
- Resisting moment is an internal moment equal and opposite to a bending moment, generated by a force couple to maintain equilibrium of the section being considered
- Bending stress is a combination of compressive and tension stresses developed at a cross section of a structural member to resist a transverse force, having a maximum value at the surface furthest from the neutral axis
- The neutral axis is an imaginary line passing through the centroid of the cross section of a beam or other member subject to bending, along which no bending stresses occur
- Transverse shear occurs at a cross section of a beam or other member subject to bending, equal to the algebraic sum of transverse forces on one side of the section
- Vertical shearing stress develops to resist transverse shear, having a maximum value at the neutral axis and decreasing nonlinearly toward the outer faces
- Horizontal or longitudinal shearing stress develops to prevent slippage along horizontal planes of a beam under transverse loading, equal at any point to the vertical shearing stress at that point

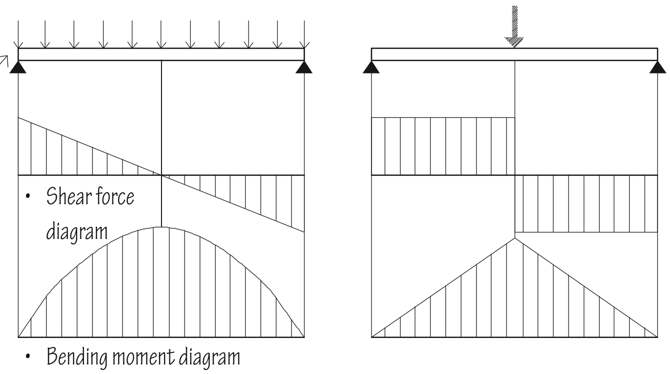


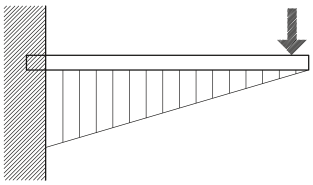
The efficiency of a beam is increased by configuring the cross section to provide the required moment of inertia or section modulus with the smallest possible area, usually by making the section deep with most of the material at the extremities where the maximum bending stresses occur. For example, while halving a beam span or doubling its width reduces the bending stresses by a factor of 2, doubling the depth reduces the bending stresses by a factor of 4.

- Moment of inertia is the sum of the products of each element of an area and the square of its distance from a coplanar axis of rotation. It is a geometric property that indicates how the cross-sectional area of a structural member is distributed and does not reflect the intrinsic physical properties of a material
- Section modulus is a geometric property of a cross section, defined as the moment of inertia of the section divided by the distance from the neutral axis to the most remote surface

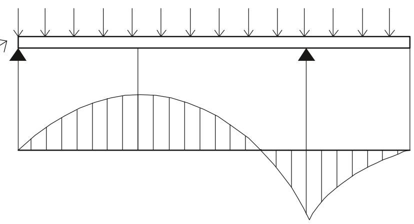
2.14 BEAM SPANS

- A simple beam rests on supports at both ends, with the ends free to rotate and having no moment resistance. As with any statically determinate structure, the values of all reactions, shears and moments for a simple beam are independent of its cross-sectional shape and material

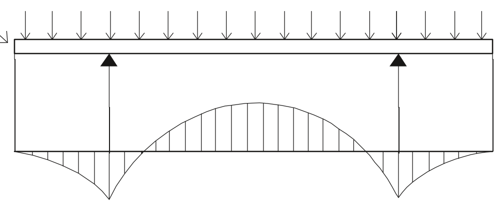




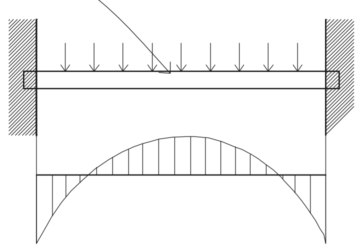
- A cantilever is a projecting beam or other rigid structural member supported at only one fixed end
- An overhanging beam is a simple beam extending beyond one of its supports. The overhang reduces the positive moment at mid span while developing a negative moment at the base of the cantilever over the support. Assuming a uniformly distributed load, the projection for which the moment over the support is equal and opposite to the moment at mid span is approximately $^3/_8$ of the span



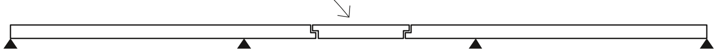
- A double overhanging beam is a simple beam extending beyond both of its supports. Assuming a uniformly distributed load, the projections for which the moments over the supports are equal and opposite to the moment at mid span are approximately $^1/_3$ of the span



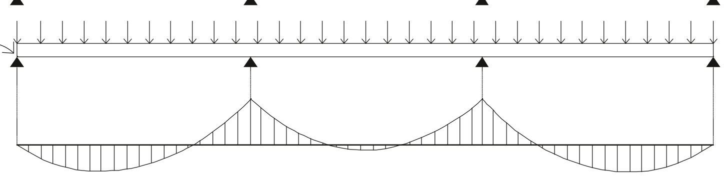
- A fixed-end beam has both ends restrained against translation and rotation. The fixed ends transfer bending stresses, increase the rigidity of the beam and reduce its maximum deflection



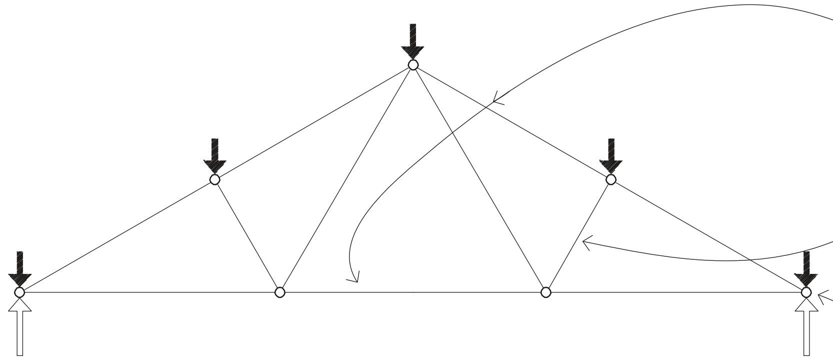
- A suspended span is a simple beam supported by the overhangs of two adjoining spans with pinned construction joints at points of zero moment



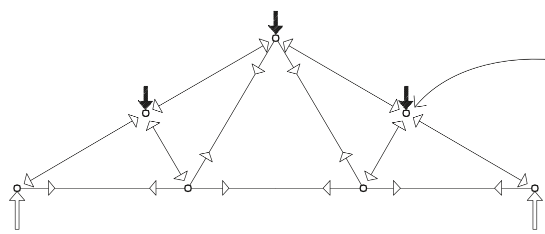
- A continuous beam extends over more than two supports in order to develop greater rigidity and smaller moments than a series of simple beams having similar spans and loading. Both fixed-end and continuous beams are indeterminate structures for which the values of all reactions, shears and moments are dependent not only on span and loading but also on the cross-sectional shape and material of the beam



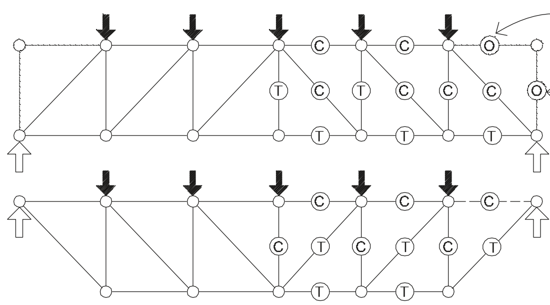
A truss is a structural frame based on the geometric rigidity of the triangle and composed of linear members subject only to axial tension or compression.



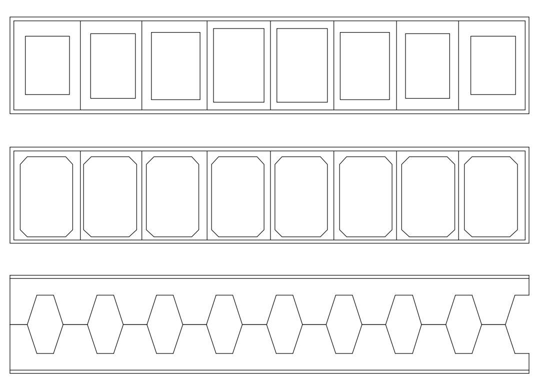
- Top and bottom chords are the principal members of a truss extending from end to end and connected by web members, the bottom chord acts as a tie
- Web is the integral system of members connecting the upper and lower chords of a truss
- Heel is the lower, supported end of a truss



- Node points is any of the joints between a principal web member and a chord. A truss must be loaded only at its node points if its members are to be subject only to axial tension or compression. To prevent secondary stresses from developing, the centroidal axes of truss members and the load at a joint should pass through a common point



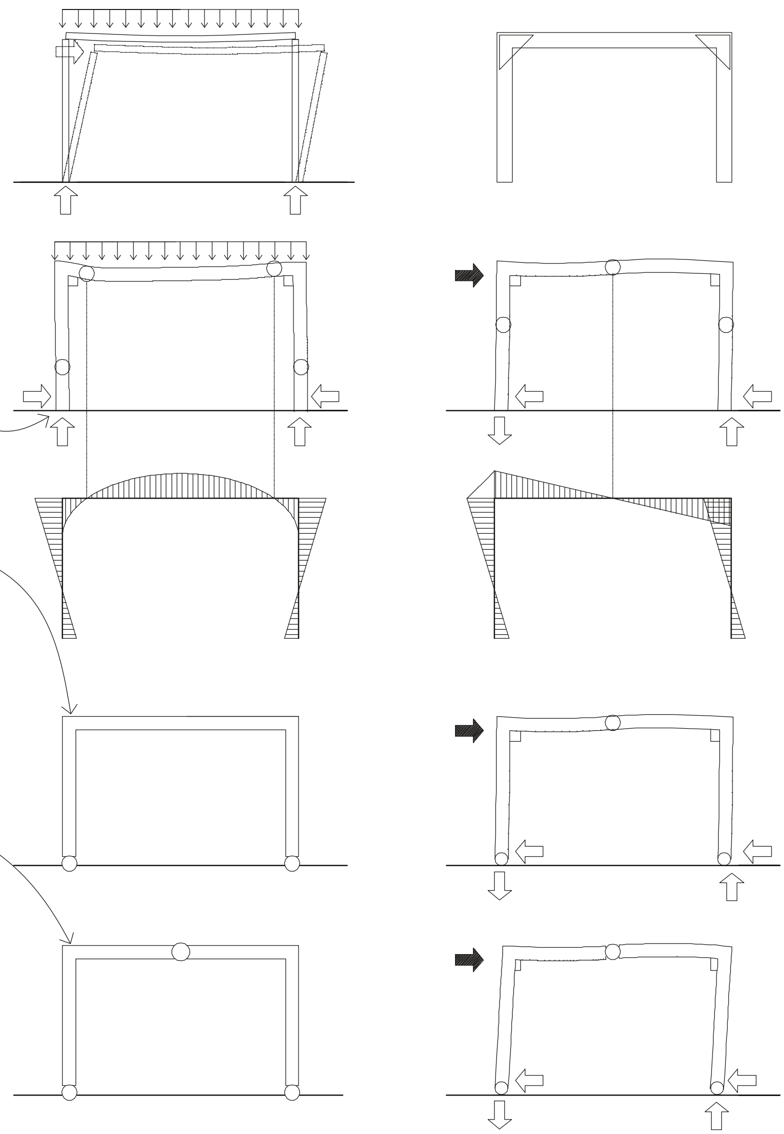
- Zero-force members theoretically carry no direct load; their omission would not alter the stability of the truss configuration
- See 6.09 for types of trusses and truss configurations



- Lattice beams use the structural efficiency of triangulation to extend the potential span of a beam
- Castellated beams are framed beam structures having vertical web members rigidly connected to parallel top and bottom chords

2.16 FRAMES & WALLS

A beam simply supported by two columns is not capable of resisting lateral forces unless it is braced. If the joints connecting the columns and beam are capable of resisting both forces and moments, then the assembly becomes a rigid frame. Applied loads produce axial, bending and shear forces in all members of the frame because the rigid joints restrain the ends of the members from rotating freely. In addition, vertical loads cause a rigid frame to develop horizontal thrusts at its base. A rigid frame is statically indeterminate and rigid only in its plane.



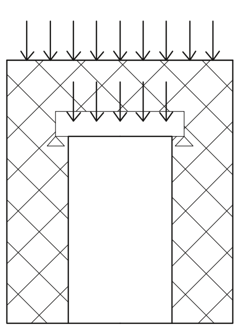
- Fixed frame is a rigid frame connected to its supports with fixed joints. A fixed frame is more resistant to deflection than a hinged frame but also more sensitive to support settlements and thermal expansion and contraction

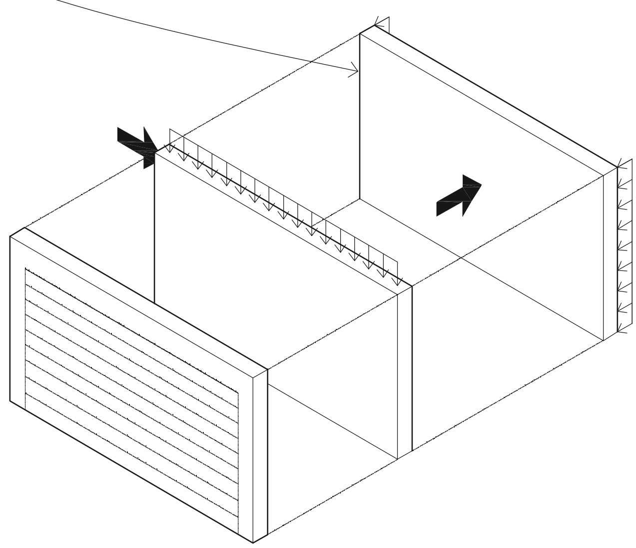
- Hinged frame is a rigid frame connected to its supports with pin joints. The pin joints prevent high bending stresses from developing by allowing the frame to rotate as a unit when strained by support settlements, and to flex slightly when stressed by changes in temperature

- Three-hinged frame is a structural assembly of two rigid sections connected to each other and to its supports with pin joints. While more sensitive to deflection than either the fixed or hinged frame, the three-hinged frame is least affected by support settlements and thermal stresses. The three-pin joints also permit the frame to be analysed as a statically determinate structure

If we fill in the plane defined by two columns and a beam, it becomes a load-bearing wall that acts as a long, thin column in transmitting compressive forces to the ground. Load-bearing walls are most effective when carrying coplanar, uniformly distributed loads and most vulnerable to forces perpendicular to their planes. For lateral stability, load-bearing walls must rely on buttressing with piers, cross walls, transverse rigid frames or horizontal slabs.

Any opening in a load-bearing wall weakens its structural integrity. A lintel or arch must support the load above a door or window opening and allow the compressive stresses to flow around the opening to adjacent sections of the wall.





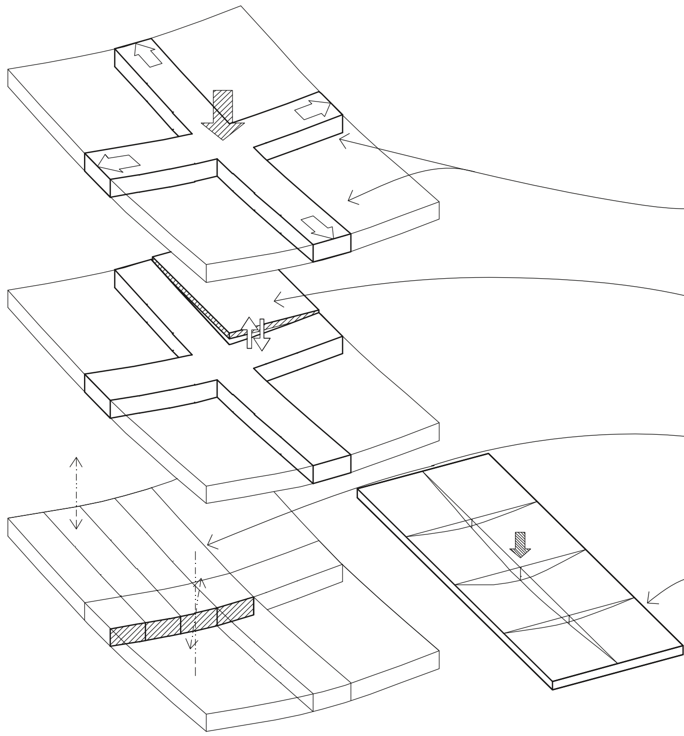
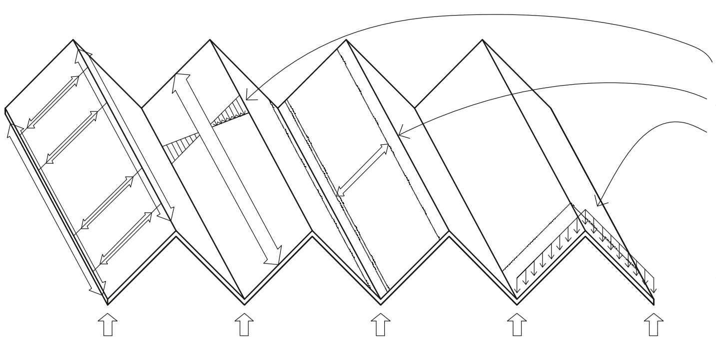


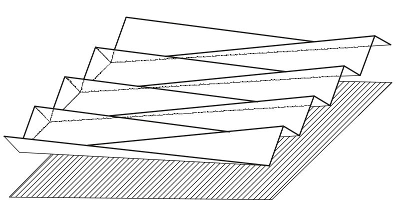
Plate structures are rigid, planar, usually monolithic structures that disperse applied loads in a multidirectional pattern, with the loads generally following the shortest and stiffest routes to the supports. A common example of a plate structure is a reinforced-concrete slab.

A plate can be envisioned as a series of adjacent beam strips interconnected continuously along their lengths. As an applied load is transmitted to the supports through bending of one beam strip, the load is distributed over the entire plate by vertical shear transmitted from the deflected strip to adjacent strips. The bending of one beam strip also causes twisting of transverse strips, whose torsional resistance increases the overall stiffness of the plate. Therefore, while bending and shear transfer an applied load in the direction of the loaded beam strip, shear and twisting transfer the load at right angles to the loaded strip.

A plate should be square or nearly square to ensure that it behaves as a two-way structure. As a plate becomes more rectangular than square, the two-way action decreases and a one-way system spanning the shorter direction develops because the shorter plate strips are stiffer and carry a greater portion of the load.



Folded plate structures are composed of wide, thin elements joined rigidly along their boundaries and forming sharp angles to brace each other against lateral buckling. Each plane behaves as a beam in the longitudinal direction. In the short direction, the span is reduced by each fold acting as a rigid support. Transverse strips behave as a continuous beam supported at fold points. Vertical diaphragms or rigid frames stiffen a folded plate against deformation of the fold profile. The resulting stiffness of the cross section enables a folded plate to span relatively long distances.

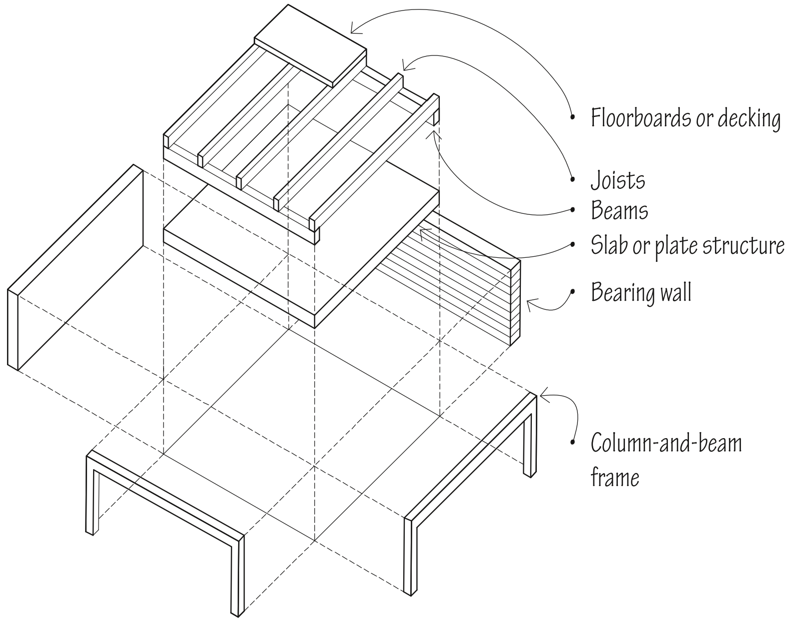


A space frame is composed of short rigid linear elements triangulated in three dimensions and subject only to axial tension or compression. The simplest spatial unit of a space frame is a tetrahedron having four joints and six structural members. Because the structural behaviour of a space frame is analogous to that of a plate structure, its supporting bay should be square or nearly square to ensure that it acts as a two-way structure. Enlarging the bearing area of the supports increases the number of members into which shear is transferred and reduces the forces in the members. See 6.11 for more information on space frames.

2.18 STRUCTURAL UNITS

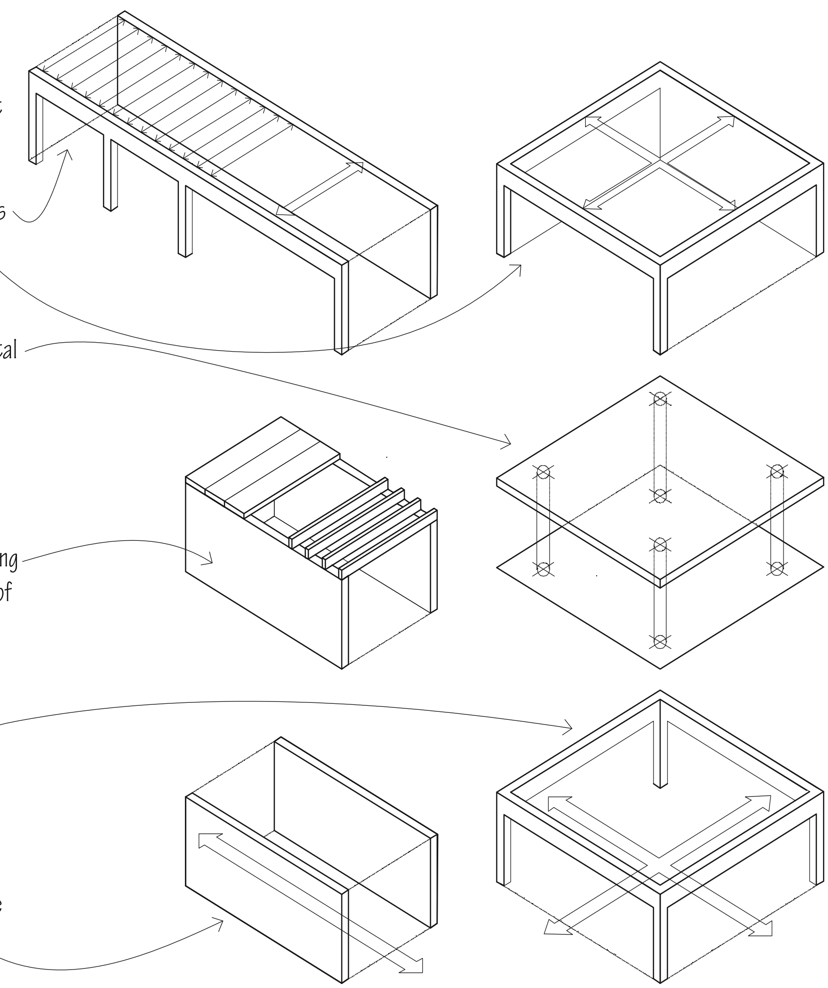
With the principal structural elements of column, beam, slab and load-bearing wall, it is possible to form an elementary structural unit capable of defining and enclosing a volume of space for habitation. This structural unit is the basic building block for the structural system and spatial organisation of a building.

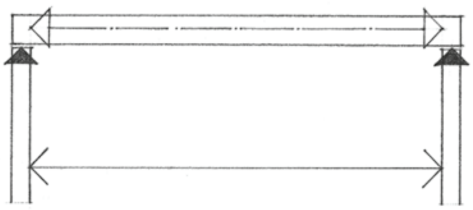
- Horizontal spans may be traversed by reinforced-concrete slabs or by a layered, hierarchical arrangement of beams and joists supporting floorboards or decking
- The vertical support for a structural unit may be provided by load-bearing walls or by a framework of columns and beams



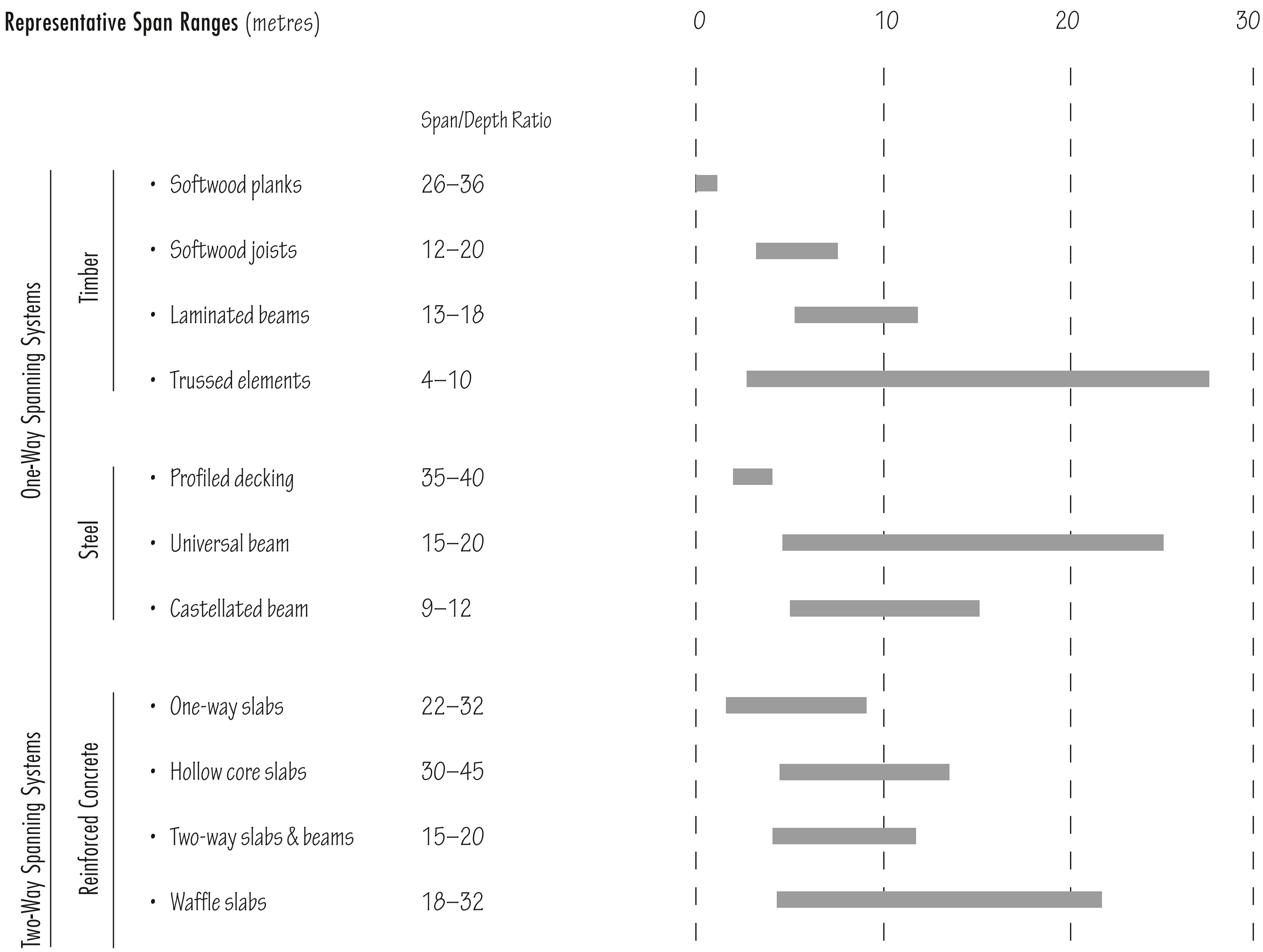
The dimensions and proportions of a structural unit or bay influence the selection of an appropriate spanning system.

- One-way systems of joists, planks or slabs are more efficient when structural bays are rectangular, that is, when the ratio of the long to the short dimensions is greater than 1.5:1, or when the structural grid generates a linear pattern of spaces
- Two-way systems of beams and slabs are more effective for square or nearly square bays
- A two-way slab supported by four columns defines a horizontal layer of space
- The parallel nature of load-bearing walls leads naturally to the use of one-way spanning systems
- Because load-bearing walls are most effective when supporting a uniformly distributed load, they typically support a series of joists, planks or a one-way slab
- A linear framework of columns and beams defines a three-dimensional module of space capable of being expanded both horizontally and vertically
- Two load-bearing walls naturally define an axial, bidirectional space. Secondary axes can be developed perpendicular to the primary axis with openings within the load-bearing walls





The spanning capability of horizontal elements determines the spacing of their vertical supports. This fundamental relationship between the span and spacing of structural elements influences the dimensions and scale of the spaces defined by the structural system of a building. The dimensions and proportions of structural bays, in turn, should be related to the programmatic requirements of the spaces. The ability of a structural element to span a distance will be determined by the material properties and the span-to-depth ratio of the element.

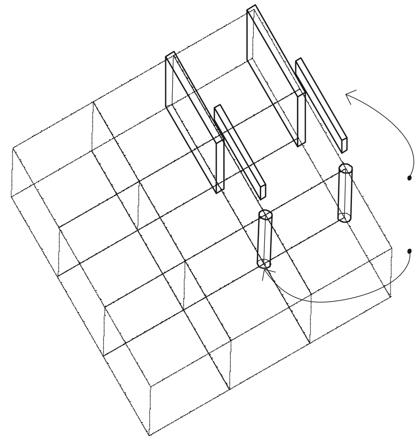


The above span ranges should be used for indicative purposes only. Consult a suitably qualified engineer for detailed design purposes

2.20 STRUCTURAL PATTERNS

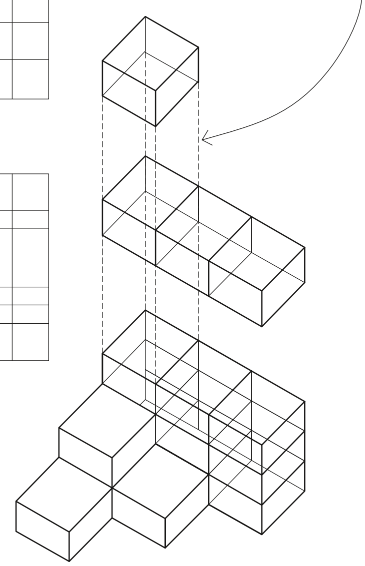
The arrangement of principal vertical supports not only regulates the selection of a spanning system, it also establishes the possibilities for the ordering of spaces and functions in a building.

The principal points and lines of support for a structural system typically define a grid. The critical points of the grid are those at which columns and load-bearing walls collect loads from beams and other horizontal spanning elements and channel these loads vertically to the ground foundation.

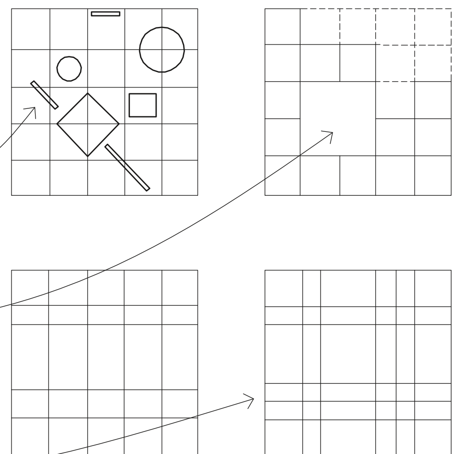


- Grid lines represent horizontal beams and load-bearing walls
- Intersections of grid lines represent the locations of columns or concentrated gravity loads

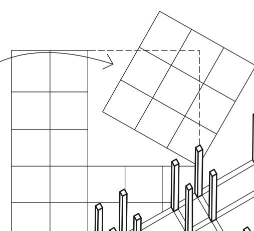
The inherent geometric order of a grid can be used in the design process to initiate and reinforce the functional and spatial organisation of a building design.



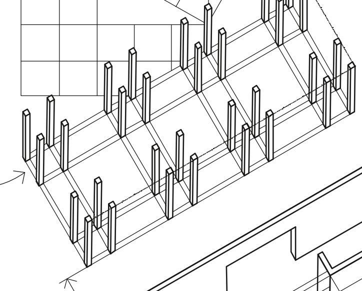
- A basic structural unit or bay can be logically extended vertically along the axes of columns and horizontally along the spans of beams and load-bearing walls



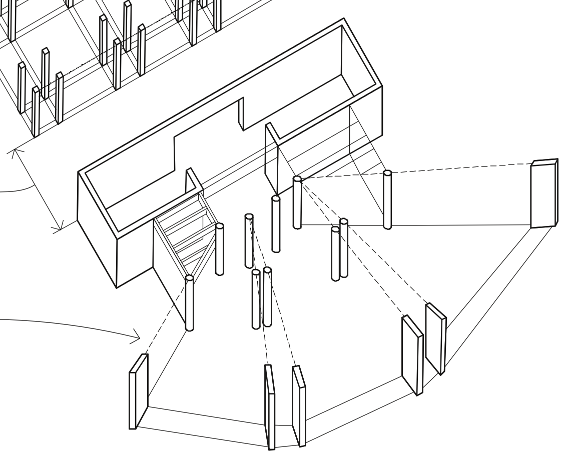
- Non-load-bearing walls may be placed to define a variety of spatial configurations and allow a building to be more flexible in responding to the programmatic requirements of its spaces
- A structural grid can be modified by addition or subtraction to accommodate special needs such as large spaces or unusual site conditions
- A grid may be irregular in one or two directions to accommodate the dimensional requirements of programme spaces



- A portion of the grid can be dislocated and rotated about a point in the basic pattern



- Two parallel grids can be offset from each other to develop intervening or interstitial spaces that define patterns of movement, mediate between a series of larger spaces or house mechanical services

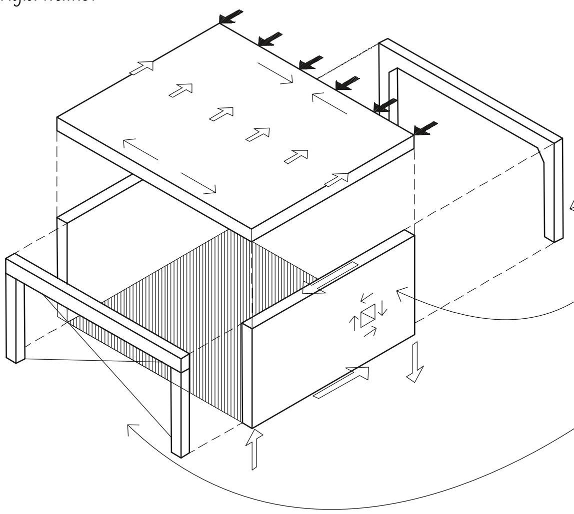


- When two structural patterns cannot be conveniently aligned, a third element, such as a load-bearing wall, a mediating space or a finer-grained spanning system can be used
- Non-uniform or irregular grids can be employed to reflect the hierarchical or functional ordering of spaces within a building

The structural elements of a building must be sized, configured and joined to form a stable structure under any possible load conditions. Therefore, a structural system must be designed to not only carry vertical gravity loads, but also withstand lateral wind and seismic forces from any direction. The following are the basic mechanisms for ensuring lateral stability.

Horizontal diaphragm

- A rigid floor structure, acting as a flat, deep beam, transfers lateral loads to vertical shear walls, braced frames or rigid frame.



Rigid frame

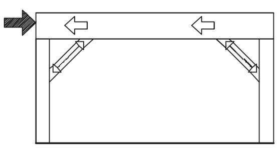
- A steel or reinforced-concrete frame with rigid joints capable of resisting changes in angular relationships

Shear wall

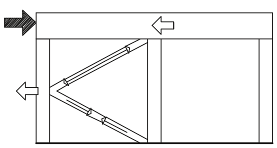
- A wood, concrete or masonry wall capable of resisting changes in shape and transferring lateral loads to the ground foundation

Braced frame

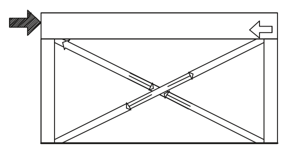
- A timber or steel frame braced with diagonal members



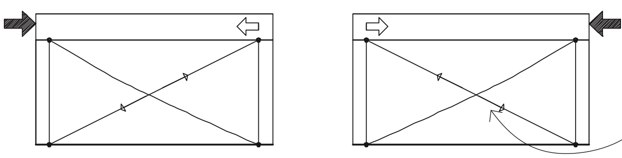
- Knee bracing



- K-brace

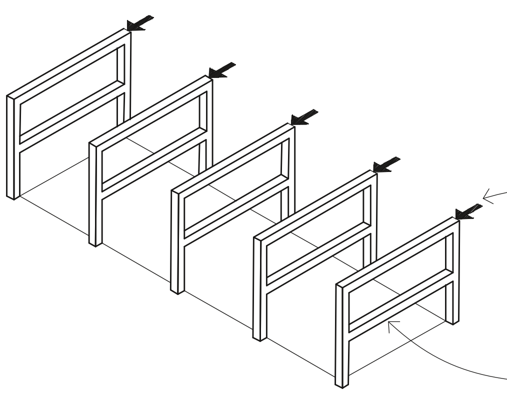


- Cross bracing



- When using cable bracing, two are necessary to stabilise the structure against lateral forces from either direction. For each direction, one cable will operate effectively in tension while the other would simply buckle. If rigid bracing is used, a certain degree of redundancy is involved because a single member is capable of stabilising the structure

Any of these systems may be used singly or in combination to stabilise a structure. Of the three vertical systems, a rigid frame tends to be the least efficient. However, rigid frames can be useful when employing braced frames or shear walls would form undesired barriers between adjacent spaces.

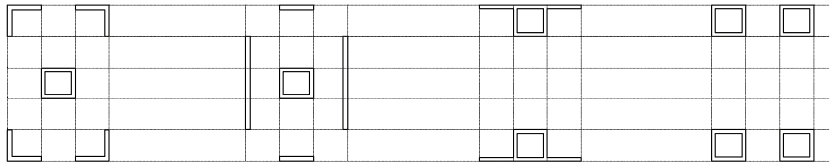


- Lateral forces tend to be more critical in the short direction of rectangular buildings, and more efficient shear walls or braced frames are typically used in this direction. In the long direction, any of the lateral force-resisting elements may be used

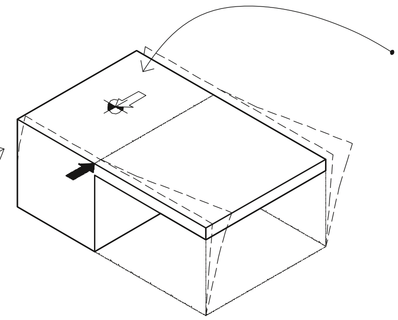
- Braced or rigid frames can be designed to carry vertical and lateral loads transverse to the length of a framed structure

2.22 LATERAL STABILITY

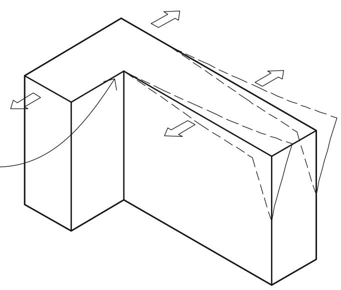
To avoid destructive torsional effects, structures subject to lateral forces should be arranged and braced symmetrically with centres of mass and resistance as coincident as possible. The asymmetrical layout of irregular structures generally requires dynamic analysis in order to determine the torsional effects of lateral forces.

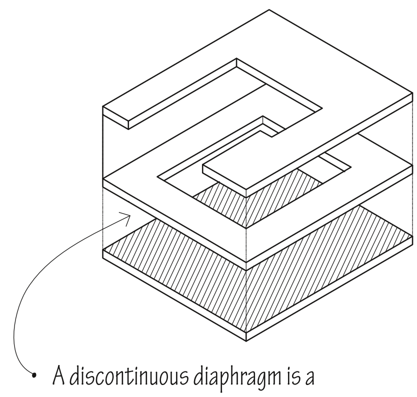


Irregular structures are characterised by any of various plan or vertical irregularities, such as the asymmetrical layout of mass or lateral-force resisting elements, a soft or weak storey, or a discontinuous shear wall.

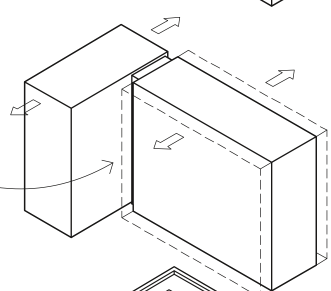


- The centre of resistance is the centroid of the vertical elements of a lateral force-resisting system, through which the shear reaction to lateral forces acts
- Torsional irregularity refers to the asymmetrical layout of mass or lateral force-resisting elements, resulting in non-coincident centres of mass and resistance

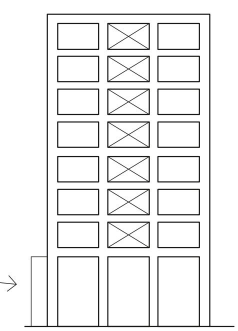


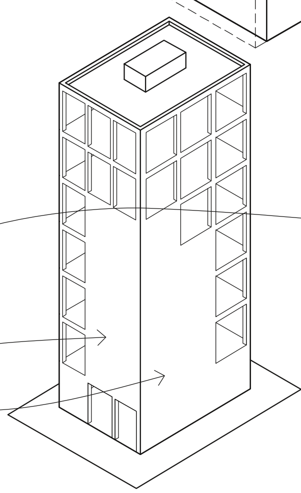


- A re-entrant corner is a plan configuration of a structure having projections beyond a corner significantly greater than the plan dimension in the given direction. A re-entrant corner tends to produce differential motions between different portions of the structure, resulting in local stress concentrations at the corner. Solutions include providing a construction joint to separate the building into simpler shapes, tying the building together more strongly at the corner, or splaying the corner



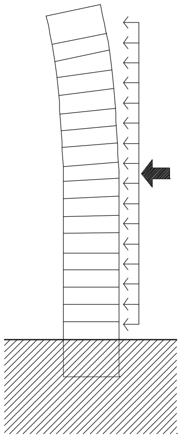
- Construction joints physically separate adjacent building masses so that free vibratory movement in each can occur independently of the other
- A discontinuous diaphragm is a horizontal diaphragm having a large cut-out or open area, or a stiffness significantly less than that of the storey above or below

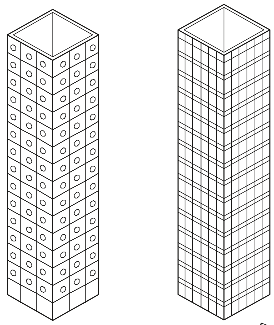




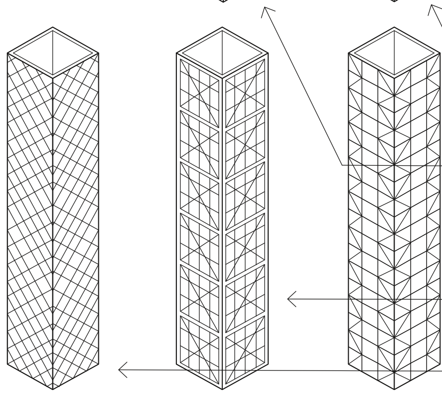
- A soft or weak storey has lateral stiffness or strength significantly less than that of the storeys above
- A discontinuous shear wall has a large offset or a significant change in horizontal dimension

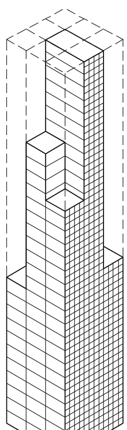
EN Eurocode 8: Design of Structures for Earthquake Resistance, Part 1



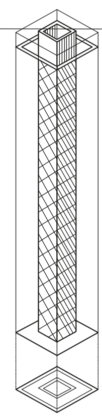


Tall buildings are particularly susceptible to the effects of lateral forces. A rigid frame is the least efficient way to achieve lateral stability and is appropriate only for low- to medium-rise structures. As the height of a building increases, it becomes necessary to supplement a rigid frame with additional bracing mechanisms, such as diagonal bracing or a rigid core. An efficient type of high-rise structure is a tube structure that has perimeter lateral force-resisting systems internally braced by rigid floor plates. The structure acts essentially as a cantilevered box beam in resisting lateral forces.

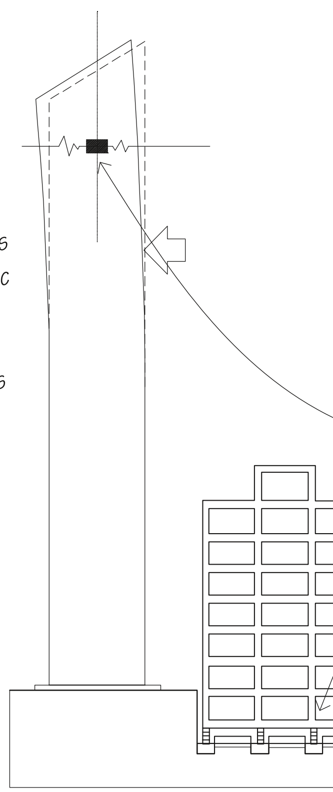




- A framed tube has closely spaced perimeter columns rigidly connected by deep spandrel beams
- A perforated shell tube has perimeter shear walls with less than 30% of the surface area perforated by openings
- A braced tube is similar to a framed tube but tied together by a system of diagonal braces
- A trussed tube has trussed wall frames of widely spaced columns tied together by diagonal or cross bracing
- A latticed truss tube has perimeter frames of closely spaced diagonals with no vertical columns
- Bundled tubes system has a series of closely spaced columns around the exterior of the building and across the interior which are tied together to provide additional strength



- A tube-in-tube structure has an inner braced core added to the perimeter tube to improve its shear stiffness in resisting lateral forces

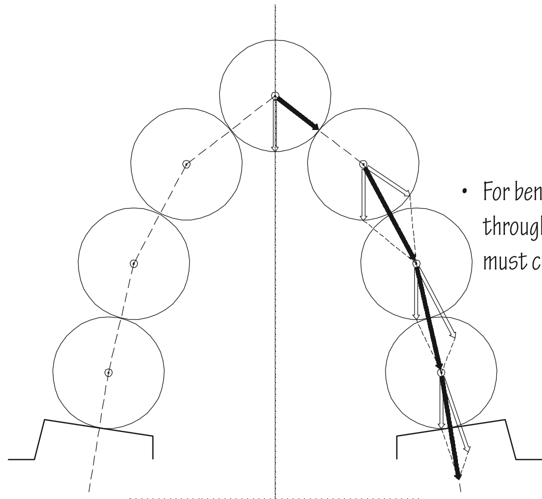


- Internal damping is the damping that naturally occurs as a building undergoes elastic or plastic deformation, as from the internal friction of a stressed material (hysteresis damping), from the friction between two moving parts (frictional damping) or from the viscous resistance of a fluid such as air (viscous damping)

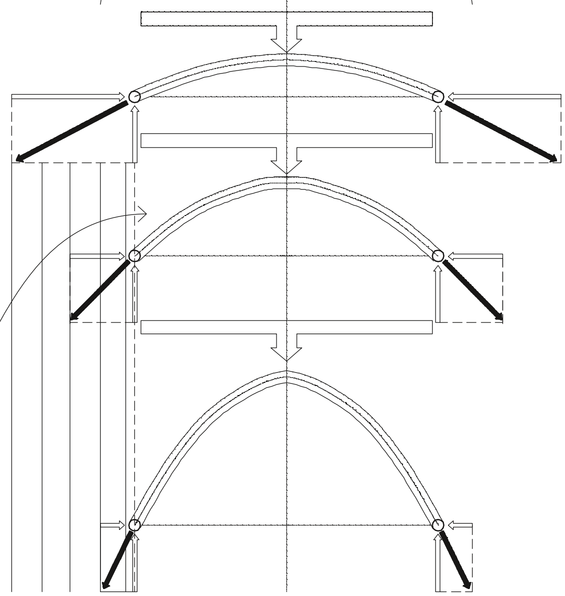
Damping mechanisms are viscoelastic devices that are typically installed at structural joints to absorb the energy generated by wind or earthquake forces, to progressively diminish or eliminate vibratory or oscillatory motions and to prevent destructive resonances from occurring.

- A tuned mass damper is a heavy mass mounted on rollers and attached to the upper portion of a tall building, having an inertial tendency to remain at rest and thus counteracting and dissipating any building movements
- Base isolation refers to isolating the base of a building from the ground with damping mechanisms to allow the superstructure to float as a rigid body and alter the natural period of vibration of the structure so that it is different from that of the ground, thus preventing destructive resonances from occurring. This is of most relevance in areas of seismic activity

Columns, beams, slabs and bearing walls are the most common structural elements because of the rectilinear building geometry they are capable of generating. There are, however, other means of spanning and enclosing space. These are generally form-active elements that, through their shape and geometry, make efficient use of their material for the distances spanned. While beyond the scope of this book, they are briefly described in the following section.



- For bending to be eliminated throughout an arch, the line of thrust must coincide with the arch axis

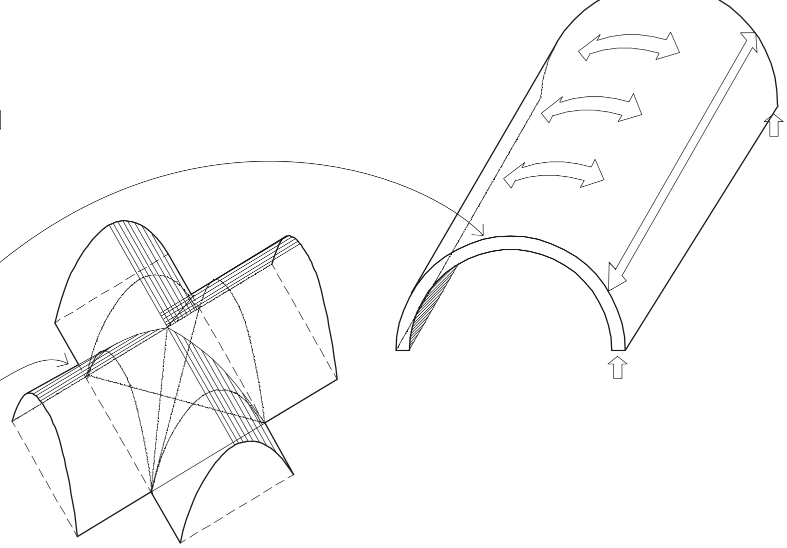


Arches are curved structures for spanning an opening, designed to support a vertical load primarily by axial compression. They transform the vertical forces of a supported load into inclined components and transmit them to abutments on either side of the archway.

- Masonry arches are constructed of individual wedge-shaped stone or brick voussoirs; for more information on masonry arches; see 5.23
- Rigid arches consist of curved, rigid structures of timber, steel or reinforced concrete capable of carrying some bending stresses

- The thrust of an arched structure on its abutments is proportional to the total load and span, and inversely proportional to the rise

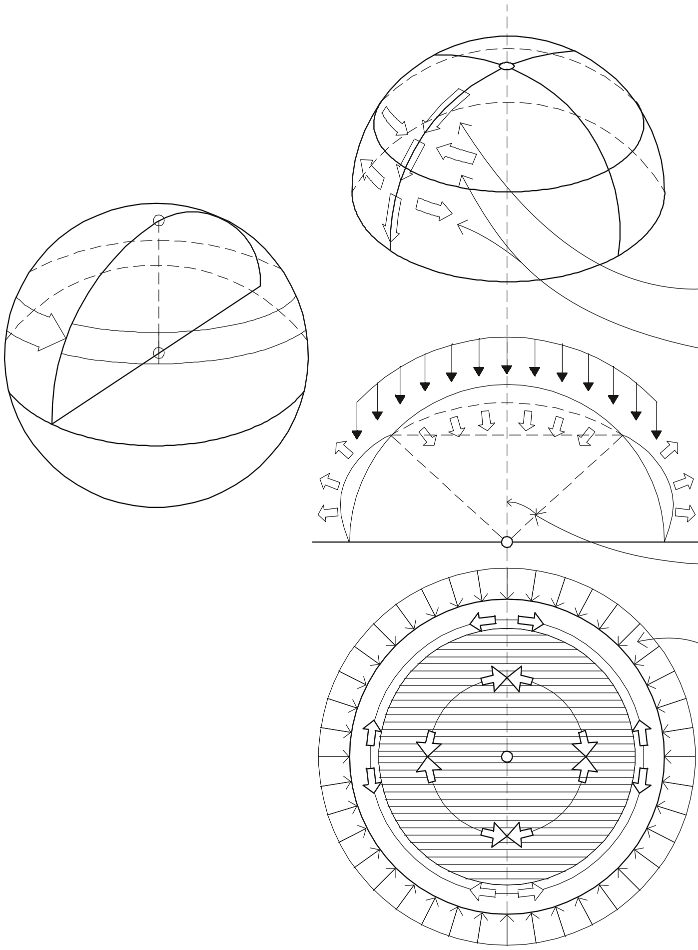
Vaults are arched structures of stone, brick or reinforced concrete, forming a ceiling or roof over a hall, room or other wholly or partially enclosed space. Because a vault behaves as an arch extended in a third dimension, the longitudinal supporting walls must be buttressed to counteract the outward thrusts of the arching action.



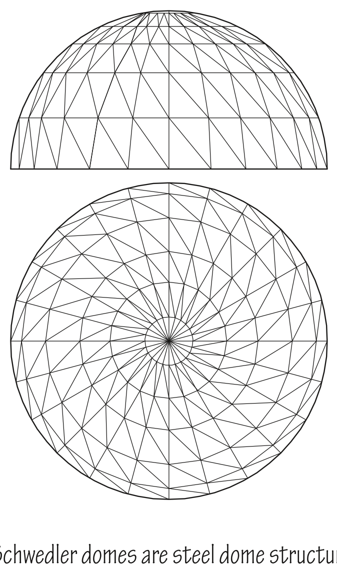
- Barrel vaults have semicircular cross sections

- Cross vaults are formed by the perpendicular intersection of two vaults, forming arched diagonal arrises

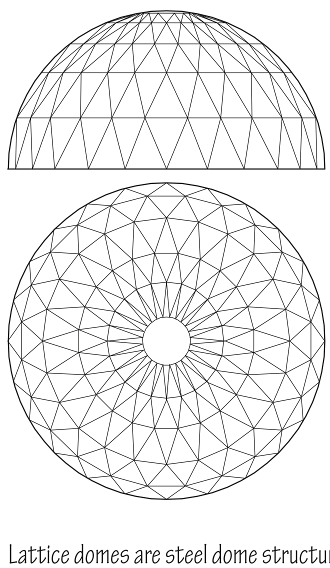
A dome is a spherical surface structure having a circular plan and constructed of stacked blocks, a continuous rigid material like reinforced concrete, or of short, linear elements, as in the case of a geodesic dome. A dome is similar to a rotated arch except that circumferential forces are developed that are compressive near the crown and tensile in the lower portion.



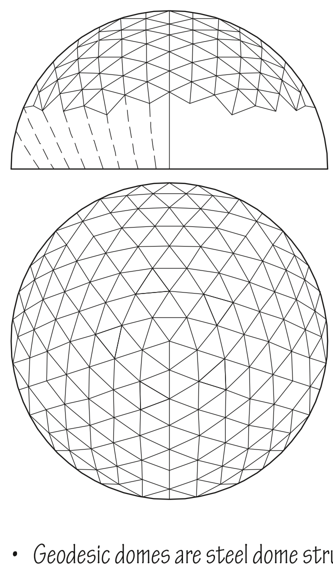
- Meridional forces acting along a vertical section cut through the surface of the dome are always compressive under full vertical loading
- Hoop forces, restraining the out-of-plane movement of the meridional strips in the shell of a dome, are compressive in the upper zone and tensile in the lower zone
- The transition from compressive hoop forces to tensile hoop forces occurs at an angle of from 45° to 60° from the vertical axis
- A tension ring encircles the base of a dome to contain the outward components of the meridional forces. In a concrete dome, this ring is thickened and reinforced to handle the bending stresses caused by the differing elastic deformations of the ring and shell



- Schwedler domes are steel dome structures having members that follow the lines of latitude and longitude, and a third set of diagonals completing the triangulation



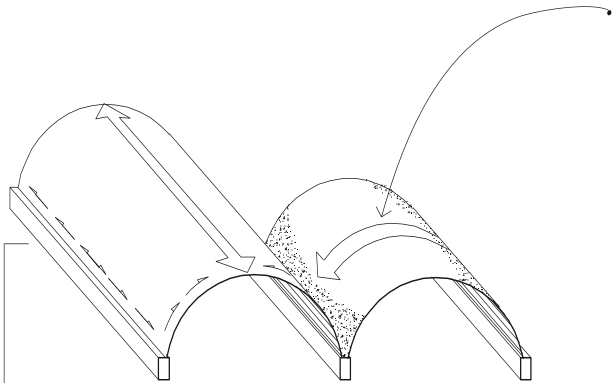
- Lattice domes are steel dome structures having members that follow the circles of latitude, and two sets of diagonals forming a series of isosceles triangles



- Geodesic domes are steel dome structures having members that follow three principal sets of great circles intersecting at 60°, subdividing the dome surface into a series of equilateral spherical triangles

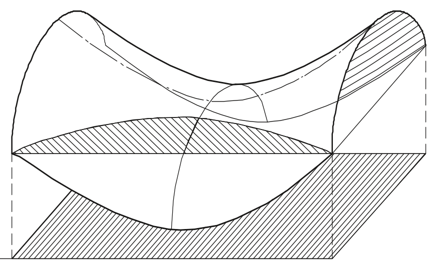
2.26 SHELL STRUCTURES

Shells are thin, curved plate structures typically constructed of reinforced concrete. They are shaped to transmit applied forces by membrane stresses – the compressive, tensile and shear stresses acting in the plane of their surfaces. A shell can sustain relatively large forces if uniformly applied. Because of its thinness, however, a shell has little bending resistance and is unsuitable for concentrated loads.

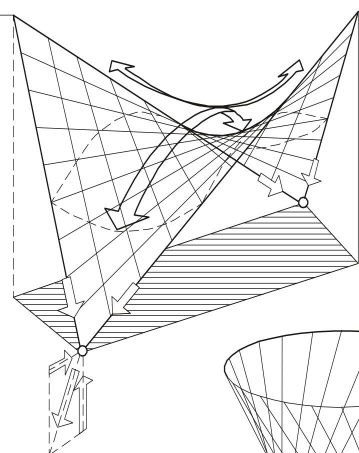


- Barrel shells are cylindrical shell structures. If the length of a barrel shell is three or more times its transverse span, it behaves as a deep beam with a curved section spanning in the longitudinal direction. If it is relatively short, it exhibits arch-like action. Tie rods or transverse rigid frames are required to counteract the outward thrusts of the arching action

- Translational surfaces are generated by sliding a plane curve along a straight line or over another plane curve

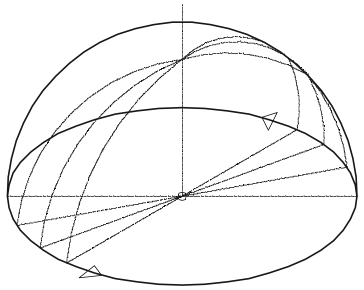


- A hyperbolic paraboloid is a surface generated by sliding a parabola with downward curvature along a parabola with upward curvature, or by sliding a straight line segment with its ends on two skew lines. It can be considered to be both a translational and a ruled surface

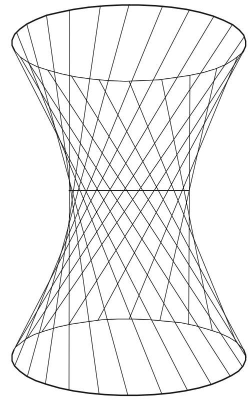


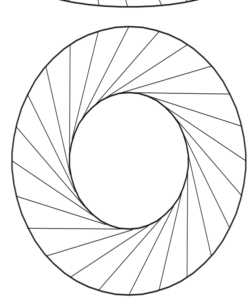
- Saddle surfaces have an upward curvature in one direction and a downward curvature in the perpendicular direction. In a saddle-surfaced shell structure, regions of downward curvature exhibit arch-like action, while regions of upward curvature behave as a cable structure. If the edges of the surface are not supported, beam behaviour may also be present

- Ruled surfaces are generated by the motion of a straight line. Because of its straight-line geometry, a ruled surface is generally easier to form and construct than a rotational or translational surface



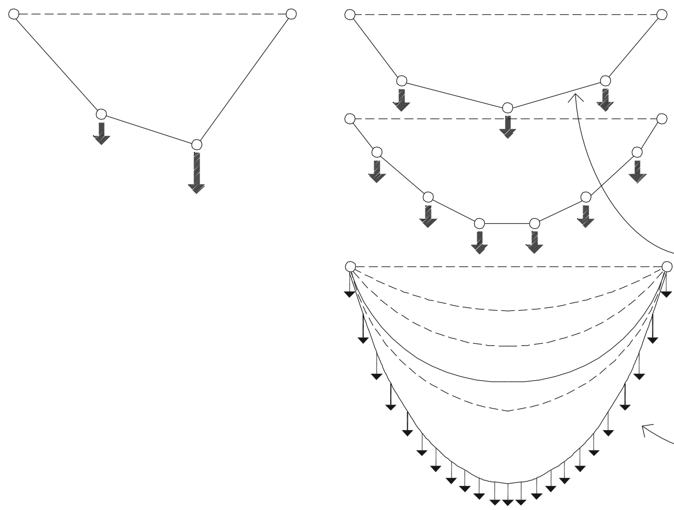
- Rotational surfaces are generated by rotating a plane curve about an axis. Spherical, elliptical and parabolic dome surfaces are examples of rotational surfaces





- A one-sheet hyperboloid is a ruled surface generated by sliding an inclined line segment on two horizontal circles. Its vertical sections are hyperbolas

EN Eurocode 3: Design of Steel Structures, Part 1-6, General Strength and Stability of Shell Structures

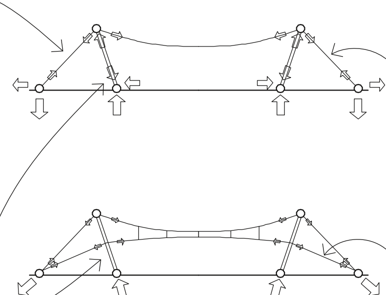


Cable structures utilise the cable as the principal means of support. Because cables have high tensile strength but offer no resistance to compression or bending, they must be used purely in tension. When subject to concentrated loads, the shape of a cable consists of straight-line segments. Under a uniformly distributed load, it will take on the shape of an inverted arch.

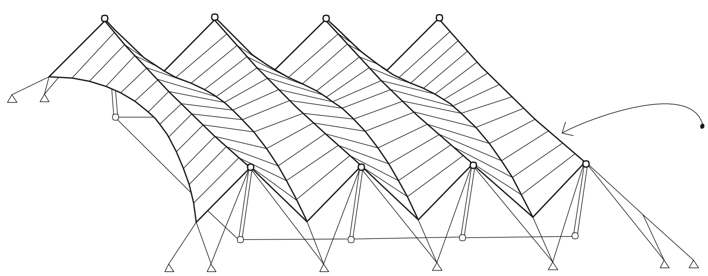
- The 'form active shape' is the shape assumed by a freely deforming cable in direct response to the magnitude and location of external forces. A cable always adapts its shape so that it is in pure tension under the action of an applied load. If the loads are concentrated at individual points the shape will be straight edged
- A catenary is the curve assumed by a perfectly flexible, uniform cable suspended freely from two points not in the same vertical line. For a load that is uniformly distributed in a horizontal projection, the curve approaches that of a parabola

Suspension structures utilise a network of cables suspended and prestressed between compression members to directly support applied loads.

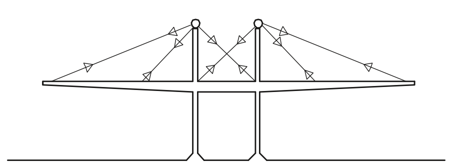
- Guy cables absorb the horizontal component of thrust in a suspension or cable-stayed structure and transfer the force to a ground foundation
- The mast is a vertical or inclined compression member in a suspension or cable-stayed structure, supporting the sum of the vertical force components in the primary and guy cables. Inclining the mast enables it to pick up some of the horizontal cable thrust and reduces the force in the guy cables



- Single-curvature structures utilise a parallel series of cables to support surface-forming beams or plates. They are susceptible to flutter induced by the aerodynamic effects of wind. This liability can be reduced by increasing the dead load on the structure or by anchoring the primary cables to the ground with transverse guy cables
- Double-cable structures have upper and lower sets of cables of different curvatures, pretensioned by ties or compression struts to make the system more rigid and resistant to flutter



- Double-curvature structures consist of a field of crossed cables of different and often reverse curvatures. Each set of cables has a different natural period of vibration, thus forming a self-dampening system that is more resistant to flutter

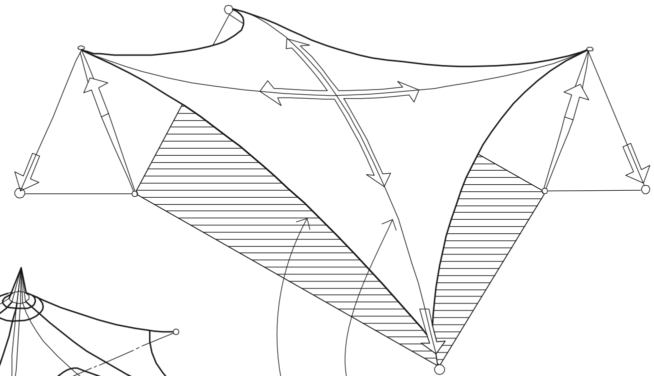


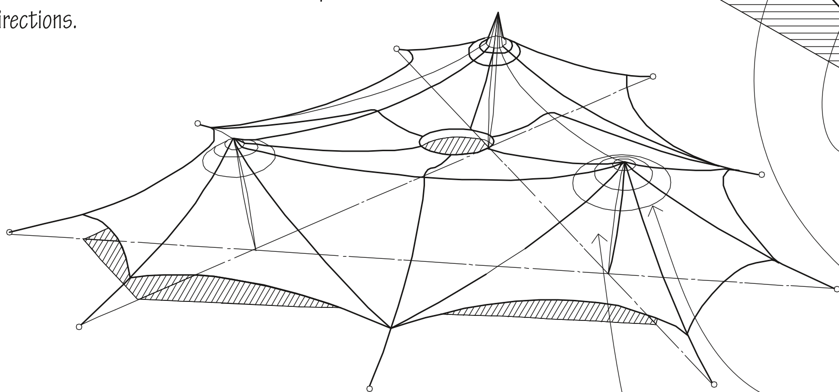
- Cable-stayed structures have vertical or inclined masts from which cables extend to support horizontally spanning members arranged in a parallel or radial pattern

EN Eurocode 3: Design of Steel Structures, Part 1-11, Design of Structures with Tension Components

Membranes are thin, flexible surfaces that carry loads primarily through the development of tensile stresses. They may be suspended or stretched between posts, or be supported by air pressure.

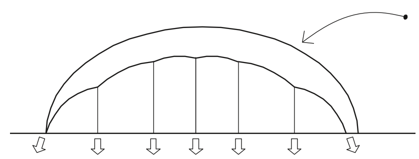
Tent structures are membrane structures that are prestressed by externally applied forces and held completely taut under all anticipated load conditions. To avoid extremely high tensile forces, membrane structures should have relatively sharp curvatures in opposite directions.





- Membrane and steel cables transmit external loads to masts and ground anchors by means of tensile forces
- Reinforcing edge cables stiffen the free edges of a tent structure
- The membrane may be tied to the mast supports by a reinforcing cable loop or be stretched over a distribution cap
- The masts are designed to resist buckling under compressive loading

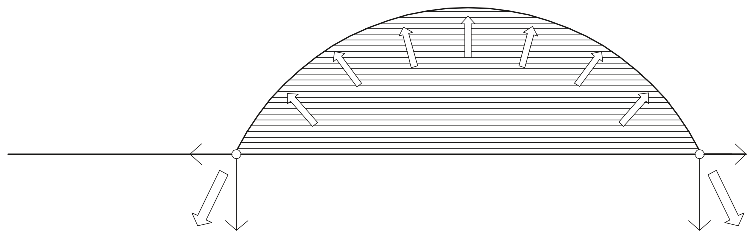
Pneumatic structures are membrane structures that are placed in tension and stabilised against wind and snow loads by the pressure of compressed air. The membrane is usually a woven textile or fibreglass fabric coated with a synthetic material such as silicone. Translucent membranes provide natural illumination, gather solar radiation in the winter, and cool the interior space at night. Reflective membranes reduce solar heat gain. A fabric liner can capture air space to improve the thermal resistance of the structure.

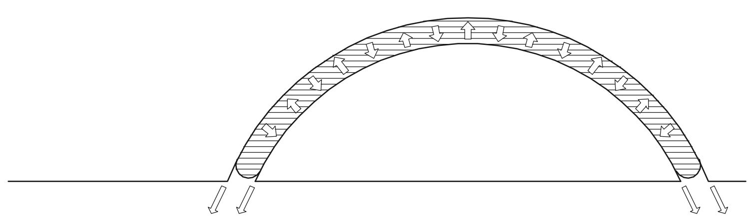


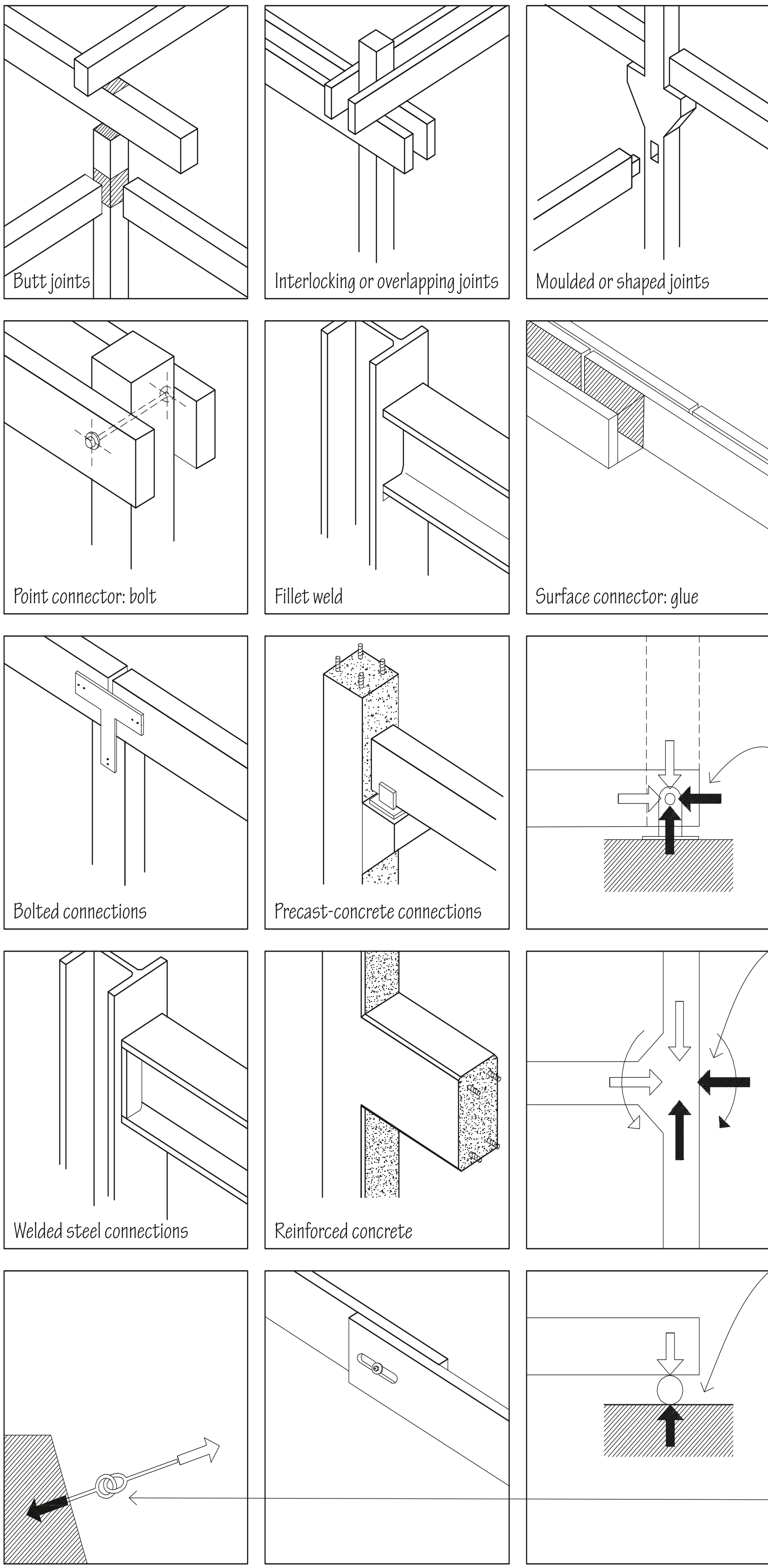
- Some air-supported structures use a net of cables placed in tension by the inflating force to restrain the membrane from developing its natural inflated profile

There are two kinds of pneumatic structures: air-supported structures and air-inflated structures.

- Air-supported structures consist of a single membrane supported by an internal air pressure slightly higher than normal atmospheric pressure, and securely anchored and sealed along the perimeter to prevent leaking. Air locks are required at entrances to maintain the internal air pressure
- Air-inflated structures are supported by pressurised air within inflated building elements. These elements are shaped to carry loads in a traditional manner, while the enclosed volume of building air remains at normal atmospheric pressure. The tendency for a double-membrane structure to bulge in the middle is restrained by a compression ring or by internal ties or diaphragms







The manner in which forces are transferred from one structural element to the next and how a structural system performs as a whole depend to a great extent on the types of joints and connections used. Structural elements can be joined to each other in three ways. Butt joints allow one of the elements to be continuous and usually require a third mediating element to make the connection. Overlapping joints allow all of the connected elements to bypass each other and be continuous across the joint. The joining elements can also be moulded or shaped to form a structural connection.

The connectors used to join the structural elements may be in the form of a point, a line or a surface. While linear and surface types of connectors resist rotation, point connectors do not unless a series of them is distributed across a large surface area.

- Pinned joints theoretically allow rotation but resist translation in any direction
- Rigid or fixed joints maintain the angular relationship between the joined elements, restrain rotation and translation in any direction, and provide both force and moment resistance
- Roller joints allow rotation but resist translation in a direction perpendicular into or away from their faces. They are not employed in building construction as often as pinned or fixed connections but they are useful when a joint must allow expansion and contraction of a structural element to occur
- A cable anchorage allows rotation but resists translation only in the direction of the cable

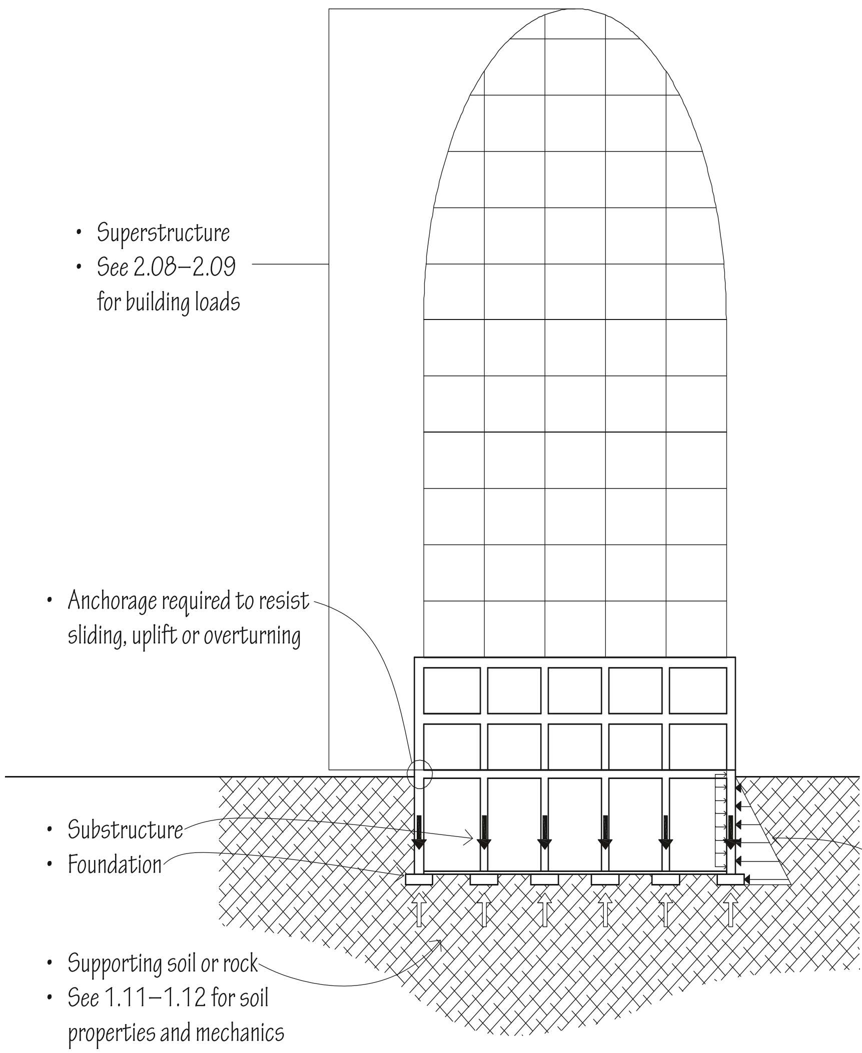
EN Eurocode 3: Design of Steel Structures, Part 1-8, General Design of Joints

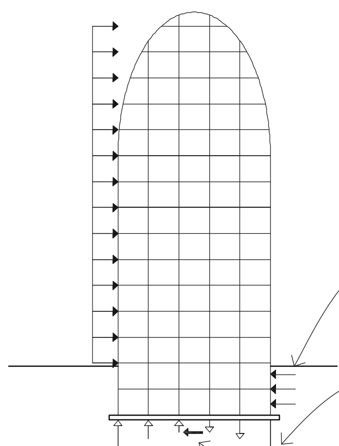
3

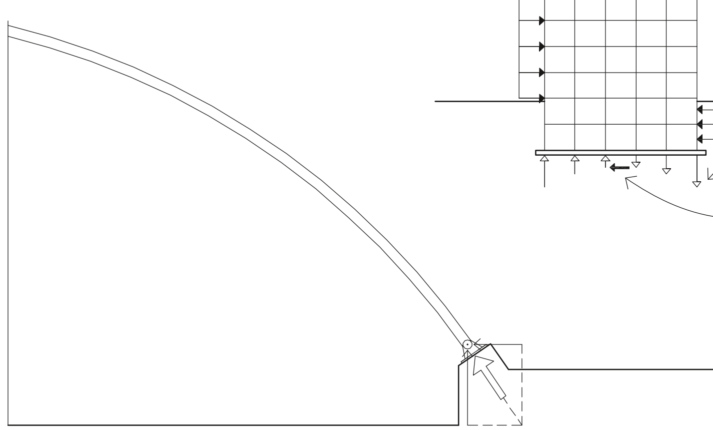
FOUNDATION SYSTEMS

The foundation is the lowest division of a building — its substructure — constructed partly or wholly below the surface of the ground. Its primary function is to support and anchor the superstructure above and transmit its loads safely into the earth. Because it serves as a critical link in the distribution and resolution of building loads, the foundation system must be designed to both accommodate the form and layout of the superstructure above and respond to the varying conditions of soil, rock and water below.

The principal loads on a foundation are the combination of dead and live loads acting vertically on the superstructure. In addition, a foundation system must anchor the superstructure against wind-induced sliding, overturning and uplift, withstand sudden ground movements (in an earthquake zone) and resist the pressure imposed by the surrounding soil mass and groundwater on basement walls. In some cases, a foundation system may also have to counter the thrust from arched or tensile structures.

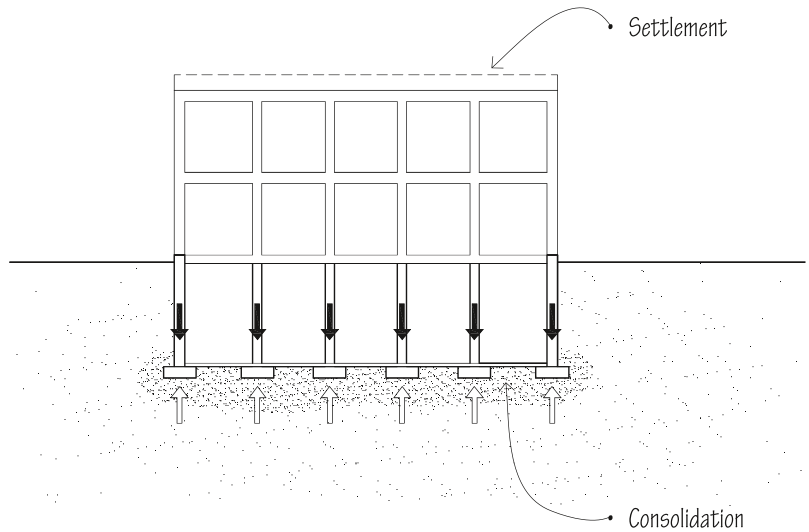




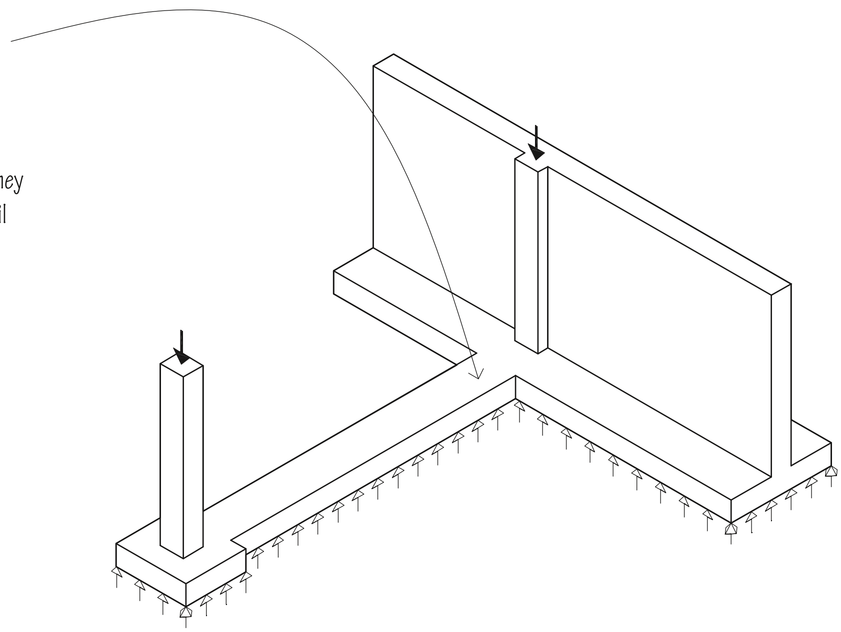


• Thrust from arched or tensile structures

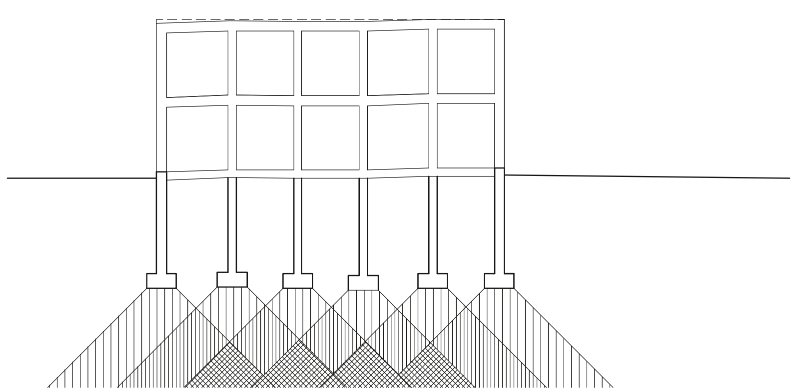
A structure gradually experiences settlement as the soil beneath its foundation consolidates under loading. As a building is constructed, some settlement is to be expected as the load on the foundation increases and causes a reduction in the volume of soil voids containing air or water. This consolidation is usually slight and occurs rather quickly as loads are applied on dense, granular soils, such as coarse sand and gravel. When the foundation soil is a moist, cohesive clay, which has a scale-like structure and a relatively large percentage of voids, consolidation can be quite substantial and occur slowly over a longer period of time.

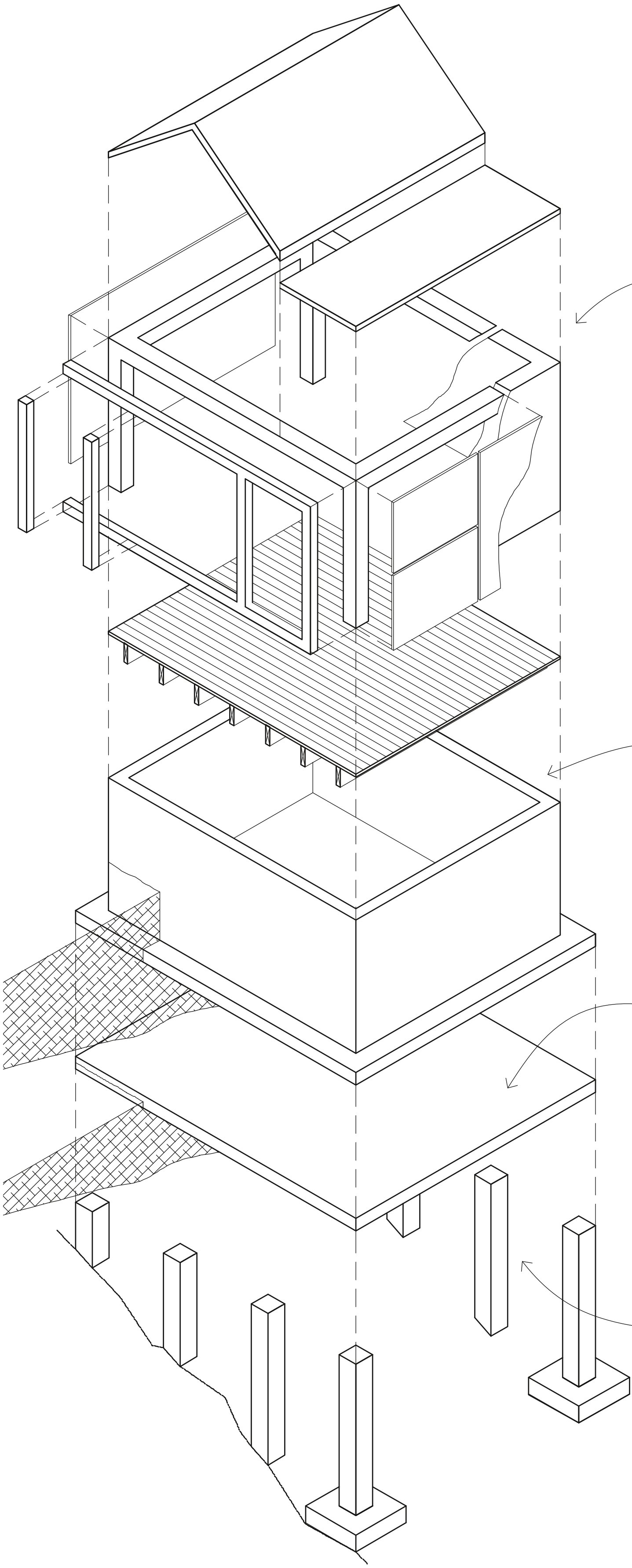


A properly designed and constructed foundation system should distribute its loads so that whatever settlement occurs is minimal or is uniformly distributed under all portions of the structure. This is accomplished by laying out and proportioning the foundation supports so that they transmit an equal load per unit area to the supporting soil or rock without exceeding its bearing capacity.



Differential settlement — the relative movement of different parts of a structure caused by uneven consolidation of the foundation soil — can cause a building to shift out of plumb and cracks to occur in its foundation, structure or finishes. If extreme, differential settlement can result in the failure of the structural integrity of a building.

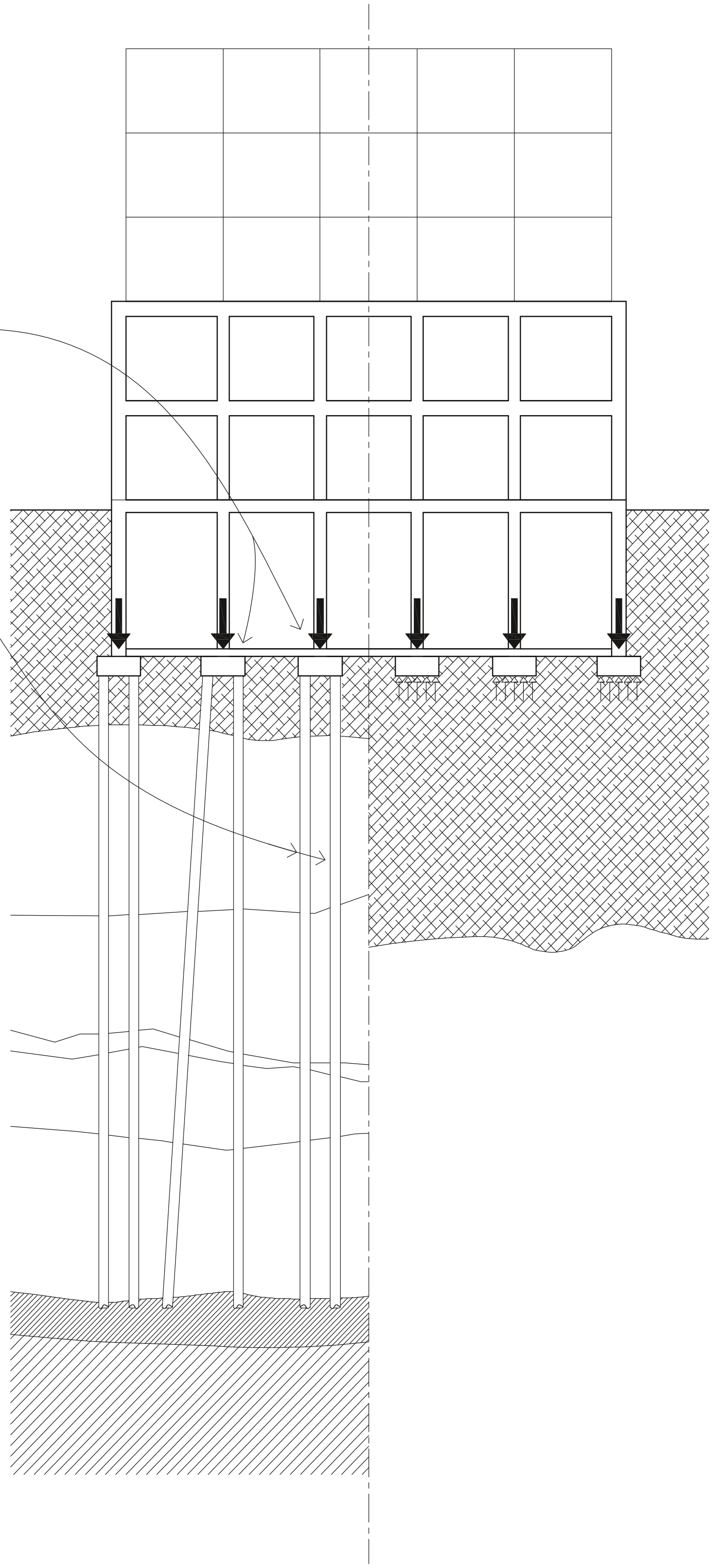




Foundations utilise a combination of load-bearing walls, columns and piers to transmit building loads directly to the earth. These structural elements can form various types of substructures:

- Solid and framed above-ground walls transfer roof, floor and other imposed loads on the building to suitably placed and sized foundations
- Basements wholly or partly below grade require a continuous retaining wall to hold back the surrounding earth and support the exterior walls and columns of the superstructure above
- Concrete slabs-on-grade supported directly by the earth and thickened to carry wall and column loads (raft foundations) can form an economical foundation and floor system for one- and two-storey structures where suitable ground conditions exist
- A grid of independent piers or columns can elevate the superstructure above the surface of the ground. Below-grade piles can also transfer loads to deeper levels where unsuitable soil conditions exist closer to the surface

We can classify foundation systems into two broad categories: shallow foundations and deep foundations.



Shallow Foundations

Shallow or spread foundations are employed when stable soil of adequate bearing capacity occurs relatively near to the ground surface. They are placed directly below the lowest part of a substructure and transfer building loads directly to the supporting soil by vertical pressure.

Deep Foundations

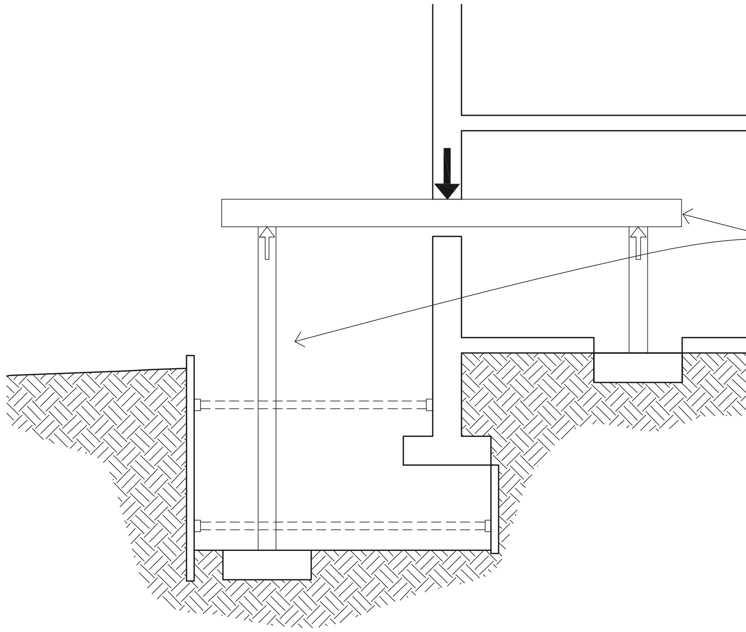
Deep foundations are employed when the soil underlying a foundation is unstable or of inadequate bearing capacity. They extend down through unsuitable soil to transfer building loads to a more appropriate bearing stratum of rock or dense sands and gravels well below the superstructure.

Factors to consider in selecting and designing the type of foundation system for a building include:

- Pattern and magnitude of building loads
- Subsurface and groundwater conditions
- Topography of the site
- Impact on adjacent properties
- Building regulation requirements
- Construction method and risk

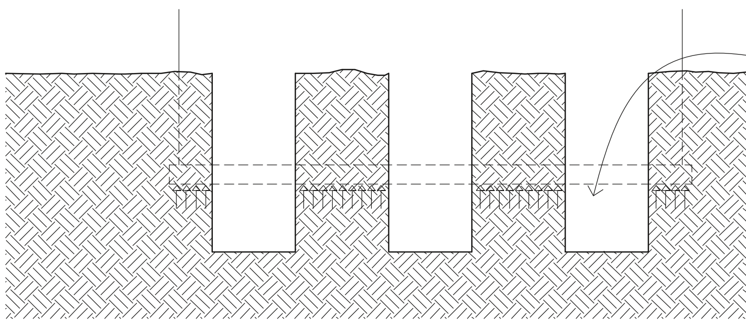
The design of a foundation system requires professional analysis and design by a suitably qualified geotechnical, civil or structural engineer. When designing anything other than a single-family dwelling on stable soil, it is also advisable to have a geotechnical engineer undertake a subsurface investigation in order to determine the type and size of foundation system required for the building design.

3.06 UNDERPINNING

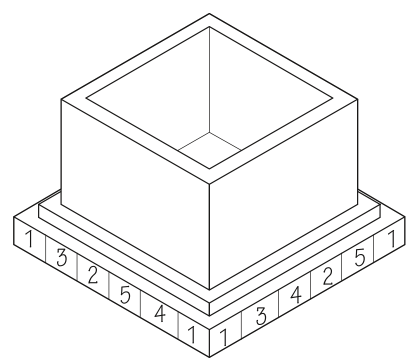


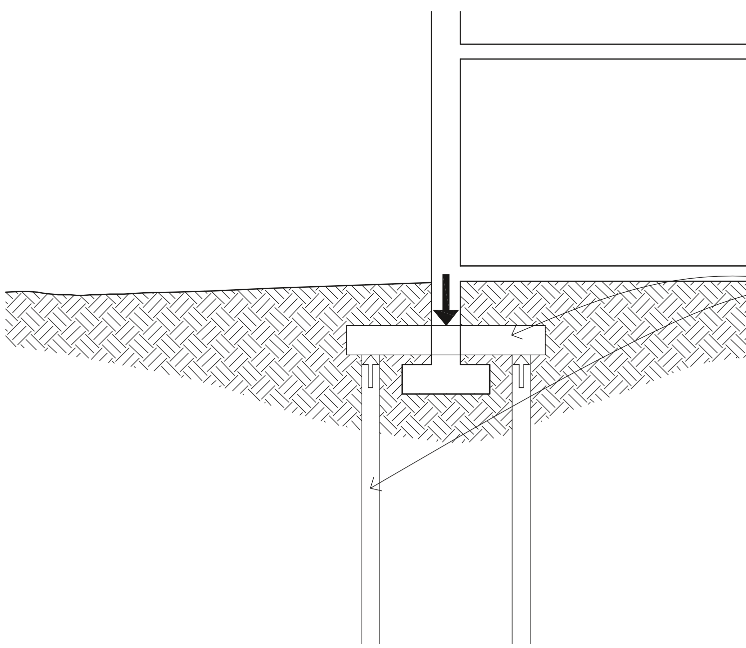
Underpinning refers to the process of rebuilding or strengthening the foundation of an existing building, or extending it when a new excavation in adjoining property is deeper than the existing foundation or when other alterations with structural implications are being made.

- To provide temporary support while an existing foundation is repaired, strengthened or deepened, needle beams are passed through the foundation wall and carried by hydraulic jacks and shores



- Another method for providing temporary support is to dig intermittent pits under the existing foundation down to the level of the new footings. After the new foundation wall and footing sections are placed, additional pits are dug until the entire wall has been deepened
- Pits are dug in 1.2 m sections and scheduled to ensure no one area is over excavated

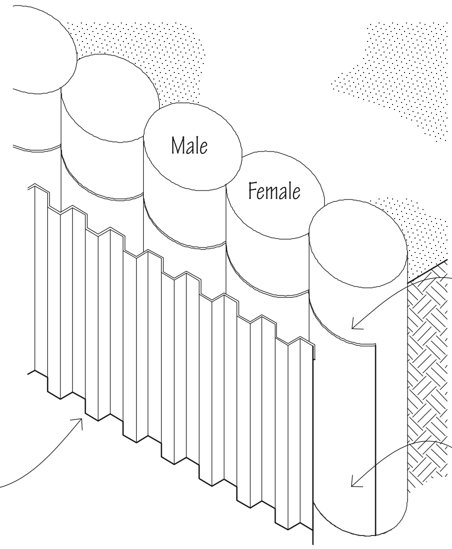




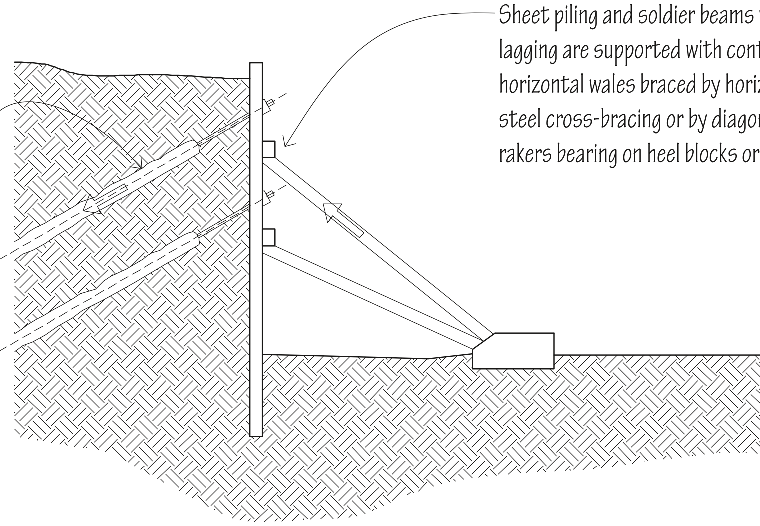
- An alternative to extending a new foundation wall and placing new footings is to construct piles on either side of the existing foundation, remove a section of foundation wall and replace the section with a reinforced-concrete pile cap

EN Eurocode 7: Geotechnical Design, Part 1

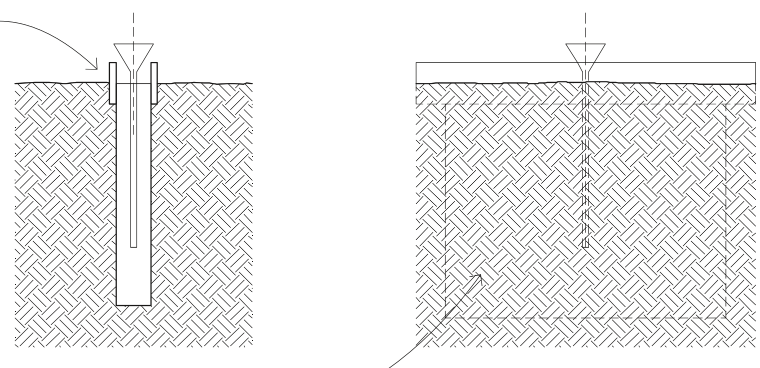
When excavations are to take place on site, the safety of the people who will work in the excavated area should be of paramount concern. Where ground conditions and depth of excavation risk any slippage, shoring should be used. The requirement for shoring should be assessed by a competent person. In addition, where deep excavation takes place barriers should be included to minimise the risk of falls from height.



- Contiguous bored piles in suitable ground conditions can be installed close together to form a perimeter wall before excavation takes place. Where a more water-resistant structure is required (beside a body of water or in naturally wet soils) secant piles can be used which interlock with each other through a series of male and female piles
- Sheet piling consists of timber, steel or precast-concrete planks driven vertically side by side to retain earth and prevent water from seeping into an excavation. Steel and precast-concrete sheet piling may be left in place as part of the substructure of a building
- A tanking membrane can later be applied to ensure a water-tight structure

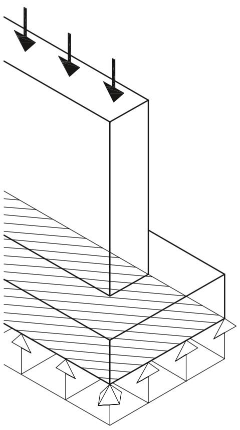


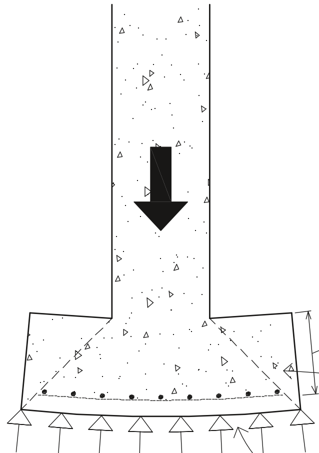
- Sheet piling and soldier beams with lagging are supported with continuous horizontal wales braced by horizontal steel cross-bracing or by diagonal steel rakers bearing on heel blocks or footings
- Ground anchors (Eurocode 7 Part 1, Section 8: Anchorages) may be used if cross-bracing or rakers would interfere with the excavation or construction operation. Grout is forced through the anchor to securely fix it to the ground. Alternatively, tensioned anchors or tiebacks consisting of steel cables or tendons can be inserted into holes pre-drilled through the sheet piling and into rock or a suitable stratum of soil, grouted under pressure to anchor them to the rock or soil, and post-tensioned with a hydraulic jack. The tiebacks are then secured to continuous, horizontal steel wales to maintain the tension



- A diaphragm wall is a concrete wall cast in a trench to serve as sheeting while deep excavation is taking place and often acts as a permanent foundation wall. It is constructed by excavating a trench in short lengths, filling it with a slurry of bentonite and water to prevent the side walls from collapsing
- Reinforcement is placed in the trench and concrete is placed and located via the tremie, displacing the slurry which is drawn out and can be cleaned and reused in the next section

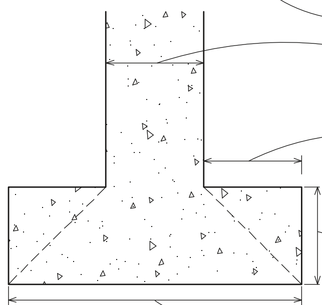
EN Eurocode 7: Geotechnical Design, Part 1, Sections 8 & 9



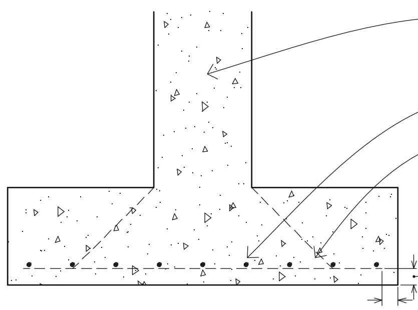


The lowest part of a shallow foundation are spread footings. They are extended laterally to distribute their load over an area of soil wide enough that the allowable bearing capacity of the soil is not exceeded. The contact area required is equal to the quotient of the magnitude of forces transmitted and the allowable bearing capacity of the supporting soil mass.

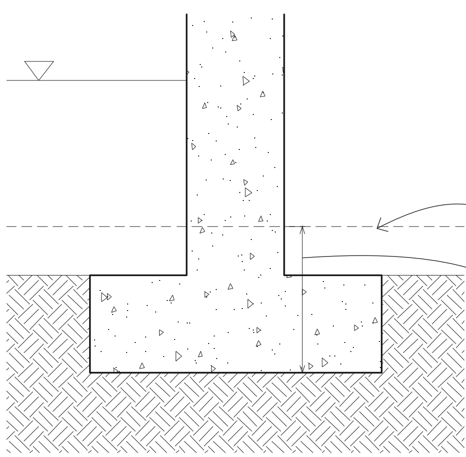
- d = effective depth
- Compression zone
- Tension zone



- Thickness (T) of wall to be supported by the foundation
- Projection minimum width = T
- Depth of foundation (D) at least equal to or greater than T (D=>T) minimum 150 mm
- Overall footing width generally three times T (300–650 mm)



- Concrete having a minimum compressive strength of 25 kilo newtons per metre squared (kN/m^2) at 28 days
- Longitudinal reinforcement
- Tensile reinforcement is required when a spread footing projects more than half of the foundation wall thickness and is subject to bending
- 50 mm minimum clearance between reinforcing bars and concrete surface



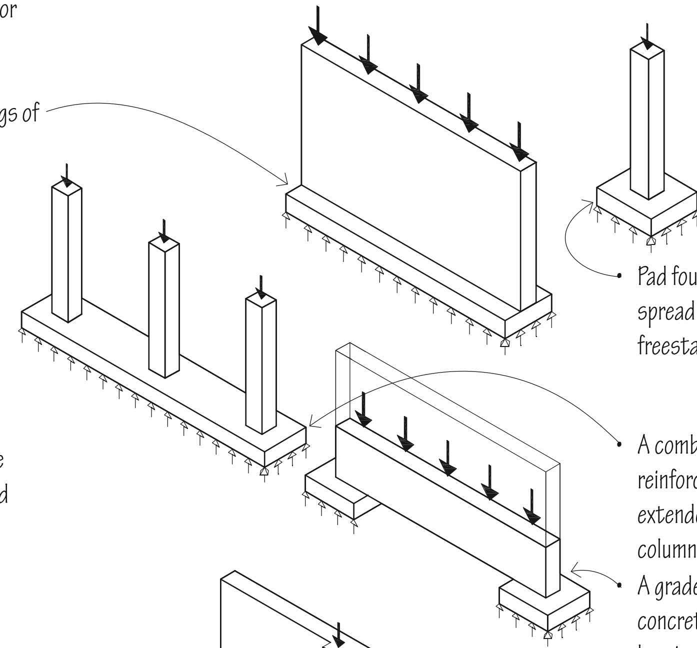
To minimise the effects of ground movement when groundwater freezes and expands in cold weather, building standards require that footings be placed below the depth of frost penetration expected at the building site.

- Frost line is the average depth at which soil is frozen or frost penetrates the ground
- 450 mm

To minimise settlement, footings should always rest on stable, compacted soil free of organic material.

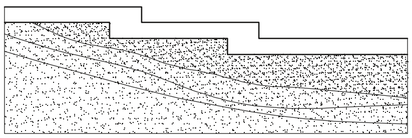
The most common forms of spread footings are strip (or trench fill) and pad foundations.

- Strip foundations are the continuous spread footings of foundation walls



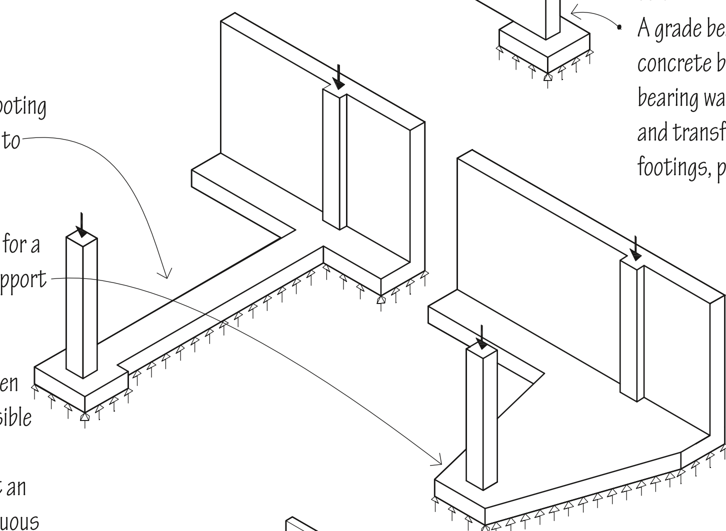
- Pad foundations are the individual spread footings supporting freestanding columns and piers

Other types of spread footings include the following:

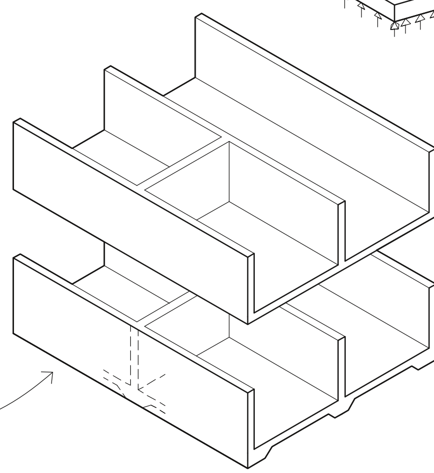


- Stepped footings are strip foundations that change levels in stages to accommodate a sloping grade and maintain the required depth at all points around a building

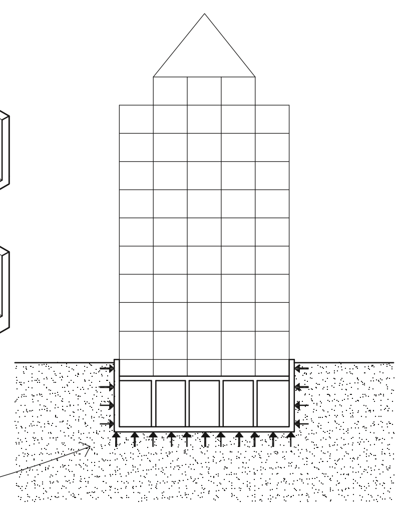
- A combined foundation is a reinforced-concrete footing extended to support a row of columns
- A grade beam is a reinforced-concrete beam supporting a bearing wall at or near ground level and transferring the load to pad footings, piers or piles



- A cantilever or strap footing consists of a column footing connected by a tie beam to another footing in order to balance an asymmetrically imposed load
- A combined footing is a reinforced-concrete footing for a perimeter foundation wall or column extended to support an interior column load
- Cantilever and combined footings are often used when a foundation abuts a property line and it is not possible to construct a symmetrically loaded footing. To prevent the rotation or differential settlement that an asymmetrical loading condition can produce, continuous and cantilever footings are proportioned to generate uniform soil pressure



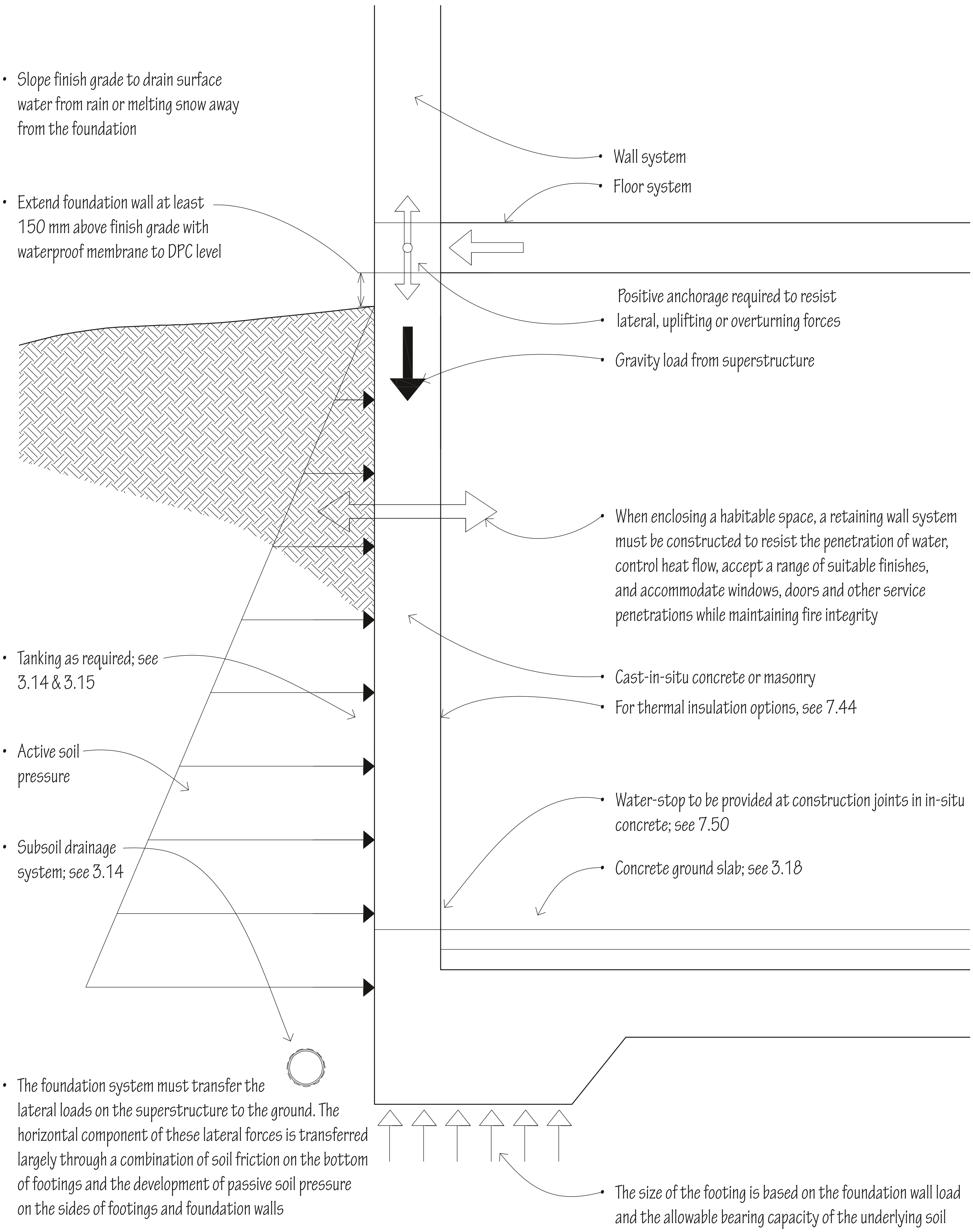
- A raft foundation is a thick, reinforced-concrete slab that serves as a single monolithic footing for a number of walls/columns or an entire building. Raft foundations are used when the allowable bearing capacity of a foundation soil is low relative to building loads and interior column footings become so large that it becomes more economical to merge them into a single slab

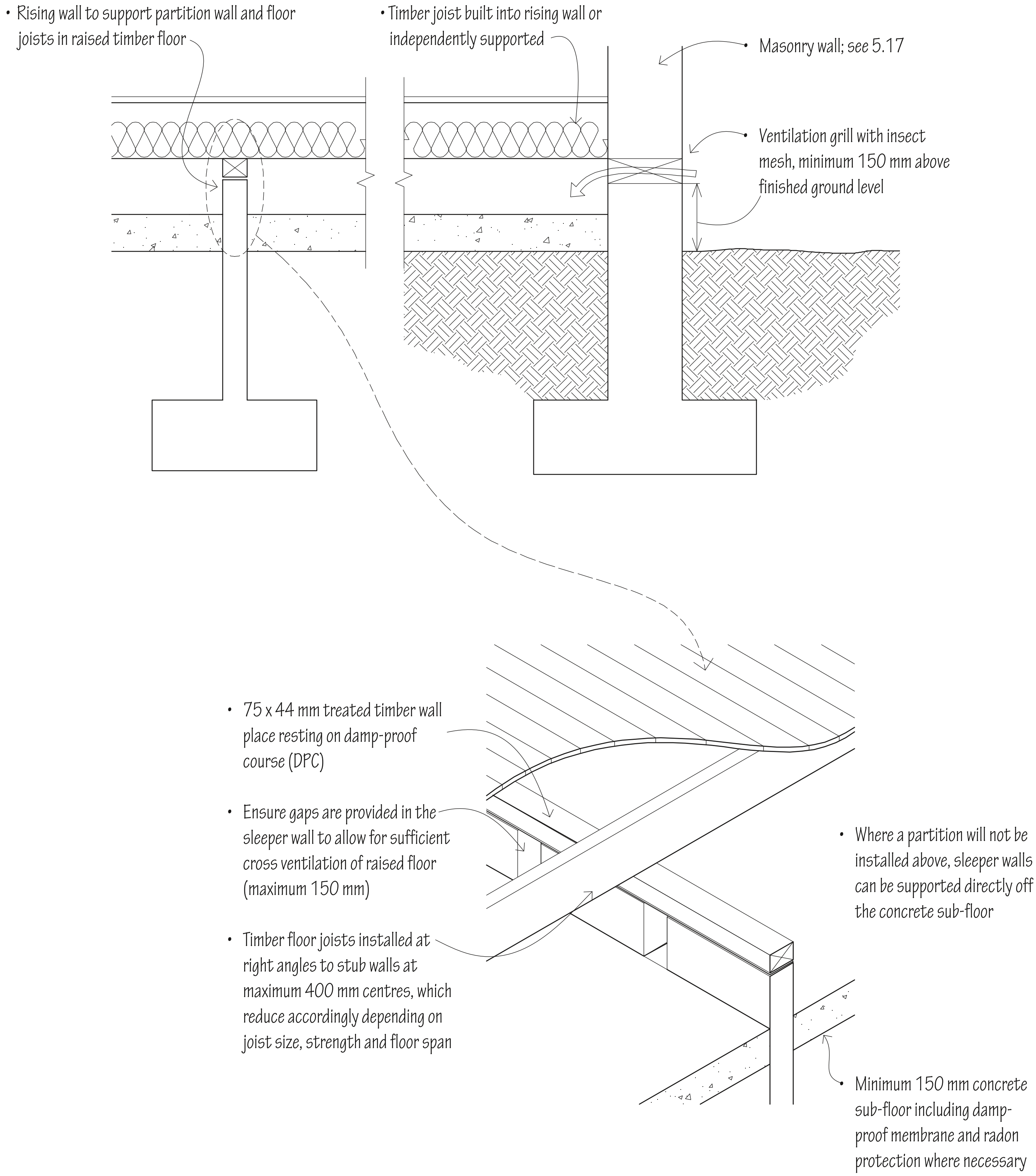


- A floating foundation used in yielding soil has for its footing a raft placed deep enough that the weight of the excavated soil is equal to or greater than the weight of the construction supported

EN Eurocode 7: Geotechnical Design, Part 1 Section 6

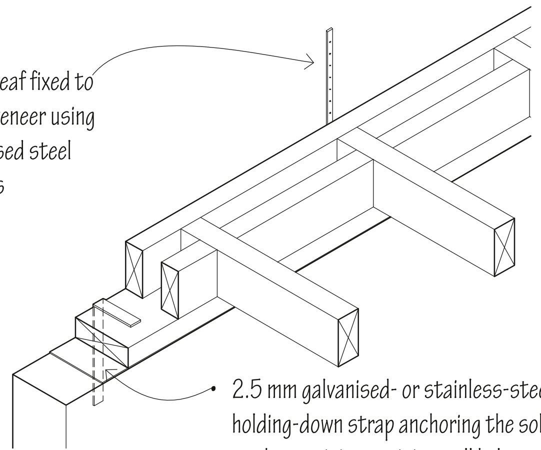
3.10 BASEMENT WALLS

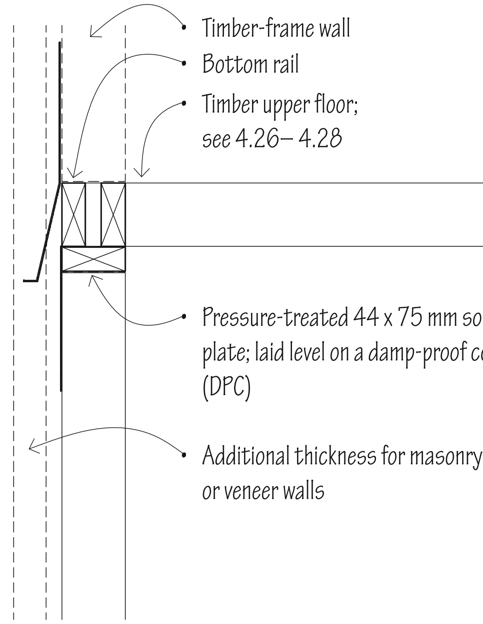



• Rising wall to support partition wall and floor joists in raised timber floor
• Timber joist built into rising wall or independently supported
• Masonry wall; see 5.17
• Ventilation grill with insect mesh, minimum 150 mm above finished ground level
• 75 x 44 mm treated timber wall place resting on damp-proof course (DPC)
• Ensure gaps are provided in the sleeper wall to allow for sufficient cross ventilation of raised floor (maximum 150 mm)
• Timber floor joists installed at right angles to stub walls at maximum 400 mm centres, which reduce accordingly depending on joist size, strength and floor span
• Where a partition will not be installed above, sleeper walls can be supported directly off the concrete sub-floor
• Minimum 150 mm concrete sub-floor including damp-proof membrane and radon protection where necessary

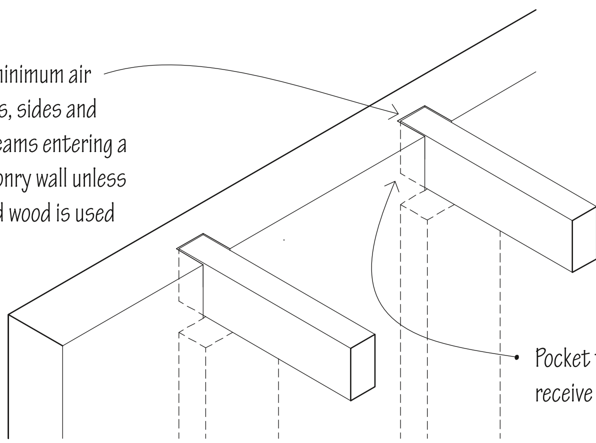
3.12 RETAINING WALLS

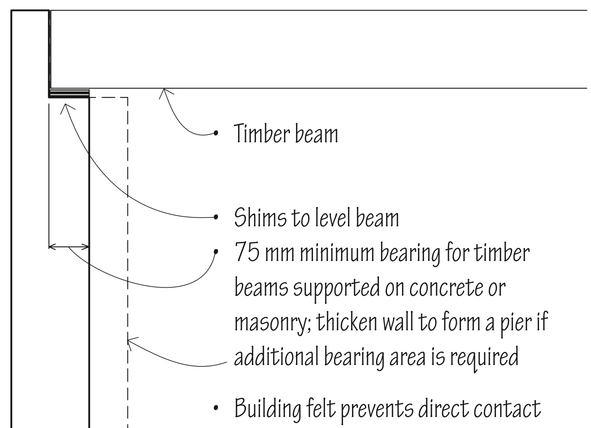
The top of a foundation wall must be prepared to receive, support and anchor the wall and floor systems of the superstructure.



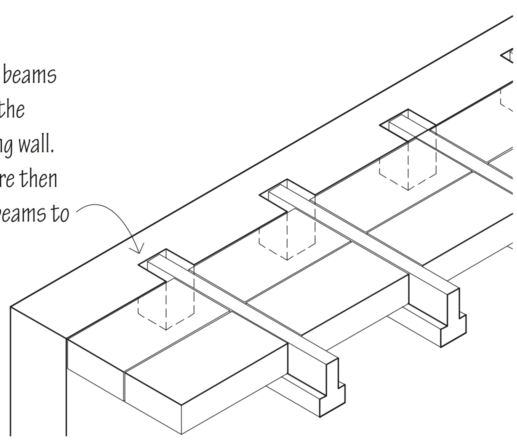


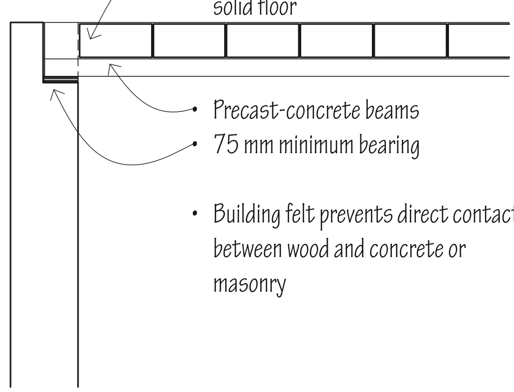
Connection to Timber Frame





Timber Beams

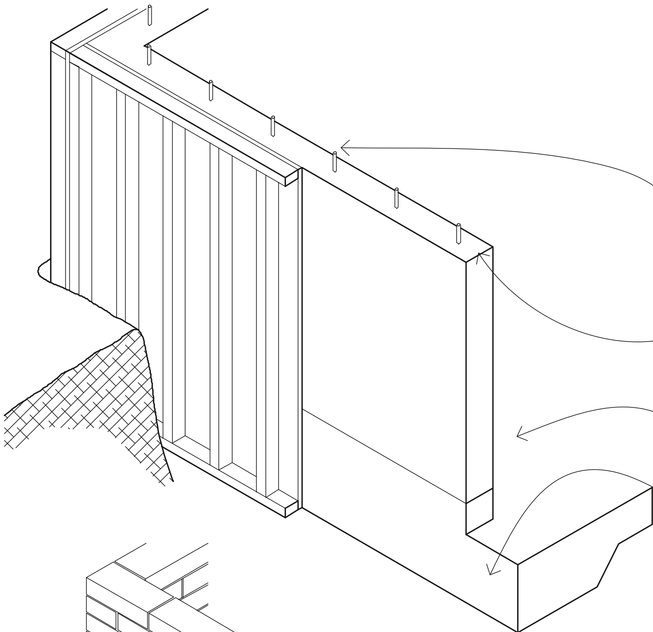




Beam and Block Floor

In-Situ Concrete Retaining Walls

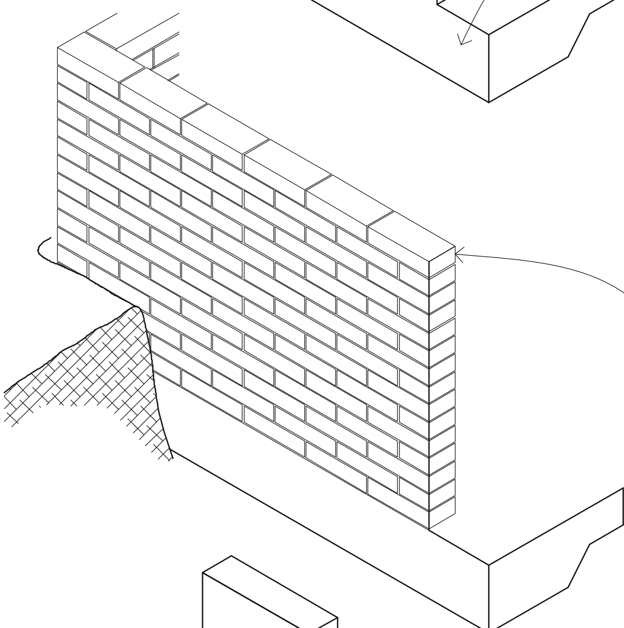
Cast-in-situ concrete foundation walls require formwork and access to place the concrete.



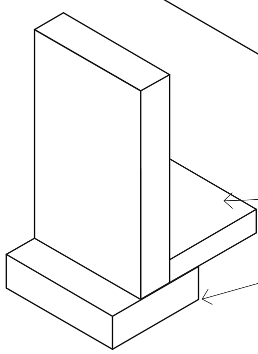
- Anchor bolts/ holding down straps for sole plates of light-frame construction; see 3.12 and 4.28
- Horizontal and vertical reinforcement as required by engineering analysis; see 5.06
- 250 mm minimum wall thickness
- Concrete ground slab; see 3.18
- Concrete footing; see 3.08, 3.09

Concrete Masonry Retaining Walls

Concrete masonry retaining walls utilise easily handled small units and do not require formwork. Because concrete masonry is a modular material, all major dimensions should be based on standard block dimensions.



- 215 mm concrete blocks laid on the flat in a stretcher bond
- Vertical reinforcement in grouted cells and horizontal bond beams as required by engineering analysis
- See 5.18 for reinforcement of masonry walls

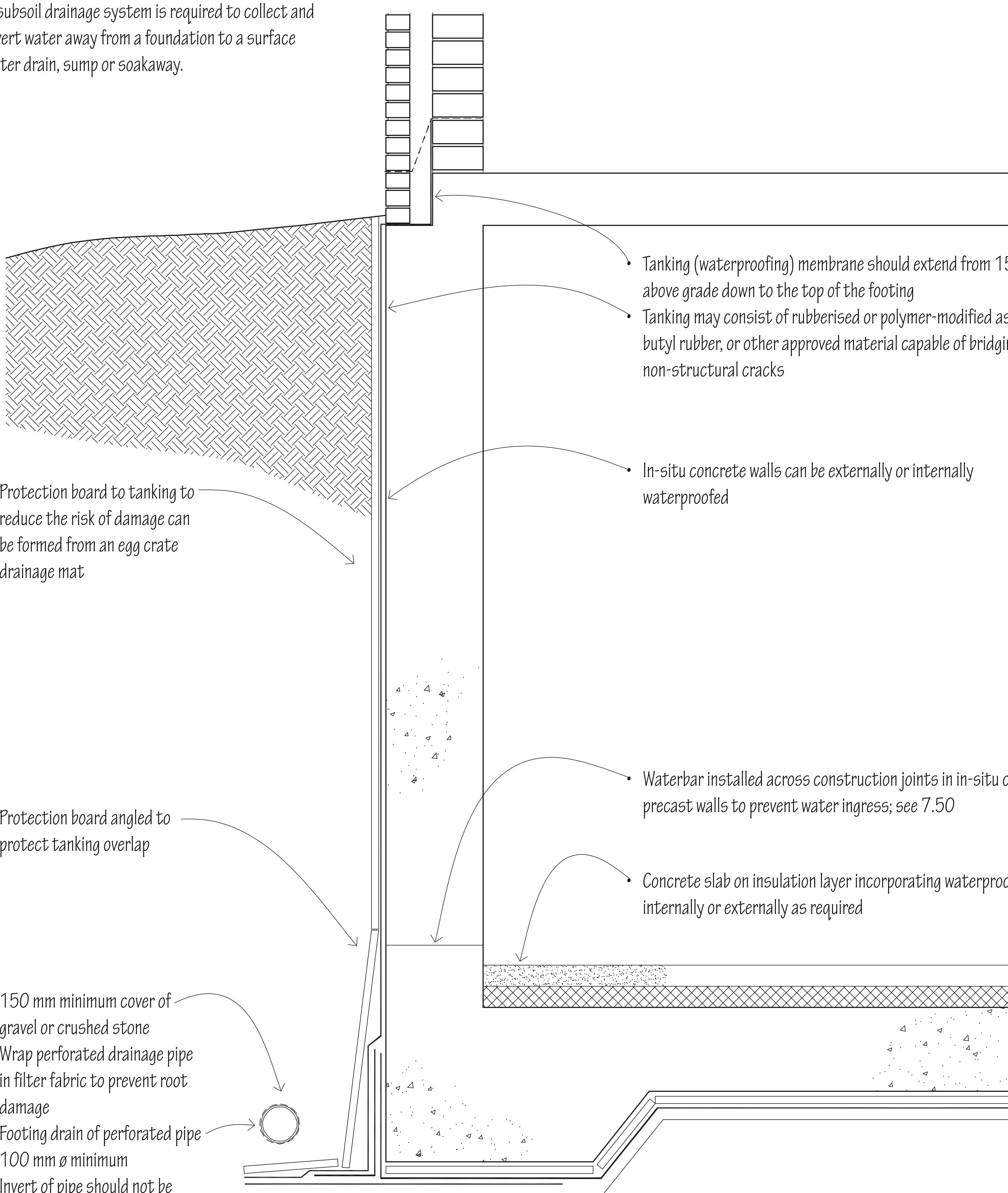


- Concrete ground slab; see 3.18
- Concrete footing; see 3.08, 3.09

EN Eurocode 7: Geotechnical Design, Part 1
EN Eurocode 2: Design of Concrete Structures, Part 1
EN Eurocode 6: Design of Masonry Structures, Part 1

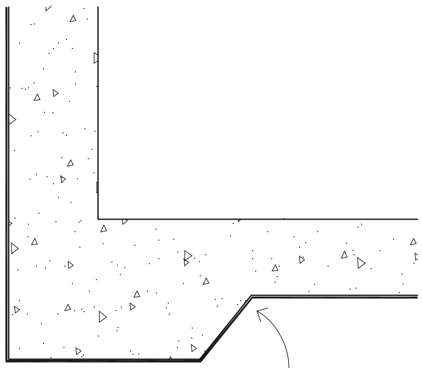
3.14 RETAINING WALLS

A subsoil drainage system is required to collect and divert water away from a foundation to a surface water drain, sump or soakaway.

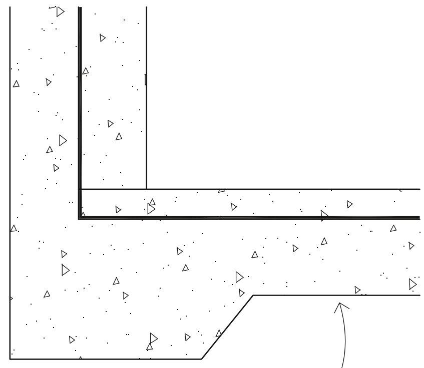


- Tanking (waterproofing) membrane should extend from 150 mm above grade down to the top of the footing
- Tanking may consist of rubberised or polymer-modified asphalt, butyl rubber, or other approved material capable of bridging non-structural cracks
- In-situ concrete walls can be externally or internally waterproofed
- Protection board to tanking to reduce the risk of damage can be formed from an egg crate drainage mat
- Waterbar installed across construction joints in in-situ or precast walls to prevent water ingress; see 7.50
- Protection board angled to protect tanking overlap
- Concrete slab on insulation layer incorporating waterproofing internally or externally as required
- 150 mm minimum cover of gravel or crushed stone
- Wrap perforated drainage pipe in filter fabric to prevent root damage
- Footing drain of perforated pipe 100 mm ø minimum
- Invert of pipe should not be above elevation of slab; slope to drain to a surface water sewer, sump or soakaway
- Protection board for waterproofing
- Tanking extended beyond the slab edge to allow for overlap

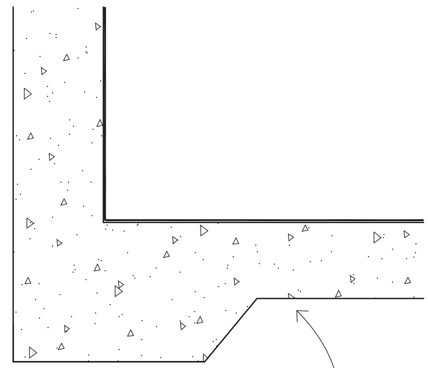
EN Eurocode 7: Geotechnical Design, Part 1
EN Eurocode 2: Design of Concrete Structures, Part 1



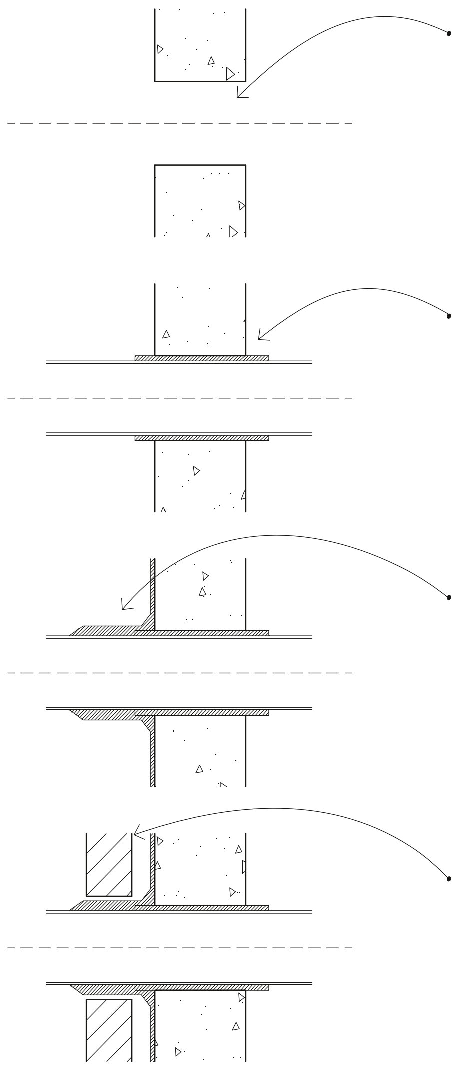
- External tanking membrane requires protection from a block wall or protection membrane



- Sandwich tanking is protected internally by a non-structural concrete wall

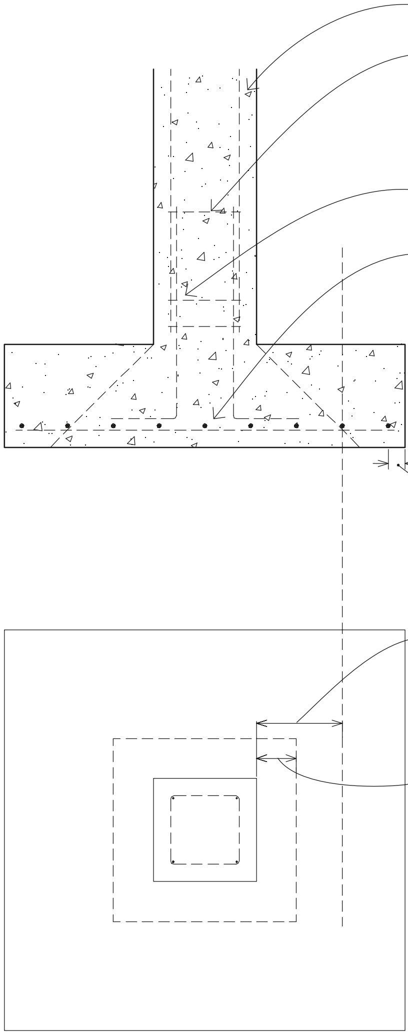


- Internal tanking system requires additional protection to avoid puncture or other damage



- An opening can be cast into the wall during construction or drilled using a hole-saw once the concrete has been allowed to cure
- Service pipe is passed through the opening wrapped in a waterproofing sleeve of asphalt or an alternatively suitable waterproofing membrane
- External tanking membrane applied to wall and lapped over sleeve
- External protection board or block wall to provide additional protection

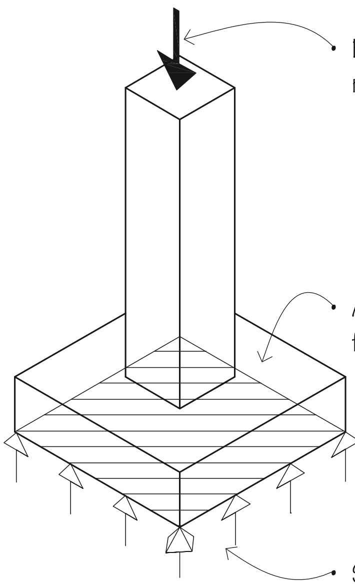
Service Penetrations



- Vertical reinforcement
- Lateral reinforcement
- See also 5.04 for concrete column details
- Steel dowels anchor column to footing
- Two-way reinforcement uniformly spaced
- d = effective depth
- 75 mm minimum cover for steel reinforcement when concrete is cast against and permanently exposed to earth
- Critical section for one-way shear
- Critical section for two-way shear

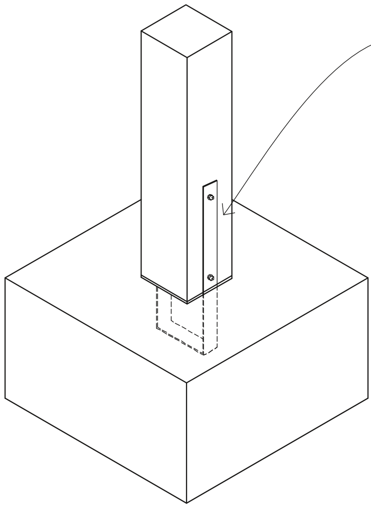
Reinforced-Concrete Column

- In simple terms the required size of a column footings contact area with the ground is related to the load on the column in relation to the bearing capacity of the soil. This is complicated by varying ground conditions and adjoining structures



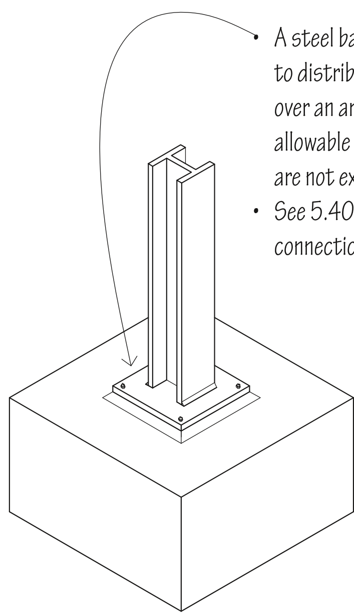
A = P/S where:

- P = column load in kilo-newtons (kN)
- A = contact area of footing
- S = soil-bearing capacity in kilo-newtons per metre squared (kN/m^2)



- A variety of proprietary post bases are available. Consult manufacturer for allowable loads and installation details. Post bases can also be fabricated to satisfy specific design conditions

Timber Post



- A steel base plate is necessary to distribute the column load over an area wide enough that the allowable stresses in the concrete are not exceeded
- See 5.40 for steel base plate connections

Steel Column

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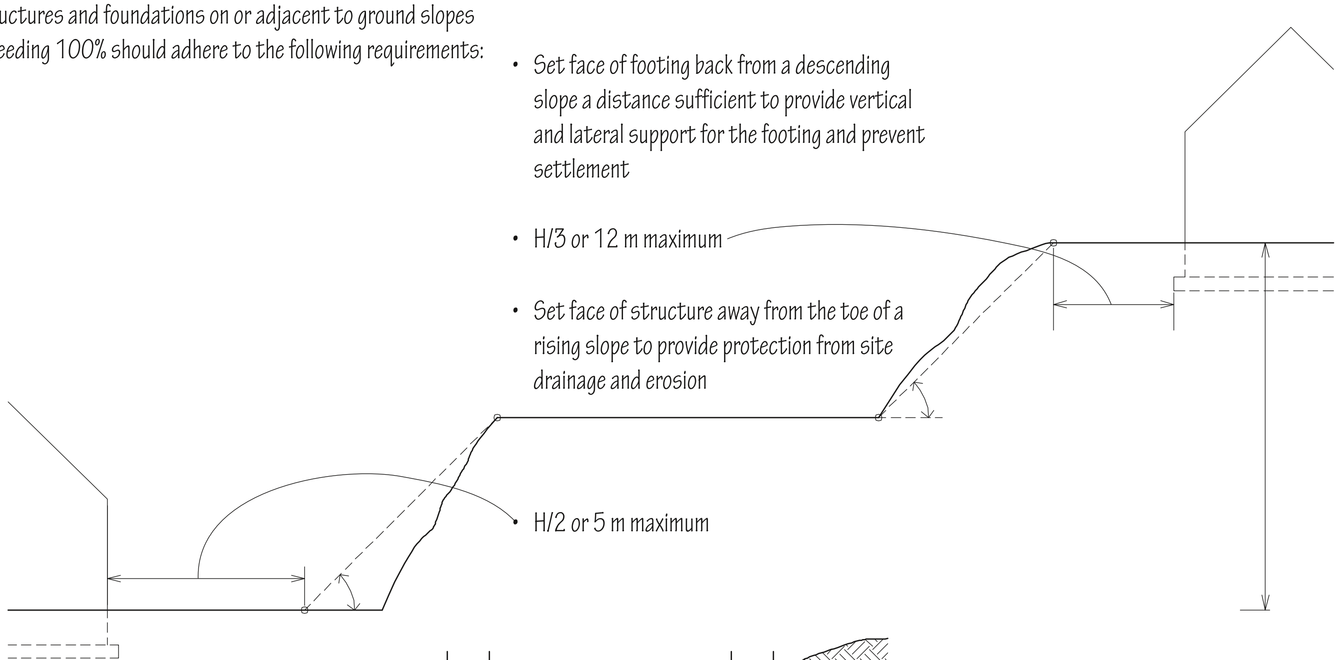
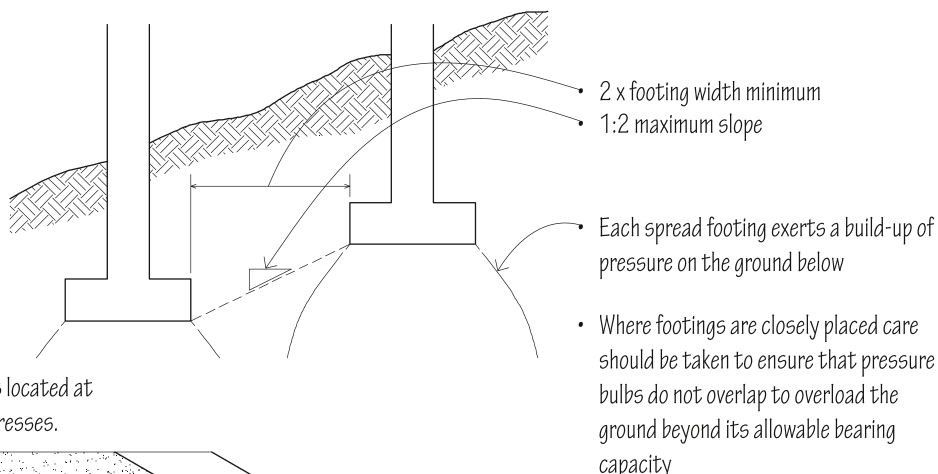
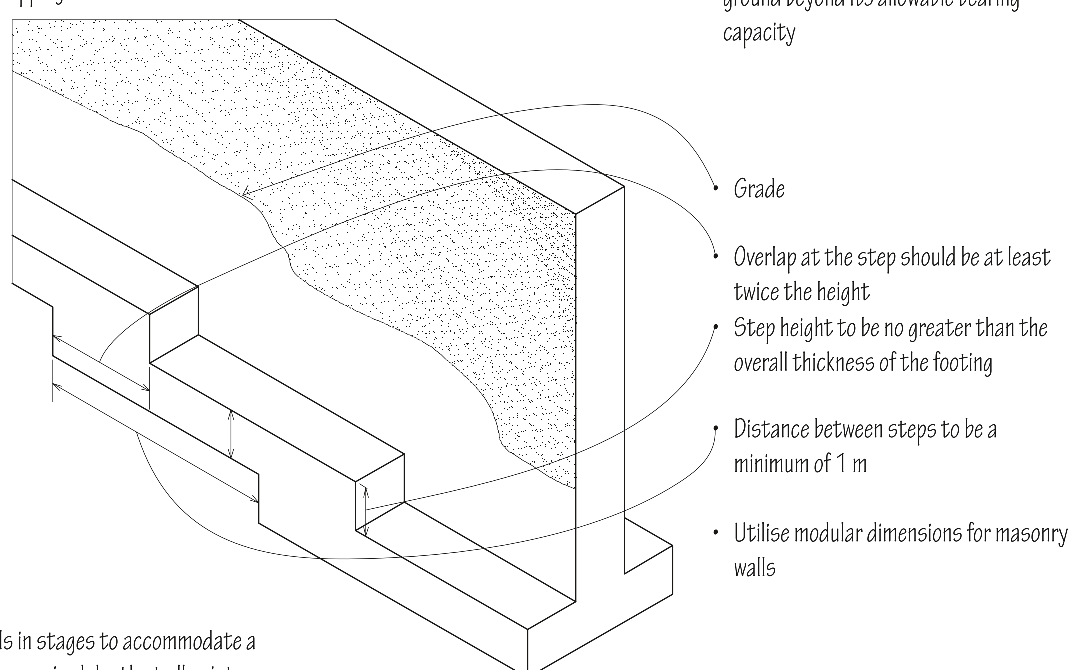
Structures and foundations on or adjacent to ground slopes exceeding 100% should adhere to the following requirements:

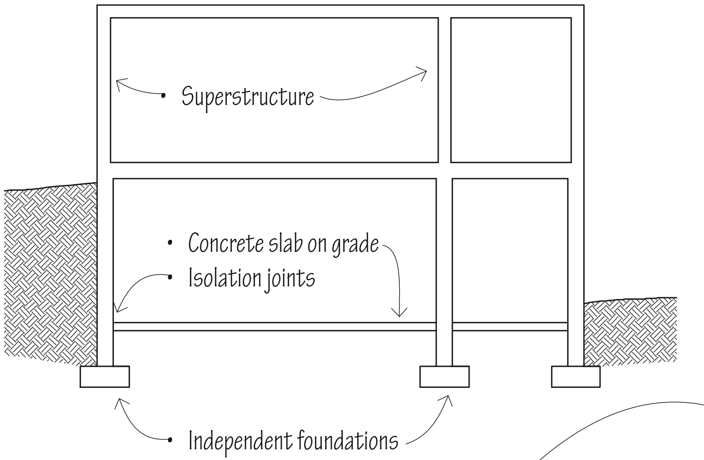




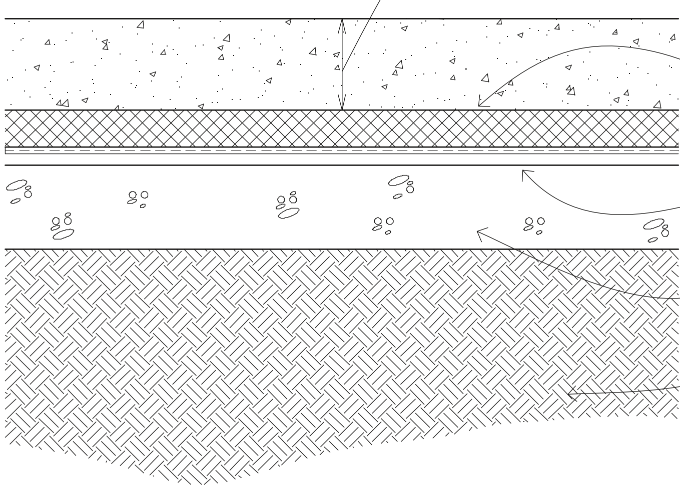
Closely spaced footings or adjacent footings located at different levels can cause overlapping soil stresses.



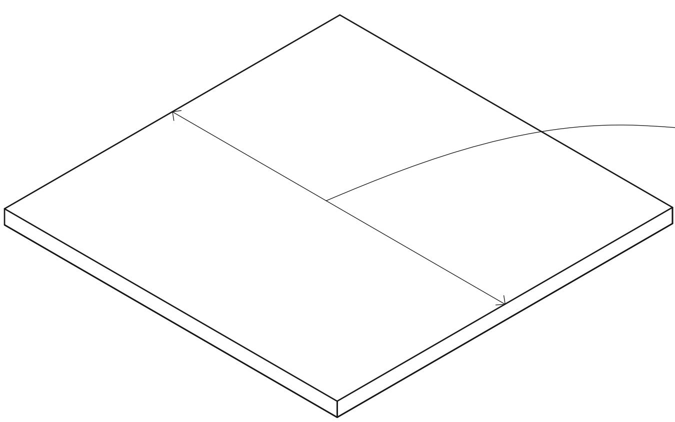
Stepped footings change levels in stages to accommodate a sloping grade and maintain the required depth at all points around a building.



Concrete slabs on grade require the support of a level, stable, uniformly dense or properly compacted soil base containing no organic matter. When placed over soil of low bearing capacity or over highly compressible or expansive soils, a concrete ground slab must be designed as a raft foundation, which requires professional analysis and design by a suitably qualified engineer.



- 150 mm concrete slab thickness; thickness required depends on expected use and load conditions
- Welded wire fabric reinforcement set at or slightly above the mid-depth of the slab controls thermal stresses, shrinkage cracking and slight differential movement in the soil bed; a grid of reinforcing bars may be required for slabs carrying heavier-than-normal floor loads
- Admixtures of glass, steel or polypropylene fibres may be added to concrete mix to reduce shrinkage cracking
- Rigid insulation placed above DPM
- Damp-proof membrane/radon barrier as required
- Base course of fully compacted good-quality hard-core to prevent capillary rise of groundwater; 225 mm minimum
- Stable, uniformly dense soil base; compaction may be required to increase soil stability, load-bearing capacity and resistance to water penetration

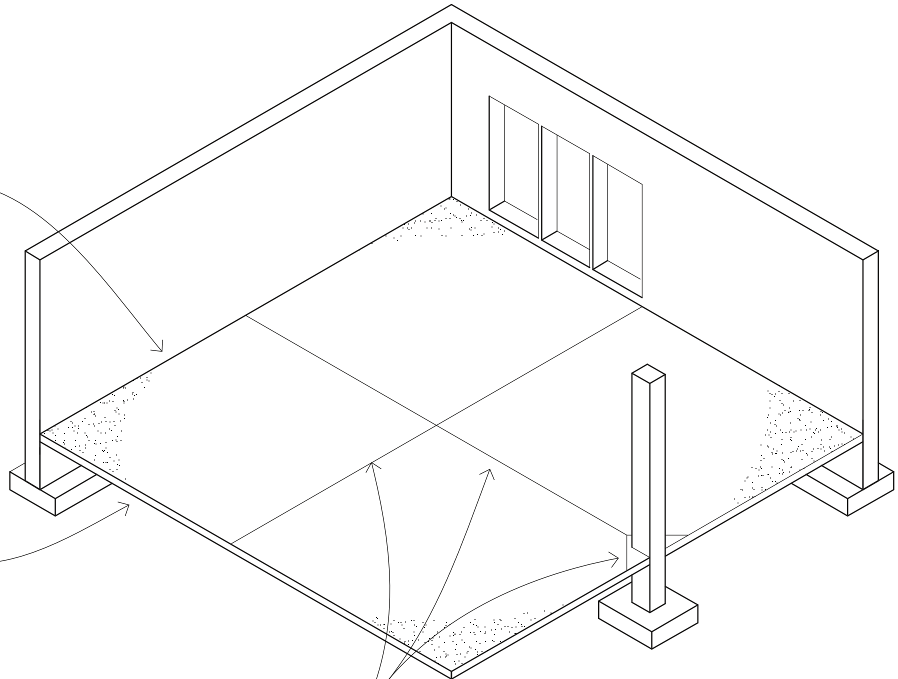


- Square mesh reinforcement is normally used to reduce cracking in large on grade concrete floors, in specification this type of mesh is noted as A393. A represents a square mesh and 393 the cross-sectional area of the main bar in mm^2/m width of reinforcement

Reinforcement Specification	Mesh Size millimetres	Nominal Bar Size millimetres
A142	200 x 200	6
A193	200 x 200	7
A252	200 x 200	8
A393	200 x 200	10

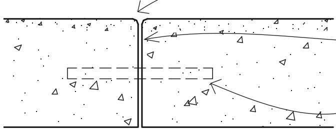
BS 4483:2005: Steel Fabric for the Reinforcement of Concrete – Specification
EN Eurocode 2: Design of Concrete Structures, Part 1

Three types of joints may be created or constructed in order to accommodate movement in the plane of a concrete slab on grade – isolation joints, construction joints and control joints.



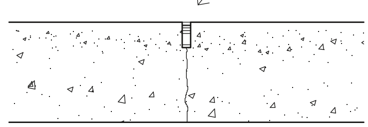
Isolation Joints
Isolation joints, often called expansion joints, allow movement to occur between a concrete slab and adjoining columns and walls of a building.

Construction Joints
Construction joints provide a place for construction to stop and then continue at a later time. These joints, which also serve as isolation or control joints, can be keyed or dowelled to prevent vertical differential movement of adjoining slab sections.

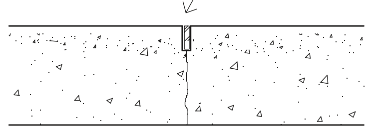


- 3 mm radius chamfer
- Prevent bond
- Coated dowels or a keyed joint if required to prevent vertical differential movement

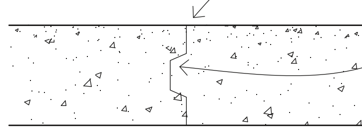
Control Joints
Control joints create lines of weakness so that the cracking that may result from tensile stresses occurs along predetermined lines. Space control joints in exposed concrete at up to 4.5 m centres, or wherever required to break an irregular slab shape into square or rectangular sections.



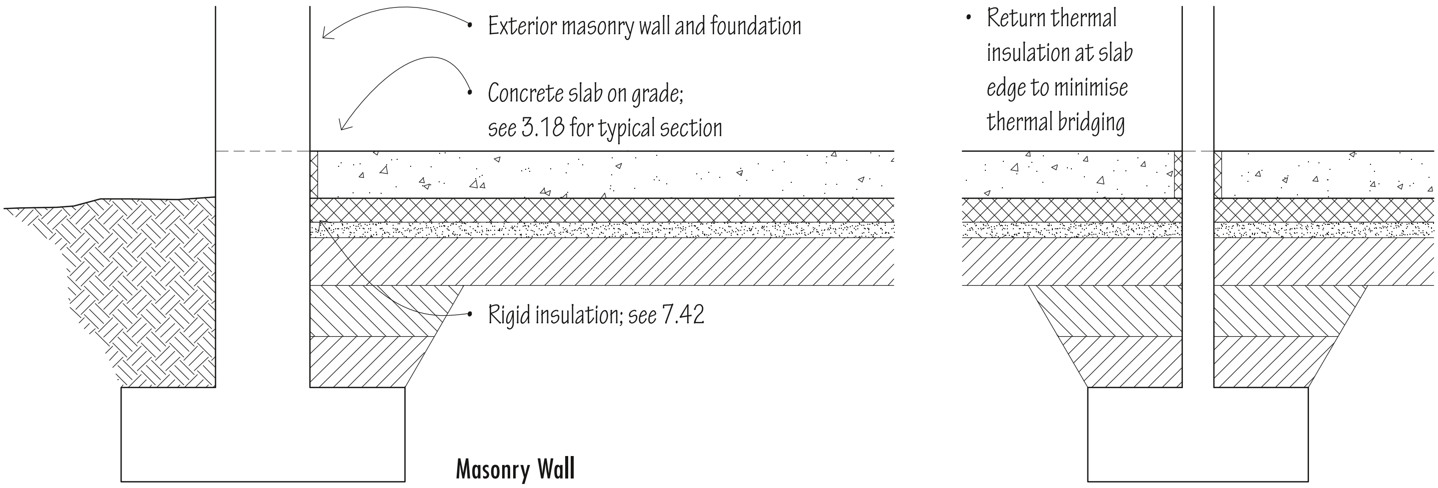
- Sawn joint 3 mm wide and ¼ of slab depth; fill with joint filler



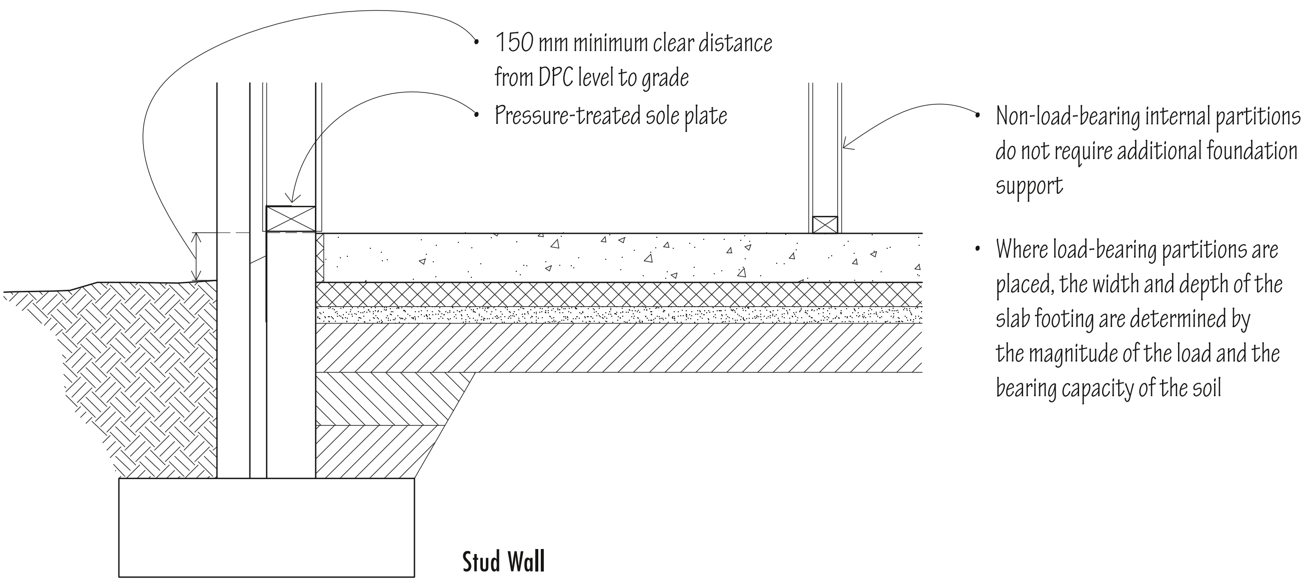
- 3 mm pre-moulded or metal strip inserted when concrete is placed; finish flush with surface



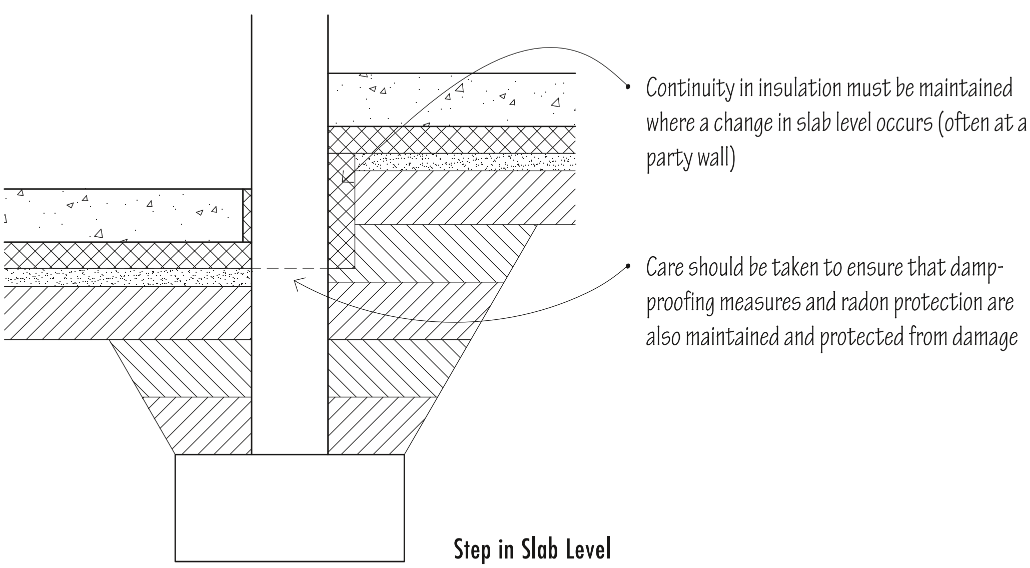
- Keyed joint
- Prevent bond by using a preformed metal or plastic joint material, or by applying curing compound to one side before other side is placed



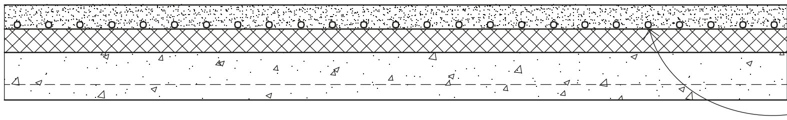
Masonry Wall



Stud Wall

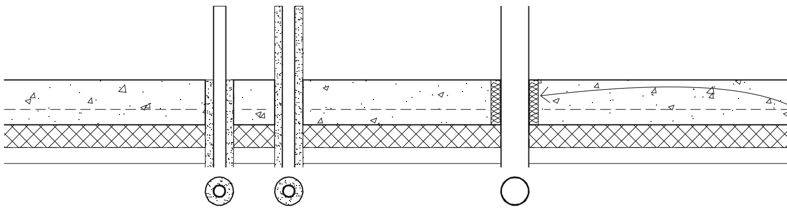


Step in Slab Level



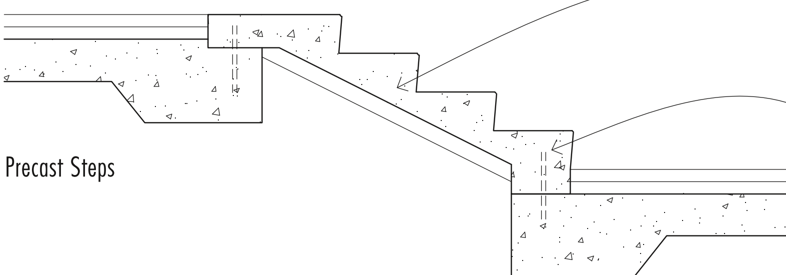
Underfloor Heating Pipes

- 50 mm minimum cover (floating screed)
- Copper or polybutylene piping is clipped to insulation below
- Above-slab insulation recommended to increase response time of underfloor heating



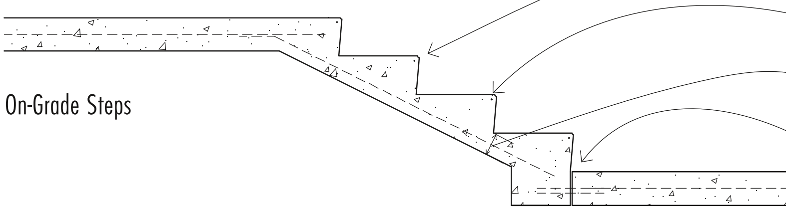
Pipe Penetration 'Pop-Ups'

- Foamed plastic pipe insulation isolates water supply and waste piping from the concrete slab



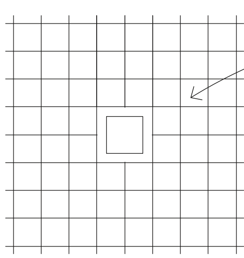
Precast Steps

- 100 mm nominal thickness of precast slab
- Vertical location dowels cast into floor slab to align with pre-drilled location holes in precast stairs



On-Grade Steps

- Chamfer or radius edge
- Nosing bar; provide 38 mm cover
- 100 mm minimum thickness
- Expansion or construction joint
- Use coated dowels or a shear key to prevent vertical differential movement

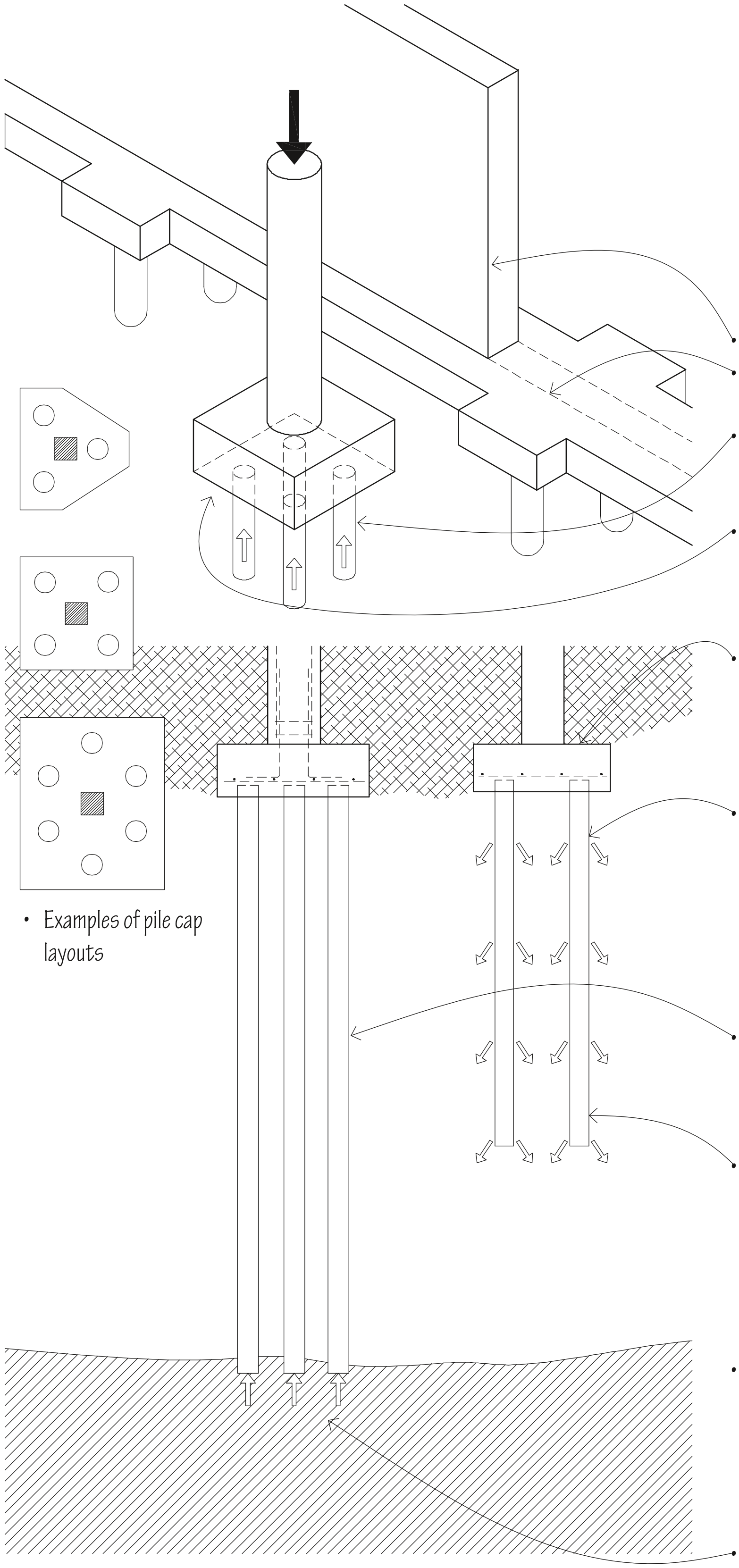


Slab Openings

- At slab openings of greater than 300 mm a second layer of wire-mesh reinforcement should be introduced. This should be specified in accordance with the guidance of a suitably qualified engineer

DEEP FOUNDATIONS

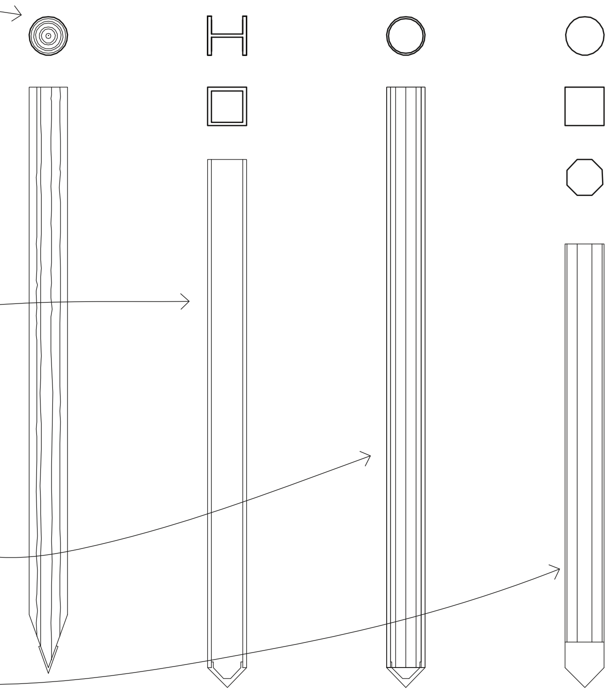
Deep foundations extend down through unsuitable or unstable soil to transfer building loads to a more appropriate bearing stratum of rock or dense sands and gravels well below the superstructure. The main type of deep foundations are pile foundations which can be driven (displacement) or bored. A pile foundation is a system of end-bearing or friction piles, pile caps and ring beams for transferring building loads down to a suitable bearing stratum.



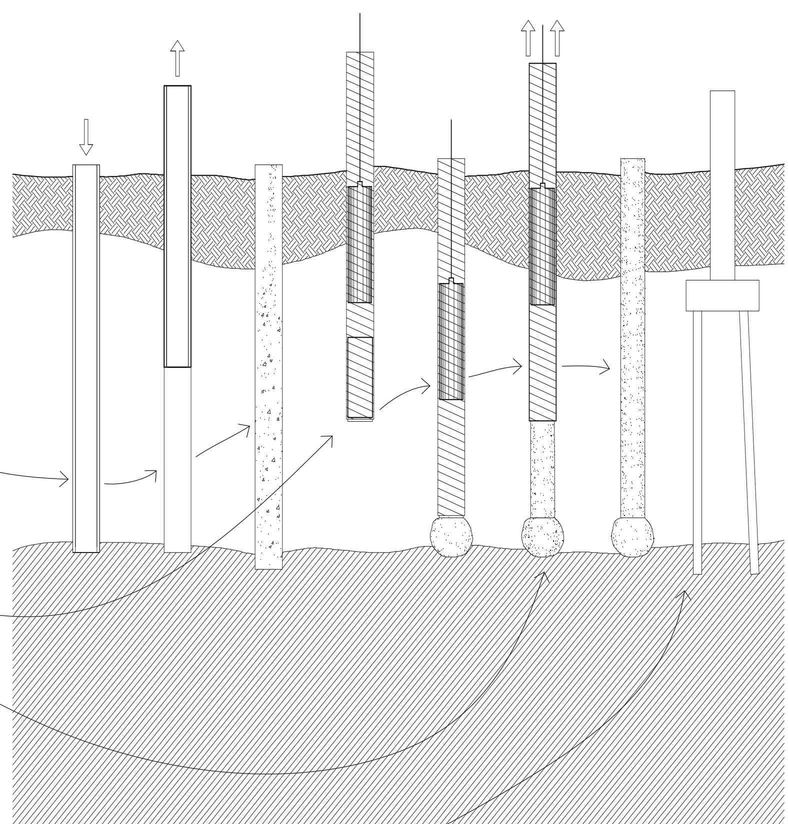
• Examples of pile cap layouts

• Load-bearing wall
• Reinforced-concrete grade or ring beam with integral pile caps
• Piles are usually driven in clusters of two or more, spaced at 750–1000 mm centres
• A reinforced-concrete pile cap joins the heads of a cluster of piles in order to distribute the load from a column or grade beam equally among the piles and to provide lateral stability to the pile
• The depth of the pile caps varies with load and soil conditions, the bottom of the pile cap should be below the frost line, and piles extend 100–150 mm into the pile cap and have a minimum 150 mm concrete cover all round
• Piles may be of timber poles, although this is now unusual in most of Europe it was popular during Roman times; treatment of the piles is recommended if used. Precast, in-situ or prestressed concrete piles are more common in large buildings
• End-bearing piles depend principally on the bearing resistance of soil or rock beneath their feet for support. The surrounding soil mass provides a degree of lateral stability for the long compression members
• Friction piles depend principally on the frictional resistance of a surrounding earth mass for support. The skin friction developed between the sides of a pile and the soil into which the pile is driven is limited by the adhesion of soil to the pile sides and the shear strength of the surrounding soil mass
• Driven piles are inserted into the ground with a mechanical drop hammer until the 'set' is reached. The 'set' is related to the desired bearing capacity of the pile calculated by knowing the force applied by the falling hammer and the distance the pile is driven into the ground
• Bearing stratum of soil or rock
• The allowable pile load is the maximum axial and lateral loads permitted on a pile, as determined by a dynamic pile formula, a static load test or a geotechnical investigation of the foundation soil

EN Eurocode 7: Geotechnical Design, Part 1, Section 7 Pile Foundations



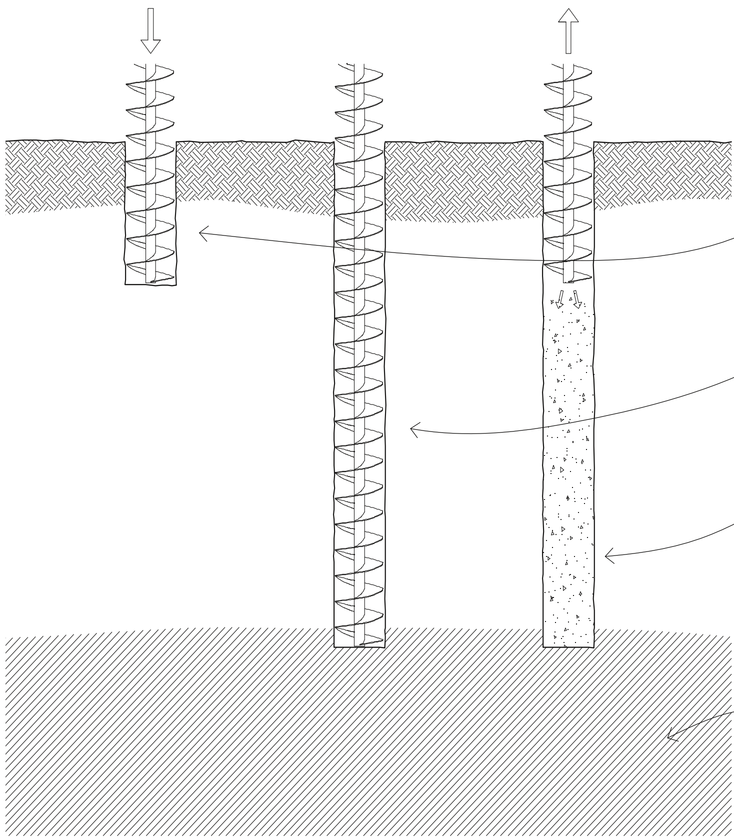
- Timber piles are logs driven usually as a friction pile. They are often fitted with a steel shoe and a drive band to prevent their shafts from splitting or shattering
- Composite piles are constructed of two materials, such as a timber pile having a concrete upper section to prevent the portion of the pile above the water table from deteriorating
- H-piles are steel H-sections, sometimes encased in concrete to a point below the water table to prevent corrosion. H-sections can be welded together in the driving process to form any length of pile
- Pipe piles are heavy steel pipes driven with the lower end either open or closed by a heavy steel plate or point and filled with concrete. An open-ended pipe pile requires inspection and excavation before being filled with concrete
- Precast reinforced-concrete piles have round, square or polygonal cross sections. Precast piles are often prestressed



- Cast-in-situ concrete piles are constructed by placing concrete into a shaft in the ground. The concrete piles may be cased or uncased
- Cased piles are constructed by driving a steel pipe or casing into the ground until it meets the required resistance and then filling it with concrete. The casing is usually a cylindrical steel section, sometimes corrugated or tapered for increased stiffness. A mandrel consisting of a heavy steel tube or core may be inserted into a thin-walled casing to prevent it from collapsing in the driving process, and then withdrawn before concrete is placed in the casing
- Uncased piles are constructed by driving a concrete plug into the ground along with a steel casing until it meets the required resistance, and then ramming concrete into place as the casing is withdrawn
- An enlarged foot to a concrete pile formed using a concrete plug forced out of the end of the pile or belling tool can increase the bearing capacity of the pile
- Micro piles are high capacity, small diameter (125–305 mm), drilled and grouted in-place piles that are typically reinforced. They are often used for foundations in urbanised areas or in locations with restricted access

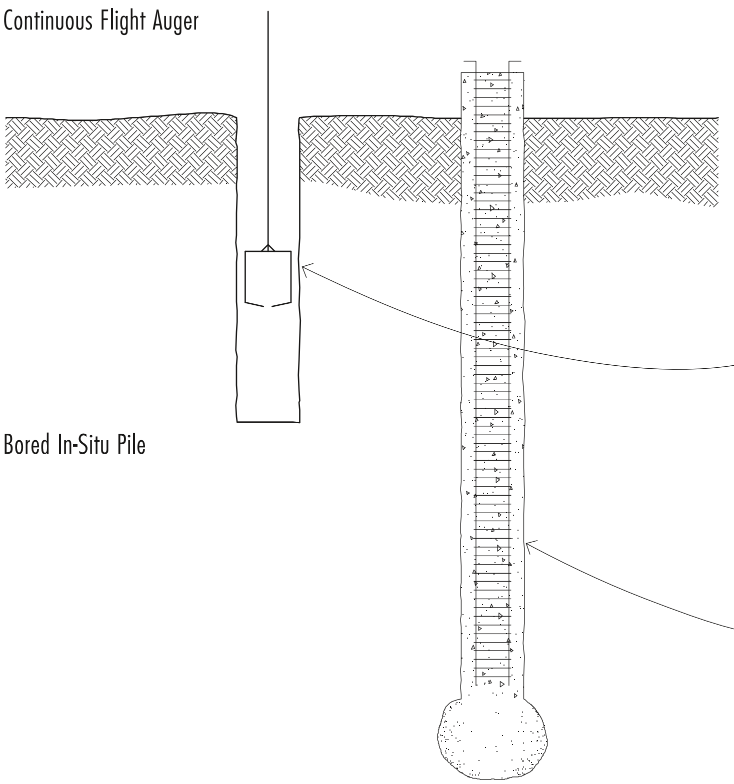
EN Eurocode 7: Geotechnical Design, Part 1, Section 7 Pile Foundations

Bored piles can work on a displacement or non-displacement method. The displacement method does not bring any earth to the surface but instead forms a void by moving the existing soil aside. Displacement piles will compress the surrounding soil and thus increase friction.



- A continuous flight auger (CFA) is a hollow stem auger with a continuous thread that cuts into the ground. As the auger drills down the soil is brought to the surface
- The auger drills down to the desired depth. While drilling, the earth being brought to the surface offers an opportunity to inspect the ground conditions locally
- As the auger is removed, concrete is pumped down the hollow stem of the auger to form the pile. Reinforcement is placed when the auger has been fully removed
- Suitable bearing stratum of soil or rock

Continuous Flight Auger

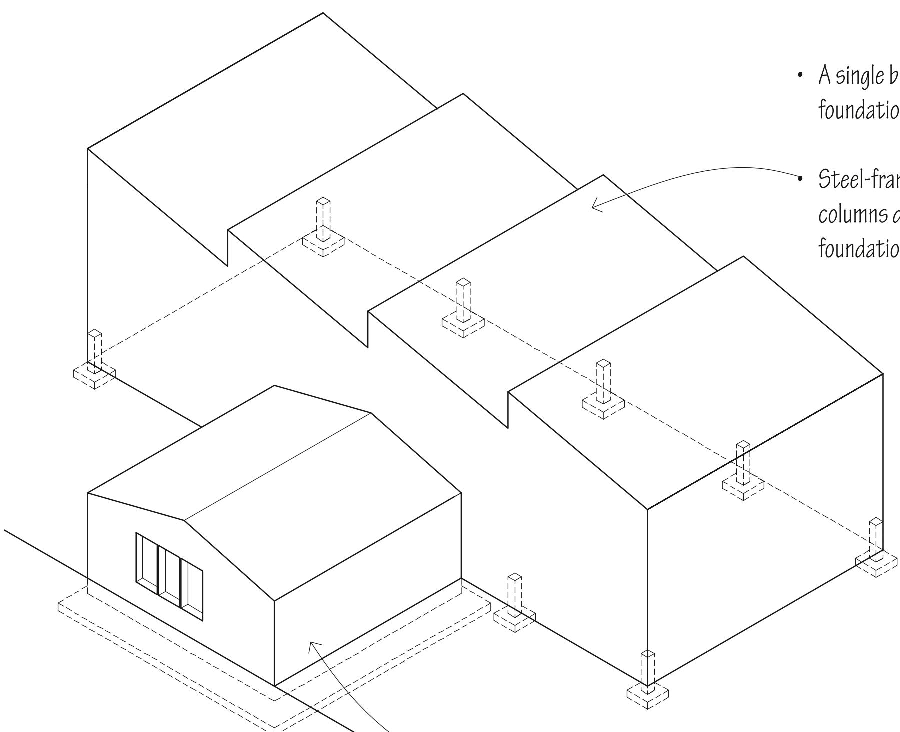


Bored In-Situ Pile

- Rotary bucket drill, driven into the ground and rotated, collecting and filling the bucket with soil. The bucket is brought to the surface and cleared before drilling recommences
- The drilling tool can be opened out when the required depth is reached to help form an enlarged toe increasing the bearing capacity of the pile. Once the void has been formed reinforcement is placed and concrete is cast into the void

EN Eurocode 7: Geotechnical Design, Part 1, Section 7 Pile Foundations

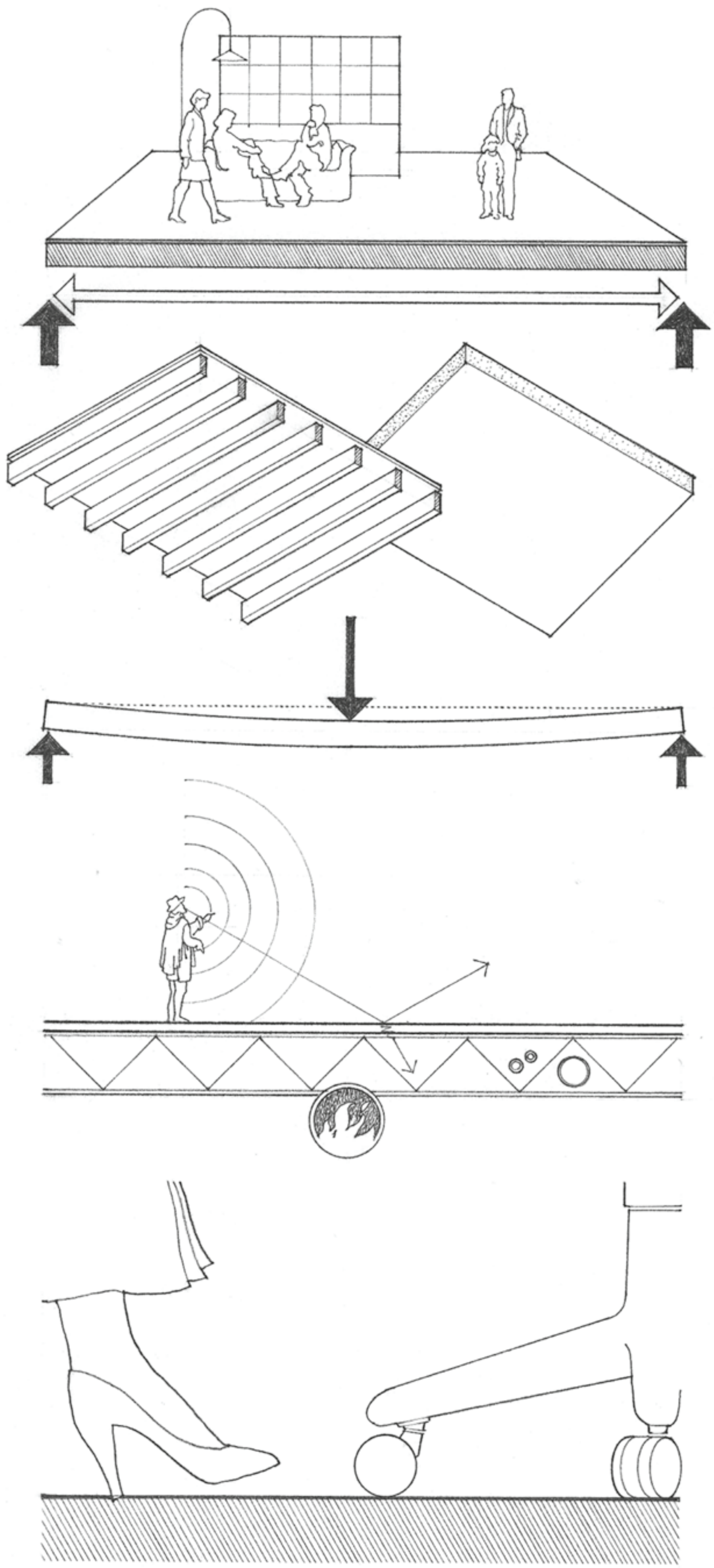
Foundation Type	Load Type	Notes
Strip Trench Fill	Uniform	Generally used in domestic or other lightweight construction projects where the building loads are transferred to the ground in a uniform and even manner
Raft	Uniform/ Point	Raft foundations are used where there is some concern over the consistency of the bearing capacity of soil close to the surface. The raft acts to spread the load over a wider area reducing risk of differential settlement. Where a series of point loads occur close to each other making up a high proportion of the overall loading, a raft may be employed over pad foundations
Pad	Point	Used for framed buildings where loads from the superstructure are transferred to the ground using a series of columns
Driven Pile	Point	Friction or end bearing piles are used where the required soil-bearing capacity is not available close to the surface and deeper foundations are required to find suitable bearing. Piles are often used on framed heavyweight buildings or to assist with underpinning of failing structures
Bored Pile	Point	Bored piles are often used in preference to driven piles on congested urban sites where noise and vibration may be an issue



- A single building can utilise a range of foundation types
- Steel-framed factory structure with columns delivering point loads to pad foundations
- Masonry built administration section with uniform loads on strip or trench fill foundations

4

FLOOR SYSTEMS



Floor systems are the horizontal planes that must support both live loads – people, furnishings and movable equipment – and dead loads – the weight of the floor construction itself. Floor systems must transfer their loads horizontally across space to either beams and columns or to load-bearing walls. Rigid floor planes can also be designed to serve as horizontal diaphragms that act as thin, wide beams in transferring lateral forces to shear walls.

A floor system may be composed of a series of linear beams and joists overlaid with a plane of sheathing or decking, or consist of a nearly homogeneous slab of reinforced concrete. The depth of a floor system is directly related to the size and proportion of the structural bays it must span and the strength of the materials used. The size and placement of any cantilevers and openings within the floor plane should also be considered in the layout of the structural supports for the floor. The edge conditions of the floor structure and its connection to supporting foundation and wall systems affect both the structural integrity of a building and its physical appearance.

Because it must safely support moving loads, a floor system should be relatively stiff while maintaining its elasticity. Due to the detrimental effects that excessive deflection and vibration would have on finish flooring and ceiling materials, as well as concern for human comfort, deflection rather than bending becomes the critical controlling factor.

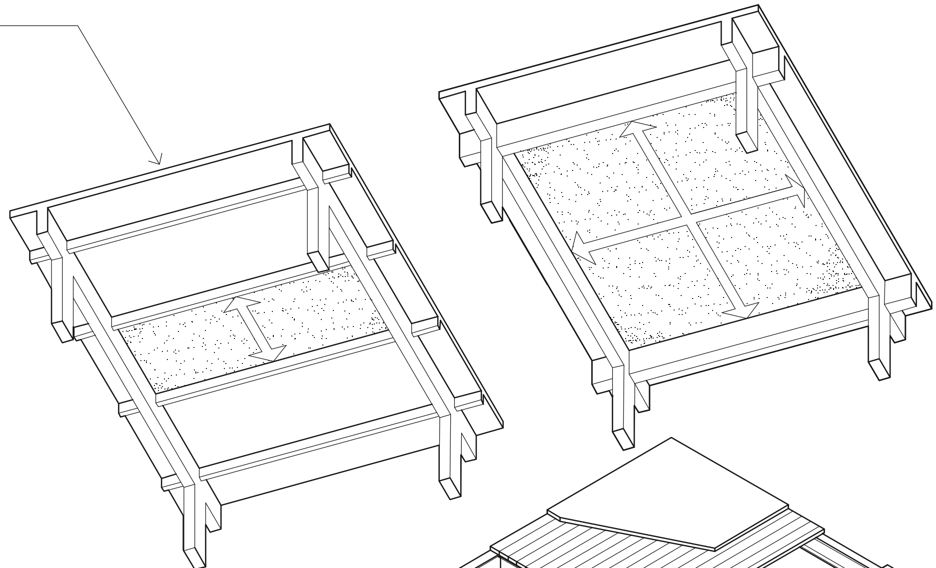
The depth of the floor construction and the cavities within it should be considered if it is necessary to accommodate runs of mechanical or electrical lines within the floor system. For floor systems between habitable spaces stacked one above another, additional factors to consider are the blockage of both airborne and structure-borne sound and the fire-resistance rating of the assembly.

Except for exterior decks, floor systems are not normally exposed to weather. Because they all must support traffic, however, durability, resistance to wear and maintenance requirements are factors to consider in the selection of a floor finish and the system required to support it.

When installing floors in areas that may become wet on a regular basis (shower areas, entrance areas with high usage) the slip resistance of the floor should be taken into account.

Concrete

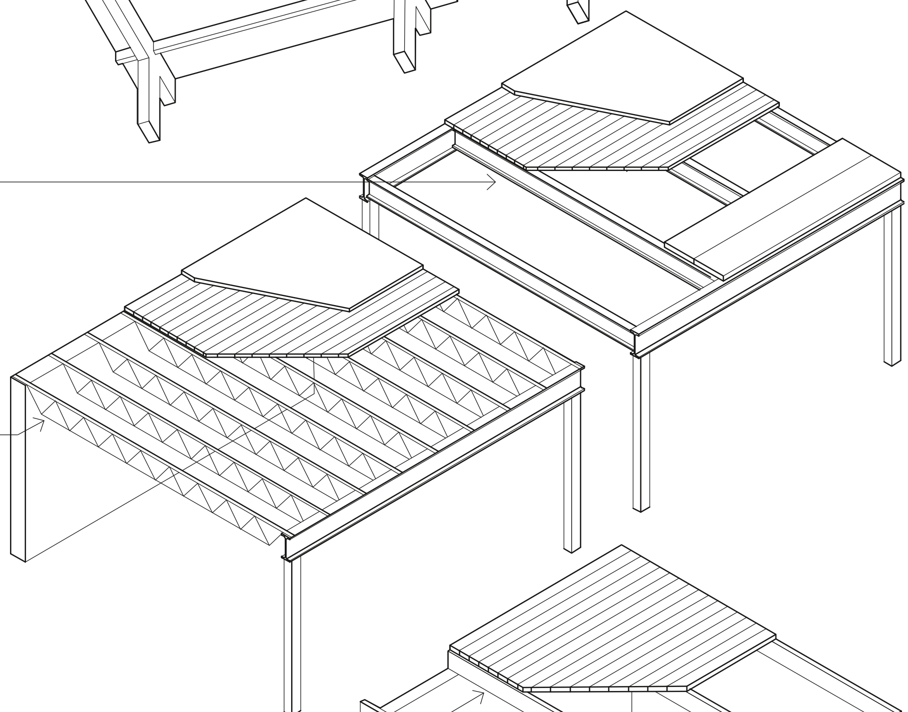
- Cast-in-situ concrete floor slabs are classified according to their span and cast form; see 4.05–4.07
- Precast-concrete planks may be supported by beams or load-bearing walls



Steel

- Steel beams support steel decking or precast-concrete planks
- Beams may be supported by columns or load-bearing walls
- Framing is typically an integral part of a steel skeleton frame system

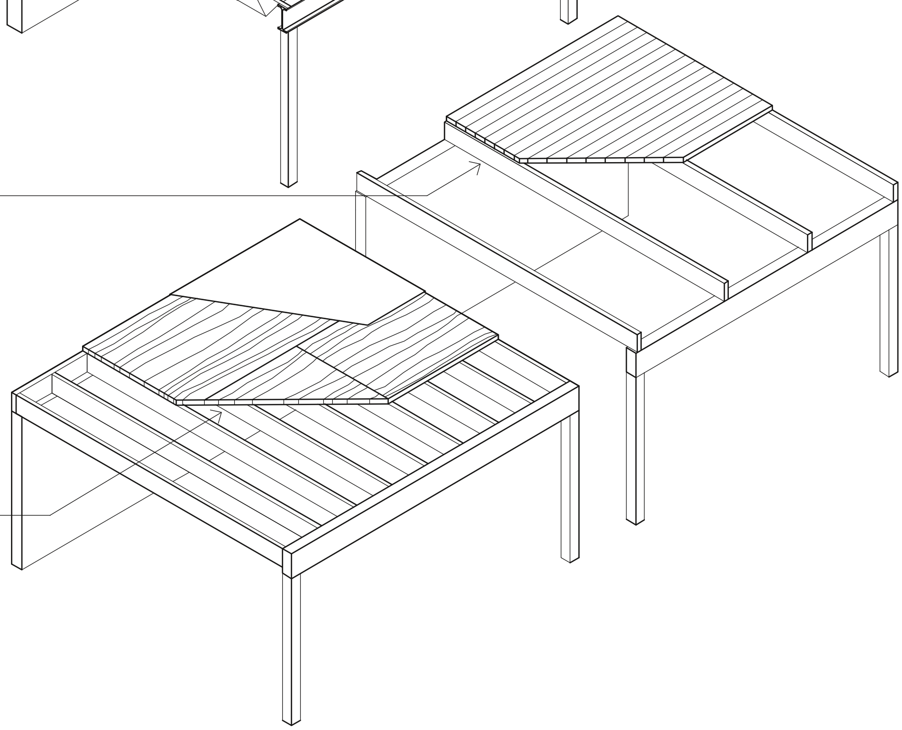
- Closely spaced light-gauge or open-web joists may be supported by beams or load-bearing walls
- Steel decking or timber floorboards have relatively short spans
- Joists have limited overhang potential



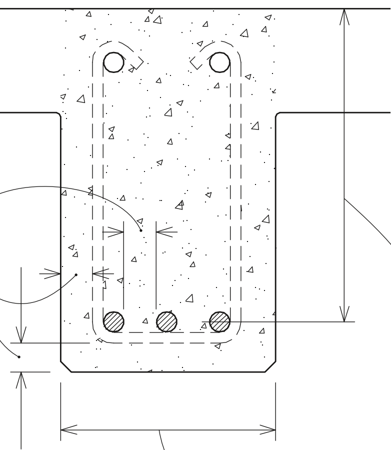
Timber

- Timber beams support structural decking
- Beams may be supported by columns, or load-bearing walls
- Concentrated loads and floor openings may require additional framing
- Underside of floor structure may be left exposed; an applied ceiling is optional

- Relatively small, closely spaced joists may be supported by beams or load-bearing walls
- Sub-flooring, underlay and applied ceiling finishes have relatively short spans
- Joist framing is flexible in shape and form

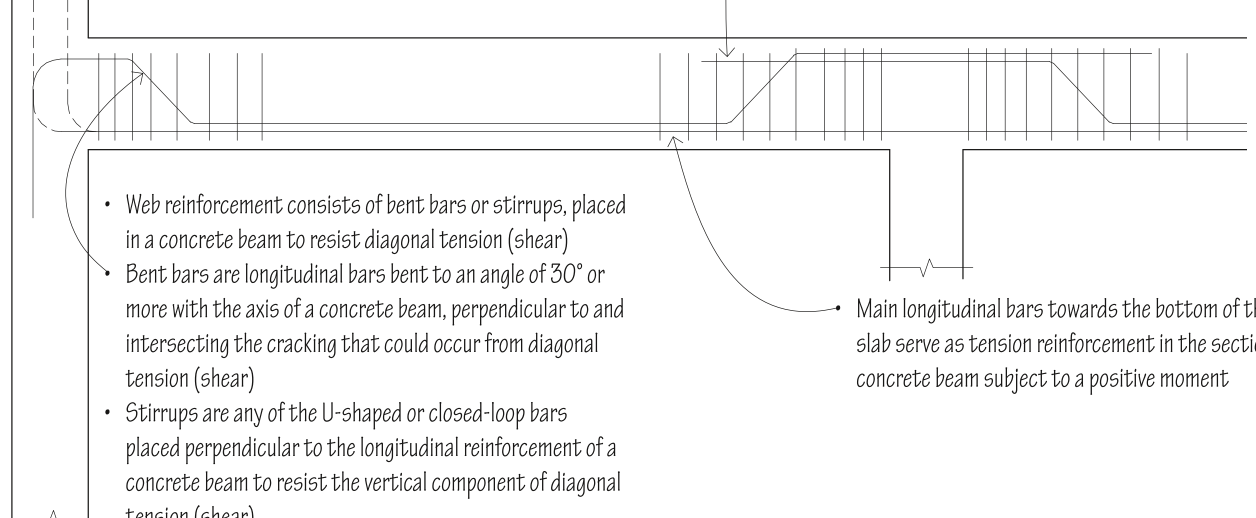


Reinforced-concrete beams are designed to act together with longitudinal and web reinforcement in resisting applied forces. Cast-in-situ concrete beams are almost always formed and placed along with the slab they support. Because a portion of the slab acts as an integral part of the beam, the depth of the beam is measured to the top of the slab.



- Distance between reinforcing bars to be greater than the maximum aggregate size used
- 50 mm minimum cover required to protect steel reinforcement from fire and corrosion

- Effective depth is measured from the compression face to the centroid of tension reinforcement
- Beam depth is of greater importance than its width in relation to its resistance to bending moments
- Beam width should be equal to or greater than width of supporting column

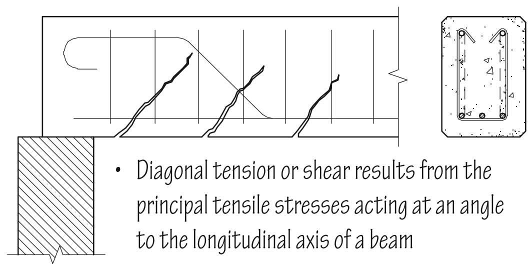


- Reinforcing bars extend into and down column support for structural continuity and to develop the required embedment length for anchorage
- Continuity between columns, beams, slabs and walls is required to minimise bending moments at these junctures. Because continuity is easily attainable in concrete construction, structures continuous over three or more spans are usually the most efficient

- Reinforcing bars towards the top of the slab act as tension reinforcement in the section of a concrete beam subject to the upward bending of a negative moment

- Web reinforcement consists of bent bars or stirrups, placed in a concrete beam to resist diagonal tension (shear)
- Bent bars are longitudinal bars bent to an angle of 30° or more with the axis of a concrete beam, perpendicular to and intersecting the cracking that could occur from diagonal tension (shear)
- Stirrups are any of the U-shaped or closed-loop bars placed perpendicular to the longitudinal reinforcement of a concrete beam to resist the vertical component of diagonal tension (shear)

- Main longitudinal bars towards the bottom of the slab serve as tension reinforcement in the section of a concrete beam subject to a positive moment



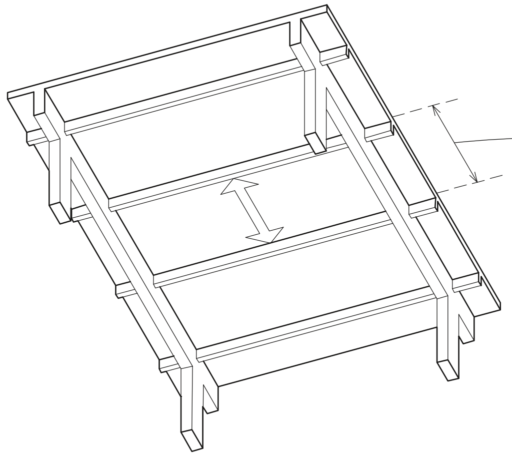
- Diagonal tension or shear results from the principal tensile stresses acting at an angle to the longitudinal axis of a beam

Concrete slabs are plate structures that are reinforced to span either one or both directions of a structural bay. Consult a structural engineer and the building regulations for the required size, spacing and placement of all reinforcement.

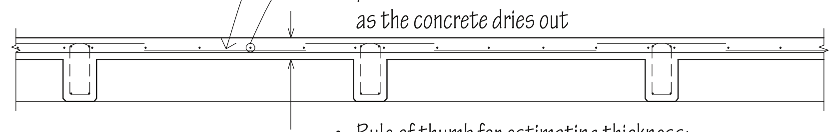
EN Eurocode 2: Design of Concrete Structures, Part 1
EN Eurocode 4: Design of Composite Steel and Concrete Structures, Part 1

One-Way Slab

A one-way slab is uniformly thick, reinforced in one direction and cast integrally with parallel supporting beams.



- Tensile reinforcement
- Distribution bars perpendicular to main tensile bars provide lateral reinforcement and resistance to cracking as the concrete dries out

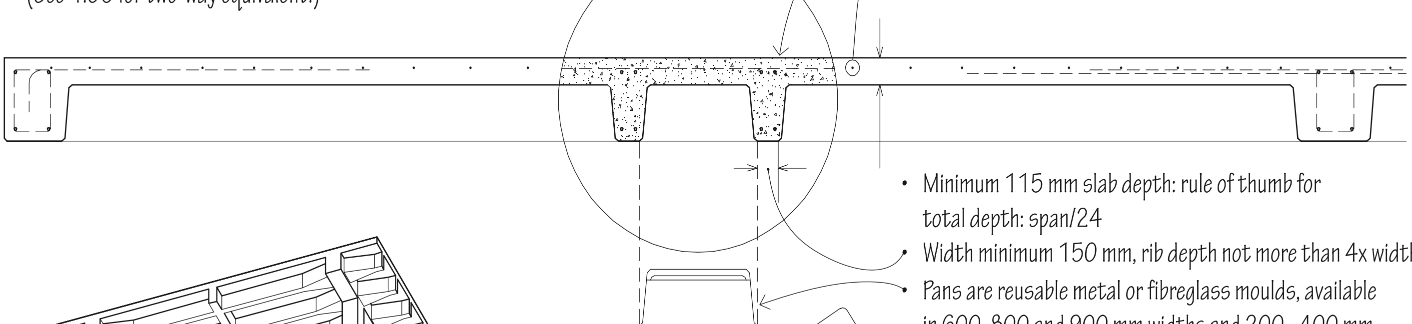


- Rule of thumb for estimating thickness: span/24 for floor slabs; minimum 100 mm thickness
- Suitable for light to moderate loads over relatively short spans of 2–6 m
- Slab is supported on two sides by beams or load-bearing walls; beams, in turn, may be supported by columns

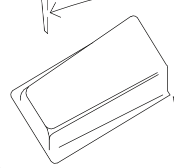
One-Way Ribbed Slab

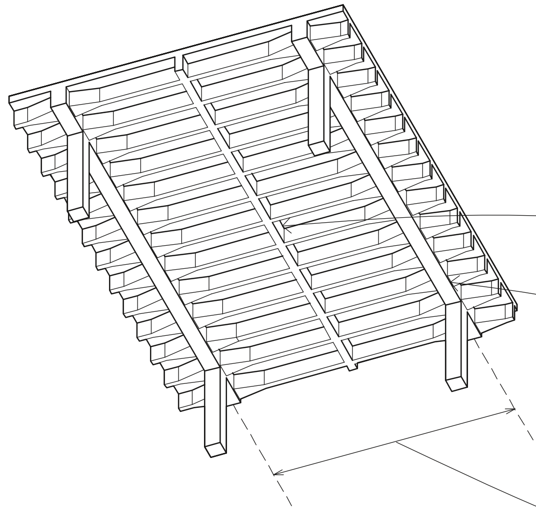
A ribbed slab is cast integrally with a series of closely spaced beams, which in turn are supported by a parallel set of beams. Designed as a series of T-beams, ribbed slabs are more suitable for longer spans and heavier loads than one-way slabs. (See 4.06 for two-way equivalent.)

- Tensile reinforcement occurs in the ribs
- Shrinkage and temperature reinforcement is placed in the slab



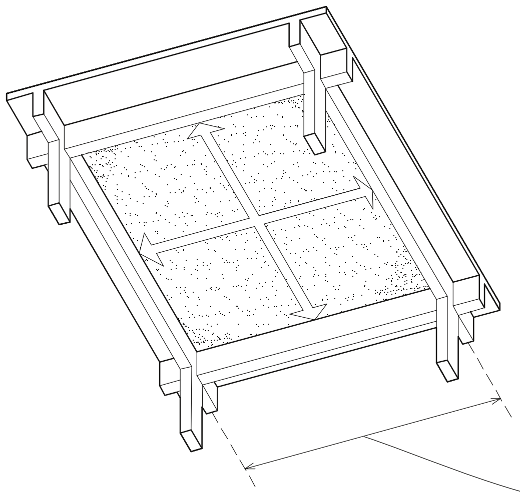
- Minimum 115 mm slab depth: rule of thumb for total depth: span/24
- Width minimum 150 mm, rib depth not more than 4x width
- Pans are reusable metal or fibreglass moulds, available in 600, 800 and 900 mm widths and 200–400 mm depths. Tapered sides allow for easier removal
- Tapered endforms are used to thicken joist ends for greater shear resistance





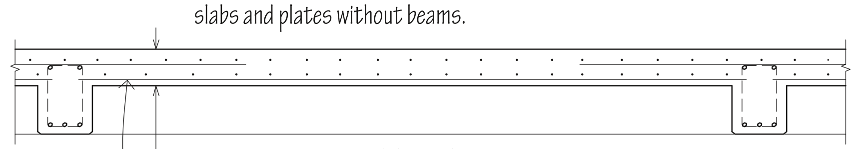
- For spans greater than 9 m a distribution rib may be necessary to distribute possible load concentrations over a larger area
- Wide, flat beam
- Suitable for light to medium live loads over spans of 5–10 m; longer spans may be possible with post tensioning

- See 12.04–12.05 for a discussion of concrete as a construction material



Two-Way Slab and Beam

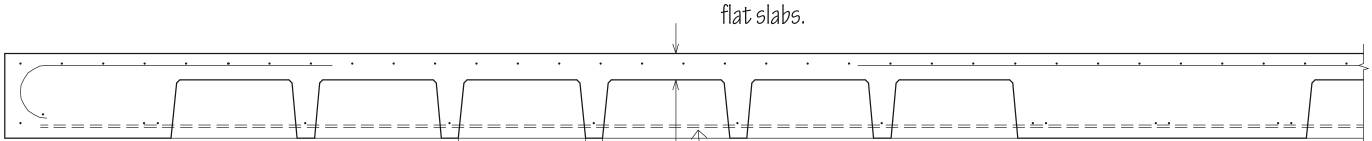
A two-way slab of uniform thickness may be reinforced in two directions and cast integrally with supporting beams and columns on all four sides of square or nearly square bays. Two-way slab and beam construction is effective for medium spans and heavy loads, or when a high resistance to lateral forces is required. For economy, however, two-way slabs are usually constructed as flat slabs and plates without beams.

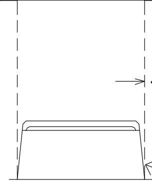


- 100 mm minimum slab depth
- Tensile reinforcement
- A continuous slab, extending as a structural unit over three or more supports in a given direction, is subject to lower bending moments than a series of discrete, simply supported slabs
- Two-way slabs are most efficient when spanning square or nearly square bays, and suitable for carrying intermediate to heavy loads over 4.5 to 12 m spans

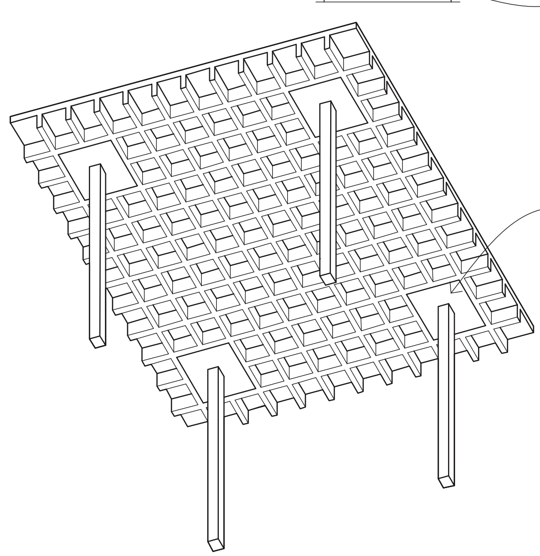
Two-Way Waffle Slab

A waffle slab is a two-way concrete slab reinforced by ribs in two directions. Waffle slabs are able to carry heavier loads and span longer distances than flat slabs.



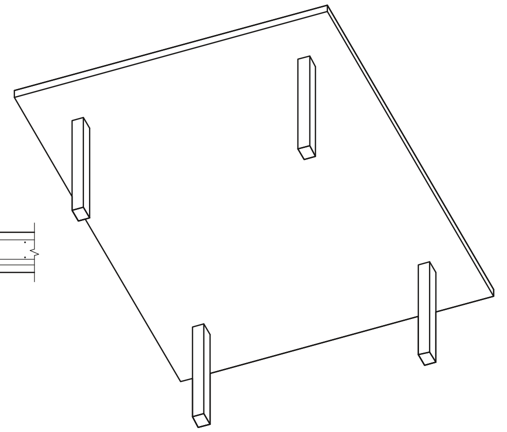


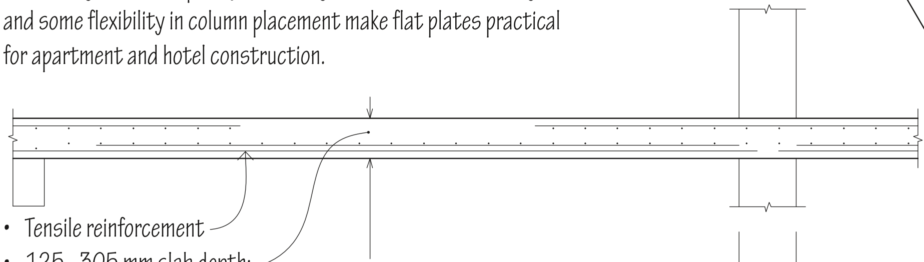
- Tensile reinforcement
- 115 mm minimum slab depth; rule of thumb for total depth: span/24
- 150 mm minimum rib width
- Square metal or fibreglass dome forms are available in 600, 800 and 900 mm widths and 200–400 mm depths. Larger sizes are also available. Tapered sides allow for easier removal
- For maximum efficiency, bays should be square or as nearly square as possible. Waffle slabs can be efficiently cantilevered in two directions up to 1/3 of the main span. When no cantilever is present, a perimeter slab band is formed by omitting dome forms
- For greater shear strength and moment-resisting capacity, solid heads at column supports are configured by omitting dome forms; size depends on span and load conditions
- Suitable for spans of 9–16 m; longer spans may be possible with post-tensioning
- Coffered underside is usually left exposed



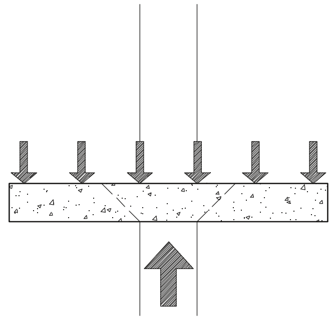
Two-Way Flat Plate

A flat plate is a concrete slab of uniform thickness reinforced in two or more directions and supported directly by columns without beams or girders. Simplicity of forming, lower floor-to-floor heights and some flexibility in column placement make flat plates practical for apartment and hotel construction.



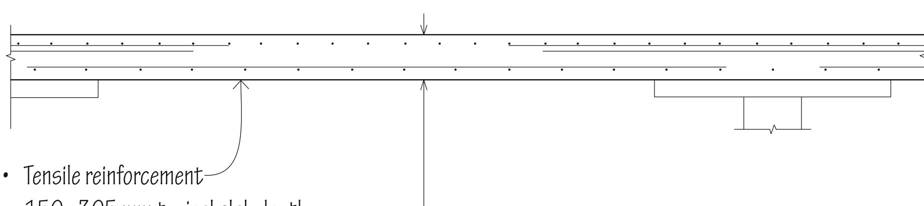


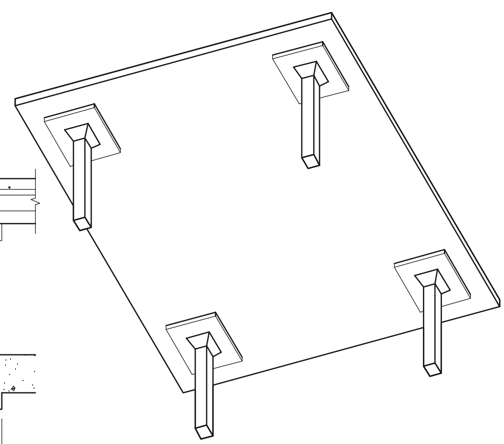
- Tensile reinforcement
- 125–305 mm slab depth;
  rule of thumb for slab depth: span/33
- Suitable for light live-to-moderate loads over relatively short spans of 3.6 to 7 m
- While a regular column grid is most appropriate, some flexibility in column placement is possible
- Shear at column locations governs the thickness of a flat plate
- Punching shear is the potentially high shearing stress developed by the reactive force of a column on a reinforced-concrete slab



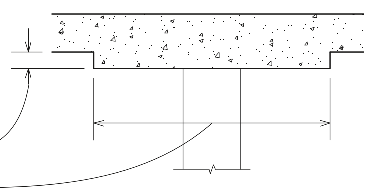
Two-Way Flat Slab

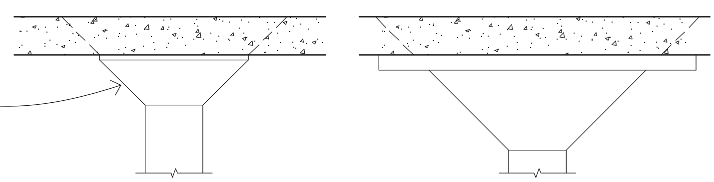
A flat slab is a flat plate thickened at its column supports to increase its shear strength and moment-resisting capacity.

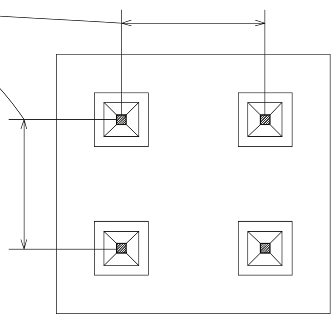




- Tensile reinforcement
- 150–305 mm typical slab depth;
  rule of thumb for slab depth: span/36
- Drop panel is the portion of a flat slab thickened around a column head to increase its resistance to punching shear
- Minimum projection of drop panel: 0.25 x slab thickness
- Minimum width of drop panel: 0.33 span
- Column capital may be used in place of or in conjunction with a drop panel for increased shear resistance
- Suitable for relatively heavy loads and spans 6–12 m







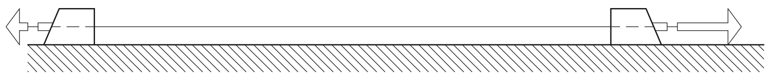
4.08 PRESTRESSED CONCRETE

Prestressed concrete is reinforced by pre-tensioning or post-tensioning high-strength steel tendons within their elastic limit to actively resist a service load. The tensile stresses in the tendons are transferred to the concrete, placing the entire cross section of the flexural member in compression. The resulting compressive stresses counteract the tensile bending stresses from the applied load, enabling the prestressed member to deflect less, carry a greater load, or span a greater distance than a conventionally reinforced member of the same size, proportion and weight.

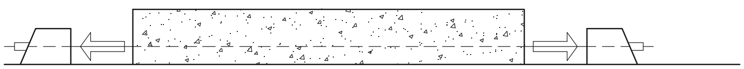
There are two types of prestressing techniques. Pre-tensioning is accomplished in a precasting plant, while post-tensioning is usually performed at the building site, especially when the structural units are too large to transport from factory to site.

Pre-tensioning

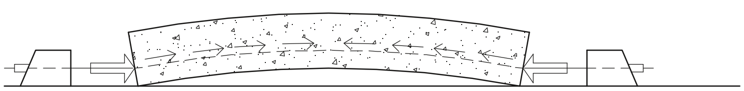
Pre-tensioning prestresses a concrete member by stretching the reinforcing tendons before the concrete is cast.



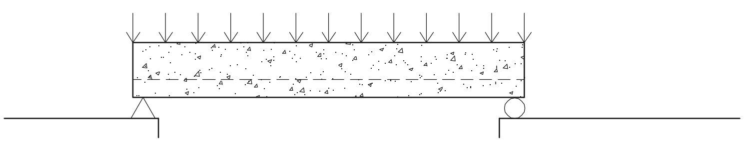
- Steel tendons are first stretched across the casting bed between two abutments until a predetermined tensile force is developed



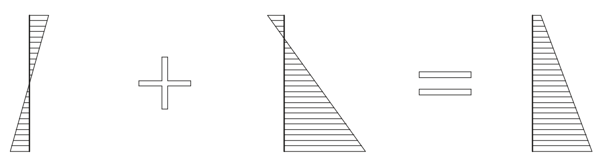
- Concrete is then cast in formwork around the stretched tendons and fully cured. The tendons are placed eccentrically in order to reduce the maximum compressive stress to that produced by bending alone



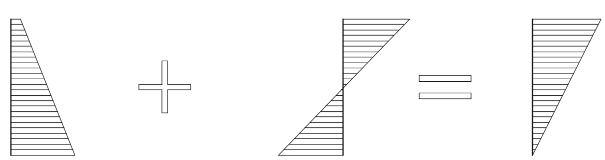
- When the tendons are cut or released, the tensile stresses in the tendons are transferred to the concrete through bond stresses. The eccentric action of the prestressing produces a slight upward curvature or camber in the member



- The deflection of the member under loading tends to equalise its upward curvature



- Dead load stresses
- Prestress stresses
- Combined dead load and prestress stresses



- Dead load and prestress stresses
- Live load stresses
- Final combined stresses

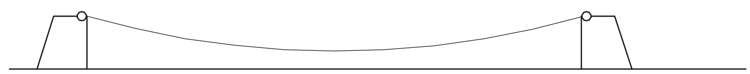
- A certain amount of initial prestress is lost due to the combined effects of elastic compression or creep of the concrete, relaxation of the steel tendons, frictional losses and slippage at the anchorages

EN Eurocode 2: Design of Concrete Structures, Part 1, Section 5.10 Prestressed Members and Structures

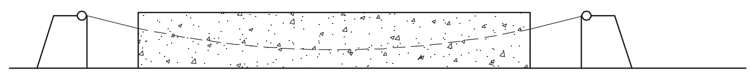
- The extremely high-strength steel tendons may be in the form of wire cables, bundled strands or bars

Post-tensioning

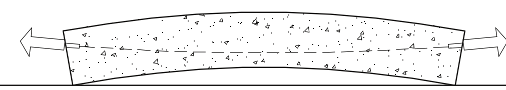
Post-tensioning is the prestressing of a concrete member by tensioning the reinforcing tendons after the concrete has set.



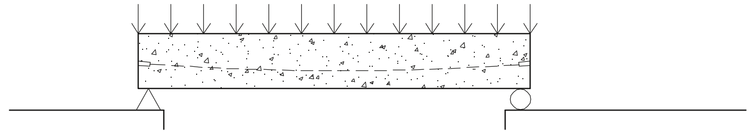
- Unstressed steel tendons, draped inside the beam or slab form, are coated or sheathed to prevent bonding while the concrete is cast. Or a duct is formed in the slab and tendons are passed through and post-tensioned, any voids must be grouted to avoid corrosion of the steel



- After the concrete has cured, the tendons are clamped on one end and jacked against the concrete on the other end until the required force is developed



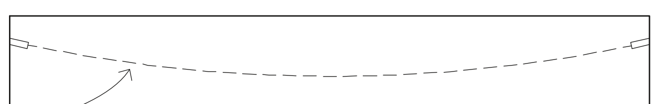
- The tendons are then securely anchored on the jacking end and the jack removed. After the post-tensioning process, the steel tendons may be left unbonded, or they may be bonded to the surrounding concrete by injecting grout into the annular spaces around the sheathed strands



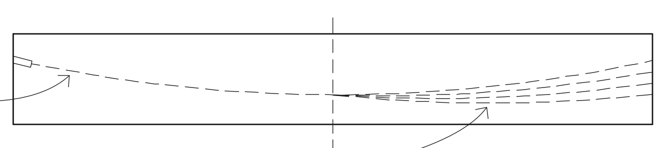
- The deflection of the member under loading tends to equalise its upward curvature

- Post-tensioned members tend to shorten over time due to elastic compression, shrinkage and creep. Adjoining elements that would be affected by this movement should be constructed after the post-tensioning process is completed and be isolated from the post-tensioned members with expansion joints

- Load balancing is the concept of prestressing a concrete member with draped tendons, theoretically resulting in a state of zero deflection under a given loading condition



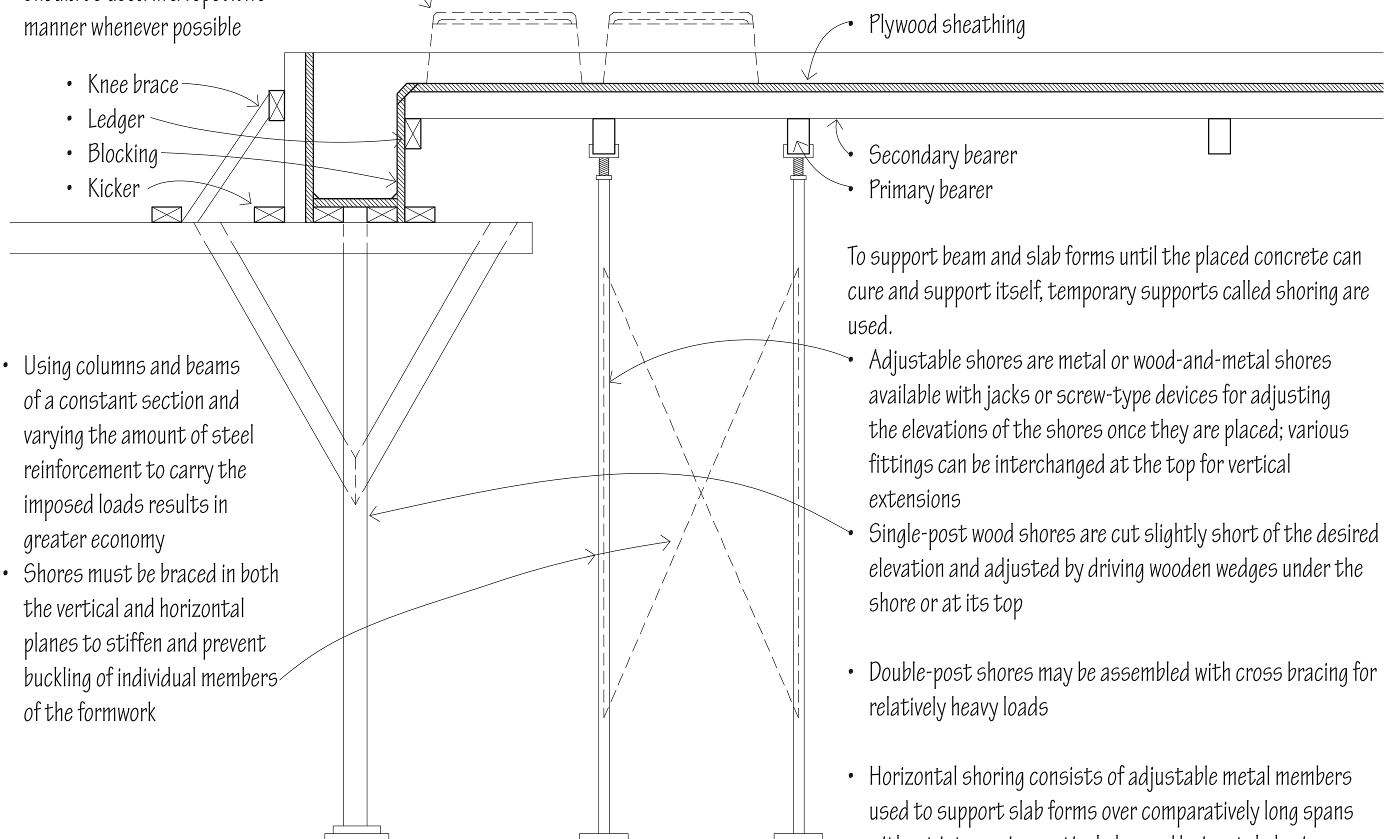
- Draped tendons have a parabolic trajectory that mirrors the moment diagram of a uniformly distributed gravity load. When tensioned, the tendons produce a variable eccentricity that responds to the variation in applied bending moment along the length of the member



- Depressed tendons approximate the curve of a draped tendon with straight-line segments. They are used in the pre-tensioning process because the prestressing force does not allow for draping the tendons. Harped tendons are a series of depressed tendons having varying slopes

Fresh concrete must be shaped and supported by formwork until it cures and can support itself. This formwork is often designed as a separate structural system by an engineer because of the considerable weight and fluid pressure a concrete mass can exert on it.

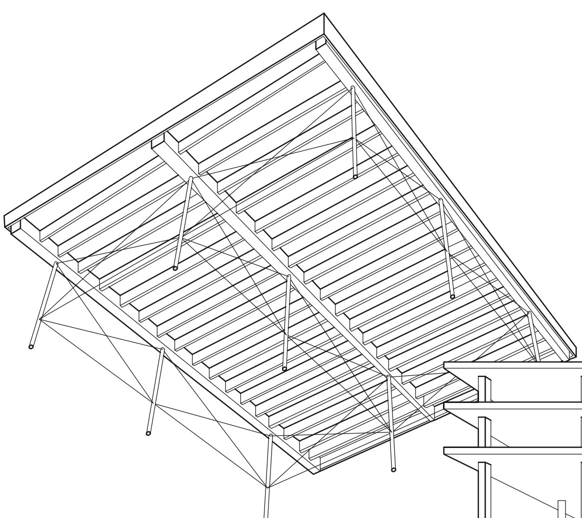
- Proprietary systems are used to form joist and waffle slabs
- For economy, standard forms should be used in a repetitive manner whenever possible



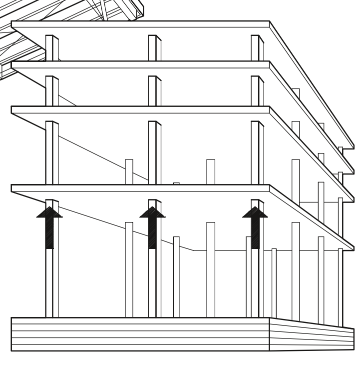
To support beam and slab forms until the placed concrete can cure and support itself, temporary supports called shoring are used.

- Adjustable shores are metal or wood-and-metal shores available with jacks or screw-type devices for adjusting the elevations of the shores once they are placed; various fittings can be interchanged at the top for vertical extensions
- Single-post wood shores are cut slightly short of the desired elevation and adjusted by driving wooden wedges under the shore or at its top
- Double-post shores may be assembled with cross bracing for relatively heavy loads
- Horizontal shoring consists of adjustable metal members used to support slab forms over comparatively long spans without intervening vertical shores. Horizontal shoring requires fewer vertical shores, each carrying a comparatively greater load, and leaves open spaces clear for work, but each vertical support carries a greater concentration of load
- After a concrete slab or beam has cured sufficiently to carry its own weight, the original formwork is removed and the slab or beam is reshored until the concrete reaches it full strength
- See 5.07–5.08 for the formwork required for concrete columns and walls

- Using columns and beams of a constant section and varying the amount of steel reinforcement to carry the imposed loads results in greater economy
- Shores must be braced in both the vertical and horizontal planes to stiffen and prevent buckling of individual members of the formwork



- Flying forms are large sections of formwork, including supporting trusses, beams or scaffolding, that can be moved by a crane in constructing the concrete floors and roofs of multi-storey buildings

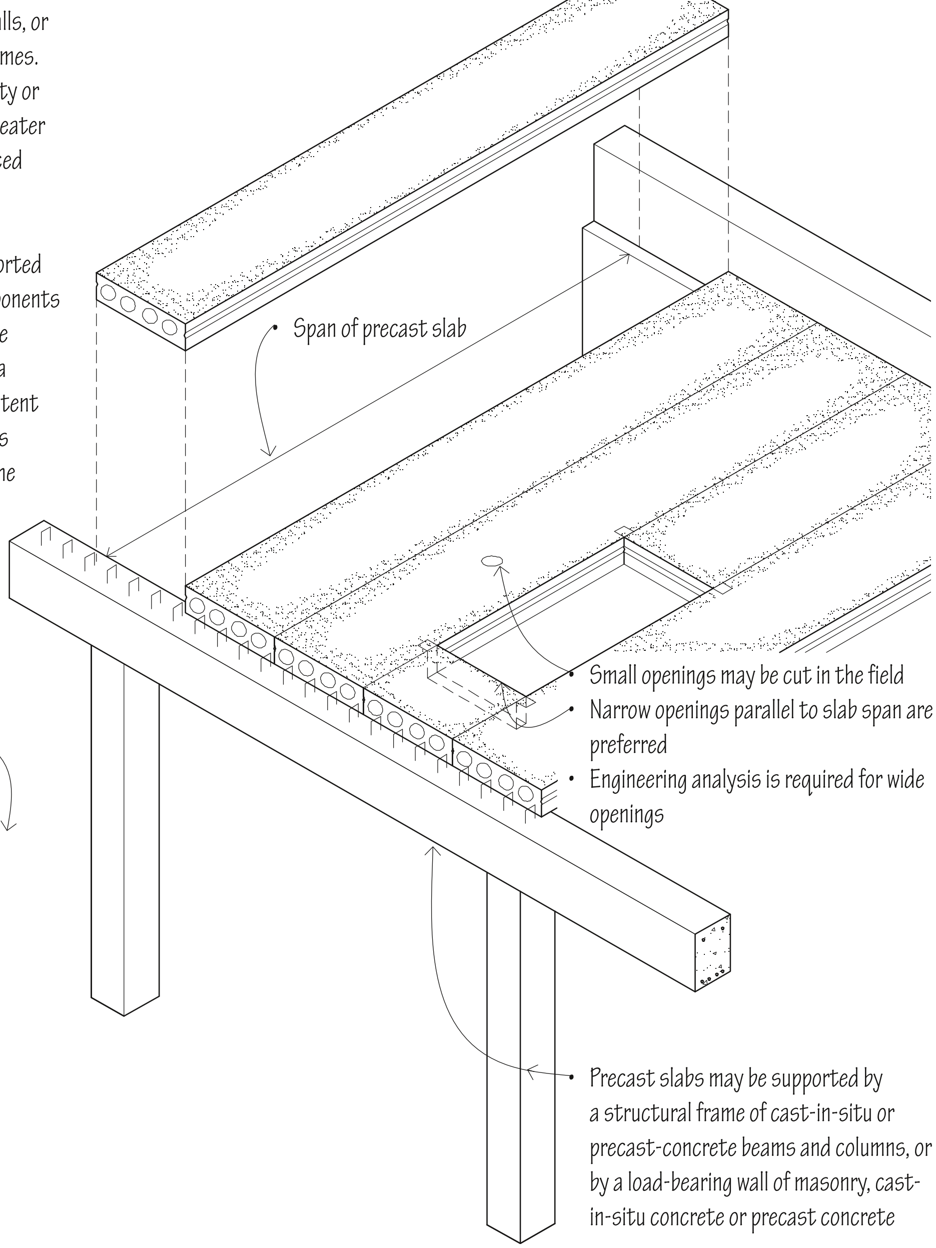


- Lift-slab construction is a technique of constructing multi-storey buildings in which all horizontal slabs are cast at ground level and, when cured, are raised into position by hydraulic jacks. The popularity of lift-slab construction has receded in recent years due to safety concerns

BS EN 5975: 2008 + A1 2011: Code of Practice for Temporary Works Procedures and Permissible Stress Design of Falsework

Precast-concrete slabs, beams and structural tees are one-way spanning units that may be supported by cast-in-situ concrete, precast-concrete or masonry bearing walls, or by steel, cast-in-situ concrete or precast-concrete frames. The precast units are manufactured with normal-density or structural lightweight concrete and prestressed for greater structural efficiency, which results in less depth, reduced weight and longer spans.

The units are cast and cured in a plant off-site, transported to the construction site, and set in place as rigid components with cranes. The size and proportion of the units may be limited by the means of transportation. Fabrication in a factory environment enables the units to have a consistent quality of strength, durability and finish, and eliminates the need for on-site formwork. The modular nature of the standard-sized units, however, may not be suitable for irregular building shapes.

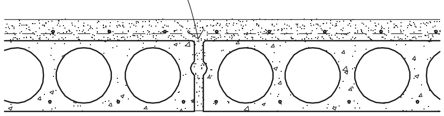


- Span of precast slab

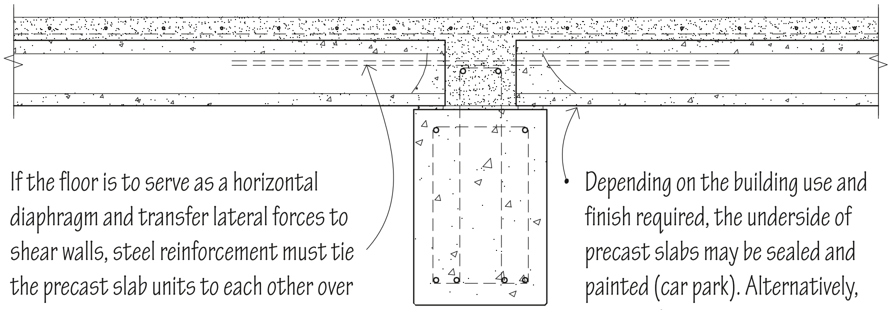
- Small openings may be cut in the field
- Narrow openings parallel to slab span are preferred
- Engineering analysis is required for wide openings

- Precast slabs may be supported by a structural frame of cast-in-situ or precast-concrete beams and columns, or by a load-bearing wall of masonry, cast-in-situ concrete or precast concrete

- A 75–150 mm concrete topping reinforced with steel fabric or reinforcing bars bonds with the precast units to form a composite structural unit
- Grout key



- The topping also conceals any surface irregularities, increases the fire-resistance rating of the slab, and accommodates underfloor conduit for wiring



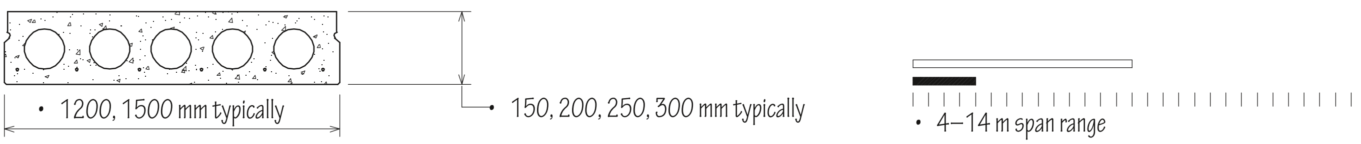
- If the floor is to serve as a horizontal diaphragm and transfer lateral forces to shear walls, steel reinforcement must tie the precast slab units to each other over their supports and at their end bearings

- Depending on the building use and finish required, the underside of precast slabs may be sealed and painted (car park). Alternatively, a ceiling finish may also be applied to the slab or a suspended ceiling installed to conceal services (office)

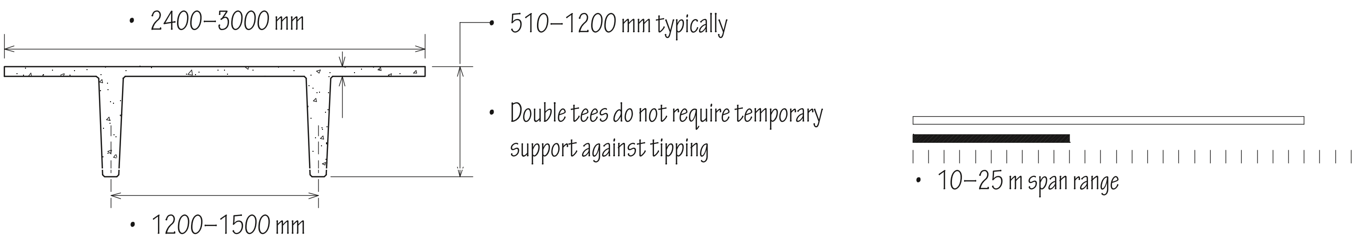
EN Eurocode 2: Design of Concrete Structures, Part 1

4.12 PRECAST-CONCRETE UNITS

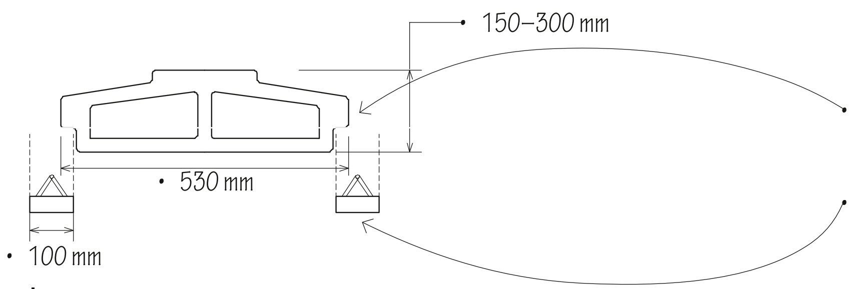
Solid Flat Slabs



Hollow Core Slabs

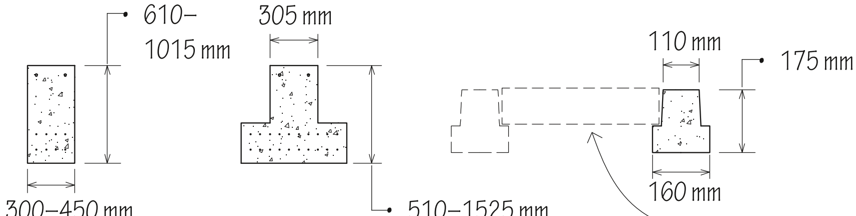


Double Tees



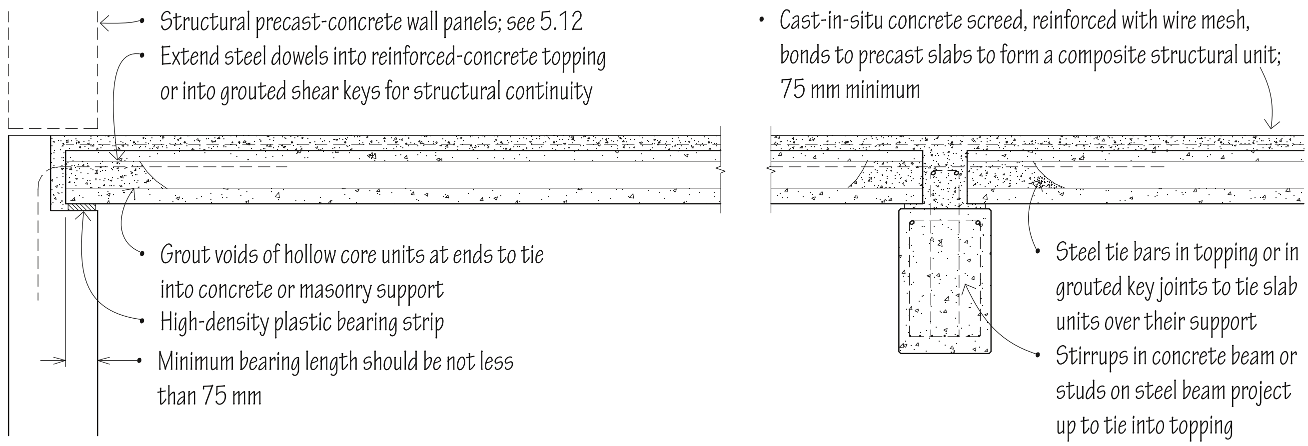
Rectangular Beams

- Precast filler blocks are relatively small and easy to manoeuvre
- Filler blocks are precast planks with reinforcement, a structural concrete screed is then poured to give the floor strength. Spans up to 12 m are possible

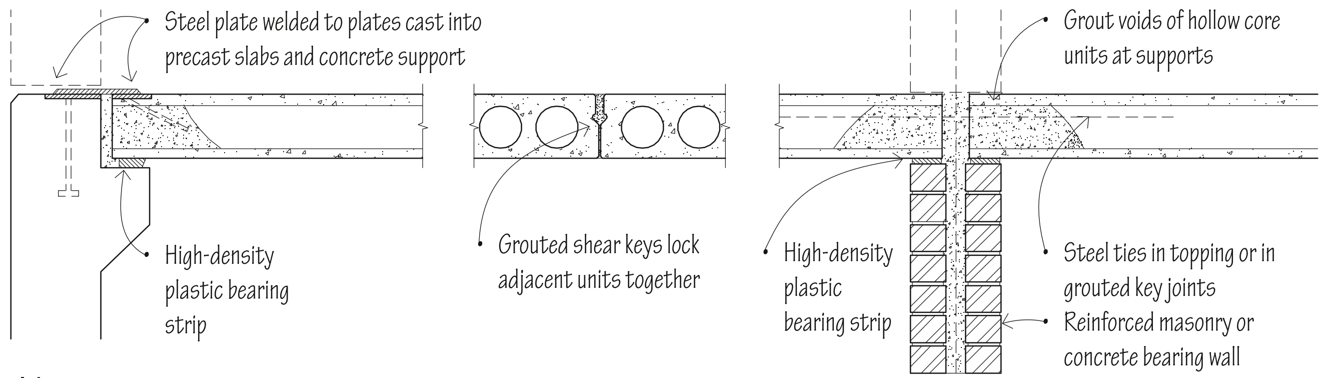


Rectangular Beams | Inverted Tee Beams | Block and Beam

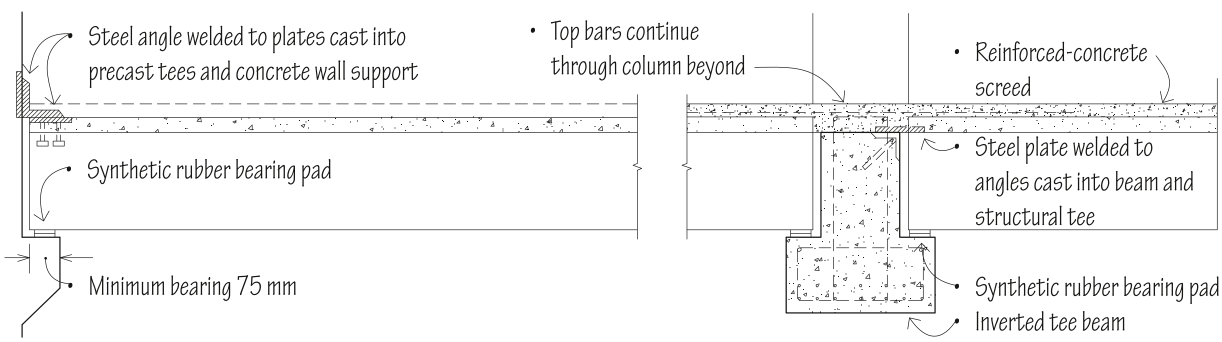
- Block and beam floors are quick and easy to install. The beams are supported on masonry walls or other supporting structures and concrete blocks are laid between



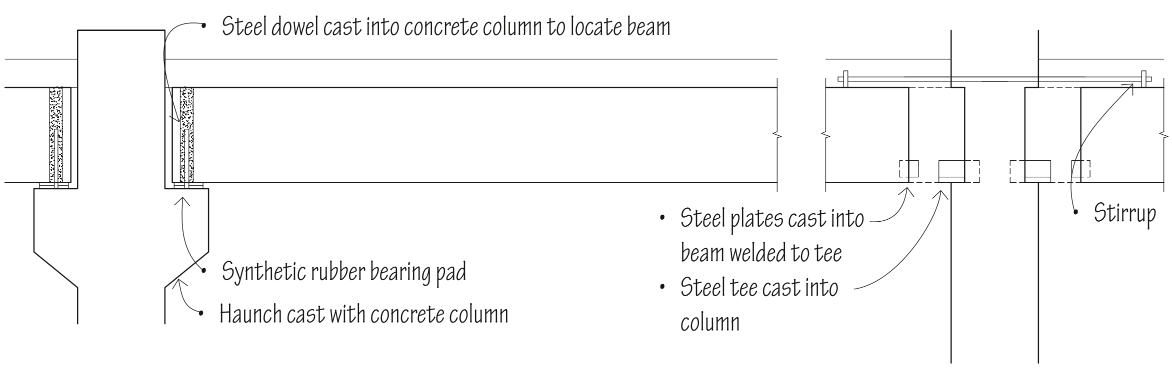
Precast Slabs



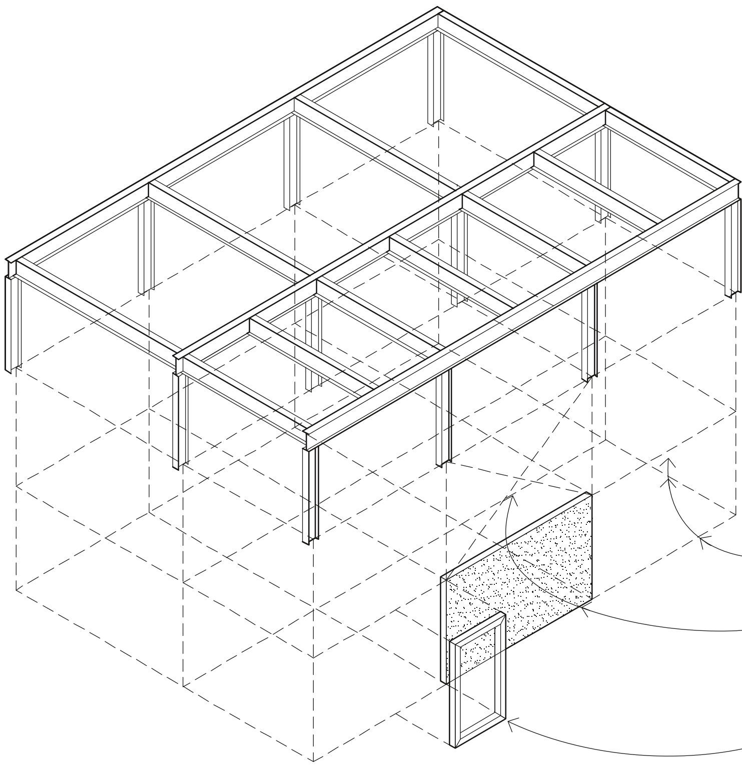
Precast Slabs



Precast Structural Tees

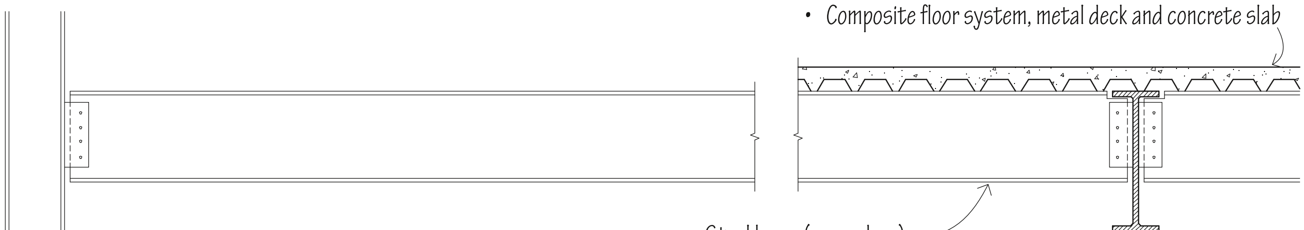


Precast Beams



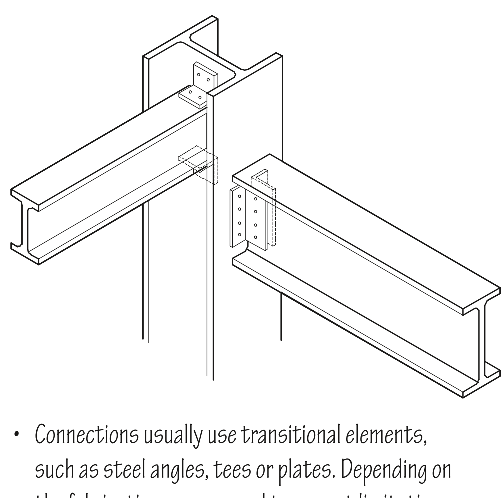
Structural steel universal beams and columns are used to construct a skeleton frame for structures ranging in size from one-storey buildings to skyscrapers. Because structural steel is difficult to work on-site, it is normally cut, shaped and drilled off-site according to design specifications; this can result in relatively fast, precise construction of a structural frame. As structural steel can lose strength rapidly in a fire, fire-rated assemblies or coatings are required for it to qualify as fire-resistant construction. In exposed conditions, corrosion resistance is also required. See 12.08 for a discussion of steel as a construction material; see the Appendix for fire-rated steel assemblies.

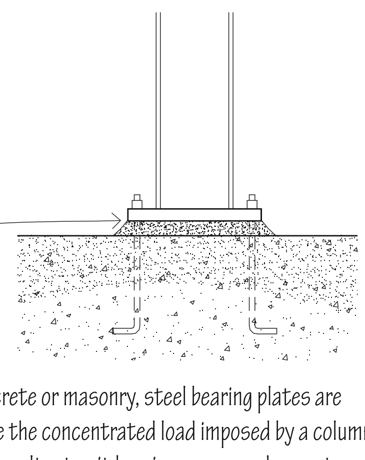
- Steel framing is most efficient when the beam and supporting columns are laid out along a regular grid
- Resistance to lateral wind or earthquake forces requires the use of shear walls, diagonal bracing or rigid framing with moment-resisting connections
- For non-bearing or curtain wall options; see 7.20



- Composite floor system, metal deck and concrete slab

- Steel beam (secondary)
- Steel beam (primary)

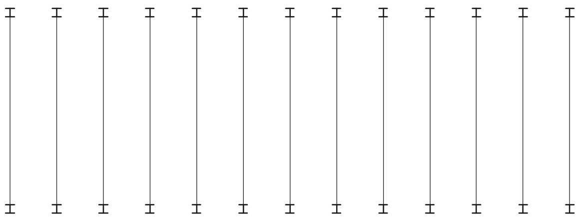




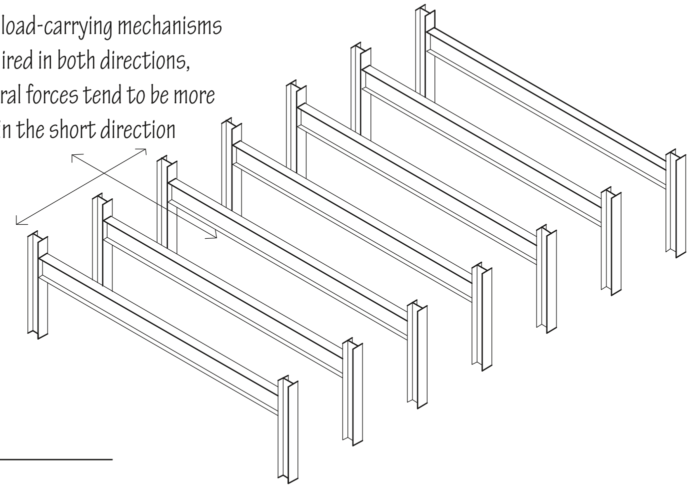
- Connections usually use transitional elements, such as steel angles, tees or plates. Depending on the fabrication process and transport limitations connections may be bolted on-site or welded off-site

- When bearing on concrete or masonry, steel bearing plates are required to distribute the concentrated load imposed by a column or beam so that the resultant unit bearing pressure does not exceed the allowable unit stress for the supporting material (grout after levelling)

EN Eurocode 3: Design of Steel Structures, Part 1

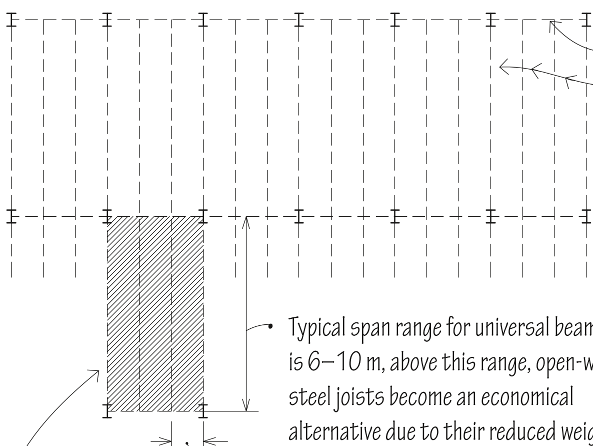


- Lateral-load-carrying mechanisms are required in both directions, but lateral forces tend to be more critical in the short direction

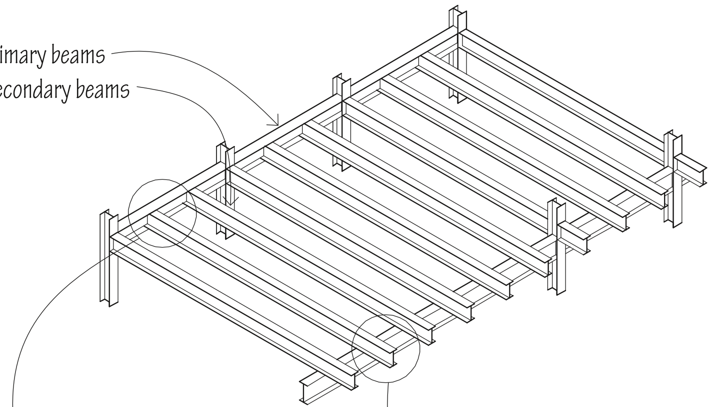


- Each pair of external columns supports a long-spanning beam. This system is suitable for long, narrow buildings, especially when a column-free space is desired

One-Way Beam System

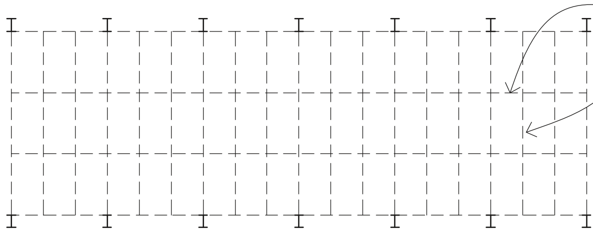


- Primary beams
- Secondary beams

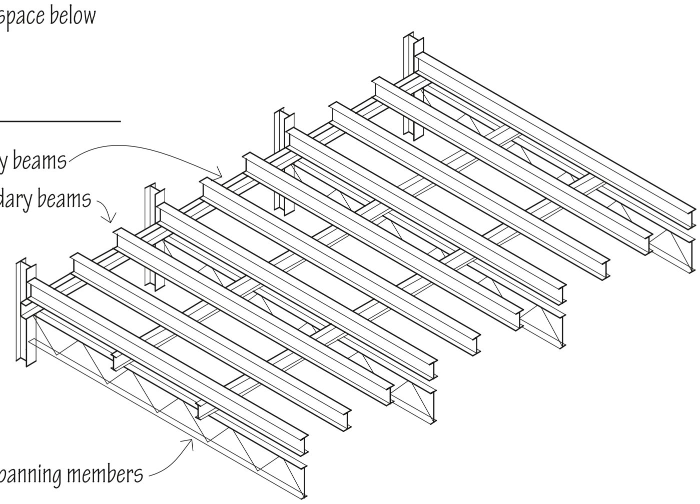


- Typical span range for universal beams is 6–10 m, above this range, open-web steel joists become an economical alternative due to their reduced weight
- Secondary beams must be placed at centres that reflect the magnitude of the applied load and type of floor deck to be installed
- Steel framing should utilise rectangular bay units, with comparatively lightly loaded beams spanning farther than more heavily loaded girders
- Framing secondary beams into the web of primary beams minimises floor depth; some mechanical services can pass through holes cut into the secondary beam webs, but large lines may have to be accommodated in a suspended ceiling space below
- Resting (and connecting) the secondary beam on the top web of the primary beam increases floor depth considerably but provides more space for mechanical services

Two-Way Beam System



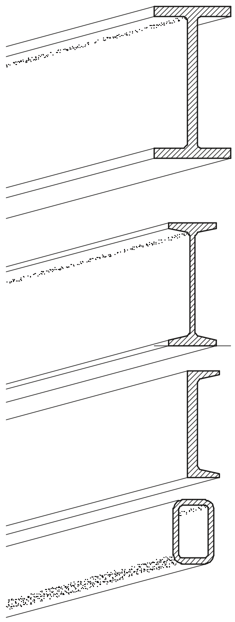
- Primary beams
- Secondary beams



- Long-spanning members

- When a large, column-free space is required, long-spanning castellated or lattice beams can be used to carry the primary beam, which in turn support a layer of secondary beams
- Used in a two-way system castellated or lattice beams can significantly increase the column-free space achievable

Triple Beam System

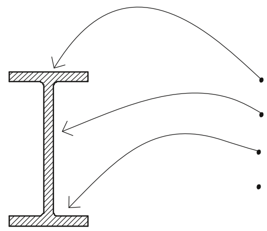


• Universal beam

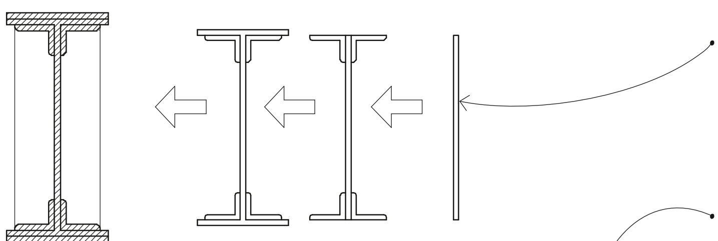
• Joist

• C channel

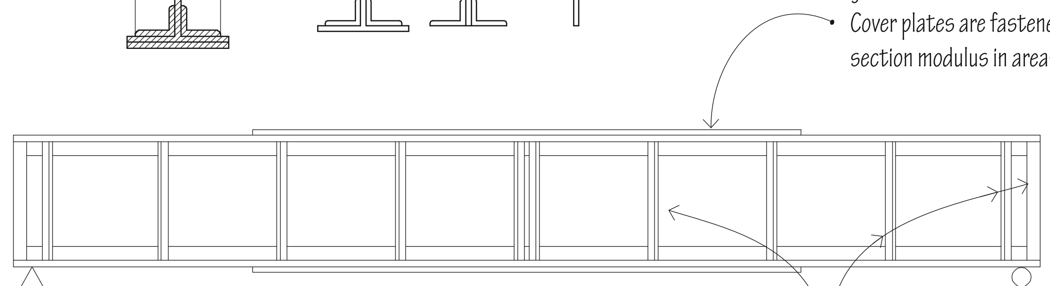
• Structural tubing



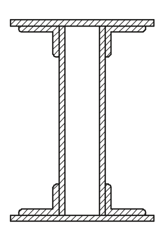
• Hot-rolled steel universal beams and columns are the most common elements used in structural steelwork. They are produced in a range of standard sizes and weights known as serial sizes. Within each serial size the web depth remains constant while the other dimensions vary
• Top flange
• Web
• Bottom flange
• The general objective is to use the lightest steel section that will resist bending and shear forces within allowable limits of stress and without excessive deflection for the intended use
• In addition to material costs also consider the labour costs required for erection

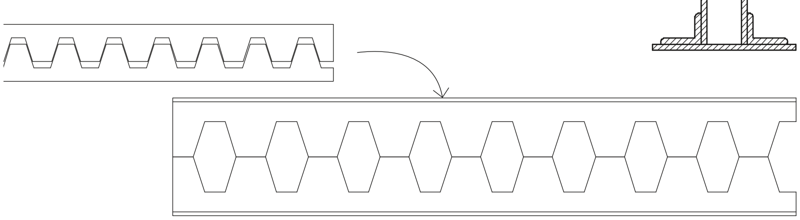


• Plate beams or girders are built up from plates or shapes that are welded together. A web plate forms the web of a place beam, while flange angles form the top and bottom flanges. Shear plates may be fastened to the web of the girder to increase its resistance to shearing stresses
• Cover plates are fastened to the flanges to increase its section modulus in areas subject to high bending stresses



• Stiffener angles are fastened to each side of a web plate to stiffen it against buckling; bearing stiffeners are placed at a point of support or under a concentrated load; intermediate stiffeners are placed between bearing stiffeners for increased resistance to diagonal compressive stresses





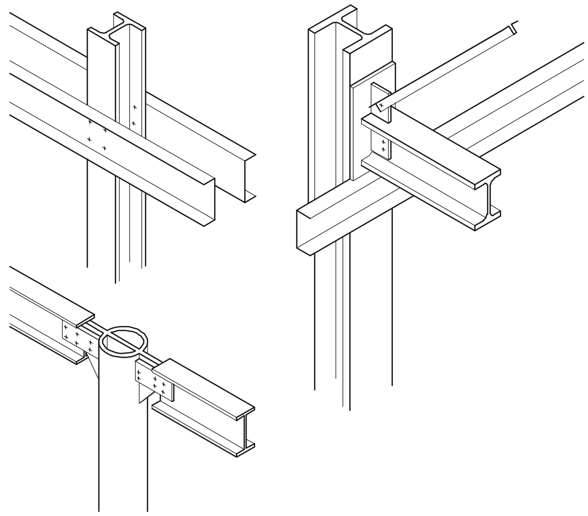
• Box beams are built up from shapes and have a hollow, rectangular cross section
• Castellated beams are fabricated by cutting a standard beam along a castellated line, the top of the castellations are then lined up and welded. This process forms a beam which is deeper than that it has been fabricated from (reducing bending) but equal in weight

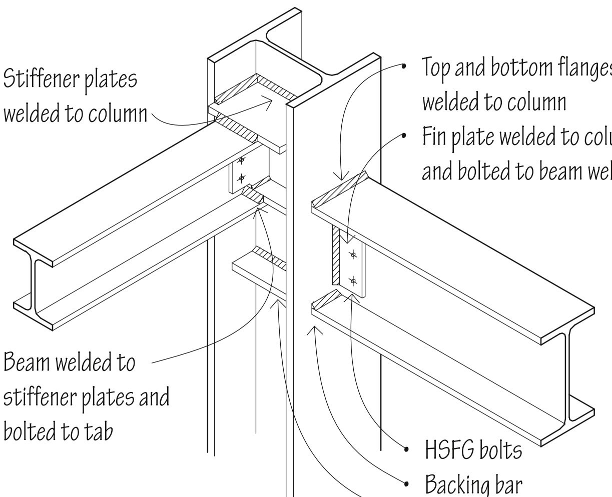
BS 4-1: 2005: Structural Steel Sections. Specification for Hot-Rolled Sections
EN Eurocode 3: Part 1, Design of Steel Structures

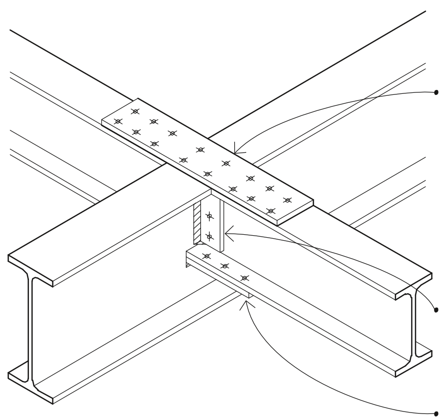
There are many ways in which steel connections can be made, using different types of connectors and various combinations of bolts and welds. Connections carried out off-site tend to be welded as quality and consistency can be controlled, connections made on-site tend to be bolted, reducing the risk of error while ensuring structural frames can be quickly assembled. The British Constructional Steelwork Association (BCSA) has produced a number of guides for various types of steelwork connections.

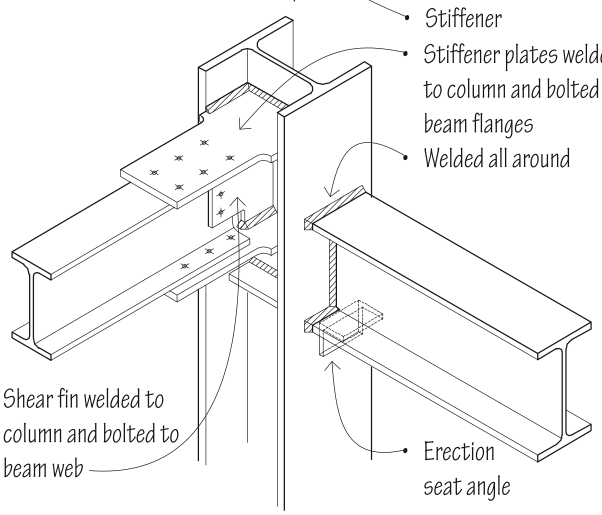
High-strength friction grip bolts (HSFG) are commonly used in bolted structural steelwork connections on-site.

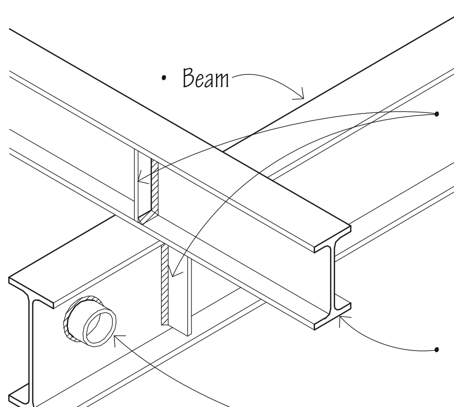
The strength of a connection depends on the sizes of the members and the connecting tees, angles or plates, as well as the configuration of bolts or welds used. BS EN 1993-1-8 (2005) identifies three main types of steel connection, simple or pinned, semi-rigid and rigid.









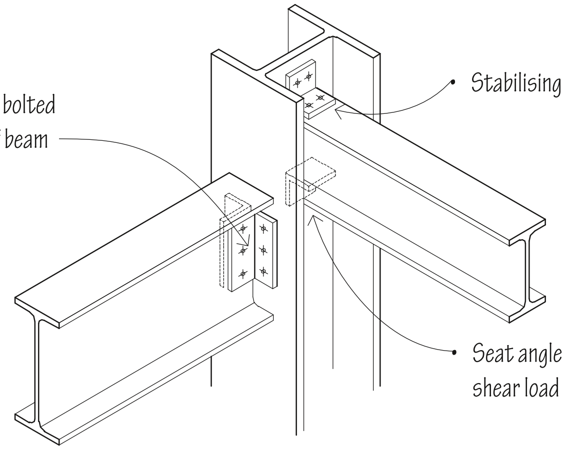


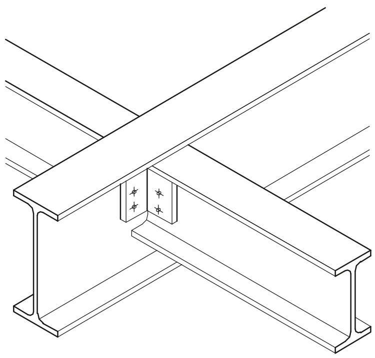
Rigid Connections

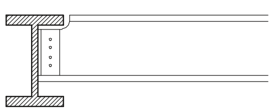
Full strength or rigid connections maintain their original angle with very little deformation under loading.

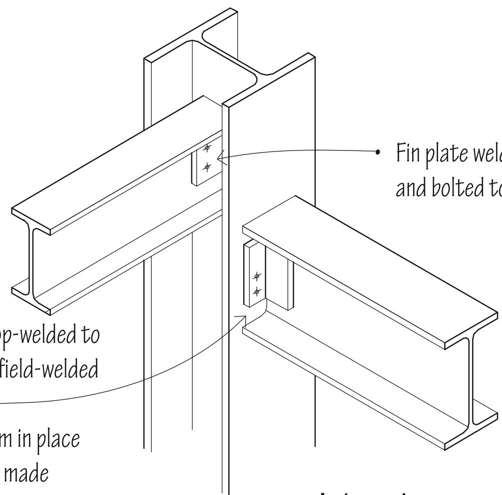
- A framed connection is a shear-resisting steel connection made by welding or bolting the web of a beam to the supporting column or girder with two angles or a single tab plate

- A seated connection is a shear-resisting steel connection made by welding or bolting the flanges of a beam to the supporting column with a seat angle below and a stabilising angle above



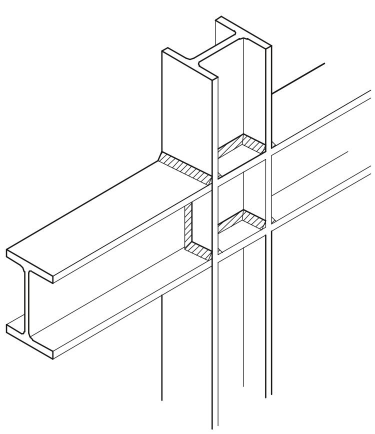


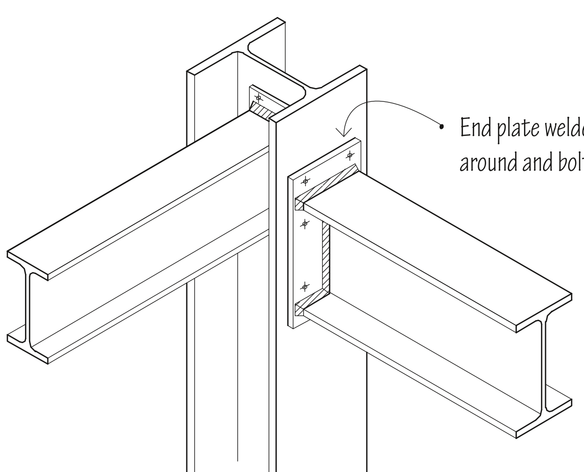




- Angles bolted or welded to webs of beams; for the top of both to be flush, the top flange of the beam is cut away

Simple/Pinned Connections
Simple connections will resist shear and direct axial loading. Structural systems with this approach require additional horizontal bracing.

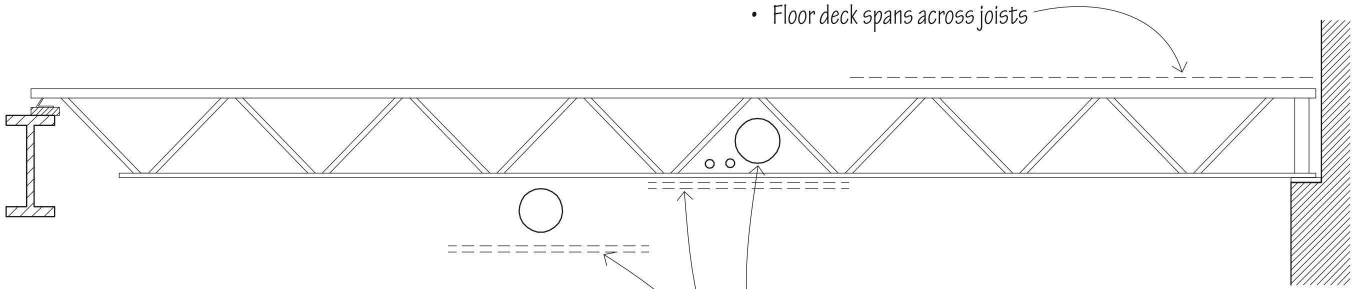


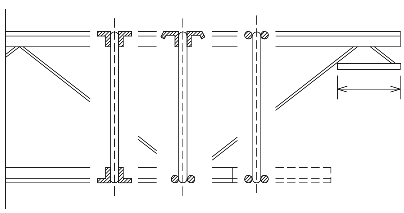


- All-welded connections are aesthetically pleasing, especially when ground smooth, but they can be very expensive to fabricate. Welding should take place off-site to help control quality

Semi-Rigid Connections
Semi-rigid connections assume the beam and column connections possess a limited but known moment-resisting capacity.

- Floor deck spans across joists





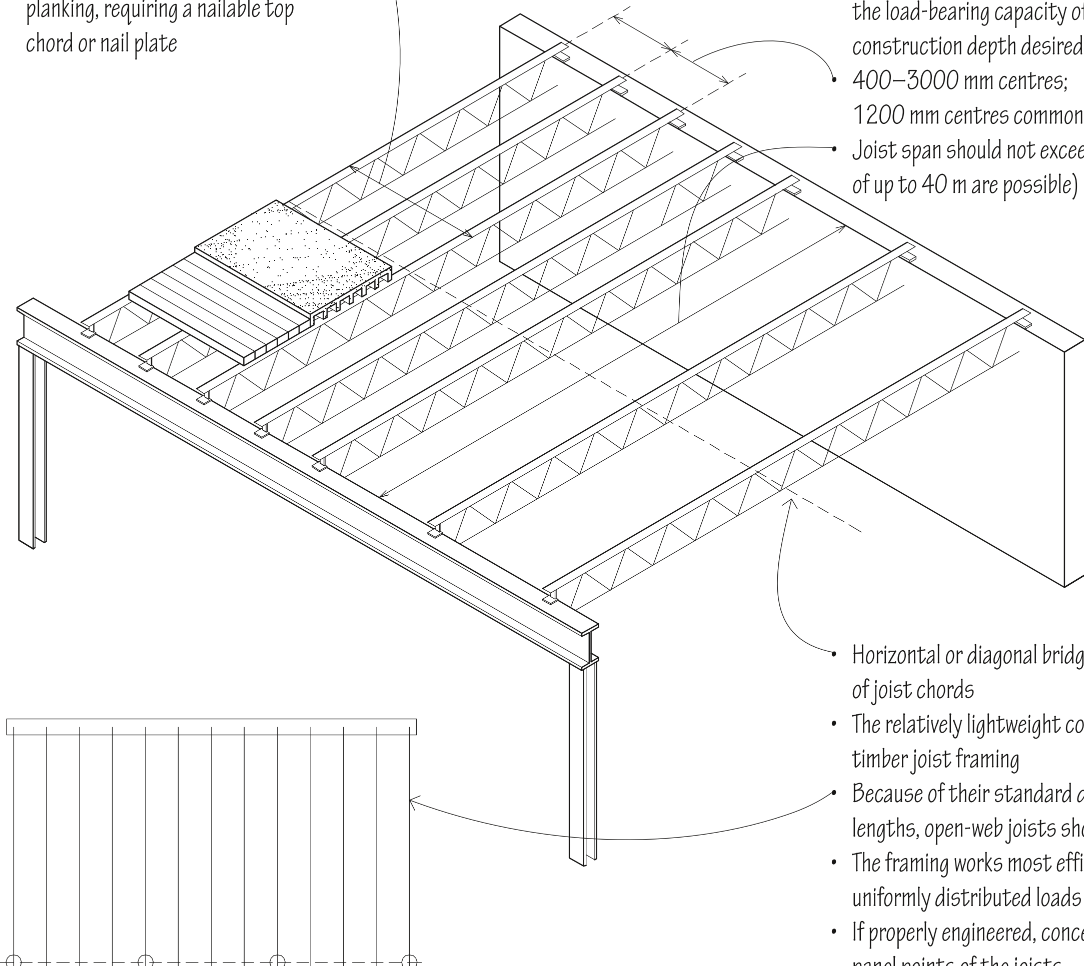
- Lattice beams are available in a range of profiles including tubular sections, plate sections and chords incorporating timber to aid fixing
- Bearing conditions should be agreed with an appropriate engineer prior to installation, generally a minimum of 100 mm is required

- Open-web steel joists may be supported by a bearing wall of masonry or reinforced concrete, or by steel beams or joist girders, which are heavier versions of open-web joists
- Open webs permit the passage of mechanical services
- Ceiling may be attached to bottom chords or be suspended if additional space for services is required; ceiling may also be omitted to expose joists and floor deck
- Fire-resistance rating depends on the fire rating of the floor and ceiling assemblies; see Appendix

- Floor deck spans joist spaces

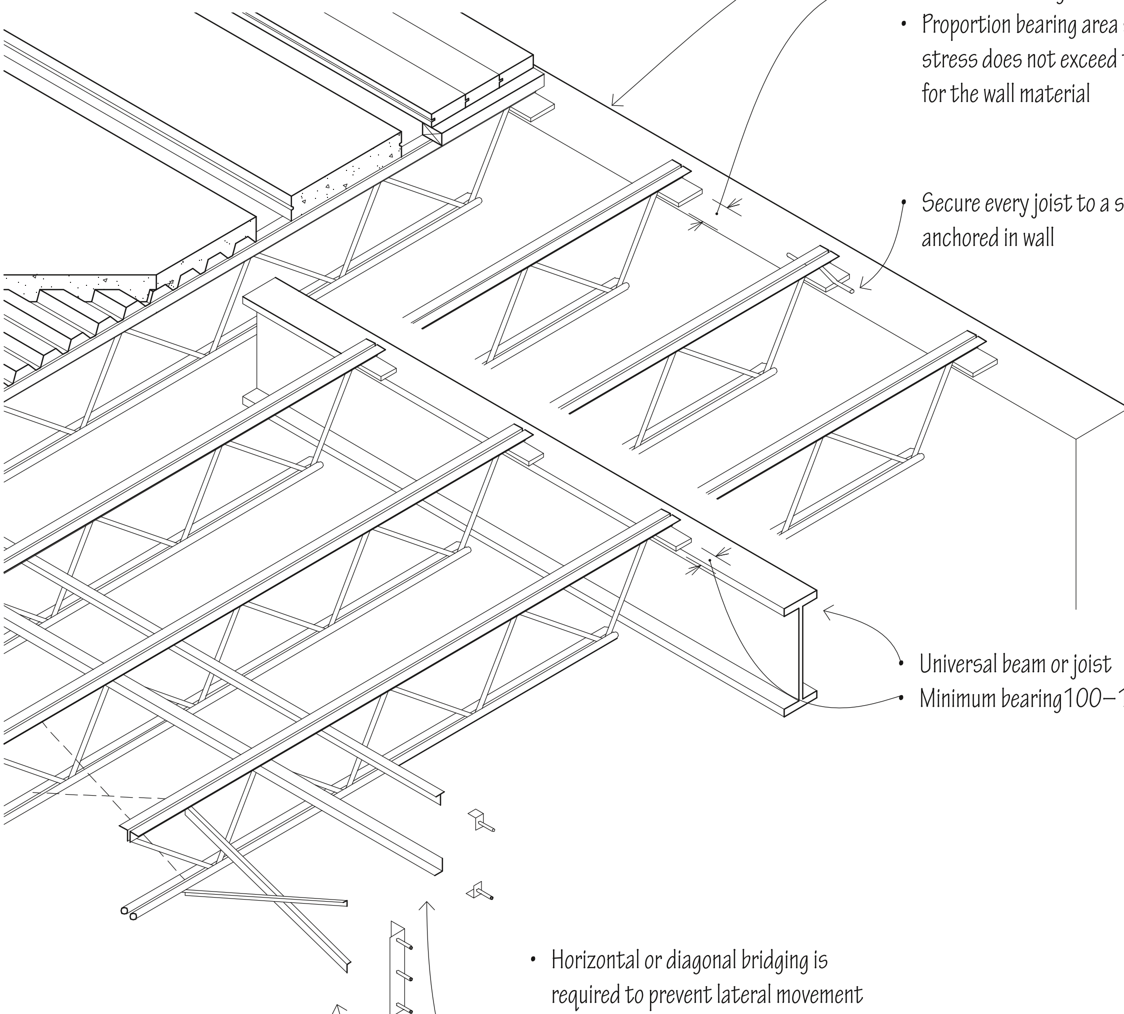
Floor deck may consist of:

- Metal decking with concrete fill
- Precast-concrete planks
- Plywood panels or wood planking, requiring a nailable top chord or nail plate



- Spacing of joists is related to the magnitude of floor load, the spanning capability of the decking material, the load-bearing capacity of the joists, and the floor construction depth desired
- 400–3000 mm centres;
  1200 mm centres common in large buildings
- Joist span should not exceed 24 x joist depth (spans of up to 40 m are possible)

- Horizontal or diagonal bridging to prevent lateral movement of joist chords
- The relatively lightweight construction is analogous to timber joist framing
- Because of their standard depths and manufactured lengths, open-web joists should span rectangular bays
- The framing works most efficiently when the joists carry uniformly distributed loads
- If properly engineered, concentrated loads may bear over the panel points of the joists

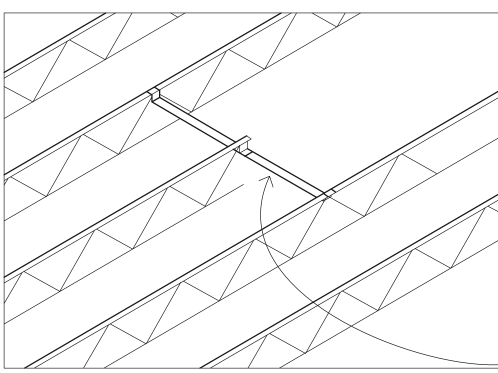


- Reinforced-concrete or masonry bearing wall
- Minimum bearing 100–150 mm
- Proportion bearing area so that unit bearing stress does not exceed the allowable unit stress for the wall material

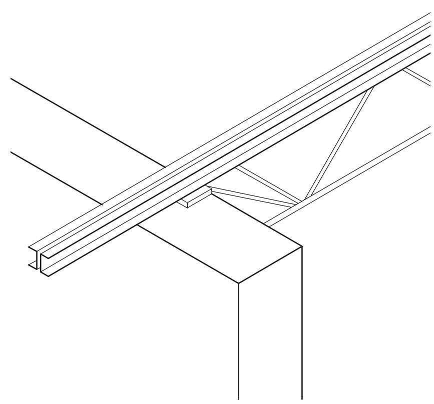
- Secure every joist to a steel bearing plate anchored in wall

- Universal beam or joist
- Minimum bearing100–150 mm

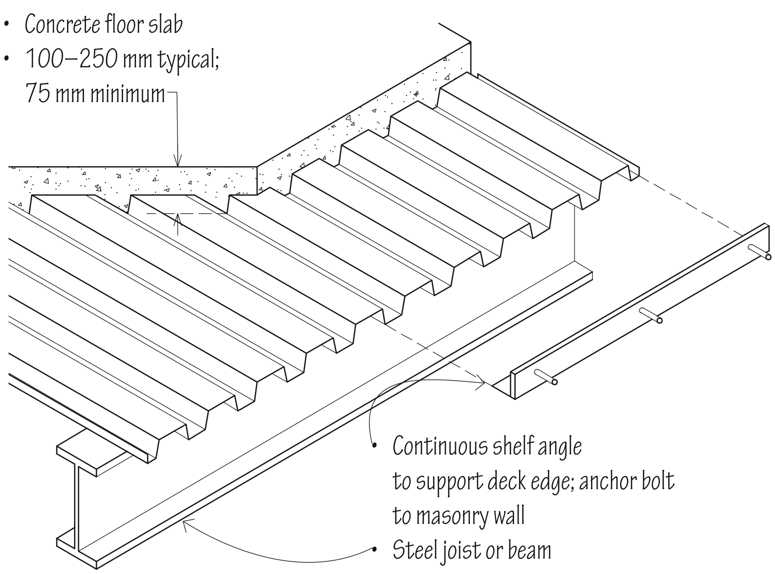
- Horizontal or diagonal bridging is required to prevent lateral movement of joist chords
- Bridging is spaced at 4–8 m centres, depending on joist span and chord size
- Horizontal bridging angles are welded to top and bottom chords
- Diagonal bridging angles can also be installed if required
- A suitably qualified engineer should be consulted regarding the required bracing, in some instances this may only be required during the construction phase



- Small openings may be framed with steel angle headers supported by trimmer joists. Large openings require structural steel framing
- Trimmer to support trimmed joist



- Limited overhangs are possible by extending the top chords
- Extended ends of steel angles or channel sections are available for short overhangs

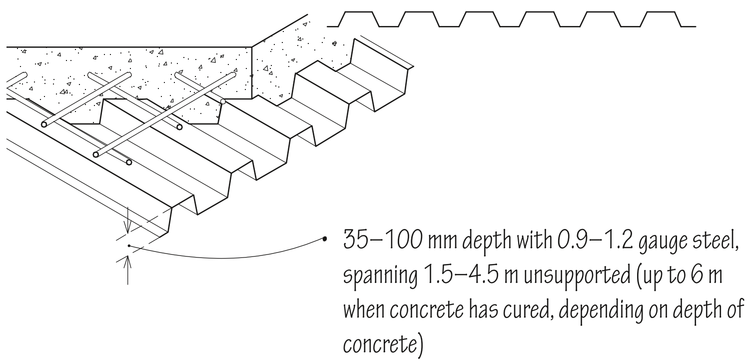


Metal decking is corrugated to increase its stiffness and spanning capability. The floor deck serves as a working platform during construction and as permanent formwork for composite construction with in-situ concrete added above the deck.

- The decking panels are laid across the top flange of the universal beam with a minimum bearing of 50–75 mm
- The panels are fastened to each other along their sides with screws or welds
- A reinforcement mesh will be required to be placed along with the in-situ concrete, although the deck itself will contribute to the overall reinforcement of the composite structure

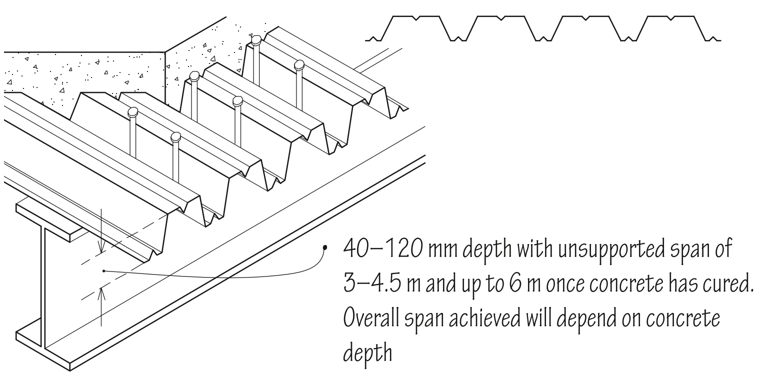
There are three major types of metal decking.

Permanent Formwork



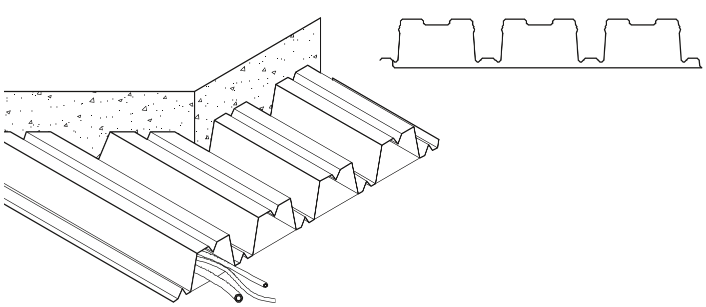
- Decking serves as permanent formwork for a reinforced concrete slab until the slab can support itself and its live load. This removes the need for the use of timber formwork and falsework as the decking can be used as a temporary working platform until the floor is complete

Composite Decking



- Composite decking serves as tensile reinforcement for the concrete slab to which it is bonded with embossed rib patterns. Composite action between the concrete slab and the floor beams or joists can be achieved by welding shear studs through the decking to the supporting beam below

Cellular Decking



- The format of steel decking lends itself to the creation of integrated service runs which can accommodate electrical wiring. The majority of composite metal deck floors will be fitted with a suspended ceiling allowing for significant services runs, ducting etc

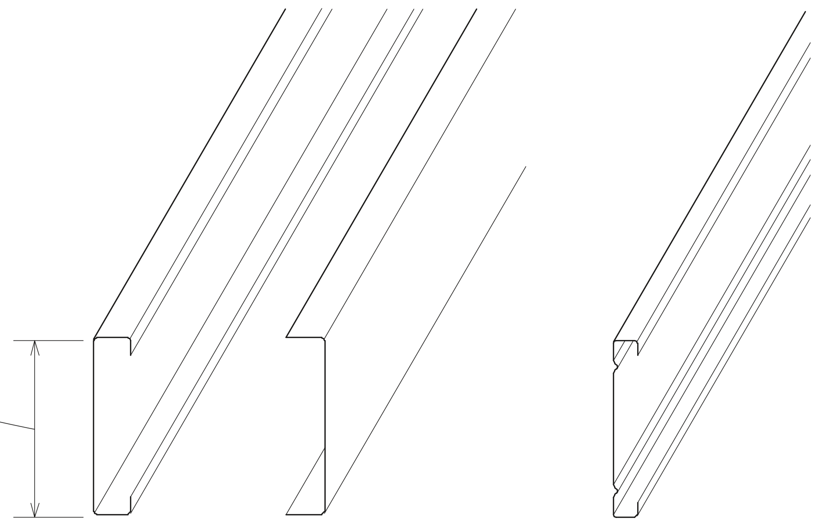
- Where the overall floor depth is critical a slim deck system may be installed. In this system the deck incorporates deep ribs which are fitted with reinforcing bars reducing the overall structural depth of the floor. The steel deck rests on a wide flange welded to the bottom flange of a universal beam

EN Eurocode 4: Design of Composite Steel and Concrete Structures, Part 1

4.22 LIGHT-GAUGE STEEL JOISTS

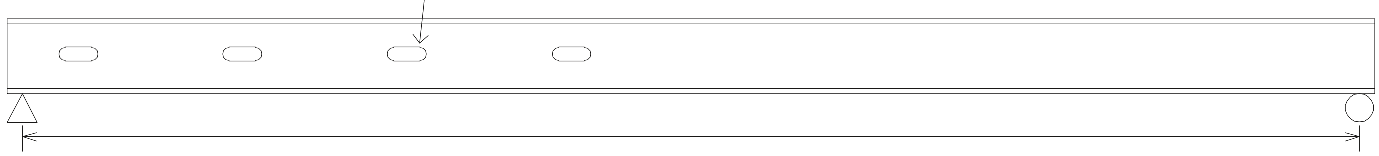
Light-gauge steel joists are manufactured by cold-forming sheet or strip steel. The resulting steel joists are lighter, more dimensionally stable, and can span longer distances than their timber counterparts but conduct more heat and require more energy to process and manufacture. The cold-formed steel joists can be easily cut and assembled with simple tools into a floor structure that is lightweight, non-combustible, and damp-proof. As in timber light-frame construction, the framing contains cavities for utilities and thermal insulation and accepts a wide range of finishes.

- Nominal depths: 75, 100, 120, 150, 200, 250, 300, 340 mm
- Flange widths: 40, 50, 55, 65, 70, 75 mm
- Gauges: 1.2 – 3.0 mm



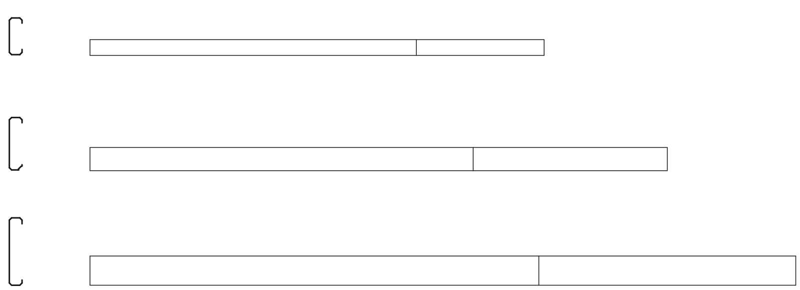
Typical Light-Gauge Steel Sections

- Prepunched holes reduce joist weight and allow the passage of piping, wiring and bridging straps



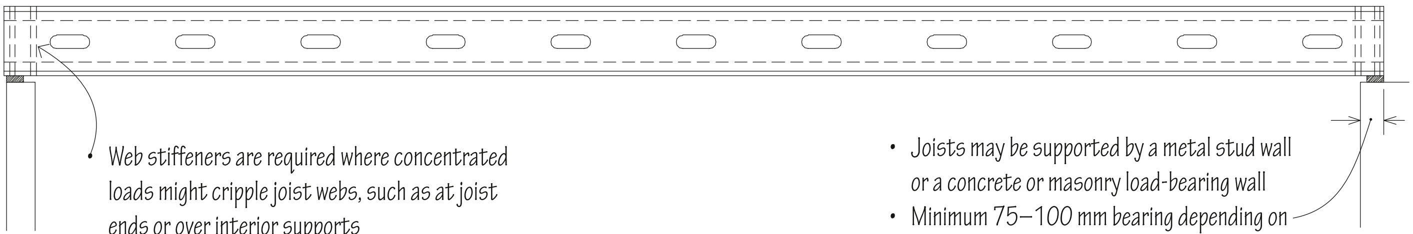
Span Ranges for Light-Gauge Steel Joists

- 150 mm channel 3–4 m
- 250 mm channel 4–6 m
- 300 mm channel 5–8 m



- Consult manufacturer for exact joist dimensions, framing details and allowable spans and loads

EN Eurocode 3: Design of Steel Structures Part 1-3, Cold Formed Thin Gauge Members and Sheeting



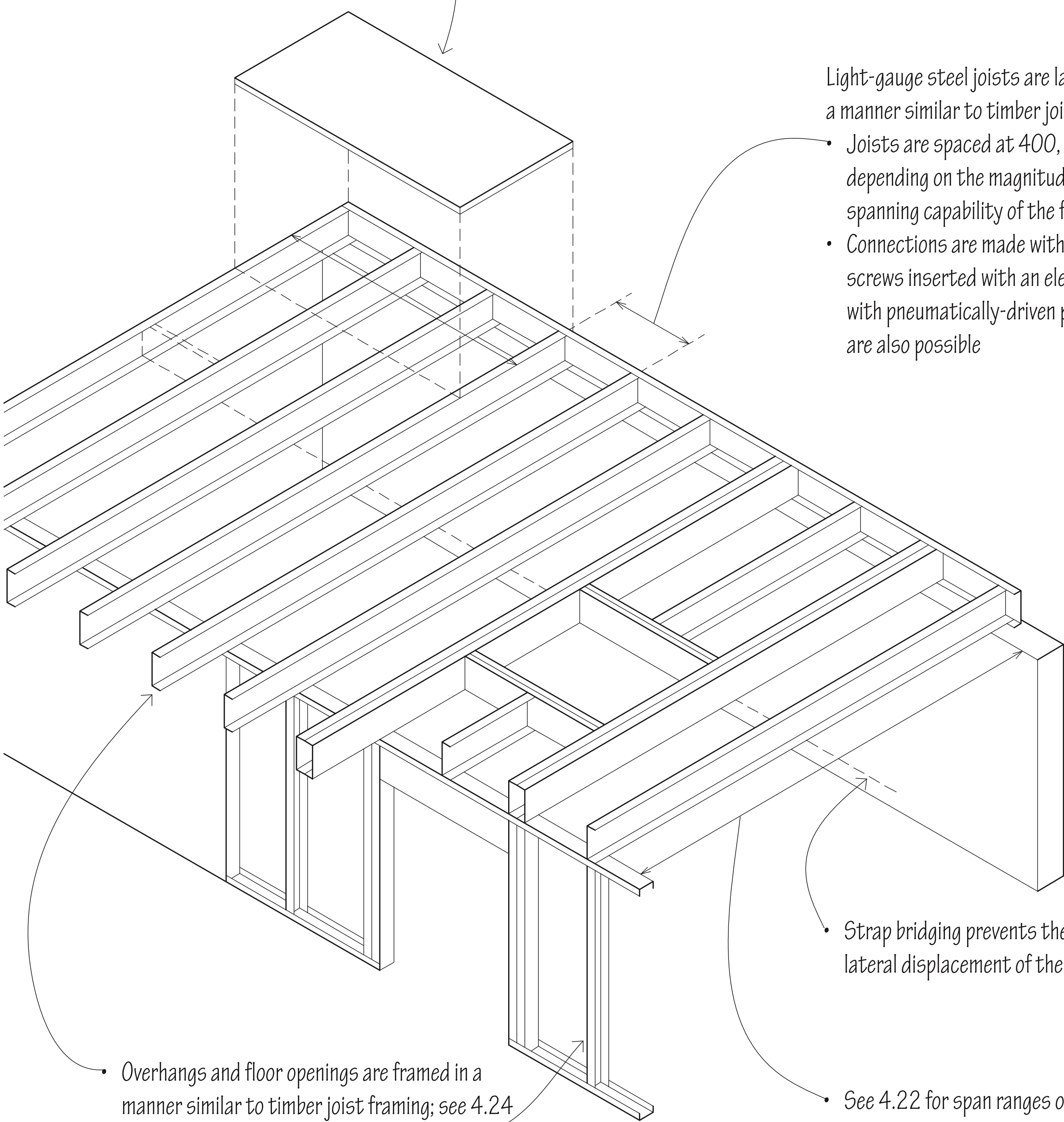
- Web stiffeners are required where concentrated loads might cripple joist webs, such as at joist ends or over interior supports

- Joists may be supported by a metal stud wall or a concrete or masonry load-bearing wall
- Minimum 75–100 mm bearing depending on support type

- Reinforced concrete over metal decking or timber panel sub-flooring

Light-gauge steel joists are laid out in and assembled in a manner similar to timber joist framing.

- Joists are spaced at 400, 600 or 800 mm centres, depending on the magnitude of applied loads and spanning capability of the floor deck
- Connections are made with self-drilling, self-tapping screws inserted with an electric or pneumatic tool, or with pneumatically-driven pins; welded connections are also possible

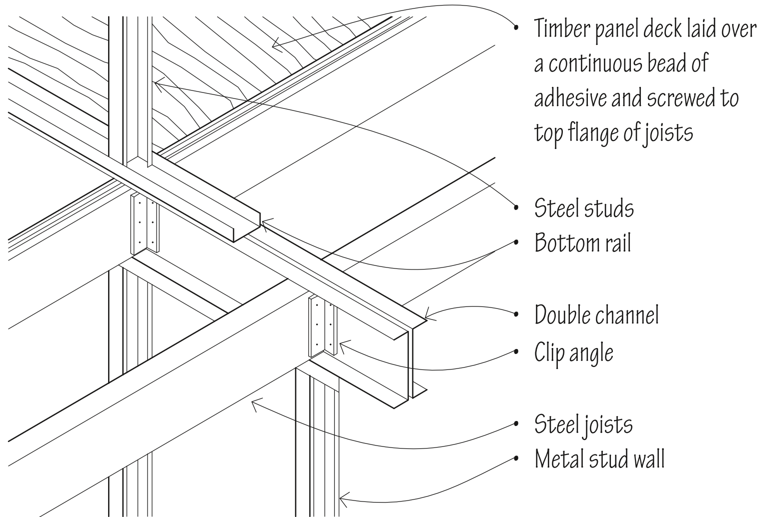


- Strap bridging prevents the rotation or lateral displacement of the joists

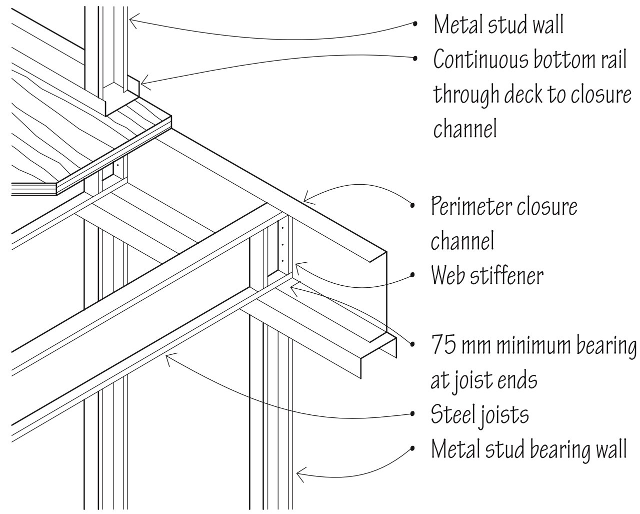
- Overhangs and floor openings are framed in a manner similar to timber joist framing; see 4.24
- See 5.41 for metal stud wall framing

- See 4.22 for span ranges of light-gauge steel joists

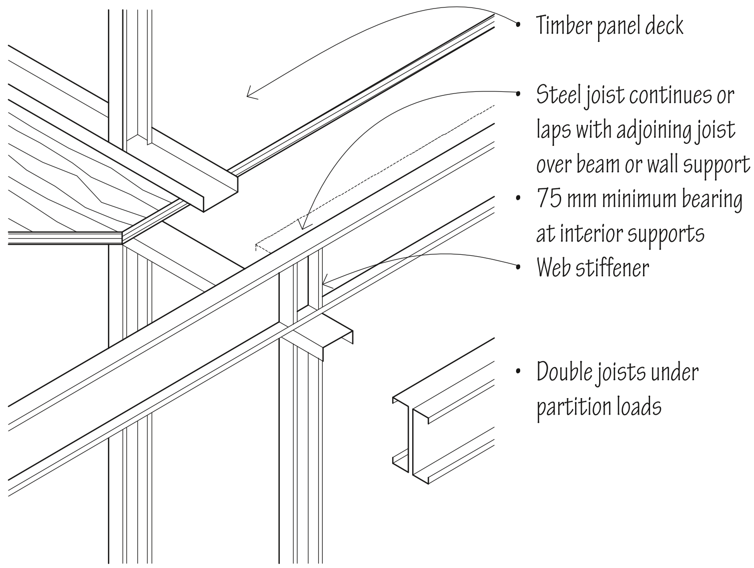
4.24 LIGHT-GAUGE JOIST FRAMING



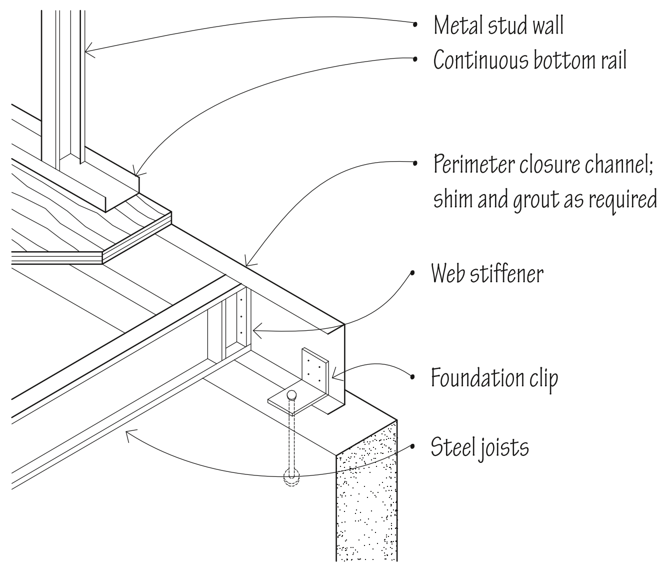
Interior Bearing



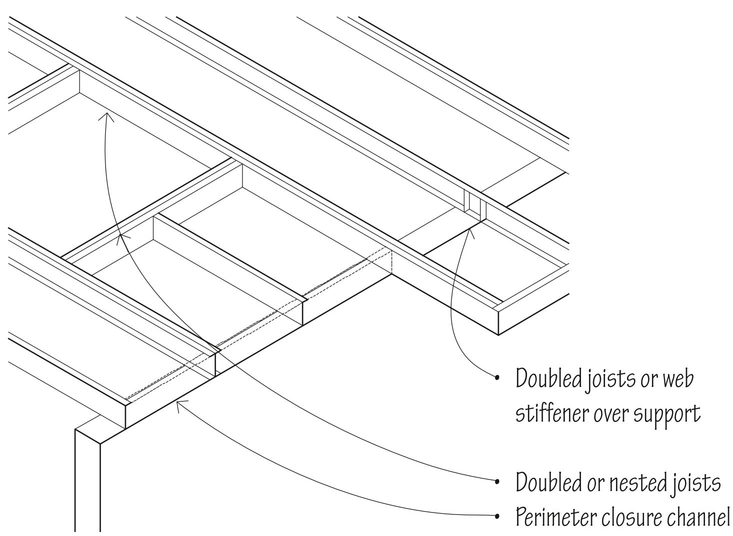
Exterior Bearing



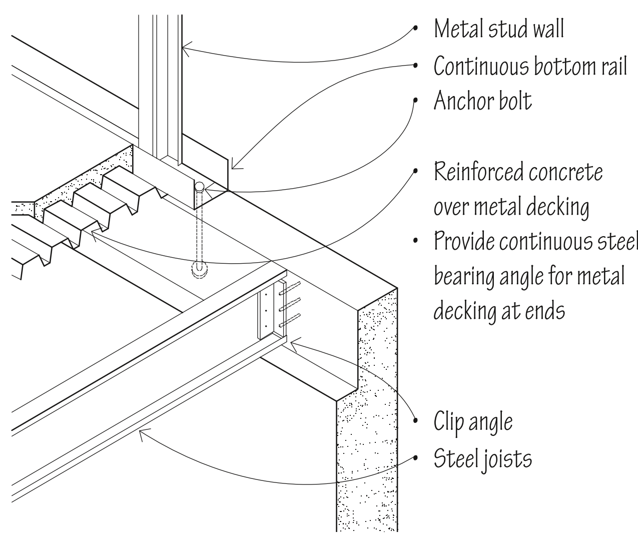
Interior Bearing



Exterior Bearing



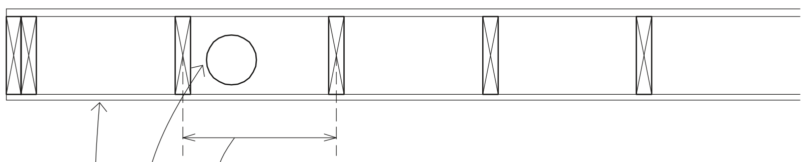
Floor Projections and Openings



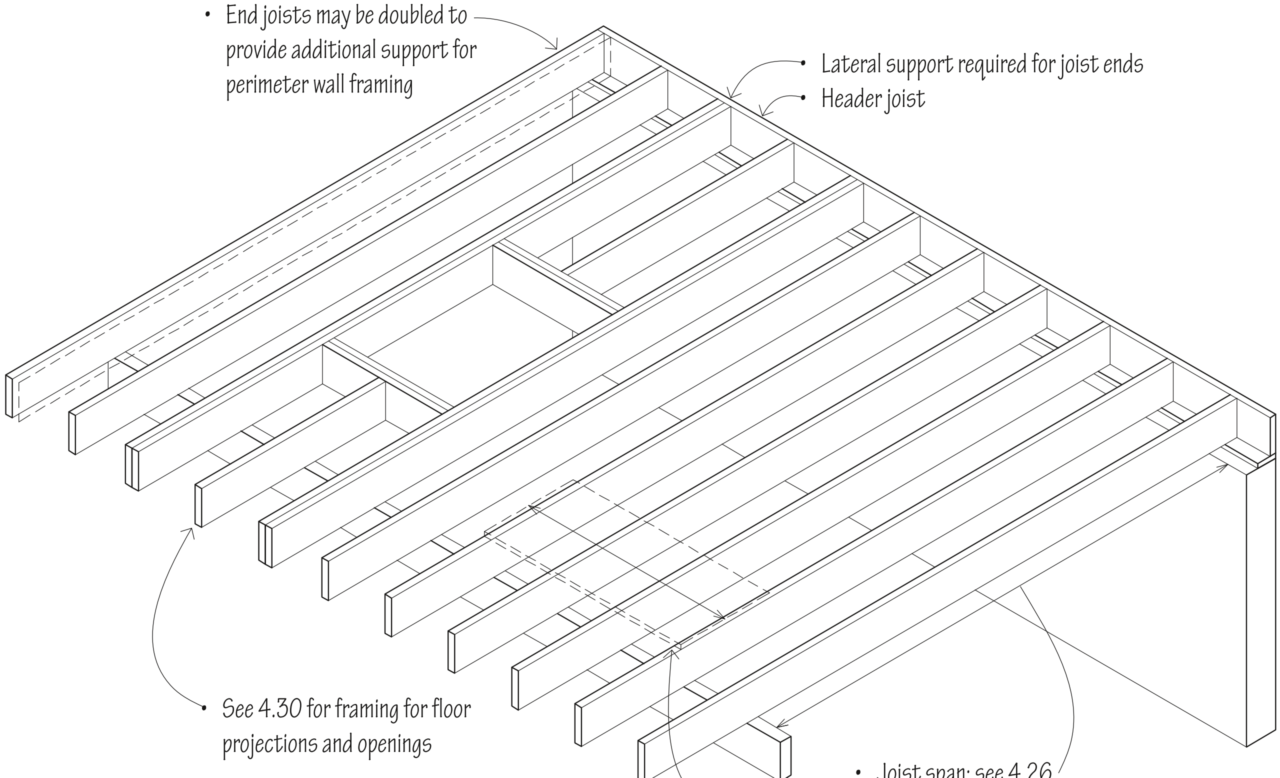
Exterior Bearing

Timber joist floors are an essential subsystem of wood light-frame construction. The dimension timber used for joists is easily worked and can be quickly assembled on site with simple tools. Together with timber panel sheathing or sub-flooring, the timber joists form a level working platform for construction. If properly engineered, the resulting floor structure can serve as a structural diaphragm to transfer lateral loads to shear walls; consult the building regulations for specific requirements.

- Because timber framing is combustible, it must rely on finish flooring and ceiling materials for its fire-resistance rating
- The susceptibility of timber framing to decay and insect infestation requires positive site drainage, adequate separation from the ground, appropriate use of pressure-treated timber and ventilation to control condensation in enclosed spaces
- See 12.11–12.12 for discussion of wood as a construction material

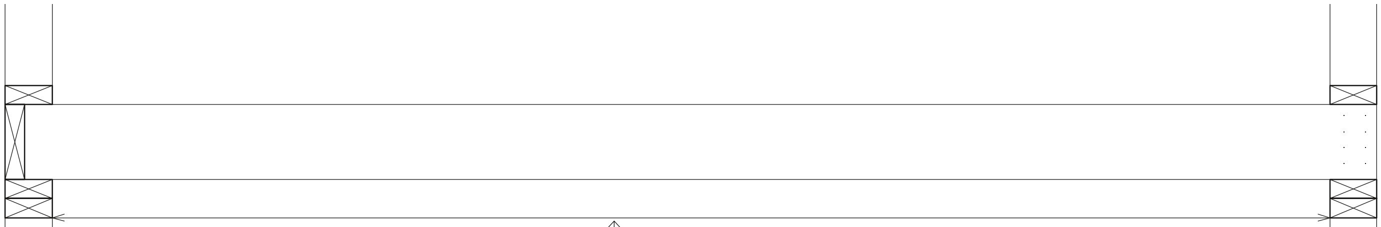


- Joists are spaced at 400, 450 or 600 mm centres depending on the magnitude of applied loads and the straight class of the timber (generally C16 or C24)
- Cavities can accommodate piping, wiring and thermal insulation
- Ceiling may be applied directly to joists, or be suspended to lower ceiling area or conceal mechanical runs perpendicular to joists



- End joists may be doubled to provide additional support for perimeter wall framing
- Lateral support required for joist ends
- Header joist
- See 4.30 for framing for floor projections and openings
- Joist span; see 4.26
- Sheathing or sub-flooring ties and stabilises the joists to prevent twisting and buckling
- Finish flooring is laid over sheeting or floorboards; some finish flooring materials may require additional underlays

EN Eurocode 5: Design of Timber Structures, Part 1



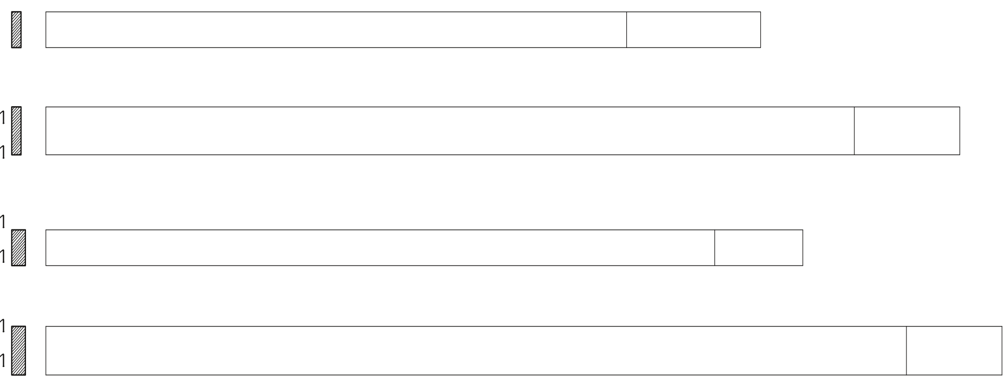
- In platform frame construction, floor joists rest directly on the top plate of the wall below and are fixed to the header joist
- The position of joists should coincide with the location of the studs in the panel below

Joist span is related to the:
- Magnitude of applied loads
- Joist-size, spacing and strength class
- Deflection allowable for the intended use

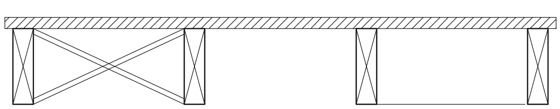
- Joints in joists should only occur over load-bearing walls
- Joints in joists can either be lapped and nailed or butt-jointed and connected using a splice plate

Span Ranges for Timber Joists Based on Eurocode 5 Span Tables

- 38 x 170 mm (C16) up to 3.10 m (C24) up to 3.70 m
- 38 x 220 mm (C16) 3.00–4.29 m (C24) 3.40–4.70 m
- 44 x 170 mm (C16) 2.50–3.50 m (C24) 2.70–3.90 m
- 44 x 220 mm (C16) 3.20–4.50 m (C24) 3.60–5.00 m



- The stiffness of the joist framing under stress is more critical than its strength
- If the overall construction depth is acceptable, deeper joists spaced further apart are more desirable for stiffness than shallow joists spaced more closely together



Strutting consists of timber or metal cross-bracing or full-depth blocking between joists. The strutting requirement will be determined by the span and depth of the floor and will provide lateral restraint. Generally spans less than 2.5 m will not require strutting, 2.5–4.5 m will require strutting at mid span and greater than 4.5 m spans will require strutting at every 1/3.

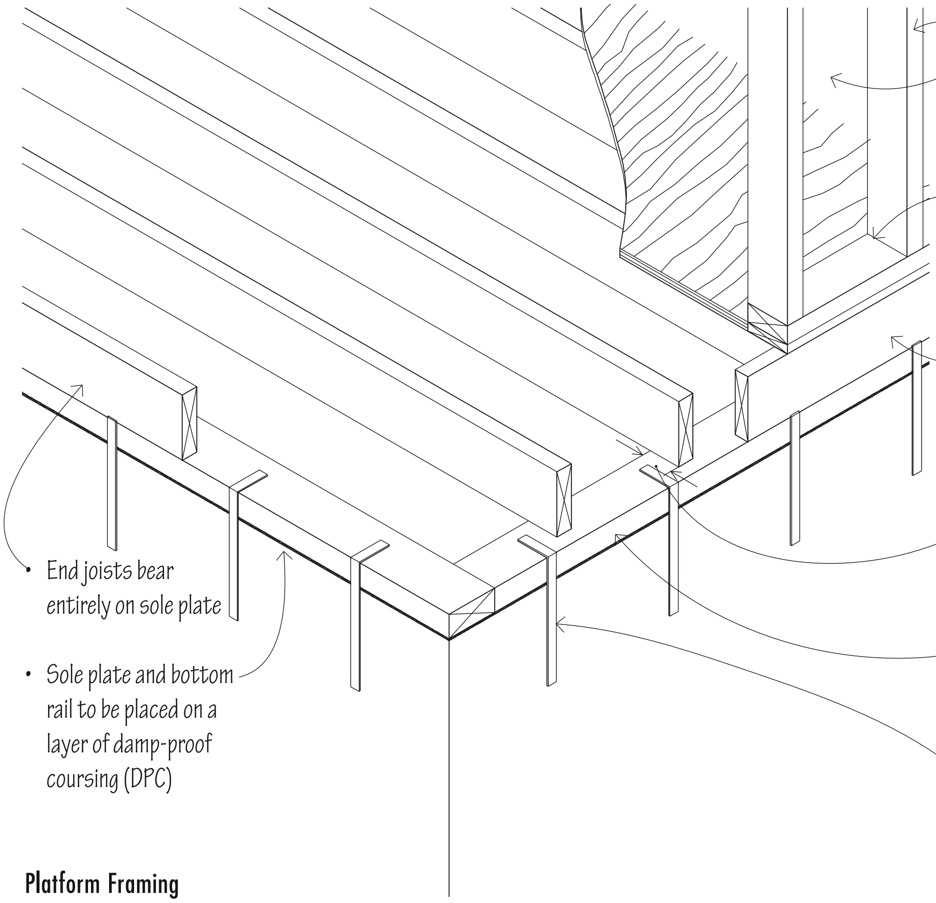
- Maximum diameter = 1/4 joist depth, not within first 1/4 of span or beyond first 4/10

- 1/8 of joist depth maximum and not beyond first and last 1/4 of the span

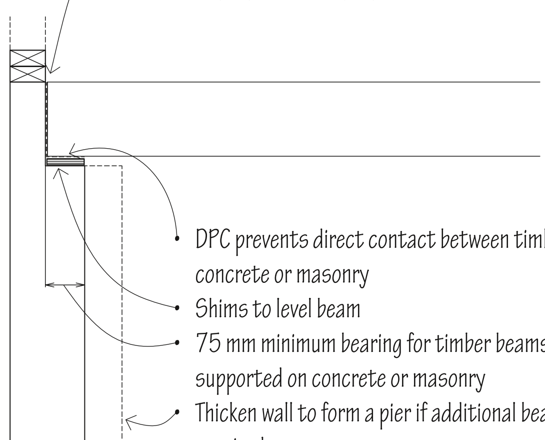
To allow plumbing and electrical lines to pass through floor joists, cuts may be made according to the guidelines illustrated above.

All notches and holes must be kept at least 100 mm apart.

Additional guidance and recommendations can be found in BS 5268-2



Platform Framing

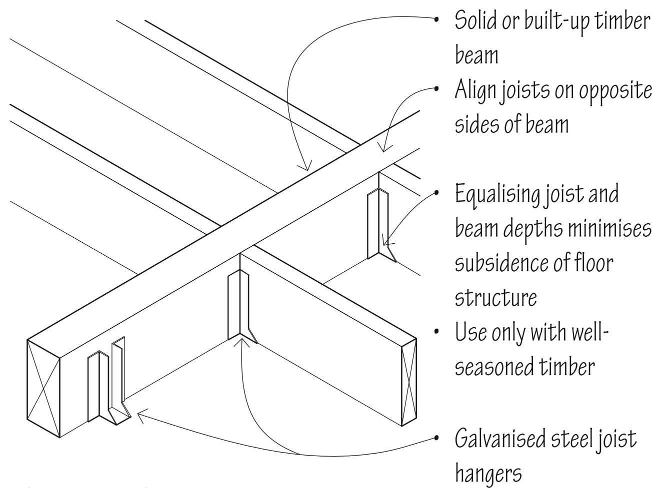


Beam Pocket

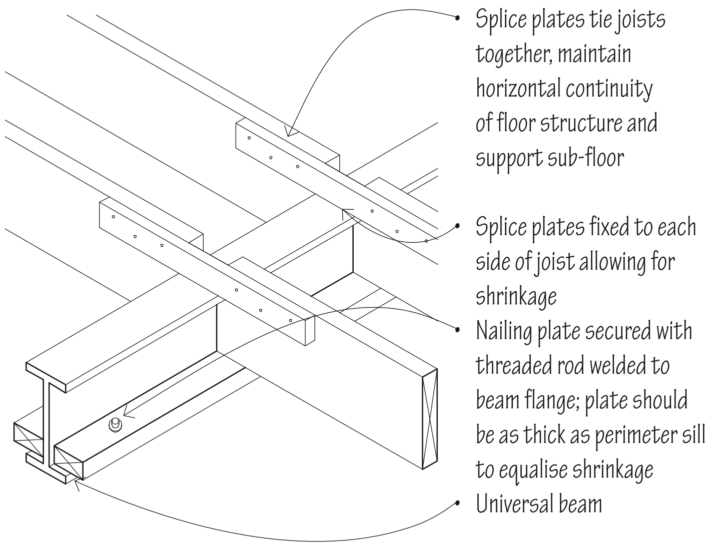
• See 5.43–5.44 for discussion of balloon and platform framing

4.28 TIMBER JOIST FRAMING

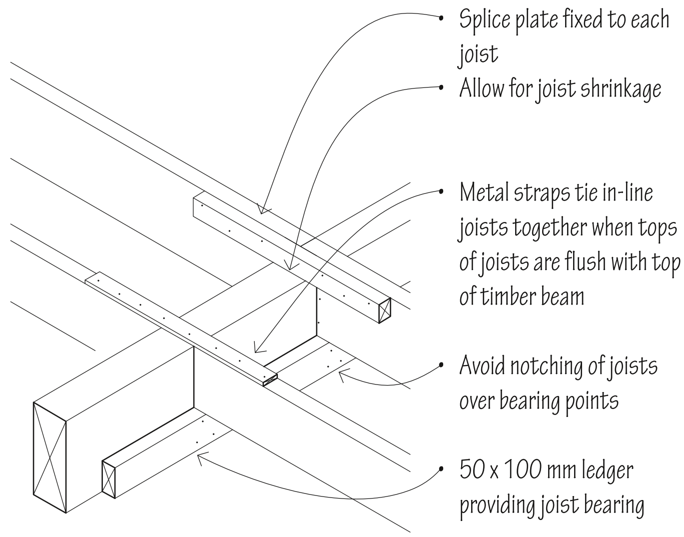
Timber joists may be supported by timber or steel beams or by load-bearing walls. Timber is susceptible to shrinkage perpendicular to its grain. For this reason, the total depth of timber construction for both the bearing condition and the joist–beam connection should be equalised to avoid subsidence of the floor plane.



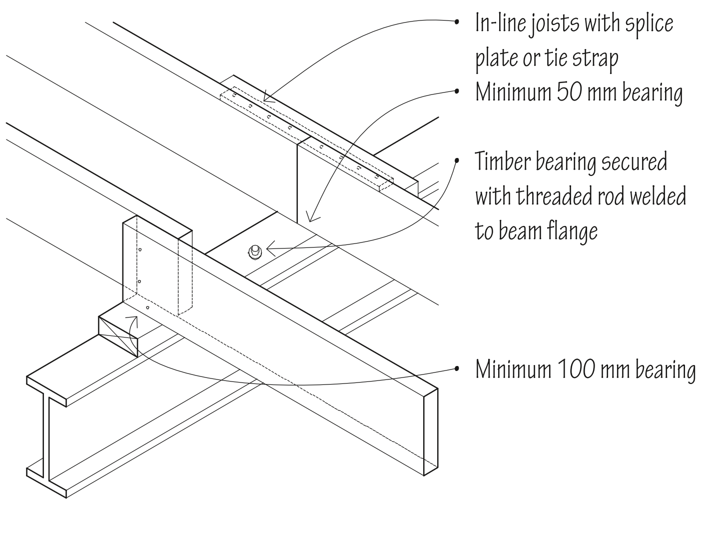
Timber Beam with Joist Hangers



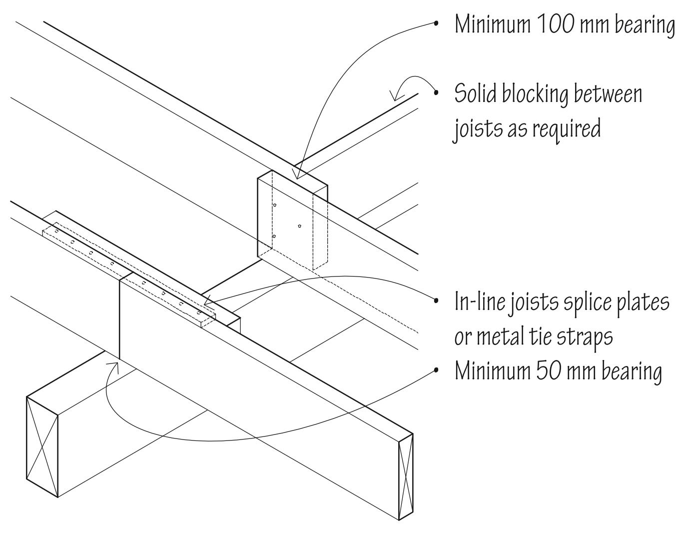
Steel Beam with Ledger



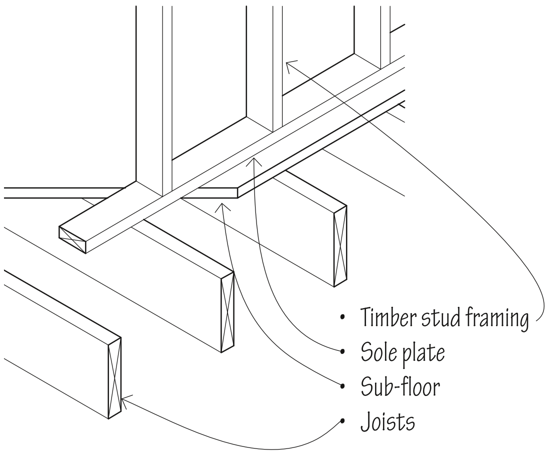
Timber Beam with Ledger



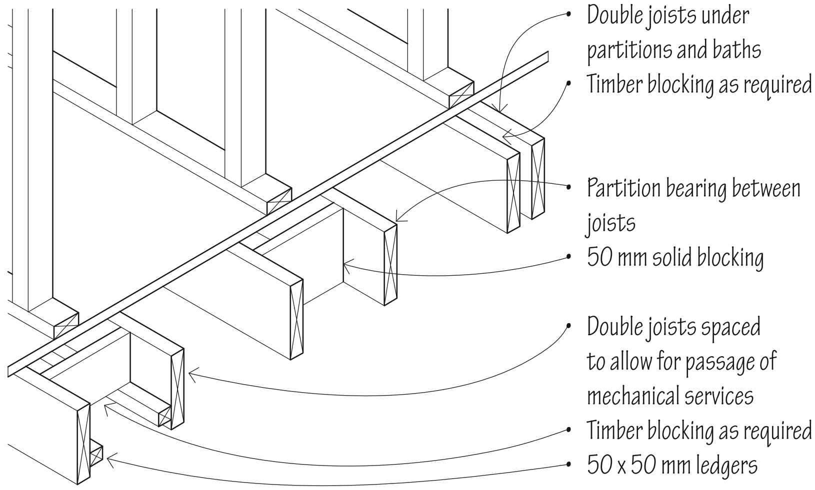
Steel Beam Under Joists



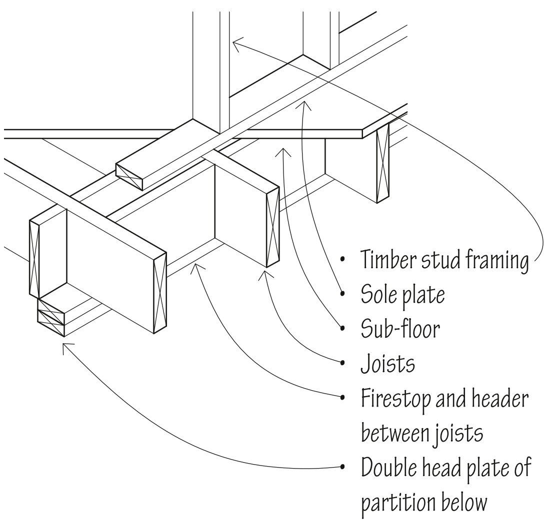
Timber Beam with Lapped or Spliced Joists



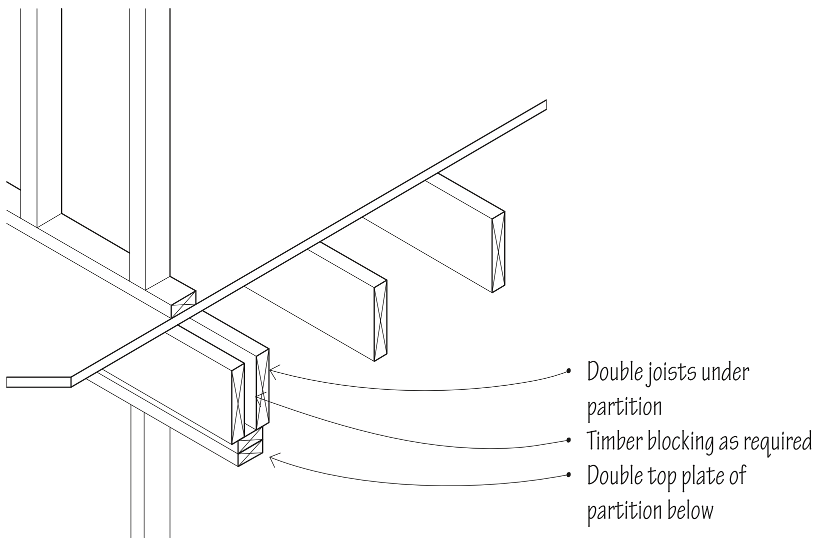
Non-bearing Partition ⊥ to Joists – No Partition Below



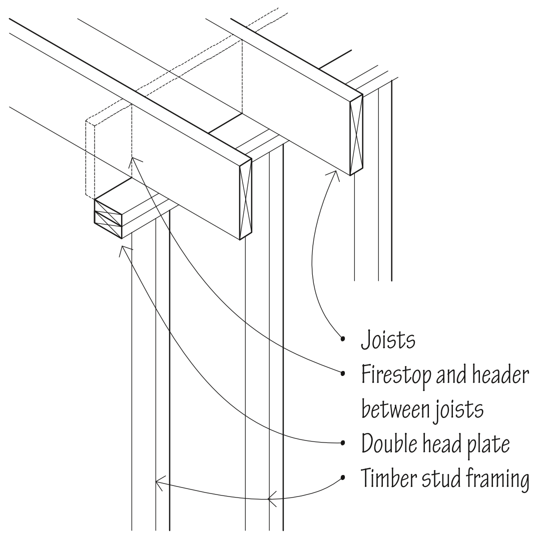
Non-bearing Partition Parallel to Joists – No Partition Below



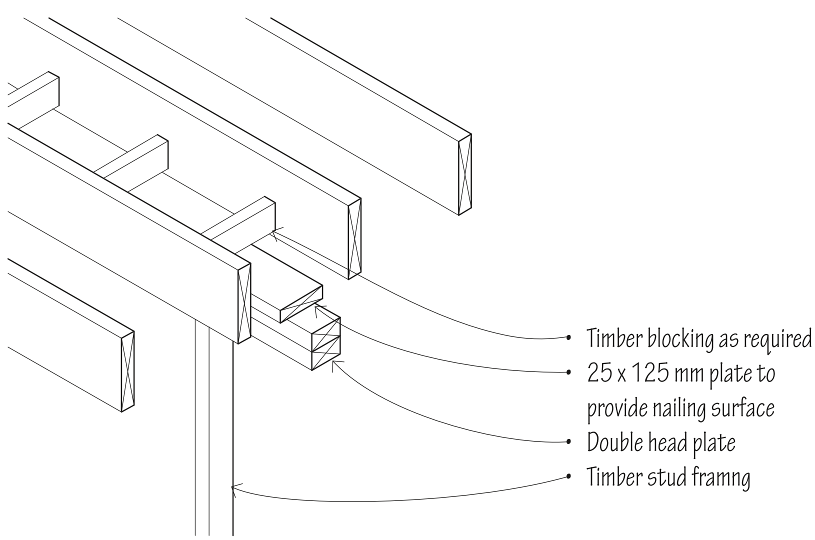
Bearing Partition ⊥ to Joists



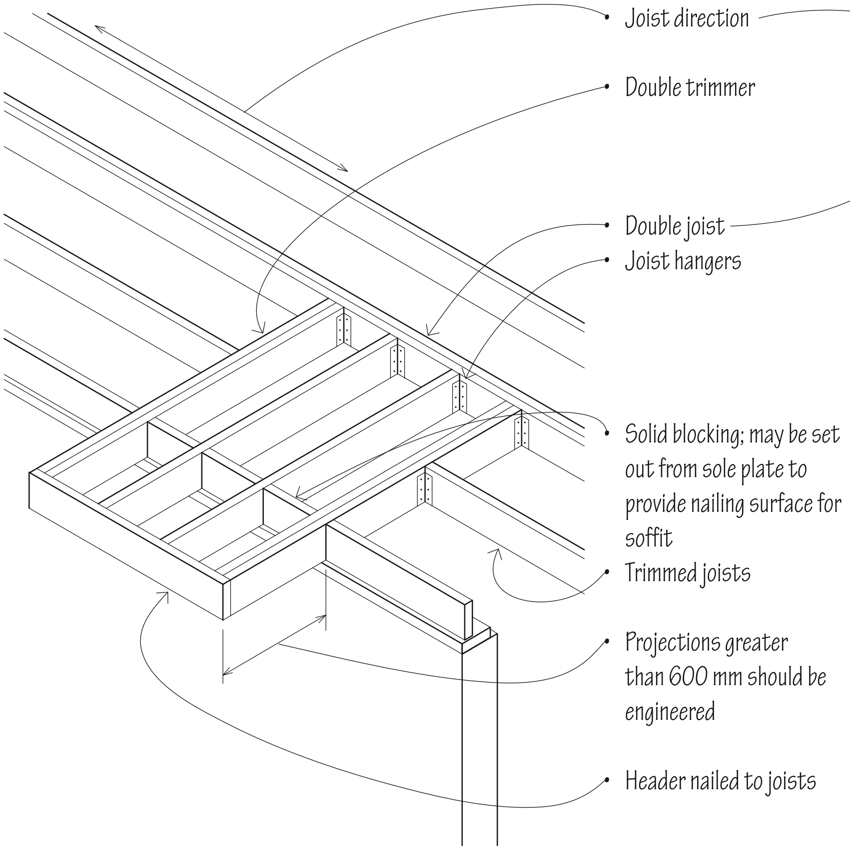
Bearing Partition Parallel to Joists



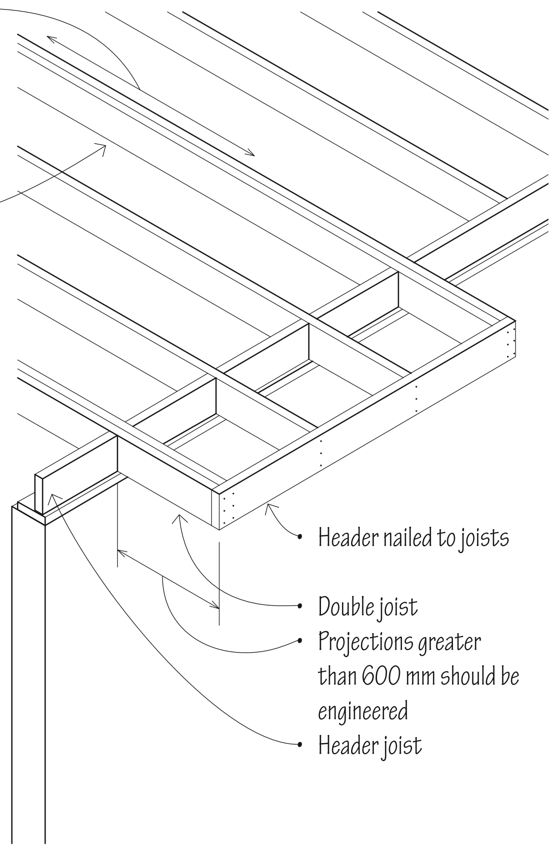
Bearing Partition ⊥ to Joists – No Partition Above



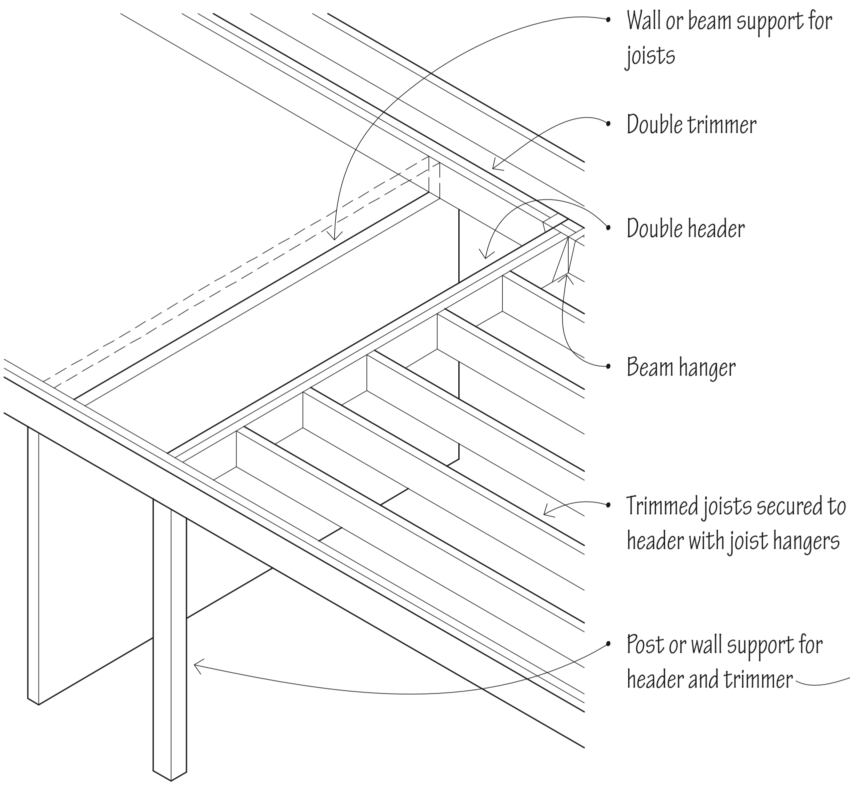
Non-bearing Partition Parallel to Joists – No Partition Above



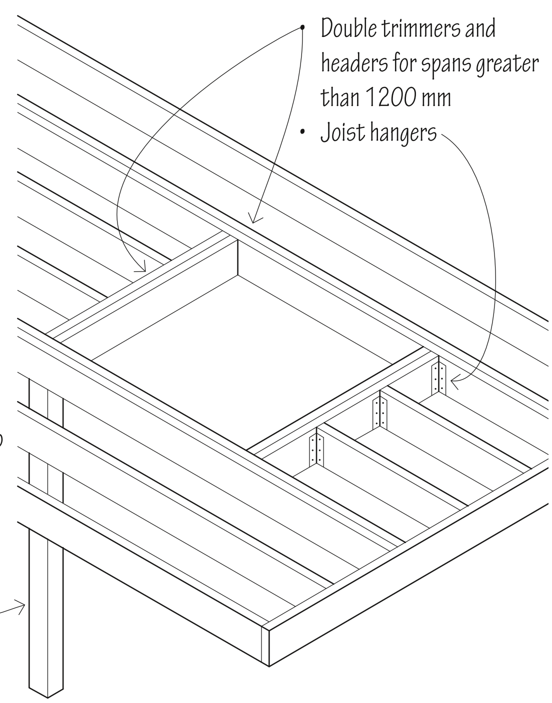
Floor Projection ⊥ to Joists



Floor Projection Parallel to Joists

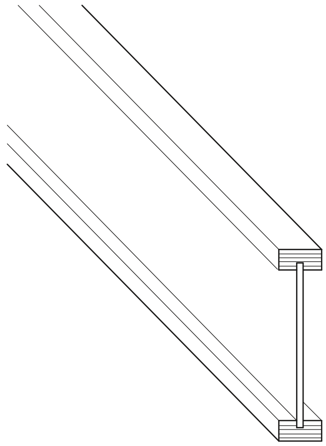


Floor Opening – Length ⊥ to Joists



Floor Openings – Length Parallel to Joists

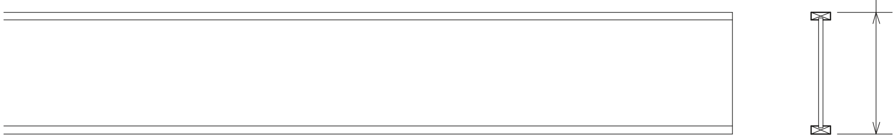
Prefabricated, pre-engineered timber joists and trusses are increasingly used in the place of dimension timber to frame floors because they are generally lighter and more dimensionally stable than sawn timber, are manufactured in greater depths and lengths, and can span longer distances.

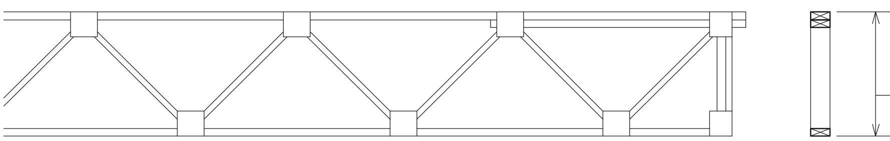


- I-joists are manufactured with sawn or laminated veneer timber flanges along the top and bottom edges of a single plywood or OSB web

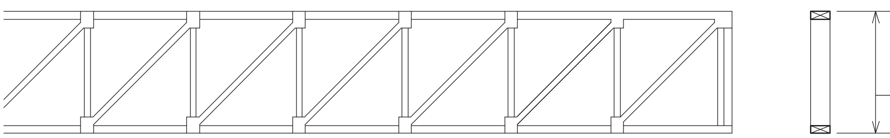
- 140–450 mm nominal depths at 300–600 mm centres

Typical span ranges for I-joists (400 mm centres):
- 140 mm depth can span up to 2800 mm
- 250 mm depth can span up to 4900 mm
- 350 mm depth can span up to 6500 mm
- 450 mm depth can span up to 7500 mm

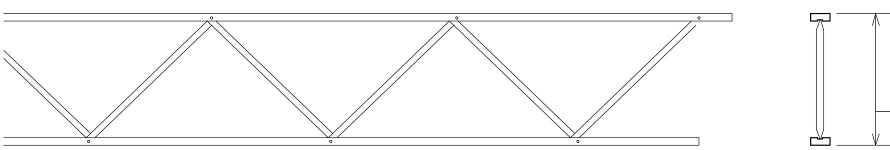




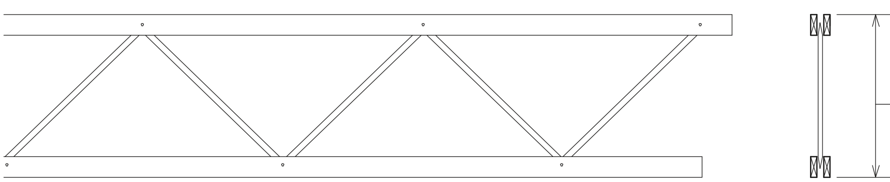
- 50 x 100 mm chords and webs with metal toothed plate connectors
- 300–600 mm depths
- 12–18 m spans



- Timber chords and verticals with diagonal steel web members
- 300–600 mm depths
- 12 –24 m spans



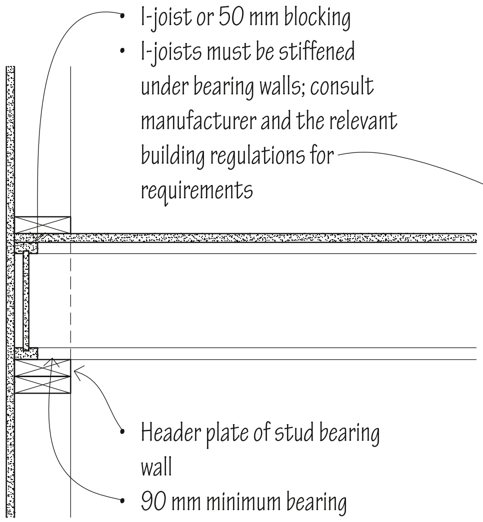
- Timber chords with 25 –38 mm ø tubing webs
- Up to 1 m depth
- 12–24 m spans



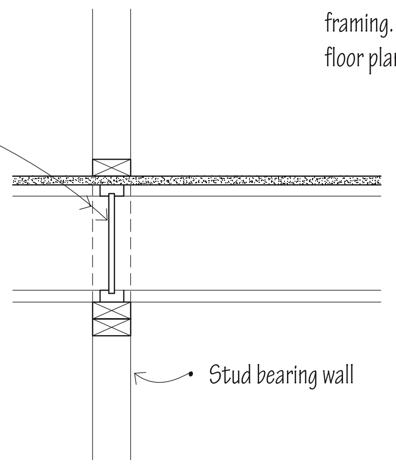
- Two 50 x 150 mm chords with 50 mm ø steel webs
- Up to 1.5 m depth
- 18–30 m spans

- Rule of thumb for estimating depth of trussed joists: span/18
- Openings in webs allow the passage of electrical and mechanical lines
- Consult manufacturer for available lengths and depths, recommended spacing and allowable spans and required bearing conditions

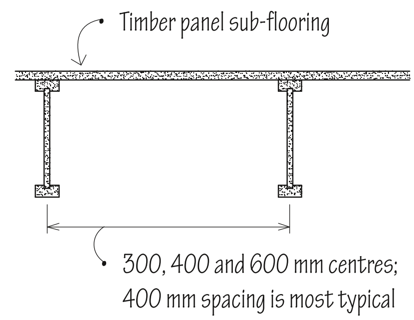
While the precise form of a prefabricated floor joist or truss varies with the manufacturer, the way they are laid out to frame a floor is similar in principle to conventional timber joist framing. They are most appropriate for long spans and simple floor plans; complex floor layouts may be difficult to frame.

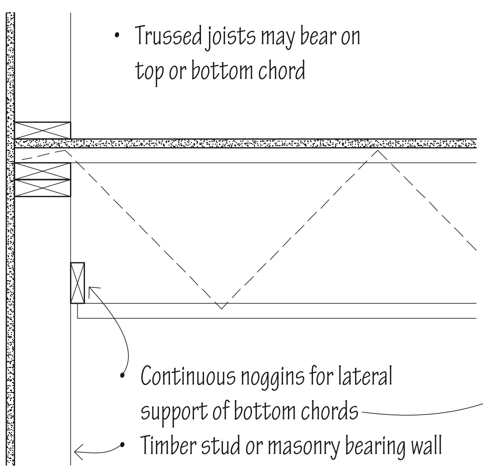


I-joist @ Exterior

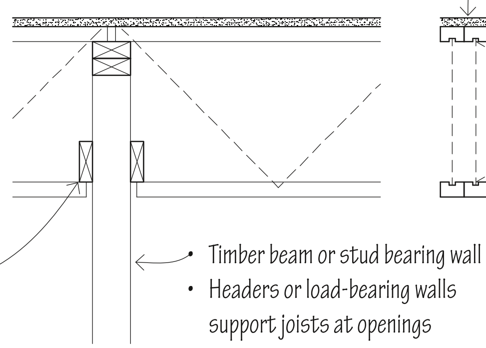


I-joist @ Interior

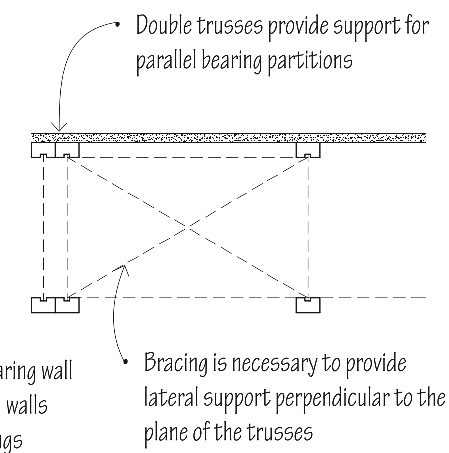


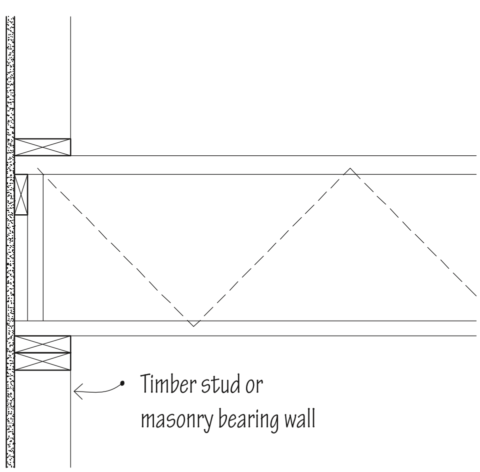


Top Chord Bearing

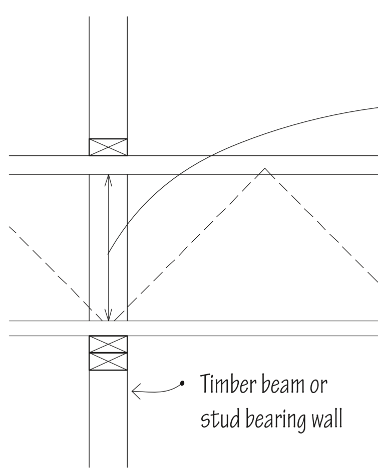


Top Chord Bearing @ Interior

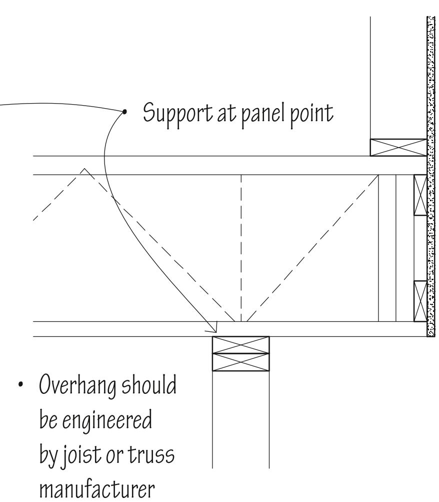




Bottom Chord Bearing



Bottom Chord Bearing @ Interior

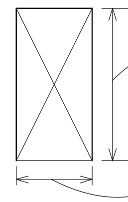


Bottom Chord Bearing @ Overhang

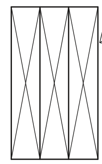
Solid Sawn Timber

In the selection of a timber beam the following should be considered: timber species, structural grade, modulus of elasticity, allowable bending and shear stress values, and the minimum deflection permitted for the intended use. In addition, attention should be paid to the precise loading conditions and the types of connections used. See Bibliography for sources of more detailed span and load tables.

The connection and support system used will depend on the framing system employed, type of timber beam, loading conditions and building use.

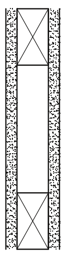


- Rule of thumb for estimating the depth of a timber beam: span/15
- Beam width = 1/3 to 1/2 of beam depth
- Limit deflection to 1/360 of span



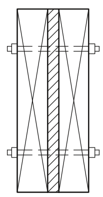
Built-Up Beam

- Equal in strength to the sum of the strengths of the individual pieces if none of the laminations is spliced



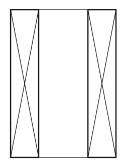
Box Beam

- Made by gluing two or more plywood or OSB webs to sawn or laminated veneer flanges
- Engineered to span up to 25 m



Flitch Beam

- Timbers set on edge and bolted side by side to steel plates or sections
- Engineered design

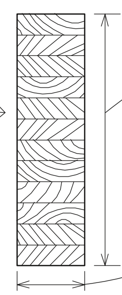


Spaced Beam

- Blocked and securely nailed at frequent intervals to enable individual member to act as an integral unit

Glue-Laminated Beams

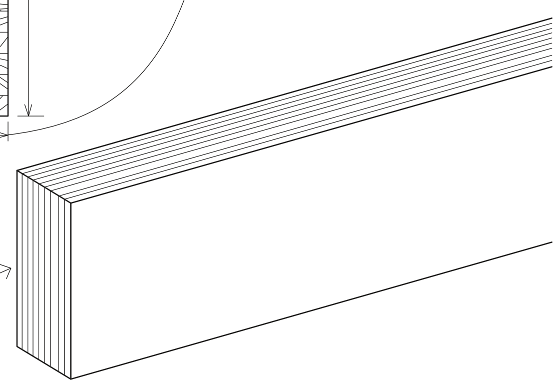
Glue-laminated timber is made by laminating stress-grade timber with adhesive under controlled conditions, usually with the grain of all plies being parallel. The advantages of glue-laminated timber over traditional sawn timber are generally, higher allowable unit stresses, improved appearance and availability of various sectional shapes. Glue-laminated timbers may be end-joined with scarf or finger joints to any desired length, or edge-glued for greater width or depth. Used where long spans are desired or as a vertical member where curved or arched shapes are required.



- Engineered to span up to 24 m
- Rule of thumb for estimating the depth of glue-laminated beams: span/20
- Beam width = 1/4 to 1/3 of beam depth

Laminated Veneers

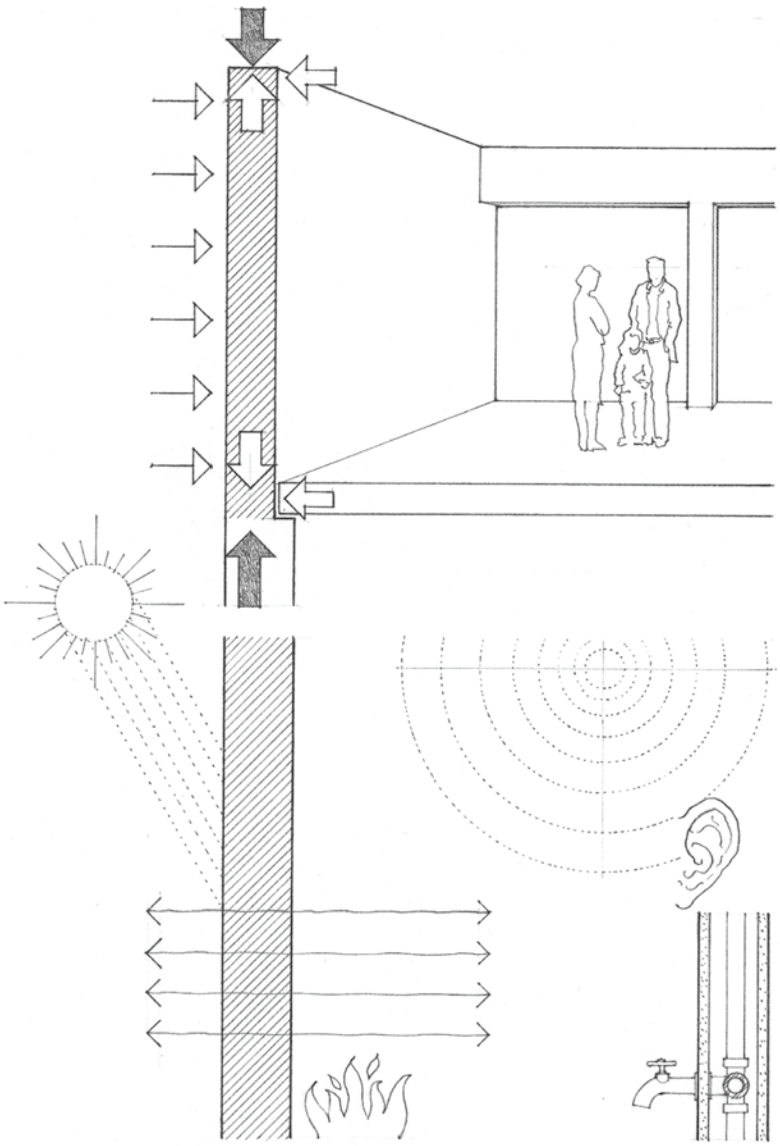
Laminated veneer elements are a structural product made by bonding layers of wood veneers together under heat and pressure using a waterproof adhesive. Having the grain of all veneers run in the same longitudinal direction results in a product that is strong when edge-loaded as a beam or face-loaded as a plank. Produced in Europe and the US in lengths up to 26 m, these are generally used as headers and beams or as flanges for prefabricated timber I-joists.



5

WALL SYSTEMS

5.02 WALL SYSTEMS



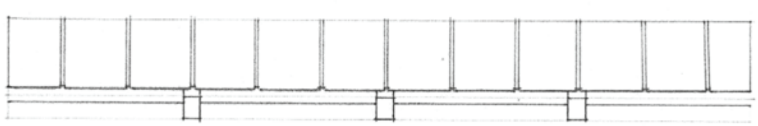
Walls are the vertical constructions of a building that enclose, separate and protect its interior spaces. They may be load-bearing structures of homogeneous or composite construction designed to support imposed loads from floors and roofs, or consist of a framework of columns and beams with non-structural panels attached to or filling in-between them. The pattern of these load-bearing walls and columns should be coordinated with the layout of the interior spaces of a building.

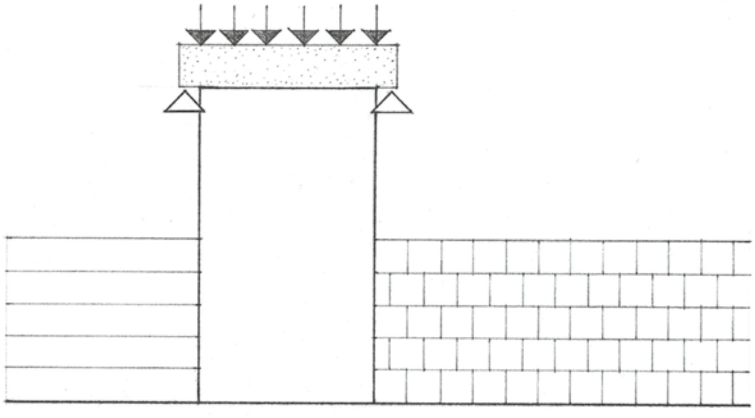
In addition to supporting vertical loads, exterior wall constructions must be able to withstand horizontal wind loading. If rigid enough, they can serve as shear walls and transfer lateral forces to the foundations and ground.

Because exterior walls serve as a protective shield against the weather for the interior spaces of a building, their construction should control the passage of heat, infiltrating air, sound, moisture and water vapour. The exterior skin, which may be either applied to or integral with the wall structure, should be durable and resistant to the weathering effects of sun, wind and rain. Building regulations specify the fire-resistance rating of exterior walls, load-bearing walls and interior partitions.

The interior walls or partitions, which subdivide the space within a building, may be either structural or non-load-bearing. Their construction should be able to support the desired finish materials, provide the required degree of acoustic separation and accommodate, when necessary, the distribution and outlets of mechanical and electrical services.

Openings for doors and windows must be constructed so that any vertical loads from above are distributed around the openings and not transferred to the door and window units themselves. Their size and location are determined by the requirements for natural light, ventilation, view and physical access, as well as the constraints of the structural system and modular wall materials.

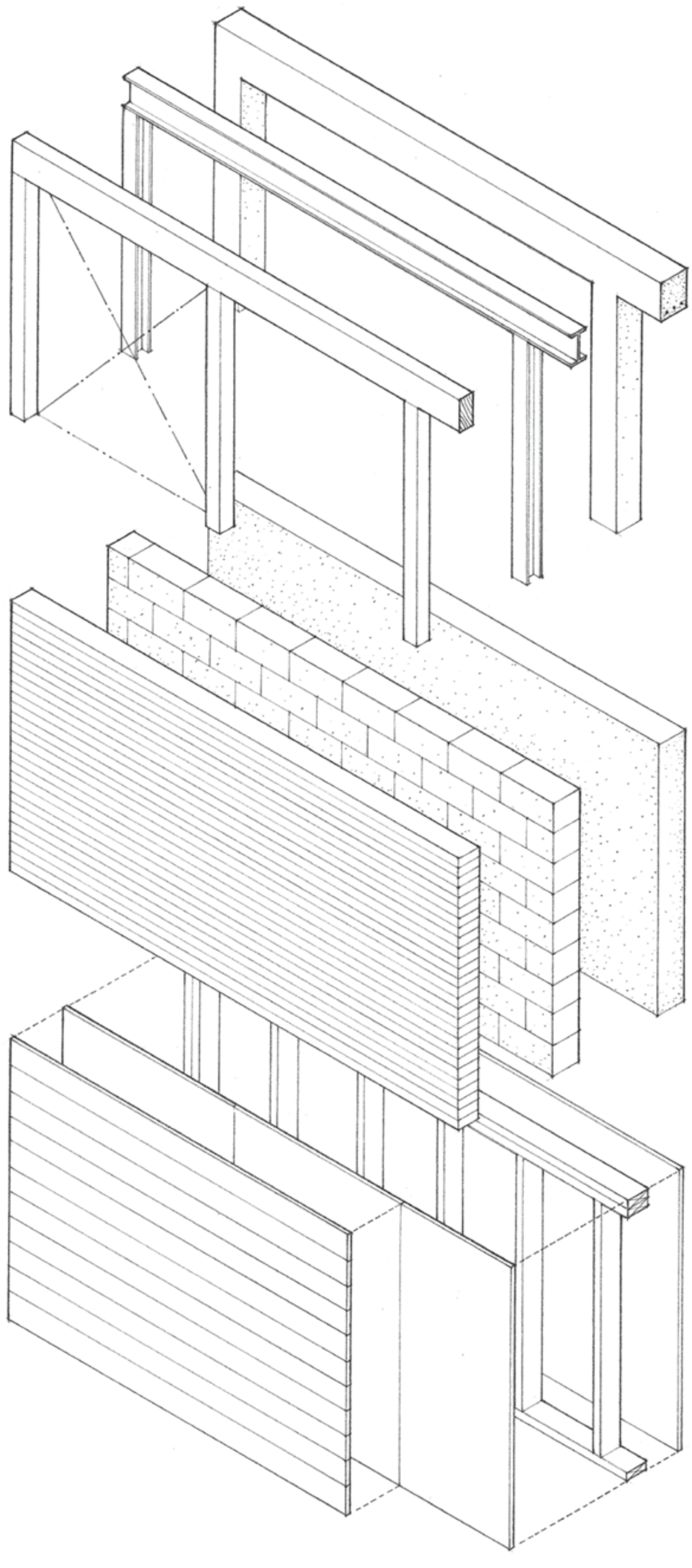




LEED EA Credit 1: Optimize Energy Performance
BREEAM ENE 01: Reduction of CO_2 Emissions

Structural Frames

- Concrete frames are typically rigid frames and qualify as non-combustible, fire-resistant construction
- Non-combustible steel frames may utilise moment connections and require fireproofing to qualify as fire-resistant construction
- Timber frames require diagonal bracing or stressed skins for lateral stability
- Steel and concrete frames are able to span greater distances and carry heavier loads than most timber structures
- Structural frames can support and accept a variety of non-bearing or curtain-wall systems
- The detailing of connections is critical for structural and visual reasons when the frame is left exposed



Concrete and Masonry Bearing Walls

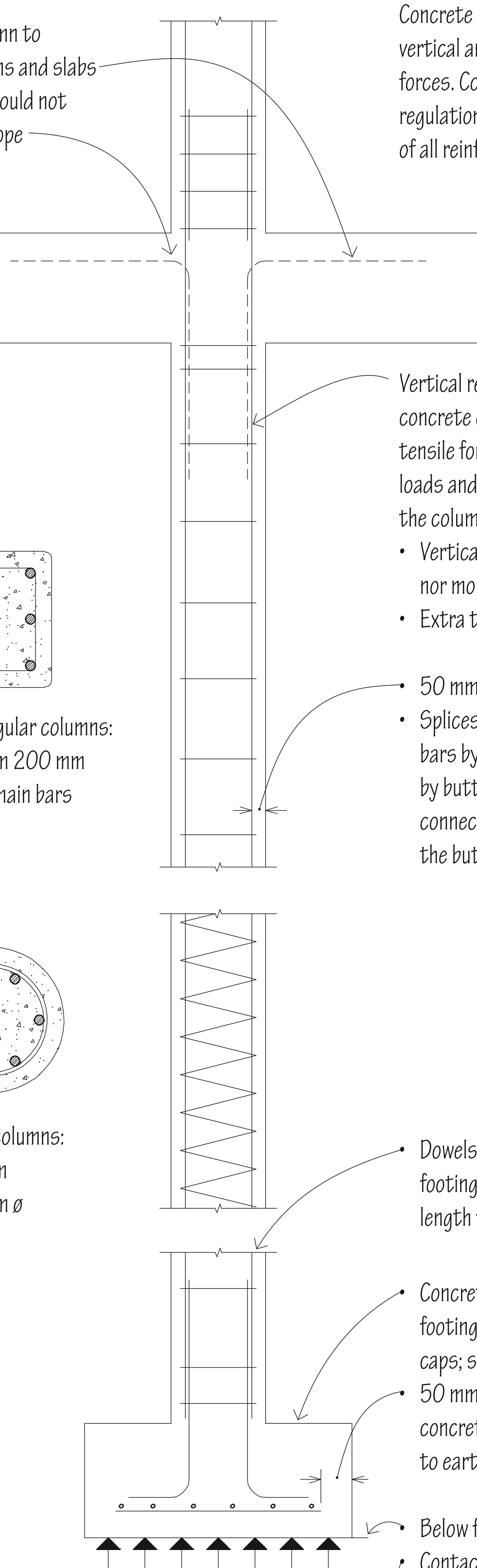
- Concrete and masonry walls qualify as non-combustible construction and rely on their mass for their load-bearing capability
- While strong in compression, concrete requires reinforcing to handle tensile stresses
- Height-to-width ratio, provisions for lateral stability, and proper placement of expansion joints are critical factors in wall design and construction
- Wall surfaces may be left exposed

Metal and Timber Stud Walls

- Studs of cold-formed metal or timber are normally spaced at 400 or 600 mm centres; this spacing is related to the width and length of common sheathing materials
- Studs carry vertical loads while sheathing or diagonal bracing stiffens the plane of the wall
- Cavities in the wall frame can accommodate thermal insulation, vapour retarders, and mechanical distribution and outlets of mechanical and electrical services
- Stud framing can accept a variety of interior and exterior wall finishes; some finishes require a nail-base sheathing
- Appropriate sheeting materials can form part of an airtightness strategy; see 7.43
- The finish materials determine the fire-resistance rating of the wall assembly
- Stud wall frames may be assembled on-site or panellised off-site
- Stud walls are flexible in form due to the workability of relatively small pieces and the various means of fastening available

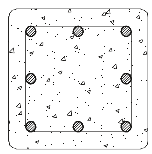
Concrete columns are designed to act together with vertical and lateral reinforcement in resisting applied forces. Consult a suitably qualified engineer and relevant regulations for the required size, spacing and placement of all reinforcement.

- Dowels tie column to supported beams and slabs
- Inclined bars should not exceed a 1:6 slope



Lateral reinforcement restrains the vertical reinforcement and strengthens the column against buckling.

- Lateral ties should have a minimum 6 mm ø, spaced at not more than 300 mm centres



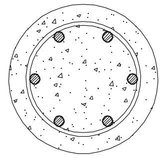
- Rectangular columns: minimum 200 mm with 4 main bars

Vertical reinforcement augments the ability of a concrete column to carry compressive loads, resists tensile forces when the column is subject to lateral loads and reduces the effects of creep and shrinkage in the column.

- Vertical reinforcement should not be less than 0.8% nor more than 8% of gross cross-sectional area
- Extra ties may be required at support points

- 50 mm minimum cover for steel reinforcement
- Splices may be made by lapping the ends of vertical bars by a length specified in bar diameters, or by butting the ends of vertical bars and either connecting them with a sleeve clamp or arc-welding the butt joint

- Helical reinforcement consists of an evenly spaced continuous spiral held firmly in place by vertical spacers
- Helical reinforcement bars should have a minimum 6 mm ø



- Round columns: 255 mm minimum ø

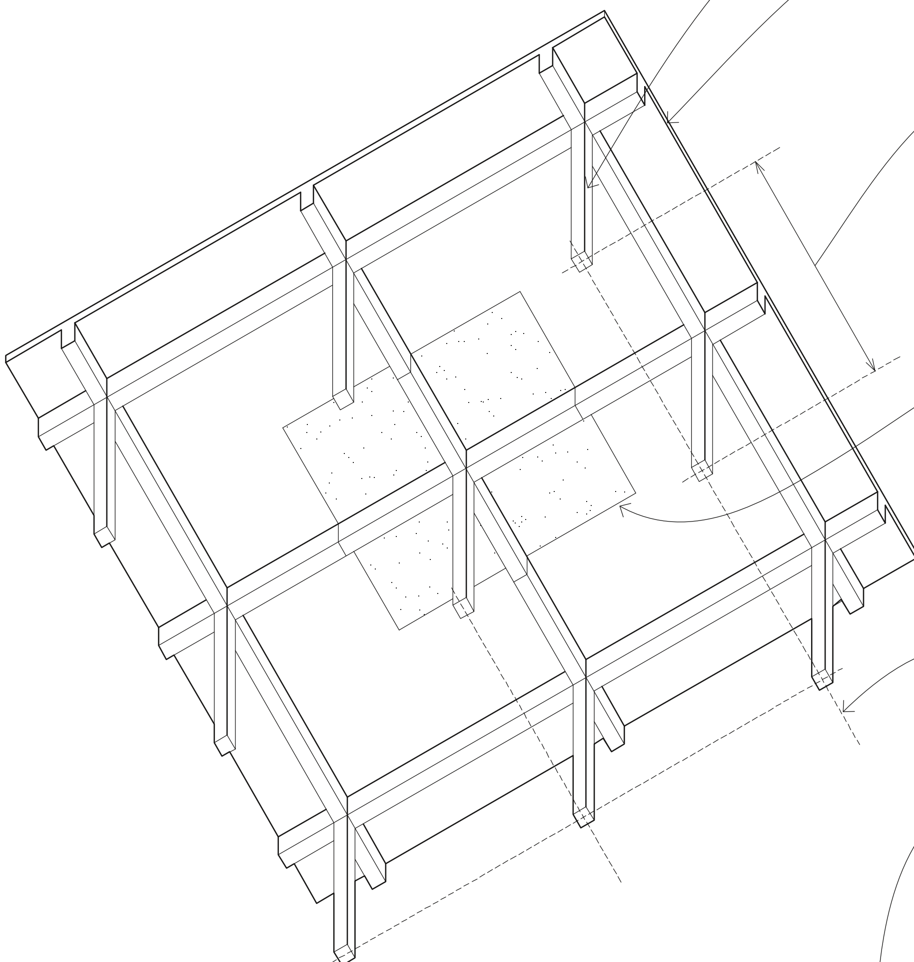
- Dowels overlap vertical bars; extend down into footing or pile cap far enough to develop adequate length for anchorage

- Concrete columns may be supported by isolated footings, by a mat or combined footing, or by pile caps; see 3.09 and 3.16
- 50 mm minimum cover for steel reinforcement when concrete is cast against and permanently exposed to earth

- Below frost line
- Contact area of footing distributes column load to ensure that the allowable bearing capacity of the supporting soil is not exceeded

EN Eurocode 2: Design of Concrete Structures

Reinforced-concrete columns are usually cast with concrete beams and slabs to form a monolithic structure.



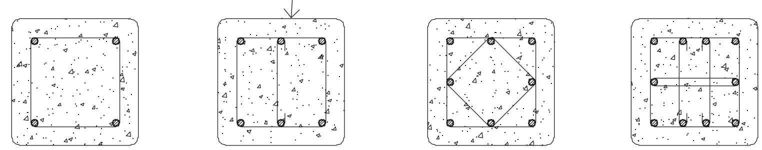
- Reinforced-concrete columns
- Reinforced-concrete beams and slabs; see 4.04–4.05
- Reinforced-concrete two-way slabs; see 4.06–4.07

- Column spacing = beam or slab span
- Column spacing determines imposed loads

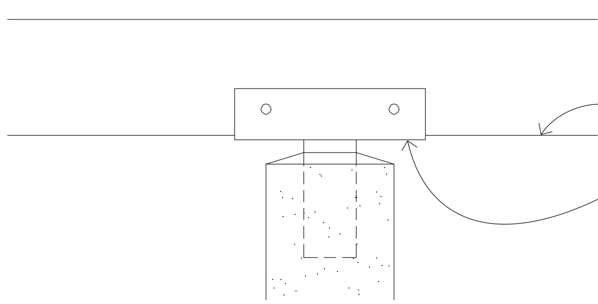
- 305 mm column can support up to 185 m^2 of floor and roof area
- 405 mm column can support up to 280 m^2 of floor and roof area
- 510 mm column can support up to 370 m^2 of floor and roof area

These areas are indicative only, a suitably qualified engineer should be consulted for detailed design calculations.

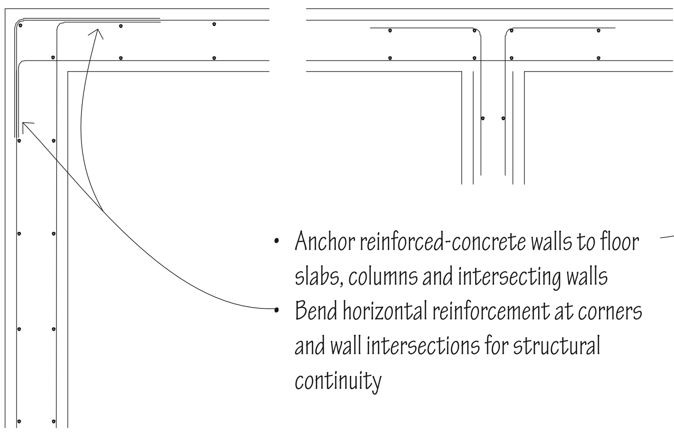
- Lay out columns along a regular grid for economical forming of beams and slabs
- Columns should be continuous to the building foundation
- Whenever possible, vary required steel reinforcement rather than column size; when necessary, vary only one dimension of a column at a time



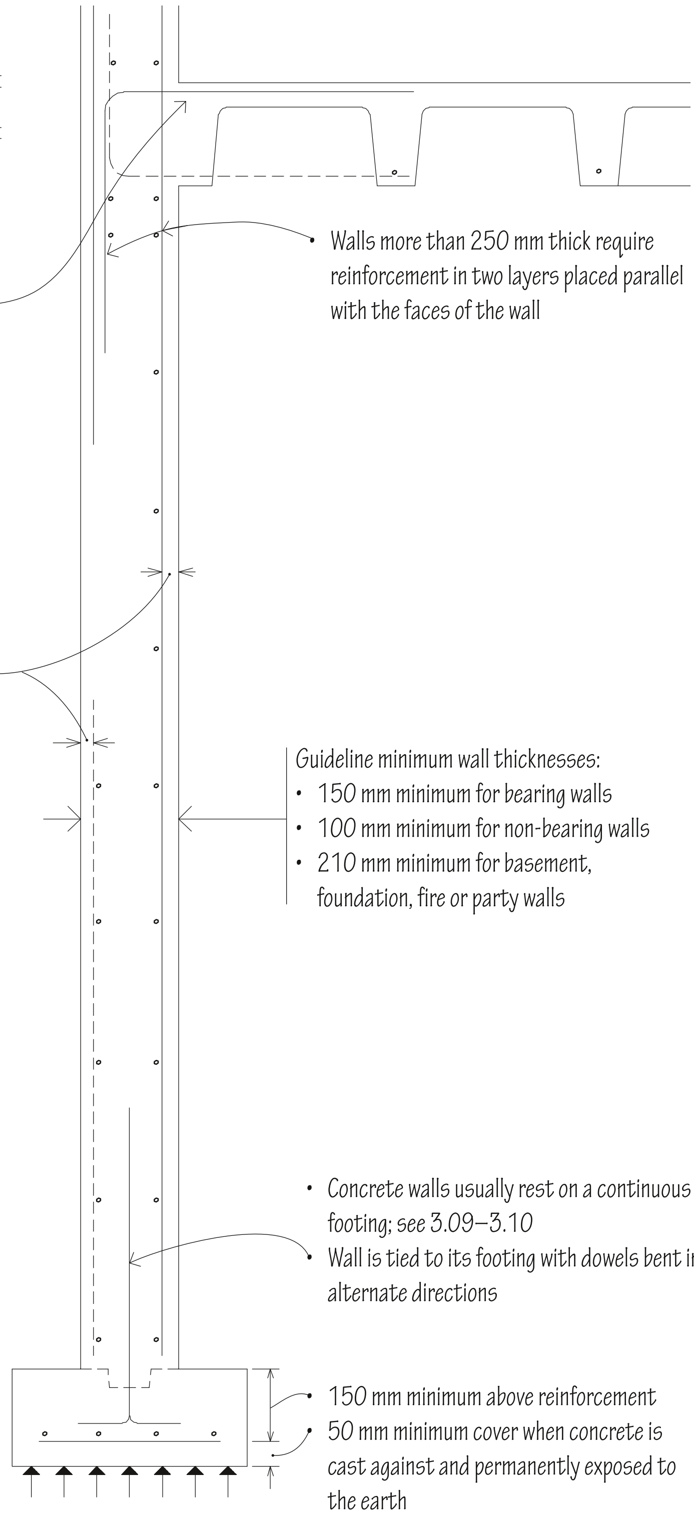
With the aid of a variety of steel connectors, reinforced-concrete columns can also support a grid of timber or steel beams.



- Timber or steel beams
- Steel connectors are required to support and anchor timber or steel beams to concrete columns



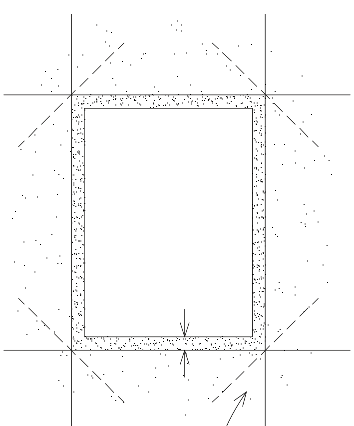
- Anchor reinforced-concrete walls to floor slabs, columns and intersecting walls
- Bend horizontal reinforcement at corners and wall intersections for structural continuity



- Walls more than 250 mm thick require reinforcement in two layers placed parallel with the faces of the wall

- See EN Eurocode 2: Design of Concrete Structures for details of the required minimum cover for various above and below ground situations

Guideline minimum wall thicknesses:
- 150 mm minimum for bearing walls
- 100 mm minimum for non-bearing walls
- 210 mm minimum for basement, foundation, fire or party walls

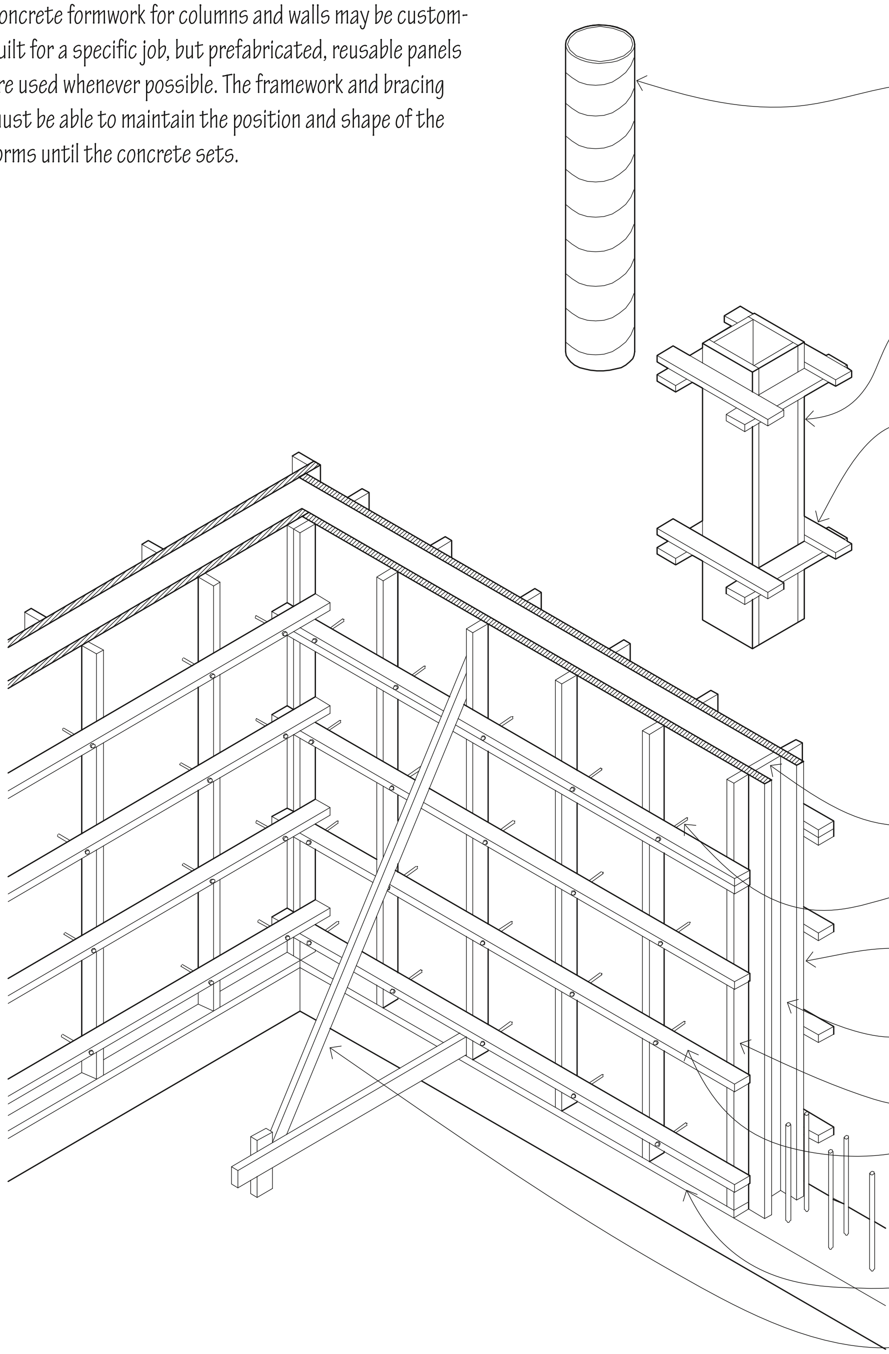


- At openings for windows and doors in concrete sections, additional reinforcing may be required

- Concrete walls usually rest on a continuous footing; see 3.09–3.10
- Wall is tied to its footing with dowels bent in alternate directions

- 150 mm minimum above reinforcement
- 50 mm minimum cover when concrete is cast against and permanently exposed to the earth
- Consult a suitably qualified engineer for the required size, spacing and placement of all reinforcement
- See 12.04–12.05 for a discussion of concrete as a construction material

Concrete formwork for columns and walls may be custom-built for a specific job, but prefabricated, reusable panels are used whenever possible. The framework and bracing must be able to maintain the position and shape of the forms until the concrete sets.



Column Forms

- Fibre forms have a smooth or spiral pattern finish and are disposable
- 300–800 mm diameter

- Timber formwork
- Reusable forms may have a square or rectangular cross section
- 'Yokes' are clamping devices for keeping column forms and the tops of wall forms from spreading under the fluid pressure of newly placed concrete

Wall Forms

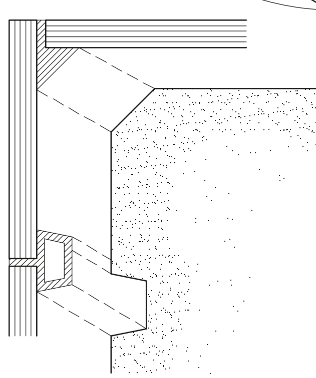
- Spreaders, usually of timber, space and keep the wall or forms apart
- Form ties; see 5.08

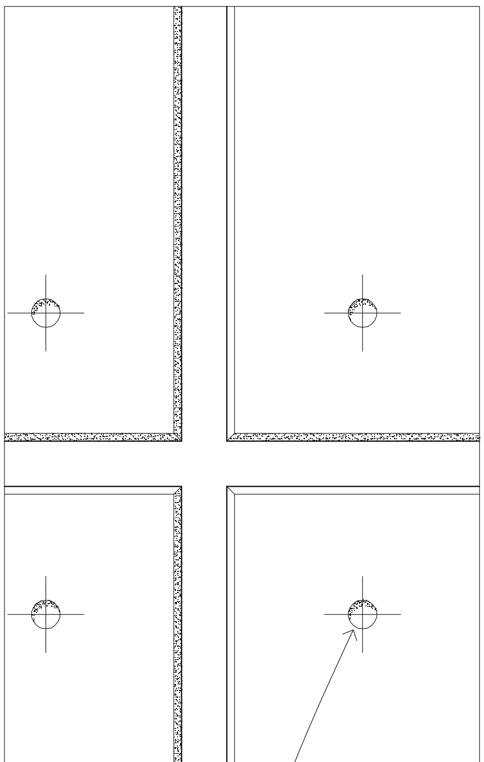
- Plywood sheathing
- Inner surface of panels leaves an impression on the concrete

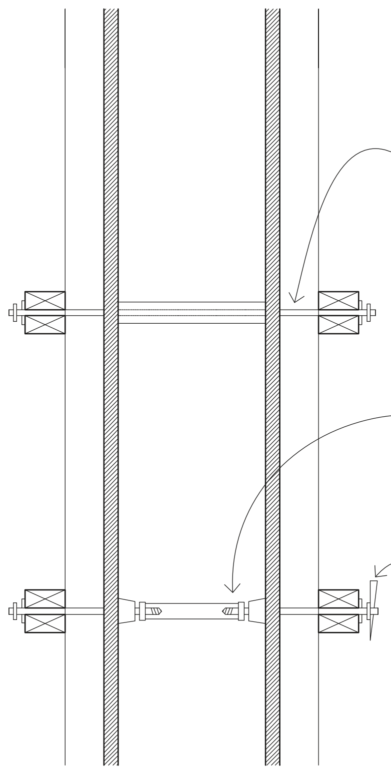
- Timber studs
- Horizontal walers reinforce the vertical members of formwork
- If necessary, struts provide vertical support for aligning and reinforcing walers
- Sole plate

- Bracing

- The contact surfaces of forms are coated with a parting compound – oil, wax or plastic – to aid in their removal. From a design standpoint, the shape of a concrete section must allow for the easy removal of the formwork. Tapered sections are used where the formwork might otherwise be trapped by the surrounding concrete. Sharp external corners are usually bevelled or rounded to avoid chipping and ragged edges



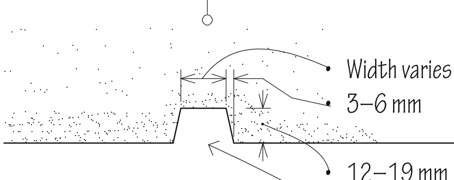




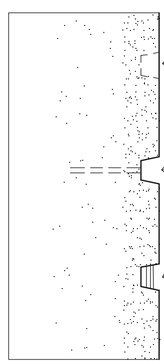
Form ties are required to keep wall forms from spreading under the fluid pressure of newly placed concrete. Various proprietary forms are available, two basic examples are detailed below.

- Through bolts consist of a threaded bar fed through a plastic sleeve/tube which is greased so that it can later be removed. The threaded bars are removed as the formwork is taken down and voids made good
- Coil ties consist of threaded rods that are inserted through the form and threaded onto the ends of an inner rod. After stripping, the rods are removed for reuse while the inner rod remains in the concrete
- A variety of wedges and slotted devices tighten the formwork and transfer the force in a form tie to the walers

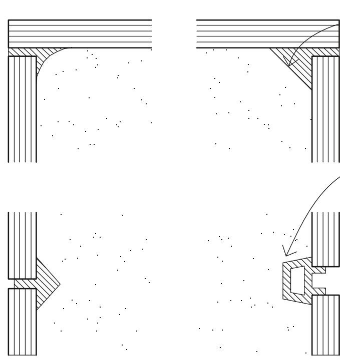
- When exposed or visible, the tie hole locations should be coordinated with the wall's surface design



- Linear recesses can be used to create a pattern on the surface of a concrete wall, separate different wall surface treatments, and help to conceal construction joints

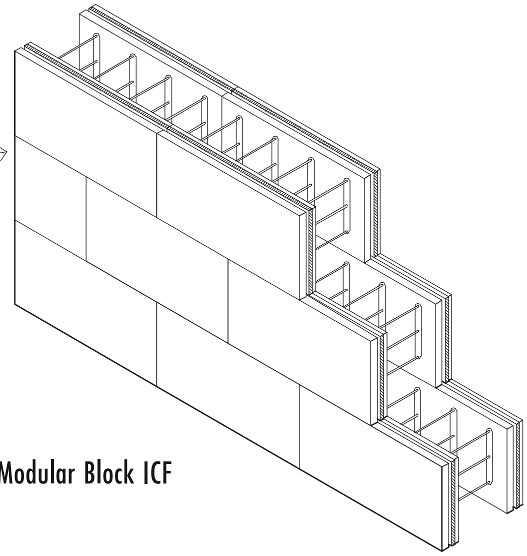


Tie holes may be:
- Patched to match the surrounding finish
- Left exposed with the exposed tie end epoxied
- Filled with a plastic cap

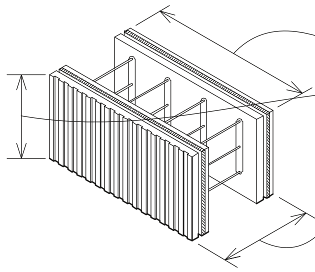


- Chamfer strips of timber or other material are attached to the inside of a form to produce a smooth, rounded or bevelled edge on the outside corner of a concrete member
- Strips of timber or other material are attached to the inside face of a form to produce a groove in the surface of a concrete member. These strips are also available as parts of plastic form-liner systems

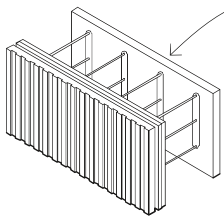
Insulating concrete formwork or ICF consists of two layers of expanded (EPS) or extruded (XPS) polystyrene held in place by polystyrene, plastic or metal ties which provide permanent formwork for cast-in-situ concrete walls. Prefabricated modular blocks fit together through vertical and horizontal tongue and grooves to form a wall structure before concrete is pumped in to the cavity. The system allows for the quick assembly of formwork and a simple construction method. The EPS or XPS serves the dual purpose of formwork and thermal insulation.



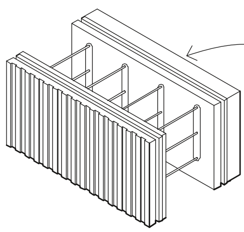
Modular Block ICF



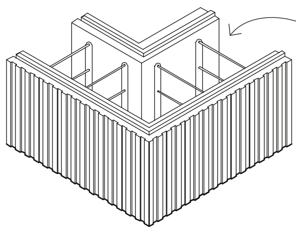
- Typical length 500–1250 mm
- Typical height 250–400 mm
- Typical width 240–600 mm with concrete core of 100–300 mm and insulating formwork leaves of 100–300 mm



- The internal leaf of insulation is sometimes substituted for a fibre cement of similar board allowing for internal fixings and ease of finishing

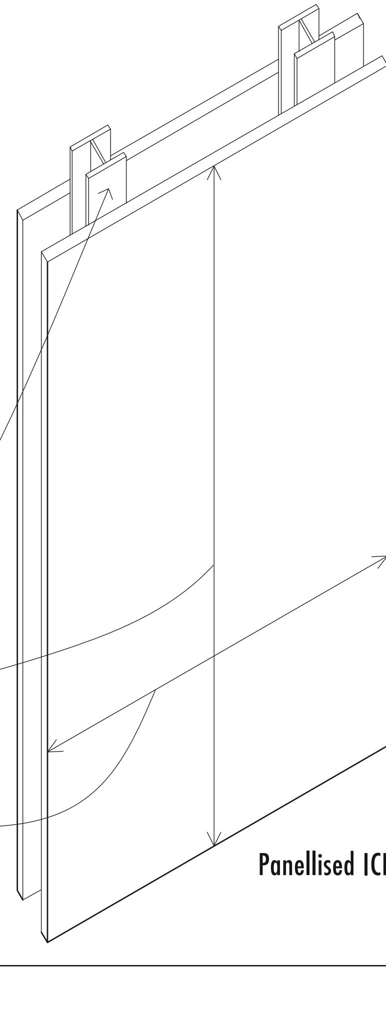


- Internal or external insulating leaf can be thickened if greater thermal performance is required

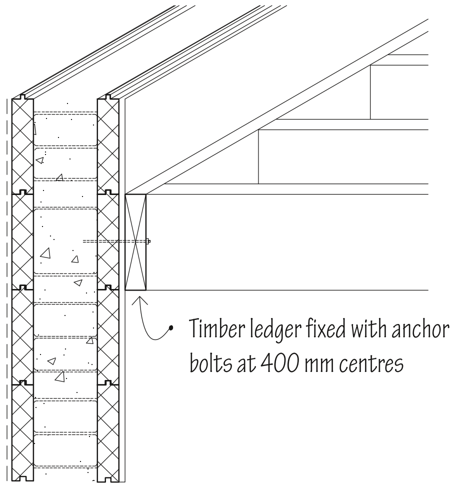


- 45º, 60º and 90º corners and curved sections are available to reduce waste on site and allow for a variety of building forms to be accommodated

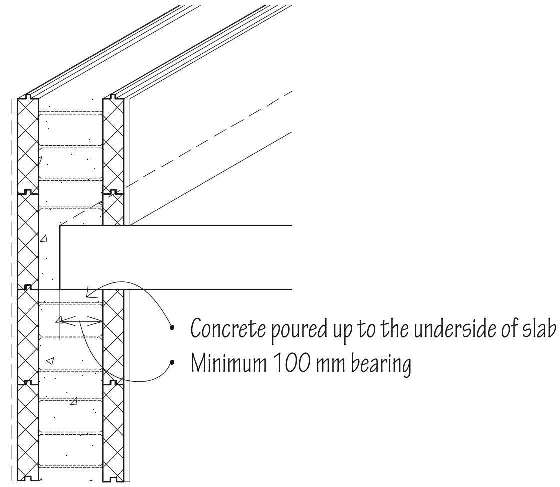
- Panellised systems can be used on larger scale projects
- Galvanised steel sections as ties
- Typically 2400 mm in height
- Typically 1200 mm wide



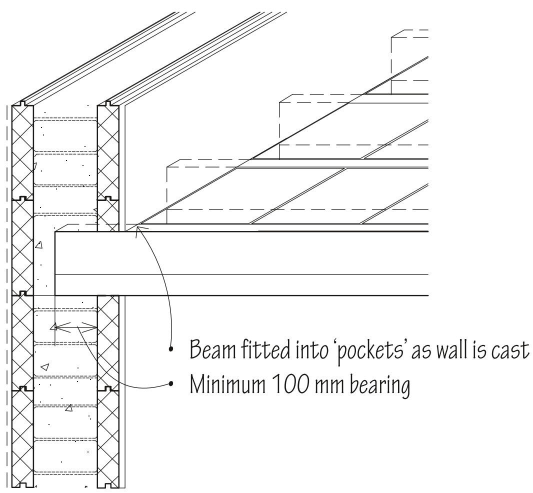
Panellised ICF



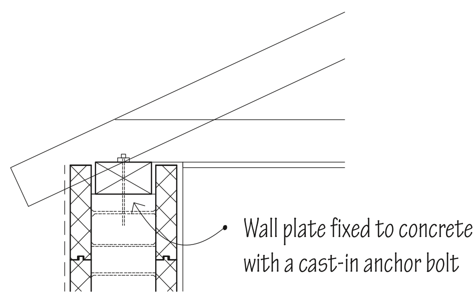
Timber Joists



Concrete Slab

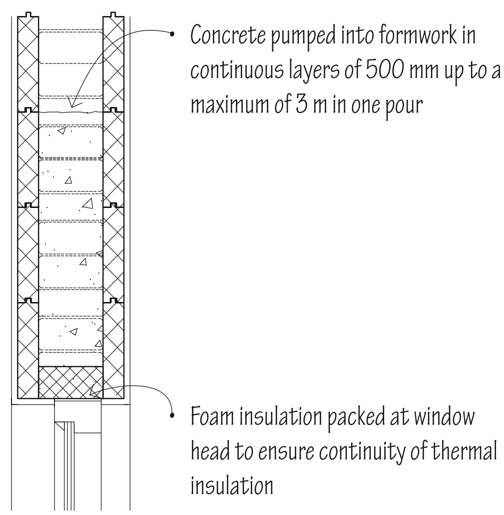


Block and Beam



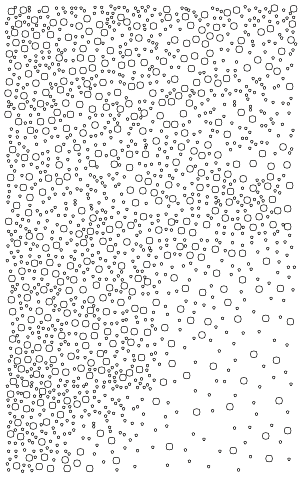
Eaves

- ICF structures should be temporarily braced prior to the addition of concrete to reduce the risk of collapse and concrete 'blow outs'
- Bracing can be removed 24 hours after concrete is poured
- ICF allows for quick construction of buildings up to 7 storeys in height (although normally not more than 2 or 3 storeys in practice)
- ICF offers limited adaptability for future building alterations

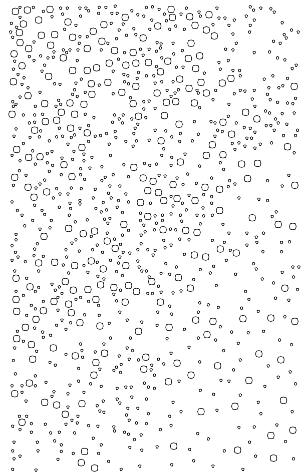


Window Head

A variety of surface patterns and textures can be produced by the following methods.



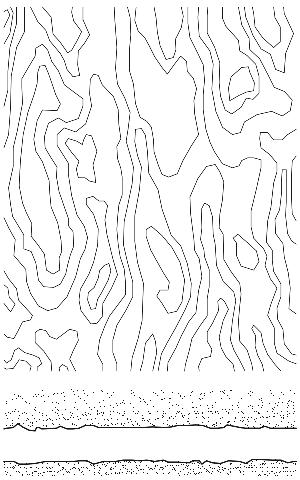
Exposed Fine Aggregate



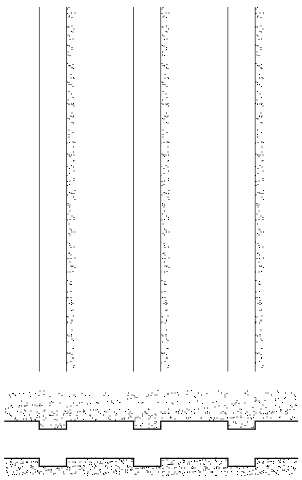
Exposed Coarse Aggregate

Selection of the Concrete Ingredients

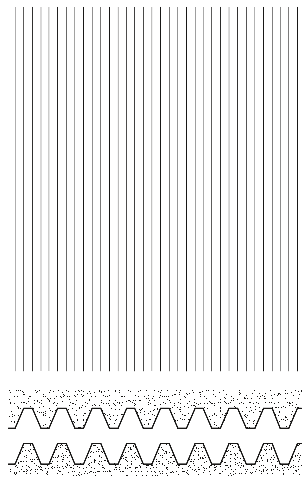
- The colour of concrete can be controlled with the use of coloured cement and aggregates
- Exposed aggregate finishes are produced by sandblasting, etching with an acid, or scrubbing a concrete surface after the initial set in order to remove the outer layer of cement paste and expose the aggregate. Chemicals can be sprayed on the forms to help retard the setting of the cement paste



Sandblasted Plywood



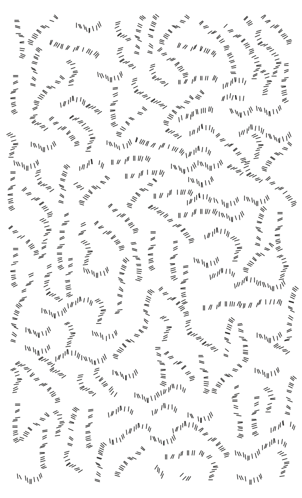
Board-and-Batten Pattern



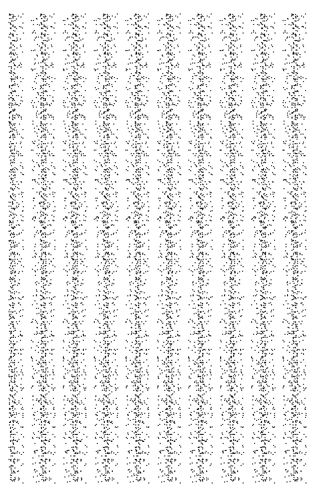
Ribbed Texture Form Liner

The Impressions Left by the Forms

- Béton brut refers to concrete that is left in its natural state after formwork is removed, especially when the concrete surface reflects the texture, joints and fasteners of a board form
- Plywood forms can be smooth, or be sandblasted or wire brushed to accentuate the grain pattern of the face ply
- Sheathing produces a board texture
- Metal or plastic form liners can produce a variety of textures and patterns



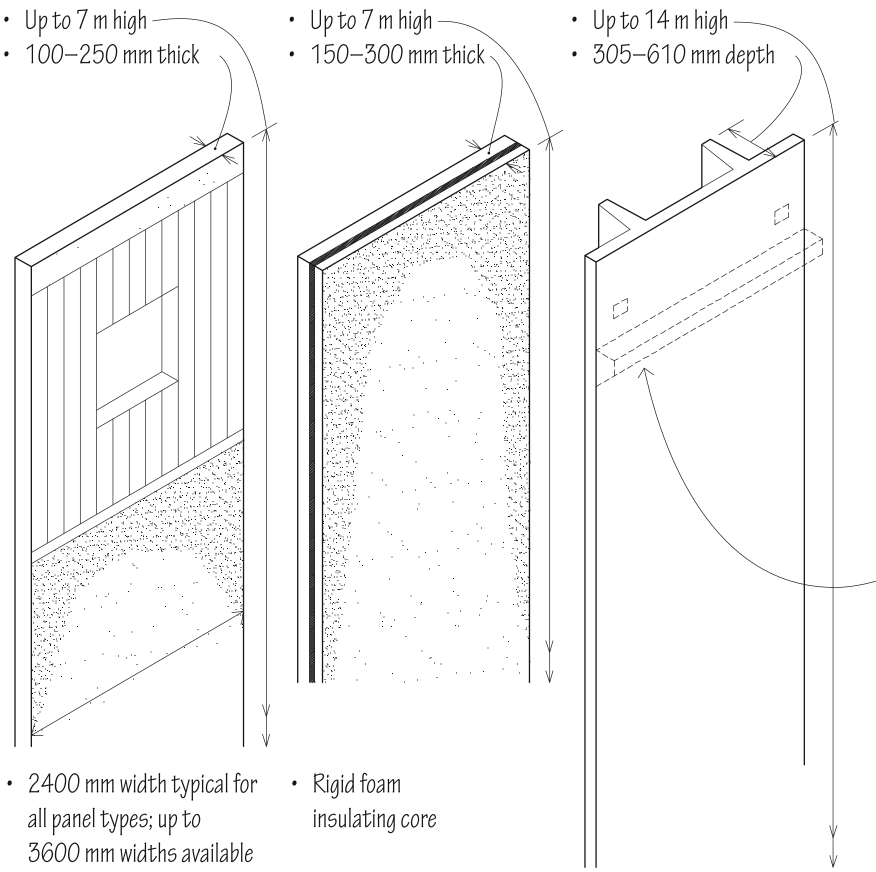
Bush-Hammered Surface



Ribbed Surface Bush Hammered

Treatment after the Concrete Sets

- Concrete can be painted or dyed after it has set
- The concrete surface can be sandblasted, rubbed or ground smooth
- Both smooth and textured surfaces can be bush- or jack-hammered to produce coarser textures
- Bush-hammered finishes are coarse-textured finishes obtained by fracturing a concrete or stone surface with a power-driven hammer having a rectangular head with a corrugated, serrated or toothed face



Solid Panels | Composite Panels | Ribbed Panels

Precast-Concrete Wall Panels

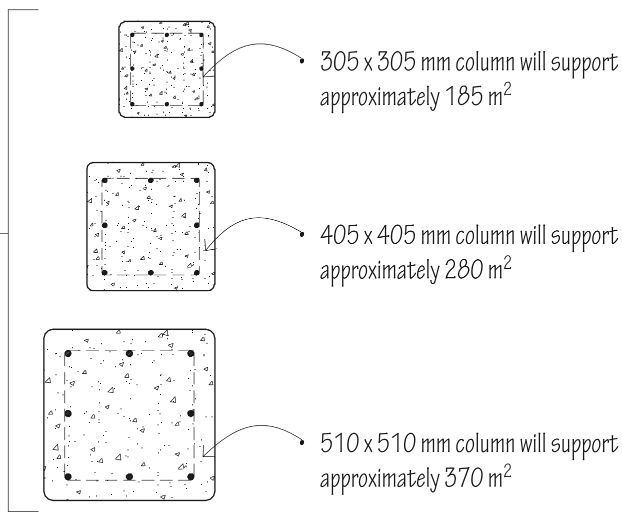
Precast-concrete wall panels are cast and steam-cured in a plant off-site, transported to the construction site and set in place with cranes as rigid components. Fabrication in a factory environment enables the units to have a consistent quality of strength, durability and finish, and eliminates the need for on-site formwork.

The precast wall panels may be conventionally reinforced or prestressed for greater structural efficiency, reduced panel thicknesses and longer spans. In addition to the required tensile, shrinkage and temperature reinforcement, extra reinforcement may be necessary to resist the stresses of transportation and erection.

- Precast wall panels may be of solid, composite or ribbed construction
- Window and door openings, corbels and anchoring devices are cast into the wall panels
- A variety of quality-controlled surface textures and patterns are available; consult manufacturer

Precast-Concrete Columns

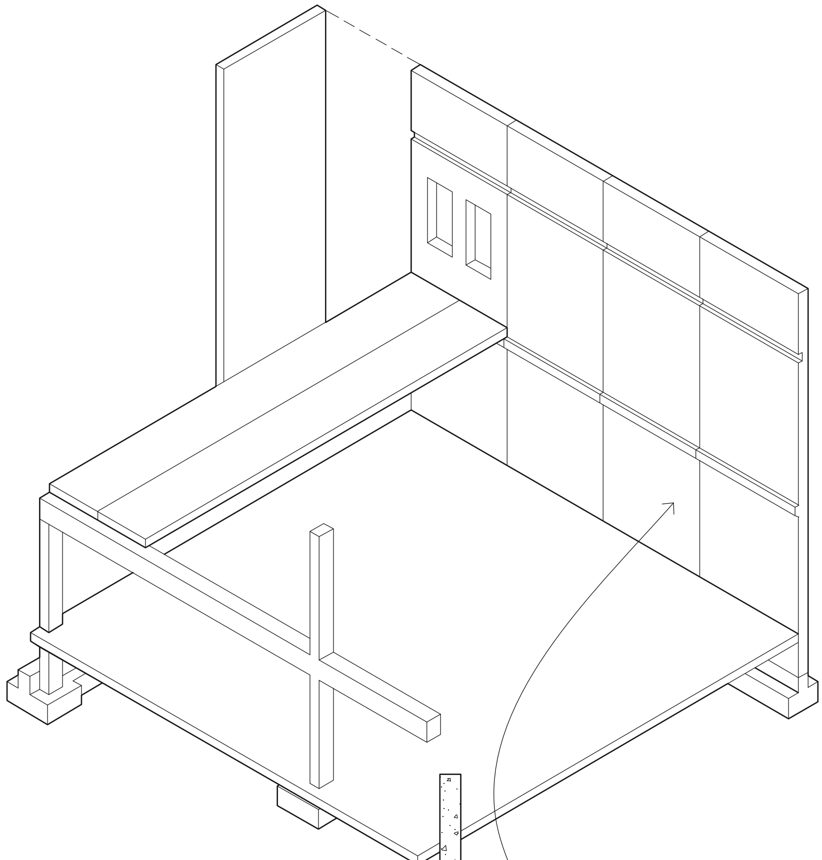
Precast-concrete columns are typically used with precast beams to form a structural frame; see 4.11. Because rigid joints are difficult to fabricate in a precast structural frame, shear walls or diagonal bracing are normally relied upon to stabilise the structure against lateral forces.

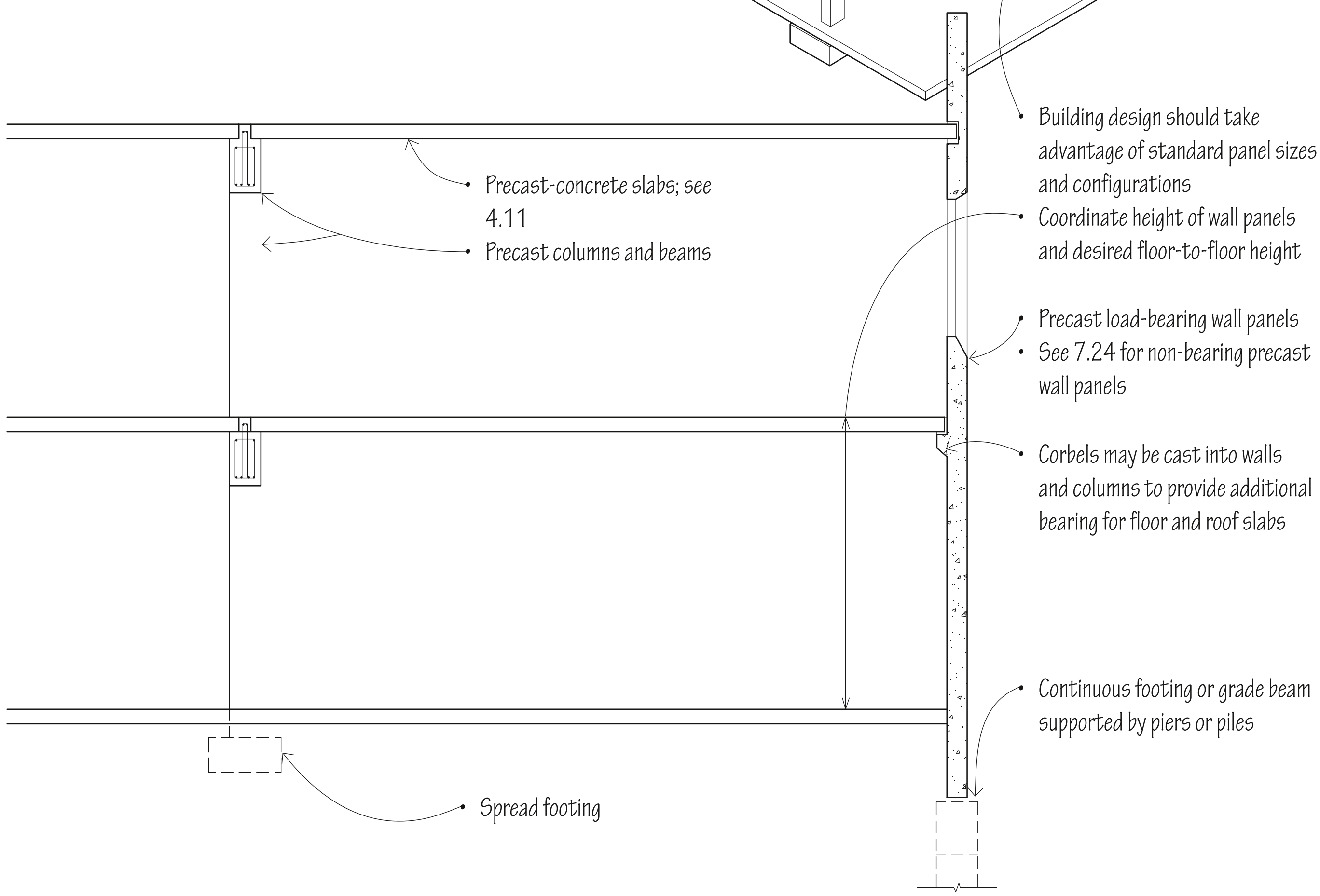


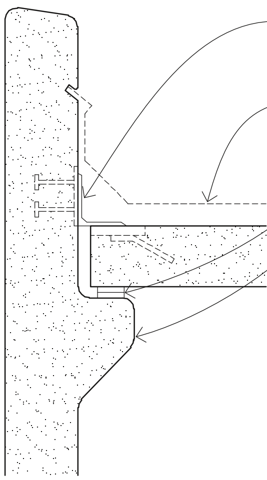
- The areas above are indicative only, consult a suitably qualified engineer for detailed design calculations

Precast-concrete wall panels may serve as bearing walls capable of supporting cast-in-situ concrete or steel floor and roof systems. Together with precast-concrete columns, beams and slabs, the wall panels form an entirely precast structural system that is inherently modular and fire-resistant. See also 4.11 and 4.13. For non-structural precast-concrete panels, see 7.24.

The lateral stability of a precast-concrete structure requires that those floors and roofs that serve as horizontal diaphragms be able to transfer their lateral forces to shear-resisting wall panels. The wall panels, in turn, must be stabilised by columns or cross walls as they transfer the lateral forces to the ground foundation. All forces are transferred by a combination of grouted joints, shear keys, mechanical connectors, steel reinforcement and reinforced-concrete toppings.

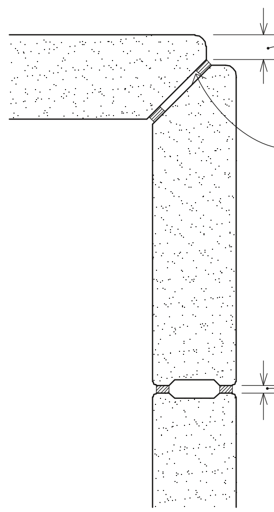






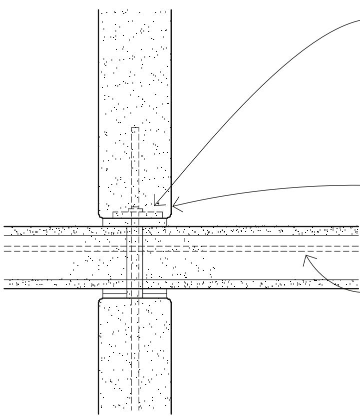
- Steel angle welded to plates anchored in wall and slab units
- Built-up or membrane roofing system; see 7.09–7.10
- Neoprene bearing strip
- Corbel provides required bearing area
- Minimum bearing length at least 75 mm

Precast-Concrete Slab



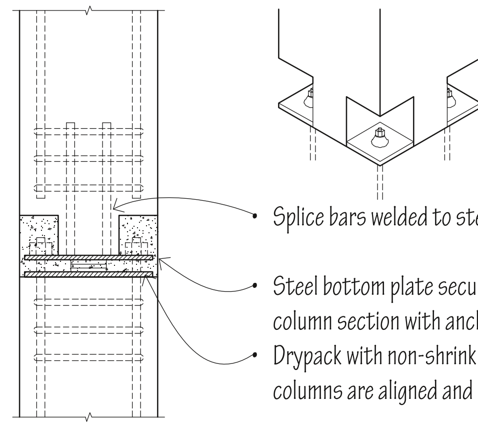
- Quirk mitre: 19–38 mm
- Backer rod and sealant
- Vertical joint; 13 mm minimum
- Discontinue sealant at vertical joints for drainage

Panel Joints



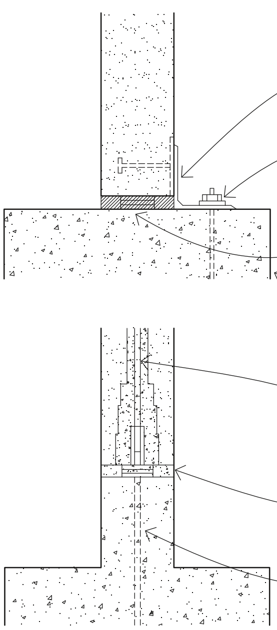
- Steel base plate cast with upper wall panels and secured with anchor bolt cast into lower wall panels
- Grout pocket after bolted connection is made
- Dowels in reinforced-concrete topping or grouted shear keys tie slabs across supporting wall panels

Precast-Concrete Slab



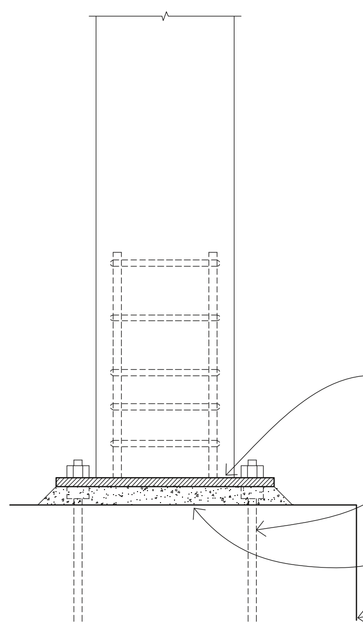
- Splice bars welded to steel angles
- Steel bottom plate secured to column section with anchor bolts
- Drypack with non-shrink grout after columns are aligned and bolted

Column Splice



- Clip angle welded to anchor plate
- Anchor bolt
- Shim pads and non-shrink grout
- Continuous strip footing
- Post-tensioned rod
- Shim pads and non-shrink grout
- Post-tensioned anchor cast into footing

Concrete Footings



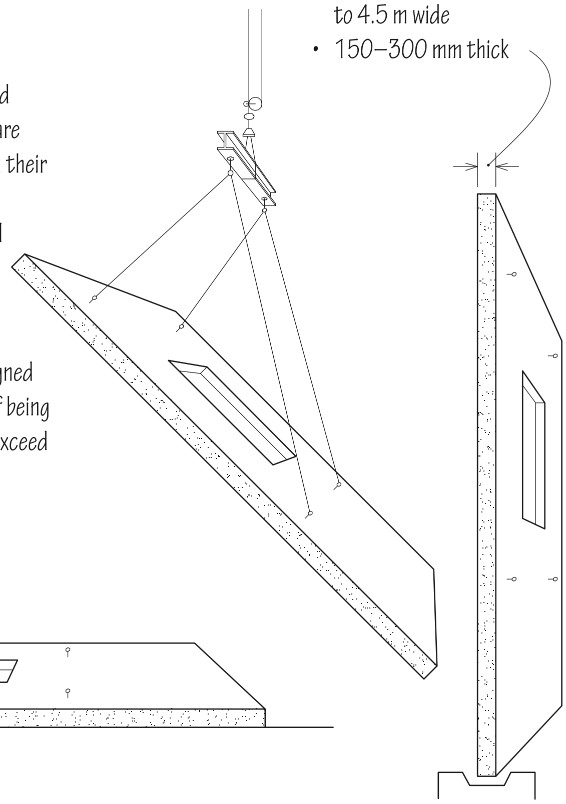
- See also 4.13 for column, beam and slab connections
- Consult a suitably qualified engineer for detailed structural requirements
- Steel base plate secured to column
- Anchor bolts; minimum 25 mm ø
- Drypack with non-shrink grout after column is aligned
- Column footing

Column Base

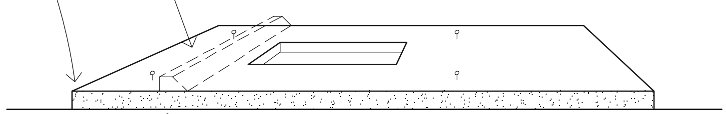
Tilt-up construction is a method of casting reinforced-concrete wall panels on-site in a horizontal position, then tilting them up into their final position. The principal advantage of tilt-up construction is the elimination of the costs associated with constructing and stripping vertical wall forms; this cost saving is offset by the cost of the crane required to lift the completed wall panels into place.

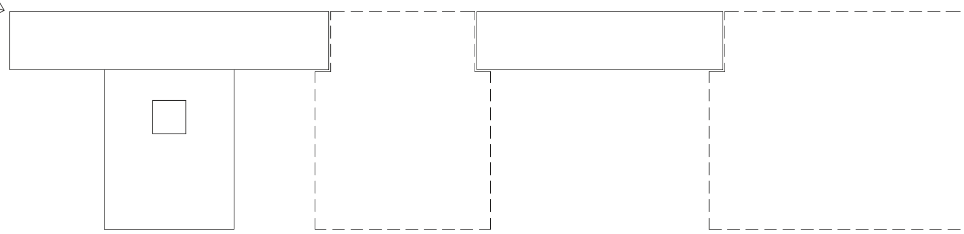
- Once the wall panels are cured to sufficient strength, they are lifted with a crane and set on their footings or piers. They are then temporarily braced until connections can be made to the remaining part of the structure
- The wall panels must be designed to withstand the stresses of being lifted and moved, which can exceed the in-place loads

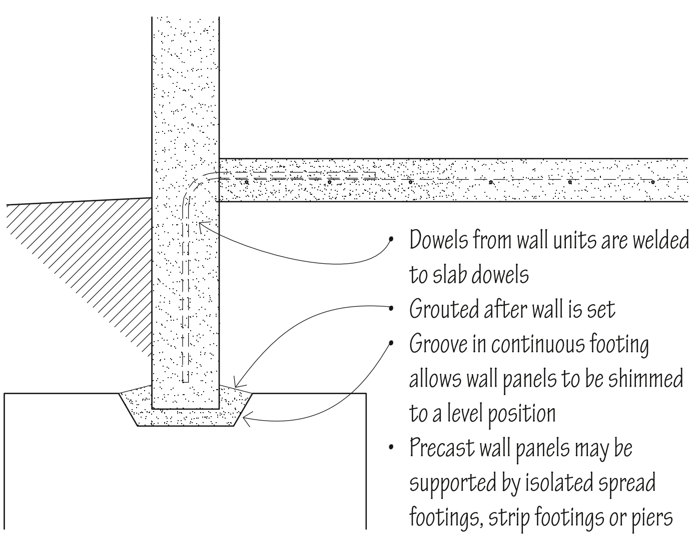
- Full-size panels may be up to 4.5 m wide
- 150–300 mm thick



- Projections and pick-up devices are cast into the upper face
- The concrete ground slab for the building under construction usually serves as the casting platform, although earth, plywood or steel moulds can also be used. The slab must be designed to withstand the crane load if the lifting operation requires the presence of the crane on the slab
- The casting platform should be level and smoothly trowelled; a bond breaking agent is used to ensure a clean lift
- Reveals and recessed steel plates may be cast into the underside of the panels
- Spandrel units can overhang and span openings up to 9 m wide
- The floor and roof connections are similar to those shown in 4.13 and 5.14. Shown are typical wall panel connections to adjacent panels and footings

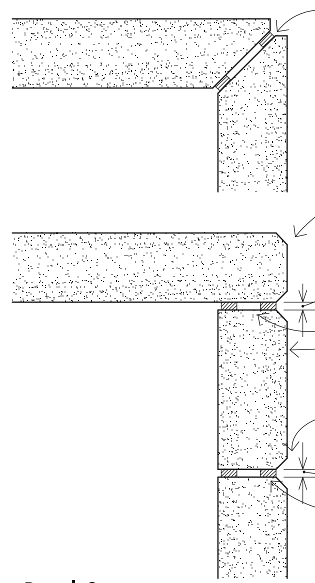






- Dowels from wall units are welded to slab dowels
- Grouted after wall is set
- Groove in continuous footing allows wall panels to be shimmed to a level position
- Precast wall panels may be supported by isolated spread footings, strip footings or piers

Foundations



- Quirk mitre: 19–38 mm
- Lapped corner
- 13 mm minimum
- Backer rod and sealant
- Precast wall panels
- 19 mm chamfers at panel joints
- 13 mm minimum
- Backer rod and sealant

Panel Connections

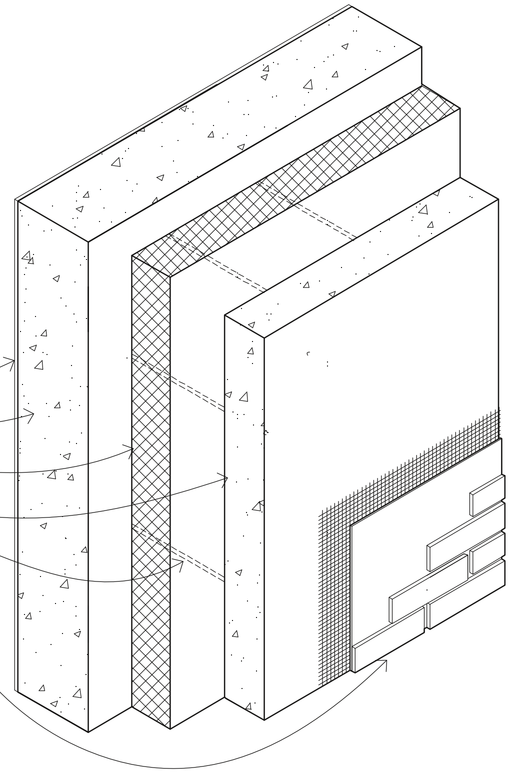
5.16 COMPOSITE PREFABRICATED SYSTEMS

Composite prefabricated systems often in a panellised form may incorporate internal and external finishes, thermal insulation and weathering. Their main advantage is a reduction in the fabrication that takes place on-site and the overall construction time. They do, however, require a longer lead-in time and a high level of coordination. Prefabricated composite systems can be based on precast concrete, timber or steel frame or a hybrid system. Composite aluminium-clad timber windows are becoming increasingly popular. Most composite prefabricated systems are likely to attract a cost premium, however the reduced construction time and increased quality control can justify such an approach.

Composite Concrete Panels

Composite concrete panels will include concrete structural elements and thermal insulation, they may also incorporate internal and external finishes.

- Internal finish
- Internal structural concrete
- EPS or XPS insulation layer
- Outer concrete leaf
- Structural connections
- Brick slip or rendered finish

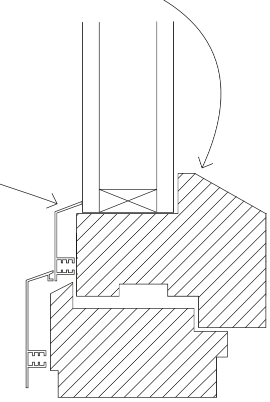


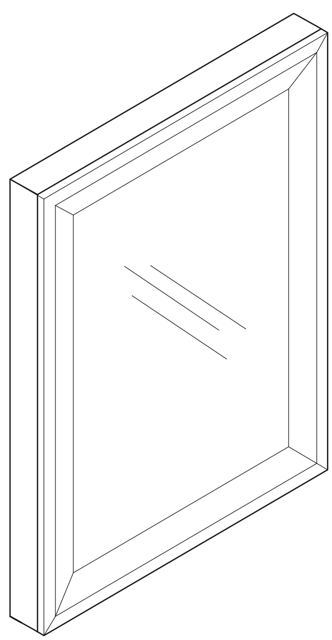
Aluminium-Clad Timber-Frame Windows

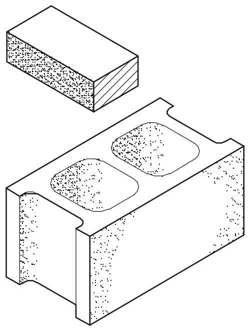
Timber-frame windows clad in aluminium externally offer the benefits of a timber window with the durability offered by the external aluminium cladding. The cladding systems allow for a wide range of colour finishes while also reducing the maintenance requirements.

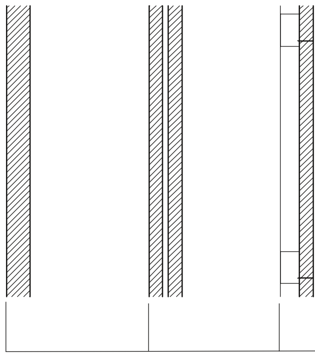
Alternatively the bottom rail of a timber window can be replaced with an aluminium strip as this is the part of the window most likely to suffer from water damage without maintenance.

- Timber frame
- Aluminium cladding



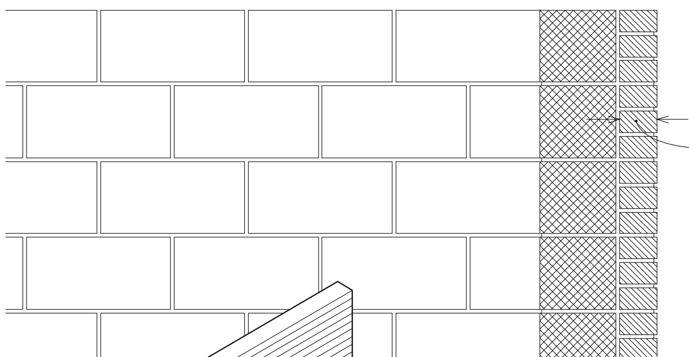


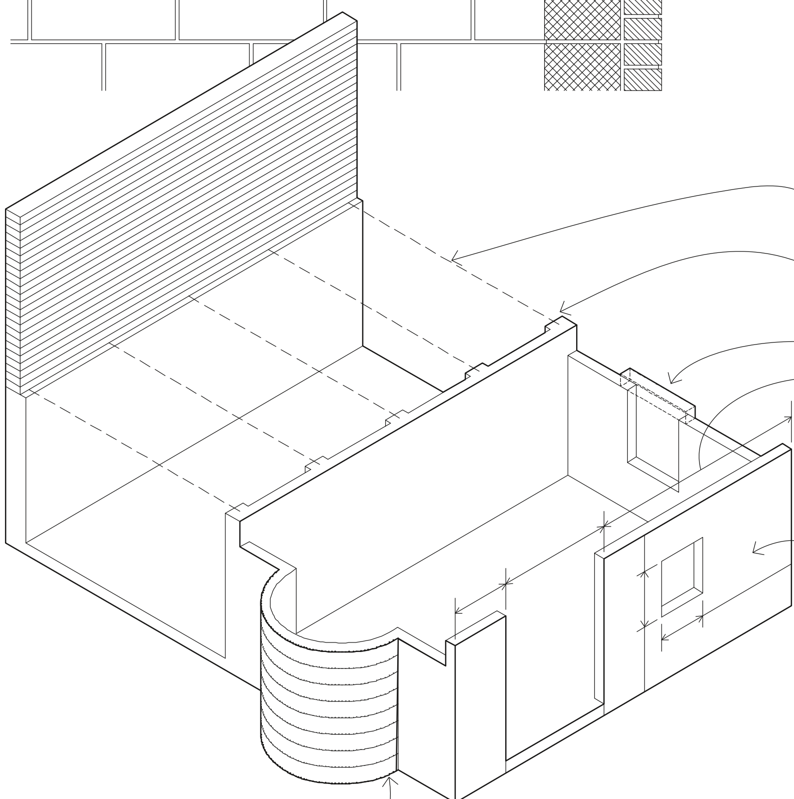




Masonry walls consist of modular building blocks bonded together with mortar to form walls that are durable, fire-resistant and structurally efficient in compression. The most common types of masonry units are bricks, which are heat-hardened clay units, and concrete blocks, which are chemically hardened units. Other types of masonry units include structural clay tile, structural glass block, and natural or cast stone. See 12.06–12.07 for a discussion of masonry as a construction material.

- Masonry walls may be constructed as solid walls, cavity walls or veneered walls
- See 7.25–7.26 for masonry veneer systems
- Masonry walls may be unreinforced or reinforced
- Masonry cavity walls incorporate metal wall ties to bond leaves together; solid walls may incorporate reinforcing; see 5.18–5.20 for solid and cavity masonry walls
- A leaf refers to a continuous vertical section of a wall that is one brick or block in thickness
- Reinforced masonry walls utilise steel reinforcing bars embedded in grout-filled joints and cavities to aid the masonry in resisting stresses
- Masonry bearing walls are typically arranged in parallel sets to support steel, timber or concrete spanning systems





- Common spanning elements include open-web steel joists, timber or steel beams, and cast-in-situ or precast-concrete slabs
- Piers stiffen masonry walls against lateral forces and buckling, and provide support for large concentrated loads
- Openings may be arched or spanned with lintels
- Modular dimensions; see 12.06–12.17 for brick and block dimensions

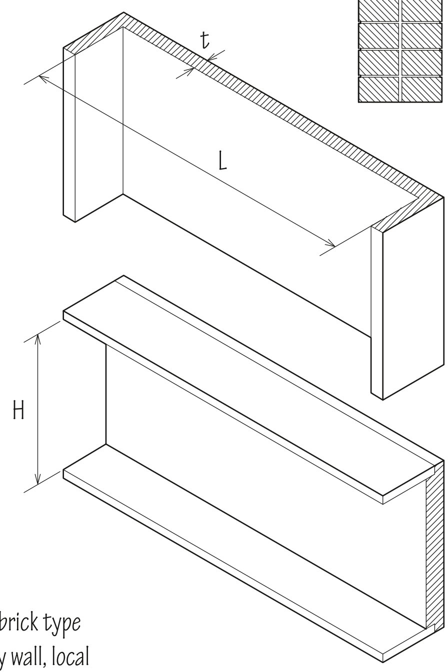
- Exterior masonry walls must be weather-resistant and control heat flow
- Water penetration must be controlled through the use of tooled joints, cavity spaces, flashing/damp-proof membranes and caulking
- Cavity walls are traditionally preferred for their increased resistance to water penetration, however in some cases thermal bridging problems may reduce thermal performance; see 7.36–7.37
- Differential movements in masonry walls due to changes in temperature or moisture content, or to stress concentrations, require the use of expansion and control joints
- For installation of thermal insulation, see 7.42
- For fire-resistance ratings of non-combustible masonry walls, see A.10–A.11

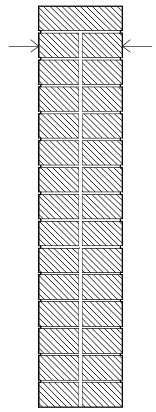
- Relatively small unit sizes make curvilinear and irregular forms possible

EN Eurocode 6: Design of Masonry Structures

A number of variables set limitations on the allowable height and length of a masonry wall.

- L/t = ratio of wall length to thickness; lateral support may be provided by cross walls, columns or piers
- H/t = known as the slenderness ratio considering ratio of the wall height (H) to thickness (t); lateral support may be provided by floors, beams or roofs
- Consult a suitably qualified engineer for the structural requirements of all masonry walls





Minimum Wall Thickness

215 mm minimum nominal thickness for:

- Masonry bearing walls
- Masonry shear walls
- Masonry parapets; height of parapet not to exceed 3 x parapet thickness

150 mm minimum nominal thickness for:

- Reinforced masonry bearing walls
- Solid masonry walls in one-storey buildings not more than 2700 mm high

Exposure

When considering finishing, mortar choice, brick type and general wall construction for a masonry wall, local environmental conditions must be taken into account. Buildings on exposed sites in coastal regions may be subject to attack from salt in seawater, which can cause materials and finishes to degrade more rapidly than in less exposed conditions.

Structural Eurocode 6 identifies five microconditions for masonry construction:

- MX1: Dry environments
- MX2: Exposed to moisture or wetting
- MX3: Exposure to moisture or wetting plus freeze thaw action
- MX4: Exposed to saturated salt air or seawater
- MX5: In aggressive chemical environments

Mortar

Mortar is a plastic mixture of cement or lime, or a combination of both, with sand and water, used as a bonding agent in masonry construction.

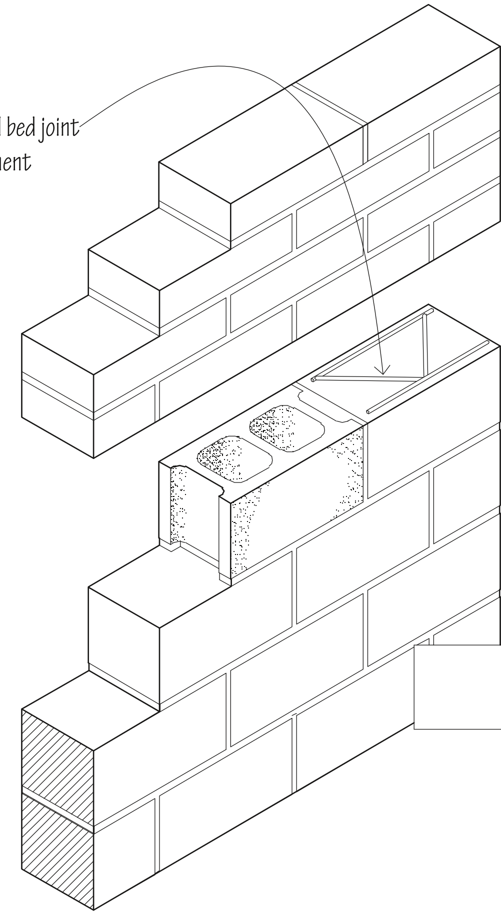
- Cement mortar is made by mixing portland cement, sand and water
- Lime mortar is a mixture of lime, sand and water that is less commonly used because of its slow rate of hardening and low compressive strength
- Cement-lime gauged mortar is a cement mortar to which lime is added to increase its plasticity and water-retentivity
- Masonry cement is a proprietary mix of portland cement and other ingredients, such as hydrated lime, plasticisers, air-entraining agents and gypsum, requiring only the addition of sand and water to make cement mortar

When choosing a suitable mortar for a particular situation a number of variables are of importance including bond strength and compressive strength. These properties should be declared by the supplier. Generally mortars are divided into a number of compressive strength categories (as set out in EN 998), designated 'M' and measured in N/mm^2. M1, M2.5, M5, M10, M15 and M20 are common mortar classes and can be related back to specific mortar mixes.

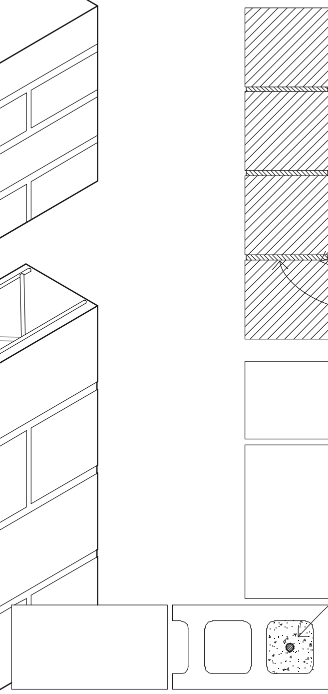
Solid Masonry

Solid masonry walls may be constructed of either solid or hollow masonry units laid contiguously with all joints solidly filled with mortar.

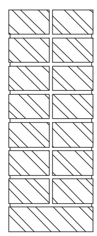
Solid block walls generally consist of a single leaf of hollow block or solid masonry.



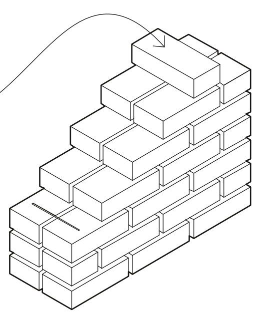
- Horizontal bed joint reinforcement



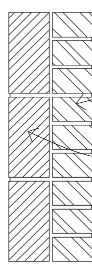
- 150 mm solid block
- Horizontal joint reinforcement where required is fully embedded in bed joint mortar
- Vertical cells of the concrete blocks may be reinforced with steel bars embedded in grout



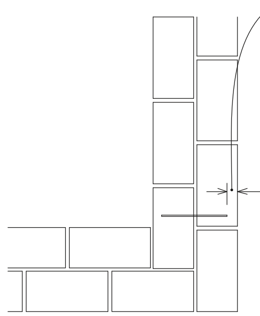
Solid masonry walls may also consist of multiple layers bonded by grout, corrosion-resistant metal wall ties or horizontal joint reinforcement.



- In traditional solid brick walls, a header acts to bond brick leaf together

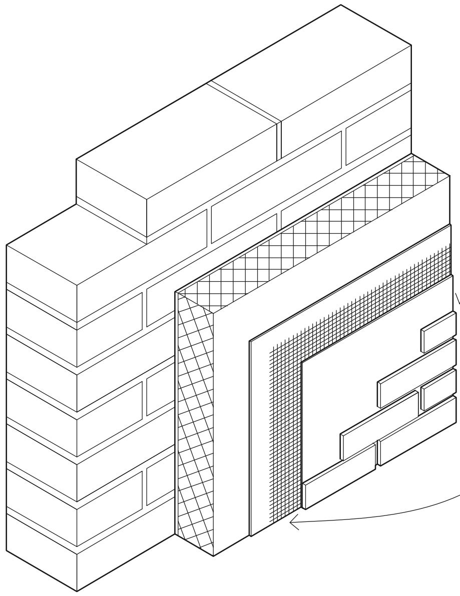


- Veneered walls are solid masonry walls having a facing leaf and a back-up inner of different solid or hollow masonry units
- Facing leaf (outer)
- Back-up leaf (inner)



- 15mm minimum mortar cover between ties or joint reinforcement and any exposed face
- Mortar joints between courses generally 10 mm to allow for reinforcement and bonding between courses

Brick Slips



- Where a solid wall with external insulation (see 7.34) or structural insulated panel (SIP, see 6.27) is to be used, a brick slip finish can be applied to give a more traditional aesthetic
- A brick slip is a thin cut of the facing of a standard brick, the thickness of the slip can be varied but is normally 20 mm
- For an external insulation system, a reinforcing mesh is bedded in mortar on rigid insulation before the brick slips are adhered in another bed of mortar
- For SIPs the brick slips are adhered to a sheeting panel, fixed to battens at suitable centres and in turn fixed to the SIPs

Cavity Walls

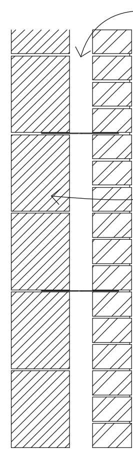
Cavity walls are constructed of an outer leaf of brick or block and an inner leaf of either solid or hollow blocks, completely separated by a continuous air space and bonded with wall ties. Cavity walls have two advantages over other types of masonry walls:

1. The air space acts as a barrier against water penetration if the cavity is kept clear, and if adequate weep holes and flashing are provided

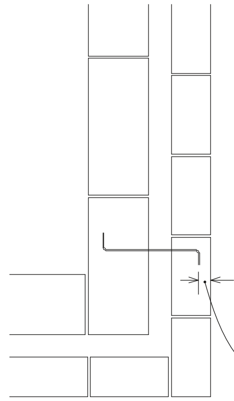
2. The cavity can enhance the thermal insulation value of the wall and permit the installation of additional thermal insulation material

Cavity walls are a common form of construction in the UK and Ireland but less common in other parts of Europe, care must be taken on-site to ensure good quality of workmanship when using a cavity wall solution, potential difficulties include:

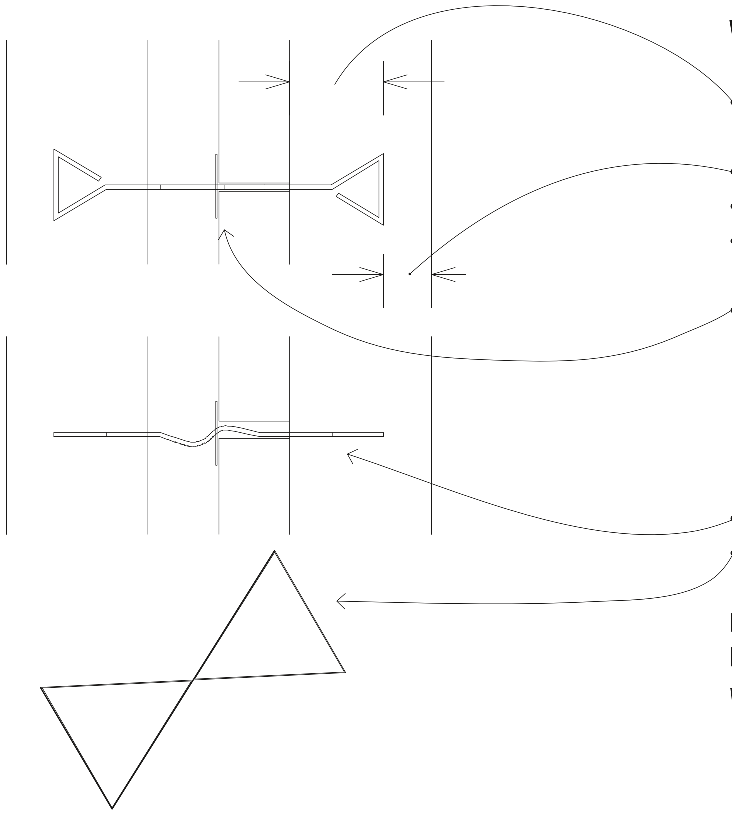
- Poorly installed rigid insulation leading to thermal looping; see 7.36
- Difficulties keeping wall cavities clear of waste mortar and other materials leading to thermal bridging; see 7.37



- Clear cavity to be not less than 40 mm and generally not more than 200 mm although cavities of 300 mm are possible with suitable wall ties
- Solid or hollow masonry units
- The inner leaf of a cavity wall is the structural element of the wall, while the outer leaf offers protection from the elements
- Weep holes and stepped damp-proof courses (DPC) above openings allow trapped water to escape; see 7.26



- Wall ties should be provided at 900 mm centres horizontally and 450 mm vertically
- Stagger ties in alternate courses
- Additional wall ties should be provided around openings within 225 mm of the opening and at not more than 300 mm centres vertically
- 15 mm minimum mortar cover

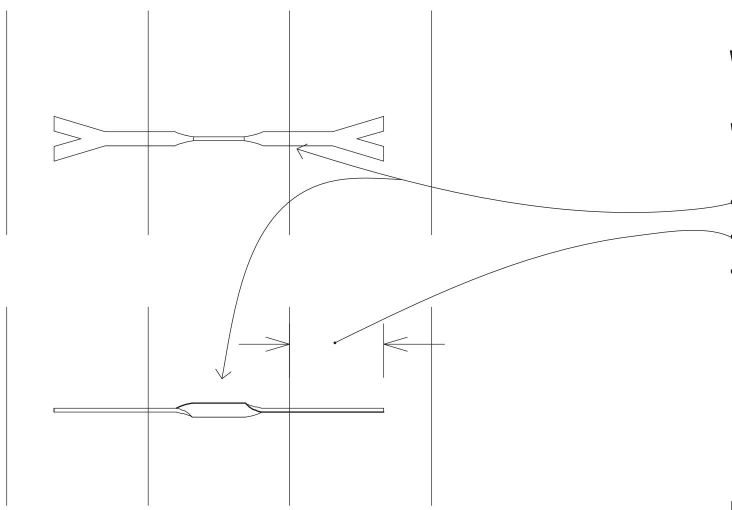


Wire Wall Tie

- There are a wide range of wire wall ties with gauges from 2 to 3 mm
- Wall ties should have a minimum bearing of 75 mm
- Minimum cover to end of wall tie 15 mm
- Wall ties incorporate a drip to prevent water/condensation reaching the inner leaf
- Insulation restraint clip to hold rigid insulation panels in place within the wall cavity

- Double triangle tie
- Butterfly wall tie

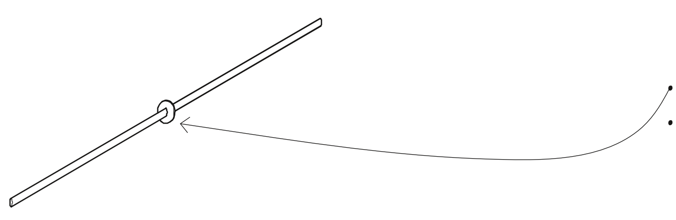
For existing buildings without wall ties or where existing wall ties have failed, helical wall ties can be drilled into place to stabilise the wall structure.



Vertical Twist Wall Tie

Vertical twist wall ties are commonly found in existing buildings.

- Twist in wall tie acts as a drip mechanism
- Minimum 75 mm bearing
- Minimum cover to end of wall tie 15 mm

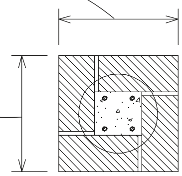


Low Thermal Conductivity Wall Ties

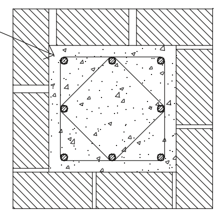
- Low thermal conductivity wall ties can reduce the amount of heat loss due to repeating thermal bridging through an external wall; see 7.36–7.37
- Drip to ensure water/condensation does not meet the inner leaf
- Made using basalt fibres in an epoxy resin, the Teplo Tie by Ancon Building Products® is one such commercially available example

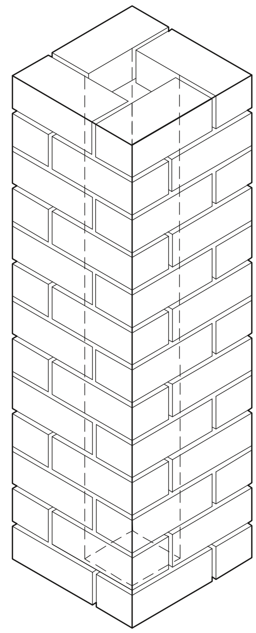
5.22 MASONRY COLUMNS & PIERS

- Minimum nominal width = 325 mm
- Minimum nominal length = 325 mm; maximum = 3 x column width

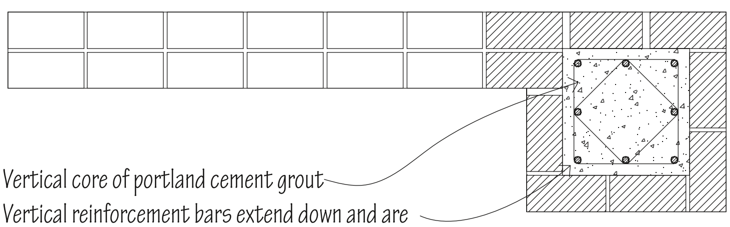


- Minimum of four main reinforcing bars with lateral ties as required

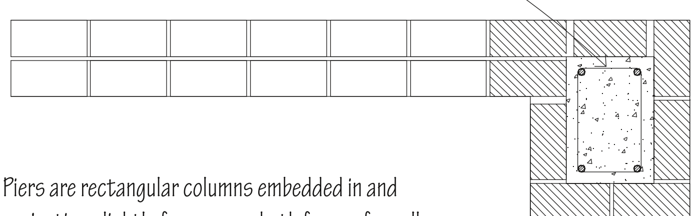




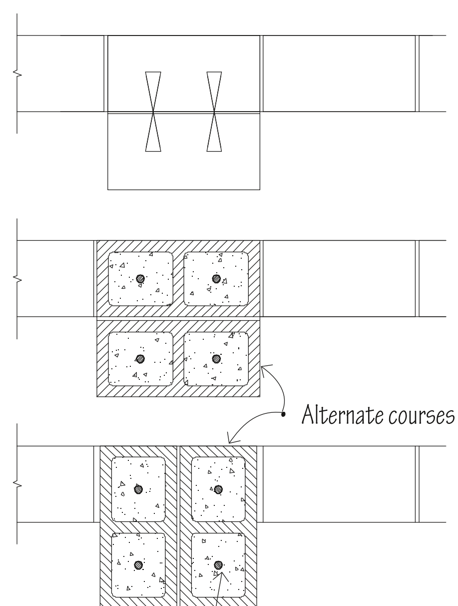
Masonry Columns



- Vertical core of portland cement grout
- Vertical reinforcement bars extend down and are tied to dowels embedded in pier footing
- Lateral ties



- Piers are rectangular columns embedded in and projecting slightly from one or both faces of a wall. In addition to carrying vertical concentrated loads, piers provide lateral support for masonry walls

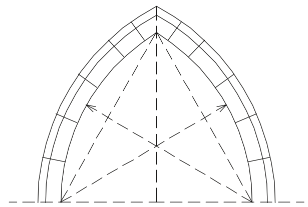


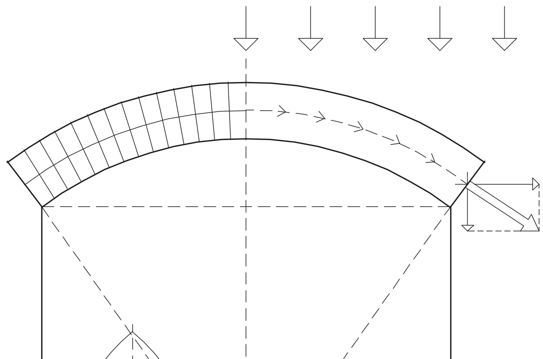
- Alternate courses
- Vertical reinforcement in grout-filled cores

Masonry Piers

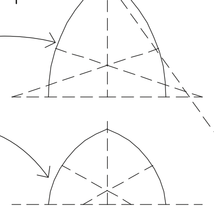
Masonry arches utilise the compressive strength of brick and stone to span openings by transforming the vertical forces of a supported load into inclined components. These outward thrusts of the arching action, which are proportional to the total load and span, and inversely proportional to the rise, must be resisted by abutments adjacent to the opening or by equal but opposite thrusts from adjoining arches. For bending to be eliminated throughout an arch, the lines of thrust must coincide with the arch axis.

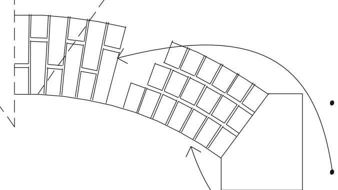
- A segmental arch is struck from a centre below the springing line



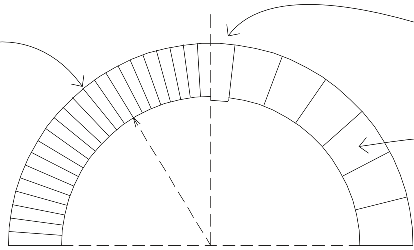


- A Gothic arch is a pointed arch having two centres and usually equal radii
- A lancet arch is a pointed arch having two centres and radii greater than the span
- A drop arch is a pointed arch having two centres and radii less than the span

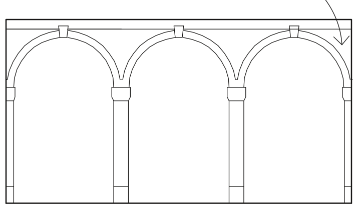


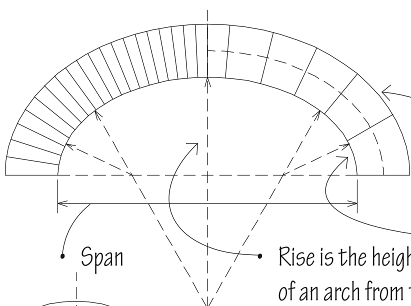


- A masonry arch may consist of brick coursework or individual stone voussoirs
- Alternating soldier and rowlock courses
- Two or three rowlock courses



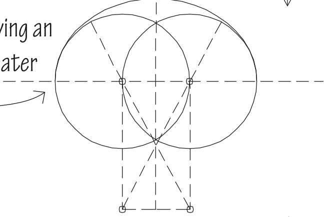
- A Roman arch has semi-circular intrados
- Spandrel refers to the triangular-shaped area between the extrados of two adjoining arches, or between the left or right extrados of an arch and the rectangular framework surrounding it
- Keystone is the wedge-shaped, often embellished voussoir at the crown of an arch
- Voussoirs are any of the wedge-shaped units in a masonry arch, having side cuts converging at one of the arch centres

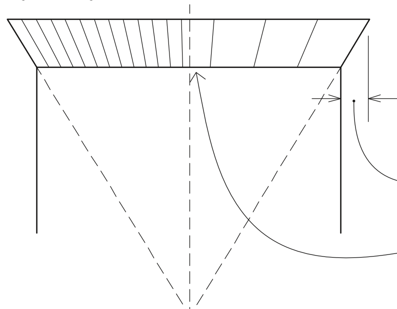




- Span
- Rise is the height of an arch from the springing line to the highest point of the soffit
- Extrados is the exterior curve or boundary of the visible face of an arch
- Intrados is the inner curve of the visible face of an arch; soffit refers to the inner surface of an arch forming the concave underside
- Spring is the point at which an arch, vault or dome rises from its support

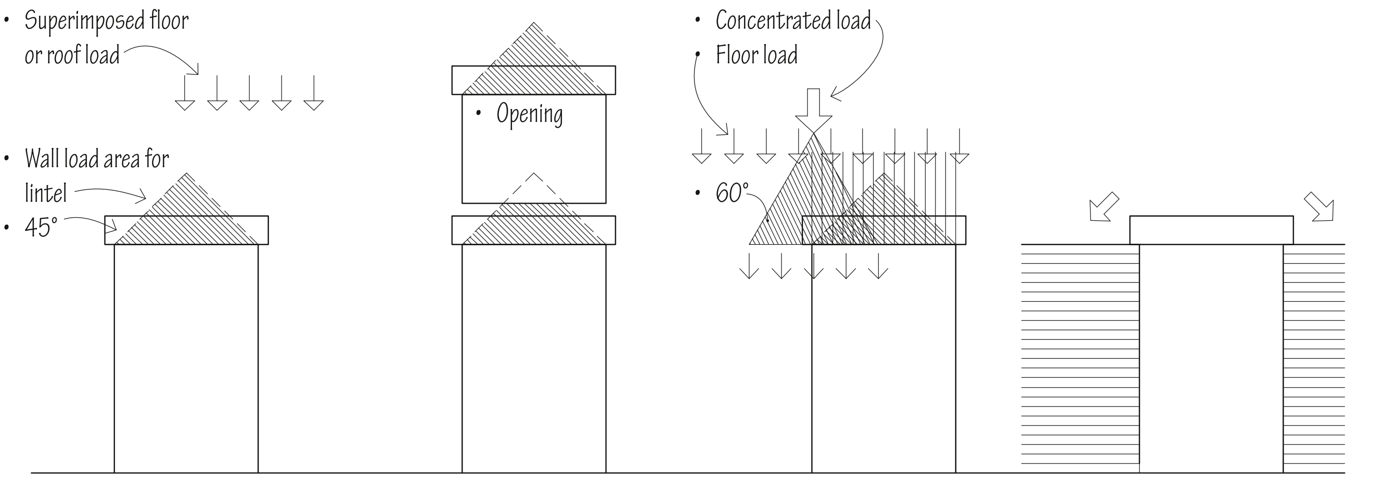
- A basket-handle arch is a three-centred arch having a crown with a radius much greater than that of the outer pair of curves
- A Tudor arch is a four-centred arch having an inner pair of curves with radii much greater than of the outer pair





- A jack arch has a horizontal soffit with voussoirs radiating from a centre below, often built with a slight camber to allow for settling
- Skewback
- Camber = 3 mm per 300 mm span

5.24 MASONRY LINTELS



• Arching action of masonry above opening supports wall load outside load triangle

• Lintel carries less wall load than normal load triangle

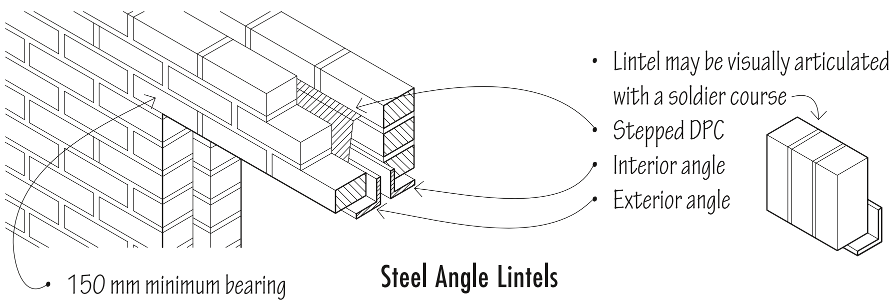
• Lintel must carry an additional load if a concentrated load or floor or roof loads fall within normal load triangle

• Horizontal thrust from any arching action must be resisted by the wall mass on either side of the opening

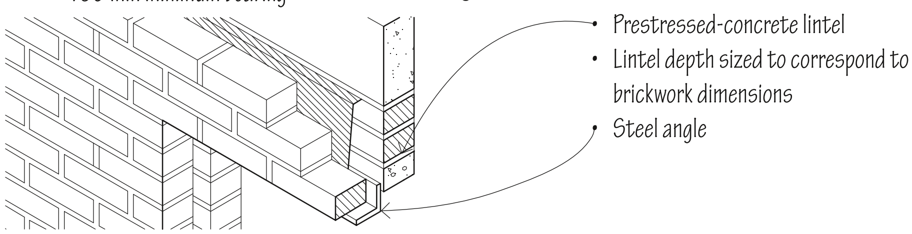
Lintel Spans

Steel Lintels		
Type	**Depth (mm)**	**Clear Span (mm)**
Box		
	120	1200
	180	2400
	220	3300
Angle		
	90	900–1200
	130	1800

• Confirm with suitably qualified engineer



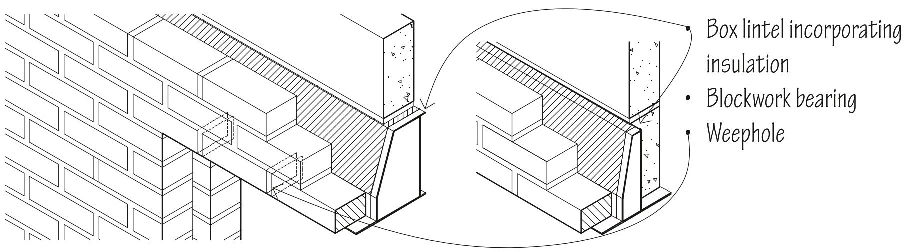
Steel Angle Lintels



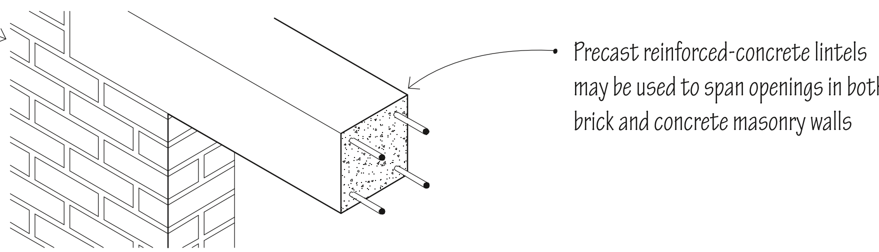
Precast Prestressed-Concrete Lintels

• Prestressed concrete composite lintels require the composite action of brick/blockwork to ensure meeting their load-bearing capacity

• Where sufficient brick/blockwork is not available above the lintel, non-composite lintels should be used



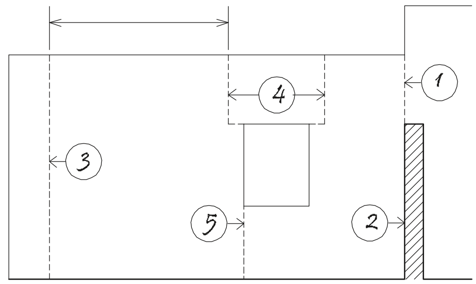
Pressed Metal Lintels



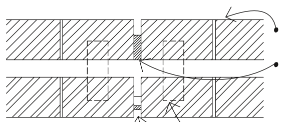
Precast-Concrete Lintels

Movement joints should be spaced every 8 to 12 m along unbroken wall lengths, and:

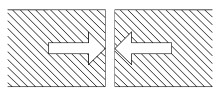
(1) At changes in wall height or thickness
(2) At columns, piers and wall intersections
(3) Near corners
(4&5) At opening where required



Masonry materials expand and contract with changes in temperature and moisture content. Clay masonry units tend to absorb water and expand, while concrete masonry units usually shrink as they dry after manufacture. Movement joints to accommodate these dimensional changes should be located and constructed so as not to compromise the structural integrity of the masonry wall.



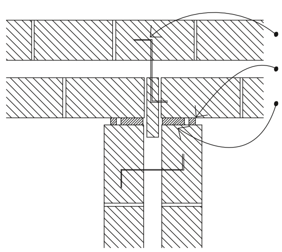
- Cavity wall
- Pre-moulded compressible joint filler
- Adjustable ties
- Backer rod and sealant



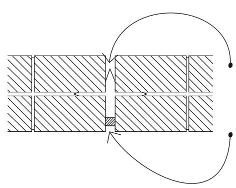
- Brick masonry expands; joint closes slightly
- See 7.49 for sizes of movement joints

Expansion Joints

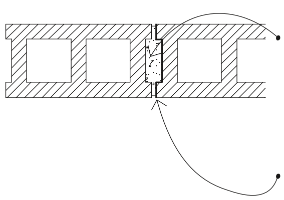
Expansion joints are continuous, unobstructed slots constructed to close slightly to accommodate the moisture expansion of brick and stone masonry surfaces. Expansion joints should provide lateral stability across the joint, and be sealed to prevent the passage of air and water.



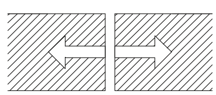
- Wall ties
- Joint sealant
- Pre-moulded compressible joint filler



- Waterstop with anchor tabs
- Backer rod and sealant



- Mortar fill interlocks adjacent wall sections
- Building felt on one side to break bond

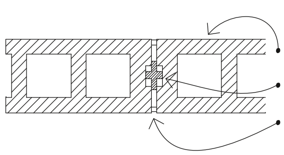


- Concrete masonry shrinks; joint opens slightly
- See 7.49 for sizes of movement joint

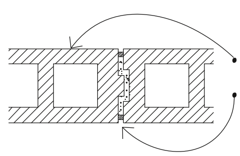
Control Joints

Control joints are constructed to open slightly to accommodate the shrinkage of a concrete masonry wall as it dries after construction.

Control joints should be sealed to prevent the passage of air and water and interlock to prevent out-of-plane movement. Joint reinforcement should be interrupted to allow in-plane movement.

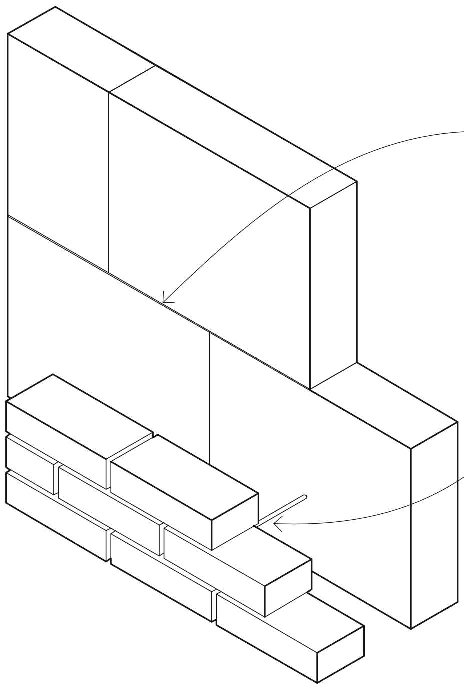


- Hollow blocks
- Pre-formed gasket
- Rake joint 19 mm and caulk



- Control joint blocks
- Backer rod and sealant

- Movement joints are also required to prevent the deflection of a steel or concrete structural frame from placing stress on a supported masonry wall or panel

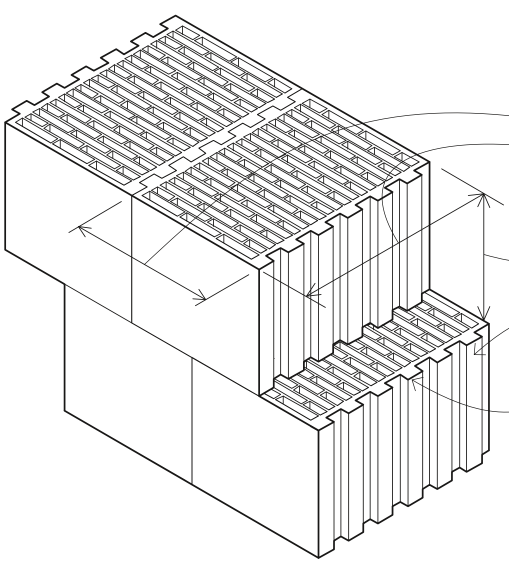


Thin joint construction offers greater dimensional control and reduced construction time. Often used in conjunction with autoclaved aerated concrete blocks (AAC), calcium silicate blocks and structural clay tiles or brick.

- 3 mm mortar applied with trowel or serrated scoop to mortar bed and perpend
- Larger blocks can be used to increase productivity
- In cavity wall situations where a combination of thin joint and traditional joints (brick external leaf) are used helical wall ties should be used

Thin Joint Systems

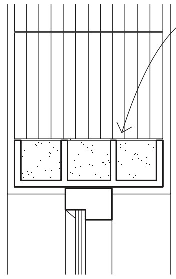
Clay blocks incorporate a honeycomb structure and interlocking mechanism that provides good thermal performance and a rapid construction method incorporating a thin joint system.



- Length 250 mm
- Width 300–450 mm
- Height 250 mm

- Blocks interlock in the vertical plane
- 3 mm rapid setting mortar used in the vertical bed

- Finish with render, rainscreen or brick veneer externally
- Finish with wet plaster or plasterboard and skim coat internally providing for a services void



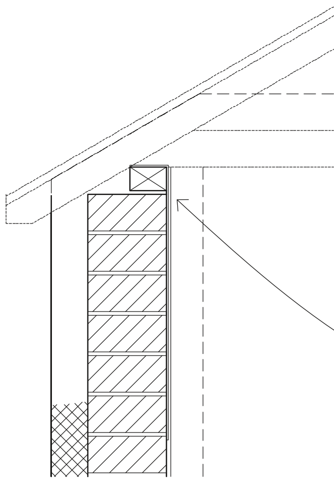
- Precast composite lintel, minimum 125 mm end bearing

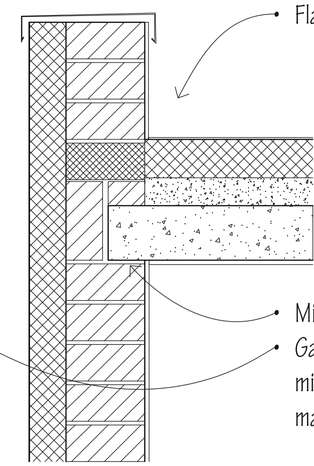
The ThermoPlan® system is a well known thin joint system using clay or 'Ziegel' blocks popular in many parts of Europe.

Structural Clay Blocks

ThermoPlan® is the registered trademark of JUWÖ Engineering GmbH

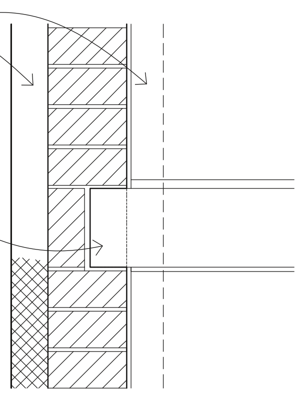
The wall sections on this and the following page illustrate how concrete and timber floor and roof systems are supported by and tied to cavity and solid masonry bearing walls. The bearing area of masonry should be proportioned so as not to exceed the allowable compressive stress of the masonry material.

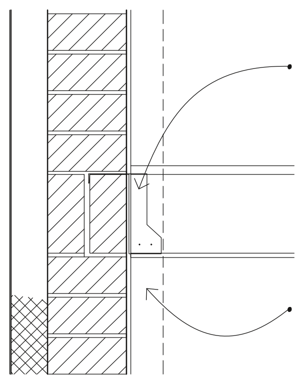




- Flat roof assembly; see 7.08
- Minimum bearing 100 mm
- Galvanised steel strap extending minimum 750 mm down wall at maximum 2 m centres

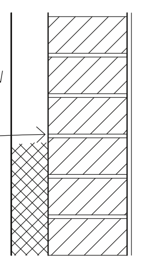
- Solid masonry wall can be insulated externally or internally
- Timber joist built into 'pockets' in wall construction
- See 7.42 for thermal insulation options
- See 5.24 for lintel options



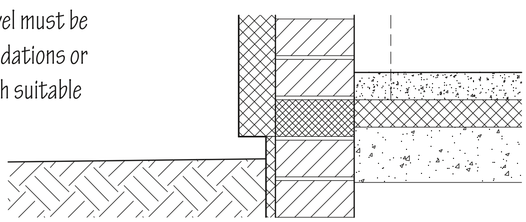


- Timber joist supported on galvanised steel joist hanger
- Maintaining the continuity of internal insulation can be difficult with internal insulation strategies; see 7.42

- Solid masonry walls externally insulated can be finished with a thin coat acrylic render
- Internally insulated walls can be finished externally with a coat of render, rainscreen cladding of brick veneer

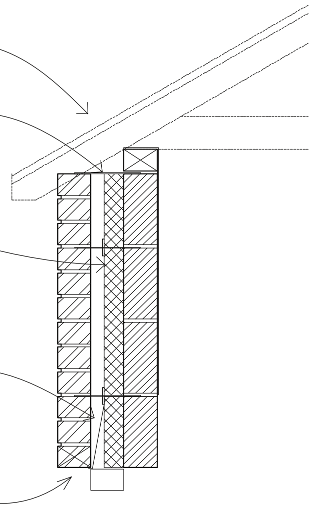


- Loads at ground level must be transferred to foundations or basement walls with suitable connections

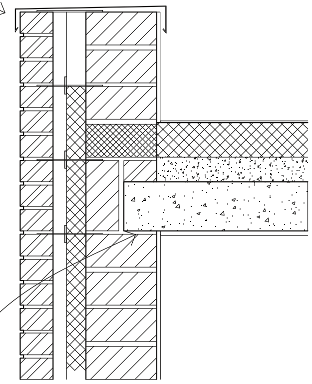


Concrete Masonry Bearing Wall

- Roof truss bearing on treated wall plate
- Close cavity using proprietary closer at top of wall
- Insulation zone, maintaining minimum 40 mm air cavity
- Include a stepped damp-proof course (DPC) and weep holes in brickwork above all opening sections
- See 5.24 for lintel options

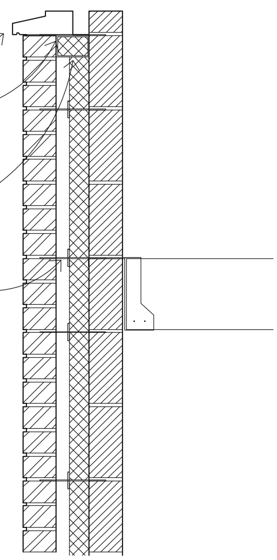


- Masonry parapet
- Pressed metal capping. See 7.15 for coping and flashing

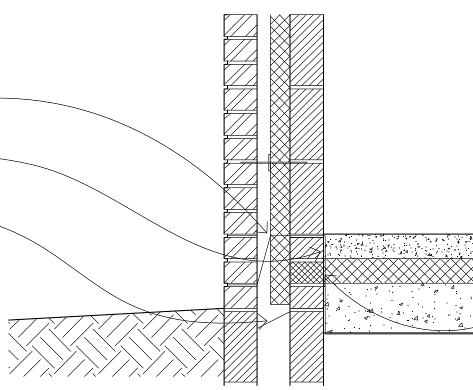


- Minimum bearing 100 mm
- Close cavity with proprietary cavity closer
- For internal finishes, see 10.03

- Precast-concrete window sill incorporating drip
- Sit precast sill on DPC tray
- Close cavity at opening sections with insulated cavity closer
- Metal wall tie including insulation retaining clip
- The continuity of rigid insulation can be interrupted by wall ties and mortar droppings

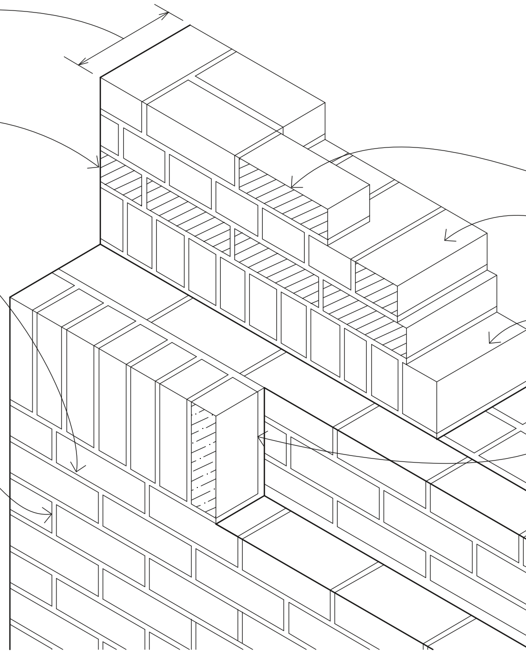


- Stepped DPC
- Damp-proof membrane
- Weak fill concrete in wall cavities below ground level
- Ensure continuity of floor and wall insulation



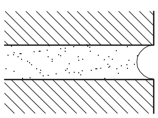
Cavity Bearing Wall

Masonry Terminology

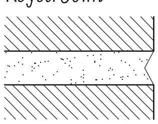


- Leaf is a continuous vertical section of a masonry wall one unit in thickness
- Course is a continuous horizontal range of masonry units
- Bed joint is the horizontal joint between two masonry courses. The term bed may refer to the underside of a masonry unit, or to the layer of mortar in which a masonry unit is laid
- Perpend is the vertical joint between two masonry units, perpendicular to the face of a wall

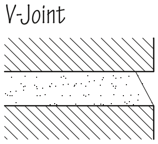
- Stretcher is a masonry unit laid horizontally with the longer edge exposed or parallel to the surface
- Header is a masonry unit laid horizontally with the shorter end exposed or parallel to the surface
- Rowlock is a brick laid horizontally on the longer edge with the shorter end exposed
- Soldier is a brick laid vertically with the longer edge face exposed



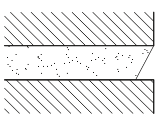
- Keyed Joint



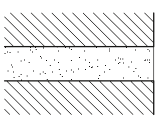
- V-Joint



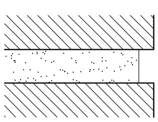
- Weathered Joint



- Struck Joint



- Flush Joint



- Raked Joint

- Mortar joints vary in thickness from 8 to 13 mm but are typically 10 mm thick

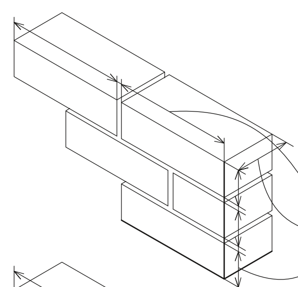
- Tooled joints are mortar joints compressed and shaped with any tool other than a trowel. Tooling compresses the mortar and forces it tightly against the brick surfaces, providing maximum protection against water penetration in areas subject to high winds or heavy rains

- Trowelled joints are finished by striking off excess mortar with a trowel. In trowelled joints, the mortar is cut or struck off with a trowel. The most effective of these is the weathered joint because it sheds water

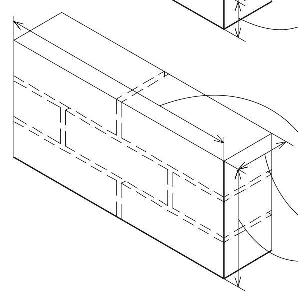
- Raked joint is made by removing mortar to a given depth with a square-edged tool before hardening. Raked joints are for interior use only
- For mortar types, see 5.18

Mortar Joints

Common bricks and blocks are manufactured in standard and corresponding sizes to reduce on-site waste and allow for the planning of interfaces with other materials.



Standard brick
- 215 mm
- 102.5 mm
- 65mm (+10 mm mortar)

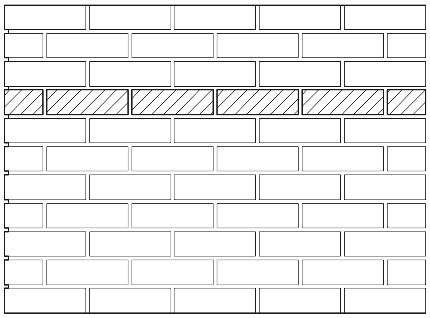


Standard block
- 440 mm (2 brick lengths plus mortar joint)
- 100 mm
- 215 mm (3 brick courses plus 2 mortar joints)

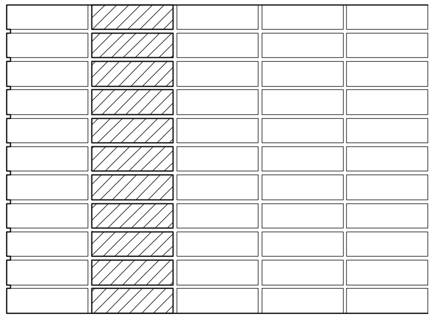
Brick/Block Dimensions

- Relative course heights are nominal dimensions that include the thickness of the mortar joints
- For lengths, use multiples of 100, 215 and 440 mm allowing for 10 mm mortar joints
- For brick types and sizes, see 12.06
- Wall thicknesses vary with the type of masonry wall; see 5.17–5.18

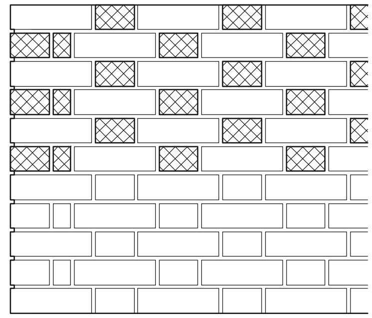
5.30 MASONRY BONDING



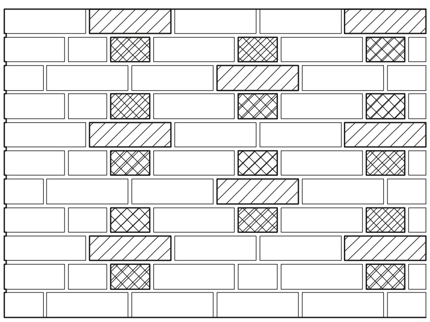
- Stretcher bond, commonly used for cavity and veneer walls, is composed of overlapping stretchers



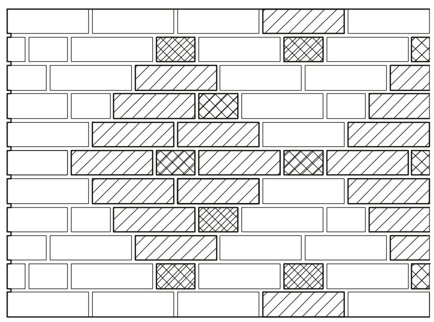
- Stack bond has successive courses of stretchers with all head joints aligned vertically. Because units do not overlap, bed joint reinforcement is required



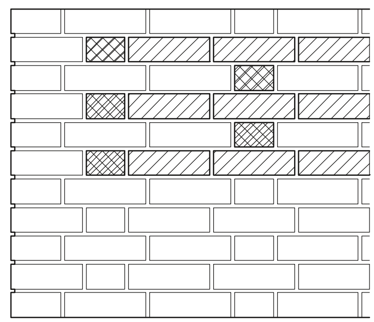
- Flemish bond has alternating headers and stretchers in each course, each header being centred above and below a stretcher. Flare headers with darker ends are often exposed in patterned brickwork. Queen closers are used at corners in each alternating course to maintain the pattern



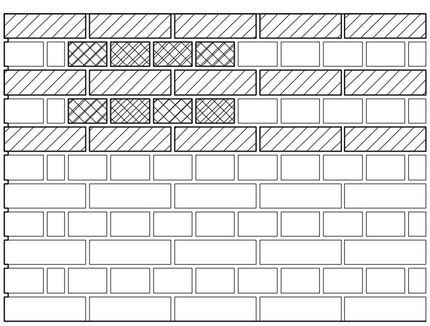
- Flemish cross bond is a modified Flemish bond in which courses of alternate headers and stretchers alternate with stretching courses



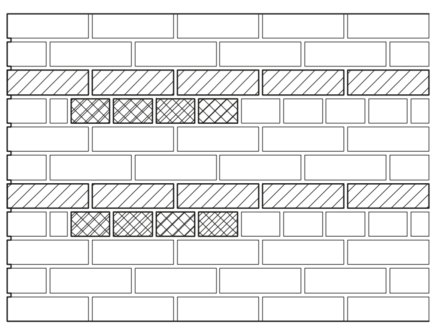
- Flemish diagonal bond is a form of Flemish cross bond in which the courses are offset to form a diamond pattern



- Flemish garden-wall bond, used for lightly loaded boundary walls, has a sequence of a header and three stretchers in each course, with each header being centred over a header in alternate courses



- English bond has alternate courses of headers and stretchers in which the headers are centred on stretchers and the joints between stretchers line up vertically in all courses



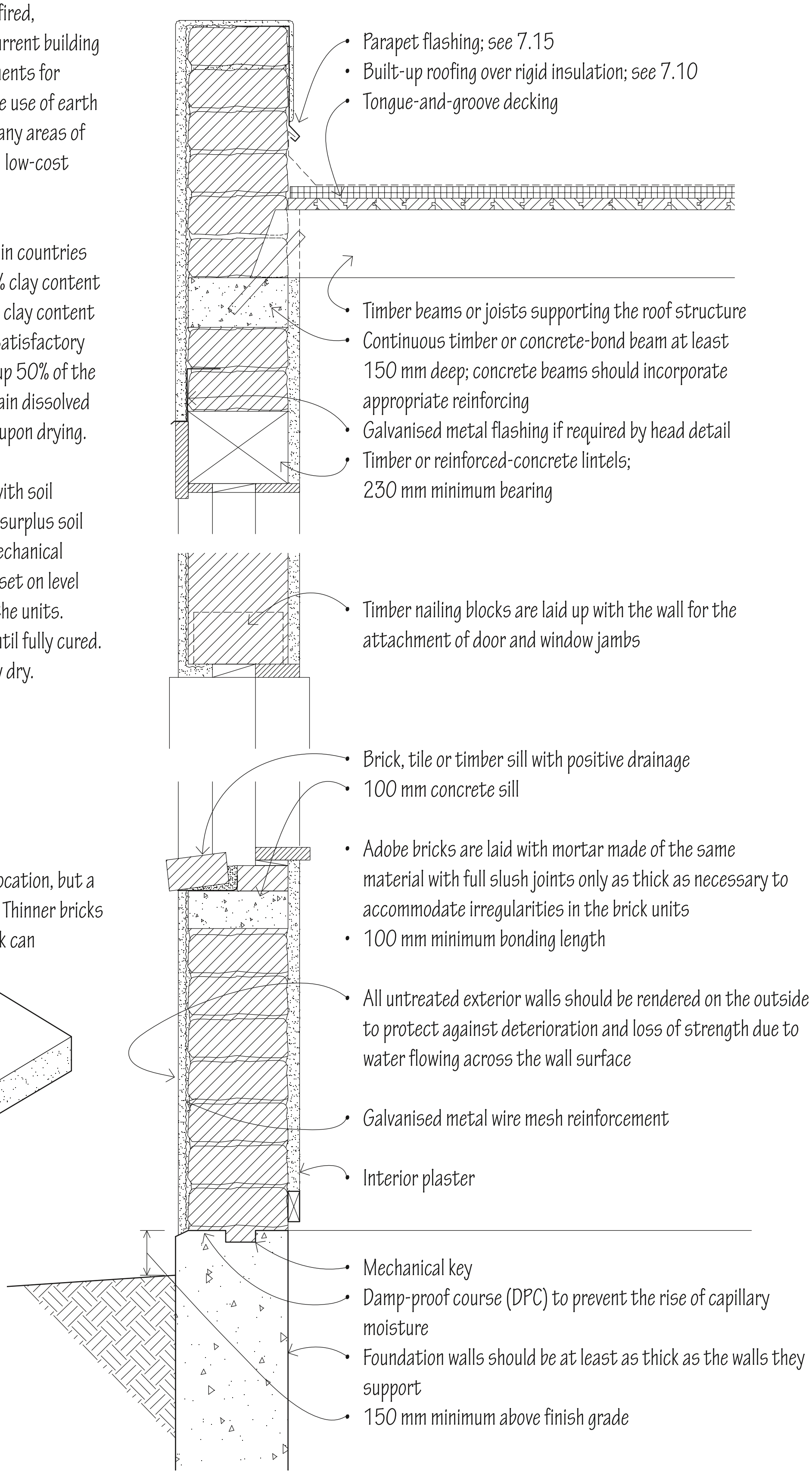
- English garden-wall bond has a single course of headers to every three courses of stretchers with headers centred over the joint between stretchers

- To minimise the cutting of brick and enhancing the appearance of bonding patterns, the major dimensions of masonry walls should be based on the size of the modular units used

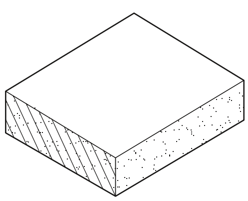
Adobe and rammed-earth construction both use unfired, stabilised earth as the primary building material. Current building regulations vary in their acceptance of and requirements for adobe and rammed-earth construction. However, the use of earth as a building material is an economic necessity in many areas of the world, and both adobe and rammed earth remain low-cost alternative building systems.

Adobe is sun-dried clay masonry, traditionally used in countries with little rainfall. Almost any soil having a 15–25% clay content may be used for the mud mixture; soils with a higher clay content may require tempering with sand or straw to make satisfactory bricks. Gravel or other coarse aggregate may make up 50% of the volume of the mix. The mixing water should not contain dissolved salts, which can recrystallise and damage the brick upon drying.

Adobe brick is typically made near the point of use with soil obtained from the excavation of basements or from surplus soil from site grading. The mud is mixed by hand or by mechanical means and cast in timber or metal forms, which are set on level ground and wetted with water to aid separation of the units. After initial drying, the units are stacked on edge until fully cured. The brick units are extremely fragile until completely dry.

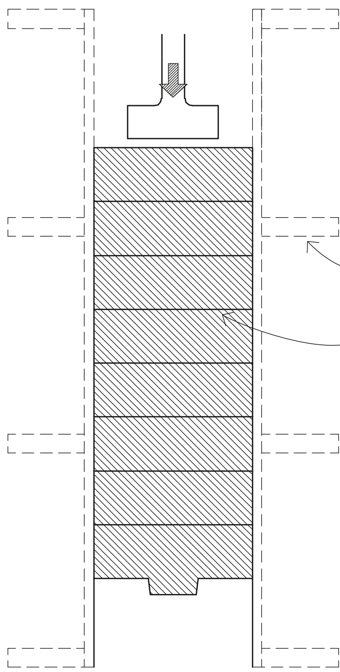


- The dimensions of adobe brick vary according to location, but a common size is 255 x 355 x 50–100 mm thick. Thinner bricks dry and cure faster than thicker bricks. Each brick can weigh 11–14 kg
- Stabilised or treated adobe contains an admixture of portland cement, asphalt emulsion and other chemical compounds to limit the water absorption of the bricks



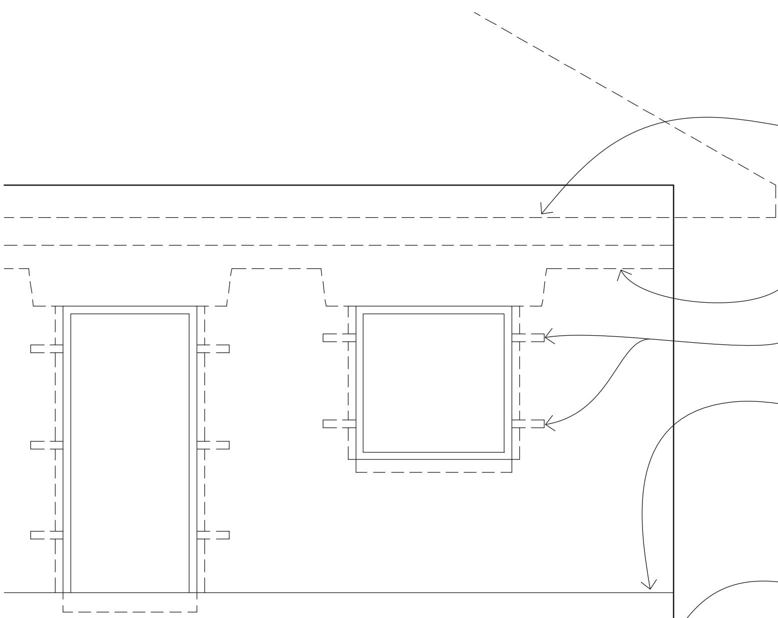
- LEED MR Credit 5: Regional Materials
- BREEAM MAT 01: Life Cycle Impacts

- Adobe and rammed earth have low tensile strength but a compressive strength of 14 kPa or more
- The strength of adobe and rammed-earth construction lies in the mass and homogeneous nature of the wall
- While not as thermally efficient as other insulating materials, adobe and rammed-earth walls serve effectively as thermal mass for heat storage
- LEED MR Credit 5: Regional Materials
- BREEAM MAT 01: Life Cycle Impacts



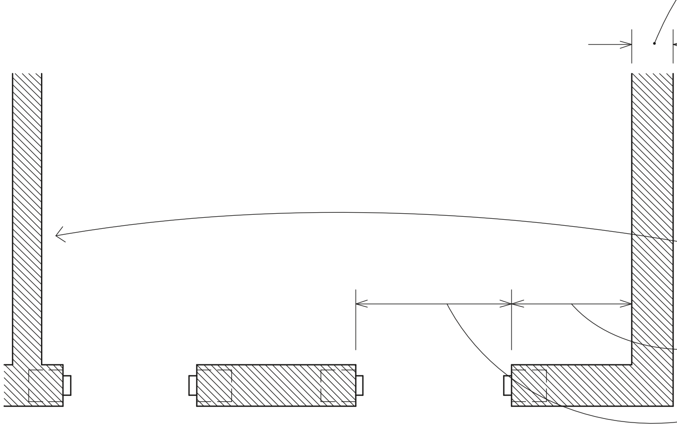
Rammed earth, also called *pisé de terre*, is another traditional building material. It is essentially a stiff mixture of clay, silt, sand and water that is compressed and dried within forms as a wall construction. The soil mixture should contain less than 35% clay and silt, and a maximum aggregate size of 5 mm. Saltwater should never be used in the mix.

- Rammed-earth walls are constructed with slip forms 610–915 mm high and 3000–3660 mm long
- The damp soil mixture (approximately 10% moisture content) is fully compacted by hand or mechanically in lifts or layers not more than 150 mm high before the next lift is placed. Each lift should bond securely with the preceding lift
- Structural loads cannot be placed until the earth has fully dried and cured



General Requirements

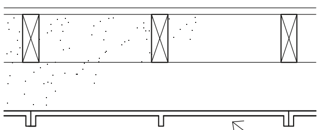
- Requirements for adobe and rammed-earth construction are similar
- Bond beams are required to distribute roof loads and stabilise the tops of bearing walls, as well as at each floor level and at regular intervals to maintain the required thickness-to-unsupported-wall-height ratio
- Bond beams should be reinforced against tension, especially at corners
- Timber anchors for attaching door and window frames are cast with the earth wall
- Sound foundations and ample roof overhangs that protect exterior walls from rain improve the durability of earthen structures

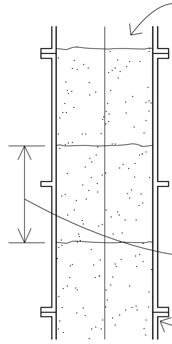


Minimum wall thickness; maximum height:

- 125–200 mm for interior non-bearing walls
- 300 mm for one-storey bearing walls
- 450 mm for the first storey of two-storey bearing walls and 305 mm for the second

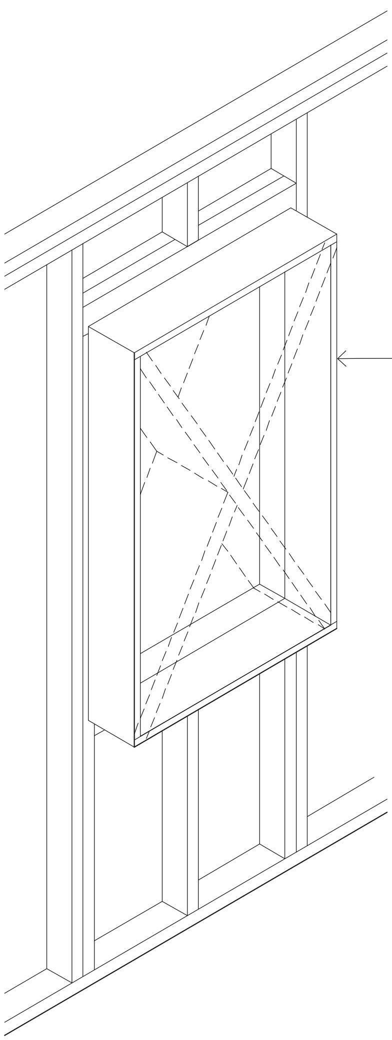
- The height of a freestanding wall should not exceed 10 times its thickness, laterally restrained walls should not exceed 18 times wall thickness
- Provide cross-wall supports maximum 18 times wall thickness
- Window and door openings should be no closer than 750 mm to any corner, with minimum 600 mm between openings
- The total length of wall openings should be limited to 1/3 of the wall length

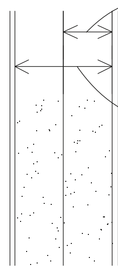




Hemp shiv used in conjunction with a lime-based binder in the ratio of 5:1, when combined with small amounts of water, forms a hemp lime which can be cast into wall, floor or roof constructions. Hempcrete is non-load-bearing so must be used in conjunction with a structural system such as a timber frame.

- Timber frame construction as load-bearing element
- Built up in layers of 200–300 mm and lightly 'tamped' (over tamping can reduce thermal performance)
- Double temporary shuttering or:
- Permanent internal shuttering and temporary external shuttering





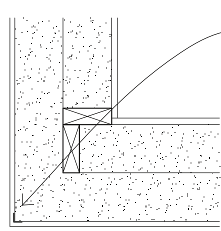
- System becomes self supporting after 24 hours and temporary shuttering can be removed
- Finish with lime-based render to ensure build-up retains its 'breathability'

- Wall thickness ranges from 300 to 500 mm to meet suitable thermal requirements

- Hempcrete is a lightweight material, generally other than permanent shuttering no additional load-bearing elements are required around openings

- Where openings are being formed, temporary propping may be required during the casting process

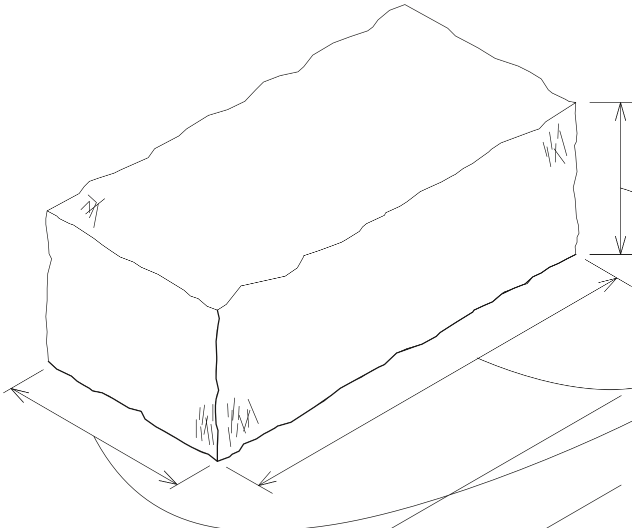
- Building loads should be transferred in the normal way through the supporting structural frame



- Stainless-steel bead to form sharp corner

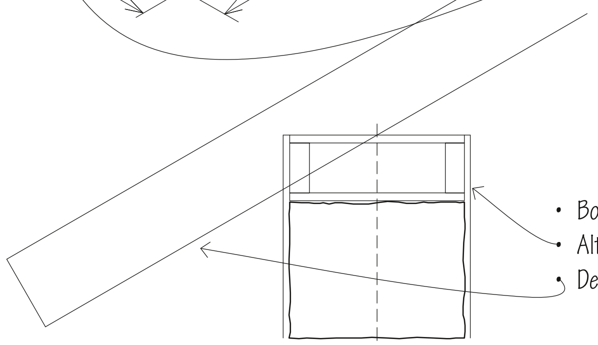
The advantages of hempcrete include:
- Increased thermal performance with minimal thermal bridging
- Vapour open construction; see 7.46
- Relatively low-tech and inexpensive solution
- Carbon neutral

As a construction material the use of straw bale provides a low-impact thermally-efficient material which is often available locally. The modular straw bales can be used directly as a construction material for walls or as part of a prefabricated system. In non-load-bearing scenarios straw bales are often used as infill material in a timber frame. Straw bale can also be used in lightly loaded situations up to two storeys in height. It is important to ensure the bales are kept in a state of compression to maintain stability. Careful detailing is required to avoid moisture-related damage.

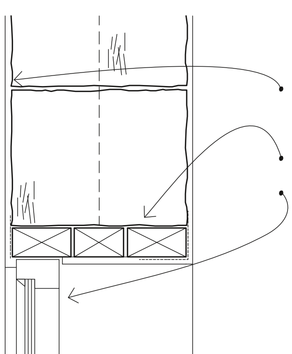


- Typical height 350–400 mm
- Typical length 950–1050 mm
- Typical width 400–500 mm

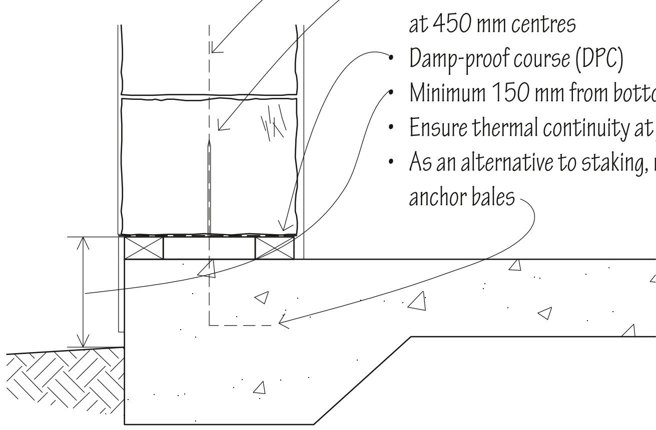
- Ensure bales are tightly bound with a non-degrading material and allowances are made for the likely variation in bale dimensions



- Box beam formed at top of wall to take roof structure
- Alternatively roof structure rests on timber frame in infill construction
- Deep roof overhang to give protection from driven rain



- Lime render or alternative vapour-open finish to minimise the risk of moisture build-up in the construction
- Timber beams to window head
- Window towards the front of the reveal to reduce the risk of water ingress

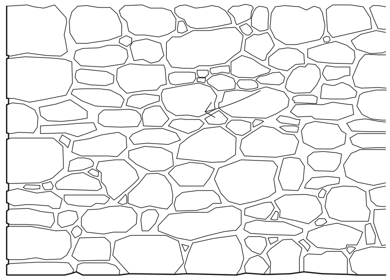


- Hazel stakes driven into wall to improve stability
- Timber stake fixed to slab or rising wall to anchor first course of straw bale at 450 mm centres
- Damp-proof course (DPC)
- Minimum 150 mm from bottom of bale to ground
- Ensure thermal continuity at junction of rising wall and straw bale
- As an alternative to staking, reinforcing bar can be cast into the slab to anchor bales

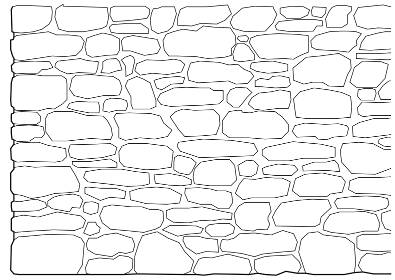
Natural stone is a durable, weather-resistant construction material that may be laid in mortar much like clay and concrete masonry units to make both bearing and non-bearing walls. Some differences result, however, from the irregular shapes and sizes of rubble, the uneven coursing of ashlar masonry, and the varying physical properties of the different types of stone that may be used in the wall construction.

Natural stone may be bonded with mortar and laid up in the traditional manner as a double-faced load-bearing wall. More often, however, stone is used as a facing veneer tied to a concrete or masonry back-up wall. To prevent discoloration of the stone, only non-staining cement and non-corrosive ties, anchors and flashing should be used. Copper, brass and bronze may stain under certain conditions.

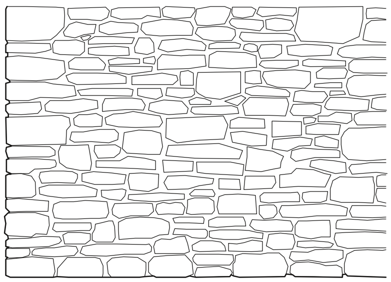
- See 7.27 for stone veneer walls
- See 12.10 for a discussion of stone as a construction material



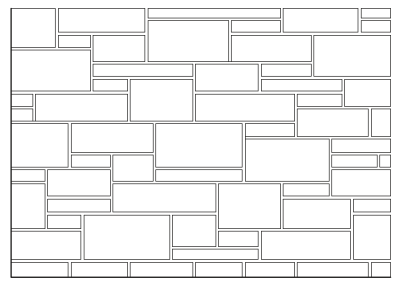
- Random rubble is a masonry wall of broken stones having discontinuous but approximately level beds or courses. The mortar joints are usually held back from the stone faces to emphasise the natural stone shapes



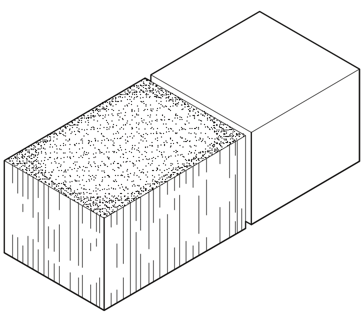
- Coursed rubble is a masonry wall of broken stones having approximately level bed joints and brought at intervals to continuous level courses
- 12–40 mm face joints



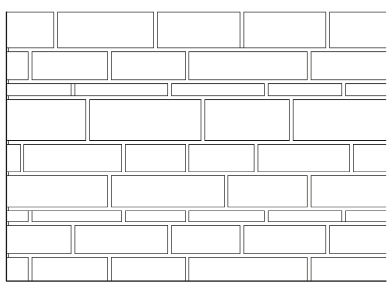
- Squared rubble is a masonry wall built of squared stones of varying sizes and coursed at every third or fourth stone



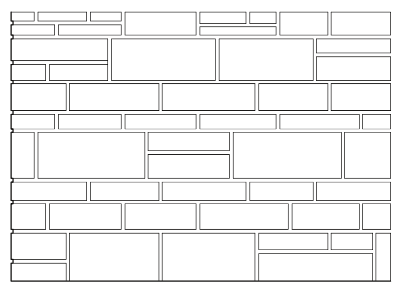
- Random ashlar is built with stones in discontinuous courses



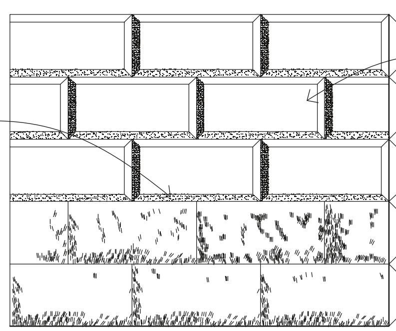
- Ashlar refers to cut building stone finely dressed on all faces adjacent to those of other stones so as to permit very thin mortar joints



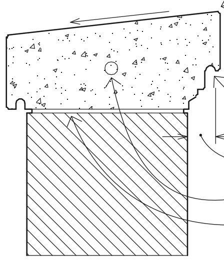
- Coursed ashlar is built of stones having the same height within each course, but with each course varying in height



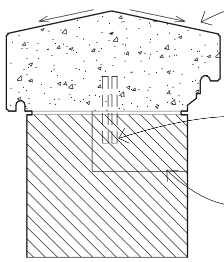
- Broken rangework is ashlar masonry laid in horizontal courses of varying heights, any one of which may be broken at intervals into two or more courses



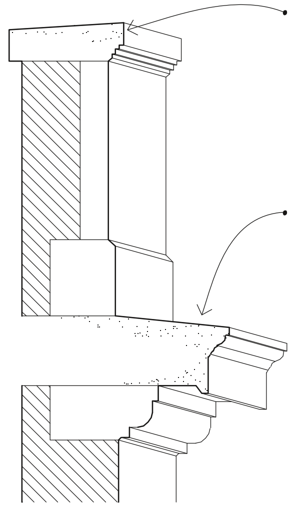
- 10–19 mm face joints
- Rustication is masonry having the visible faces of the dressed stones raised or otherwise contrasted with the horizontal and usually the vertical joints, which may be rabbeted, chamfered or bevelled



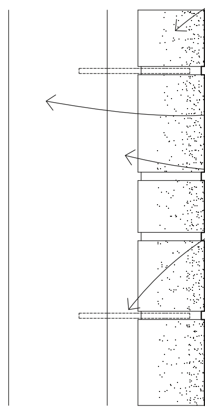
- Splayed copings slope only in one direction
- Drip on each side
- 38 mm minimum
- Centre dowel
- Damp-proof course (DPC)



- Saddle copings slope to either side of a centre ridge
- Two vertical dowels per stone
- Stepped DPC

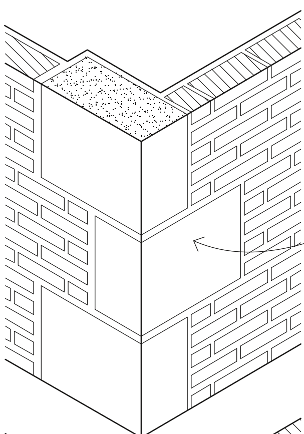


- Copestones form a coping, the finishing or protective course to an exterior wall, usually sloped or curved to shed water
- Dripstone is a stone moulding used as a drip, as on a cornice over a window or doorway

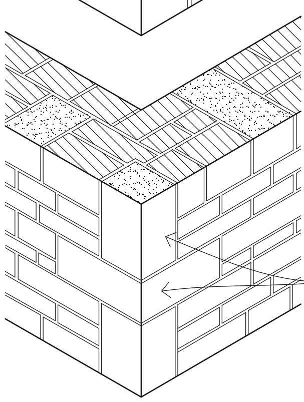


- Stone facing; 100 mm minimum
- Masonry or reinforced-concrete back-up leaf
- The position of the insulation zone in this build-up needs careful consideration
- Non-corrosive metal ties or anchors in dovetail slots
- See 7.27 for stone veneer walls

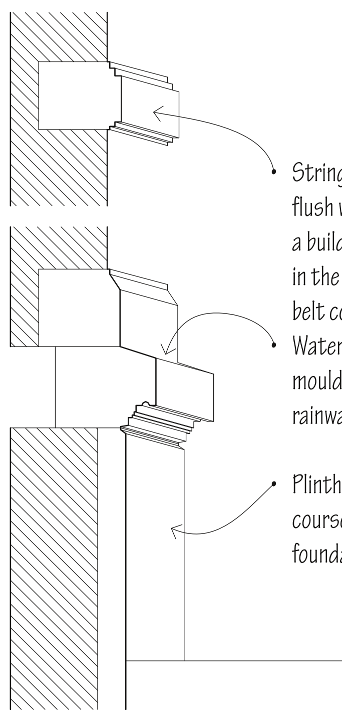
Stone Masonry over a Back-up Wall



- Quoin refers to an exterior angle of a masonry wall, or one of the stones or bricks forming such an angle, usually differentiated from adjoining surfaces by material, texture, colour, size or projection

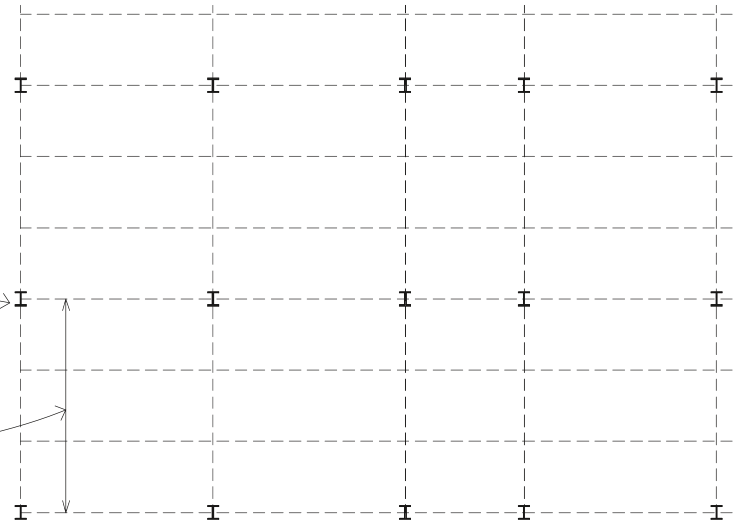


- Long-and-short work is an arrangement of rectangular quoins or jambstones set alternately horizontally and vertically

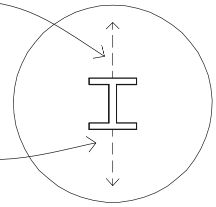


- String course is a horizontal masonry course flush with or projecting beyond the face of a building, often moulded to mark a division in the wall. String courses are also known as belt courses
- Water table is a projecting string course, moulding, or ledge placed so as to divert rainwater from a building
- Plinth is a continuous, usually projecting course of stones forming the base or foundation of a wall

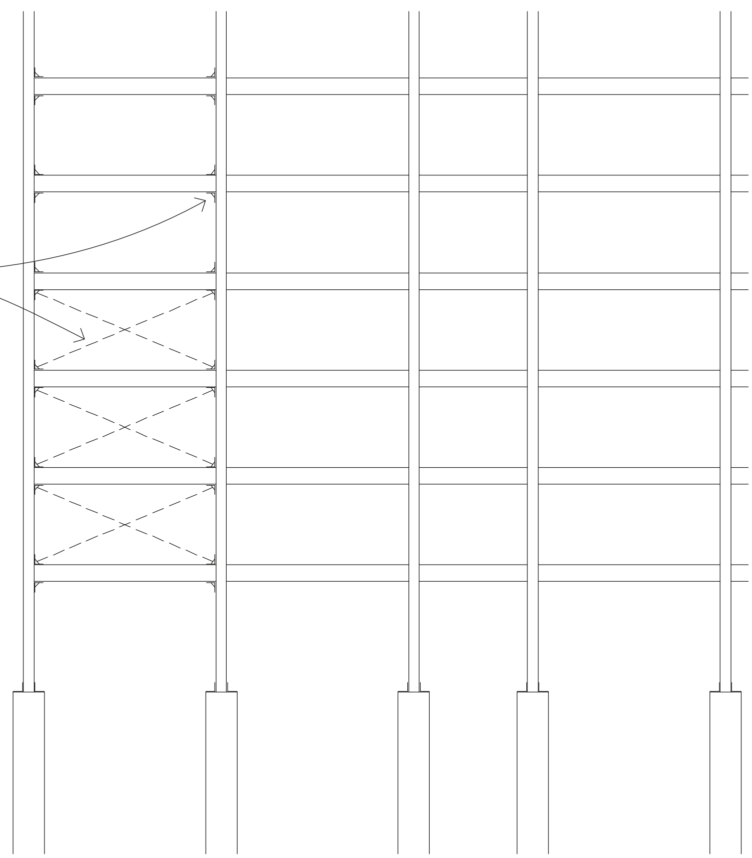
Conventional steel-framed structures are constructed of hot-rolled beams and columns, open-web joists and metal decking. Since structural steel is difficult to work on-site, it is normally cut, shaped and drilled off-site according to design specifications; this can result in relatively fast, precise construction.



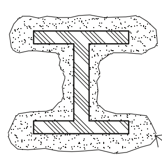
- Steel framing is most efficient when columns are laid out to support a regular grid of beams and/or joists
- Column spacing = main beam spans



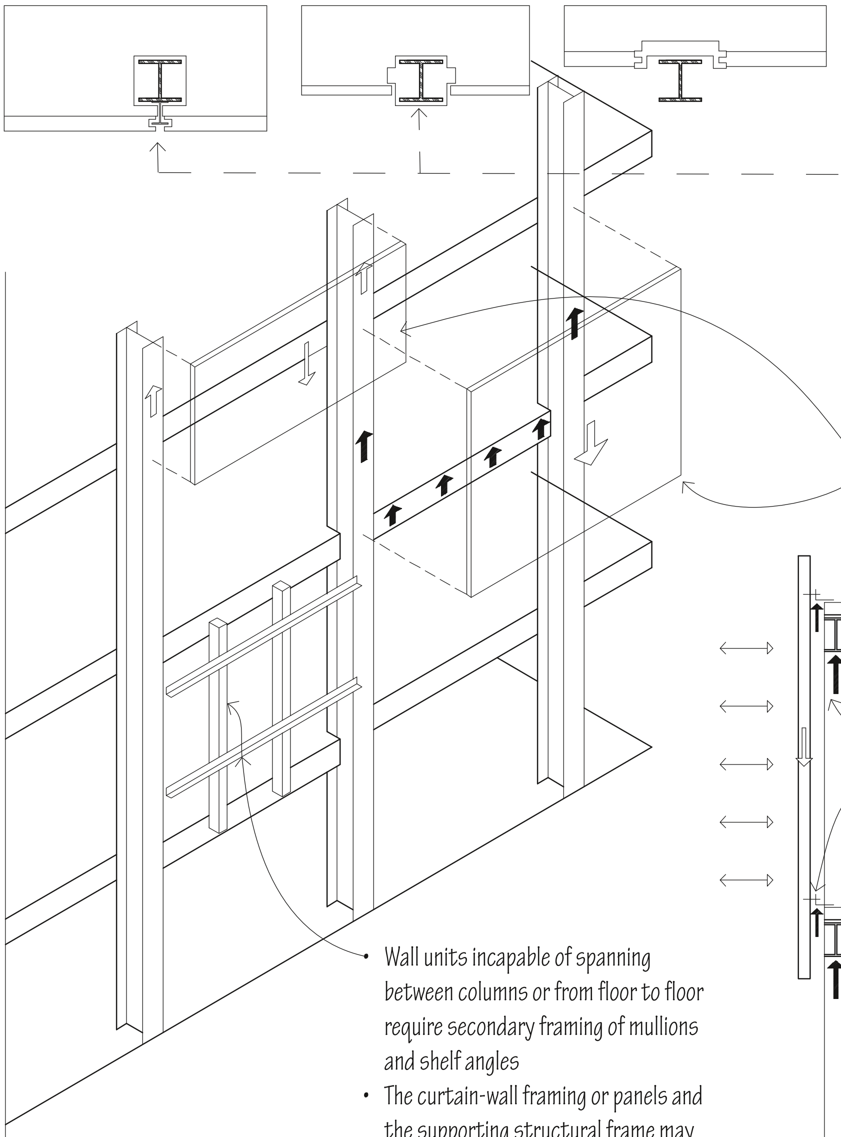
- Orient the webs of columns parallel to the short axis of the structural frame or the direction along which the structure is most susceptible to lateral forces
- Orient the flanges on perimeter columns to the outside to facilitate attachment of curtain walls to the structural frame



- Resistance to lateral wind and seismic forces requires the use of shear planes, diagonal bracing or rigid framing with moment-resisting connections



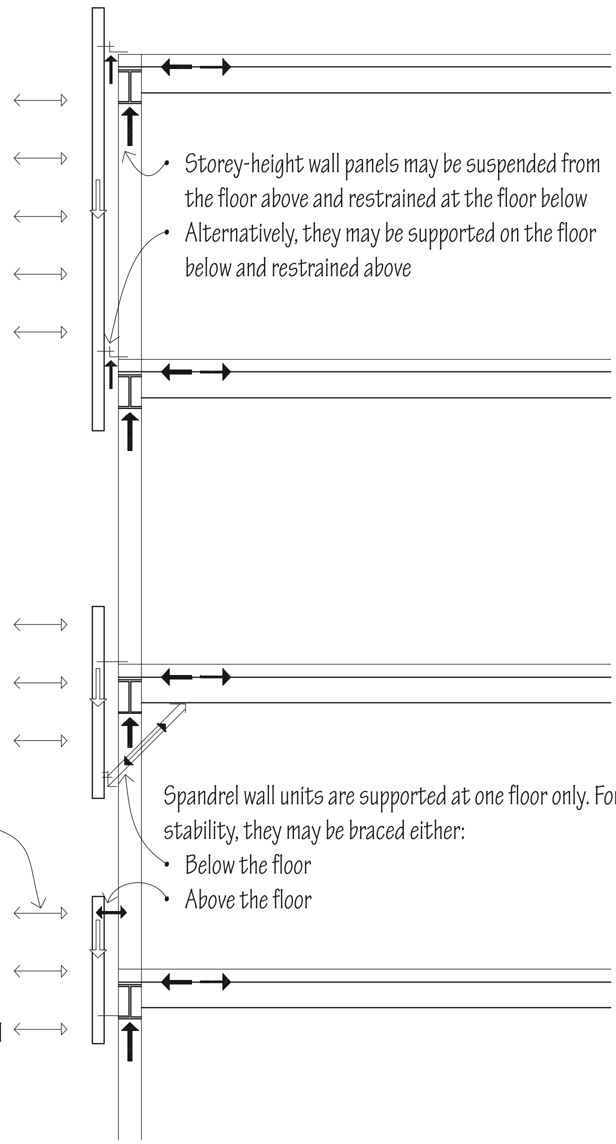
- Because steel can lose strength rapidly in a fire, fire-resistive assemblies or coatings are required; see A.10. In unprotected non-combustible construction, steel framing may be left exposed
- See 4.14 for steel beams and floor framing systems
- See 12.08 for a discussion of steel as a construction material



Because the columns in a steel-frame structure transfer the gravity and lateral loads down to the foundation system, the exterior walls are essentially non-load-bearing curtain walls.

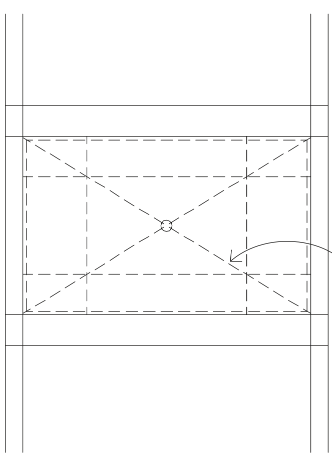
There are three basic relationships that may be established between a structural steel frame and the curtain wall or cladding it supports:
- Column in front of the wall plane
- Column within the wall plane
- Column behind the wall plane

The framing or panels of a curtain wall may be supported in one of two ways:
- By the columns alone
- By the columns as well as by spandrel beams or the edges of floor slabs



- Storey-height wall panels may be suspended from the floor above and restrained at the floor below
- Alternatively, they may be supported on the floor below and restrained above

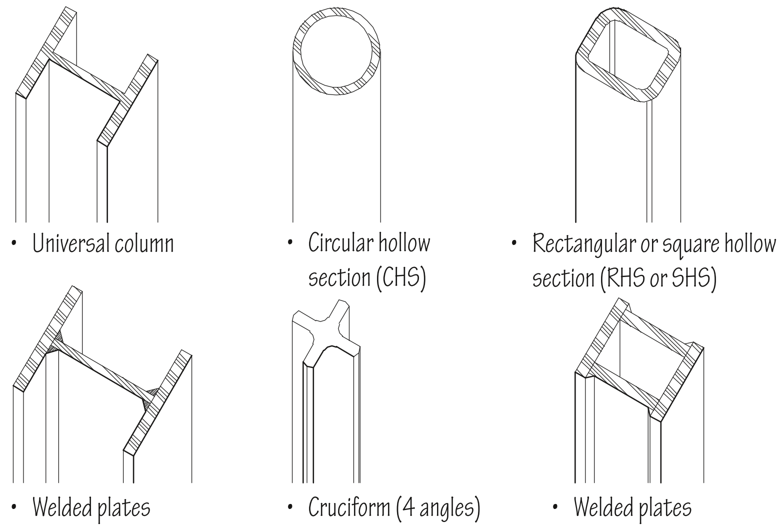
Spandrel wall units are supported at one floor only. For stability, they may be braced either:
- Below the floor
- Above the floor



- Wall units incapable of spanning between columns or from floor to floor require secondary framing of mullions and shelf angles
- The curtain-wall framing or panels and the supporting structural frame may respond differently to variations in temperature and to gravity or wind loads. Connection details should allow for the differential movement between the wall and structural frame, as well as between the wall units themselves
- The wall may be subject to both wind pressure and suction
- If diagonals are used to brace the structural frame, they will affect the design of the wall units

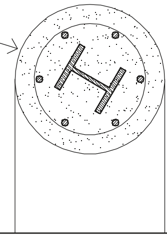
- For general information on curtain-wall systems, see 7.20–7.22
- For glazed curtain walls, see 8.31–8.33

The most frequently used section for columns is the universal column (I-shaped). It is suitable for connections to beams in two directions, and all of its surfaces are accessible for making bolted or welded connections. Other steel shapes used for columns are round pipes and square or rectangular tubing. Column sections may also be fabricated from a number of shapes or plates to fit the desired end-use of a column.



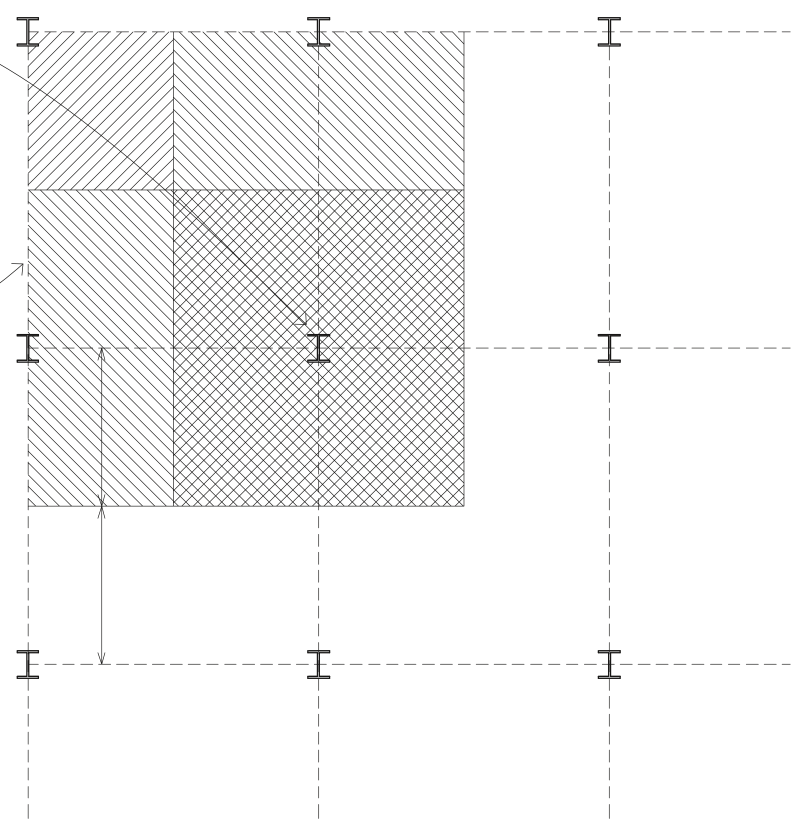
Column Shapes

- Compound columns are structural steel columns encased in concrete at least 75 mm thick, reinforced with wire mesh
- Composite columns are structural steel sections thoroughly encased in concrete reinforced with both vertical and spiral reinforcement



The allowable load on a steel column depends on its cross-sectional area and its slenderness ratio (L/r), where (L) is the effective length of the column in millimetres and (r) is the smallest radius of gyration for the cross section of the column.

- In structural grid, floor loads are evenly distributed into beams and columns



- Column spacing = beam span; see 4.16
- Increased sizes or weights are required for columns supporting heavy loads, rising to greater heights, or contributing to the lateral stability of a structure
- Consult a structural engineer for final design requirements

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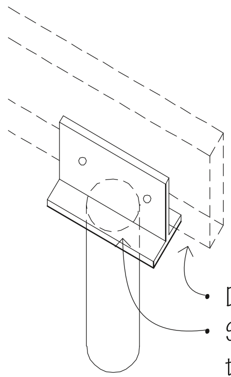
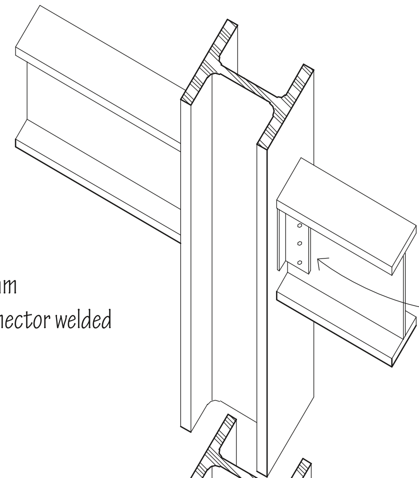
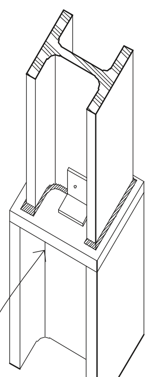


- Double timber beam
- Steel T-plate connector welded to column

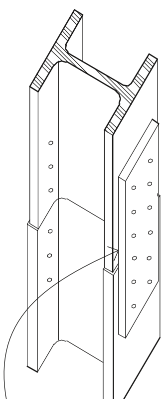


- For steel beam connections, see 4.17–4.18

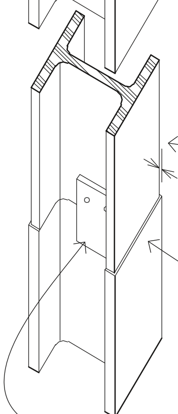
Beam Connections



- When a change in the nominal size of a column occurs, a thick butt plate welded to both column sections is used to transfer the load



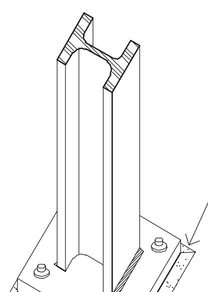
- A backer plate can make up the difference in flange thicknesses at a bolted connection



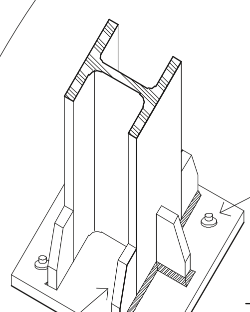
- Plate to keep columns aligned until welds are formed
- Welded butt connection
- As the load on a column diminishes, different flange thicknesses may be used at a column-to-column connection

Column Splices

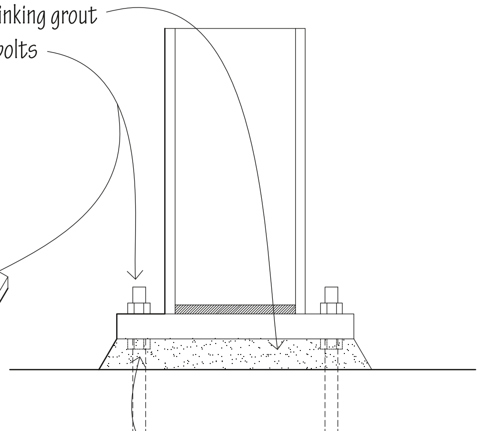
- Non-shrinking grout
- Anchor bolts



- Column is welded to its steel base plate after the plate is levelled on a bed of non-shrinking grout



- Stiffeners may be required when a column bears on a thin base plate

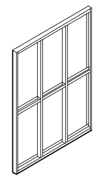


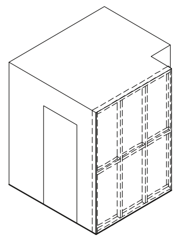
- Base plates for large columns are set on levelling nuts before grouting
- A steel base plate is required to distribute the concentrated load from a column to the concrete foundation to ensure that the allowable stresses in the concrete are not exceeded

Column Bases

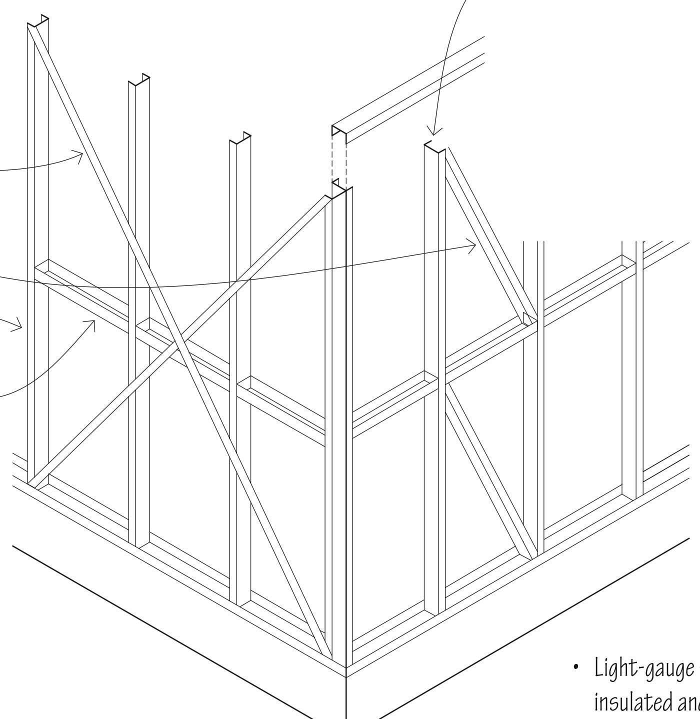
Light-gauge steel studs are manufactured by cold-forming sheet or strip steel. The cold-formed steel studs can be easily cut and assembled with simple tools into a wall structure that is lightweight, non-combustible and damp-proof. Metal stud walls may be used as non-load-bearing partitions or as bearing walls supporting light-gauge steel joists. As in timber light-frame construction, the stud framing contains cavities for building services and thermal insulation and accepts a wide range of finishes.

Light-gauge steel construction can be assembled using stick construction, panel construction or a volumetric system:





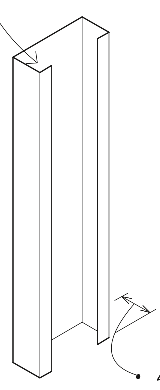
- Panel construction; prefabricated panel sections normally 1200 x 2400 mm are delivered to site for assembly
- Volumetric systems construct complete rooms or buildings in factory conditions and are delivered to site for installation; see 9.30
- Stick construction; each element is assembled on site

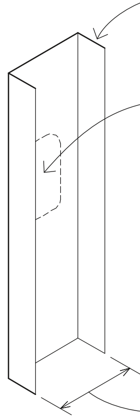


- Diagonal or 'X' bracing using flat plate steel fixed to the face of the frame
- Alternatively a stressed skin can be used
- Channel bracing using steel channels between studs
- Steel studs at 400 or 600 mm centres
- Noggins at maximum 1200 mm centres

- Light-gauge stud walls are framed, sheathed, insulated and finished as in timber light-frame construction
- Connections are made with self-drilling, self-tapping screws inserted with an electric or pneumatic tool, or with pneumatically driven pins

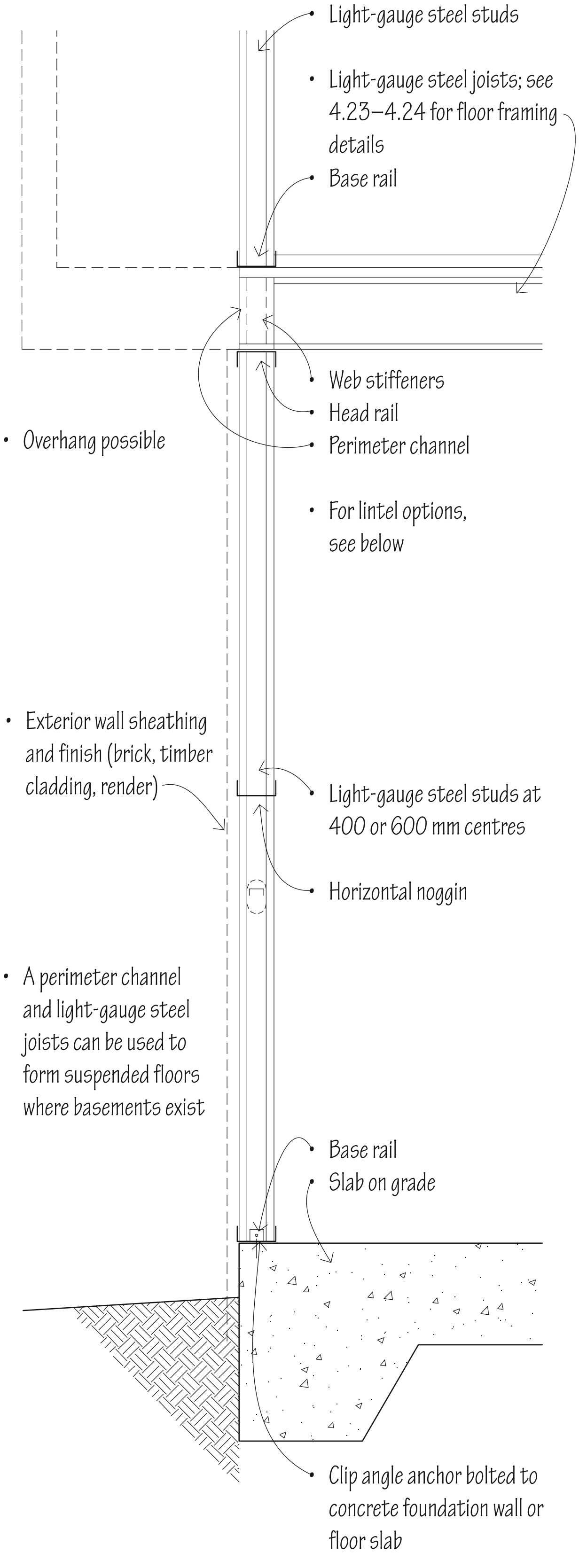
- See 4.22–4.24 for light-gauge joist framing
- See 5.48 for wall sheathing and 7.42 for thermal insulation options



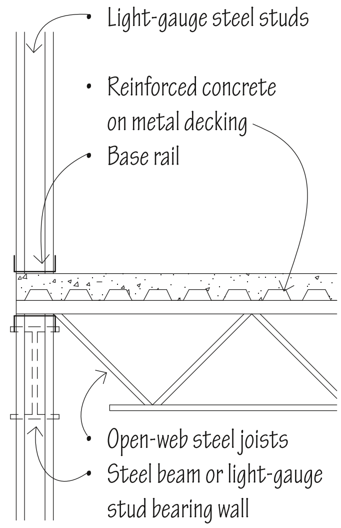


- Lipped C-section
- 40, 50, 65 mm thick
- Standard C-section 1–2 mm gauge
- Light-gauge steel studs are usually prepunched to allow piping and wiring to pass through
- Consult manufacturer for specific shapes and available sizes and gauges
- 75, 100, 120, 140, 150, 165, 180 mm wide

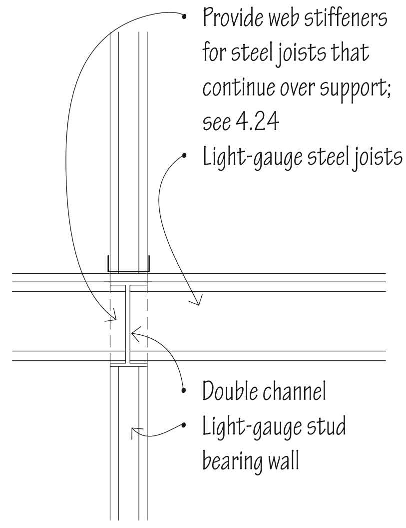
EN Eurocode 3: Design of Steel Structures



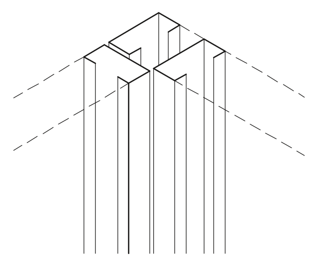
Exterior Wall Section



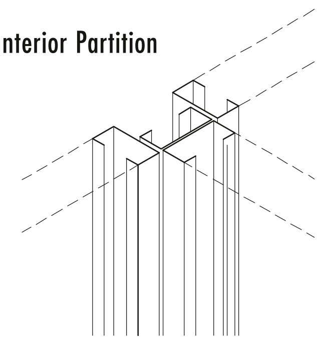
Exterior Wall



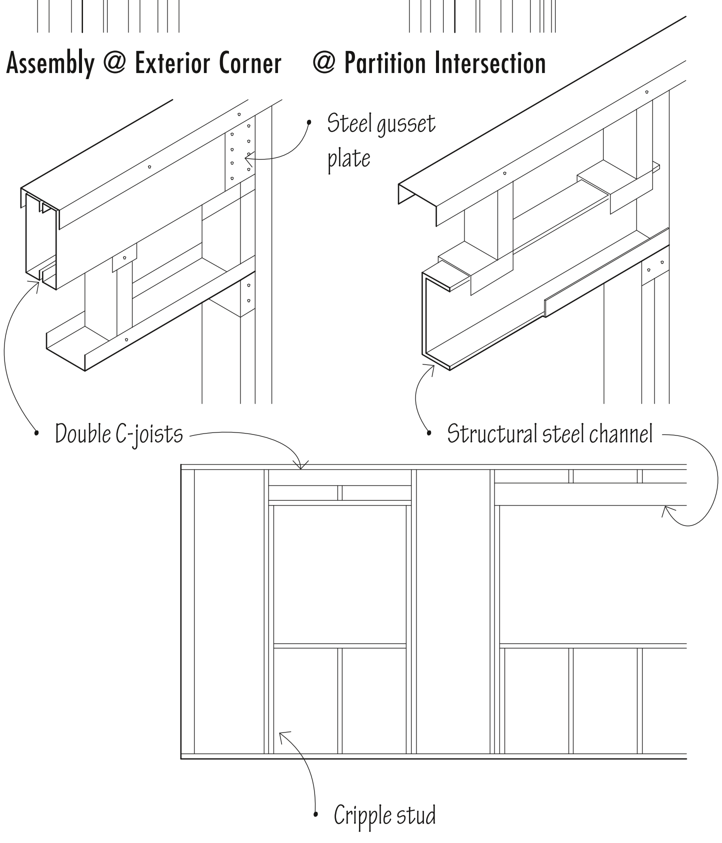
Interior Partition



Stud Assembly @ Exterior Corner

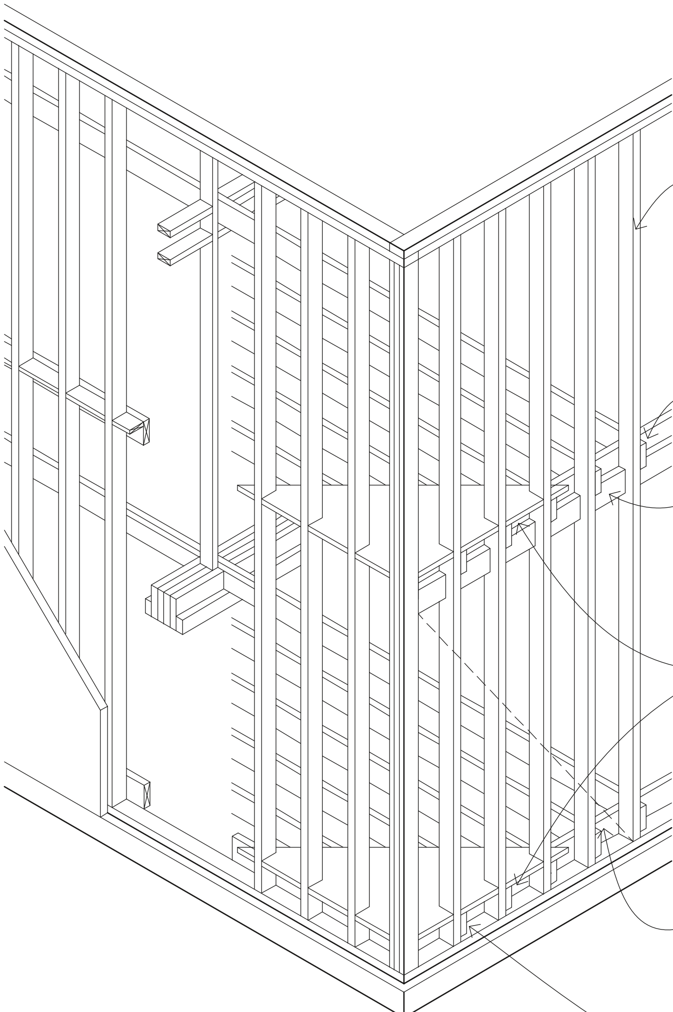


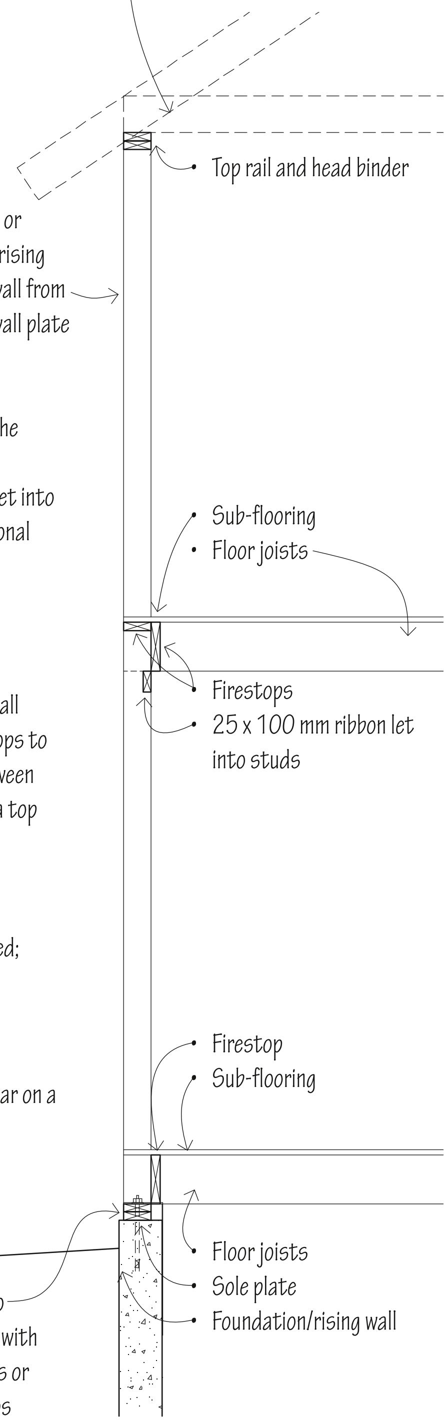
@ Partition Intersection



Framing of Openings

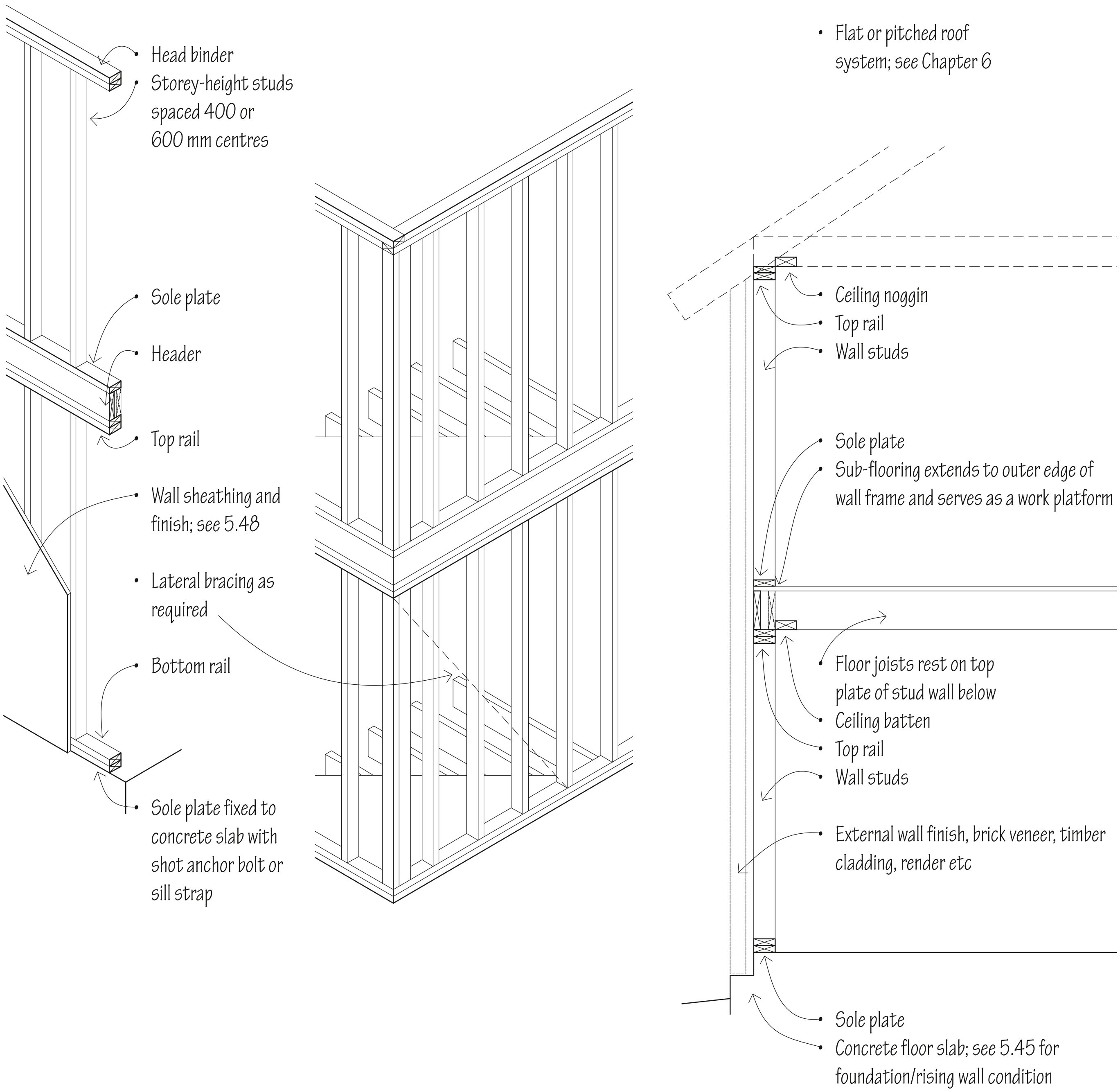
Balloon framing, although now largely superseded by platform framing, utilises studs that rise the full height of the frame from the sole plate to the wall plate, with joists nailed to the studs and supported by sills or by ribbons let into the studs.





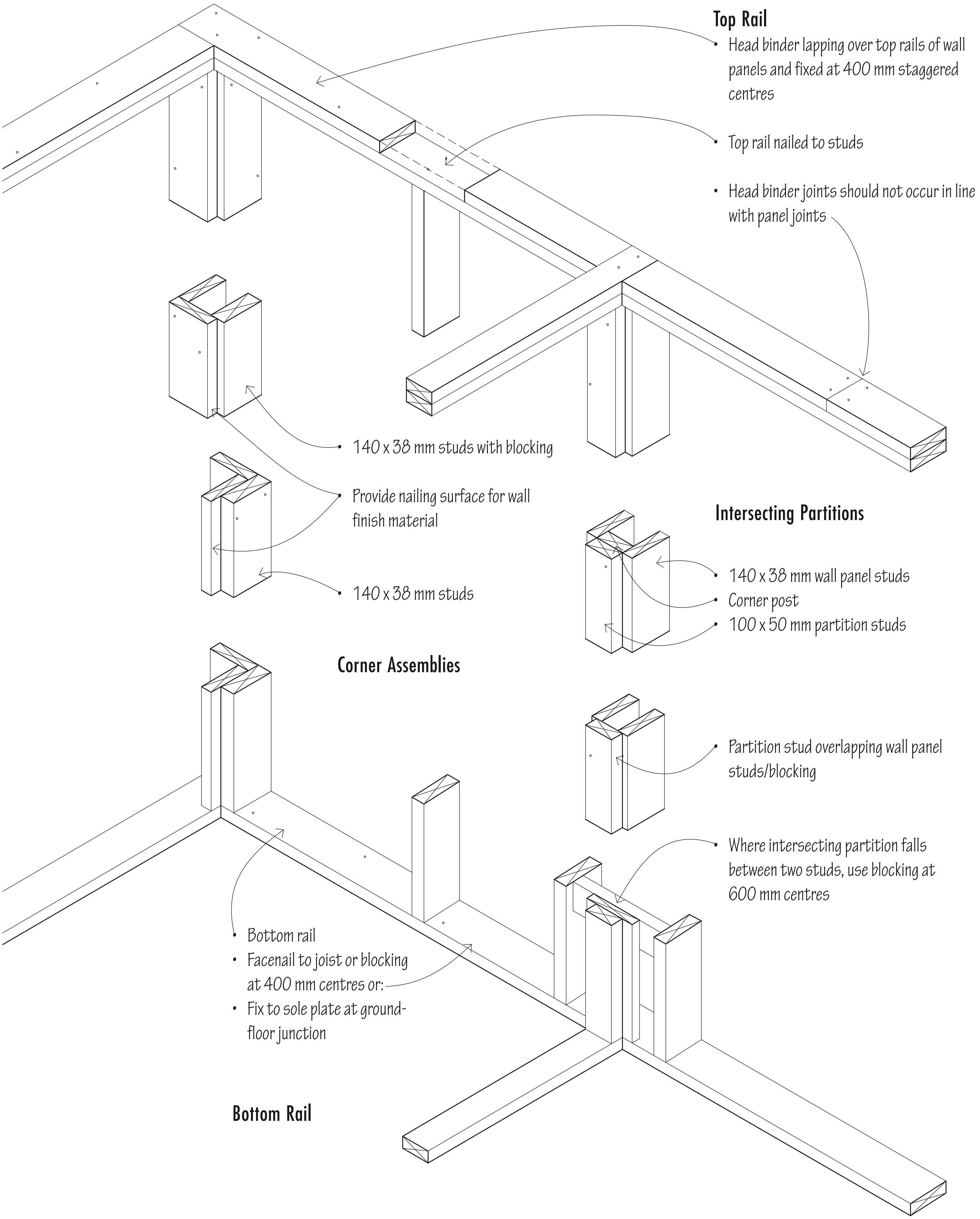
Factors to consider in the selection of an exterior wall finish for stud wall frames include:

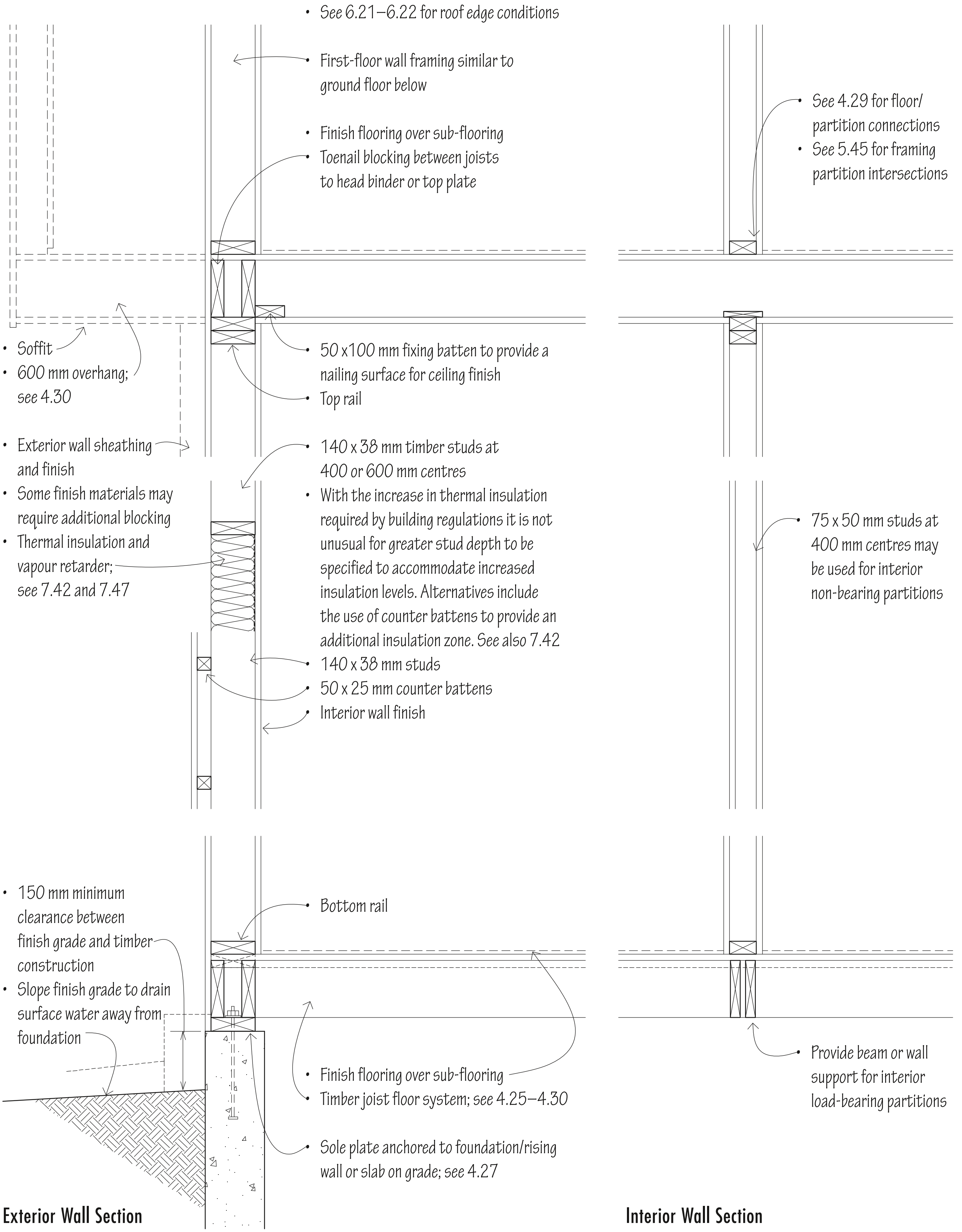
- Stud spacing required
- Sheathing or backing requirements
- Colour, texture, pattern and scale desired
- Detailing of corners and vertical and horizontal joints
- Integration of door and window openings into wall pattern
- Durability, maintenance requirements and weathering characteristics
- Heat conductivity, reflectance and porosity of the material
- Airtightness strategy
- Expansion joints, if required



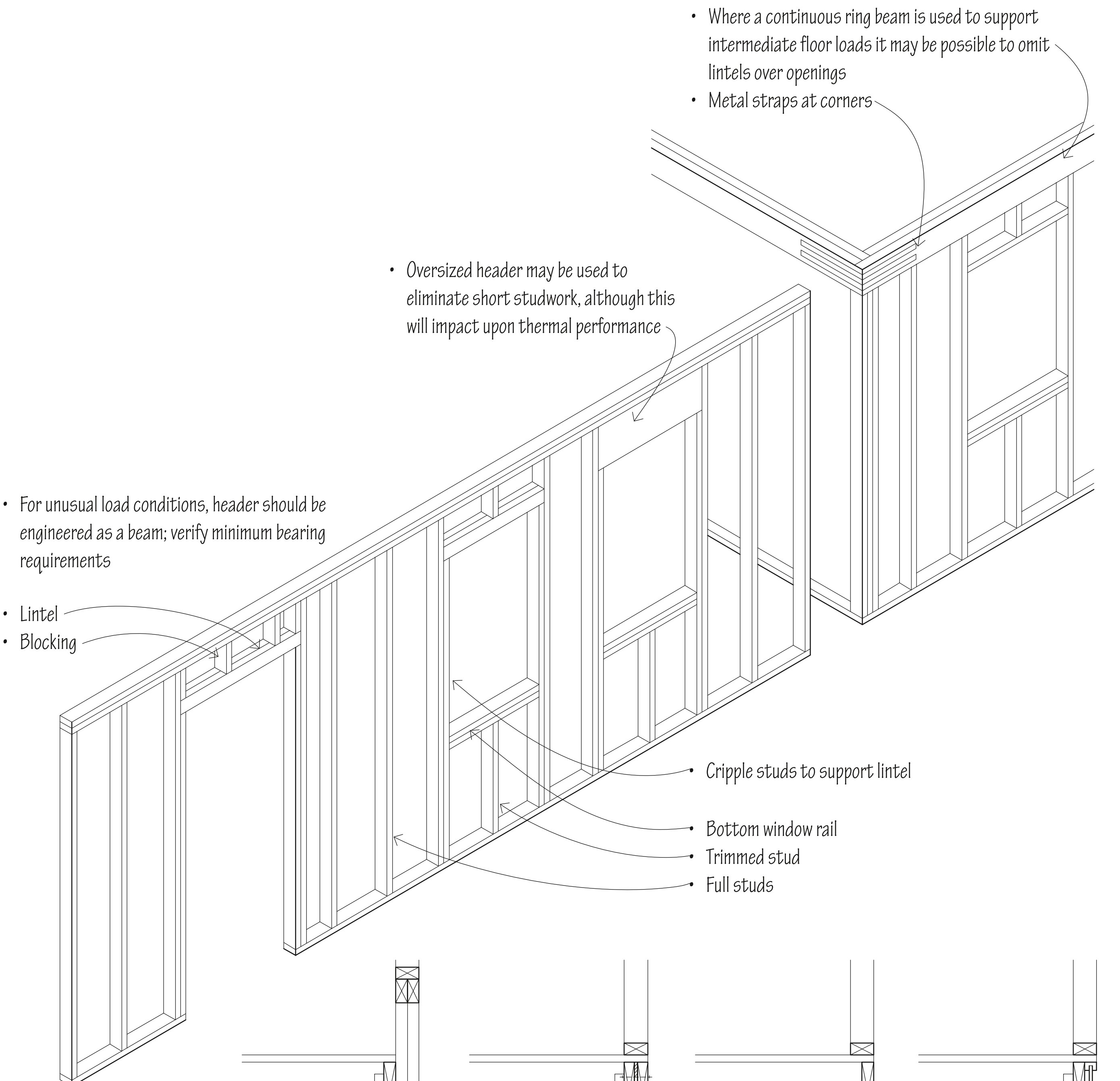
Platform framing is a light timber frame having studs only one storey high, regardless of the storeys built, each storey resting on the platform created by the storey below or on the sole plates of the foundation wall.

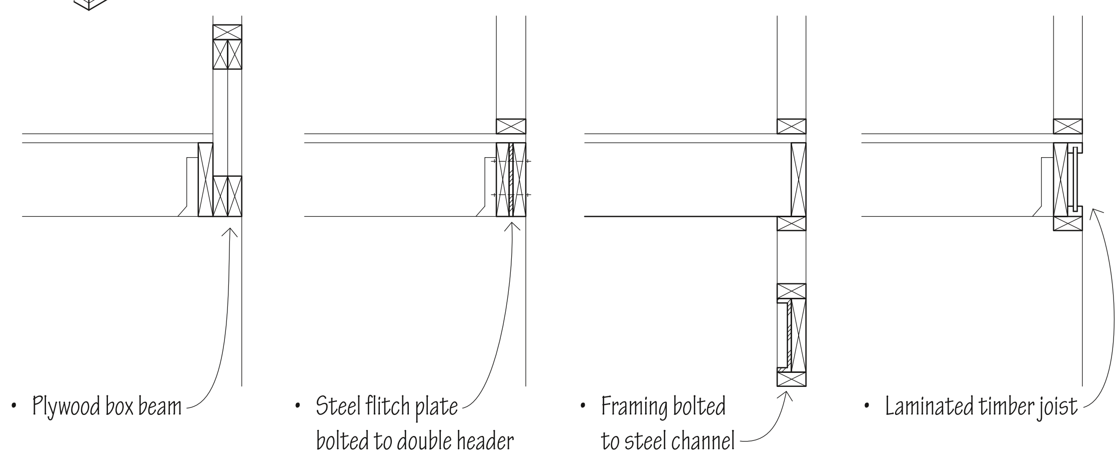
- Stud walls are adaptable to off-site fabrication as panels or as tilt-up construction
- Although vertical shrinkage is greater than in balloon framing, it is equalised between floors


Top Rail
• Head binder lapping over top rails of wall panels and fixed at 400 mm staggered centres
• Top rail nailed to studs
• Head binder joints should not occur in line with panel joints
• 140 x 38 mm studs with blocking
• Provide nailing surface for wall finish material
• 140 x 38 mm studs
Intersecting Partitions
• 140 x 38 mm wall panel studs
• Corner post
• 100 x 50 mm partition studs
Corner Assemblies
• Partition stud overlapping wall panel studs/blocking
• Where intersecting partition falls between two studs, use blocking at 600 mm centres
• Bottom rail
• Facenail to joist or blocking at 400 mm centres or:
• Fix to sole plate at ground-floor junction
Bottom Rail



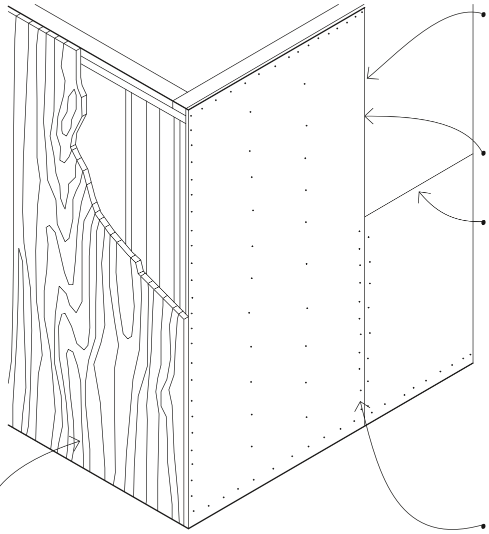
• See 6.21–6.22 for roof edge conditions
• First-floor wall framing similar to ground floor below
• Finish flooring over sub-flooring
• Toenail blocking between joists to head binder or top plate
• See 4.29 for floor/ partition connections
• See 5.45 for framing partition intersections
• Soffit
• 600 mm overhang; see 4.30
• 50 x100 mm fixing batten to provide a nailing surface for ceiling finish
• Top rail
• Exterior wall sheathing and finish
• Some finish materials may require additional blocking
• Thermal insulation and vapour retarder; see 7.42 and 7.47
• 140 x 38 mm timber studs at 400 or 600 mm centres
• With the increase in thermal insulation required by building regulations it is not unusual for greater stud depth to be specified to accommodate increased insulation levels. Alternatives include the use of counter battens to provide an additional insulation zone. See also 7.42
• 140 x 38 mm studs
• 50 x 25 mm counter battens
• Interior wall finish
• 75 x 50 mm studs at 400 mm centres may be used for interior non-bearing partitions
• 150 mm minimum clearance between finish grade and timber construction
• Slope finish grade to drain surface water away from foundation
• Bottom rail
• Finish flooring over sub-flooring
• Timber joist floor system; see 4.25–4.30
• Sole plate anchored to foundation/rising wall or slab on grade; see 4.27
• Provide beam or wall support for interior load-bearing partitions
Exterior Wall Section
Interior Wall Section





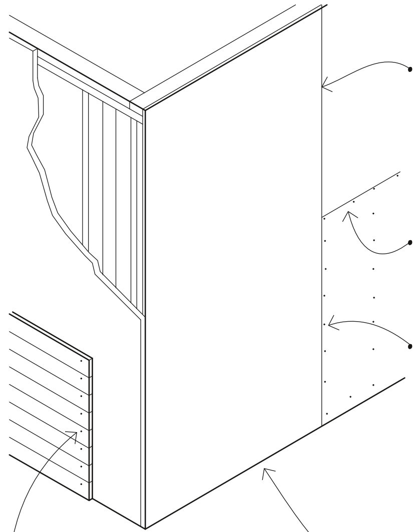
Lintel Options for Wide Openings • *These lintels should be engineered as beams; verify minimum bearing requirements*

5.48 STUD WALL SHEATHING



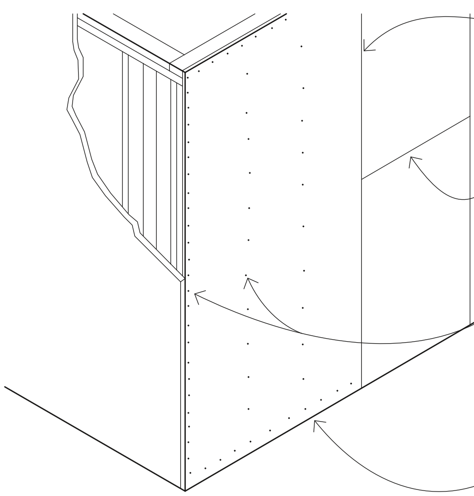
- 3 mm joint spacing unless otherwise recommended by manufacturer
- When applied horizontally, stagger vertical joints
- Support horizontal edges with blocking or plyclips; nail at 300 mm centres and 150 mm centres along edges
- For use as corner bracing, apply vertically and nail at 200 mm centres, and 100 mm centres along edges
- For use as a nailable base for exterior siding: 10 mm minimum for 400 mm stud spacing and 14 mm minimum for 600 mm stud spacing
- 1200 x 2400, 2700, 3000 mm panel sizes

Rated Panel Sheathing



- When applied horizontally, stagger vertical joints
- Support horizontal edges with blocking
- Nail at 200 mm centres
- Fixings requiring a load-bearing connection must be nailed back to the stud frame
- For use as corner bracing, apply 12 mm panels vertically and nail or use adhesives according to manufacturer's recommendations
- 1200 x 2400, 2700, 3000 mm panel sizes

Plasterboard Sheathing

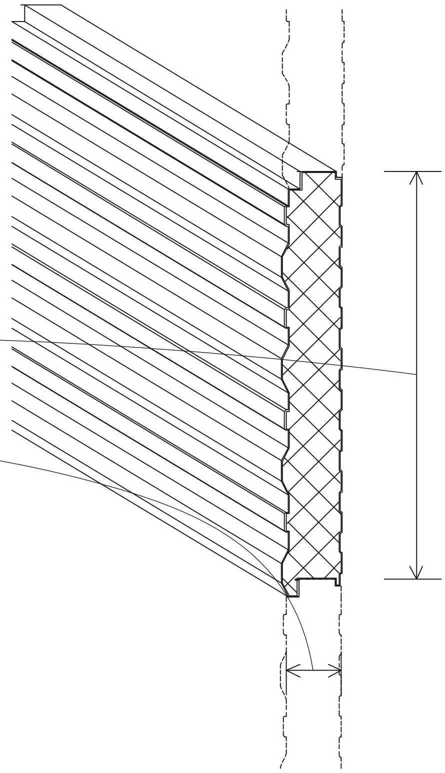


- When applied horizontally, stagger vertical joints
- Solid blocking or tongue and groove (t&g) joints along edges
- Nail at 200 mm centres and 100 mm centres along edges
- For use as corner bracing, use 14 mm high-density panels applied vertically; nail at 150 mm centres and 75 mm centres along edges
- High-density panels may be used as a nailable base for exterior cladding
- 600 x 1200, 1200 x 2400, 2700, 3000 mm panel sizes

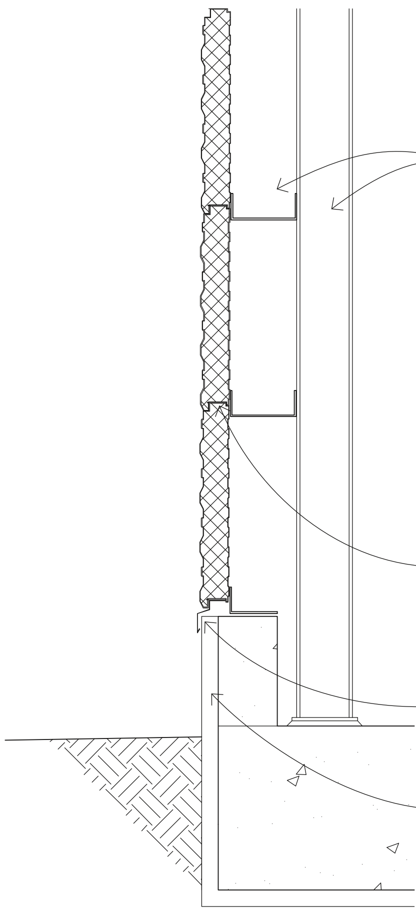
Fibreboard Sheathing

EN 300 2006: Oriented Strand Boards – Definitions, Classifications and Specifications
EN 13986: European Harmonised Standard for Wood-based Panels

Rigid-bonded sandwich panels consist of a layer of rigid foam insulation bonded to two thin layers of steel, this composite construction can resist wind and snow loads. The panels are non-load-bearing, loads must be transferred to a primary load-bearing structure. Sandwich panels are mainly used in industrial buildings to allow for relatively low-cost simple construction and a relatively quick build time.



- Proprietary systems incorporate horizontal jointing mechanisms to maintain a weathertight seal
- Panels are generally produced as 500–600 mm modules in long sections limited by transportation
- Panel thicknesses vary from 50 to 100 mm
- Steel sheets are corrugated to increase the strength of the panels



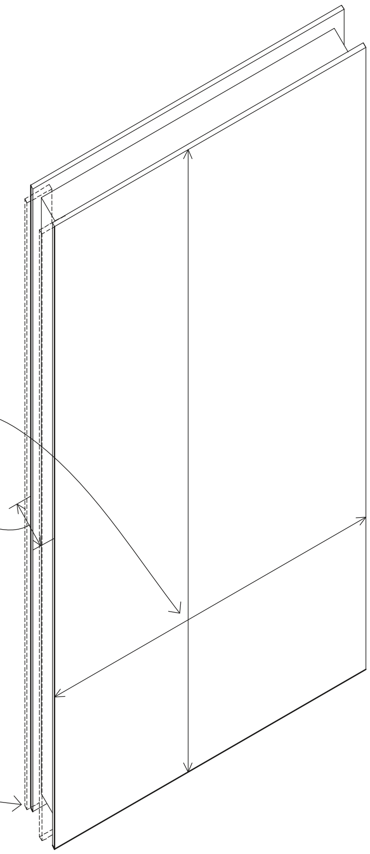
- Panels come in a range of profiles from different manufacturers
- The panels can be finished to any RAL number
- Sandwich panels can also be used for roof finishes on industrial buildings

Similar built-up systems are available and offer an alternative on-site solution; see 7.28.

- Sandwich panels fixed to purlins in turn fixed back to primary structural frame
- Panels can be installed horizontally or vertically
- Fixings required at a maximum of 500 mm centres depending on panel size and specification
- Fixings concealed within panel joints and include a rubber washer to provide a weathertight seal
- Panel profile incorporates a drip to prevent water ingress by capillary action
- Ensure continuity of insulation layer at all junctions

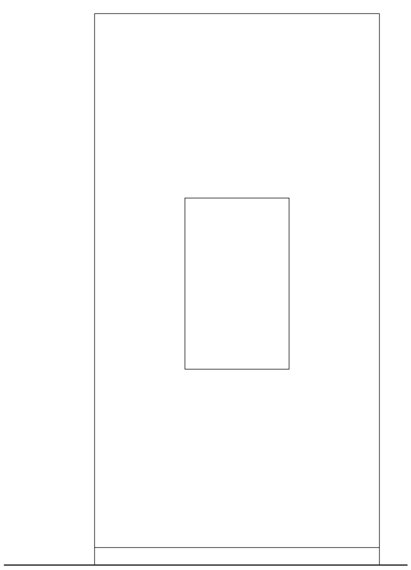
5.50 STRUCTURAL INSULATED PANELS

Structural insulated panels or SIPs consist of a layer of rigid cellular insulation sandwiched between two layers of oriented strand board (OSB) or cement-bonded particle board (CBPB) for a lightweight, thermally efficient construction that through its composite strength can be used as a load-bearing element.

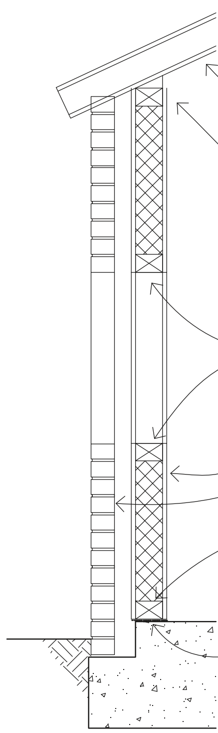


- Panels are normally produced in 1200 x 2400 mm section, although bespoke panels are available
- Standard panel thickness varies from 70 to 250 mm

- Most systems incorporate horizontal jointing mechanisms to tie panels together, improve weathertightness, reduce air infiltration and avoid thermal bridging
- OSB splines



Elevation



Wall Section

- Opening sections are formed as part of the prefabrication process, reducing waste

- SIPs can be used to form internal walls, party walls and roof members (see 6.27 for roof details)

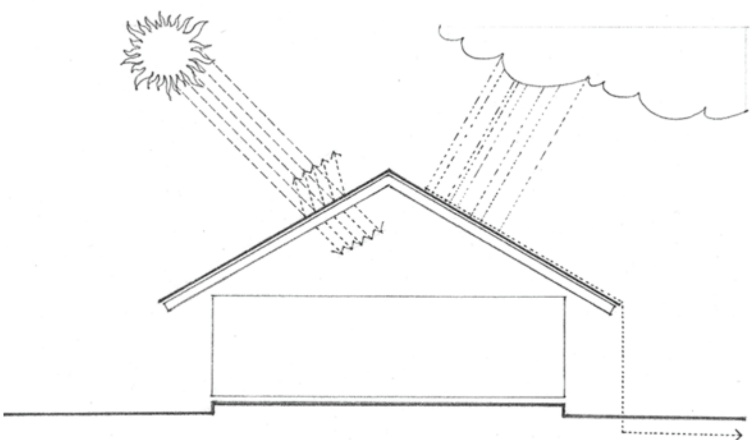
- Wall plate
- Timber blocking at opening sections
- Structural insulated panel
- Brick veneer, timber cladding or rendered external finish
- Plasterboard and skim coat internal finish

- Sole plate
- Damp-proof course

- SIPs are typically applied in low-rise construction up to three storeys in height

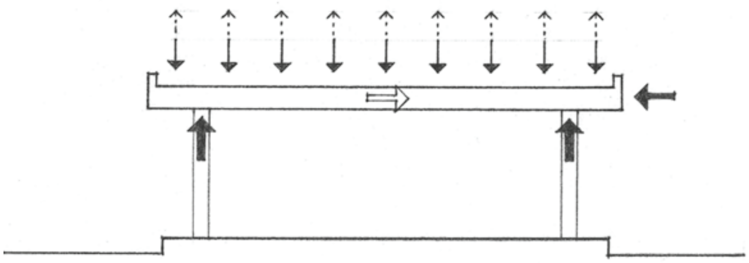
6

ROOF SYSTEMS



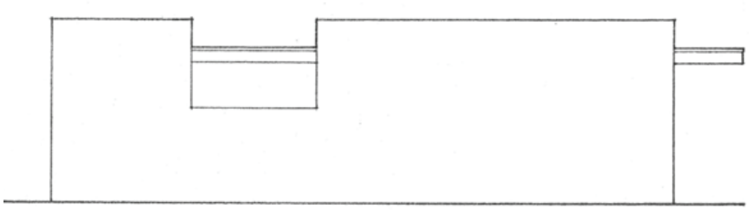
LEED EA Credit 1: Optimize Energy Performance
BREEAM ENE 01: Reduction of CO_2 Emissions

The roof system functions as the primary sheltering element for the interior spaces of a building. The form and slope of a roof must be compatible with the type of roofing – slates, tiles, sheet metal or a continuous membrane – used to shed rainwater and melting snow to a system of drains, gutters and downpipes. The construction of a roof should also control the passage of moisture vapour, the infiltration of air and the flow of heat and solar radiation. Depending on the type of construction required by the building regulations, the roof structure and assembly may have to resist the spread of fire.

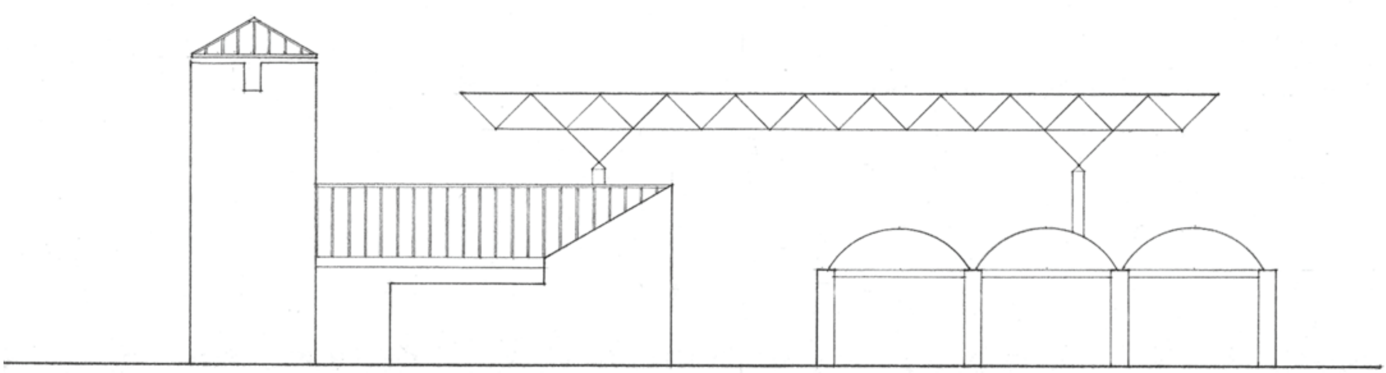


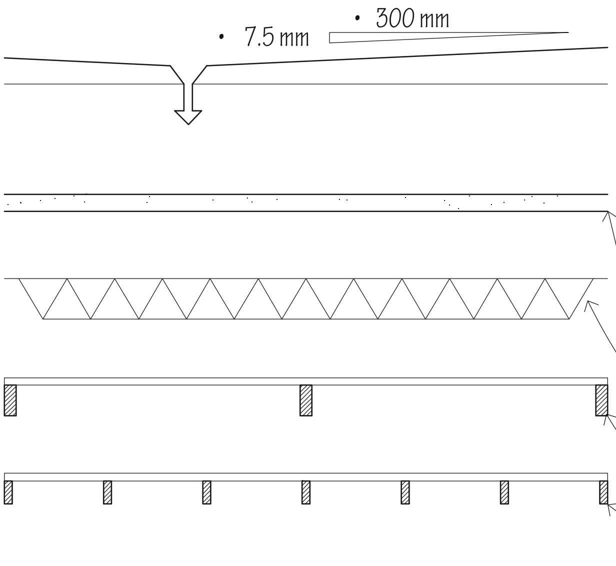
Like floor systems, a roof must be structured to span across space and carry its own weight as well as the weight of any attached equipment and accumulated rain and snow. Flat roofs used as decks are also subject to live occupancy loads. In addition to these gravity loads, the planes of the roof may be required to resist lateral wind and seismic forces, as well as uplifting wind forces, and transfer these forces to the supporting structure.

Because the gravity loads for a building originate with the roof system, its structural layout must correspond to that of the column and bearing wall systems through which its loads are transferred down to the foundation system. This pattern of roof supports and the extent of the roof spans, in turn, influences the layout of interior spaces and the type of ceiling that the roof structure may support. Long roof spans would open up a more flexible interior space while shorter roof spans might suggest more precisely defined spaces.



The form of a roof structure – whether flat or pitched, gabled or hipped, broad and sheltering, or rhythmically articulated – has a major impact on the image of a building. The roof may be exposed with its edges flush with or overhanging the exterior walls, or it may be concealed from view, hidden behind a parapet. If its underside remains exposed, the roof also transmits its form to the upper boundaries of the interior spaces below.





Flat Roofs

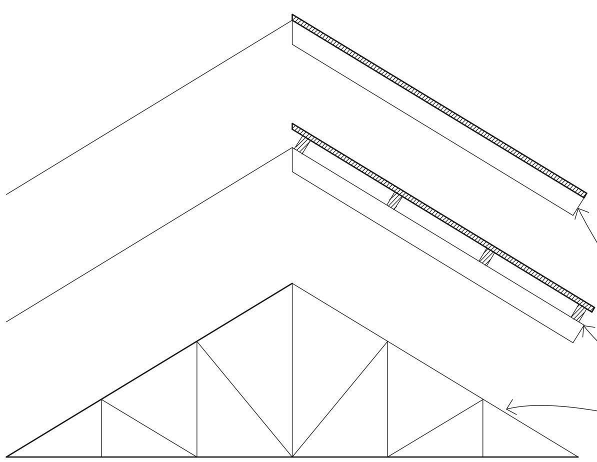
- Flat roofs require a continuous membrane roofing material
- Minimum recommended design fall: 1:40
- The roof slope may be achieved by inclining the structural members or roof deck, or by tapering the layer of thermal insulation
- Depending on design, large roofs can incorporate interior drains, while smaller roofs normally use perimeter drainage
- Flat roofs can efficiently cover a building of any horizontal dimension, and may be structured and designed to serve as an outdoor space
- The structure of a flat roof may consist of:
  - Reinforced-concrete slabs
  - Flat timber or steel trusses
  - Timber or steel beams and decking
  - Timber or steel joists and sheathing

Pitched Roofs

- Pitched roofs range from 18º to 60º, generally any pitch less than 10º should be treated as a flat roof

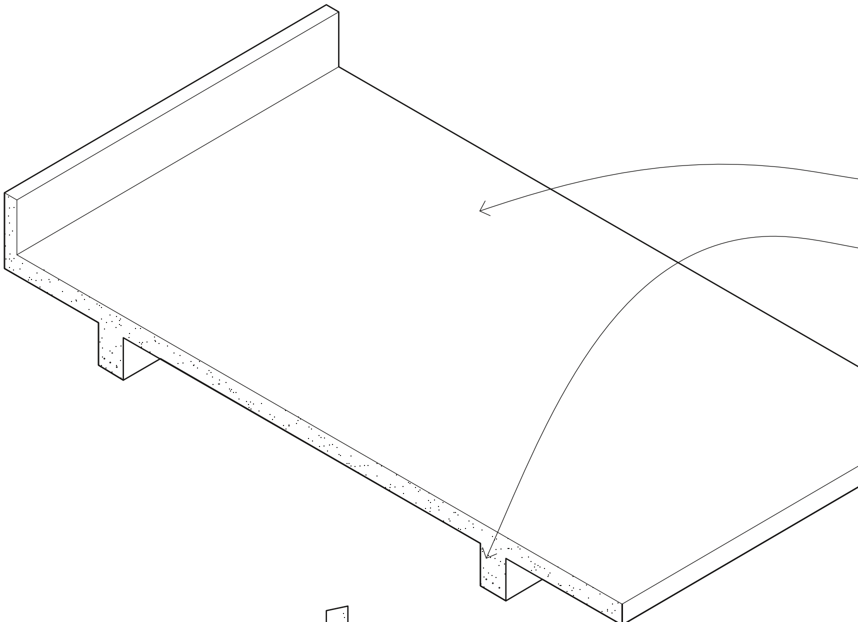
- The roof slope determines the choice of roofing material, the requirements for underlay and eaves flashing, and design wind loads
- Low-slope roofs require roll or continuous membrane roofing; some sheet materials may be used on low pitch roofs
- Medium- and high-slope roofs may be covered with slates, tiles or sheet materials
- Sloping roofs shed rainwater easily to eaves gutters

- The height and area of a sloping roof increase with its horizontal dimensions
- The space under a sloping roof may be usable
- Sloping roof planes may be combined to form a variety of roof forms

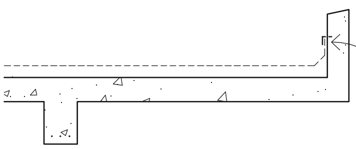


- Sloping roofs may have a structure of:
  - Wood or steel rafters and sheathing
  - Timber or steel beams, purlins and decking
  - Timber or steel trusses

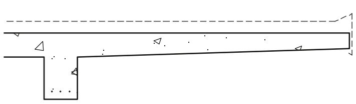
Reinforced-concrete roof slabs are formed and cast in-situ the same manner as the concrete floor systems illustrated on 4.05–4.07. Roof slabs are normally covered with a type of membrane roofing shown in the cross section below. See 7.08 for flat roof assemblies.



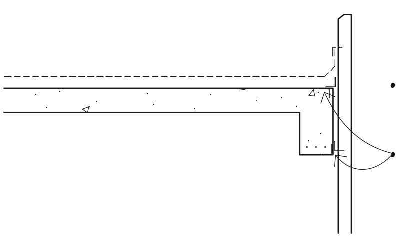
- Slope top of slab or layer of roof insulation for roof drainage; 1:40 minimum recommended
- Roof slabs may be supported by reinforced-concrete columns, reinforced-concrete frames or bearing walls of reinforced concrete or masonry



- An upturned edge beam can form a parapet wall
- Metal flashing to protect weathering at upstand

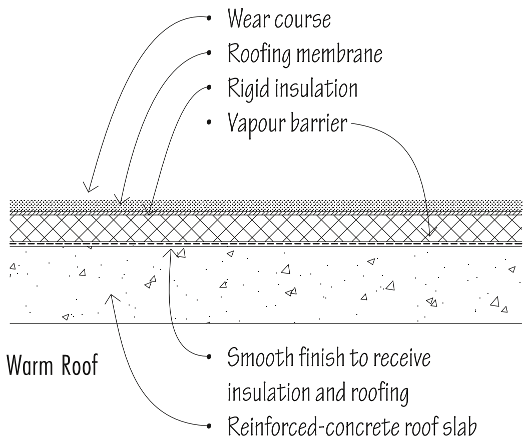


- The slab can be cantilevered beyond its perimeter supports to form an overhang

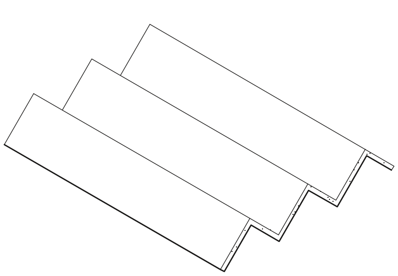


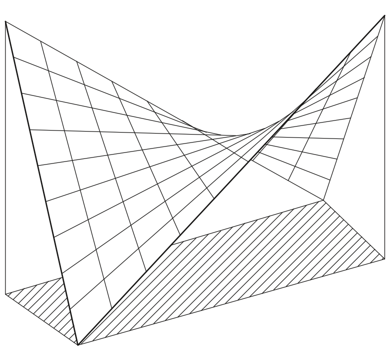
- An edge or spandrel beam can support a non-bearing curtain wall
- Metal anchors may be cast into the spandrel beams to secure the curtain wall panels

- The edge of a concrete roof slab may be treated in three different ways



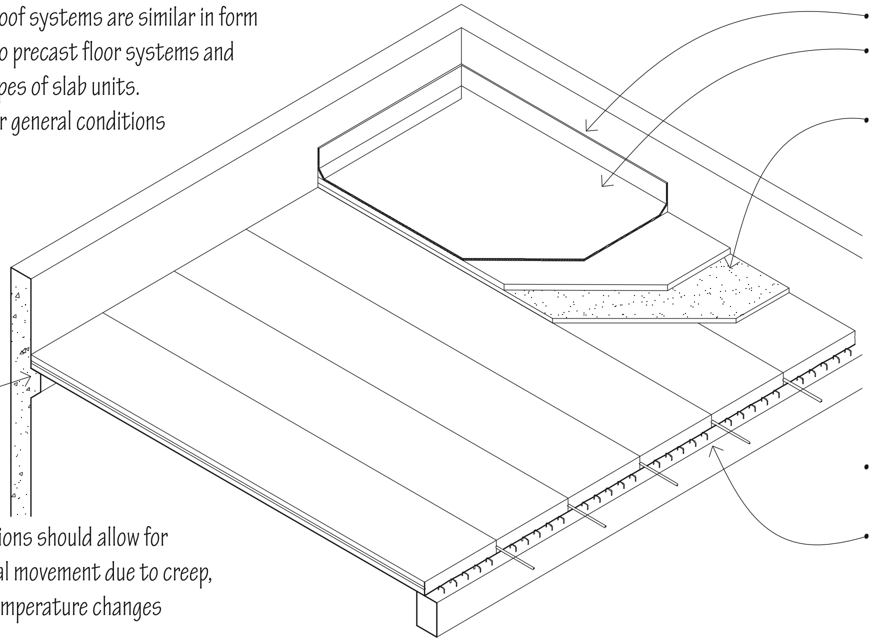
Warm Roof



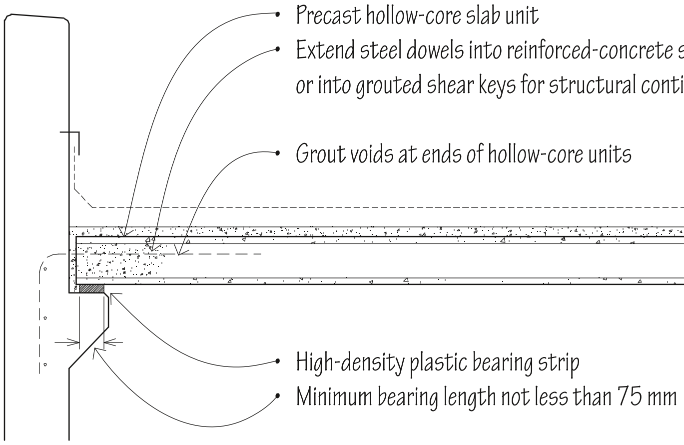


Reinforced concrete may be designed and cast into a variety of other roof forms, such as folded plates, domes and shell structures; see 2.17 and 2.25–2.26.

Precast-concrete roof systems are similar in form and construction to precast floor systems and utilise the same types of slab units. See 4.11–4.13 for general conditions and requirements.

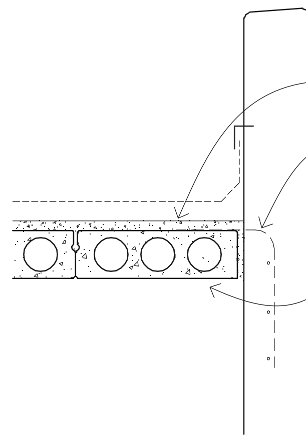


- See 7.15 for parapet flashing
- Roofing membrane over rigid insulation; see 7.08
- Concrete screed cast in-situ, reinforced with welded wire fabric or reinforcing bars, bonds to precast slabs to form a composite structural unit. The topping may be omitted if rigid foam insulation is laid over smooth-surfaced precast units
- Bearing connections should allow for limited horizontal movement due to creep, shrinkage and temperature changes
- Slope concrete topping or precast units to drain; 1:40 minimum recommended
- To serve as a horizontal diaphragm and transfer lateral forces to shear walls, steel reinforcement must tie the precast slab units to each other over their supports and at their end bearings



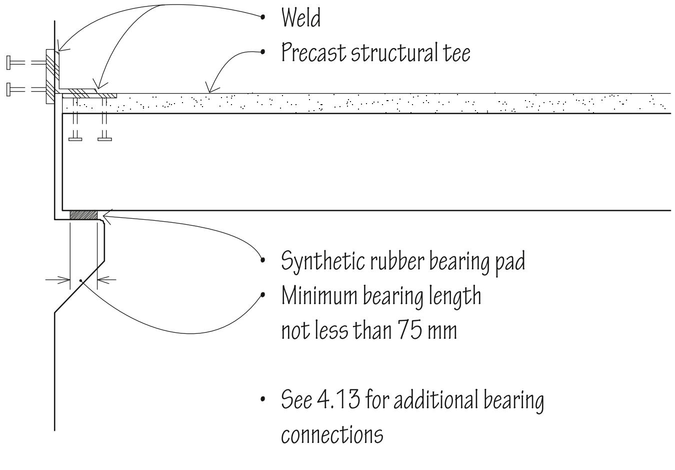
- Precast hollow-core slab unit
- Extend steel dowels into reinforced-concrete screed or into grouted shear keys for structural continuity
- Grout voids at ends of hollow-core units
- High-density plastic bearing strip
- Minimum bearing length not less than 75 mm

Bearing Wall



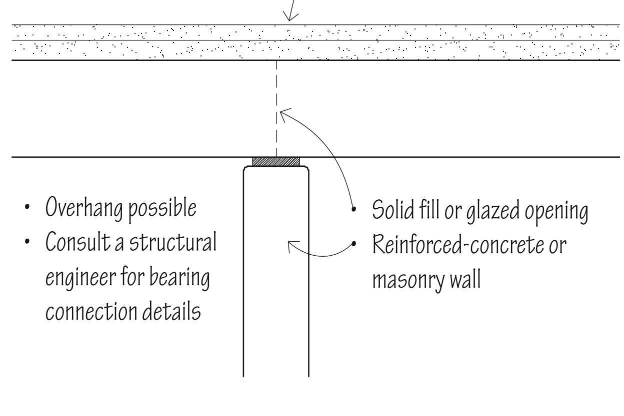
- Reinforced concrete screed; 50 mm minimum
- Hooked bars cast into slab edge
- Underside of precast slabs may be caulked and painted; a ceiling finish may also be applied to or be suspended from slab

End Wall



- Weld
- Precast structural tee
- Synthetic rubber bearing pad
- Minimum bearing length not less than 75 mm
- See 4.13 for additional bearing connections

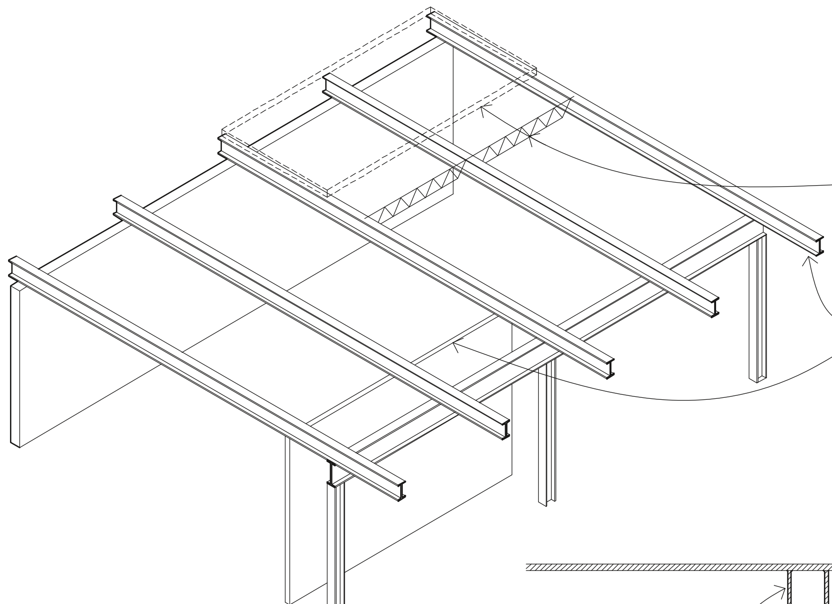
Bearing Wall



- Reinforced-concrete screed bonds tee units together
- Overhang possible
- Consult a structural engineer for bearing connection details
- Solid fill or glazed opening
- Reinforced-concrete or masonry wall

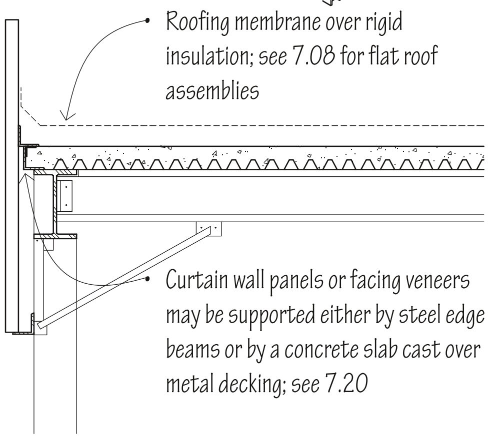
Bearing Wall

6.06 STRUCTURAL STEEL ROOF FRAMING

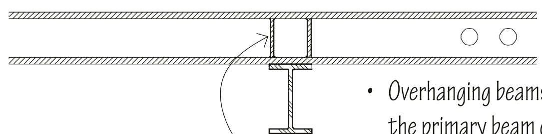


A flat roof structure may be framed with structural steel members similar to the way steel floors are framed; see 4.14–4.15.

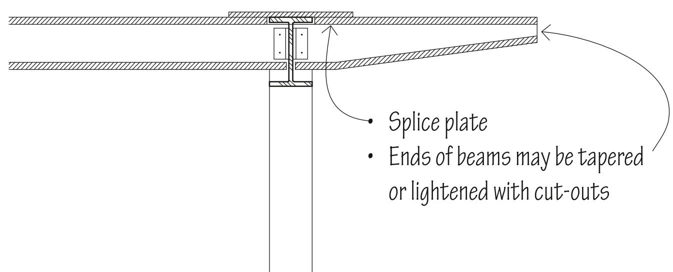
- The primary and secondary roof beams may support open-web steel joists, metal roof decking, a cast-in-situ concrete slab or precast-concrete units
- Roof overhangs may be achieved by extending the secondary roof beams over their supports or by recessing the exterior wall construction



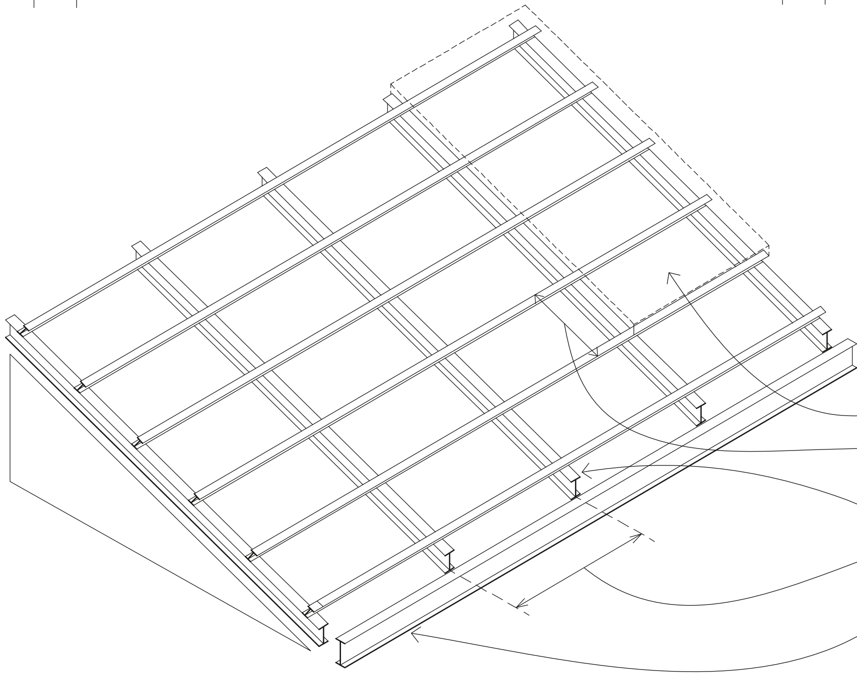
- Roofing membrane over rigid insulation; see 7.08 for flat roof assemblies
- Curtain wall panels or facing veneers may be supported either by steel edge beams or by a concrete slab cast over metal decking; see 7.20



- Overhanging beams may be framed within the depth of the primary beam or be continuous over the main beam support
- Web stiffeners



- Splice plate
- Ends of beams may be tapered or lightened with cut-outs

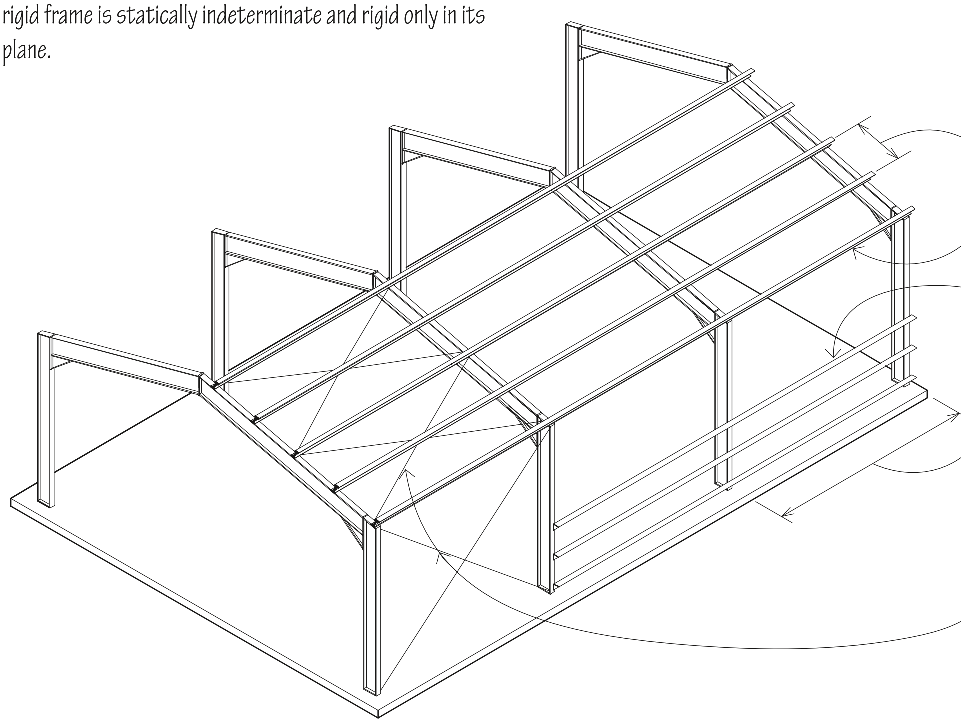


Structural steel can also be used to frame sloping roofs.

- Metal or cementitious roof decking
- Purlin spacing = decking span
- Sloping roof beams support purlins
- Beam spacing = purlin span
- Primary beams support secondary beams at the ridge and eaves

Portal frames consist of two columns and a beam that are rigidly connected at their joints. Applied loads produce axial, bending and shear forces in all members of the frame since the rigid joints restrain the ends of the members from rotating freely. In addition, vertical loads cause a rigid frame to develop horizontal thrusts at its base. A rigid frame is statically indeterminate and rigid only in its plane.

- Various shapes of rigid frames can be fabricated of steel to span from 9 to 36 m
- Rigid frames typically form one-storey structures used for light-industrial buildings, warehouses and recreational facilities



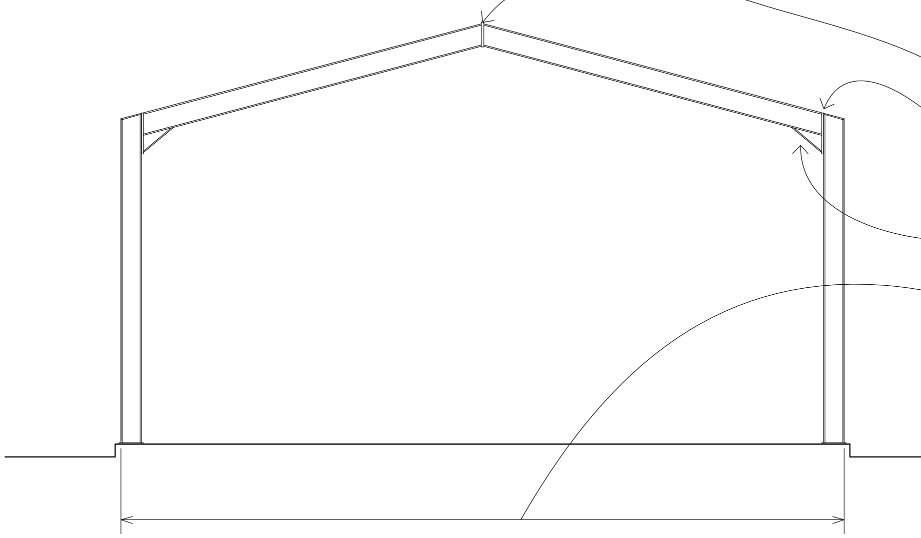
- Channel or Z-shaped purlins
- Purlin spacing = span of roof decking; 1200–1500 mm centres
- Eaves strut

- Channel or Z-shaped girts

- Frames spaced at 4500–6000 mm centres
- Frame spacing = span of purlins
- Frame spacing = span of girts

- Rigid frames provide resistance to lateral forces in their planes; they must be braced in a direction perpendicular to the frames
- Framing is typically clad with corrugated metal roofing and siding or sandwich panels; see 5.49

- Steel frames may be left exposed in unprotected non-combustible construction
- See A.10–A.11 for fireproofing of steel structures



- Crown

- Connection bolted or welded to resist moments
- Haunch gusset

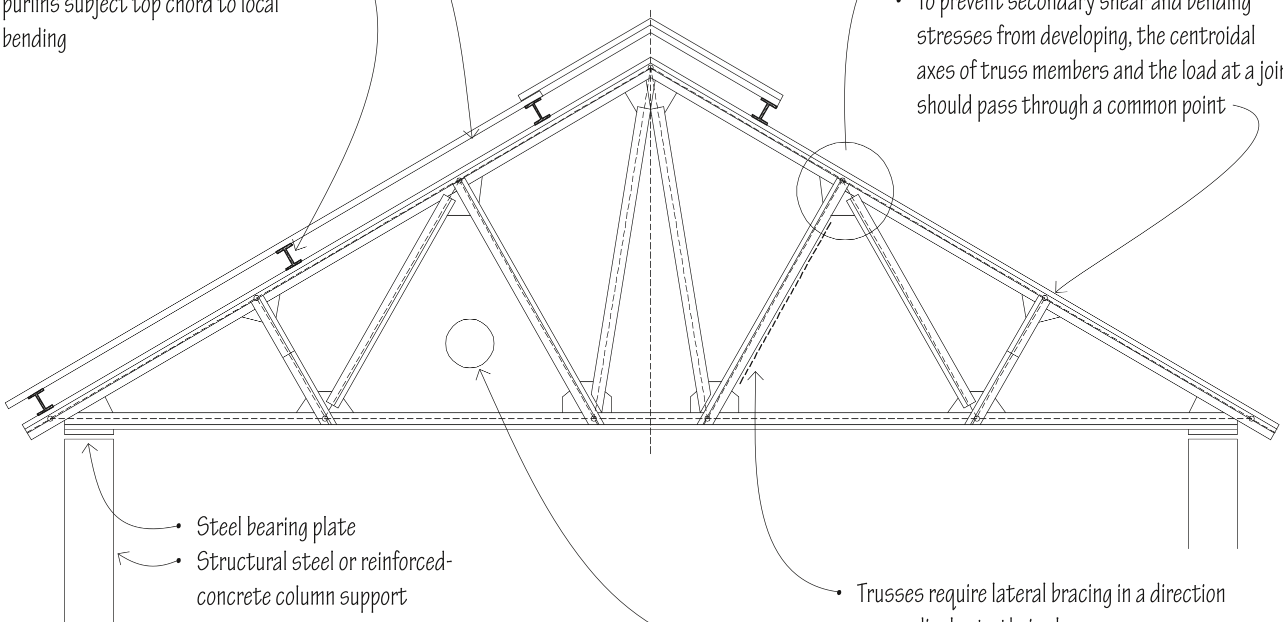
- Typical span: 9–36 m

Steel trusses are generally fabricated by welding or bolting structural angles and tees together to form the triangulated framework. Because of the slenderness of these truss members, connections usually require the use of steel gusset plates. Heavier steel trusses may utilise wide-flange shapes and structural tubing.

- See 2.15 for more information on trusses

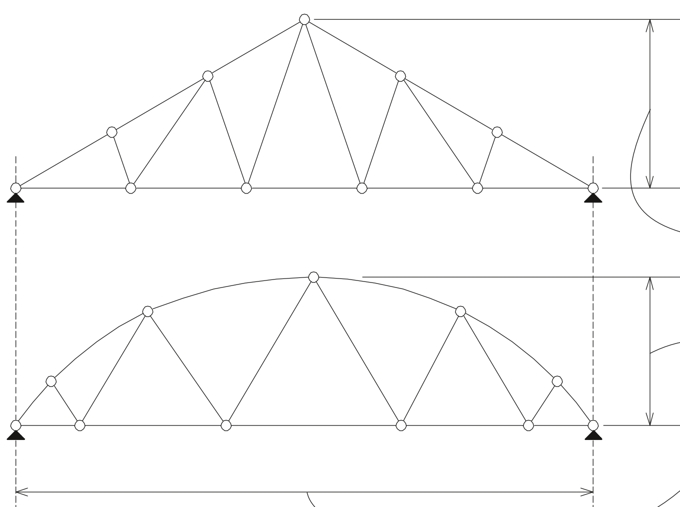
- Metal or cementitious roof decking or panels span purlin spaces
- I- or Z-shaped purlins span the truss spacing
- If not bearing at a panel point, purlins subject top chord to local bending

- Members are bolted or welded with gusset-plate connectors
- To prevent secondary shear and bending stresses from developing, the centroidal axes of truss members and the load at a joint should pass through a common point



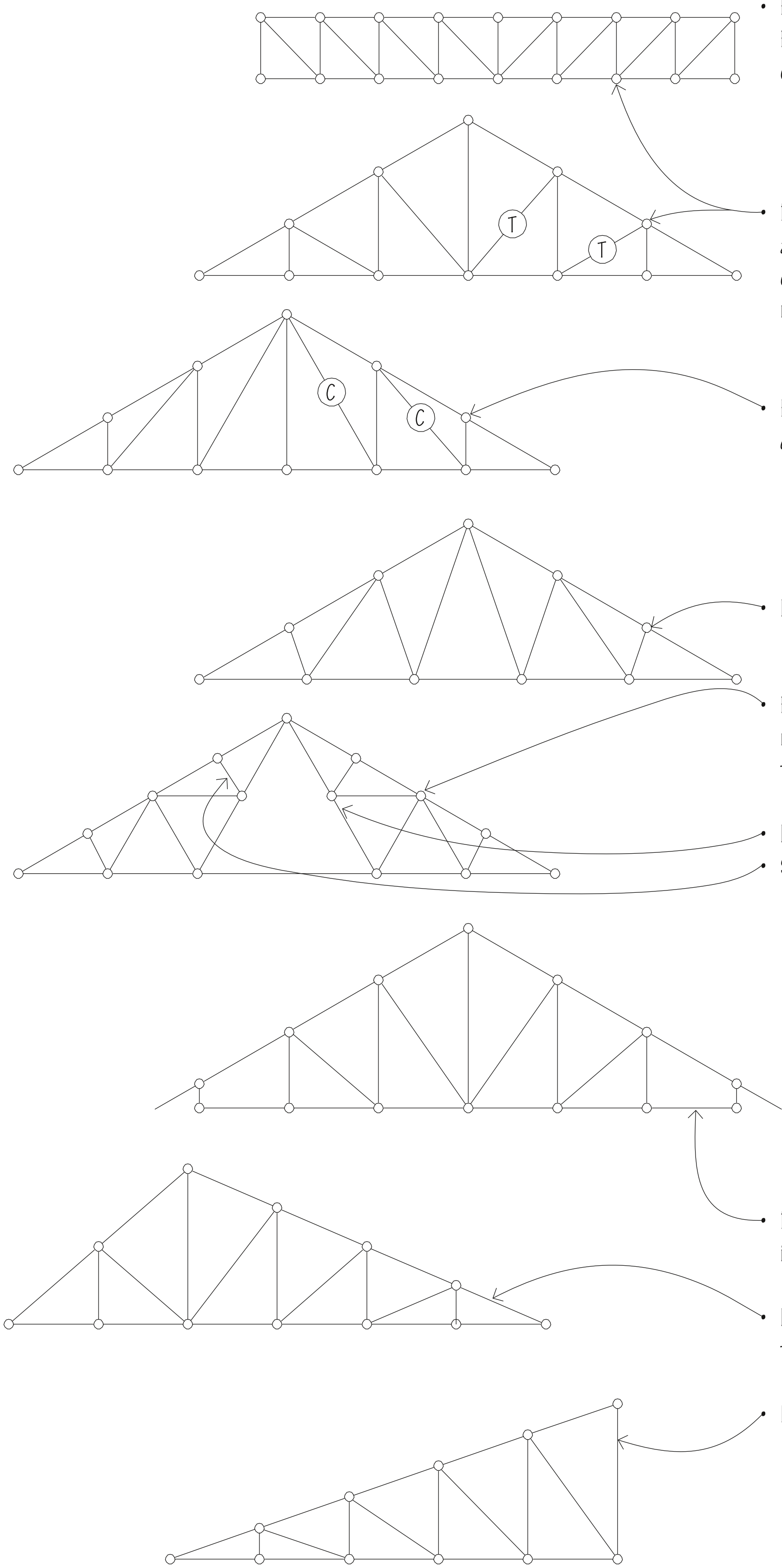
- Steel bearing plate
- Structural steel or reinforced-concrete column support

- Trusses require lateral bracing in a direction perpendicular to their planes
- Mechanical services such as piping, conduit and ductwork may pass through the web spaces
- Local building regulations should be consulted to determine fire protection requirements



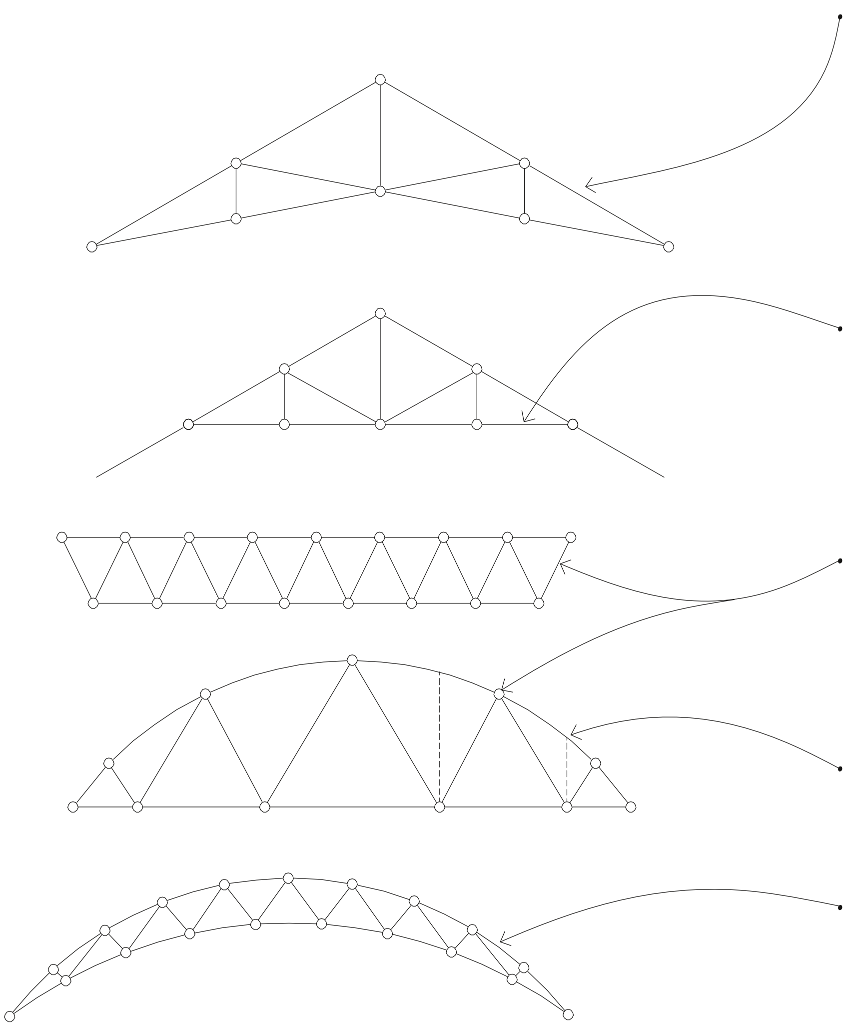
- The increased depth of trusses allows them to span greater distances than steel beams
- Depth range for pitched trusses: span/4 to span/5

- Depth range for bowstring trusses: span/6 to span/8
- Typical span range: 10–25 m; up to 40 m



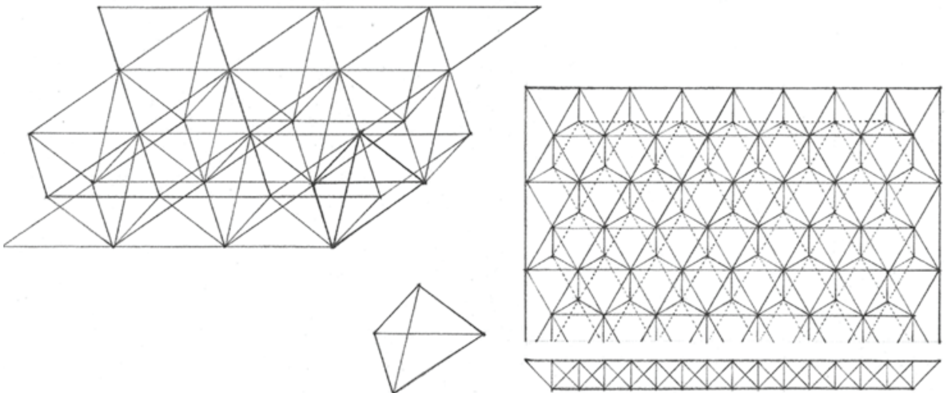
- Flat trusses have parallel top and bottom chords. Flat trusses are generally not as efficient as pitched or bowstring trusses
- Pratt trusses have vertical web members in compression and diagonal web members in tension. It is generally more efficient to use a truss type in which the longer web members are loaded in tension
- Howe trusses have vertical web members in tension and diagonal web members in compression
- Belgian trusses have only inclined web members
- Fink trusses are Belgian trusses having sub-diagonals to reduce the length of web compression members toward the centre line of the span
- Diagonals connect a top to a bottom chord
- Sub-diagonals join a chord with a main diagonal
- Raised heel trusses allow for continuity of wall and roof insulation
- Dual-pitched trusses combine two different roof pitches to allow for variation in design
- Monopitch trusses allow for a roof pitch in one direction

6.10 TRUSS TYPES

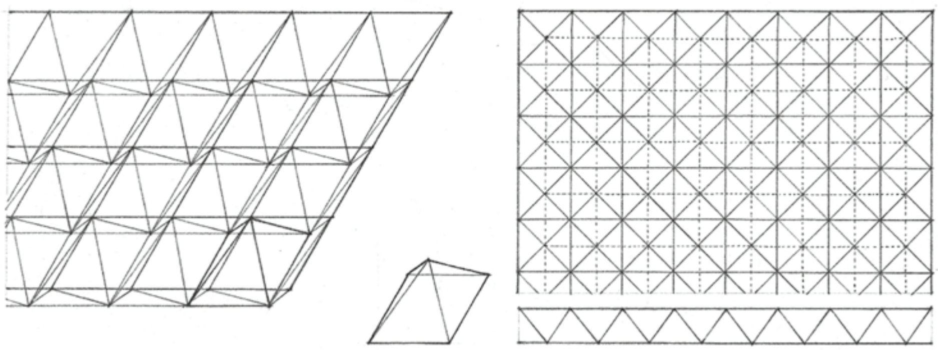


- Scissors trusses have tension members extending from the foot of each top chord to an intermediate point on the opposite top chord
- Raised-collar trusses have a bottom chord raised substantially above the level of the supports
- Warren trusses have inclined web members forming a series of equilateral triangles. Vertical web members are sometimes introduced to reduce the panel lengths of the top chord, which is in compression
- Bowstring trusses have a curved top chord meeting a straight bottom chord at each end
- Crescent trusses have both top and bottom chords curving upward from a common point at each side

A space frame is a long-spanning three-dimensional plate structure based on the rigidity of the triangle and composed of linear elements subject only to axial tension or compression. The simplest spatial unit of a space frame is a tetrahedron having four joints and six structural members.

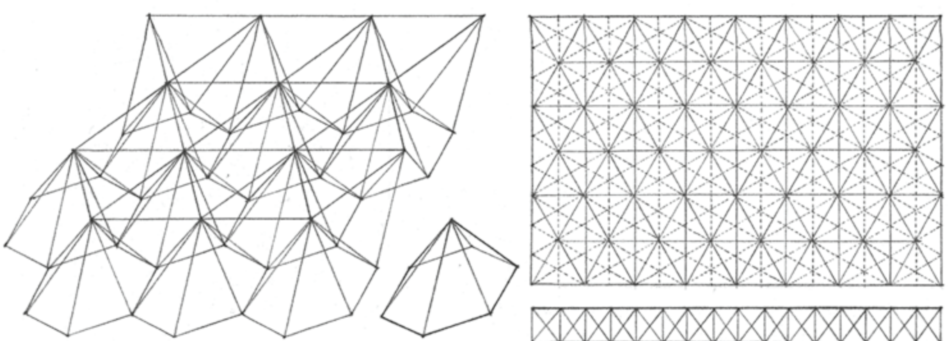


Triangular Grid



Square Grid

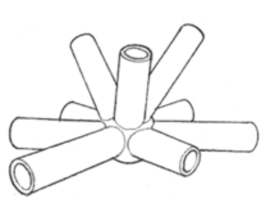
- Illustrated are three of the many patterns available
- Typical modules: 1200, 1500, 1800 mm



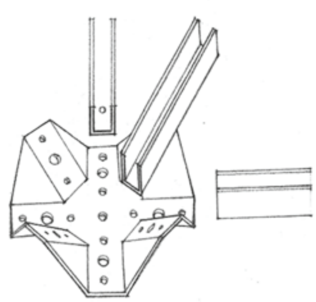
Hexagonal Grid

- Space frames may be constructed of rectangular or square hollow sections, channels, tees or universal beams

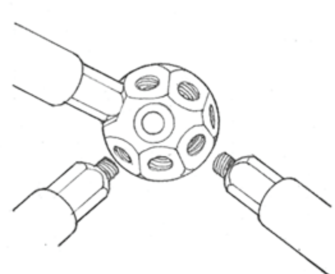
- Fabricated connectors join the members
- Consult manufacturer for details, module size and allowable spans



- Welded connection

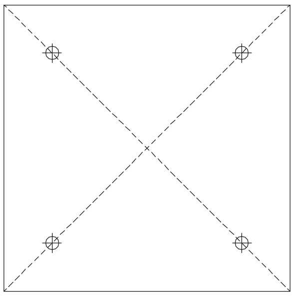


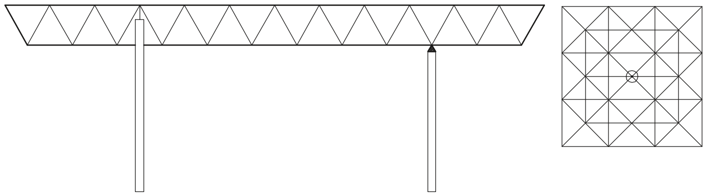
- Bolted connection



- Threaded connections

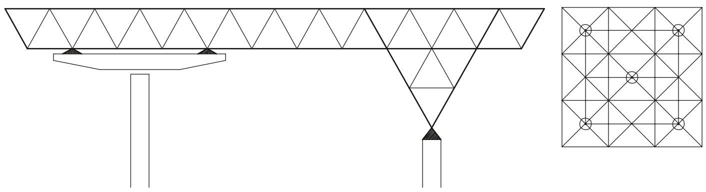
- As with other constant-depth plate structures, the supporting bay for a space frame should be square or nearly square to ensure that it acts as a two-way structure





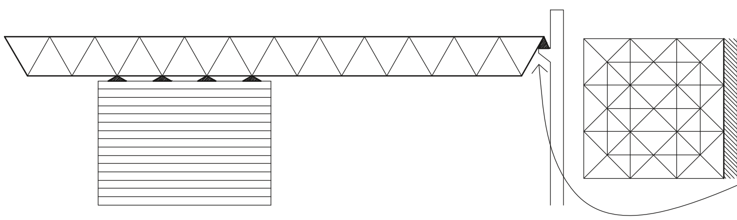
- A space frame should always be supported at a panel point

- Top-chord supported
- Bottom-chord supported



- Increasing the bearing area of the supports increases the number of members into which shear is transferred and reduces the forces in the members

- Four-point cruciform
- Frame capital



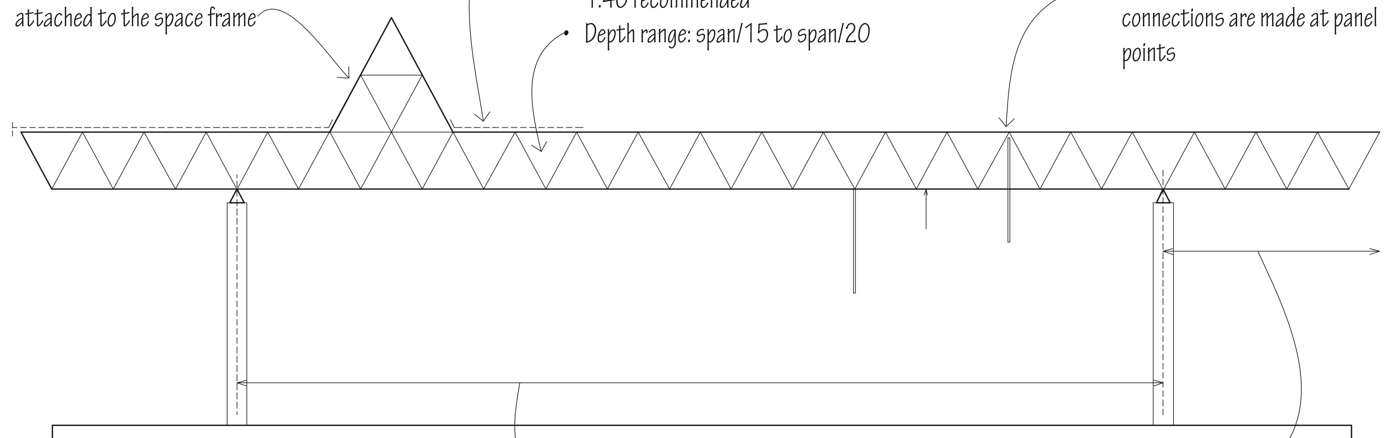
- A reinforced-concrete or masonry bearing wall distributes its support points along a line
- Steel bearing plates anchored into concrete or bond beam

- Interior wall
- Exterior wall

- Timber panel sheathing, metal roof decking or cementitious roof planks
- Slope or camber frame for drainage; minimum of 1:40 recommended
- Depth range: span/15 to span/20

- Glazing may occur within the panels of the space frame or be attached to the space frame

- Roof and partition connections are made at panel points



- Mechanical services such as piping, conduit and ductwork may pass through the web spaces

- Span: 6–36 modules
- Span range for column-supported space frames: 9–24 m
- Span range for wall-supported space frames: 9–39 m

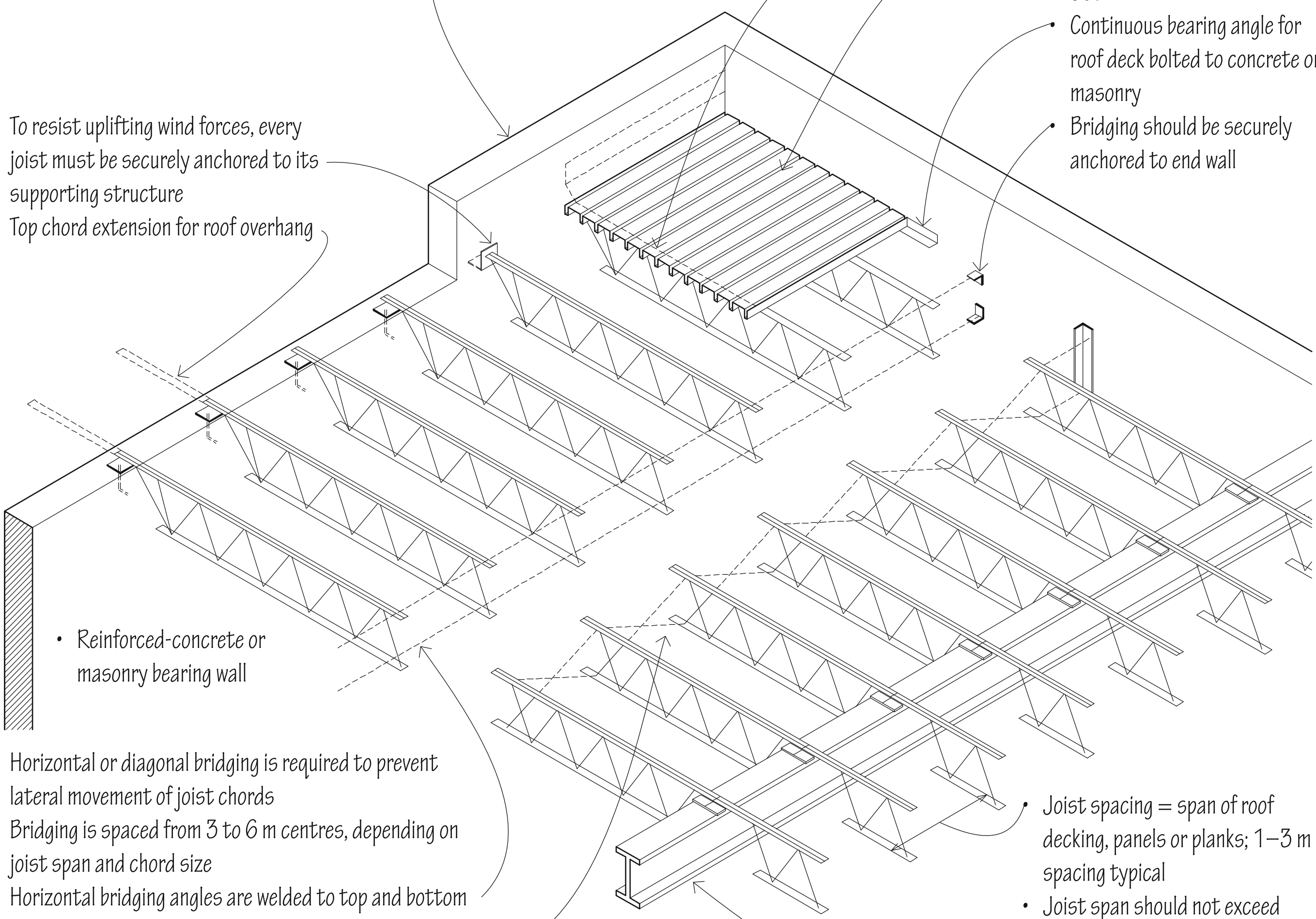
- Overhangs: 15–30% of span

Roof systems utilising open-web steel joists are similar in layout and construction to steel joist floor systems.

- Joists may frame into a bearing wall rising to form a parapet or bear on the wall to form a flush or overhanging roof edge

- Roofing membrane over rigid insulation; see 7.08 for flat roof assemblies
- Roof deck may consist of metal roof decking, plywood panels or OSB
- Continuous bearing angle for roof deck bolted to concrete or masonry
- Bridging should be securely anchored to end wall

- To resist uplifting wind forces, every joist must be securely anchored to its supporting structure
- Top chord extension for roof overhang



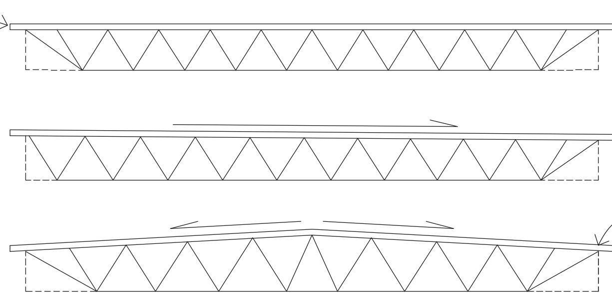
- Reinforced-concrete or masonry bearing wall

- Horizontal or diagonal bridging is required to prevent lateral movement of joist chords
- Bridging is spaced from 3 to 6 m centres, depending on joist span and chord size
- Horizontal bridging angles are welded to top and bottom chords
- Diagonal bridging angles, weld or bolt bridging to clip angles secured to masonry wall or steel edge beam

- Joist spacing = span of roof decking, panels or planks; 1–3 m spacing typical
- Joist span should not exceed 24 x joist depth

- Steel beam

- Top and bottom chords parallel; required roof slope may be achieved by shortening some of the joist supports and sloping the joists, or by tapering the insulating layer of the roof deck

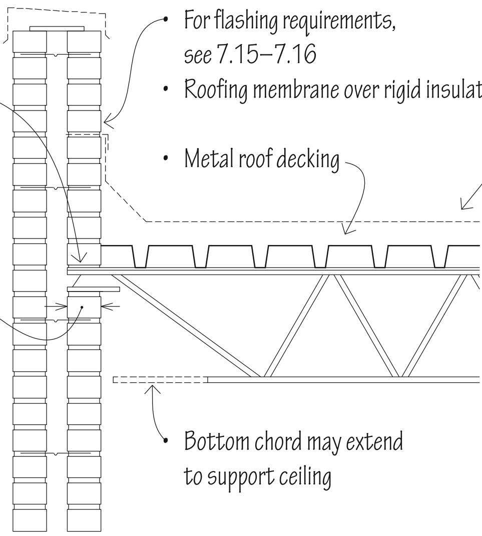


- Joists are available with single- or double-pitch top chords

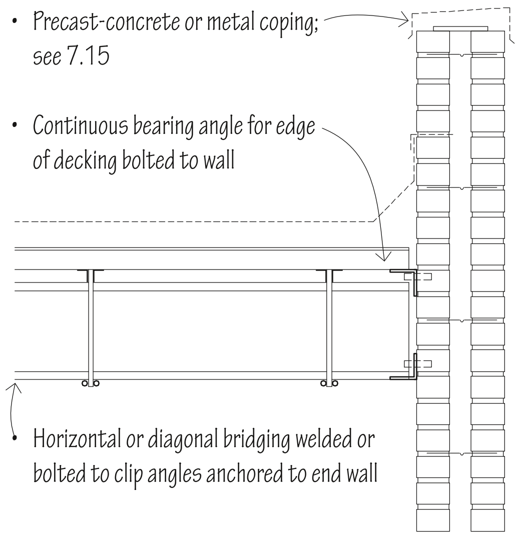
- Top chord pitched one way

- Top chord pitched two ways
- Standard slope is 1:80

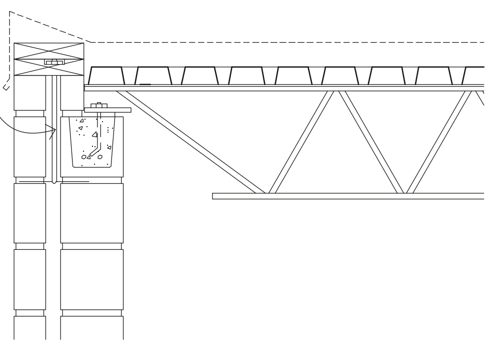
6.14 STEEL LATTICE JOISTS



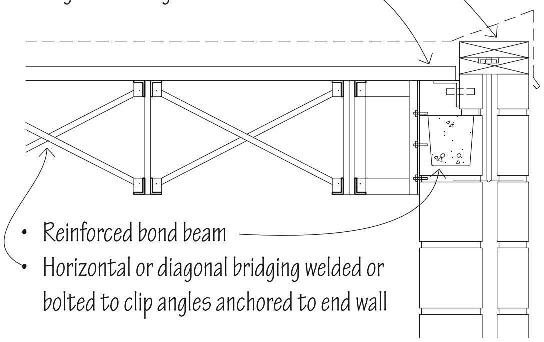
Parapet: Bearing Wall



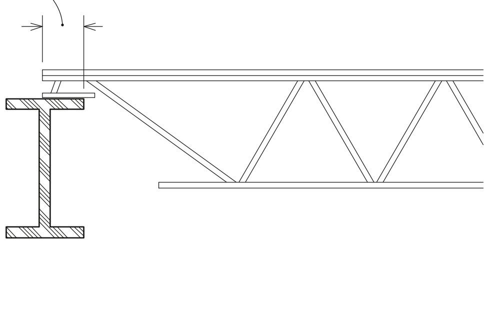
Parapet: End Wall



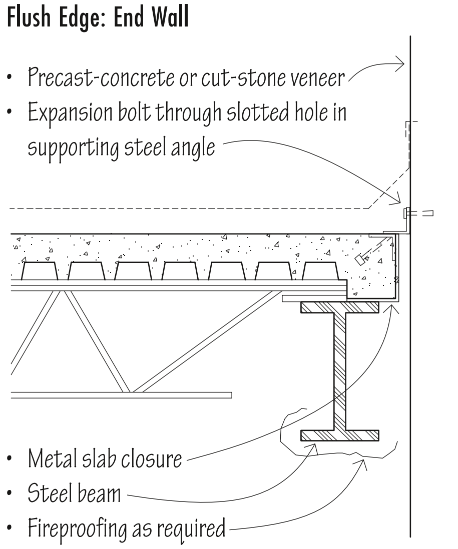
Flush Edge: Bearing Wall



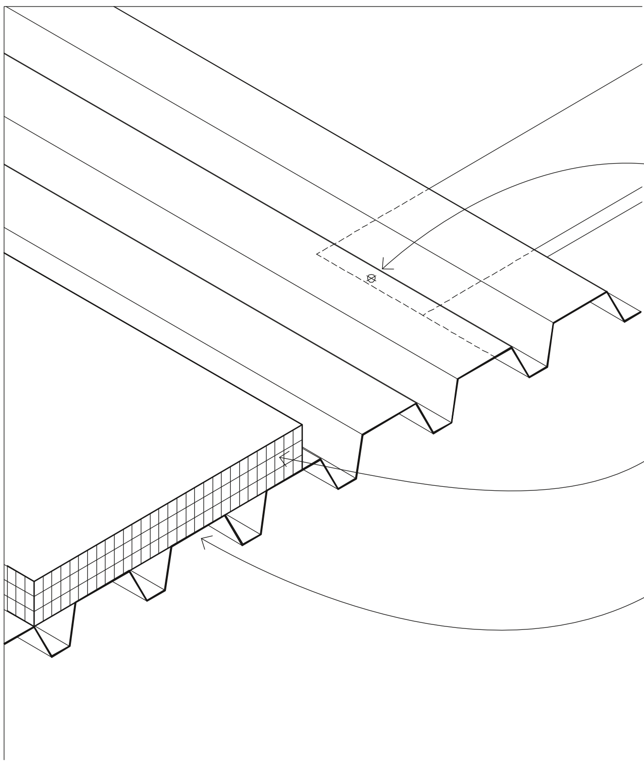
Flush Edge: End Wall



Structural Steel Frame

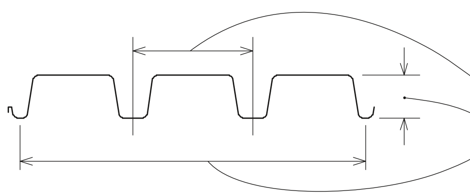


Parapet Wall

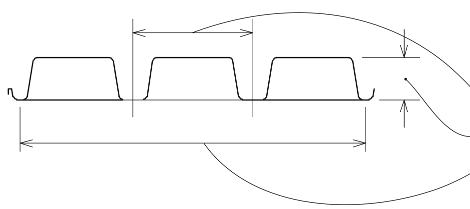


Metal roof decking is corrugated to increase its stiffness and ability to span across open-web steel joists or more widely spaced steel beams and to serve as a base for thermal insulation and membrane roofing.

- The decking panels are puddle-welded or mechanically fastened to the supporting steel joists or beams
- The panels are fastened to each other along their sides with screws, welds or button-punching standing seams
- If the deck is to serve as a structural diaphragm and transfer lateral loads to shear walls, its entire perimeter must be welded to steel supports. In addition, more stringent requirements for support and side lap fastening may apply
- Metal roof decking is sometimes used without a concrete screed, requiring structural timber or cementitious panels or rigid insulation panels to bridge the gaps in the corrugation and provide a smooth, firm surface for the thermal insulation and membrane roofing
- To provide maximum surface area for the effective adhesion of rigid insulation, the top flange should be wide and flat. If the decking has stiffening grooves, the insulation layer may have to be mechanically fastened
- Metal decking has low-vapour permeability but because of the many discontinuities between the panels, it is not airtight. If an air barrier is required to prevent the migration of moisture vapour into the roofing assembly, a concrete topping can be used



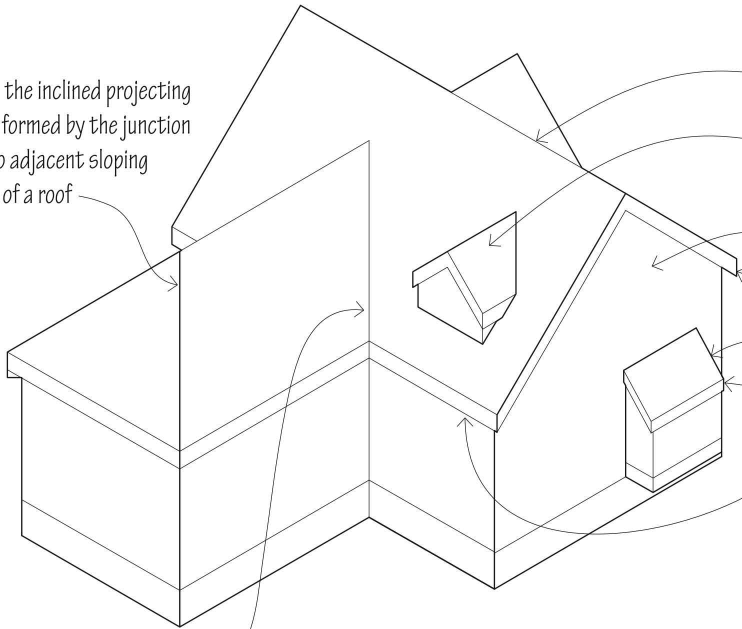
Ribbed Roof Decking
- 150 mm
- 60–100 mm depth
- 600, 750, 825, 1000 mm



Cellular Roof Decking
- 150 mm
- 60–100 mm depth
- 600–1000 mm

- Acoustic roof decking used as a sound-absorbing ceiling contains fibreglass between the perforated webs of ribbed decking or in the perforated cells of cellular decking
- Decking profiles vary. Consult manufacturer for available profiles, lengths, gauges, allowable spans and installation details

6.16 CUT ROOFS



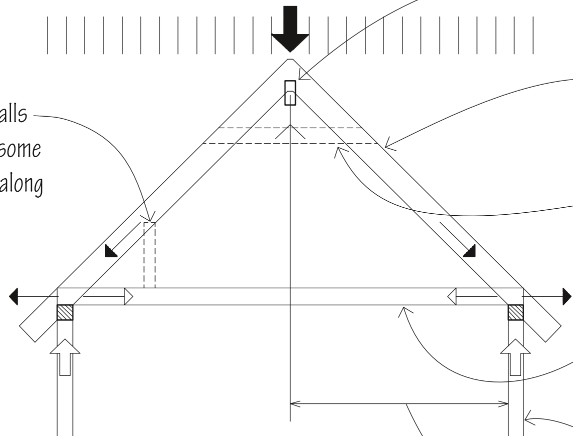
- Hip is the inclined projecting angle formed by the junction of two adjacent sloping sides of a roof
- Valley is an intersection of two inclined roof surfaces towards which rainwater flows

Roof Terminology

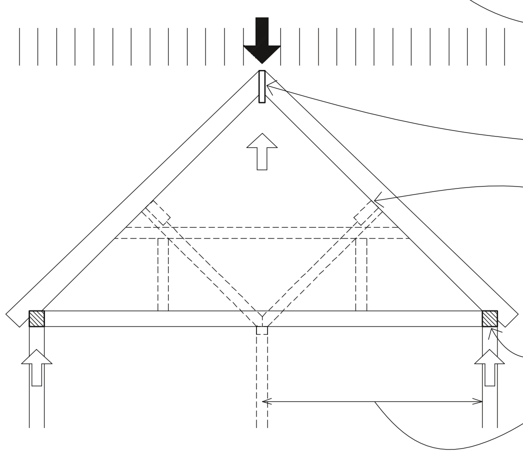
- Ridge is the horizontal line of intersection at the top between two sloping planes of a roof
- Dormers are projecting structures built out from a sloping roof and housing a vertical window or ventilating louvre
- Gable is the triangular portion of wall enclosing the end of a pitched roof from ridge to eaves
- Verge is the inclined, usually projecting edge of a sloping roof
- Lean-to is a roof having a single slope
- Eaves are the overhanging lower edge of a roof
- Soffit is the underside of overhanging roof eaves

Gable Roofs

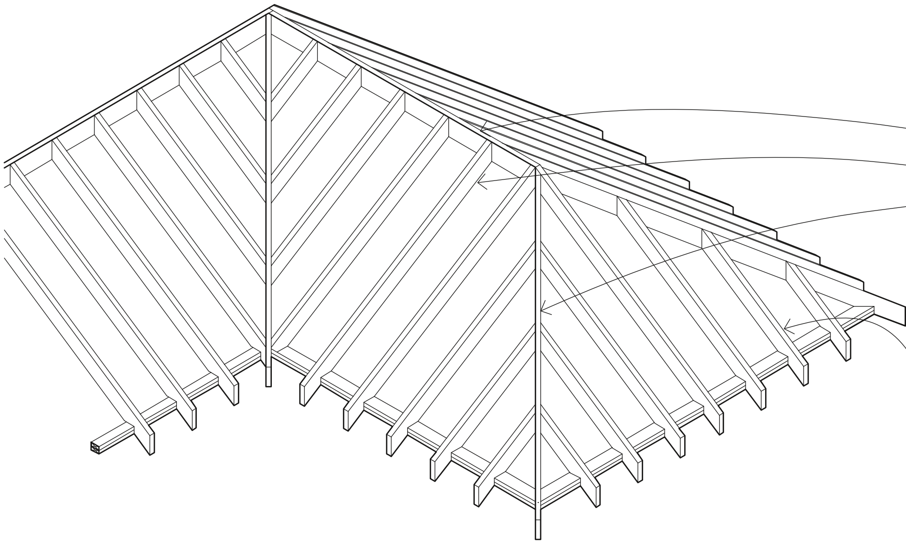
Gable roofs slope downward in two parts from a central ridge, so as to form a gable at each end.



- Knee walls are short walls supporting rafters at some intermediate position along their length
- Ridge beam is a structural horizontal member supporting the upper ends of rafters at the ridge of a roof
- Rafters extend from a wall plate to a ridge board or ridge beam and support the sheathing and covering of a roof
- Collar ties unite two opposing rafters at a point below the ridge, usually in the upper third of the rafter length
- The ties that resist the outward thrust of the rafters may be designed as ceiling joists supporting only attic loads or as floor joists supporting habitable space
- With sufficient headroom, natural light and ventilation, attic space may be habitable
- Load-bearing wall or beam
- Rafter span



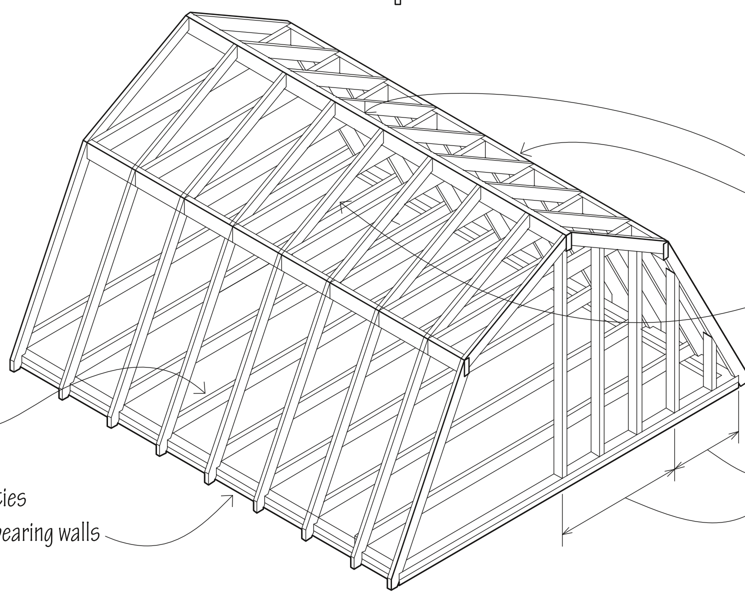
- Ridge board is a non-structural horizontal member to which the upper ends of the rafters are aligned and fastened
- A purlin is used to reduce the overall span of the rafters
- Beam or load-bearing wall
- Rafter span



Hipped Roofs

Hipped roofs have sloping ends and sides meeting at an inclined projecting angle.

- Ridge board
- Rafters
- Hip rafters form the junction of the sloping sides of a hip roof
- Jack rafter is any rafter that is shorter than the full length of the roof slope, as one meeting a hip or a valley
- Hip jacks are jack rafters extending from a wall plate to a hip rafter

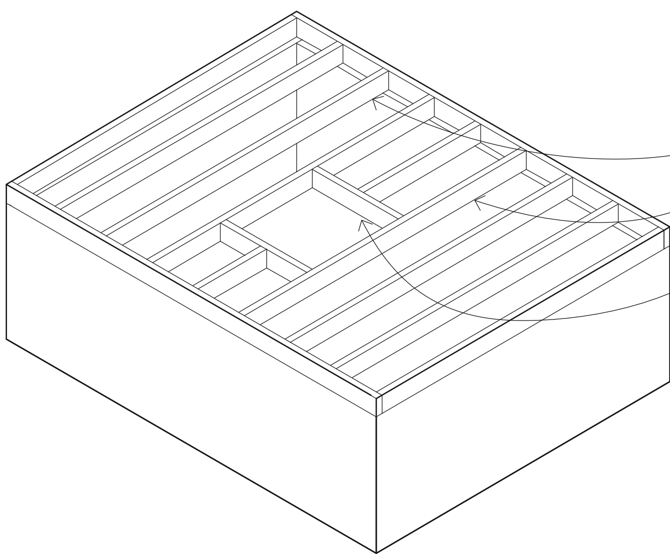


Mansard Roofs

Mansard roofs are divided on each side into a shallower slope above a steeper one.

- Ridge board
- Purlin
- Rafters
- Rafter spans

- Ceiling joists and floor joists serve as rafter ties
- Beams or load-bearing walls

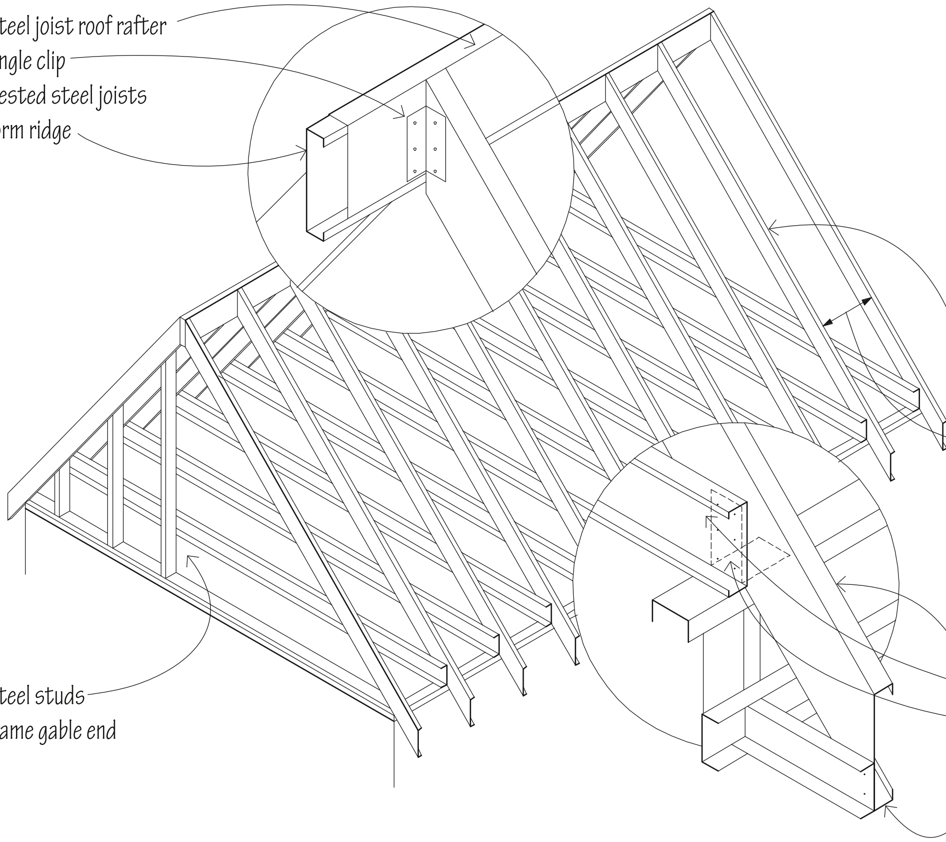


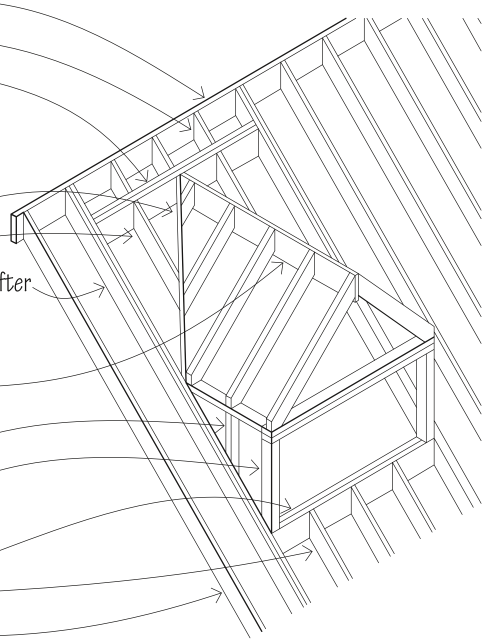
Flat Roofs

Flat roofs are framed in a manner similar to floor joist framing; see 4.25.

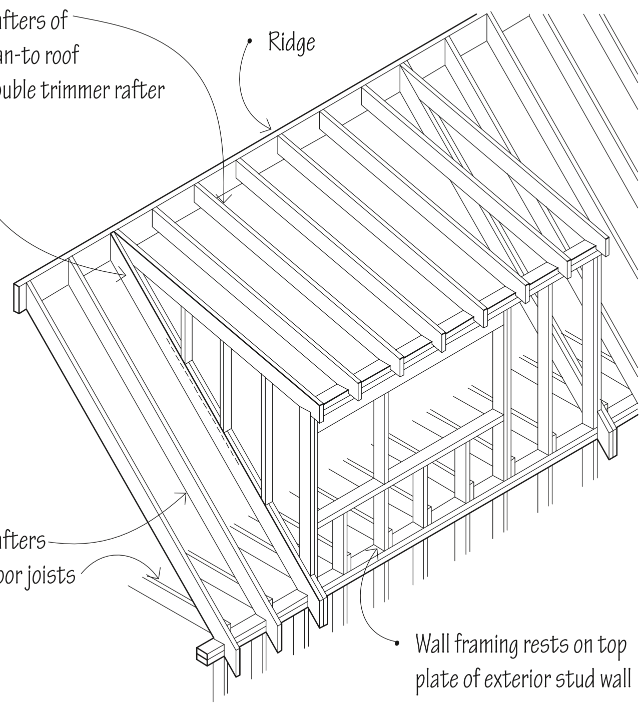
- Roof joists
- Trimmer joist
- Trimming joist to form opening in roof structure
- The required roof slope may be achieved by shortening some of the joist supports and sloping the joists, by tapering the insulating layer of the roof deck or by the use of furring pieces to create a fall

Roofs and ceilings may be constructed with light-gauge steel members in a manner similar to timber light-frame construction. The light-gauge steel members may also be screwed or welded together to form roof trusses similar to those described on 6.24.





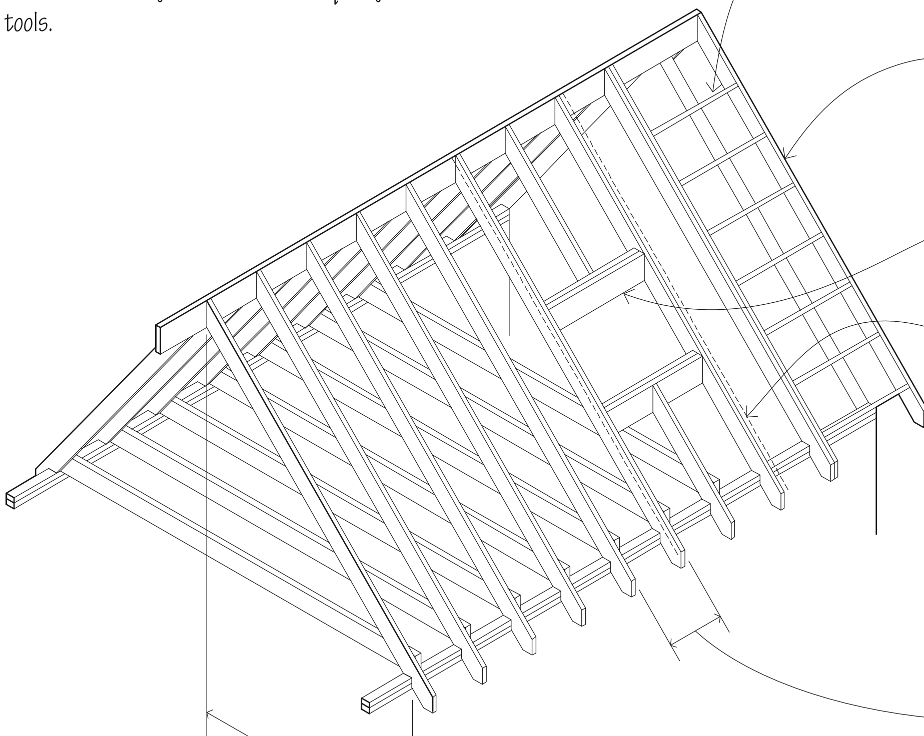
Gable Dormer



Lean-to Dormer

• See 6.16–6.17 for light-frame roof forms and terminology

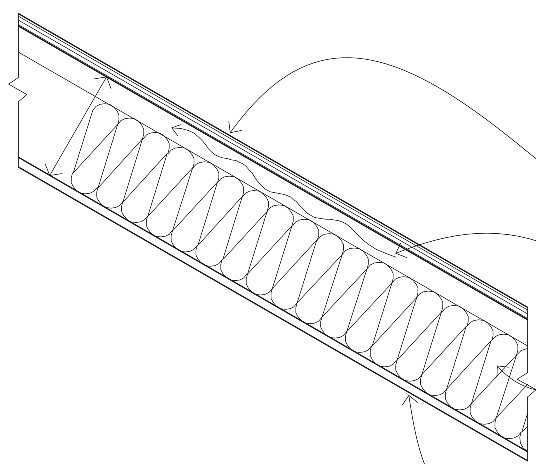
Roof structures framed with timber rafters are an essential subsystem of timber light-frame construction. The dimensioned timber used for roof joists and rafters is easily worked and can be quickly assembled on-site with simple tools.



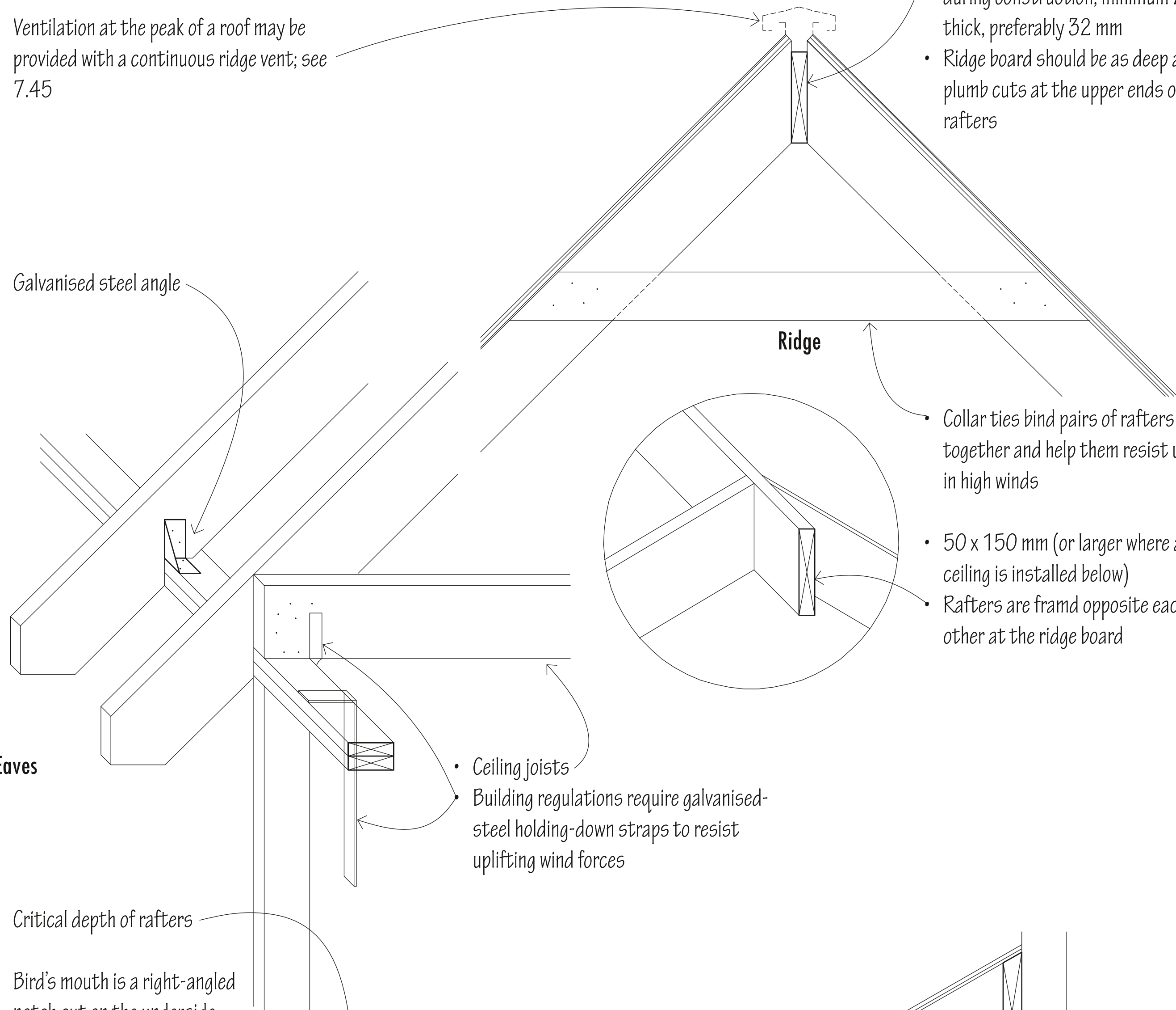
- Gable ladders are constructed with noggins framed between the barge-board and last rafter
- Bargeboards are the end rafters in the part of a gable roof that projects beyond the gable wall
- Roof openings are framed in a manner similar to floor joist openings; see 4.30
- Double rafters for large openings
- Sloping rafters and flat roof joists are typically of solid-sawn 50 mm thick timber, but I-joists and laminated timber elements may also be used
- Rafters and roof joists are typically spaced at 400, 450 or 600 mm centres, depending on the magnitude of roof loads and the spanning capability of the roof sheathing

Rafter span ranges:

- 44 x 100 mm can span up to 2500 mm
- 44 x 125 mm can span up to 3100 mm
- 44 x 150 mm can span up to 3700 mm
- Rafter spans are related to the magnitude of applied loads, the rafter size and spacing, and the species and grade of timber used
- Eurocode 1 and EN338 divide structural timber material into a number of strength classes relating to species and density. Generally C16 or C24 timber is used for roof construction. See 12.13 for more information on timber classification. 'C' relates to softwood
- Consult manufacturer for sizes and spans of laminated veneer timber joists



- Because timber framing is combustible, it must rely on roofing and ceiling materials for its fire-resistance rating
- Roof sheathing
- The susceptibility of timber to decay requires ventilation to control condensation in enclosed roof spaces
- See 7.41 for thermal insulation of roofs
- A ceiling finish is usually applied directly to the underside of roof rafters or ceiling joists
- If ceiling joists are used, attic space may accommodate mechanical equipment



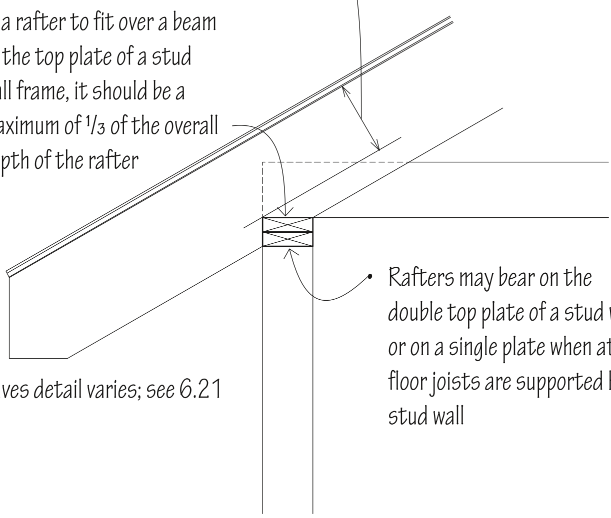
- Ventilation at the peak of a roof may be provided with a continuous ridge vent; see 7.45
- Ridge board keeps rafters aligned during construction; minimum 25 mm thick, preferably 32 mm
- Ridge board should be as deep as the plumb cuts at the upper ends of the rafters
- Galvanised steel angle

Ridge

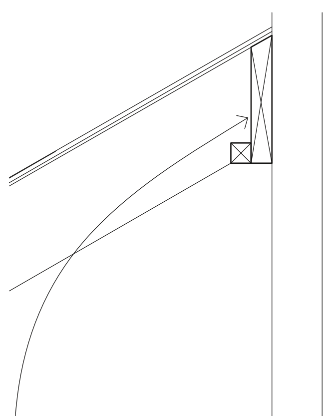
- Collar ties bind pairs of rafters together and help them resist uplift in high winds
- 50 x 150 mm (or larger where a ceiling is installed below)
- Rafters are framd opposite each other at the ridge board

Eaves

- Ceiling joists
- Building regulations require galvanised-steel holding-down straps to resist uplifting wind forces

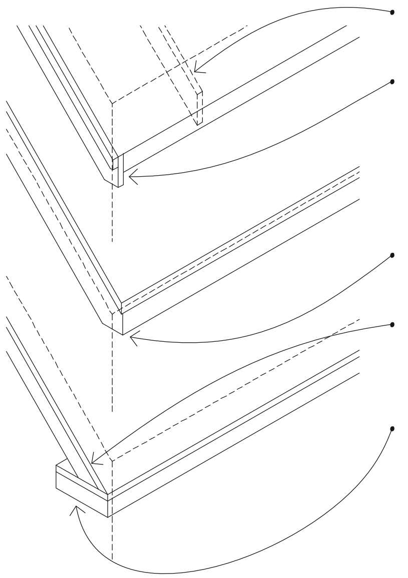


- Critical depth of rafters
- Bird's mouth is a right-angled notch cut on the underside of a rafter to fit over a beam or the top plate of a stud wall frame, it should be a maximum of 1/3 of the overall depth of the rafter
- Eaves detail varies; see 6.21
- Rafters may bear on the double top plate of a stud wall or on a single plate when attic floor joists are supported by the stud wall

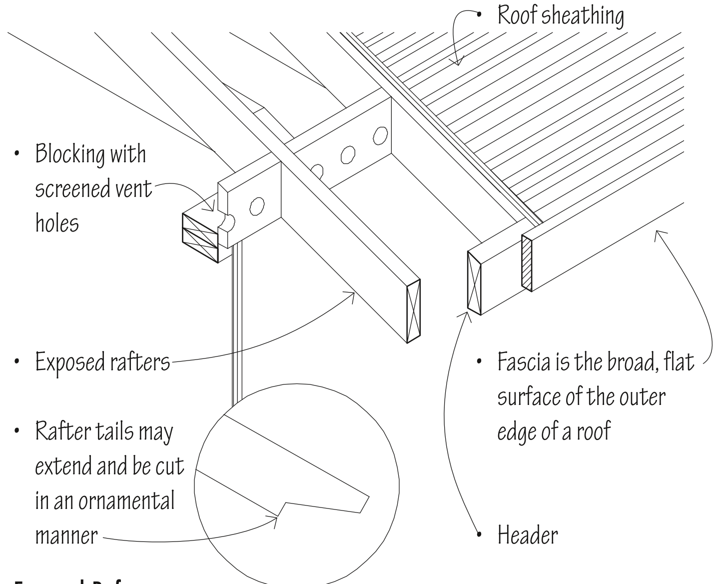


- Fix a 50 mm ledger to the bearing wall to take lean-to rafter

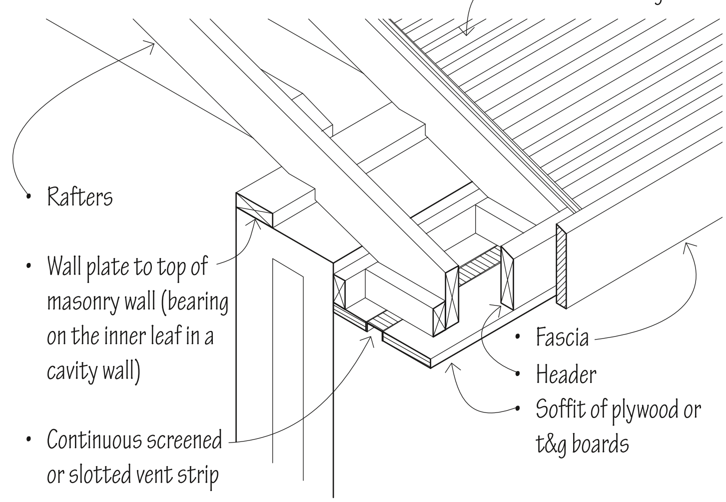
Eaves Support Conditions



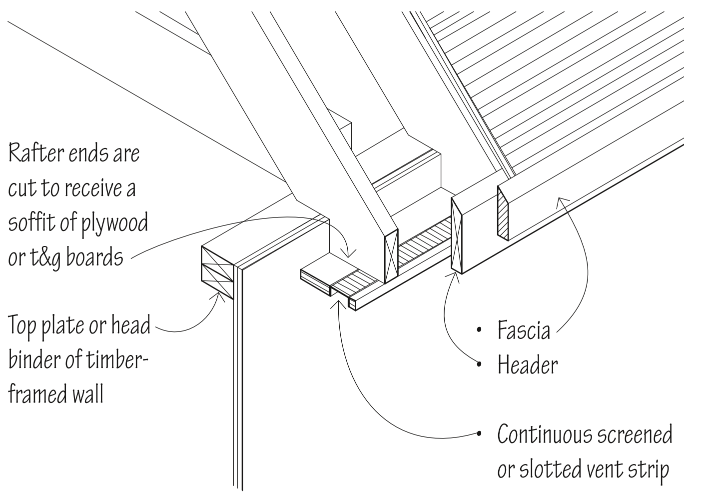
It is important to consider how the roof eaves detail turns the corner and meets the rake detail.



Exposed Rafters

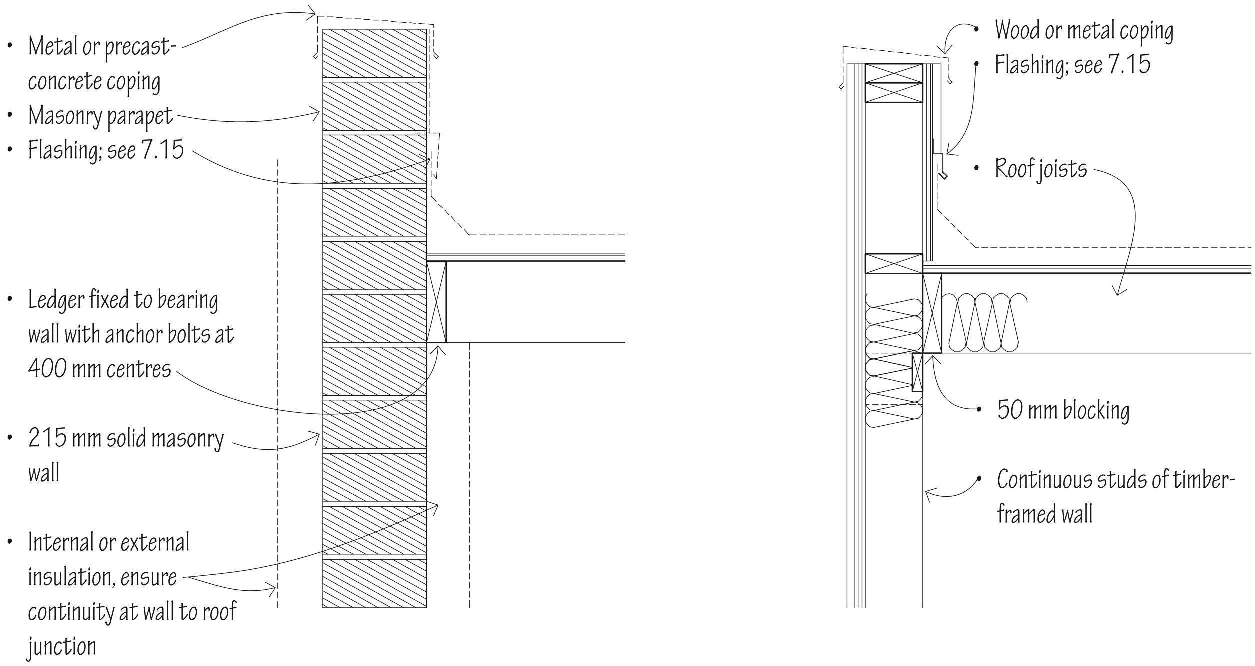


Wide-Vented Soffit



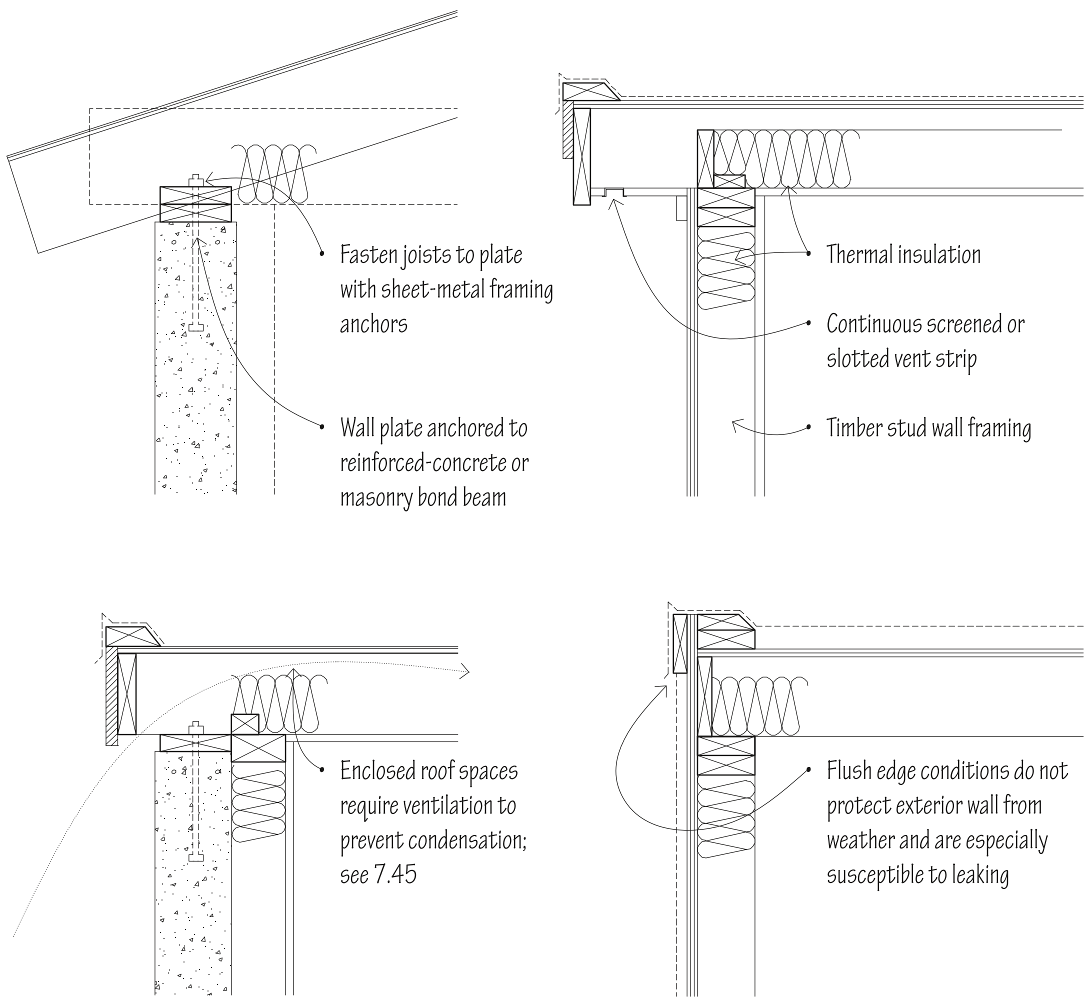
Narrow-Vented Soffit • Similar to a wide-vented soffit

Timber-framed pitched roofs can be 'cut' roofs or 'trussed' roofs. Cut roofs are constructed on-site while domestic-scale trussed roofs are generally prefabricated off-site.



Parapets

- Consult the building regulations for height and fire-regulation requirements



Flat roofs can generally be divided into three main categories depending on insulation position: warm deck, cold deck and inverted cold deck.

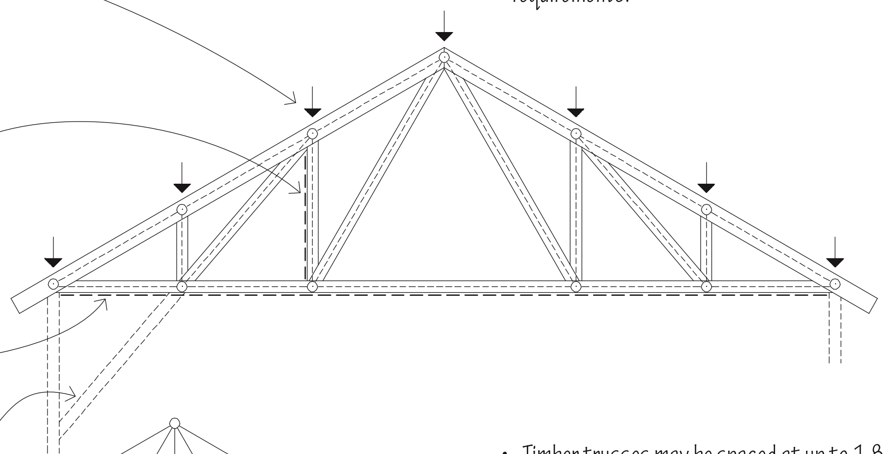
They can be further divided into single-ply or built-up roofing depending on the build-up.

See 7.41 for more detail on flat roof insulation, weathering and build up.

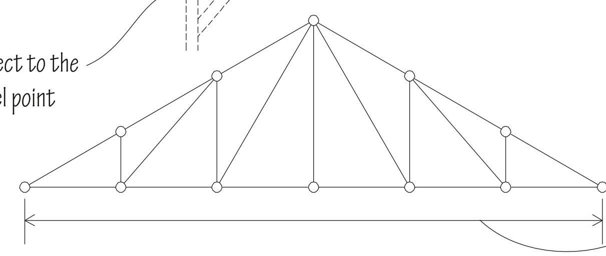
Flat Roof Joists

In contrast to monoplanar trussed rafters, heavier timber trusses can be assembled by layering multiple members and joining them at the panel points with split-ring connectors. These timber trusses are capable of carrying greater loads than trussed rafters and are spaced further apart. Consult a suitably qualified engineer for design, bracing and anchorage requirements.

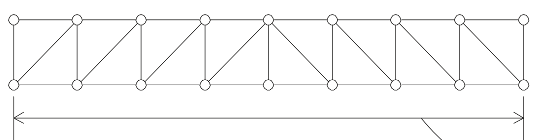
- To avoid additional bending stresses in truss members, loads should be applied at panel points
- Vertical sway bracing may be required between the top and bottom chords of adjacent trusses to provide resistance against lateral wind and seismic forces
- Horizontal cross-bracing may be required in the plane of the top or bottom chord if the diaphragm action of the roof framing is not adequate for end-wall forces
- Any knee bracing should connect to the top or bottom chord at a panel point



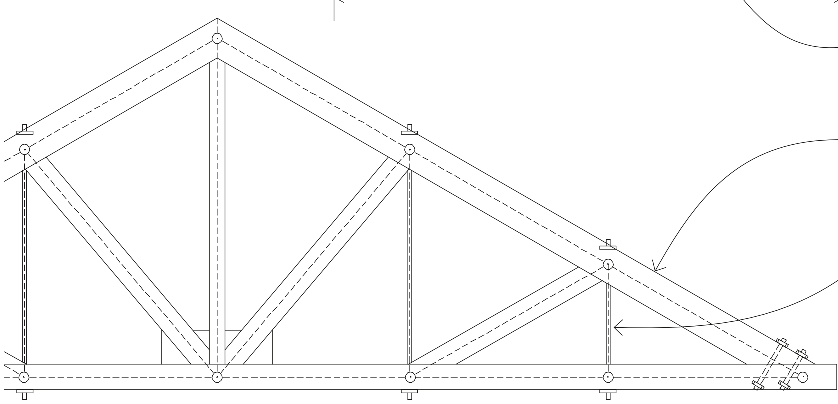
- Timber trusses may be spaced at up to 1.8 m centres, depending on the spanning capability of the roof decking or planking. When purlins span across the trusses, the truss spacing may be increased
- Span range for pitched trusses: 15–50 m



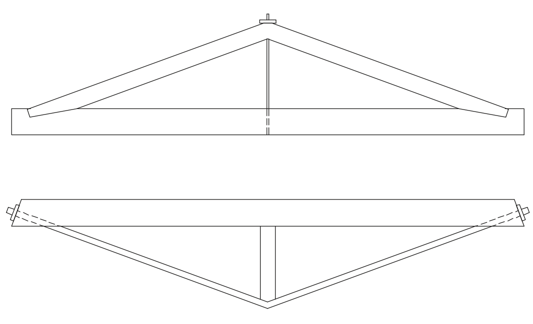
- See 6.09, 6.10 for a description of truss configurations



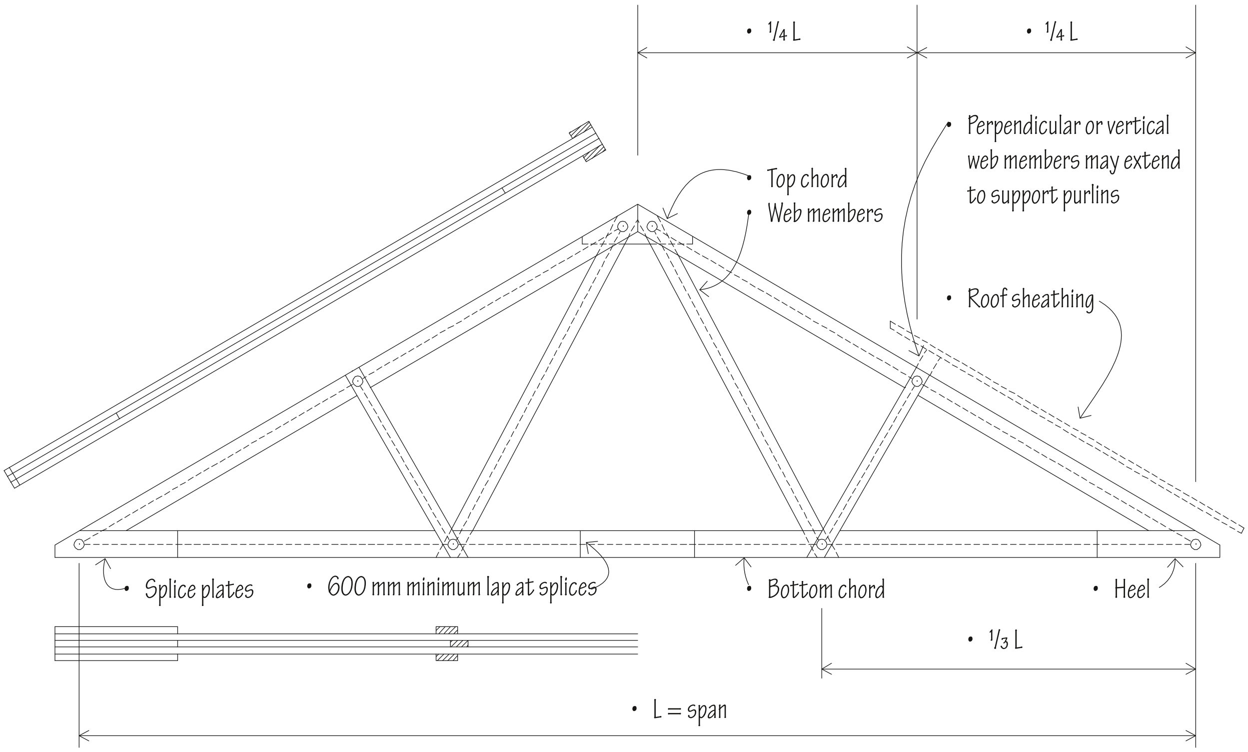
- Span range for flat trusses (also referred to as lattice beams): 15–45 m
- Composite trusses have timber compression members and steel tension members
- Truss rods are metal tie rods that serve as tension members in a truss or trussed beam



- Trussed beams are timber beams stiffened by a combination of diagonal truss rods and either compression struts or suspension rods

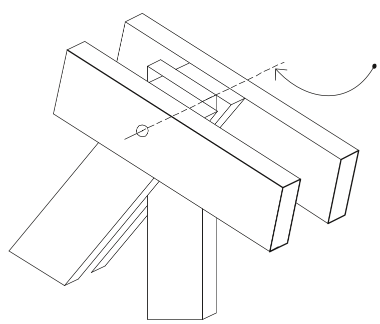


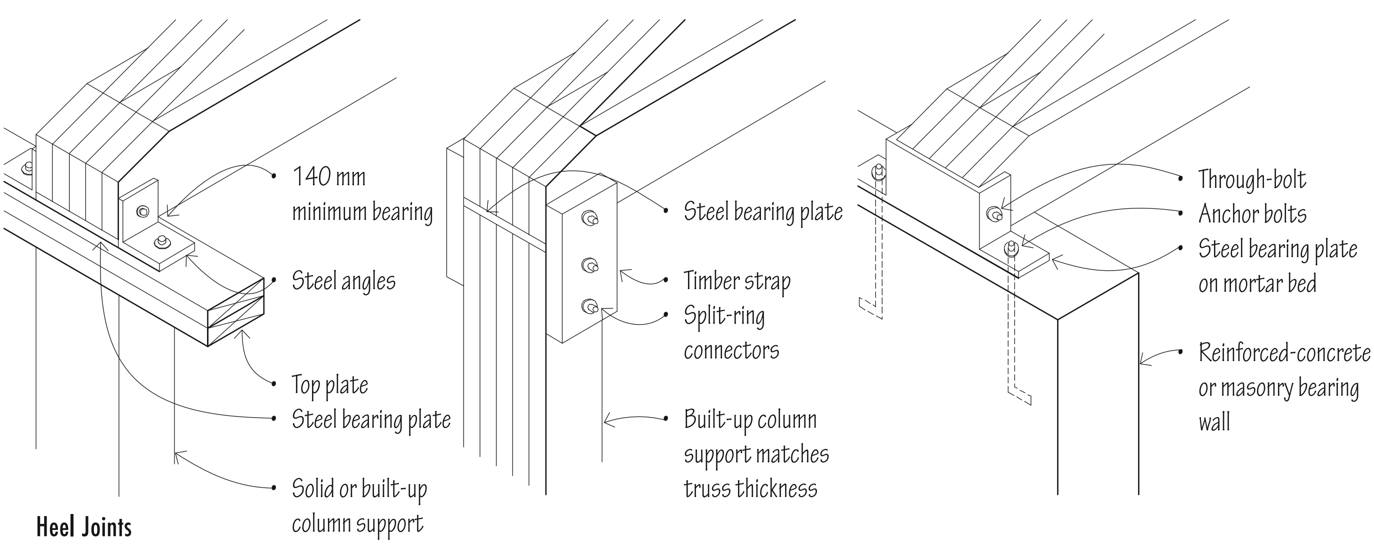
6.24 HEAVY ROOF TRUSSES



Example of a Belgian Truss

- Member sizes and joint details are determined by engineering calculations based on truss type, load pattern, span, grade and species of timber used
- The size of compression members is generally governed by buckling while the size of tension members is controlled by tensile stresses at connections

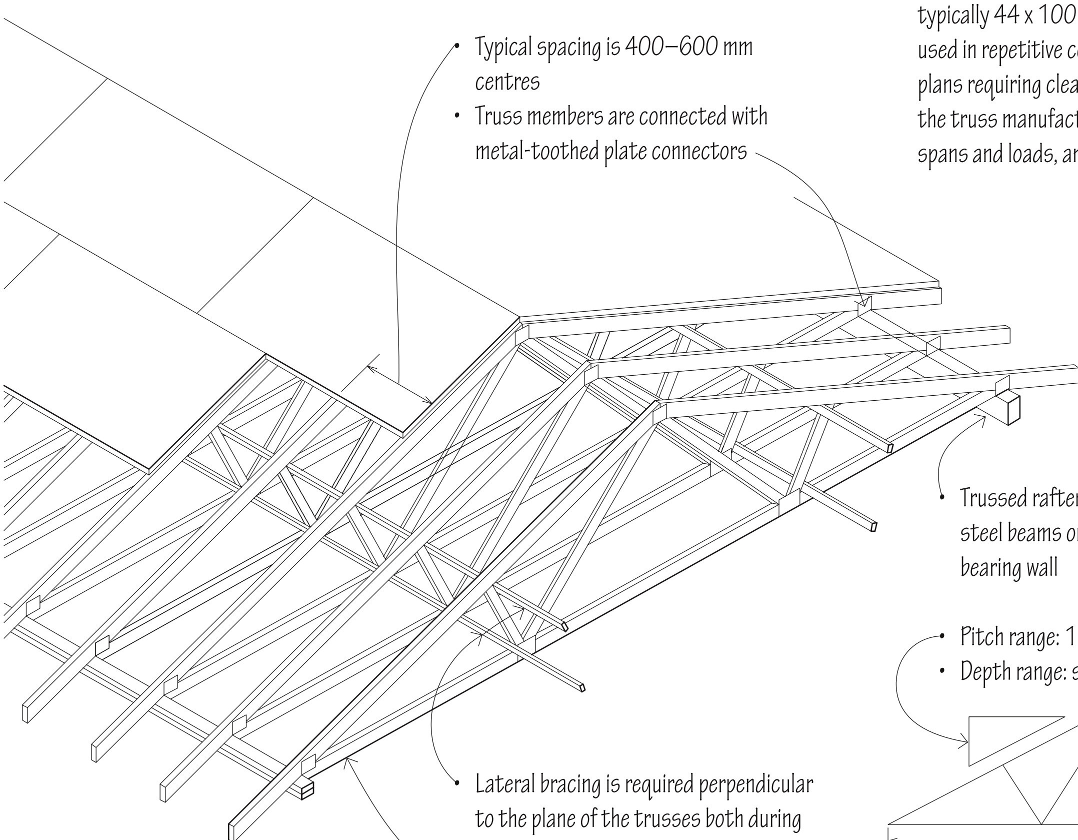




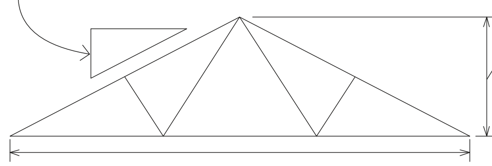
Heel Joints

Prefabricated trusses are pre-engineered monoplanar trusses. Because the individual members are subject primarily to compressive and tensile forces, they are typically 44 x 100 mm. Trussed rafters are best used in repetitive construction with rectangular plans requiring clear spans greater than 5 m. Consult the truss manufacturer for configurations, allowable spans and loads, and construction details.

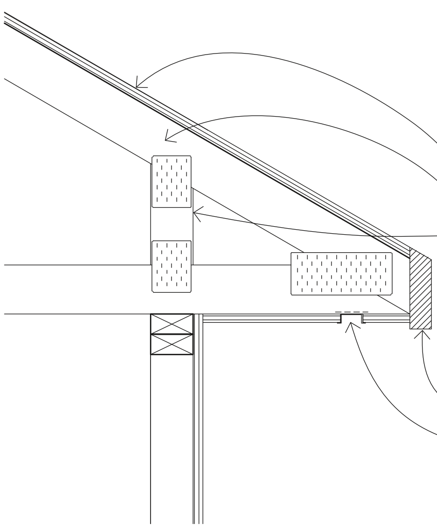
- Typical spacing is 400–600 mm centres
- Truss members are connected with metal-toothed plate connectors



- Trussed rafters may be supported by timber or steel beams or by a stud-framed or masonry bearing wall
- Pitch range: 15–45°
- Depth range: span/10 to span/20

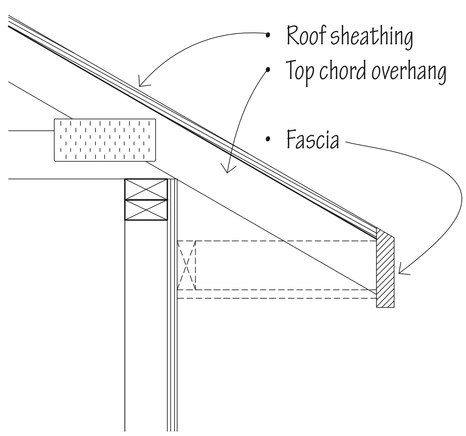


- 600 mm maximum extension of top chord for overhangs
- Lateral bracing is required perpendicular to the plane of the trusses both during installation and after erection
- A ceiling may be applied directly to the bottom chords. For trusses spaced at more than 600 mm centres, furring strips may be required to support the ceiling material
- Thermal insulation as well as electrical and mechanical equipment may be accommodated within the truss depth
- Trussed rafters typically span from 6 to 9 m although larger spans are possible
- See 6.09, 6.10 for a description of truss configurations



- Roof sheathing
- Top chord
- Web block or strut tied to web system of truss
- Fascia
- Vented soffit

Soffited Eaves



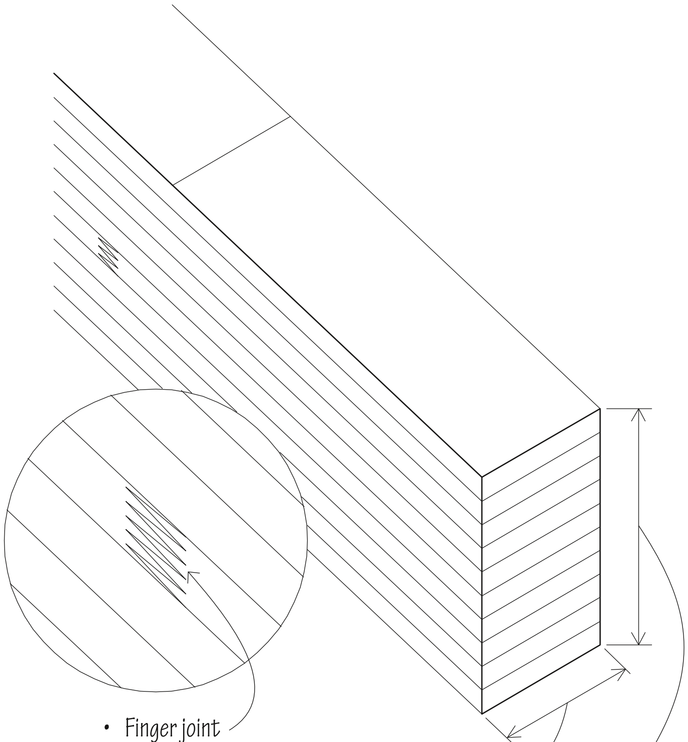
- Roof sheathing
- Top chord overhang
- Fascia

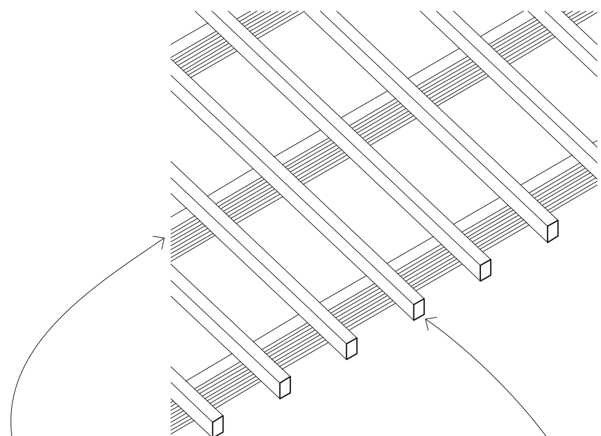
Overhanging Eaves

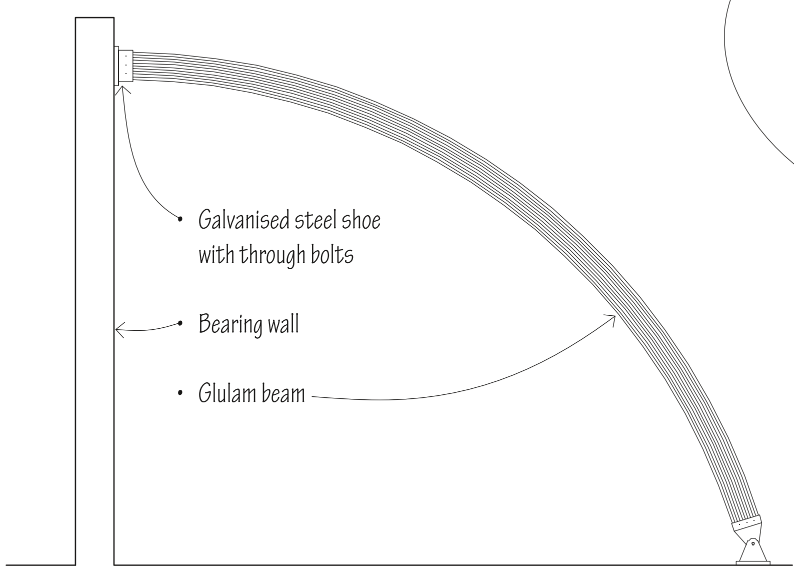
GLUE-LAMINATED BEAM ROOF STRUCTURES

Glue-laminated beams, commonly referred to as glulam, are made by bonding sheets of timber together to form a composite structure of greater strength. The sheet timber is finger-jointed to allow virtually any length to be achieved. Glue-laminated beams can achieve similar spans to trussed or steel structures but often with less weight.

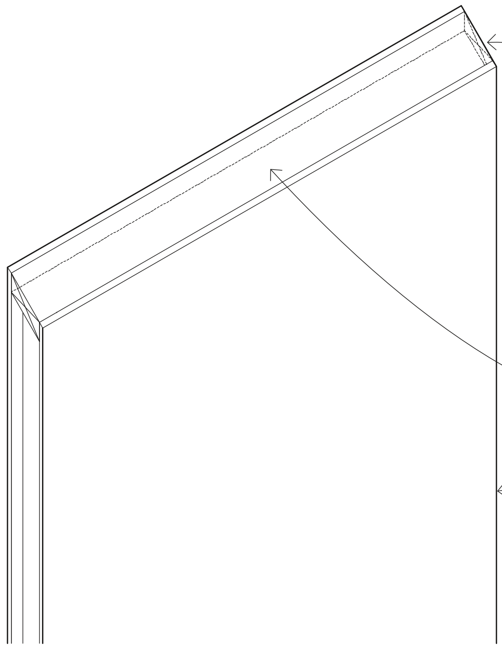
- Straight glue-laminated beams are commonly available
- Cambered and curved beams may require bespoke design
- Depth ranges of span/20 are possible depending on loading conditions and beam design
- Spans of 50 m+ are possible



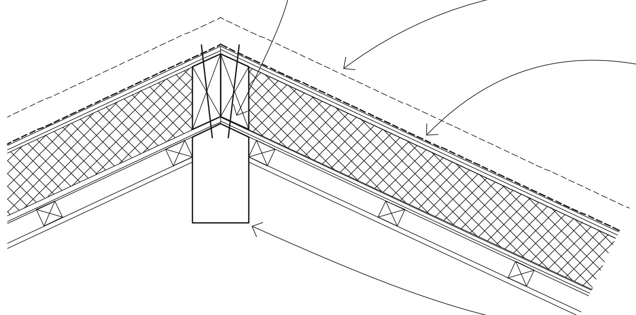


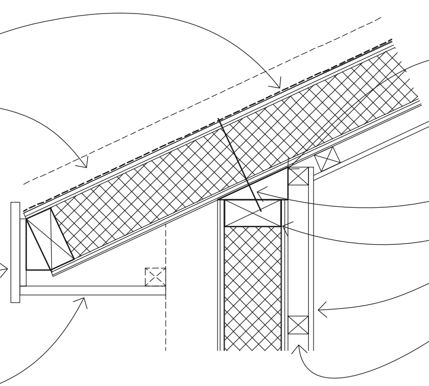


Structural insulated panels or SIPs consist of a layer of rigid cellular insulation sandwiched between two layers of oriented strand board (OSB) or cement-bonded particle board to form a lightweight, thermally efficient construction that through its composite strength can be used as a load-bearing element. SIPs can be used for both wall and roof structures. See 5.50 for details of SIPs.



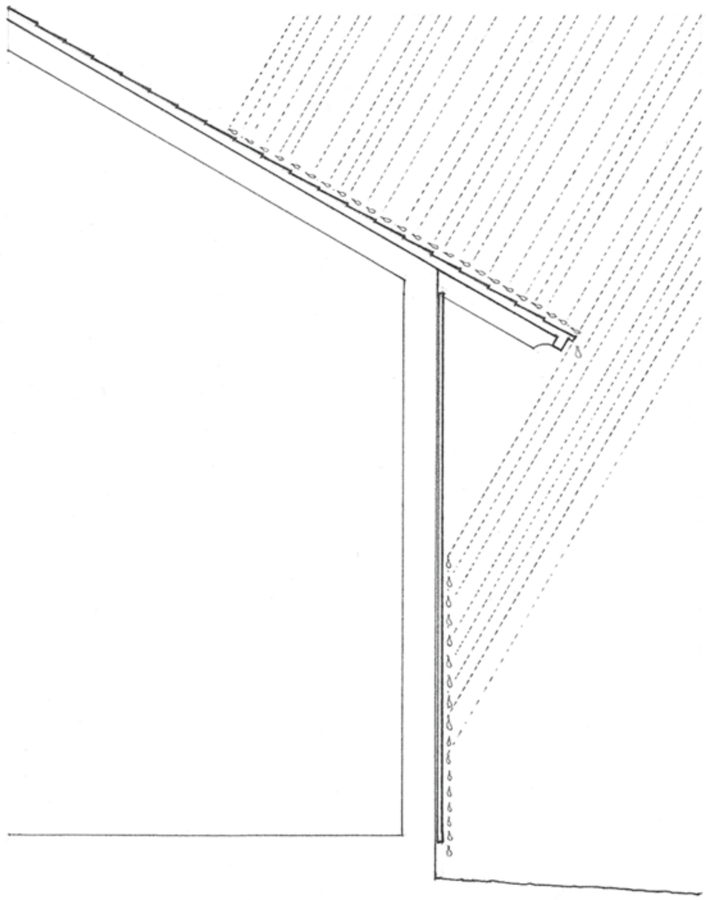
SIP panels are often employed to speed up the construction process in small- to medium-scale mainly residential developments with repetitive details; for instance multiple housing with small variation in unit types.





7

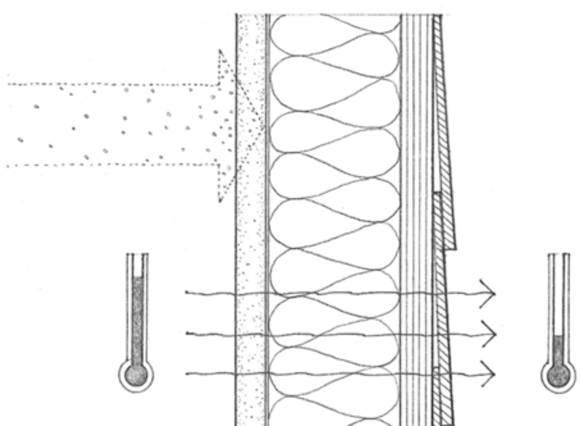
MOISTURE & THERMAL PROTECTION



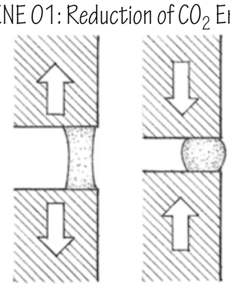
Roofing materials provide the water-resistant covering for a roof system. They range in form from virtually continuous, impervious membranes to overlapping or interlocking tiles. The type of roofing that may be used depends on the pitch of the roof structure. While a sloping roof easily sheds water, a flat roof must depend on a continuous waterproof membrane to contain the water while it drains or evaporates. A flat roof as well as any well-insulated sloping roof capable of retaining snow may therefore have to be designed to support a greater live load than a moderately- or high-pitched roof. Additional factors to consider in the selection of a roofing material include requirements for installation, maintenance and durability, resistance to wind and fire, and, if visible, the roofing pattern, texture and colour.

To prevent water from leaking into a roof assembly and eventually the interior of a building, flashing must be installed along roof edges, where roofs change slope or abut vertical planes, and where roofs are penetrated by chimneys, vent pipes and skylights. Exterior walls must also be flashed where leakage might occur – at door and window openings and along joints where materials meet in the plane of the wall.

Exterior walls also must provide protection from the weather. While some exterior wall systems, such as solid masonry and concrete load-bearing walls, use their mass as barriers against the penetration of water into the interior of a building, other wall systems, such as cavity walls and curtain walls, utilise an interior drainage system to carry away any moisture that finds its way through the facing or cladding.



LEED EA Credit 1: Optimize Energy Performance
BREEAM ENE 01: Reduction of CO_2 Emissions

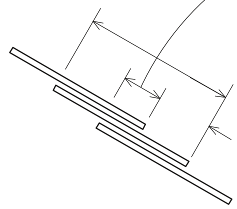


Moisture is normally present in the interior spaces of a building in the form of water vapour. When this water vapour reaches a surface cooled by heat loss to the colder outside air, condensation may occur. This condensation may be visible, as on an uninsulated window pane, or it can collect in concealed roof, wall or floor spaces. Means of combating condensation include the correct placement of thermal insulation and vapour barriers, and the ventilation of concealed spaces, such as attics and sub-floors.

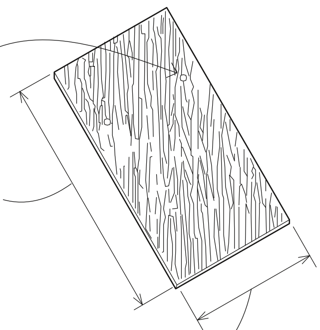
Potential heat loss or gain through the exterior enclosure of a building is an important factor when estimating the amount of mechanical equipment and energy required to maintain the desired level of environmental comfort in the interior spaces. The proper selection of building materials, the correct construction and insulation of the building enclosure and the orientation of a building on its site are the basic means of controlling heat loss and gain.

Building materials expand and contract due to variations within the normal temperature range, as well as exposure to solar radiation and wind. To allow for this movement and help relieve the stresses caused by thermal expansion and contraction, expansion joints should be flexible, weathertight, durable and correctly placed to be effective.

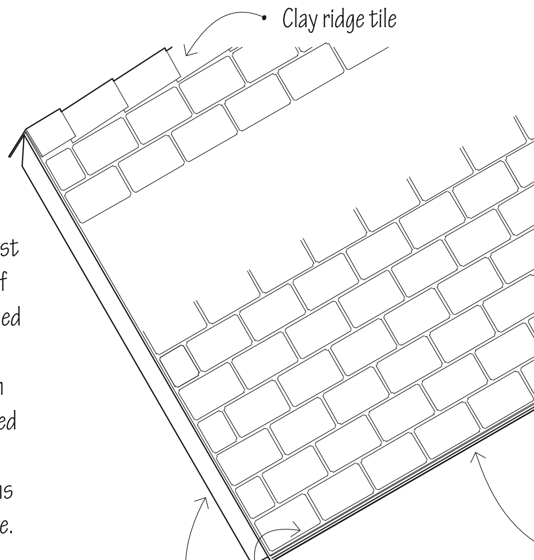
Slate is an extremely durable, fire-resistant and low-maintenance roofing material. Slates are split, trimmed and drilled to receive copper nails. Slates are traditionally laid using a double lap. Typical roof slopes are 22.5–35°.



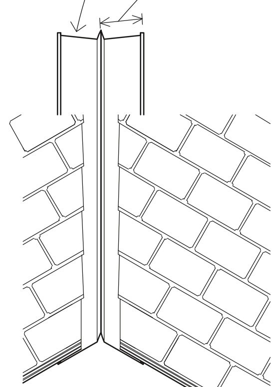
- Minimum head lap 80–110 mm
- Side lap equals half the slate width



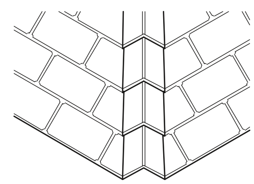
- Two nail holes per slate
- 355–650 mm in length
- Gauge or thickness 4–10 mm
- 250–350 mm wide



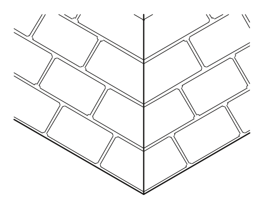
- Clay ridge tile



- Code 5 lead flashing
- 280 mm minimum; slate overlap 100 mm



- Saddle hip



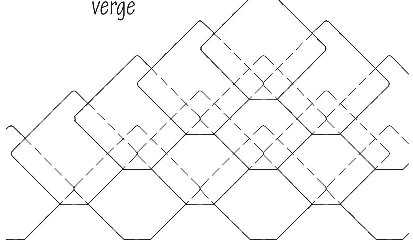
- Mitred hip

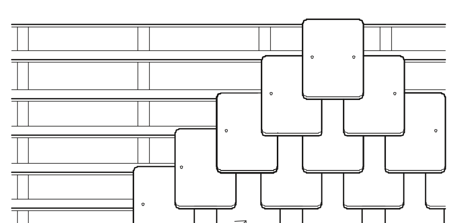
Slate can add a significant dead load to a roof structure, this must be taken into account during roof design. Slates are normally applied over a series of cross battens sitting on the rafters below, with an underlay or sarking sandwiched between. Timber sheeting is now often applied below cross battens to provide a solid working surface.

- Roof underlay traditionally known as sarking can be made from felt, polypropylene, polyethylene and other similar materials. It acts as a weathering layer, offering additional protection to the roof finish during the construction phase. Modern underlay is often vapour open minimising condensation risk

- Project 50 mm to form drip at eaves
- 30–40mm projection at the verge

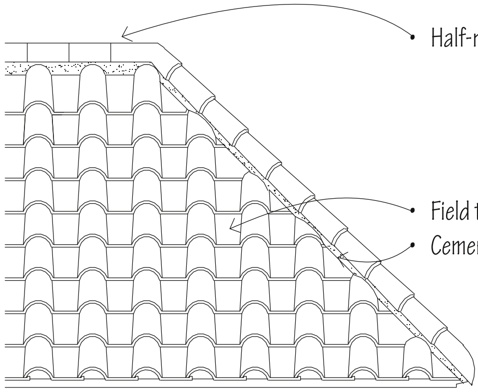
- Starter slate is used to give first course the same slope as succeeding courses





- Open or spaced slating is a method of laying roofing slates with spaces between adjacent tiles in a course

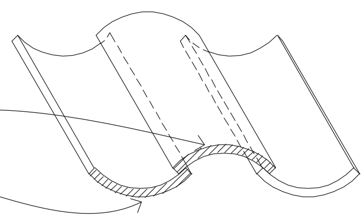
7.04 TILE ROOFING



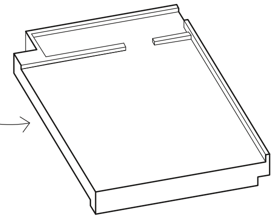
Roofing tiles are clay or concrete units that overlap or interlock to create a strong textural pattern. Like slate, roofing tiles are fire-resistant, durable and require little maintenance. They are also heavy and require roof framing that is strong enough to carry the weight of the tiles. Roofing tiles are normally installed over a solid plywood deck with a roofing underlay and cross battens. Special tile units are used at ridges, hips, verge and eaves.

The following are typical types, dimensions and weights of clay tiles. Confirm sizes, weights and installation details with tile manufacturer.

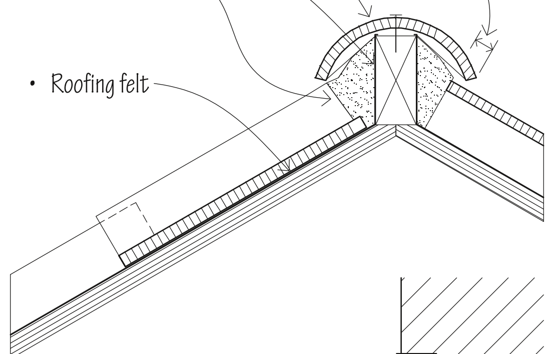
- Traditional Mission or Spanish tiles popular in Mediterranean regions are tapered, semi-cylindrical roofing tiles laid convex side up to overlap flanking, similar tiles laid concave side up
- Imbrex laid convex side up; tegula laid concave side up
- Taper allows tiles to nest into the overlapping tiles



- Interlocking tiles are flat, rectangular single lap roofing tiles having a groove along one edge that fits over a flange in the next tile in the same course
- Minimum recommended slope – 22.5º or manufacturer's minimum recommendation

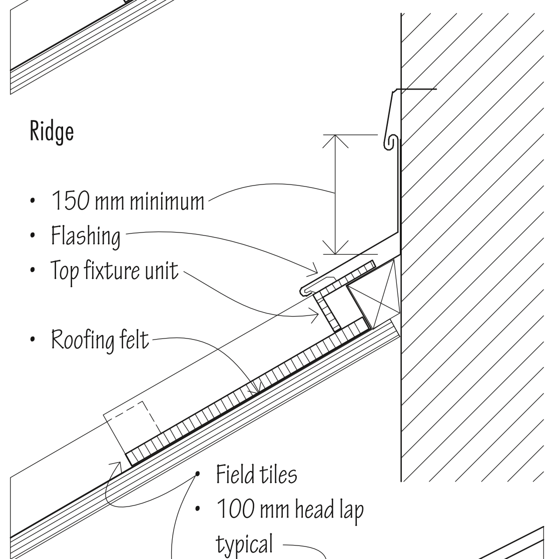


- Minimum head lap 75 mm
- Half round ridge tile
- Timber nailer
- Close with mortar
- Roofing felt



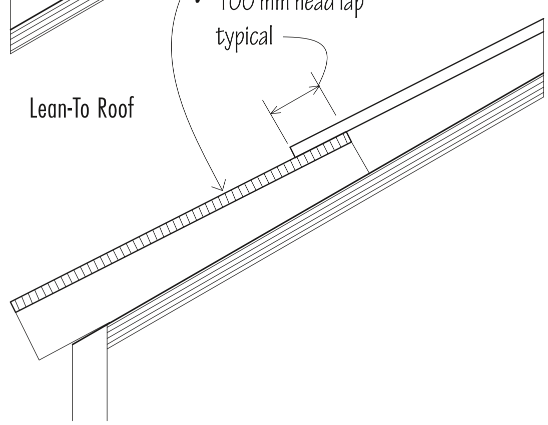
Ridge

- 150 mm minimum
- Flashing
- Top fixture unit
- Roofing felt



Lean-To Roof

- Field tiles
- 100 mm head lap typical



Eaves

Green roofing refers to a natural roof covering typically consisting of vegetation planted in engineered soil or growing medium over a waterproof membrane. While green roofing typically requires a greater initial investment, the natural covering protects the waterproof membrane from daily temperature fluctuations and the ultraviolet radiation of the sun that breaks down conventional roofing systems. Vegetated roofing also offers environmental benefits, including conserving a pervious area otherwise replaced by a building's footprint, controlling the volume of water run-off, and improving air and water quality.

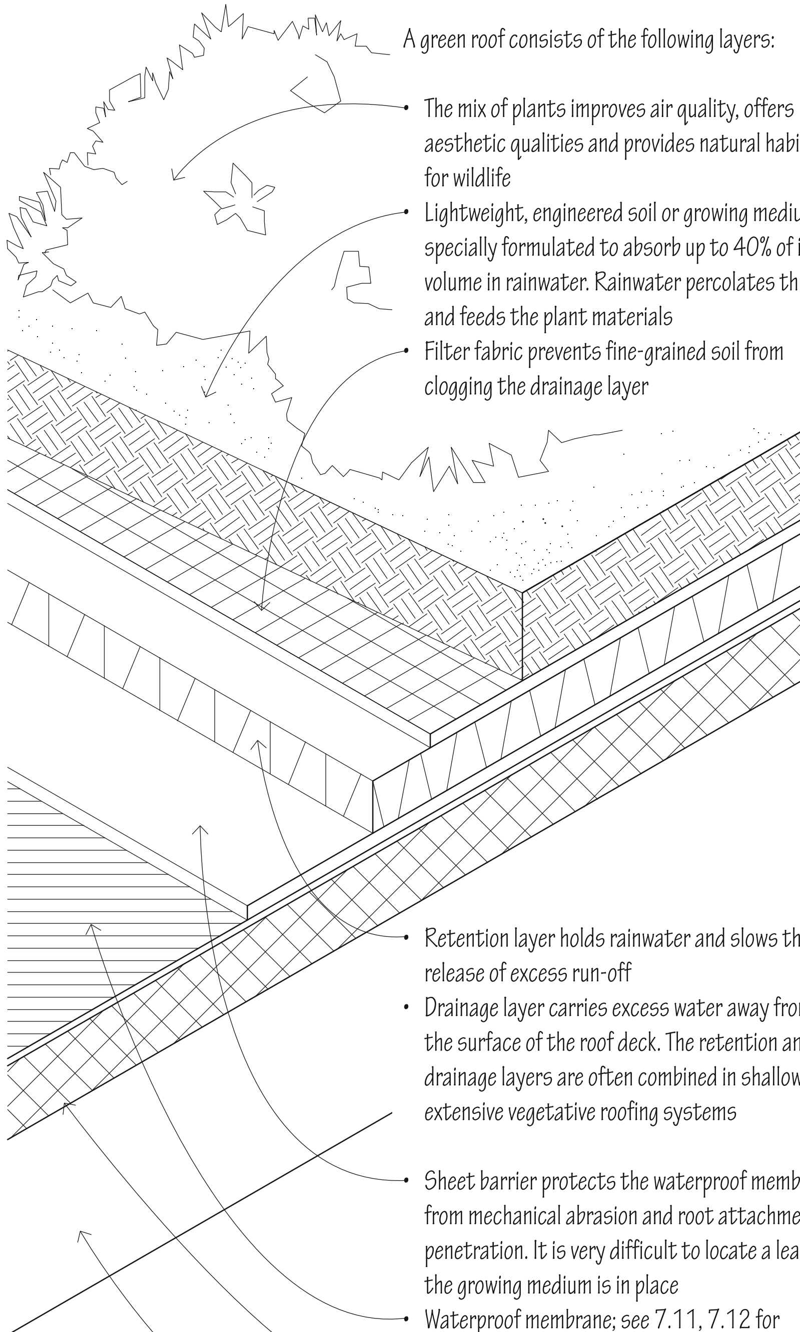
The surface temperature of traditional roofing can be up to 32°C warmer than the air temperature on a hot summer day. A green roof, having a much lower surface temperature, helps reduce the urban heat island effect. The increased insulation value of a vegetated roofing system can also help stabilise indoor air temperatures and humidity and potentially reduce the heating and cooling costs for a building.

There are two types of green roofing systems: intensive and extensive.

- Intensive vegetative roofing systems require typically 350–400 mm of soil depth to create an accessible roof garden with large trees, shrubs, meadows and other landscapes. They require irrigation and drainage systems to maintain the plant materials, which can add load on the roof structure. Concrete is usually the best choice for a roof deck
- Extensive vegetative roofing systems are low maintenance and built primarily for their environmental benefit. The lightweight growing medium they use is typically 50–100 mm in depth and contains small, hardy plants and thick grasses such as sedum that are accessed for maintenance only

- Green roofs are easiest to create on flat roofs, but extensive roofs can also be installed on sloping roofs if a suitable system for stabilising the soil or growing medium is in place

- Green wall-coverings known as 'living walls' are also possible and offer similar benefits to green roof solutions. In addition they may be used to grow food as well as provide screening



A green roof consists of the following layers:

- The mix of plants improves air quality, offers aesthetic qualities and provides natural habitat for wildlife
- Lightweight, engineered soil or growing medium is specially formulated to absorb up to 40% of its volume in rainwater. Rainwater percolates through and feeds the plant materials
- Filter fabric prevents fine-grained soil from clogging the drainage layer

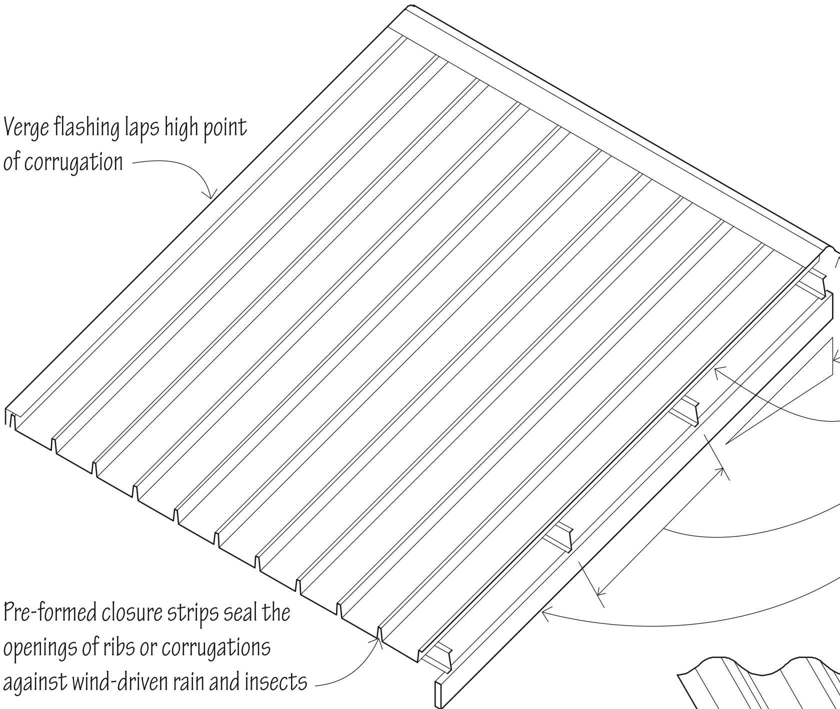
- Retention layer holds rainwater and slows the release of excess run-off
- Drainage layer carries excess water away from the surface of the roof deck. The retention and drainage layers are often combined in shallow extensive vegetative roofing systems

- Sheet barrier protects the waterproof membrane from mechanical abrasion and root attachment or penetration. It is very difficult to locate a leak once the growing medium is in place
- Waterproof membrane; see 7.11, 7.12 for membrane roofing
- See 7.08–7.09 for placement options of thermal insulation and vapour retarder
- Supporting roof structure must have the necessary load-bearing capacity to support wet densities

BREEAM POL 03: Surface Water Run-Off
BREEAM LE 03: Mitigation of Ecological Impact
LEED SS Credit 6: Stormwater Design
LEED SS Credit 7: Reduce Heat Island Effect

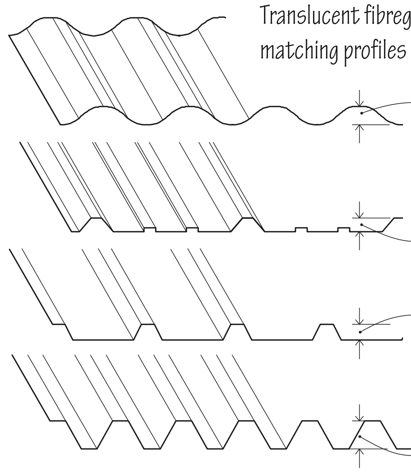
Corrugated or ribbed roofing panels span between roof beams or purlins running across the slope. The roofing panels may be of:

- Aluminium with a natural mill or enamelled finish
- Galvanised steel
- Fibreglass or reinforced plastic



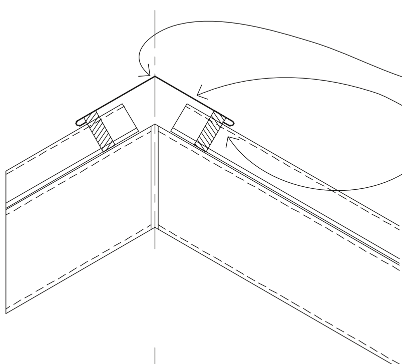
- Verge flashing laps high point of corrugation
- Pre-formed closure strips seal the openings of ribs or corrugations against wind-driven rain and insects
- Pre-formed ridge cap of same metal as roofing
- Minimum recommended roof pitch 5º
- Roofing panels may be factory-cut to the full length of the roof from ridge to eaves
- Purlin spacing = span of roofing; 600–1800 mm centres typically
- Roof beam or truss support for purlins

- Many corrugation and ribbed patterns are available. Translucent fibreglass or plastic panels with matching profiles are available for use as skylights



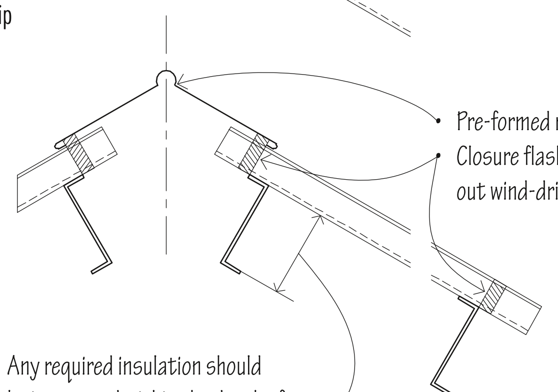
- 19–25 mm
- 19–29 mm
- 35–60 mm
- 38–50 mm

- 600–900 mm typical widths
- Consult roofing manufacturer for material specifications, panel sizes and weights, finishes, allowable spans and installation details



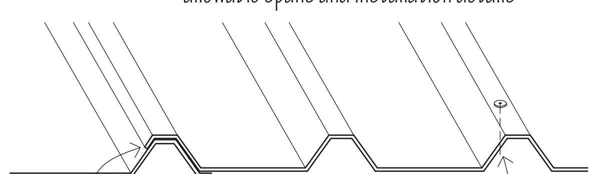
- Hip flashing
- 150 mm lap
- Closure strip or seal

Hip



- Pre-formed ridge cover
- Closure flashing or seals to keep out wind-driven rain and insects
- Any required insulation should be integrated within the depth of the roof structure making sure to minimise thermal bridging and minimise condensation risk

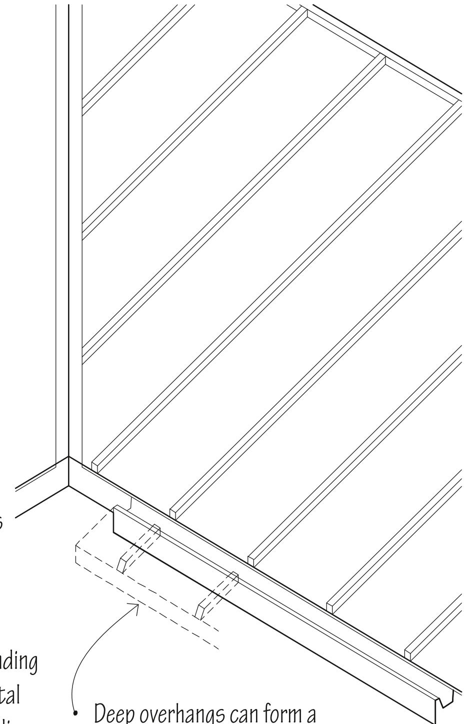
Ridge



- Lap sides one rib or 1½ corrugations
- Mechanical fastenings are made through the top portion of the corrugations or ribs. Washers and gaskets are generally required

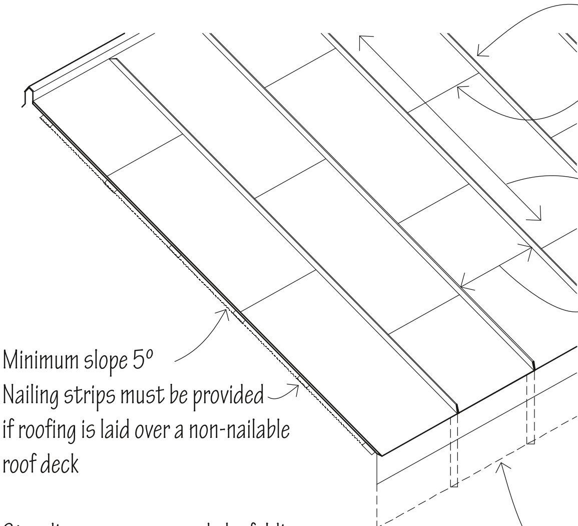
A sheet-metal roof is characterised by a strong visual pattern of interlocking seams and articulated ridges and roof edges. The metal sheets may be of copper, zinc alloy, galvanised steel or terne metal, a stainless steel plated with an alloy of tin and lead. To avoid possible galvanic action in the presence of rainwater, flashing, fastenings and metal accessories should be of the same metal as the roofing material. Other factors to consider in the use of metal roofing are the weathering characteristics and coefficient of expansion of the metal.

- Metal roofing is installed over an underlay of roofing felt

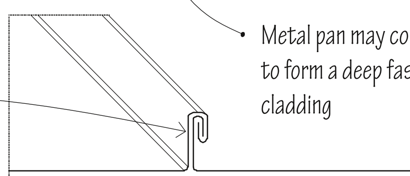


- Standing or batten seams
- Horizontal and valley seams are flat and usually soldered
- Provide expansion joints on runs exceeding 9 m
- Vertical seams are spaced from 300 to 600 mm centres, depending on the starting width of the metal sheets and the size of the standing or batten seams
- The seams on prefabricated batten roofs are spaced from 600 to 900 mm centres
- Metal pan may continue down to form a deep fascia or wall cladding

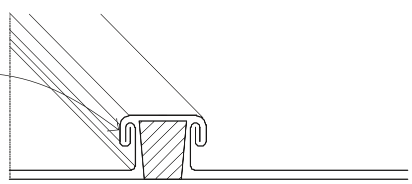
- Minimum slope 5º
- Nailing strips must be provided if roofing is laid over a non-nailable roof deck



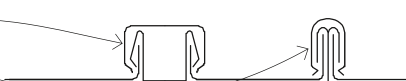
- Deep overhangs can form a concealed gutter
- Interlocking gutter and lining of same metal as roofing

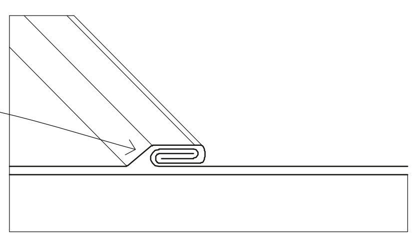


- Standing seams are made by folding up the adjoining edges against each other, then folding their upper portion over in the same direction a number of times



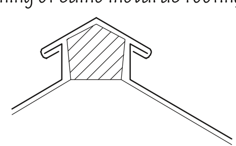
- Batten seams are made by turning up the adjoining edges against a batten and locking them in place with a metal strip placed over the batten
- Taper batten to allow for expansion of roofing
- Various prefabricated standing and batten seams are available from metal roofing manufacturers



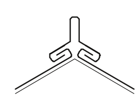


- Welted joints are made by folding up the adjoining edges against each other, folding them over and flattening the interlock

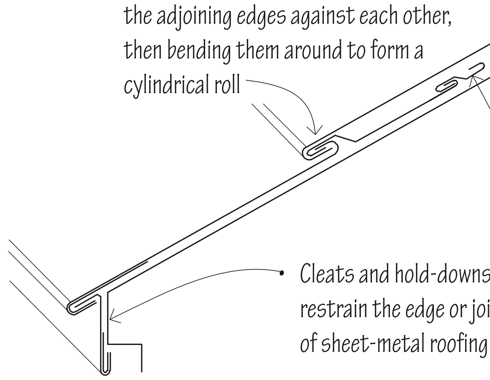
Types of Seams



- Batten ridge seam



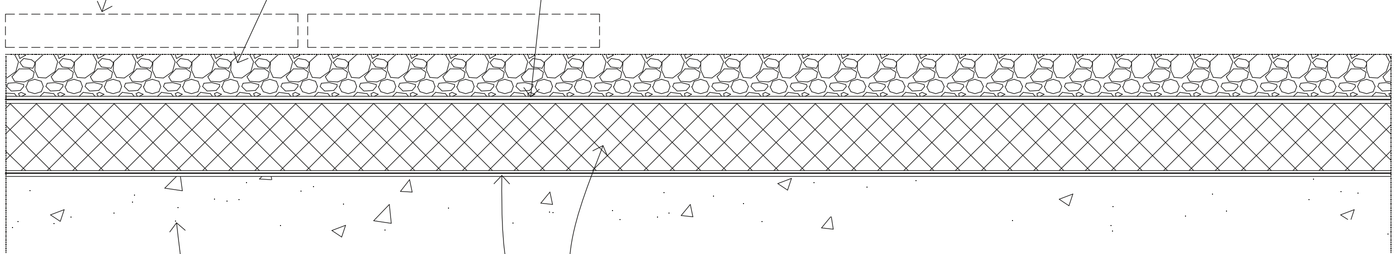
- Standing ridge seam



- Roll seams are joints between two pieces of sheet metal in the direction of fall of a curved or sloping roof, made by turning up the adjoining edges against each other, then bending them around to form a cylindrical roll
- Cleats and hold-downs restrain the edge or joint of sheet-metal roofing
- Eaves seam

The construction of a flat roof requires the following elements:

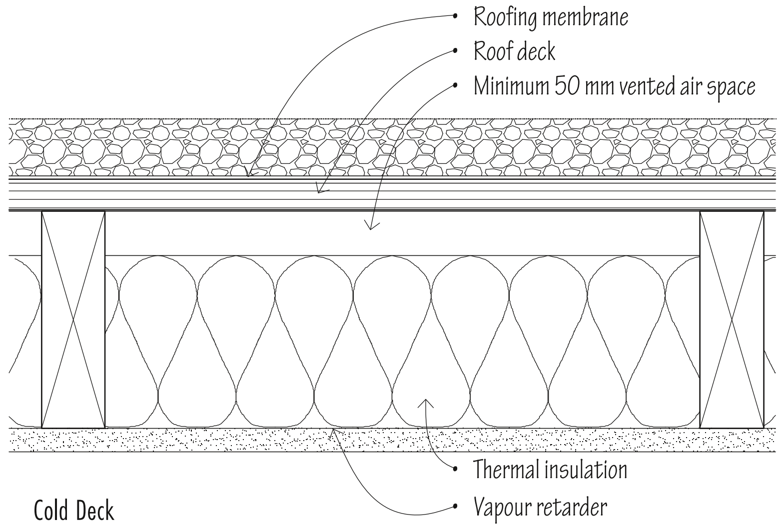
1. The wear course protects the roofing from uplifting wind forces and mechanical abrasion. It may be provided by built-up roofing aggregate, ballast aggregate or deck pavers
2. The drainage layer permits the free flow of water to the roof drains. It may consist of the aggregate layer in a built-up roofing system, the ballast layer in a loose-laid, single-ply roofing system, the surface of a fully adhered single-ply roof, or the drainage fabric or space under the pavers in a deck system
3. The roofing membrane is the waterproofing layer of the roof. It should be sloped at least 1:80 to transport rainwater to the roof drains. This slope may be created by adjusting the height of the beams that support the roof deck, placing a concrete screed to a fall, or installing tapered panels of rigid foam insulation over the roof deck. The two major types of membrane systems are
   - Built-up roofing systems; see 7.10
   - Single-ply roofing systems; see 7.11–7.12



4. Thermal insulation; see 7.09 for placement options
5. A vapour retarder impedes the passage of water vapour into the roofing assembly. The vapour retarder is placed on the predominantly warm side of an assembly. The temperature at the vapour retarder should be warmer than the dew-point temperature to prevent condensation from occurring, which can damage the thermal insulation, roofing membrane and structural materials. It is also important that the vapour retarder be continuous, sealed at all roof penetrations, and tied into the wall assembly around the perimeter of the roof. When a vapour retarder is present, topside vents may be required to allow any trapped moisture to escape from between the vapour retarder and the roofing membrane. For more information on moisture control, see 7.46
6. The roof deck must be stiff enough to maintain the desired slope under expected loading conditions, and be smooth, clean and dry enough for the rigid insulation or roofing membrane to adhere properly. See 7.10 for a list of types of roof decks and substrates. Large roof areas may require expansion joints or area dividers. For these and other flashing details, see 7.15–7.16

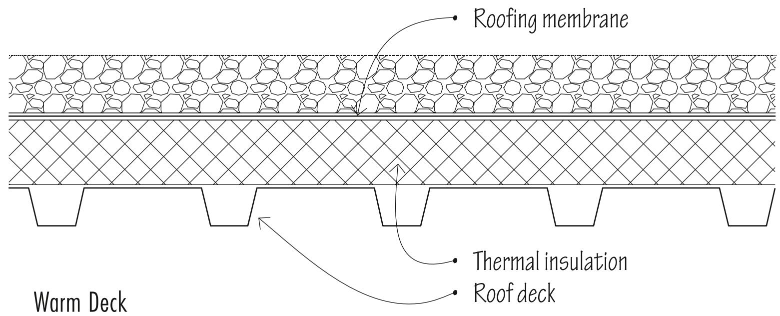
Thermal insulation provides the required resistance to heat flow through the roof assembly. It may be installed in three positions: below the structural roof deck, between the roof deck and the roofing membrane, or above the roofing membrane.

- When located below the roof deck the system is referred to as 'cold deck'. The thermal insulation typically consists of batt insulation installed over a vapour retarder or with vapour-resistant plasterboard to the ceiling below. A ventilated air space between the insulation and the roof deck is required to dissipate any water vapour that migrates into the construction assembly



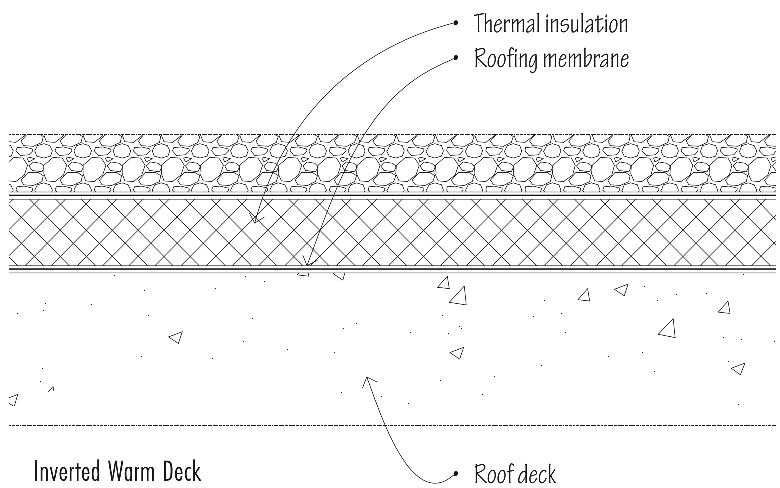
Cold Deck

- When located between above the roof deck and below the roofing membrane, the system is known as 'warm deck'. The thermal insulation is usually in the form of rigid foam insulation boards capable of supporting the roofing membrane. Rigid insulation should be installed in at least two staggered layers with tongue-and-groove (t&g) joints to minimise heat loss through the joints. The first layer should be mechanically fastened to resist wind uplift; the upper layers are fully adhered as required

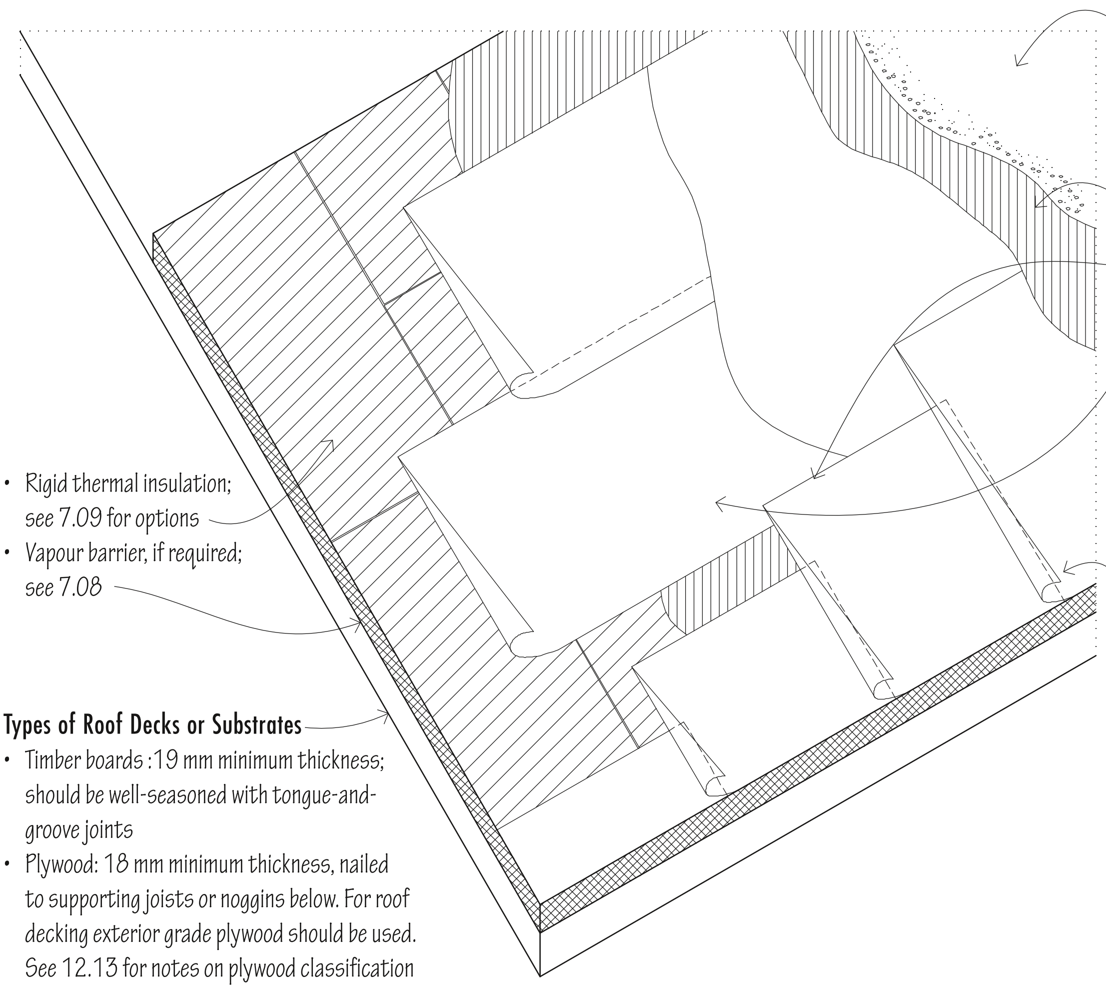


Warm Deck

- In the 'inverted warm deck' system, the thermal insulation is placed over the roofing membrane. In this position, the insulation protects the roofing membrane from temperature extremes but not from almost continual dampness. The thermal insulation consists of moisture-resistant extruded polystyrene boards laid loosely or adhered to the roofing membrane. The insulation is protected from sunlight and held in place by stone ballast laid over a filtration fabric



Inverted Warm Deck

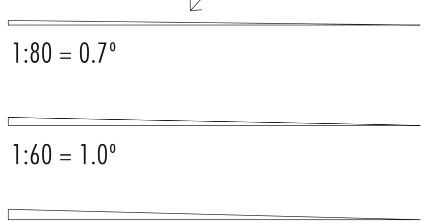


- Wear course of gravel or marble chips aids in stiffening membrane and resisting wind blow-off and offers UV protection
- Surfacing bitumen of coal tar or asphalt
- Second layer is fully bonded to base layer with staggered or cross-lapped joints
- Base sheet of glass or polyester fibre reinforced bituminous roll
- Base sheet rolled on top of poured hot bitumen
- Felt overlap
  - Minimum 50 mm side laps
  - Minimum 75 mm end laps

- Rigid thermal insulation; see 7.09 for options
- Vapour barrier, if required; see 7.08

Types of Roof Decks or Substrates

- Timber boards :19 mm minimum thickness; should be well-seasoned with tongue-and-groove joints
- Plywood: 18 mm minimum thickness, nailed to supporting joists or noggins below. For roof decking exterior grade plywood should be used. See 12.13 for notes on plywood classification
- Oriented strand board (OSB): 18 mm minimum thickness exterior grade OSB with allowance for movement made between joints and at abutments. See 12.14 for notes on OSB classification
- Cast-in-situ concrete should be well-cured, dry and frost-free.The deck should also be free of ridges and hollows, normally achieved with the application of a roof screed which is also used to provide a slope to drainage
- Precast concrete must have all joints grouted; any unevenness between units must be levelled with a screed. Falls can be achieved by the structure itself or tapered insulation
- Consult roofing manufacturer for approved types of deck, insulation, fastenings and installation requirements for vapour retarder and venting



- Minimum recommended slope – 1:80; often designed to 1:40 or 1:60 to allow for workmanship, tolerance and other imperfections

Bituminous built-up roofing is normally applied in two or more layers of roof roll, built up on site. Mastic asphalt, a combination of bitumen and limestone aggregate, can be used as a wearing course for built-up roofing or in areas subject to high usage as a waterproof finish in its own right. Mastic asphalt is spread over the roof deck in two layers giving a minimum overall thickness of 20 mm.

EN 13707: 2004. Flexible Sheets for Waterproofing

Single-ply membrane roofing may be applied in liquid or sheet form. Large domed, vaulted or complex roof forms require that the roofing membrane be rolled or sprayed on in liquid form. Materials used for liquid-applied membranes include silicone, neoprene, butyl rubber and polyurethane. On planar roof forms, the roofing membrane may be applied in sheet form. Sheet materials used for single-ply roofing include:

- Thermoplastic membranes which may be heat- or chemically-welded
- PVC (polyvinyl chloride) and PVC alloys
- Polymer-modified bitumens, asphaltic materials to which polymers have been added for increased flexibility, cohesion and toughness; often reinforced with glass fibres or plastic films
- Thermosetting membranes can be bonded only by adhesives
- EPDM (ethylene propylene diene monomer), a vulcanised elastomeric material
- CSPE (chlorosulfonated polyethylene), a synthetic rubber
- Neoprene (polychloroprene), a synthetic rubber

These materials are very thin – from 0.8 to 2.5 mm thick – flexible and strong. They vary in their resistance to flame propagation, abrasion and degradation from ultraviolet rays, pollutants, oils and chemicals. Some are reinforced with fibreglass or polyester; others have coatings for greater heat-reflectance or resistance to flame spread. Consult the roofing manufacturer for:

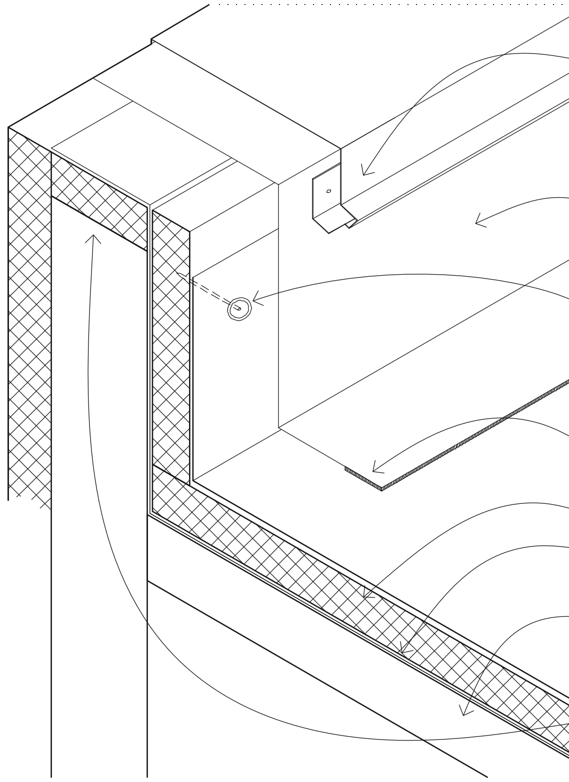
- Material specifications
- Approved types of roof deck, insulation, and fastenings
- Installation and flashing details

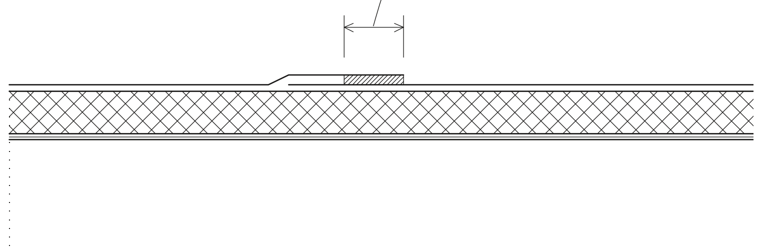
The details on this and the following page refer to EPDM roofing. Details for other single-ply membranes are similar in principle. There are three generic systems for the application of EPDM roofing:

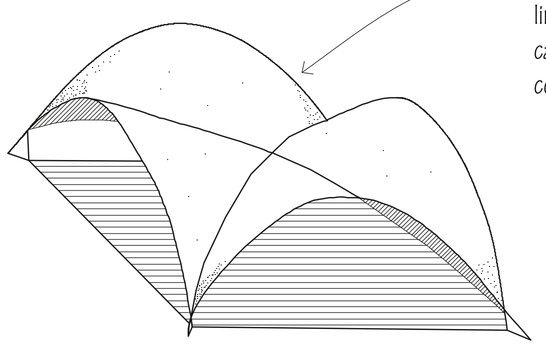
- Fully adhered system
- Mechanically fastened system
- Loose laid, ballasted system

Fully Adhered System

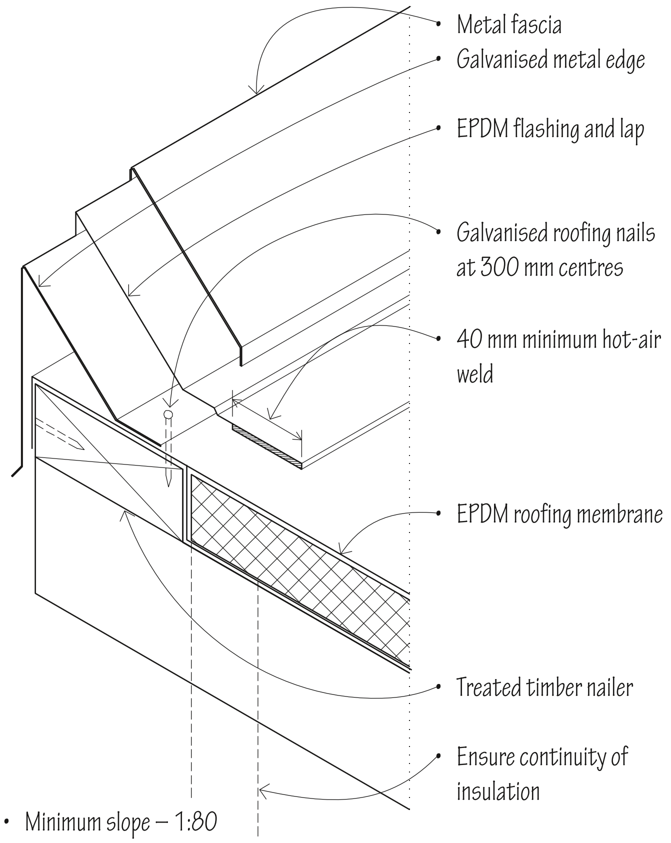
The membrane is fully adhered with bonding adhesive to a smooth-surfaced concrete or timber deck, or to rigid insulation boards that are mechanically fastened to the roof deck. The membrane is mechanically fastened along the perimeter and at roof penetrations.

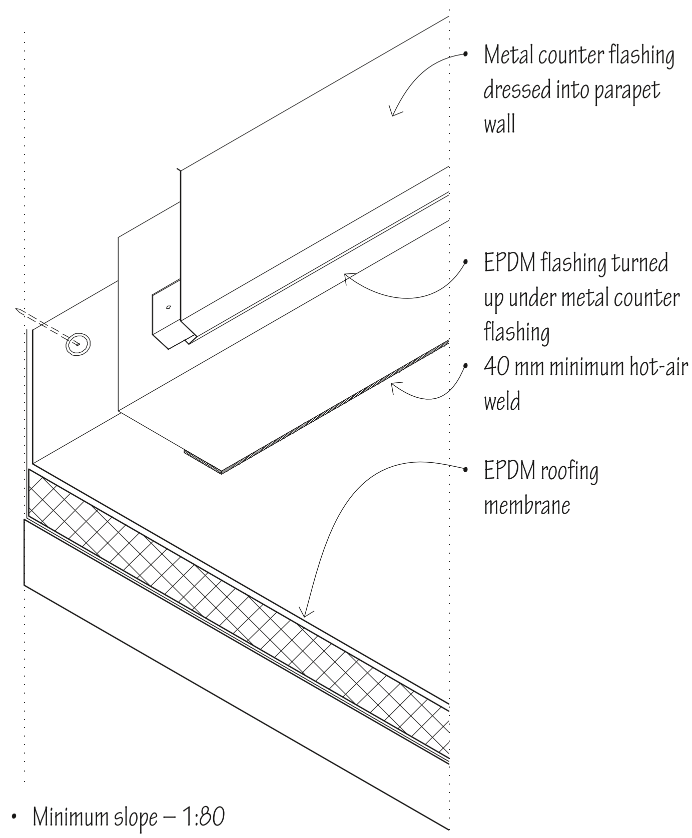


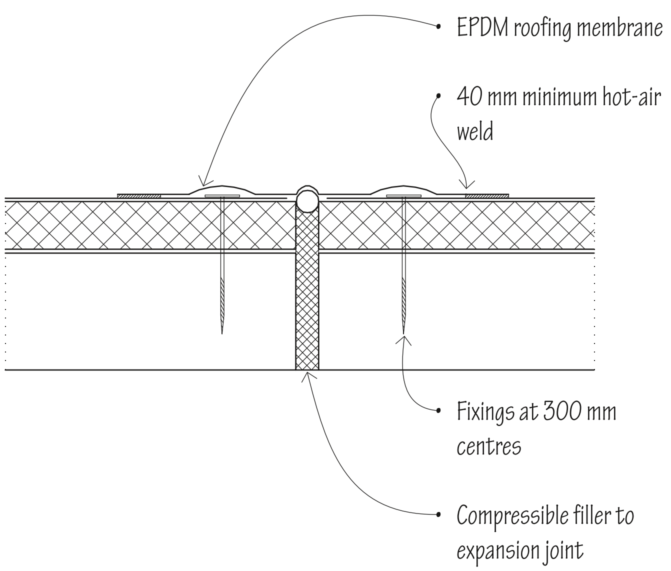


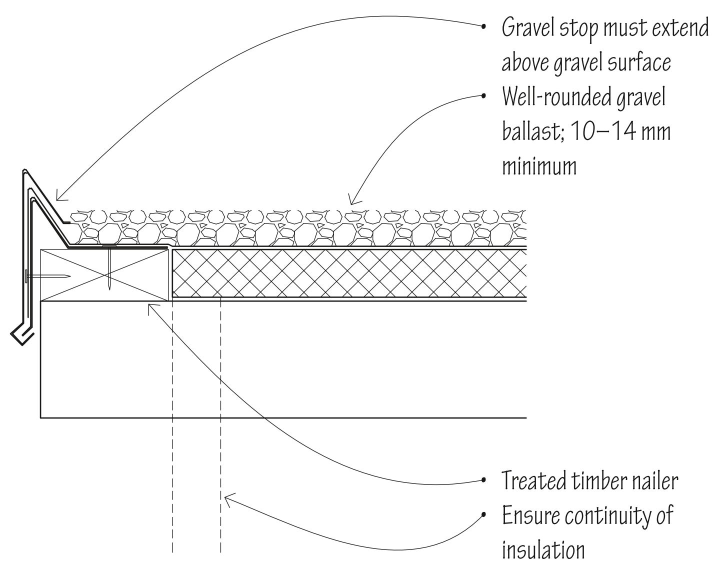


7.12 SINGLE-PLY ROOFING SYSTEMS









Mechanically Fastened System

After the thermal insulation boards have been mechanically fastened to the roof deck, the membrane is also secured to the deck with plates and fasteners in the membrane splices.

Loose Laid, Ballasted System

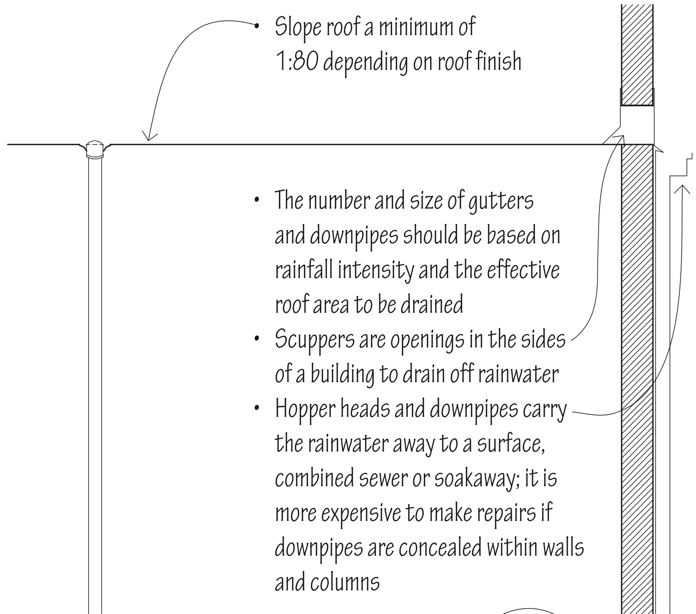
Both the insulation and the membrane are laid loosely over the roof deck and covered with a layer of river-washed gravel or a roof paver system. The membrane is mechanically fastened to the roof deck only along the perimeter and at roof penetrations.

The amount of rain or melting snow a roof and its drainage system must handle is a function of:
- The roof area leading to the roof drains or gutters
- The frequency and intensity of the rainfall for the region

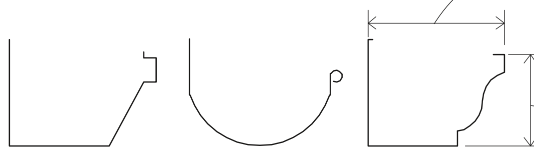
Flat roofs should be pitched to roof drains that are located at the low points and that connect to the drainage system of the building. A system of overflow drains may also be required with the inlet flow 50 mm above the low points of the roof.

Rainwater shed by sloping roofs should be caught by gutters along the eaves to prevent ground erosion. Gutters empty into vertical downpipes that, in turn, discharge into a surface water drainage system.

Gutters are typically of uPVC , galvanised steel or aluminium, although copper, stainless steel, terne steel and timber are also available. Aluminium gutters can be cold-formed on-site in continuous runs without joints.

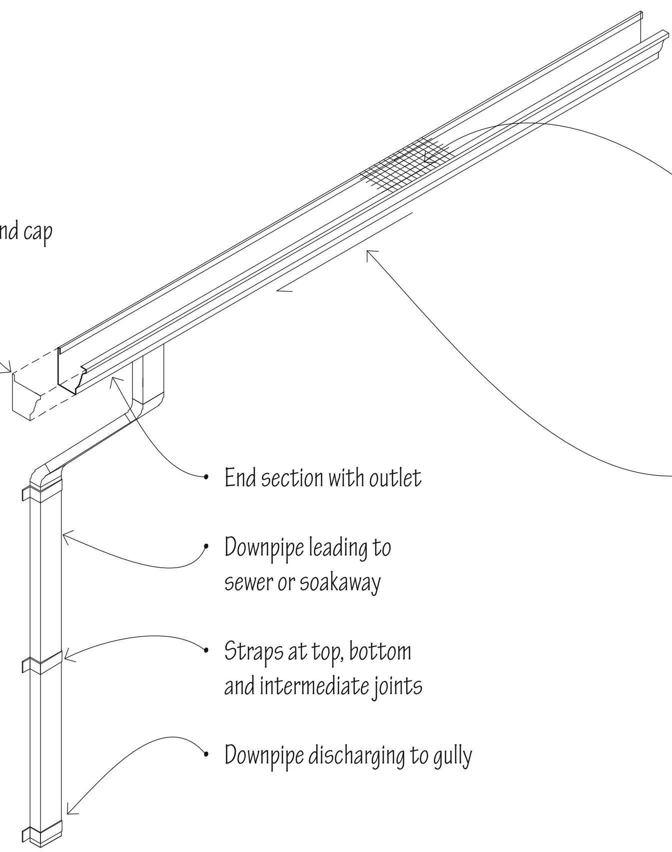


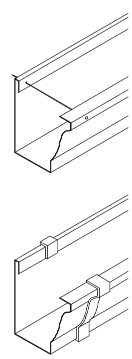
- Slope roof a minimum of 1:80 depending on roof finish
- The number and size of gutters and downpipes should be based on rainfall intensity and the effective roof area to be drained
- Scuppers are openings in the sides of a building to drain off rainwater
- Hopper heads and downpipes carry the rainwater away to a surface, combined sewer or soakaway; it is more expensive to make repairs if downpipes are concealed within walls and columns



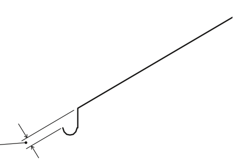
- 100–205 mm
- 70–150 mm

Gutter Shapes
- Bevelled
- Half-round
- Ogee





- Spike and ferrule hangers are spiked to fascia or to rafter tails
- Brackets are screwed to fascia or to rafter tails
- End cap
- Gutter supports are spaced at maximum 900 mm centres
- Wire mesh to protect gutter from leaves
- End section with outlet
- Downpipe leading to sewer or soakaway
- Straps at top, bottom and intermediate joints
- Downpipe discharging to gully
- Slope straight runs 1:360; lap and solder or seal joints with mastic; provide expansion joints for runs over 12 m long



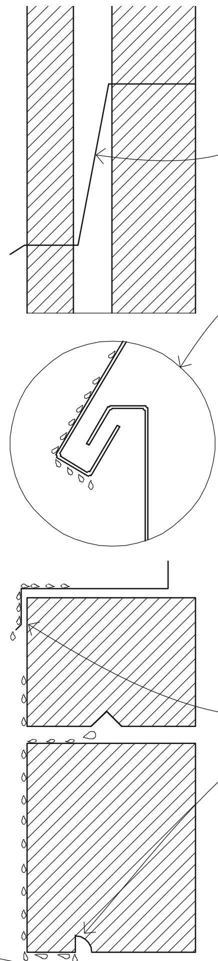
- Place gutters below the roof slope line so that snow or ice can slide free

Flashing refers to thin continuous pieces of sheet metal or other impervious material installed to prevent the passage of water into a structure from an angle or joint. Flashing generally operates on the principle that, for water to penetrate a joint, it must work itself upward against the force of gravity, or, in the case of wind-driven rain, it would have to follow a tortuous path during which the driving force would be dissipated. See also 7.19 for a discussion of pressure-equalised rainscreen-wall design.

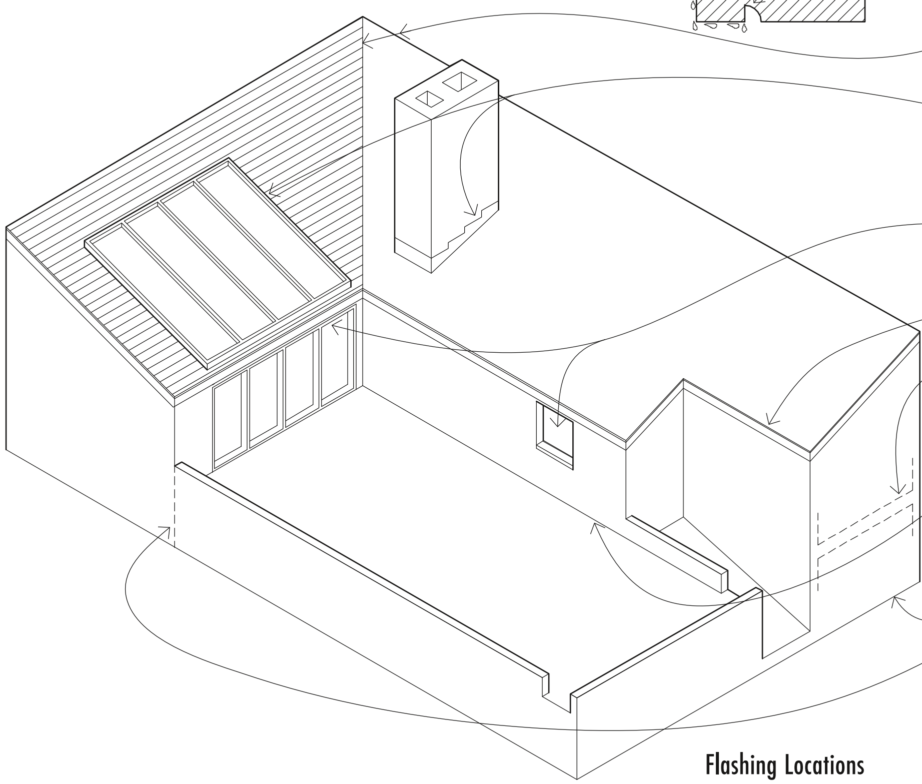
Flashing may be exposed or concealed. Exposed flashing is usually of a sheet metal, such as aluminium, copper, galvanised steel, stainless steel, zinc alloy or lead. Metal flashing should be provided with expansion joints on long runs to prevent deformation of the metal sheets. The selected metal should not stain or be stained by adjacent materials or react chemically with them. See 12.09.

Flashing concealed within a construction assembly may be of sheet metal or a waterproofing membrane such as bituminous fabric or plastic sheet material, depending on climate and structural requirements.

- Aluminium and lead react chemically with cement mortar
- Some flashing materials can deteriorate with exposure to sunlight



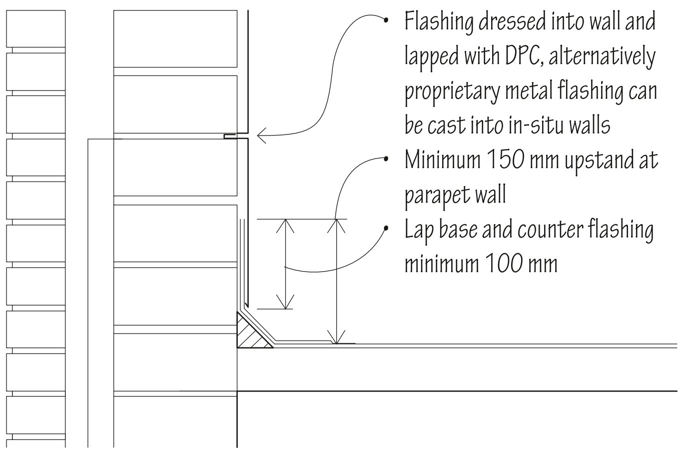
- Upturned edges and sloping surfaces use gravity to lead water to the outside
- Interlocking seams form a labyrinth that inhibits the passage of water
- Water can penetrate a joint through surface tension and capillary action
- Capillary action is a manifestation of surface tension by which the greater adhesion of a liquid to a solid surface than internal cohesion of the liquid itself causes the liquid to be elevated against a vertical surface
- Drips and cavities form capillary breaks between two surfaces wide enough to prevent the capillary action of moisture through the space



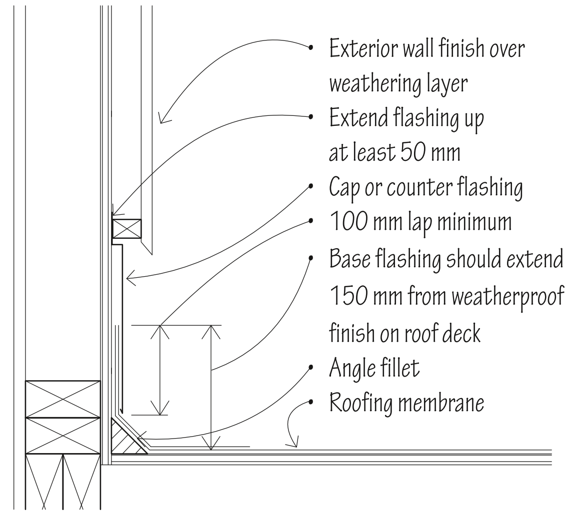
- Roof valleys, ridges, hips and changes in roof pitch
- Roof penetrations, such as chimneys, roof drains, vent pipes and skylights
- Window and door openings
- Roof eaves and verge
- Floor and wall intersections
- Intersections between roofs and vertical surfaces
- Where the building meets the ground
- Expansion joints and other breaks in the building skin

Flashing Locations

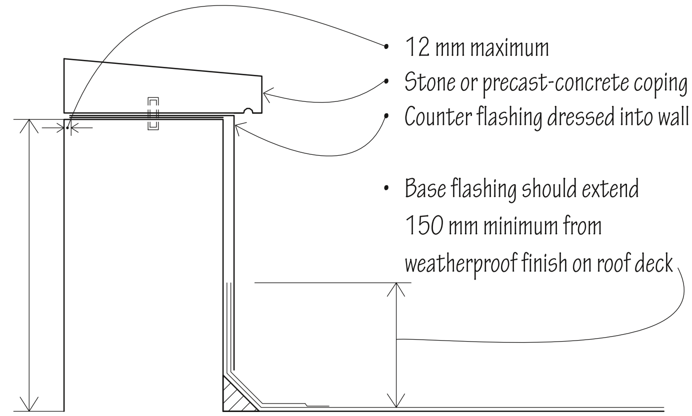
The flashing details on this and the following pages illustrate general conditions and can be adapted for use with various building materials and assemblies. All dimensions are minimum. Weather conditions and roof slope may dictate greater overlaps. Consult the manufacturer for details of flashing and flashing accessories.



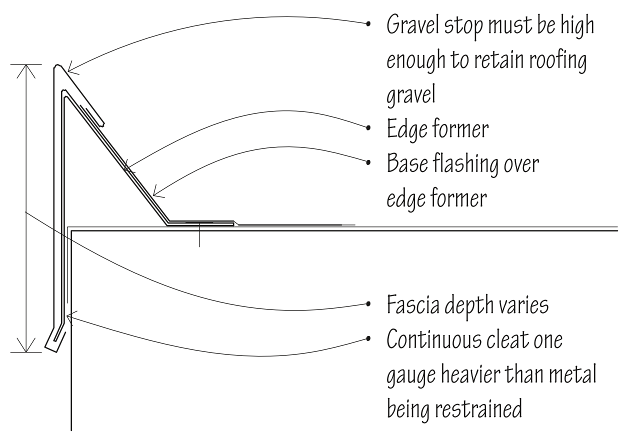
Masonry or Concrete Parapet



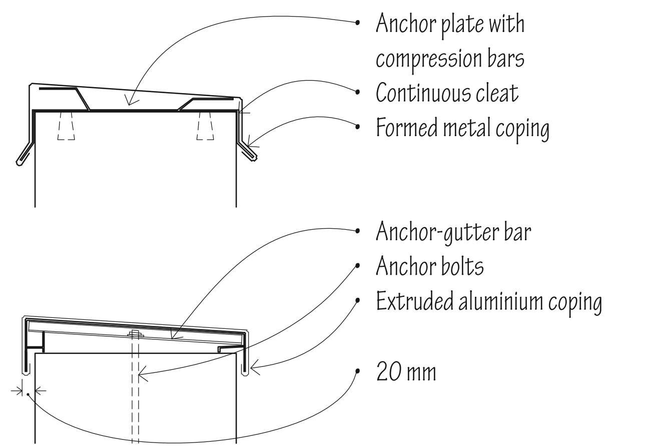
Stud-Framed Parapet



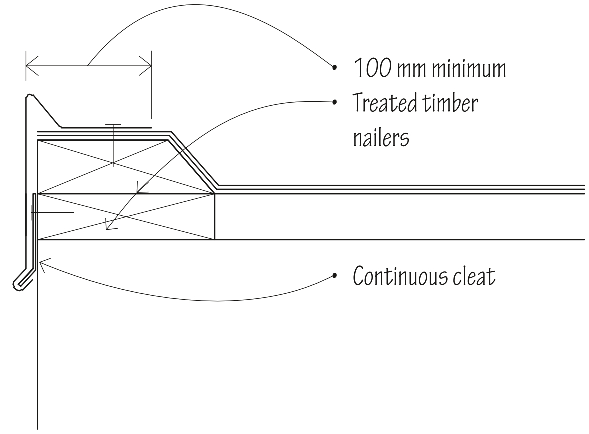
Low Parapet Wall



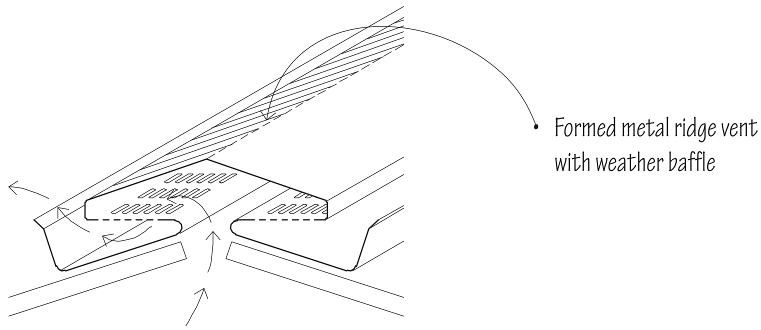
Metal Gravel Stop and Fascia



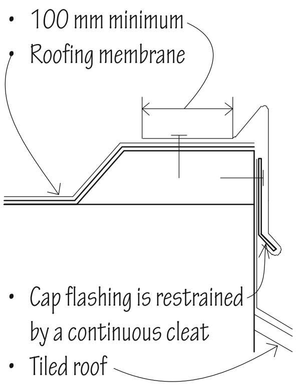
Metal Copings



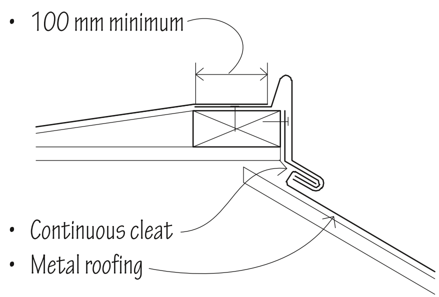
Metal Gravel Stop



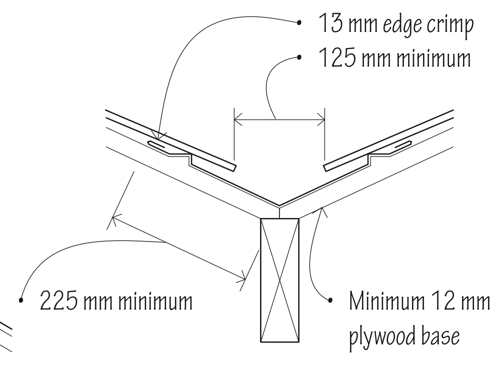
Ridge Vent



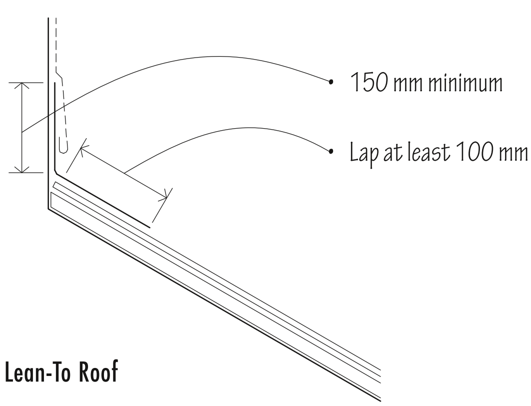
Flat to Sloping Roof



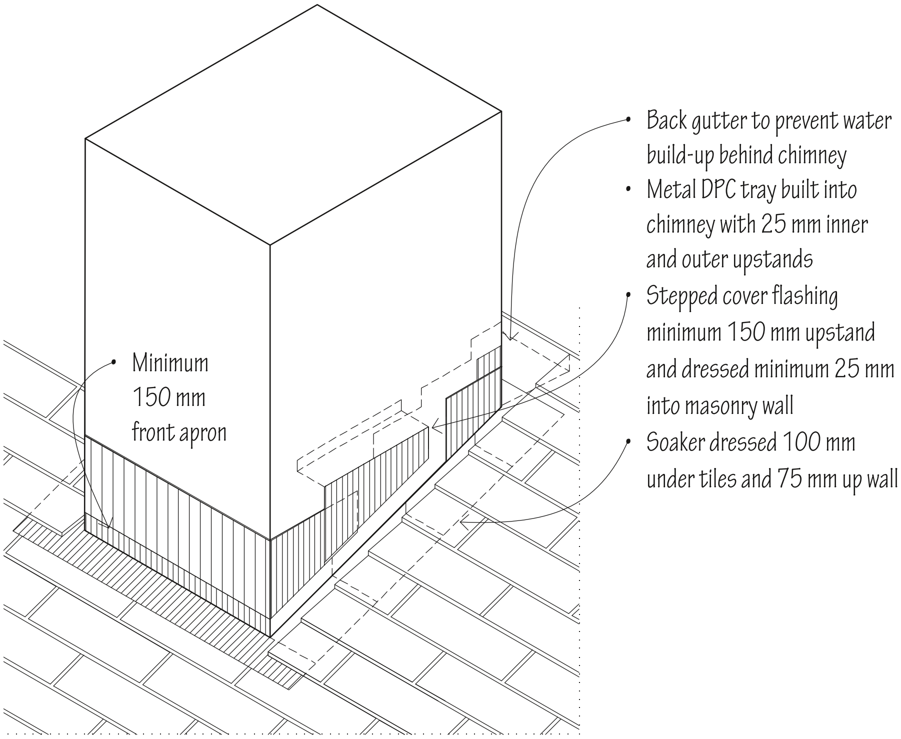
Flat to Sloping Roof



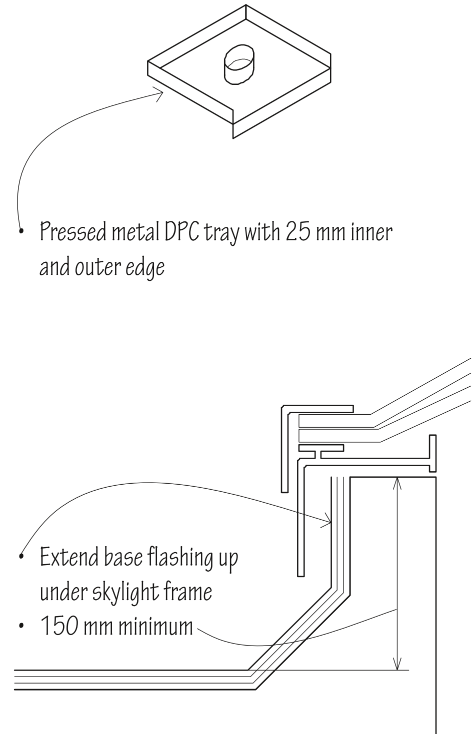
Exposed Valley



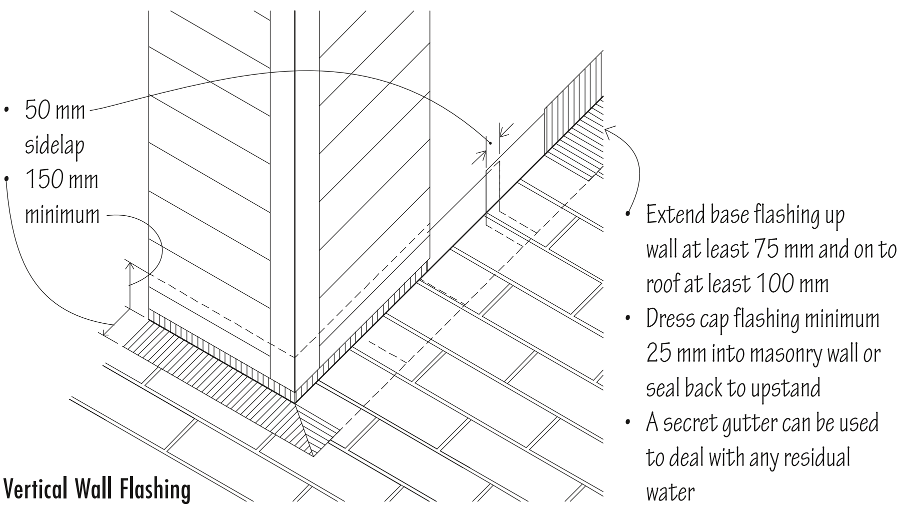
Lean-To Roof



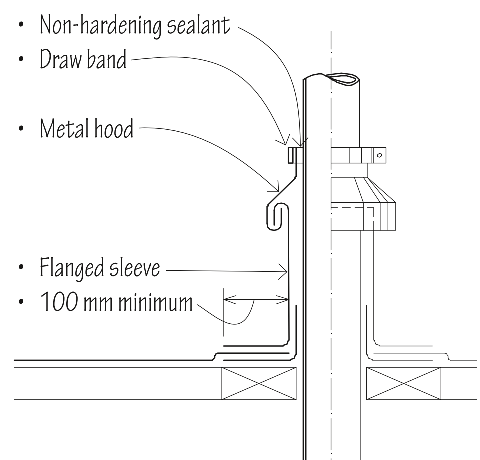
Chimney Flashing



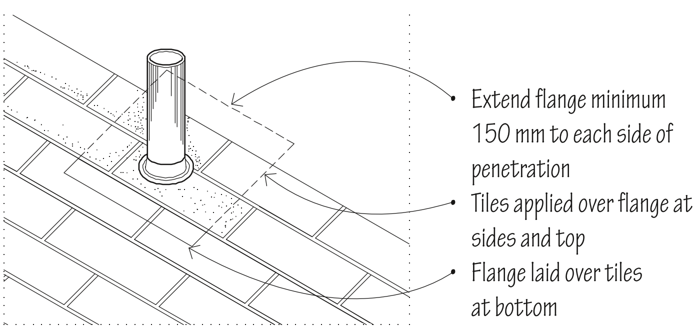
Skylight



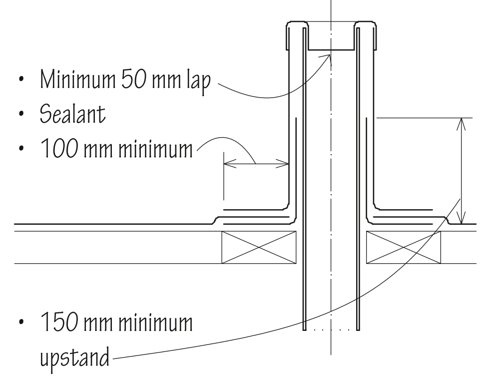
Vertical Wall Flashing



Tall Pipe or Pole



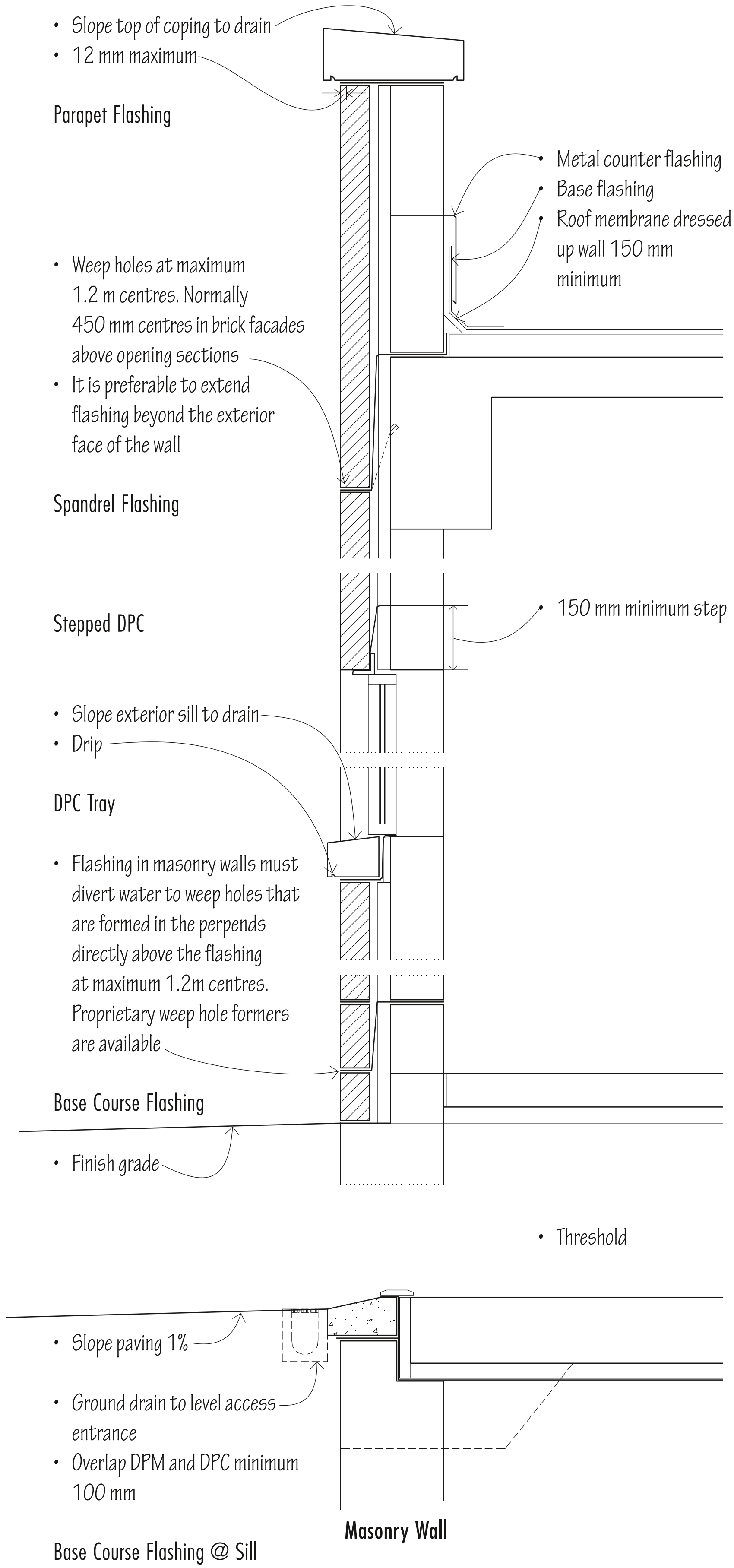
Stack Flashing



Vent Pipe

7.18 WALL FLASHING

Wall flashing is installed to collect any moisture that may penetrate a wall and divert it to the outside through weep holes. The drawings on this page illustrate where wall flashing is usually required. Masonry walls are especially susceptible to water penetration. Rain penetration can be controlled by properly tooling mortar joints, sealing joints such as those around window and door openings, and sloping the horizontal surfaces of sills and copings. Cavity walls are especially effective in resisting the penetration of water.

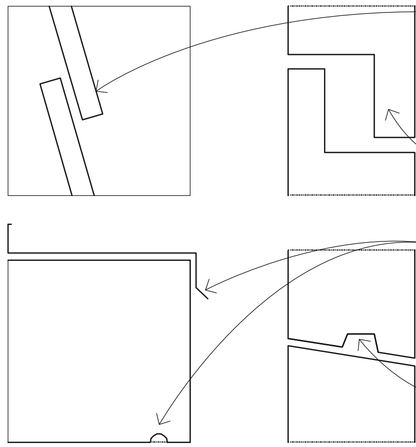


Stud-Framed Wall

Masonry Wall

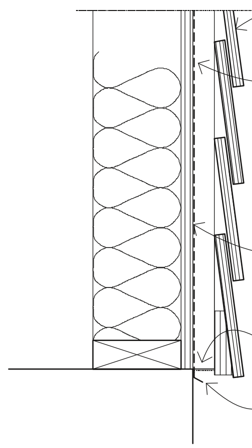
Water can penetrate exterior wall joints and assemblies by the kinetic energy of raindrops, gravity flow, surface tension, capillary action and pressure differential. According to how exterior walls deter water penetration, they can be categorised as follows:

- Solid wall systems, such as concrete and solid masonry walls, shed most rain at the exterior face, absorb the remainder, and dry by releasing the absorbed moisture as vapour
- Barrier wall systems, such as sandwich panel walls, rely on a continuous seal at the exterior face, which requires ongoing maintenance to be effective in resisting solar radiation, thermal movement and cracking
- Rainscreen walls consist of an outer layer of cladding (the rainscreen), an air cavity and a drainage plane on a rigid, water-resistant and airtight support wall



- Lapping horizontal joints in timber cladding, sealing vertical joints and sloping horizontal surfaces away from the interior can stem gravity flow
- Overlapping materials or internal baffles deflect the kinetic energy of wind-driven raindrops
- Drips break the surface tension that causes water to cling to and flow along the underside of horizontal, or nearly horizontal, surfaces
- Discontinuities or air gaps disrupt the capillary movement of water

Simple rainscreen walls, such as brick cavity and some timber-clad walls, rely on cladding to shed most of the rain while the air cavity serves as a drainage layer to remove any water that may penetrate the outer layer. The cavity should be wide enough to prevent the capillary movement of this water from bridging the cavity and reaching the support wall.

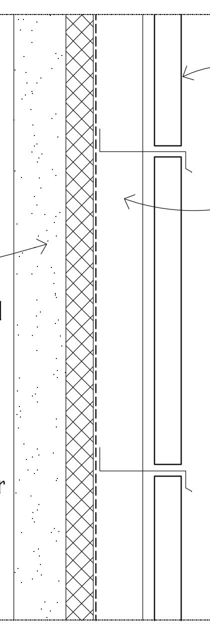


- Lapped cladding panels serve as a rainscreen
- Vertical battens space the cladding material away from the wall framing, creating a vented cavity that is drained and ventilated to promote evaporation of any collected water
- Sheathing and a weather barrier behind the vertical battens create a drainage plane
- Insect screening
- Metal flashing and drip

Pressure differential can drive water through an opening in a wall assembly, no matter how small, when water is present on one side of the opening, and the air pressure on that side is greater than that on the other side. Pressure-equalised rainscreens walls utilise vented cladding and an air cavity, often divided into drainable compartments, to facilitate pressure equalisation with the outside atmosphere and limit water penetration through joints in the cladding assembly. The primary seals against air and vapour are located on the indoor side of the air cavity, where they are exposed to little if any water.

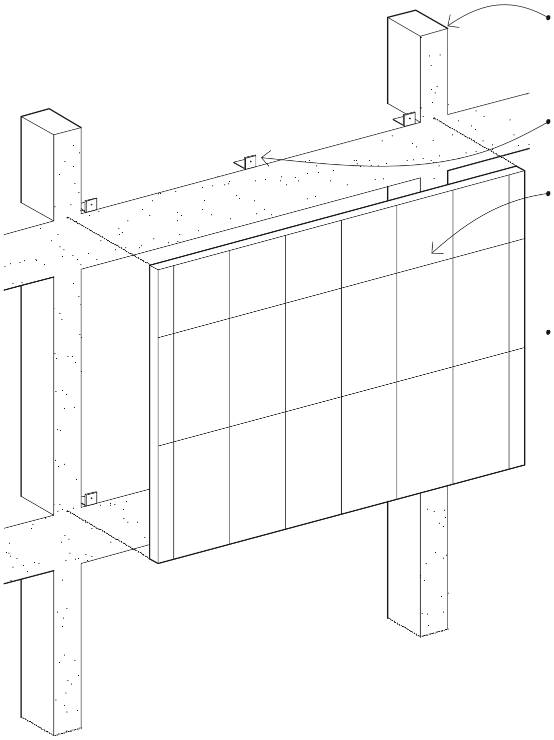
Interior Side

- An air-barrier system contains the primary joint seals, controls the flow of air and noise through the wall, and is airtight and rigid enough to withstand wind pressures
- Thermal insulation is situated on the indoor side of the air cavity. The air barrier itself may be a continuous membrane placed on either side of the insulation or either side of the interior wall layer



Exterior Side

- Vented cladding (the rainscreen) deflects the kinetic force of rain and deters water penetration at the exterior face of a wall
- An air cavity provides a place for the equalisation of air pressure to occur, is wide enough to prevent the capillary movement of water, and serves as a drainage layer for any water that manages to penetrate the rainscreen

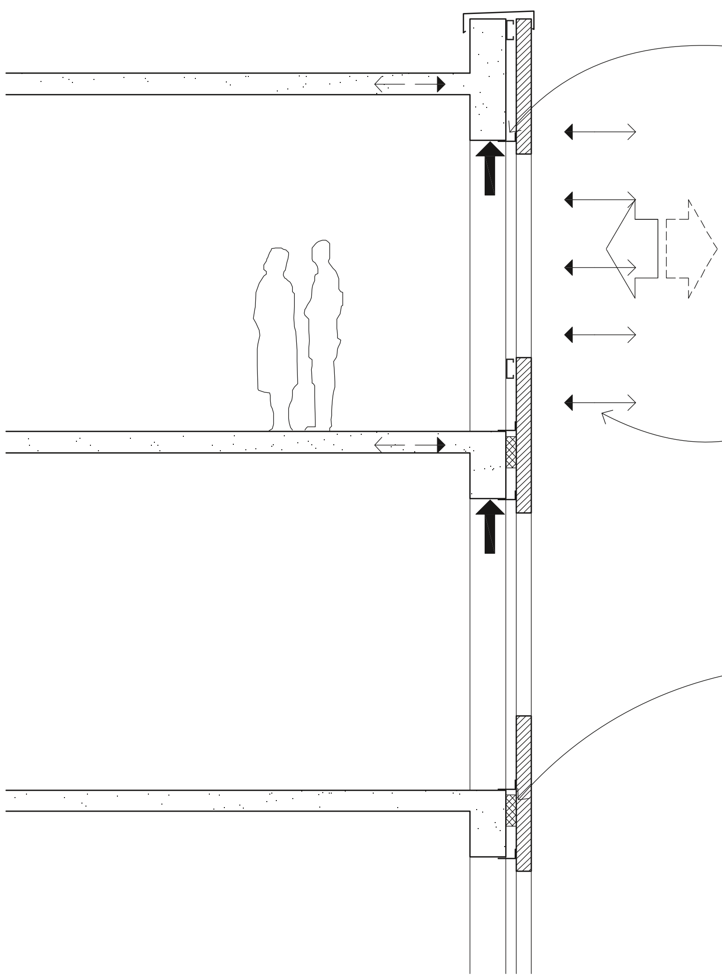


Curtain-wall panels are exterior wall elements supported wholly by the steel or concrete structural frame of a building and carrying no loads other than its own weight and wind loads. A curtain wall may consist of metal framing holding either glass or opaque spandrel units, or of thin veneer panels of concrete, stone, masonry or metal.

Panel systems consist entirely of precast-concrete, masonry or cut-stone units. The wall units may be one, two or three storeys in height, and may be pre-glazed or glazed after installation. Panel systems offer controlled shop assembly and rapid erection, but are bulky to ship and handle.

While simple in theory, curtain-wall construction is complex and requires careful development, testing and erection. Close coordination is also required between the architect, structural engineer, contractor and a fabricator who is experienced in curtain-wall construction.

As with other exterior walls, a curtain wall must be able to withstand the following elements:



Loads

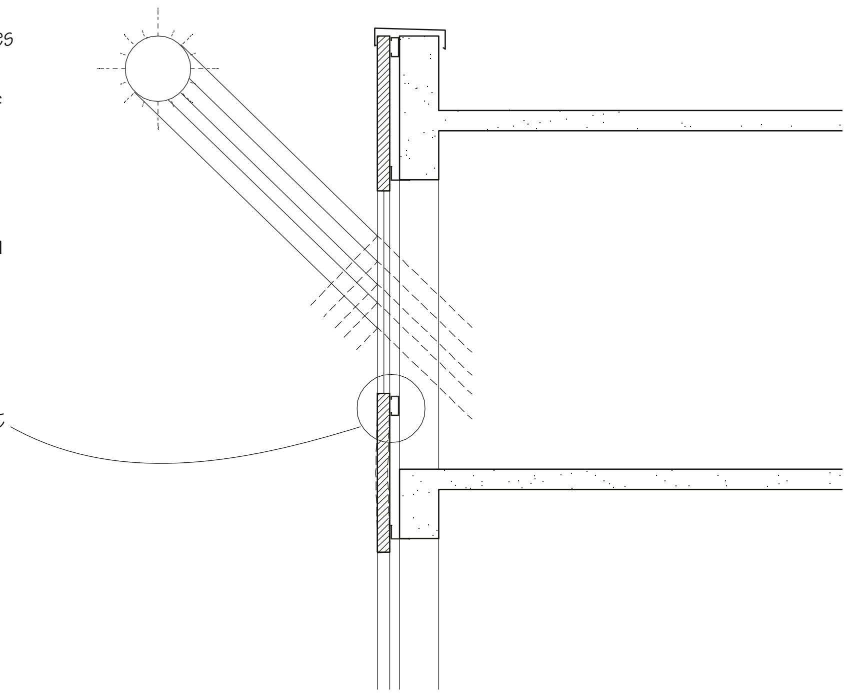
- The curtain-wall panels must be adequately supported by the structural frame
- Any deflection or deformation of the structural frame under loading should not be transferred to the curtain wall
- Seismic design requires the use of energy-absorbing connections

Wind

- Wind can create both positive and negative pressure on a wall, depending on its direction and the shape and height of the building
- The wall must be able to transfer any wind loads to the structural frame of the building without excessive deflection. Wind-induced movement of the wall should be anticipated in the design of its joints and connections

Fire

- Non-combustible material, sometimes referred to as fire batts, must be installed to prevent the spread of fire at each floor
- The building regulations also specify the fire-resistance requirements for the structural frame and the curtain-wall panels themselves



Sun

- Brightness and glare should be controlled with shading devices or the use of reflective or tinted glass
- The ultraviolet rays of the sun can also cause deterioration of joint and glazing materials and fading of interior furnishings

Temperature

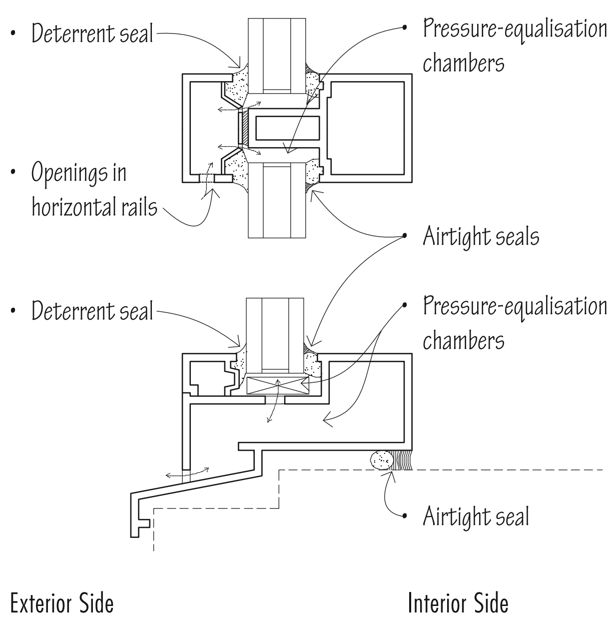
- Daily and seasonal variations in temperature cause expansion and contraction of the materials comprising a wall assembly, especially metals. Allowance must be made for differential movement caused by the variable thermal expansion of different materials
- Joints and sealants must be able to withstand the movement caused by thermal stresses
- Heat flow through glazed curtain walls should be controlled by using insulating glass, insulating opaque panels and by incorporating thermal breaks into metal frames
- Thermal insulation of veneer panels may also be incorporated into the wall units, attached to their backs or provided with a back-up wall constructed on-site

Water

- Rain can collect on the wall surface and be wind-driven under pressure through the smallest openings
- Water vapour that condenses and collects within the wall must be drained to the outside

Pressure-Equalised Design

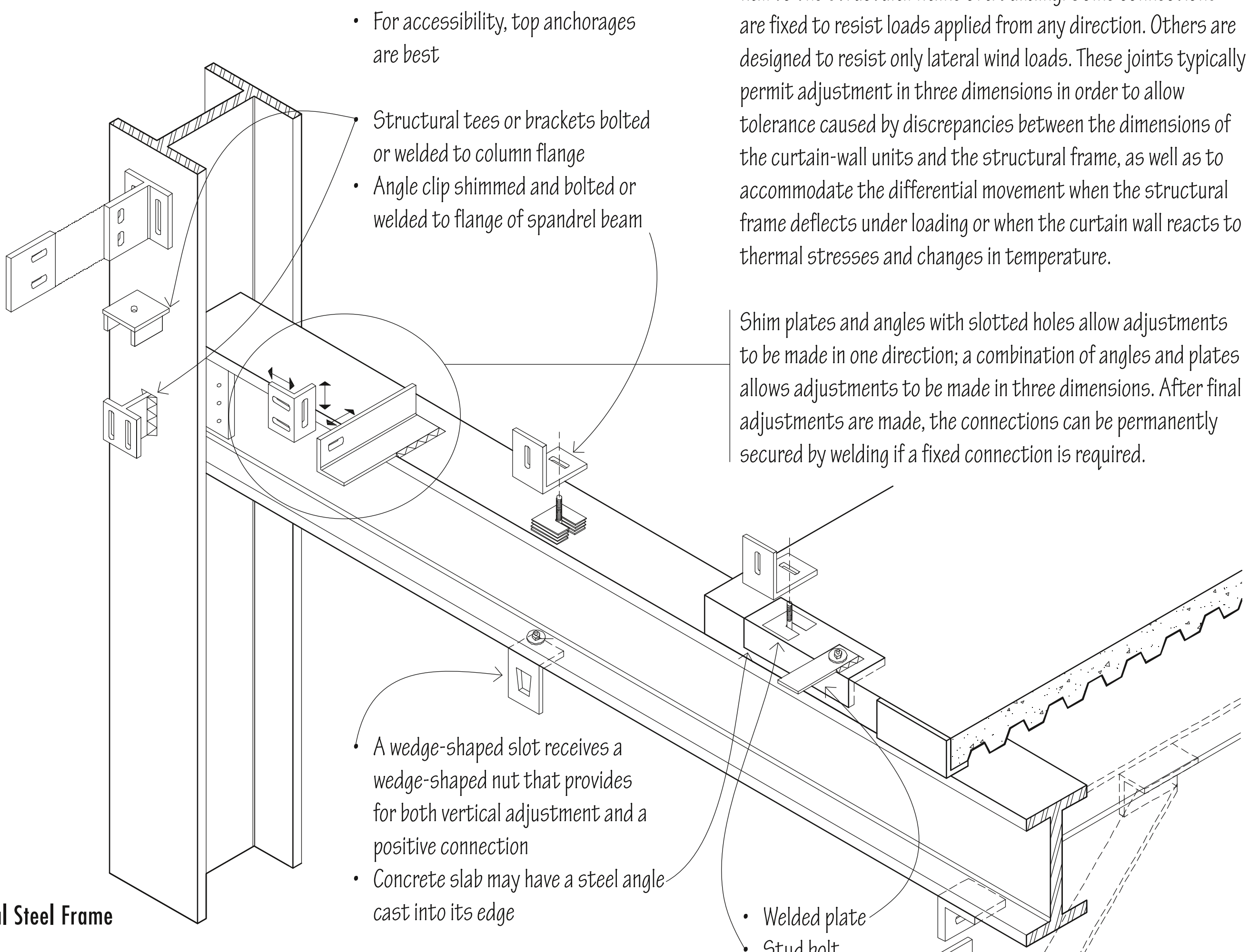
The pressure-equalised design principles outlined on page 7.19 become critical in the detailing of curtain walls, especially in larger and taller buildings, where the pressure differential between the outside atmosphere and an interior environment can cause rainwater to migrate through even the smallest openings in wall joints.

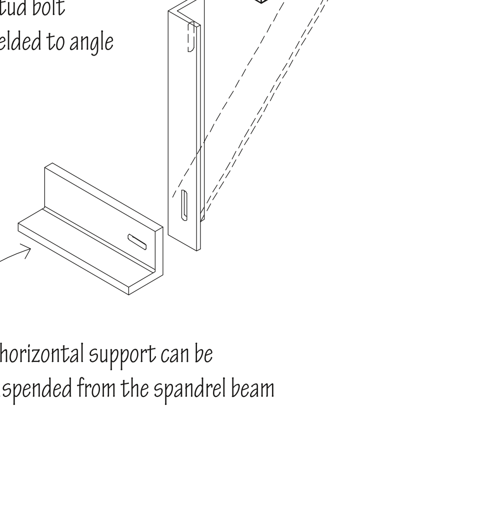


Application of Pressure-Equalisation Principle in Glazed Curtain Wall

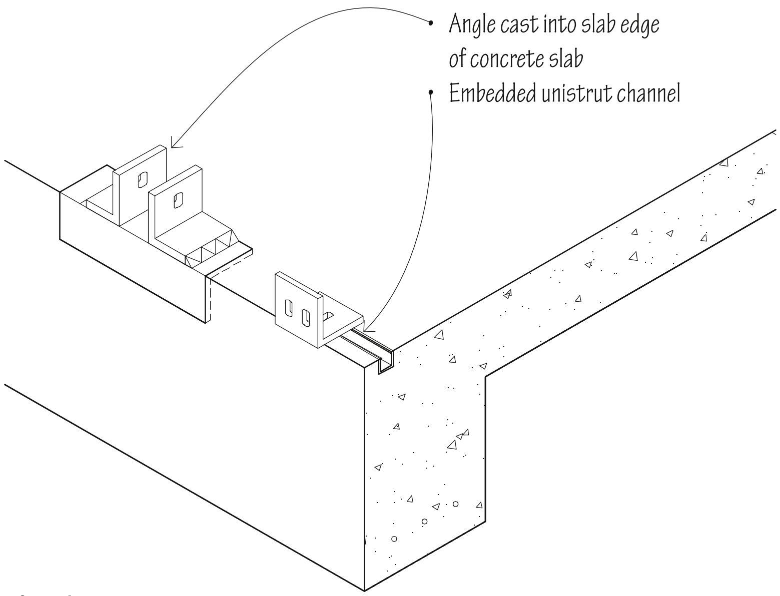
Any of various metal devices may be used to secure a curtain wall to the structural frame of a building. Some connections are fixed to resist loads applied from any direction. Others are designed to resist only lateral wind loads. These joints typically permit adjustment in three dimensions in order to allow tolerance caused by discrepancies between the dimensions of the curtain-wall units and the structural frame, as well as to accommodate the differential movement when the structural frame deflects under loading or when the curtain wall reacts to thermal stresses and changes in temperature.

Shim plates and angles with slotted holes allow adjustments to be made in one direction; a combination of angles and plates allows adjustments to be made in three dimensions. After final adjustments are made, the connections can be permanently secured by welding if a fixed connection is required.





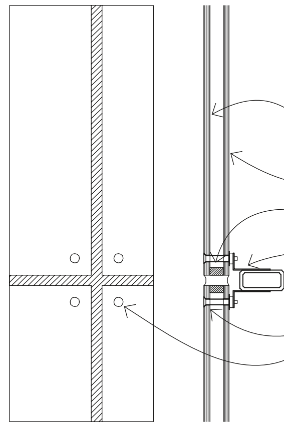
Structural Steel Frame

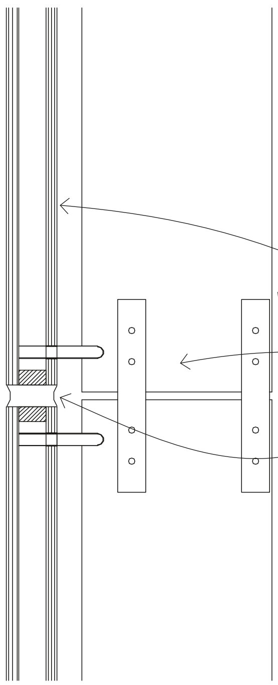


Reinforced-Concrete Frame

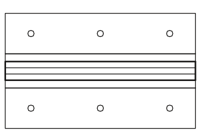
Structural glazing is a glazed facade, generally without visible mullions or transoms, where the joints between glazed panels are of silicone sealant. In structural glazing the loads on the facade are carried by the glass and transferred to a secondary supporting structure which in turn carries the load to the foundations.

The glass used must be toughened to withstand the applied loads and a tint is often added to the external pane to reduce solar gain and glare as a result of the large expanse of glazing.

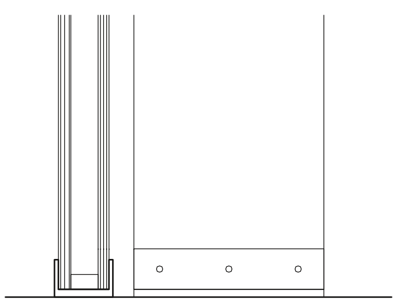




Section



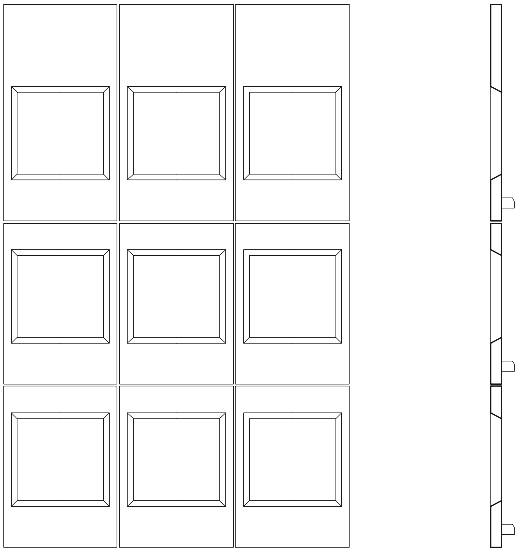
Plan



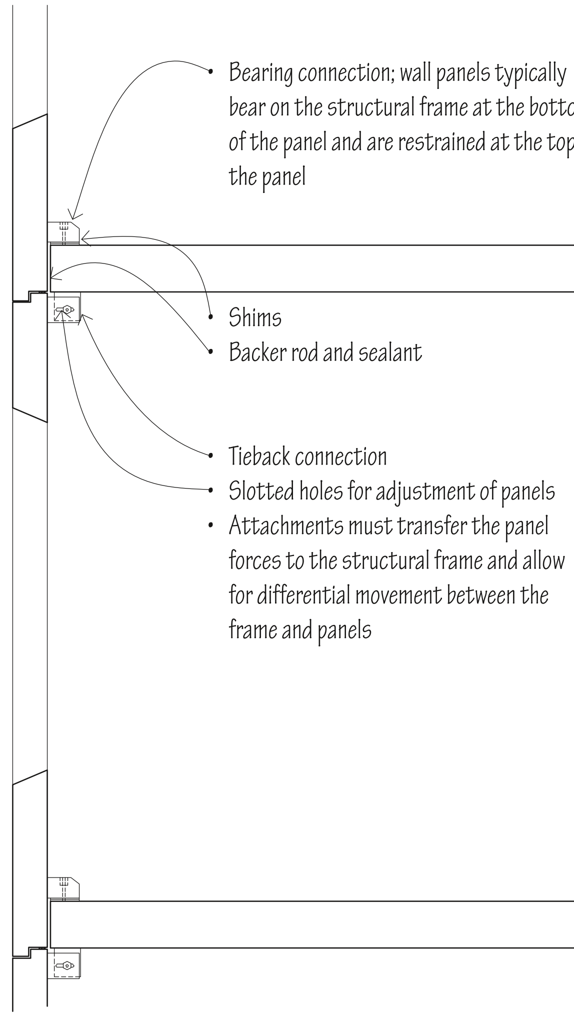
Section

7.24 PRECAST-CONCRETE PANELS

Precast-concrete wall panels may be used as non-bearing facings supported by a structural steel or reinforced-concrete frame. See 5.12 for load-bearing precast wall panels.

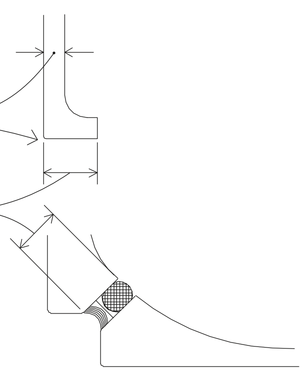


- A variety of quality-controlled smooth and textured finishes are available
- Ceramic tile and brick slip or stone facings may be fixed to the wall panels
- Thermal insulation may be sandwiched in the wall panel, attached to its back, or provided with a back-up wall constructed on-site

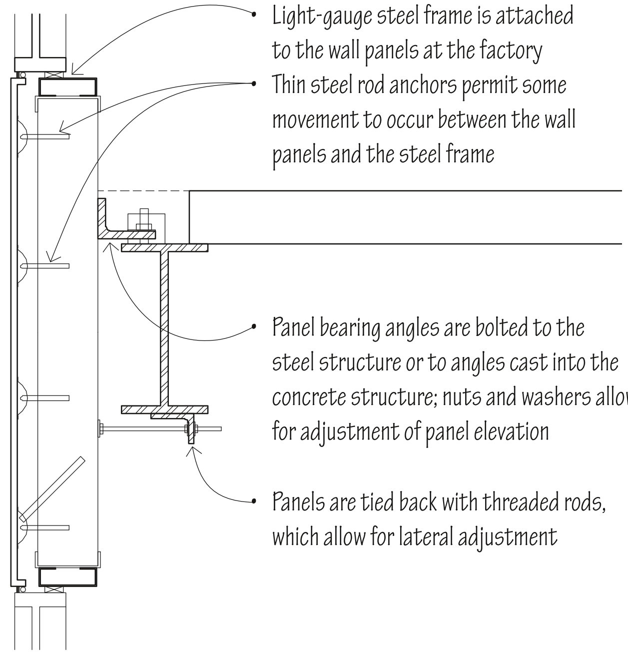


- Bearing connection; wall panels typically bear on the structural frame at the bottom of the panel and are restrained at the top of the panel
- Shims
- Backer rod and sealant
- Tieback connection
- Slotted holes for adjustment of panels
- Attachments must transfer the panel forces to the structural frame and allow for differential movement between the frame and panels

Glass-fibre-reinforced concrete (GRC) can be used in place of conventionally reinforced concrete to produce much thinner and lighter veneered panels. The panels are produced by spraying short glass fibres onto a mould with a portland cement and sand slurry. A variety of three-dimensional panel designs and finishes are possible.



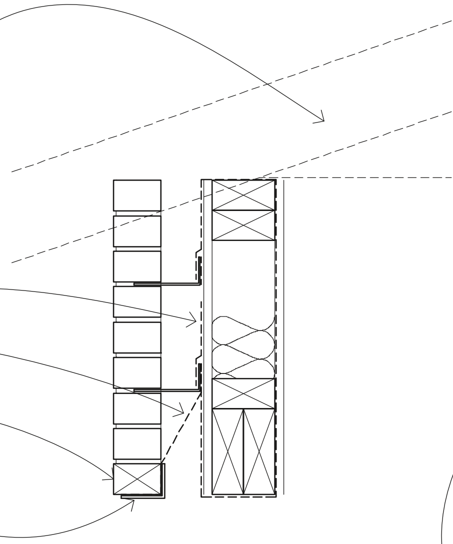
- 15 mm minimum panel thickness
- 3 mm radius typical
- 40 mm flanges are required for inserting backer rods and joint sealant at joints and corners



- Light-gauge steel frame is attached to the wall panels at the factory
- Thin steel rod anchors permit some movement to occur between the wall panels and the steel frame
- Panel bearing angles are bolted to the steel structure or to angles cast into the concrete structure; nuts and washers allow for adjustment of panel elevation
- Panels are tied back with threaded rods, which allow for lateral adjustment

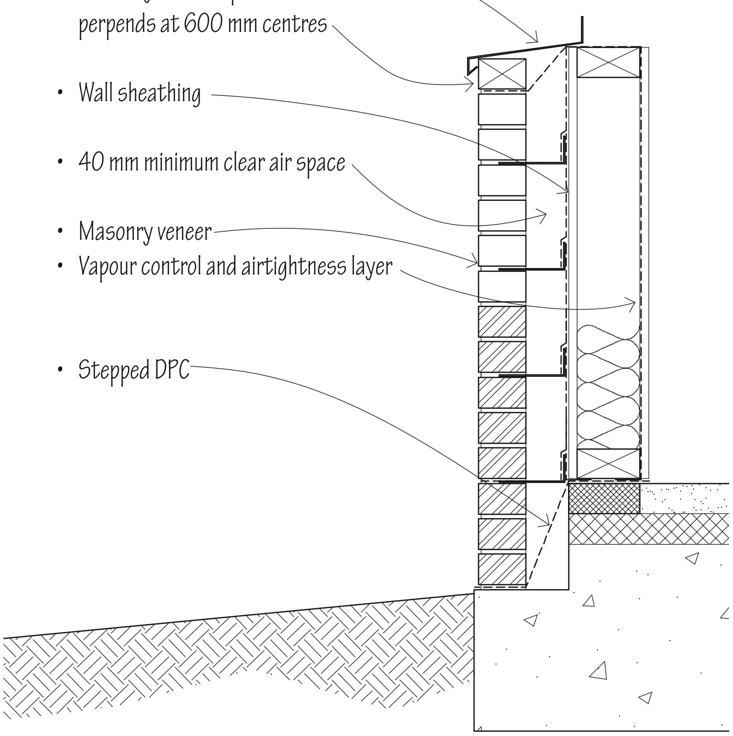
Masonry veneer construction consists of a single leaf of masonry serving as a weather barrier and anchored but not bonded to a supporting structural frame. In residential construction, timber or metal stud walls are sometimes faced with a brick veneer.

- Timber-framed roofing members

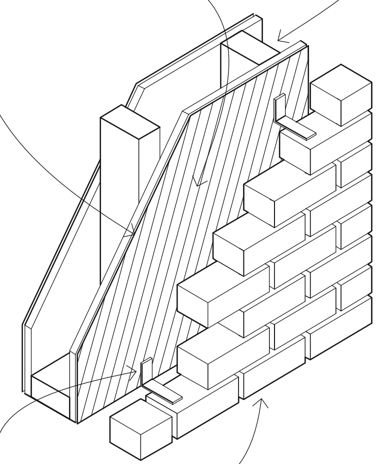


- Breather paper
- Stepped DPC
- Weep holes to perpends at 600 mm centres
- Steel angle lintel
- Height difference between masonry and stud frame depends on door or window detail

- Pressed metal sill
- DPC tray with weep holes to perpends at 600 mm centres
- Wall sheathing
- 40 mm minimum clear air space
- Masonry veneer
- Vapour control and airtightness layer
- Stepped DPC



- Timber or light-gauge metal studs
- Breather paper over wall sheathing
- 40 mm minimum clear air space

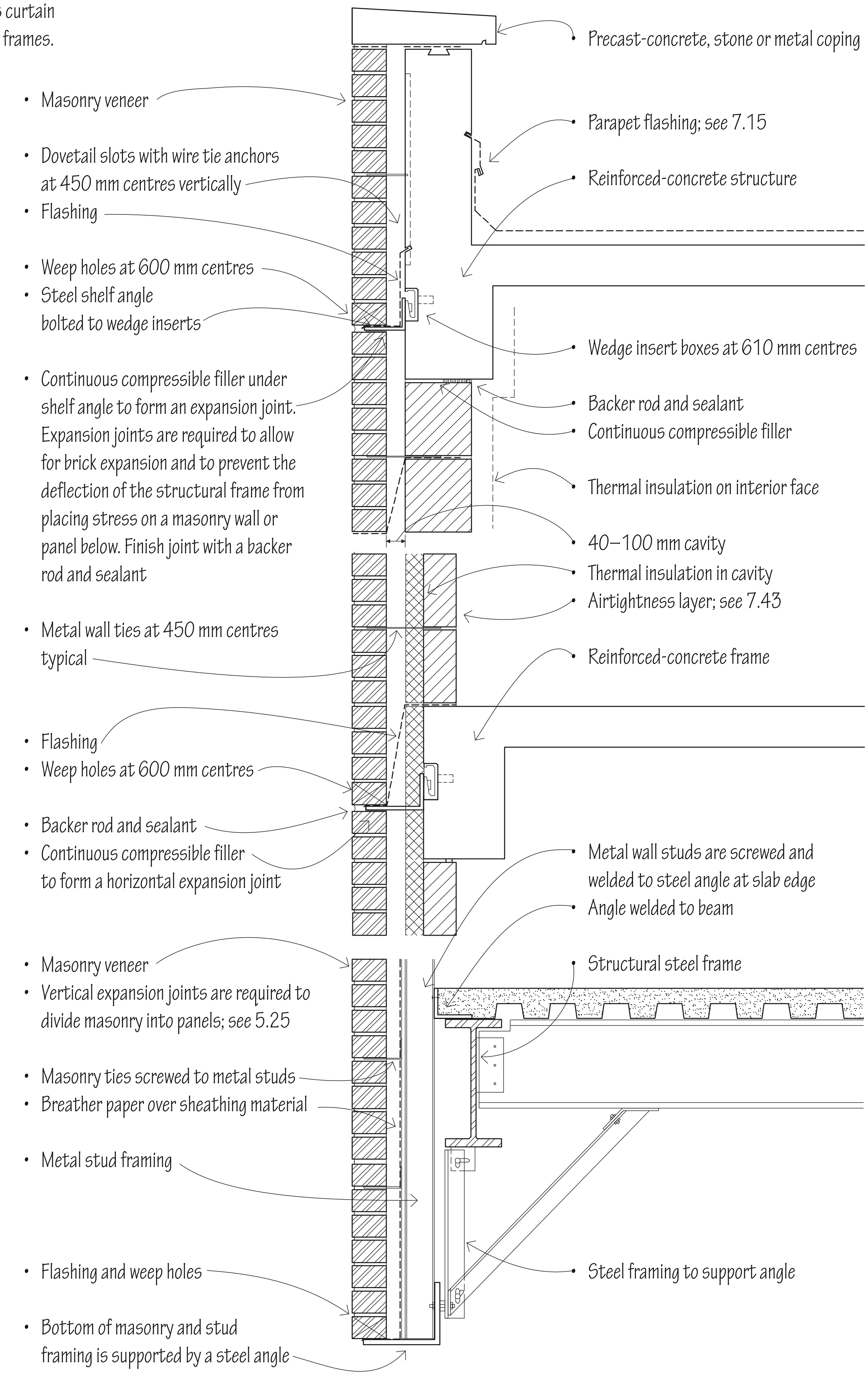


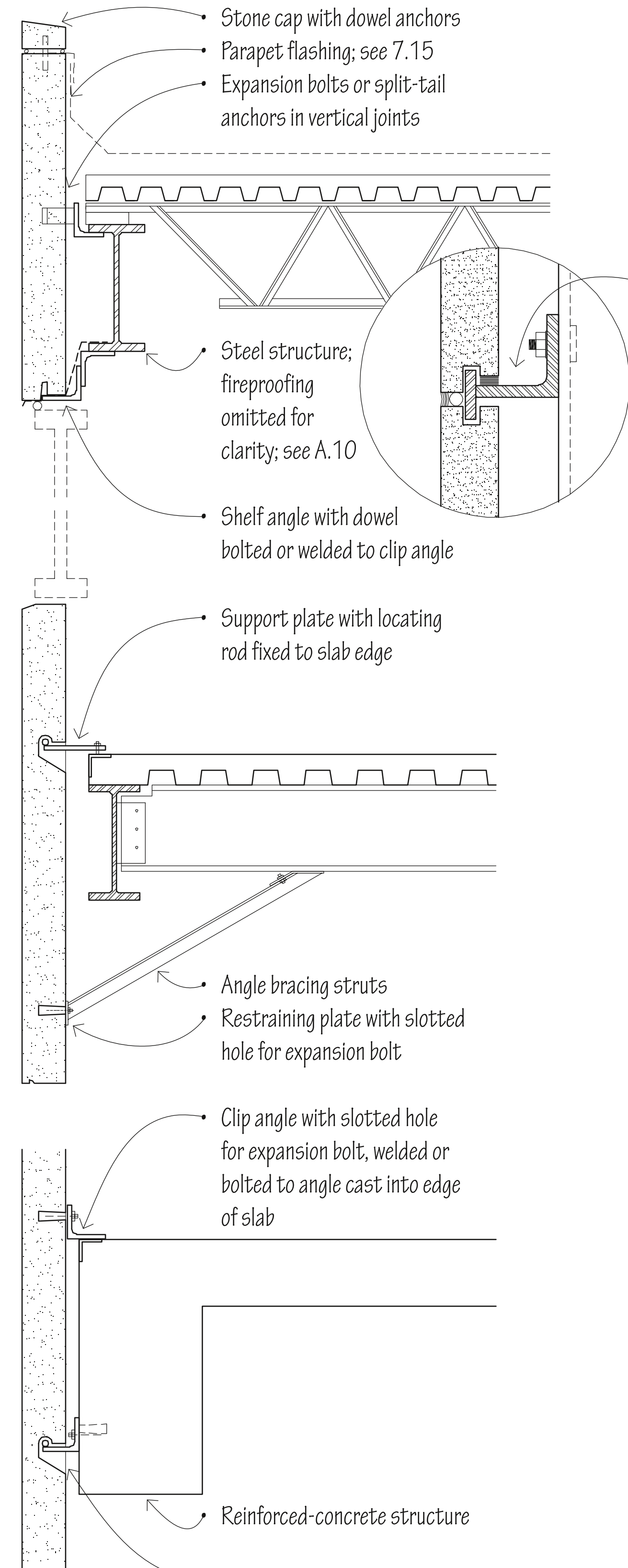
- Masonry veneer
- Wall ties fastened to wall studs; spaced at no more than 900 mm centres horizontally and 450 mm centres vertically (closer around opening)

- See 5.17–5.20 for masonry wall construction details

7.26 MASONRY VENEER

Masonry veneers can also be used as curtain walls supported by steel or concrete frames.



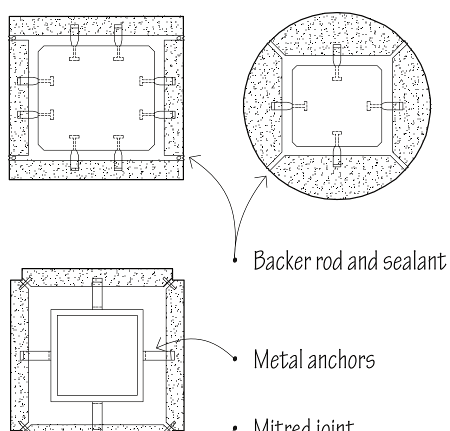


Typical Monolithic Stone Panel Details

Stone facings may be set in mortar and tied to a concrete or masonry back-up wall; see 5.35–5.36. Large stone veneer panels from 40 to 80 mm thick may also be supported by the steel or concrete structural frame of a building in a number of ways.

- Monolithic stone panels may be fastened directly to the structural frame of a building
- Stone panels may be mounted on a steel subframe designed to transmit gravity and lateral loads from the slabs to the structural frame of a building. The subframe consists of vertical steel struts that support horizontal stainless-steel or aluminium angles. Bars welded to the angles engage slots in the lower and upper edges of the stone panels
- Stone veneers may be pre-assembled into larger panels by mounting the thin slabs on non-corrosive metal framing, or by bonding them to reinforced precast-concrete panels with bent stainless-steel anchors. A moisture barrier and bonding agent may be applied between the concrete and stone to prevent concrete salts from staining the stonework

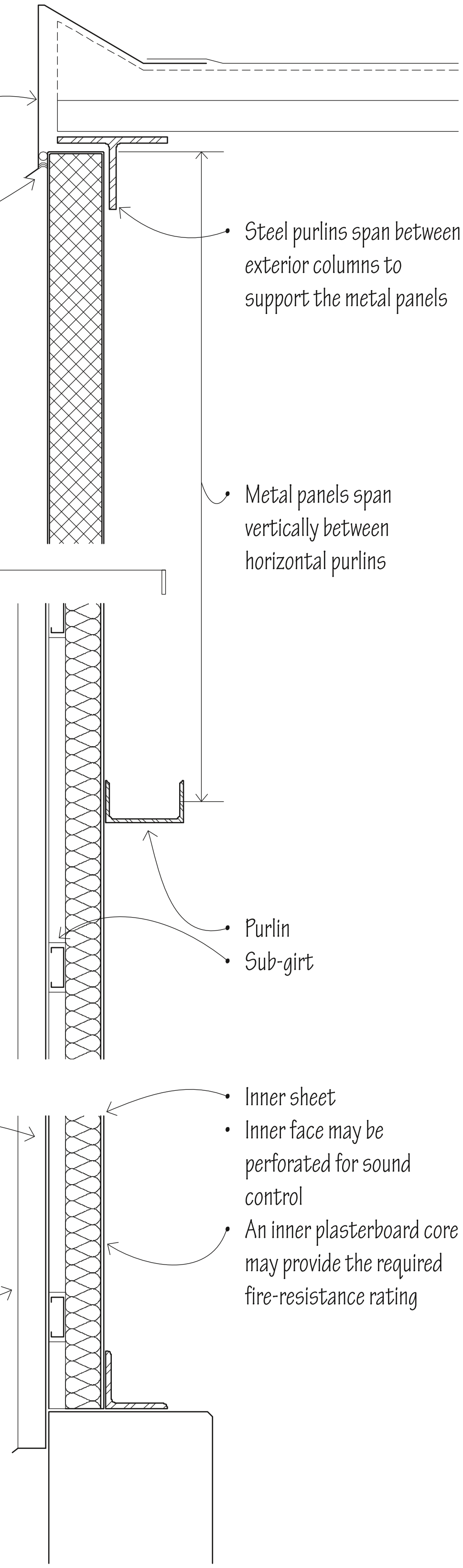
The required anchorages should be carefully engineered and take into account the strength of the stone veneer, especially at anchorage points, the gravity and lateral loads to be sustained, and the anticipated range of structural and thermal movement. Some anchors must carry the weight of the stonework and transfer the load to the supporting structural wall or frame. Others only restrain the stonework from lateral movement. Still others must offer resistance to shear. All connecting hardware should be of stainless steel, galvanised steel or non-ferrous metal to resist corrosion and prevent staining of the stonework. Adequate tolerances must be built in to allow for proper fitting and shimming, if necessary.

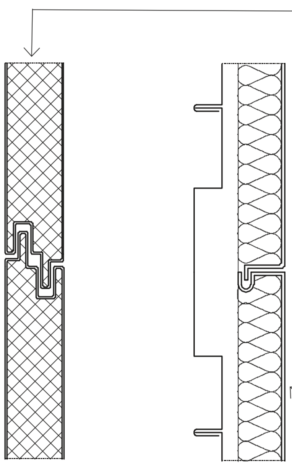


Columns

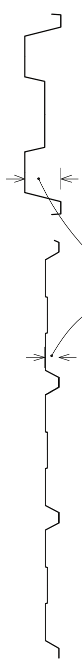
METAL CLADDING

Insulated and bonded metal panels are used primarily to clad industrial-type buildings; see 5.49 & 6.07. They may have facings of anodised aluminium or steel with porcelain, vinyl, acrylic or enamel finishes. The panels are typically up to 900 mm wide and span vertically between horizontal steel purlins spaced at 500–600 mm centres. Consult manufacturer for profiles, sizes, allowable spans, thermal and acoustic ratings, and installation details.



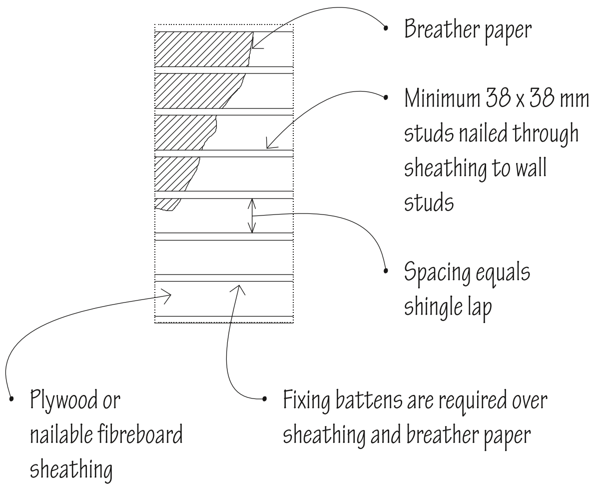


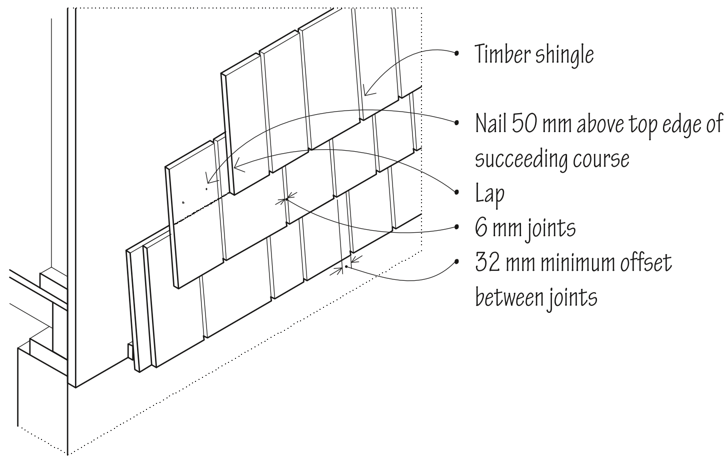
• Interlocking seams join prefabricated panels along their sides



Pre-formed metal wall panels of galvanised steel, stainless steel and aluminium are available with corrugated or ribbed profiles in 400–500 mm widths. The metal panels can be installed as part of a field-assembled wall system with liner panels or as the exterior component of a simple rainscreen-wall assembly; see 7.19.

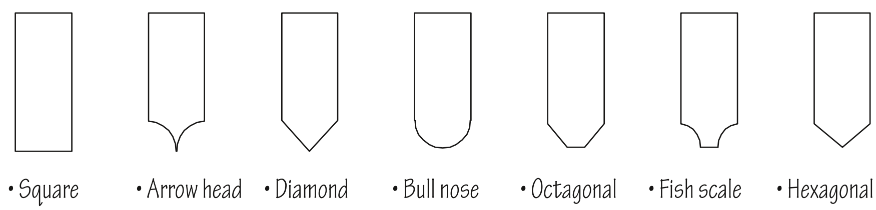
On exterior walls, timber shingles are laid in uniform courses that resemble lap cladding. The courses should be adjusted to meet the heads and sills of window openings and other horizontal bands neatly. The shingles may be stained or painted. Premium-grade shingles can be left unpainted to weather naturally.





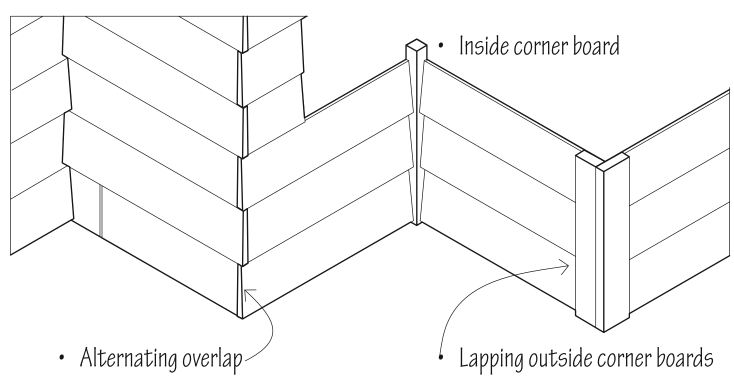
Sheathing

Shingles are cut to uniform widths and shapes. They are used on walls to create certain effects such as fish-scale textures. Combinations of shingles can be used to created varied patterns.



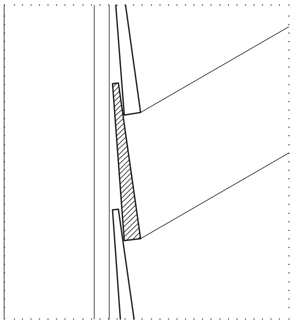
Dimension Shingles

At corners, alternating courses are lapped over the adjacent corner shingles on the other side. Exposed edges should be treated. Corner boards can also be used to receive the shingles at both interior and exterior corners. Breather paper should be used to flash corners and wherever the shingles abut timber trim.

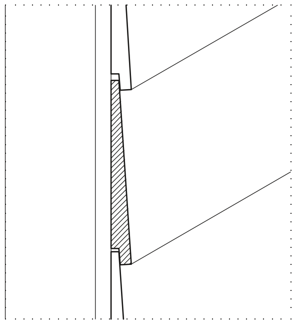


Corners

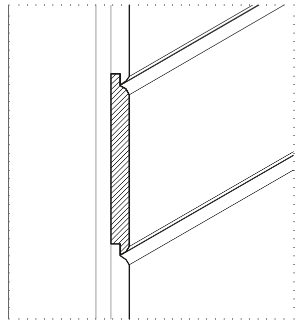
Horizontal board claddings are available in different forms.



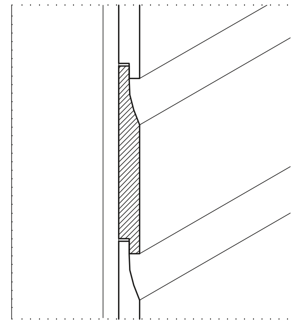
- Bevelled cladding, also known as lap cladding, is made by cutting a board diagonally across its cross section so that the cladding has one thin edge and one thick edge. The rough, resawn side can be exposed for stain finishes, while the smooth, planed side can be either painted or stained



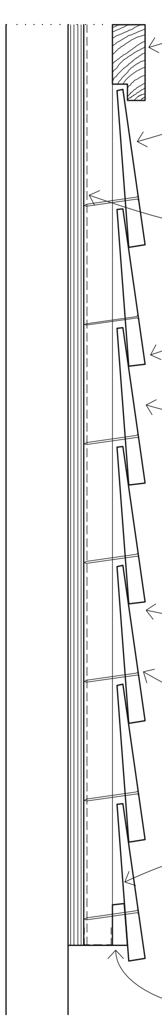
- Feather-edge cladding is bevelled cladding rebated along the lower edge to receive the upper edge of the board below it



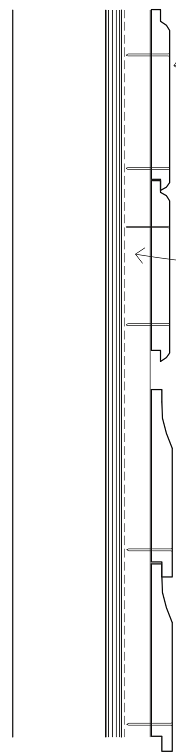
- Shiplap cladding consists of boards joined edge to edge with overlapping rebated joints



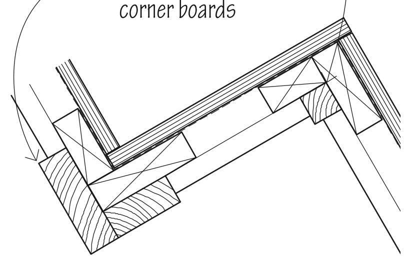
- Overlapping cladding, similar to shiplap, is composed of boards narrowed along the upper edges to fit into rebates or grooves in the lower edges, laid horizontally with their backs flat against the sheathing or studs of the wall



- Frieze board rebated or furred out to receive top course
- Horizontal cladding fixed to vertical studs
- Permeable breather paper that allows any water vapour build-up in the wall to escape to the outside
- 30 mm minimum lap
- Adjust exposure of bevel cladding so that courses align neatly with heads and sills of windows, frieze boards and other horizontal bands
- Provide 2–4 mm space for expansion depending on material
- Face nail; nails should clear 2.5 times the thickness of the cladding material into the supporting batten
- Backprime before installation
- Continuous starter strip
- 150 mm minimum clearance to grade



- Vertical battens may be aligned over the wall studs to create a simple rainscreen; see 7.19
- 19 mm minimum air space; provide for drainage and insect screening of vents
- Inside corner board
- Lapping exterior corner boards



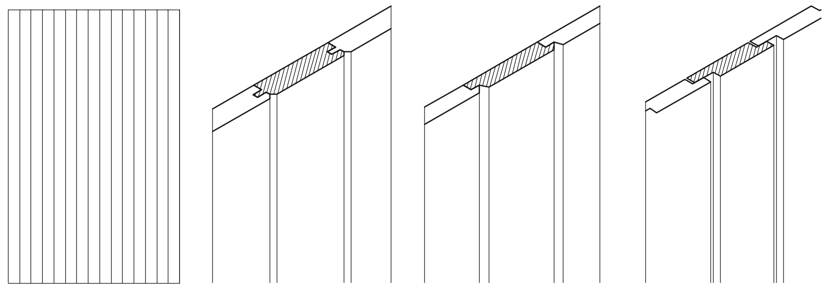
Corners

Cladding Application

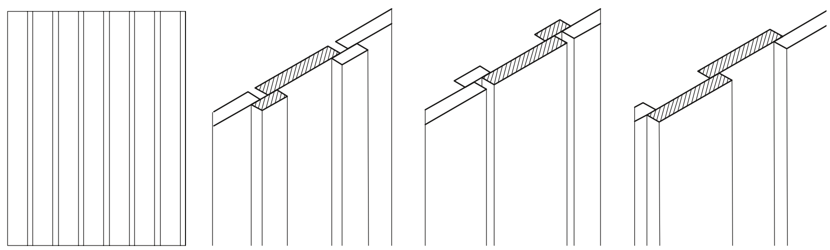
Horizontal cladding is fastened to vertical timber studs (minimum 38 mm thickness to prevent splitting) which in turn are fixed through the breather paper and sheathing into the wall studs with hot-dipped galvanised, aluminium or stainless-steel nails. Board ends should meet over a stud or butt against corner boards or window and door trim; a sealant is usually applied to the board ends during installation and the joints caulked. Timber cladding should be designed as a rainscreen using flashings and breather paper to provide a ventilation path.

Vertical timber cladding can be laid in various patterns. Matched boards that interlap or interlock can have flush, V-groove or beaded joints. Square-edged boards can be used with other boards or battens to protect their vertical joints and form board-and-board or board-and-batten patterns.

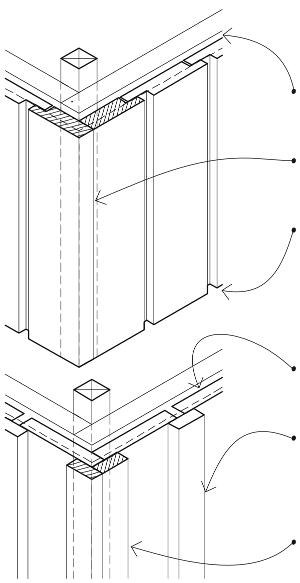
While horizontal cladding is nailed into vertical battens allowing for ventilation and drainage, vertical cladding requires cross battens to provide fixings while allowing for ventilation and drainage. Battens are provided at 600 mm centres, fixed to plywood sheathing through breather paper. Cross battens may be excluded where open-jointed systems provide sufficient ventilation and drainage. As with other timber materials, only hot-dipped galvanised or other corrosion-resistant nails should be used. Treat ends and edges of cladding, and the back of batten strips, with a preservative before installation.



Matched Cladding • Tongue and groove • Shiplap V • Channel groove



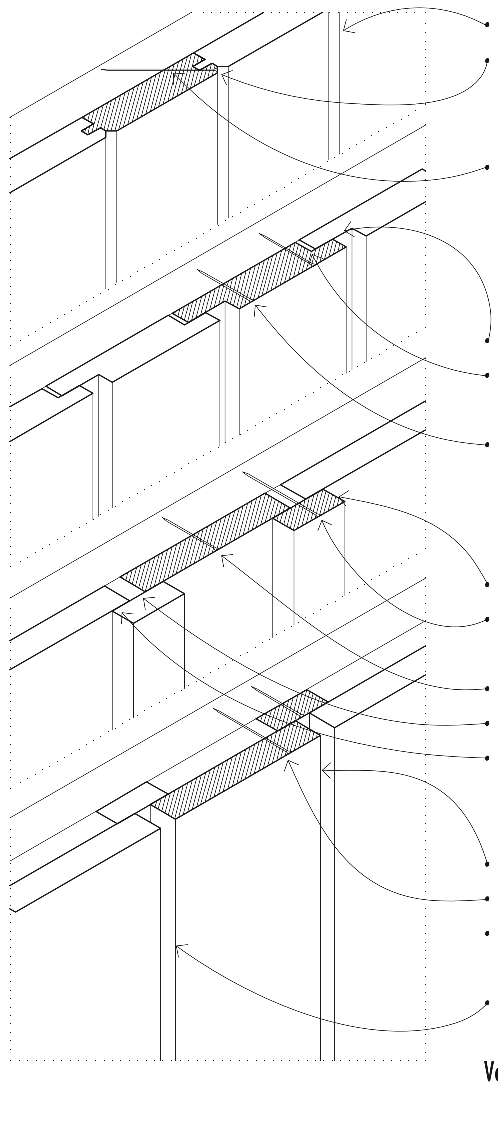
Board Cladding • Board and batten • Batten and board • Board and board



Corners

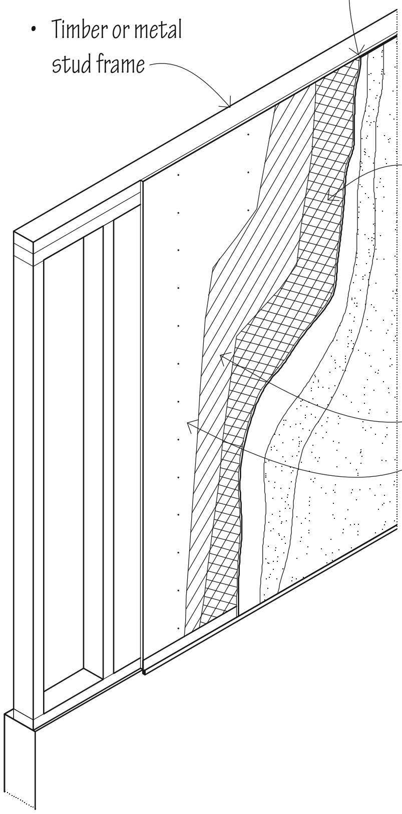
Alternative Claddings

A variety of cladding materials have been designed to mimic the appearance of traditional timber cladding, offer durability and resistance to weathering, and reduce maintenance costs. These alternatives include aluminium cladding, vinyl (PVC) cladding and fibre-cement planks and panels.



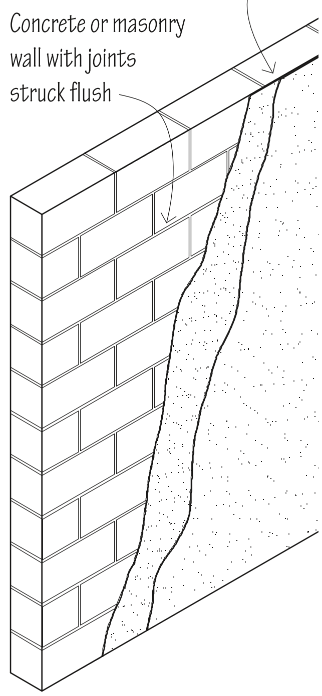
Vertical Joints

Render is a coarse plaster composed of portland or masonry cement, sand, and hydrated lime, mixed with water and applied in a plastic state to form a hard covering for exterior walls. This weather- and fire-resistant finish is normally used for exterior walls and soffits, but it can also be used for interior walls and ceilings that are subject to direct wetting or damp conditions.



- Timber or metal stud frame
- Render is applied in three coats over paper-backed expanded-metal or wire lath. See also 10.03–10.04 for general information on plaster, lath and accessories
- Metal reinforcement must be furred out 6–10 mm to permit the render to completely embed the metal; lath may be self-furring or be attached with special furring nails
- Breather membrane
- Wall frame should be covered with plywood or similar sheathing to provide a stable working platform

Stud Wall Base

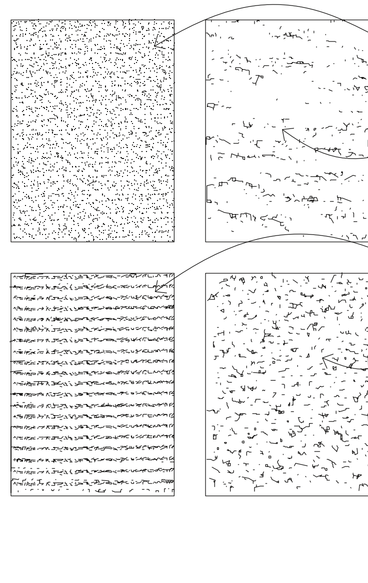


- Concrete or masonry wall with joints struck flush
- Render is applied in up to three coats depending on exposure (single coat adequate in sheltered locations) over a suitable masonry or concrete surface
- Overall thickness generally 8–18 mm with the final coat 8–12 mm depending on desired finish. Thin-coat render systems (10–12 mm) have become increasingly popular
- The masonry or concrete wall should be structurally sound and its surface should be free of dust, grease or other contaminants that would prevent good suction or chemical bond. In addition, the surface should be rough and porous enough to ensure a good mechanical bond
- Metal reinforcement, a dash coat of portland cement and sand, or a bonding agent is used if a good bond is doubtful

Masonry or Concrete Base

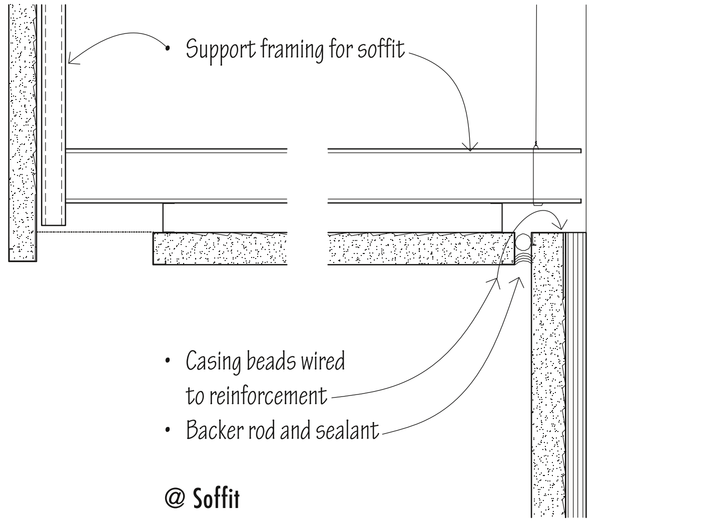
Render Finishes

The finish coat may have a smooth, stippled, rough-cast, or pebbled texture. The finish may be natural or be integrally coloured through the use of pigment, coloured sand or stone chips.



- Smooth finish is a fine-textured finish produced with a carpet or rubber-faced float
- Stipple-trowelled finish is first stippled with a broom; the high spots are then trowelled
- Rough-cast finish is formed throwing the final coat onto the wall
- Pebble-dash finish is produced by machine-spraying small pebbles on to unset render

Like internal plastering, render is a relatively thin, hard, brittle material that requires reinforcement or a sturdy, rigid, unyielding base. Unlike internal plastering, which expands slightly as it hardens, portland cement render shrinks as it cures. This shrinkage, along with the stresses caused by structural movement of the base support and variations in temperature and humidity, can cause the render to crack. Control and relief joints are required to eliminate or minimise any cracking.



@ Soffit

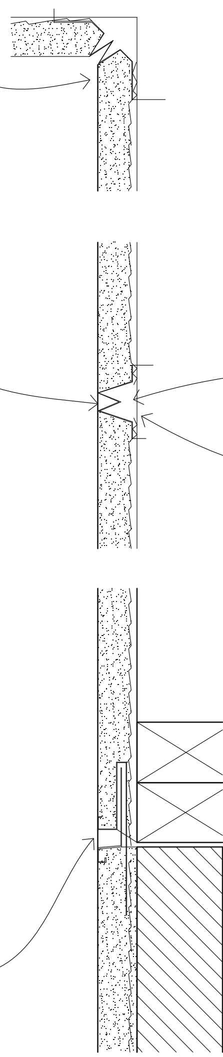
Relief Joints

- Relief joints relieve stress by permitting independent movement along the perimeter of a render membrane. They are required where two planes of render meet at an internal corner, or where a render abuts or is penetrated by a structural element, such as a beam, column or load-bearing wall

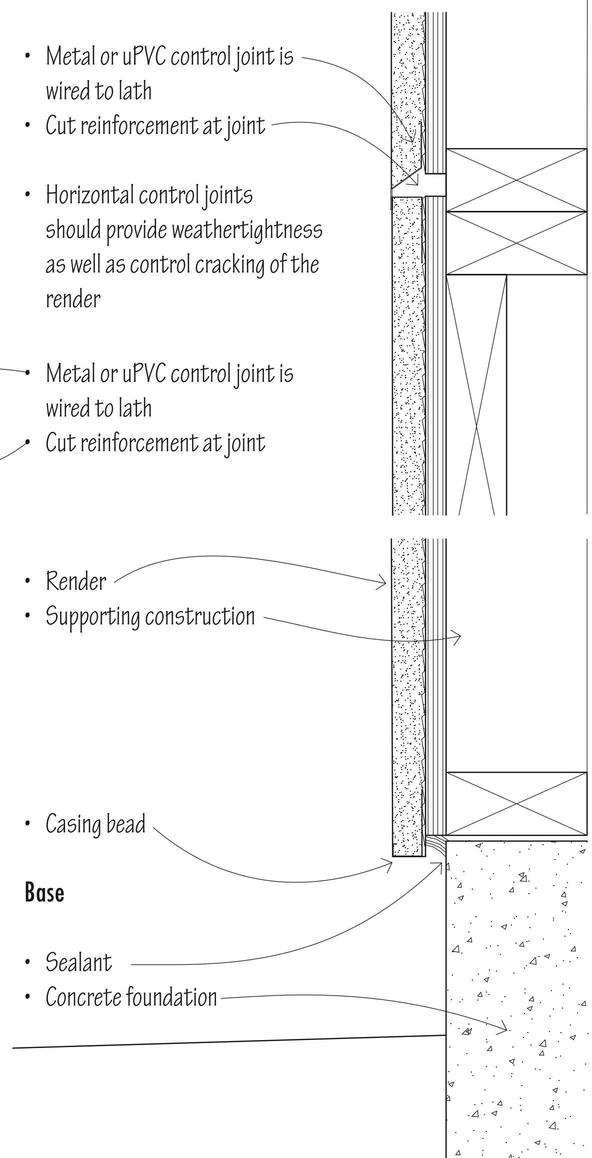
Control Joints

- Control joints relieve stress in the render and prealign the cracking that can be caused by structural movement in the supporting construction, drying shrinkage and variations in temperature. When render is applied over metal reinforcement, control joints should be spaced no more than 5 m apart and define panels no larger than 15 m^2
- When render is applied directly to a masonry base, control joints should be installed directly over and aligned with any control joints existing in the masonry base
- Control joints are also required where dissimilar base materials meet and along floor lines in timber-frame construction

@ Internal Corners

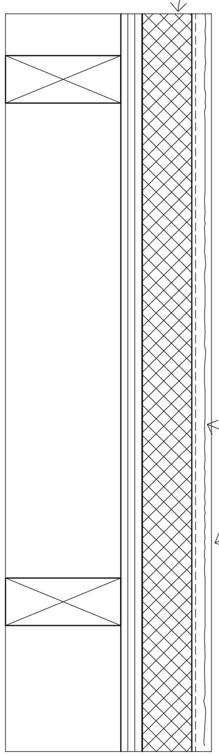


Plan

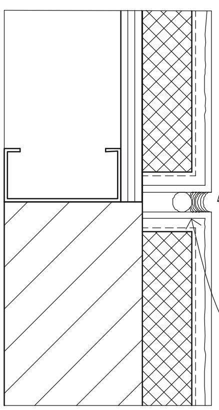


Section

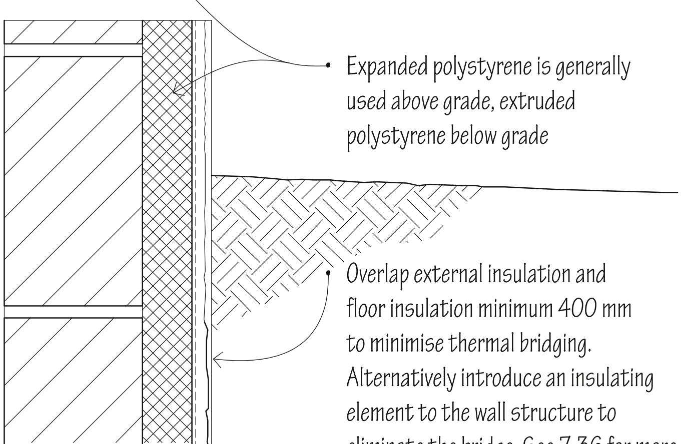
7.34 EXTERNAL INSULATION



- Rigid insulation panels 75–150 mm thick, 600 mm wide and 600, 1200 or 2400 mm long. The insulation panels are secured to frame walls with solid, water-resistant sheathing or to a suitable masonry surface with adhesive or mechanical fasteners. Damaged or brittle substrates may require a mechanically fastened track system for attachment of the insulation panels
- The base coat is reinforced with fibreglass mesh to prevent surface cracks
- The synthetic render finish is made with acrylic polymers and an aggregate of silica sand, quartz chips or marble chips to achieve the desired texture; the desired colour is achieved by painting or tinting the finish coat with pigment



- Expansion joints are required at floor levels in stud framing, where changes in the substrate occur, or wherever similar joints exist in the supporting construction
- Polymer-modified systems are susceptible to shrinkage cracking. The artificial render finish must therefore be divided into panel areas with control joints
- Backer rod and sealant



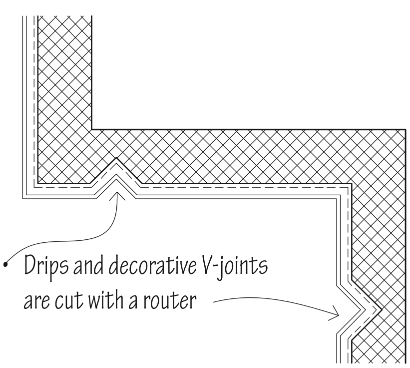
- Expanded polystyrene is generally used above grade, extruded polystyrene below grade
- Overlap external insulation and floor insulation minimum 400 mm to minimise thermal bridging. Alternatively introduce an insulating element to the wall structure to eliminate the bridge. See 7.36 for more on thermal bridging

Exterior insulation and finish systems are available for cladding the exterior of new structures as well as insulating and refacing existing buildings. The system consists of a thin layer of synthetic render trowelled, rolled or sprayed over a layer of rigid plastic foam insulation.

Thin coat render and external insulation systems are susceptible to leaking around windows and doors because of poor detailing or faulty installation. There is no internal drainage system that would allow any water that does penetrate the system to escape. This trapped water can cause the insulation layer to separate from the substrate or the sheathing to deteriorate. To address this problem, a proprietary system uses a drainage mat installed between an air and water barrier and the insulation layer to allow water to drain to plastic flashings above wall openings and at the base of the wall.

There are two generic types of thin coat render systems: polymer-modified and polymer-based systems. Polymer-modified systems consist of a portland cement base coat from 6 to 9 mm thick, reinforced with metal wire lath or fibreglass mesh fastened to the insulation layer. In areas subject to impact, heavy-duty fibreglass mesh is used in place of, or in addition to, the standard mesh. The finish coat of portland cement is modified with acrylic polymers.

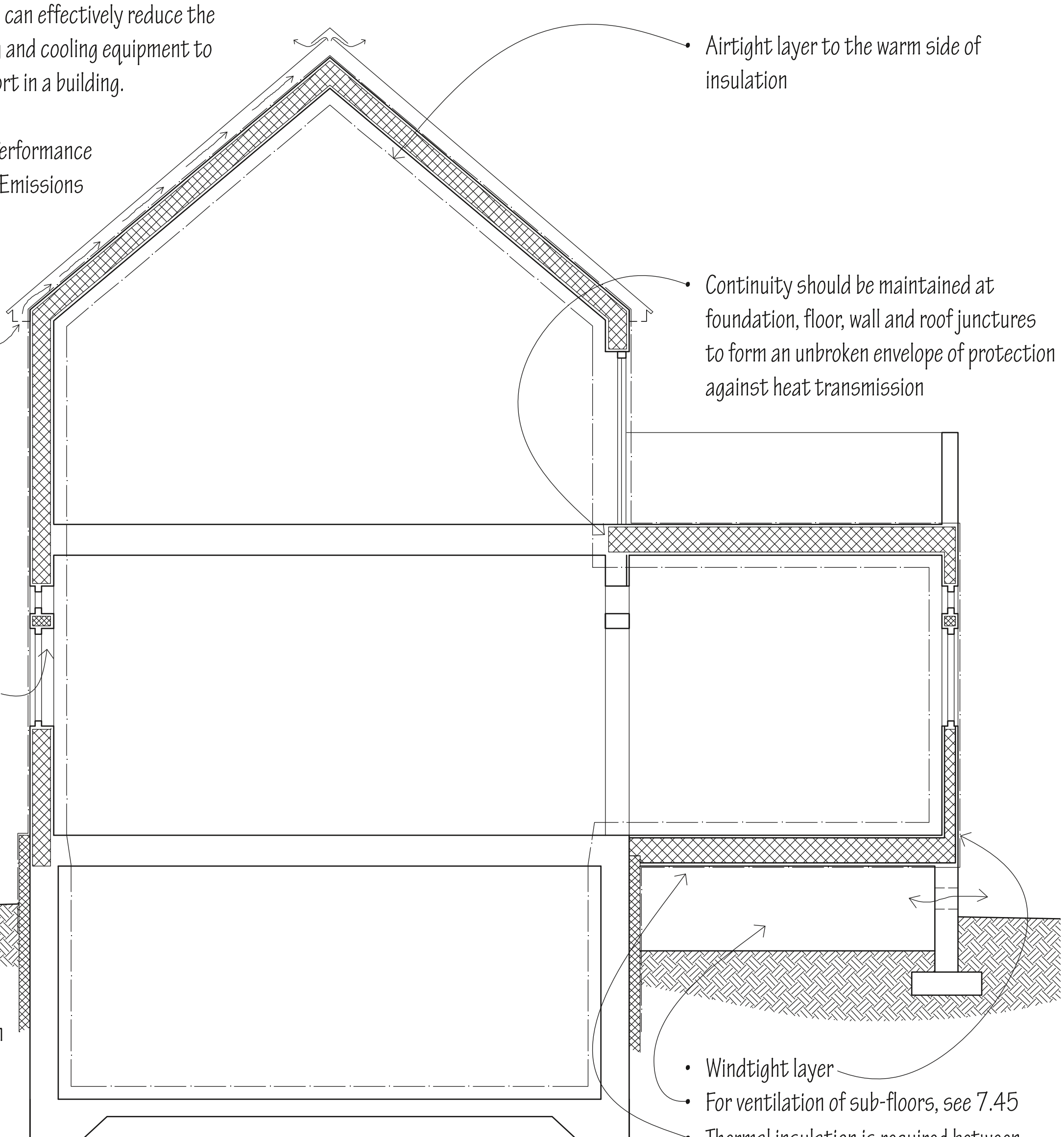
Polymer-based systems consist of a portland cement or acrylic polymer base coat 2–6 mm thick, reinforced with fibreglass mesh embedded at the time of installation. The finish coat is made with acrylic polymers. Polymer-based systems are more elastic and crack resistant than polymer-modified systems, but also more susceptible to denting and puncturing.



- Drips and decorative V-joints are cut with a router

The primary purpose of thermal insulation is to control the flow or transfer of heat through the exterior assemblies of a building and thereby prevent excessive heat loss in cold seasons and heat gain in hot weather. This control can effectively reduce the amount of energy required by heating and cooling equipment to maintain conditions for human comfort in a building.

LEED EA Credit 1: Optimize Energy Performance
BREEAM ENE 01: Reduction of CO_2 Emissions



- Airtight layer to the warm side of insulation
- Continuity should be maintained at foundation, floor, wall and roof junctures to form an unbroken envelope of protection against heat transmission
- Concealed roof spaces require ventilation to dissipate any stray water vapour; see 7.45
- Ensure wall insulation and window frame meet or overlap to maintain continuity and avoid thermal bridging. See 7.36 for more detail regarding thermal bridging
- See 7.43 for airtightness details
- The temperature differential between basement spaces and the ground is less than between indoor spaces and the outdoors above grade
- Windtight layer
- For ventilation of sub-floors, see 7.45
- Thermal insulation is required between heated and unheated spaces

Recommended Minimum U-Values for Building Elements (W/m^2K)

Element	Flat Roof	Pitched Roof	Wall	Floor	Window	Rooflight	Door
Minimum Domestic	0.16	0.13	0.20	0.25	1.80	2.00	2.00
Minimum Commercial	0.25	–	0.30	0.25	2.00	2.20	2.20
Passive House Standard*	0.15	0.08	0.15	0.15	0.80	–	0.80

Use these U-values for preliminary design purposes only. Consult local building regulations and/or relevant standards for more specific guidance.
*Passive House Institute (2013)

- For a discussion of the factors that affect human comfort, see 11.03
- For siting factors that also affect potential heat loss or gain, see Chapter 1
- For discussion concerning airtightness, see 7.43
- For discussion regarding thermal bridging, see 7.36

A thermal or cold bridge occurs within the insulated envelope of a building when there is a break in insulation or the insulation is bridged by a material of high conductivity. Thermal bridges can be repeating such as a steel wall tie in a cavity wall or a non-repeating bridge which is a one-off thermal bridge at a junction or penetration through the insulated envelope.

As building regulations call for ever increasing levels of insulation, the issue of thermal bridging has become more important as the thermal bridge can account for a relatively high proportion of overall heat loss.

Thermal bridges typically occur at the following locations:

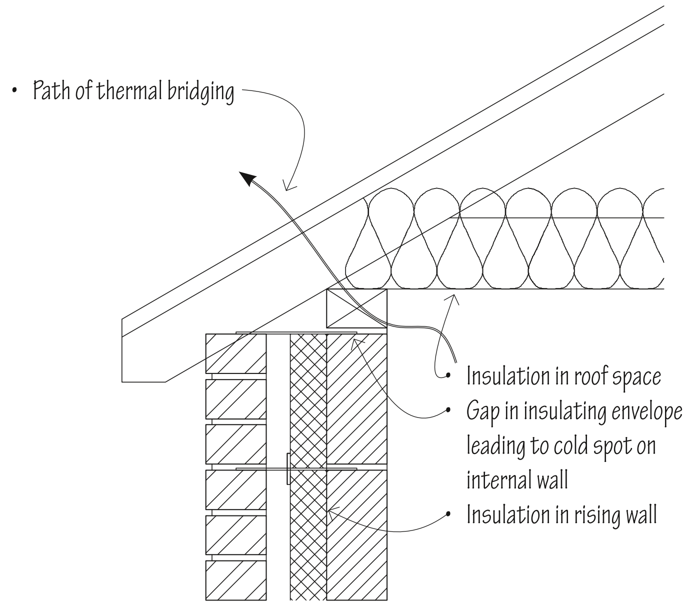
- Junction of window jamb, head or sill
- Junction of external wall and intermediate floor
- Around lintels
- Where structural connection between the wall and a protruding element is required
- Junction of roof and wall
- Service penetrations through the envelope

In addition to increasing the overall heat loss from a building, the presence of a thermal bridge can lead to cold spots on the internal face of the wall, from which if enough moisture is present within the space mould growth may occur.

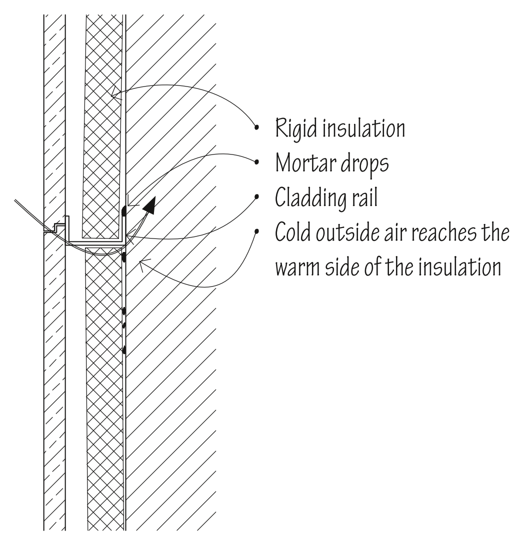
External insulation (see 7.34) offers a relatively simple method of overcoming most thermal bridges as internal wall and floor junctions do not interfere. Careful detailing is still required at junctions around openings, at service penetrations and at the roof.

A thermal loop occurs when cool outside air is able to reach the warm side of an insulation material. When this occurs the insulation is essentially bypassed, greatly reducing its effectiveness.

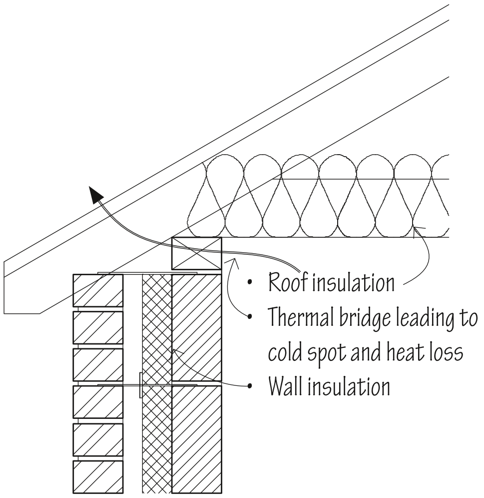
Thermal looping is most common in constructions using rigid insulation materials as poor workmanship can leave gaps between insulated panels caused by mortar or other unwanted materials around the insulation.

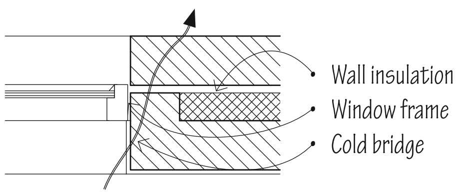


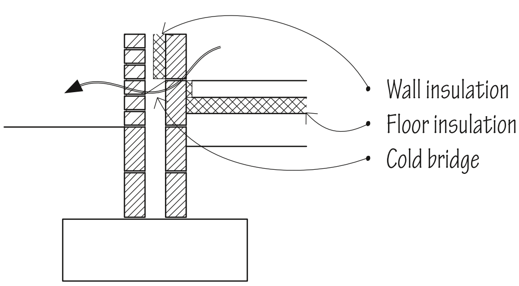
Thermal Bridging

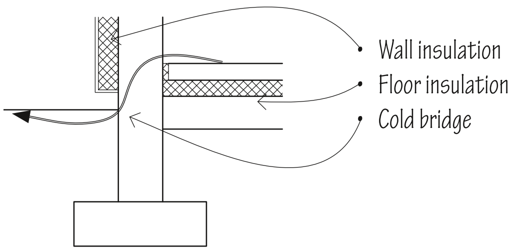


Thermal Loop

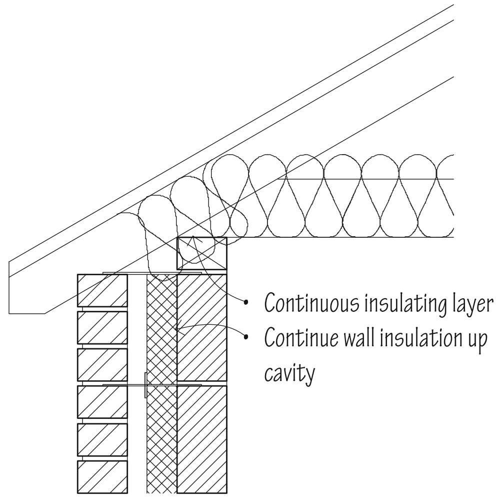


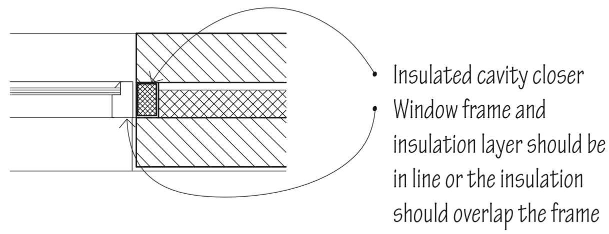


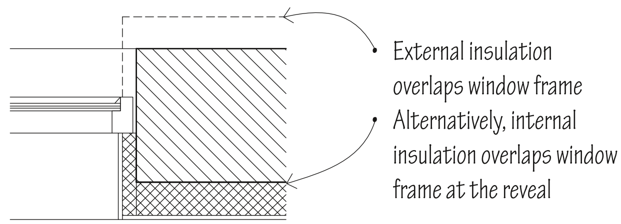


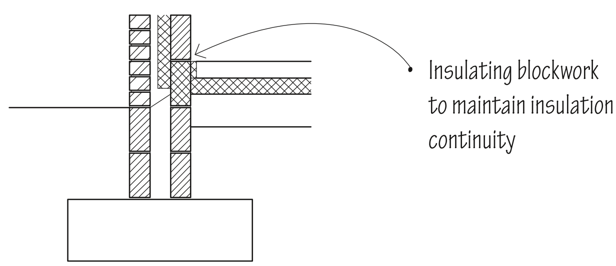


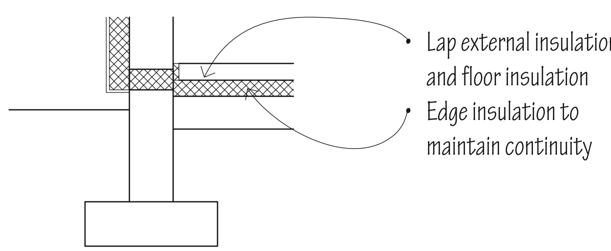
Thermal Bridging Occurrence











Thermal Bridging Solution

THERMAL RESISTANCE OF BUILDING MATERIALS

Material	Thermal Conductivity (W/mK)
Concrete	
Cast – dense	1.40
Cast – lightweight	0.38
Masonry	
Brickwork – inner leaf	0.62
Brickwork – outer leaf	0.84
Concrete block	
Heavy	1.63
Medium	0.51
Light	0.19
Metal	
Aluminium	200
Brass	132
Copper	394
Lead	35
Steel	50
Timber	
Hard timbers	0.16
Soft timbers	0.12
Plywood	0.13
OSB	0.13
Stone	
Limestone	1.50
Granite	1.70–3.50
Slate	2.00
Sandstone	1.70
Plaster & Gypsum	
Plaster – dense	0.05
Plaster – lightweight	0.16
External render	0.50
Insulation	
Expanded polystyrene	0.035
Extruded polystyrene	0.030
Polyisocyanurate	0.018
Polyurethane	0.030
Sheep's wool	0.040
Mineral wool	0.040
Rockwool	0.045

The tables to the left can be used to estimate the thermal resistance of a construction assembly. For specific k-values of materials consult the product manufacturer.

- k is the thermal conductivity measure of heat flow through a material of 1 m thickness. A material with a lower thermal conductivity will be a better insulator and a high thermal conductivity will be a good conductor and poor insulator. Materials suppliers provide thermal performance information as conductivity

  k = W/mK

- R is a measure of thermal resistance of a given material taking into account the thickness of the material. The thickness of a material divided by its conductivity gives its thermal resistance

  R = W/m^2K

- R_t is the total thermal resistance for a construction assembly and is simply the sum of the individual R-values of the component materials of an assembly

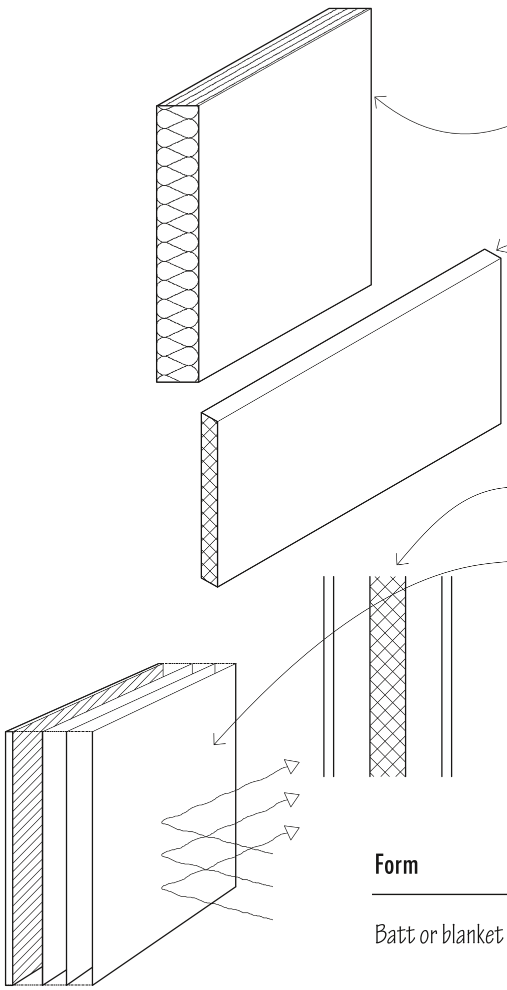
- U-value (U) is a measure of the thermal transmittance of a building component or assembly. It is expressed as the rate of heat transfer through a unit area of a building component or assembly caused by a difference of one degree between the air temperatures on the two sides of the component or assembly. The U-value for a component or assembly is the reciprocal of its R-value

  $U = 1/R_t$

- Q is the rate of heat flow through a construction assembly and is equal to:

  $U \times A \times (t_i - t_o)$, where:

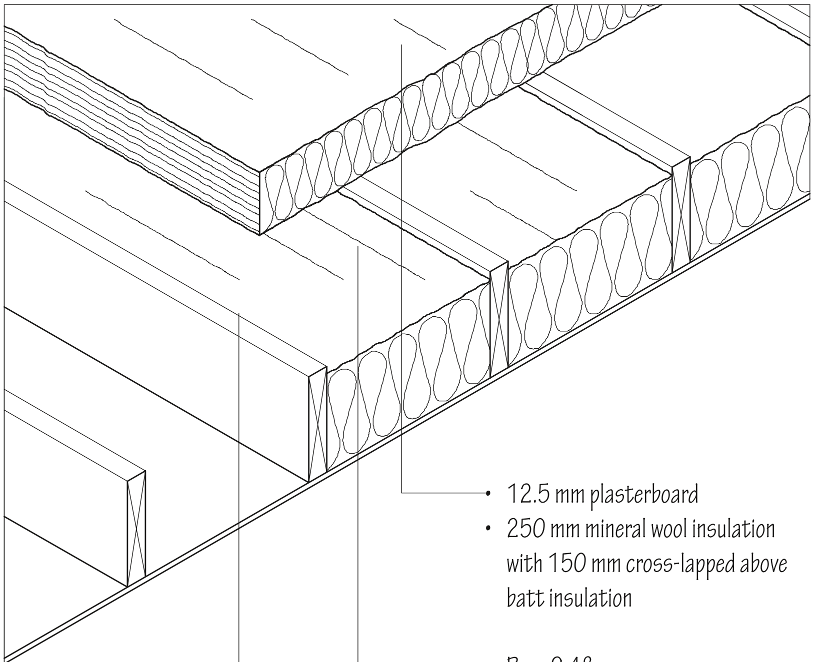
- U = overall assembly U-value
- A = heat loss area of assembly
- $(t_i - t_o)$ = difference between the inside and outside air temperatures



Almost all building materials offer some resistance to heat flow. To achieve the desired thermal resistance, however, wall, floor and roof assemblies usually require the addition of an insulating material. Below is an outline of the basic materials used to insulate the components and assemblies of a building. Note that all effective insulating materials usually incorporate some form of captured dead-air space.

- Batt insulation consists of flexible, fibrous thermal insulation of glass or mineral wool, made in various thicknesses and lengths and in 400–600 mm widths to fit between studs, joists and rafters in light timber-frame construction, sometimes faced with a vapour retarder. Batt insulation is also a component in sound-insulating construction
- Rigid foam insulation is a pre-formed, non-structural insulating board of foamed plastic or cellular glass. Largely oil-based rigid boards are dimensionally stable, suffer limited deterioration over time and are traditionally used in cavity-wall construction. Rigid insulation having closed-cell structures, as extruded polystyrene and cellular glass, is moisture-resistant and may be used in contact with the earth
- Foamed-in-place insulation consists of a foamed plastic, such as polyurethane, that is sprayed or injected into a cavity where it adheres to the surrounding surfaces
- Loose-fill insulation consists of mineral wool fibres or treated cellulosic fibres, poured by hand or blown through a nozzle into a cavity or over a supporting membrane
- Reflective insulation utilises a material of high reflectivity and low emissivity, as paper-backed aluminium foil or foil-backed plasterboard, in conjunction with a dead-air space to reduce the transfer of heat by radiation

Form	Material	Thermal Conductivity (W/mK)	
Batt or blanket	Fibreglass Rock wool	0.040 0.044	Installed between studs, joists, rafters or furring; considered non-combustible except for paper facing
Semi-rigid board	Timber fibre	0.039	Used in wall cavities to give a tight fit and reduce thermal bridging
Rigid board	Polystyrene, extruded Polystyrene expanded Polyurethane expanded Polyisocyanurate	0.030 0.037 0.025 0.02	Boards may be applied over a roof deck, over a wall, in a wall cavity or beneath an interior finish material; the plastics are combustible and give off toxic fumes when burned; extruded polystyrene can be used in contact with the earth but exposed surfaces should be protected from sunlight
Foamed in place	Polyurethane bead	0.025	Used to insulate irregularly shaped spaces
Loose fill	Cellulose	0.04	Used to insulate attic floors and wall cavities; cellulose may be combined with adhesives for sprayed application; cellulose should be treated for fire resistance



- 12.5 mm plasterboard
- 250 mm mineral wool insulation with 150 mm cross-lapped above batt insulation

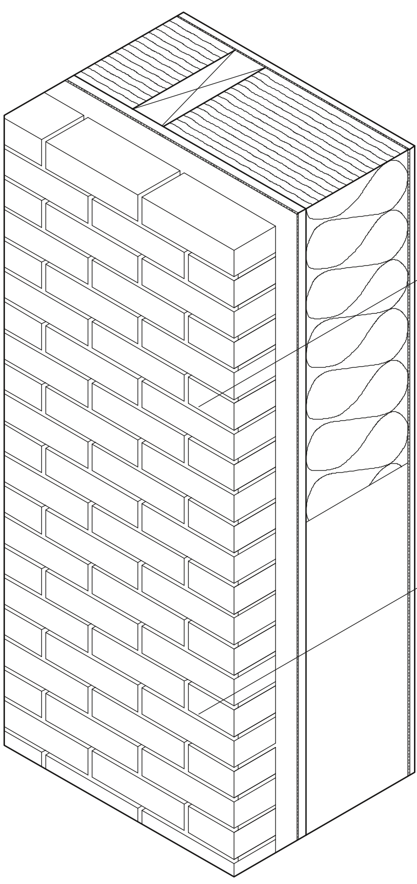
- $R_t = 9.48$
- $U = 0.10$

Uninsulated
- $R_t = 2.0$
- $U = 0.5$

The steady state method for calculating heat loss or gain takes into account primarily the total thermal resistance (R_t) of the construction assembly and the differential in air temperature. Other factors that affect heat loss or gain are:

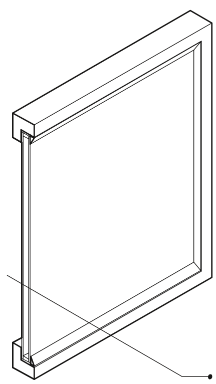
- The surface colour and reflectivity of the materials used; light colours and shiny surfaces tend to reflect more thermal radiation than dark, textured ones
- The mass of the assembly, which affects the time lag or delay before any absorbed and stored heat is released by the structure; time lag becomes a significant factor with thick, dense materials
- The orientation of the exterior surfaces of a building, which affects solar heat gain as well as exposure to wind and the attendant potential for air infiltration
- Latent heat sources and heat gain from the occupants, lighting and equipment within a building
- Proper installation of thermal insulation and vapour retarders

The inverse of the total thermal resistance (R_t), known as the U-value (U) of the assembly, is a common method of expressing the thermal performance of a build-up of materials.

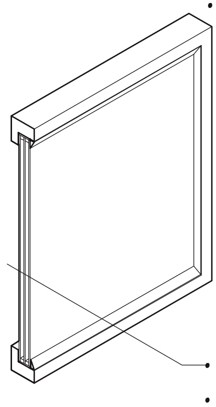


Insulated
- 12.5 mm plasterboard (vapour retarder) with 250 mm mineral wool insulation with 18 mm plywood (breather paper), 75 mm air gap and 102.5 mm external brick veneer
- $R_t = 6.95$
- $U = 0.14$

Uninsulated
- $R_t = 0.88$
- $U = 1.14$



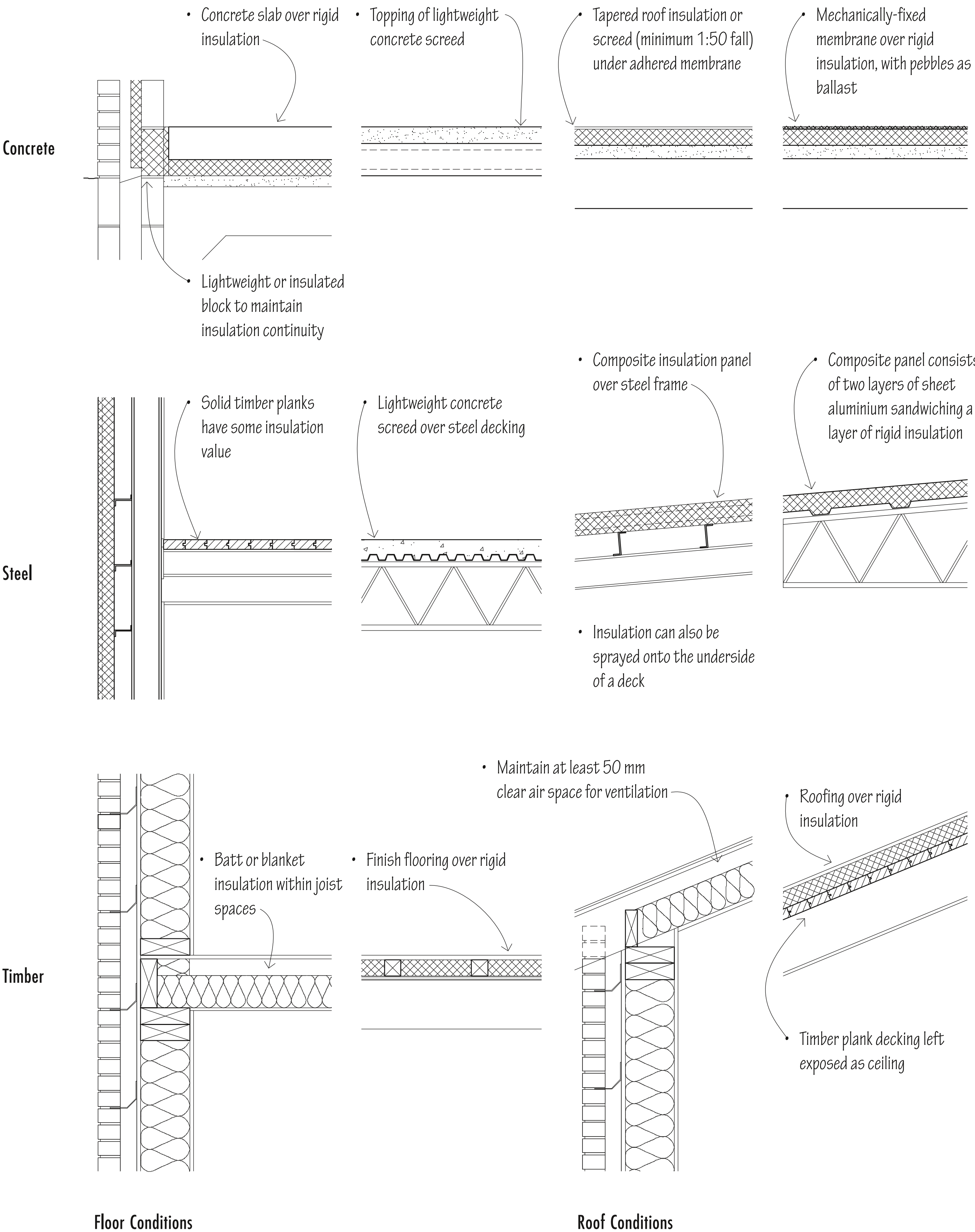
- Double glazing (24 mm air space)
- $R = 0.55$; $U = 1.81$



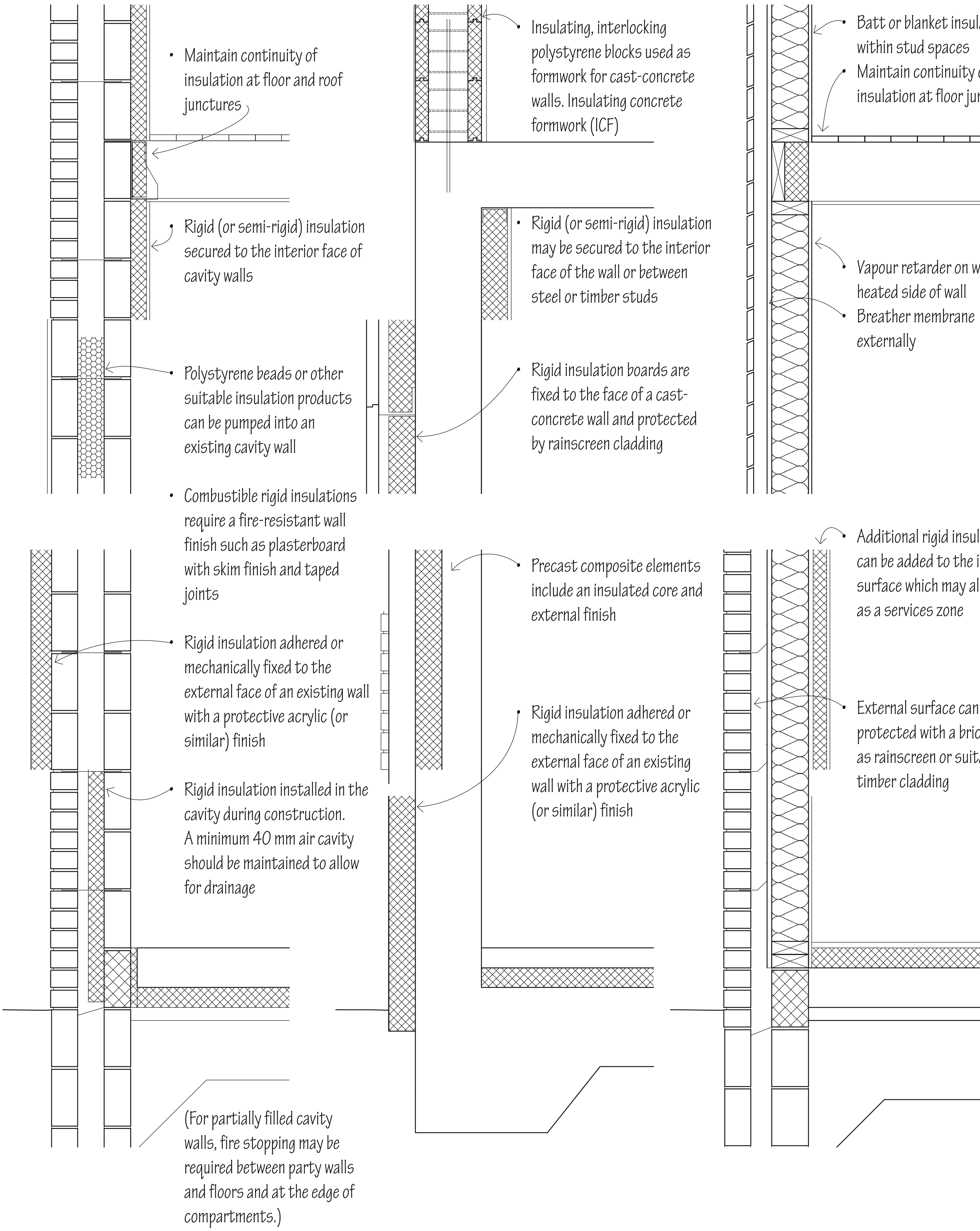
- Triple glazing (24 mm air space)
- $R = 0.83$; $U = 1.20$

(The above values do not take into account the impact of the window frame, which can be a weak point, or the installation method used.)

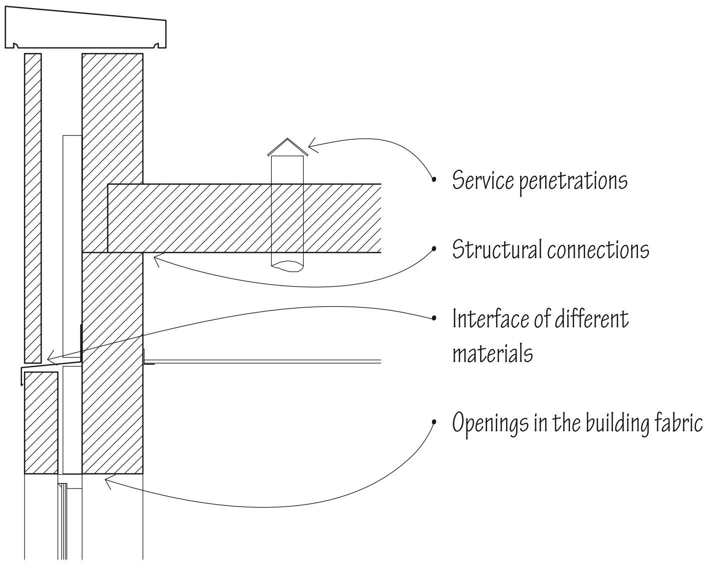
Comparison of R-Values and U-Values for Insulated and Uninsulated Assemblies


Concrete
• Concrete slab over rigid insulation
• Topping of lightweight concrete screed
• Tapered roof insulation or screed (minimum 1:50 fall) under adhered membrane
• Mechanically-fixed membrane over rigid insulation, with pebbles as ballast
• Lightweight or insulated block to maintain insulation continuity
Steel
• Composite insulation panel over steel frame
• Composite panel consists of two layers of sheet aluminium sandwiching a layer of rigid insulation
• Solid timber planks have some insulation value
• Lightweight concrete screed over steel decking
• Insulation can also be sprayed onto the underside of a deck
Timber
• Maintain at least 50 mm clear air space for ventilation
• Roofing over rigid insulation
• Batt or blanket insulation within joist spaces
• Finish flooring over rigid insulation
• Timber plank decking left exposed as ceiling
Floor Conditions
Roof Conditions

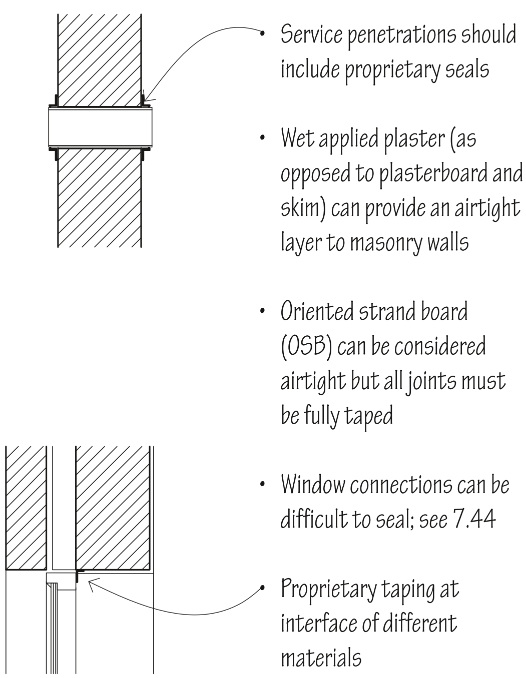
7.42 INSULATING WALLS



Masonry Cavity Walls | **Cast Concrete or ICF Walls** | **Stud Frame Walls**



Air Leakage Paths



Airtightness Detailing

In many part of Europe including Germany, Austria and other countries that experience particularly cold winters, the provision of airtight construction has been standard practice for some time. In other areas such as Ireland and the UK airtightness has more recently become an issue of growing importance.

When providing airtight buildings it is important that adequate and well-designed ventilation is also provided (see 7.45) to ensure healthy and comfortable internal environments. The mantra of 'build tight, ventilate right' should be followed. The advantage of airtight construction is the elimination of unwanted draughts or infiltration, reducing heating loss and providing more comfortable and healthy environments.

To achieve airtight construction a combination of quality workmanship, vigilance, high-quality detailing and an understanding of the materials in use is required.

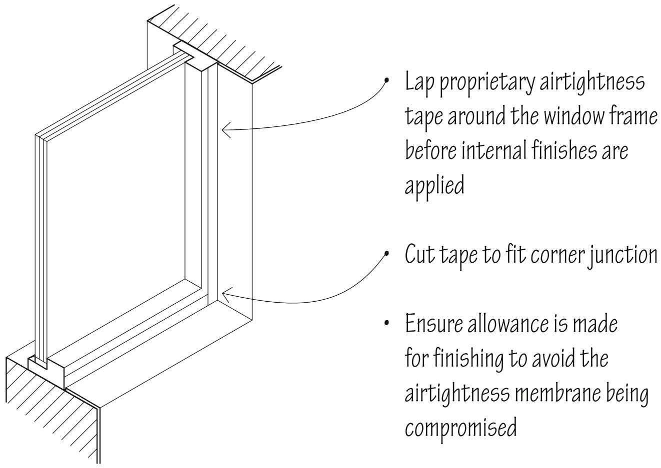
As with thermal bridging (see 7.36–7.37), the increasing levels of thermal insulation required by the building regulations has increased the importance of achieving airtight construction.

The air permeability of a building is measured by pressurising and depressurising the building by 50 pascals (pa) above or below the ambient external pressure using a blower door and then measuring the time it takes for the pressure difference created to reduce, thus measuring the leakage rate. The units used as standard are $m^3/hr/m^2$ (of building envelope) @50pa (or alternatively air changes per hour @50pa, depending on what aspect of airtightness/permeability you wish to measure). Building regulations across Europe vary significantly in the airtightness standards they require, consult local regulations for more guidance.

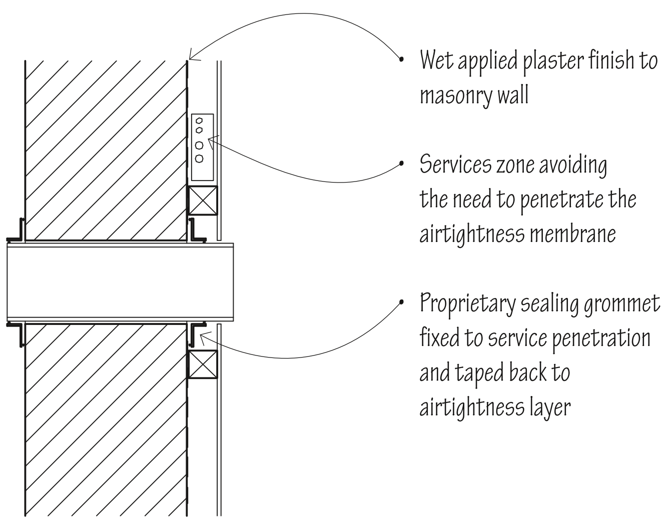
The Passive House Standard (see 1.08–1.09), a highly respected energy performance certification mechanism in Europe, requires airtightness levels of no greater than 0.6 air changes per hour (ach) @50pa.

The main paths for unwanted air leakage in typical buildings include:

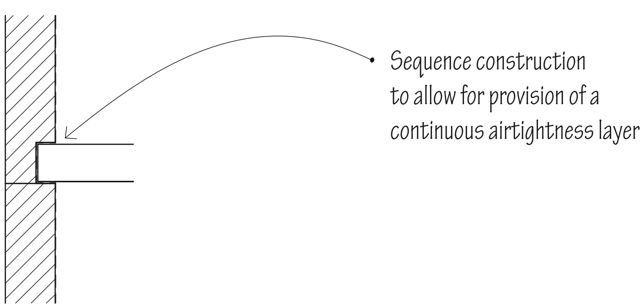
- Service penetration
- Junctions within the building (such as wall to roof)
- Openings in the building fabric (windows, doors etc)



Window Detail



Wall Details



Internal Floor Junction

Any airtightness strategy needs to first identify the location of the airtight seal; this should be on the warm side of the insulated envelope. Ideally structure, building services and airtightness elements should be independent to reduce the risk of compromising the airtightness layer. In practice this often proves difficult, but the provision of a dedicated services zone, careful detailing and appropriate material selection can result in good levels of airtightness.

For masonry construction the following strategies may help achieve good levels of airtightness:

- Wet applied plaster finish to external walls as opposed to plasterboard and skim
- Careful consideration of load-bearing connections between internal floors and the roof
- Careful consideration of all key junctions

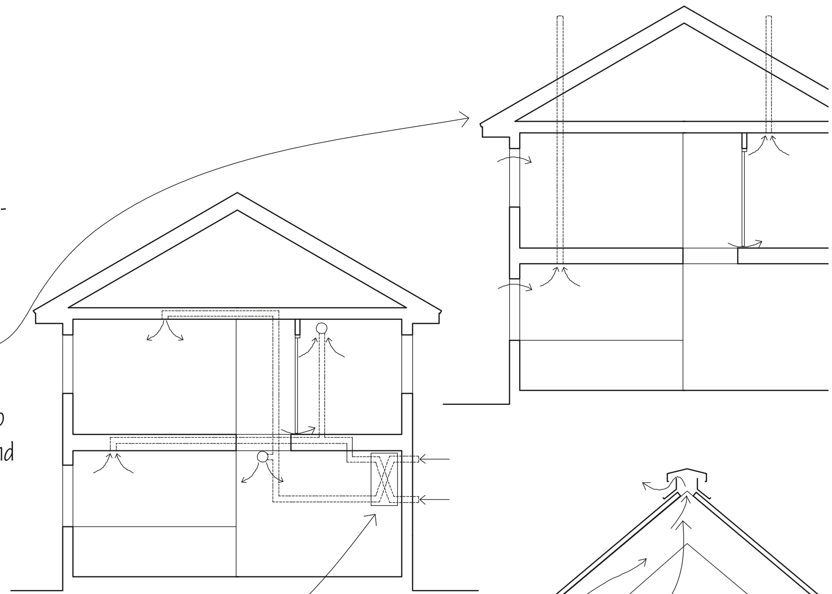
For timber-frame construction the following strategies may help to achieve good levels of airtightness:

- Oriented strand board sheeting to timber frame with all joints fully taped
- Careful consideration of sequencing for prefabricated elements to ensure a continuous airtightness layer can be provided
- Careful consideration of all key junctions

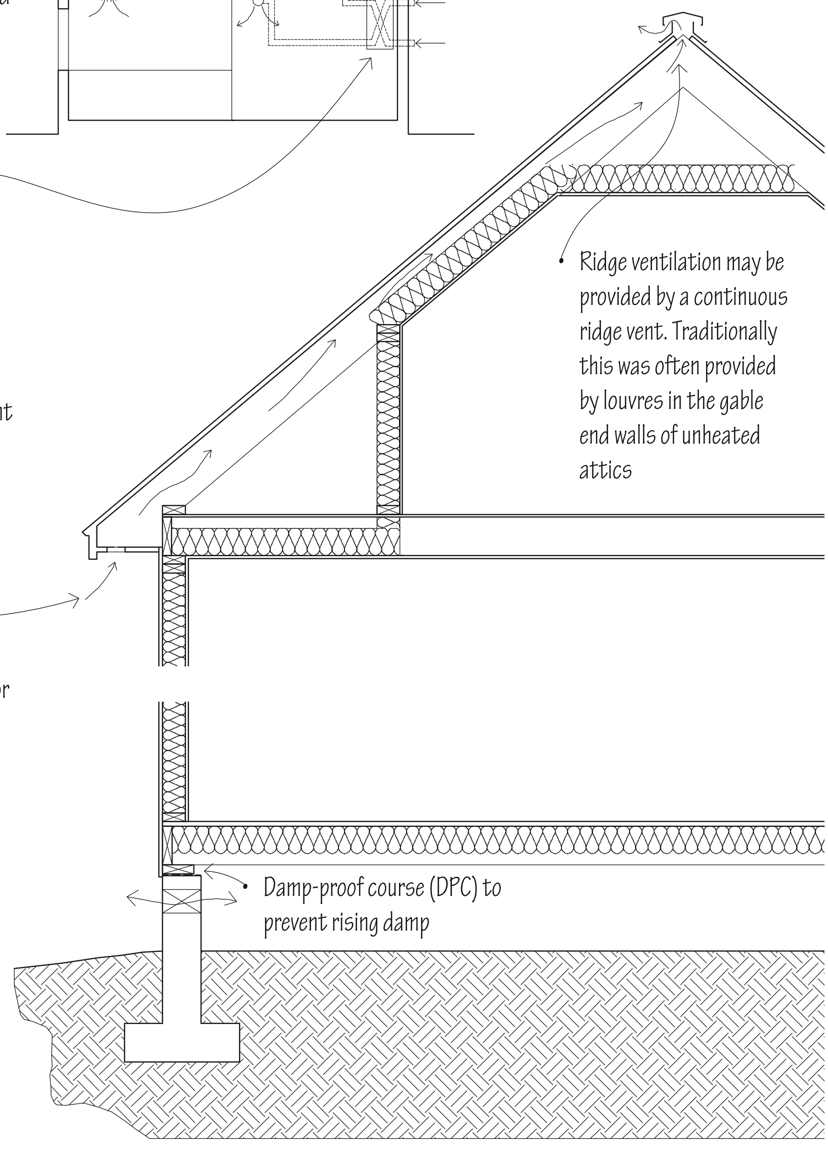
Steel frame and other construction systems can achieve the required airtightness levels by the adaptation of a considered strategy. The above lists are not exhaustive and alternative approaches may be suitable. It is vital that technical drawings identify the proposed airtightness strategy from the outset of any project.

Domestic Ventilation

- The increasing drive towards airtight construction (see 7.43) means that background infiltration levels along with traditional ventilation methods may not be enough to rid internal spaces of moisture, odours and pollutants. Passive-stack ventilation, mechanical-extract ventilation or whole-house ventilation may be adopted to overcome this



- Passive-stack ventilation works by introducing extract stacks into wet areas drawing air out from the building due to the stack effect. Ventilation inlets are placed in rooms to provide supply air with extract from kitchens, bathrooms and other areas of potentially high moisture content
- Mechanically-assisted systems use fans on the inlet or outlet to drive ventilation air
- Whole-house systems use fans to supply and extract air from the building and often include a heat exchanger to recover heat from exhaust air



Roof and Attic Ventilation

- Ventilation of concealed roof spaces is provided by eaves, ridge and/or tile vents. A minimum ventilation area equivalent to a 10 mm wide continuous ventilation strip at eaves level on both sides of the roof should be provided (see building regulations for local requirements). Openings should be protected against the penetration of rain, snow and insects

- Eaves or soffit vents may consist of a continuous screened vent slot or a metal vent strip installed in the eaves soffit, or comprise a series of evenly distributed circular plug vents in frieze boards. Care should be taken where eaves ventilation is provided to ensure the continuity of thermal insulation between the wall and roof

Sub-Floor Ventilation

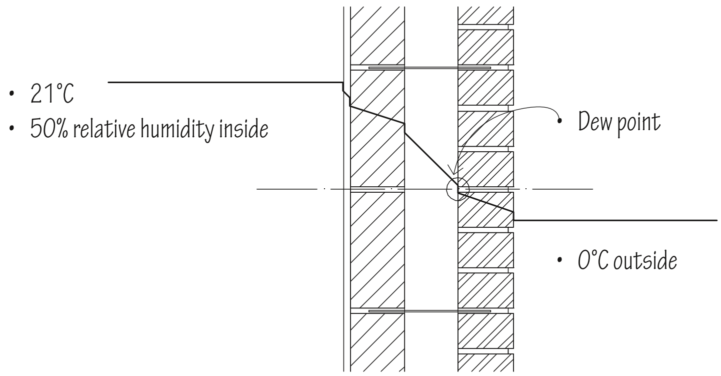
- Sub-floor spaces also require ventilation. Openings should have an area of at least 1500 mm^2/m run of perimeter wall or 500 mm^2/m^2 floor area whichever is greater (consult building regulations for local requirements). There should be at least one opening on each side of the sub-floor, located as high as possible to promote cross ventilation. Openings should be protected against insects and vermin with wire mesh screening

Moisture is normally present in the air as water vapour. Evaporation from occupants and equipment can raise the humidity of the air in a building. This moisture vapour will transform itself into a liquid state or condense when the air in which it exists becomes completely saturated with all the vapour it can hold and reaches its dew-point temperature. Warm air is capable of holding more moisture vapour and has a higher dew point than cooler air.

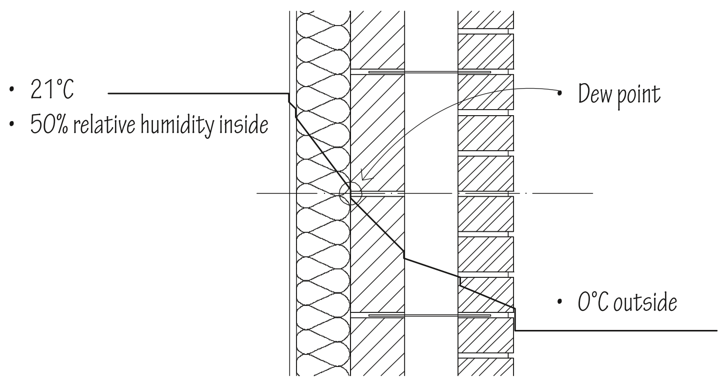
Because it is a gas, moisture vapour always migrates from high to lower pressure areas. This normally means it tends to diffuse from the higher humidity levels of a building's interior toward the lower humidity levels outside. This flow is reversed when hot, humid conditions exist outdoors and a building's interior spaces are cooler. Most building materials offer little resistance to this passage of moisture vapour. If the moisture vapour comes into contact with a cool surface whose temperature is at or below the dew point of the air, it will condense. When this occurs within a construction it is known as interstitial condensation and can be damaging.

Condensation can lessen the effectiveness of thermal insulation, be absorbed by building materials and deteriorate finishes. Moisture vapour, therefore, must be:

- Prevented by vapour retarders from condensing within the enclosed spaces of exterior construction
- Or be allowed to escape the building by the use of suitable breathable materials that will not trap moisture within the construction
- Or be allowed to escape, by means of ventilation, before it can condense into a liquid
- Surface condensation on windows can be controlled by removing sources of excessive moisture through rapid ventilation (such as a kitchen extract) or by using double- or triple-glazed windows with high thermal performance, such as triple-glazed windows with warm edge spacer bars and insulated frames, thus eliminating cold surfaces
- Great care should be taken when refurbishing an existing building to understand and avoid issues of condensation. In older buildings, replacing leaky windows with modern well-sealed units can significantly reduce the ventilation rate within the space, resulting in increased humidity levels



Uninsulated Wall



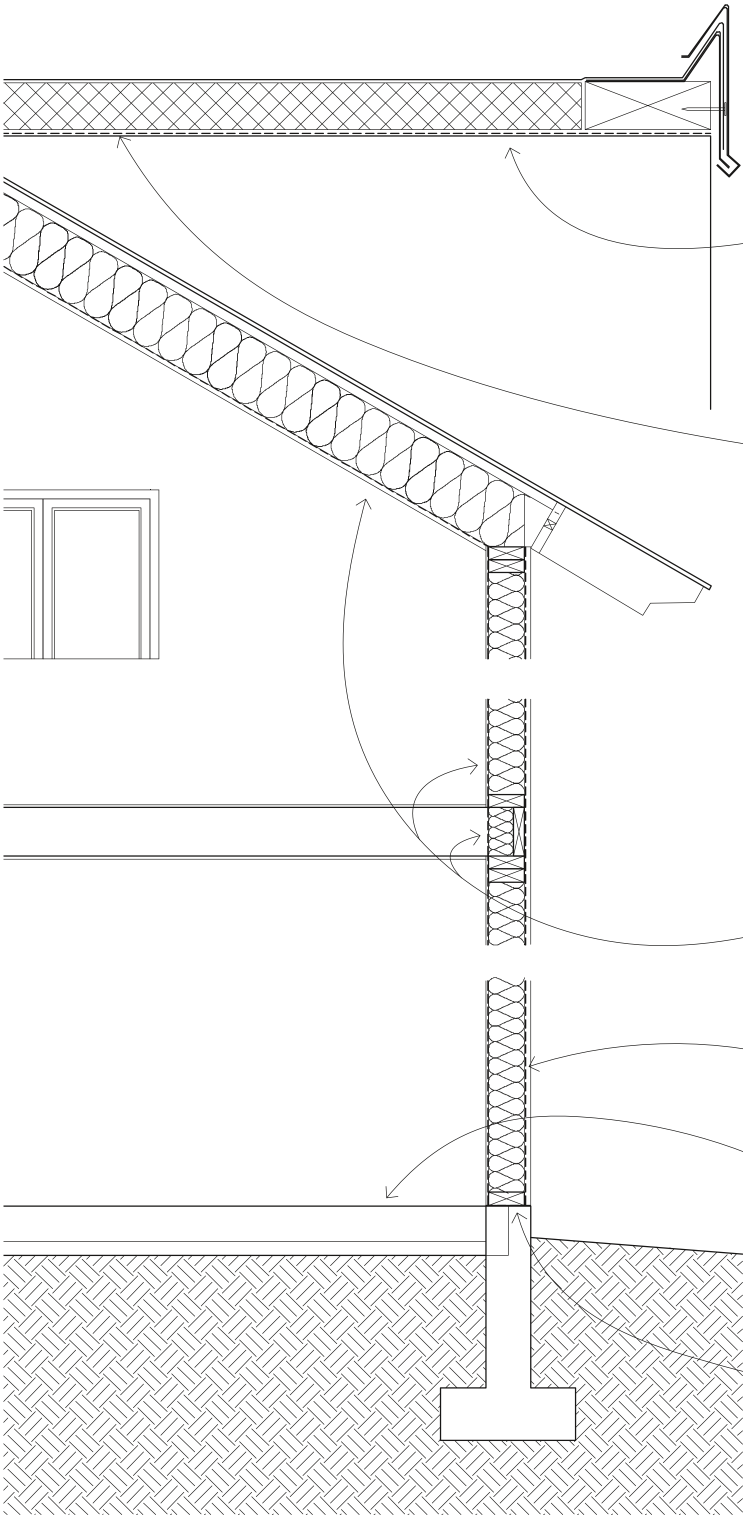
Drylined Wall

Vapour Resistance of Some Building Materials

Material	Water Vapour Resistance Factor (μ)*
Lead	∞
Cast concrete	60–100
Granite	10,000
Limestone	25–200
Internal plastering	4–10
Plywood	50–250
Polyethylene(vapour barrier)	100,000
Roofing felt	50,000
Clay roof tile	30–40
Expanded polystyrene	60
Extruded polystyrene	150
Mineral wool	1
Phenolic foam	50

*Selected data from: EN 12524:2000

- Walls may require a vapour retarder to prevent water vapour from condensing within the layer of insulation. A vapour retarder becomes more important as the level of thermal insulation increases
- The water vapour resistance factor 'μ' represents the relative resistance of a material to the passage of water vapour
- Damage to the vapour control layer could result in moisture becoming trapped within the building structure. This should be taken into consideration during the design stage



A vapour barrier is a material of low permeance installed in a construction to prevent moisture from entering and reaching a point where it can condense into a liquid. Vapour barriers are normally placed on the warm side of insulated construction in temperate and cold climates. In warm, humid climates, the vapour retarder may have to be placed closer to the outer face of the construction.

- The use of a vapour barrier is generally recommended to protect the insulation layer of flat roof assemblies in geographic locations where the average outdoor temperature in January is below 4°C and the interior relative humidity in winter is 45% or greater at 20°C
- The barrier may be in the form of asphalt-saturated roofing felt or a proprietary material of low permeance
- When a vapour barrier is present in a roof build-up, ventilation may be required to allow any trapped moisture to escape from between the vapour barrier and the roofing membrane. Consult roofing manufacturer for recommendations

- Some rigid foam insulation boards have inherent vapour resistance, while other insulating materials have a vapour-retarding facing. A vapour barrier is most effective, however, when it is applied as a separate layer of aluminium foil, polyethylene film or treated paper

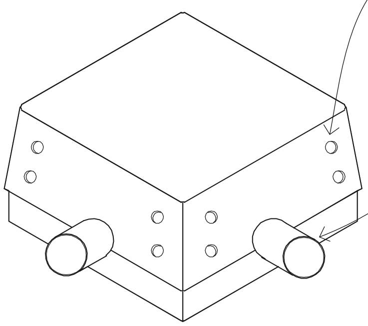
- Vapour barriers should have a flow rating of one perm or less and be installed with all seams at joints and openings lapped and sealed. The vapour barrier can sometimes double as an airtightness layer where a suitable material is used

- Exterior sheathing, breather paper and cladding should be permeable to allow any vapour in the wall construction to escape to the outside

- Over unheated spaces, the vapour barrier is placed on the warm side of the insulated floor. The vapour barrier may be laid on top of the sub-floor or be integral with the insulation

- A damp-proof course is required to retard the migration of ground moisture through a rising wall

Many traditional buildings and materials are designed to be 'vapour open', great care must be taken when installing a vapour barrier in this situation as moisture build-up can damage the building structure. Many modern natural building materials are also vapour open and the use of a poorly installed vapour barrier may have a negative impact.



Radon Sump

Radon is a naturally occurring odourless and colourless gas which has been identified as a potential carcinogen. In most locations background levels of radon exposure never reach levels which would cause concern. However, when a building is constructed in a region with a high concentration of radon, this can potentially become concentrated within the building and reach levels which over time could have an impact on occupants' health and wellbeing.

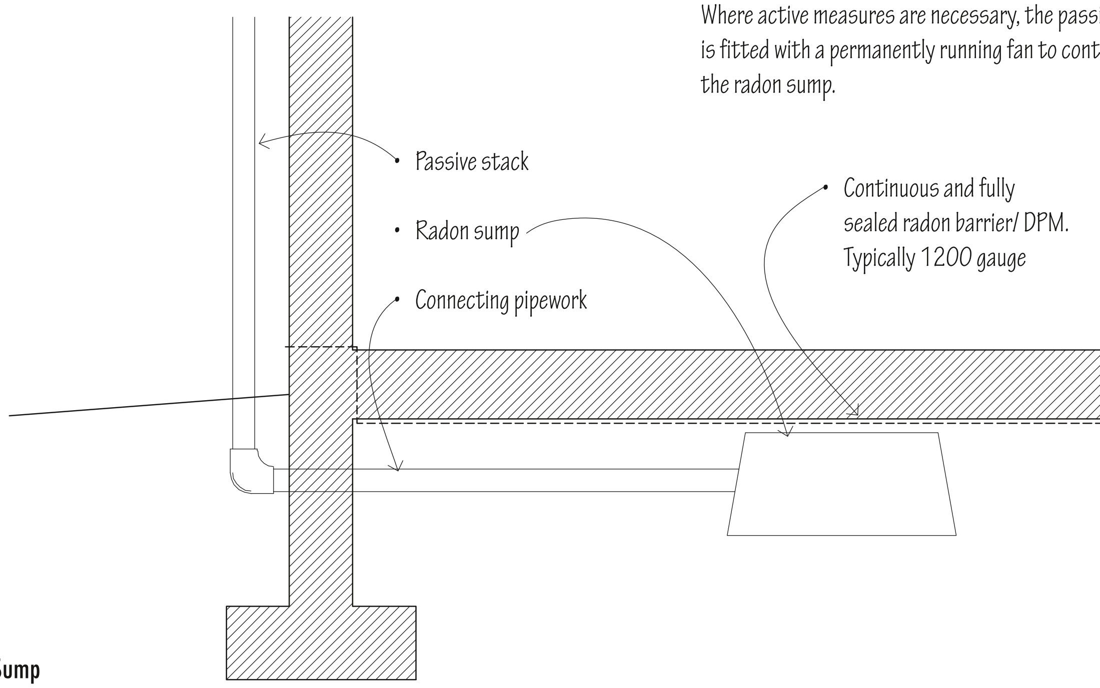
Radon levels around Europe vary significantly from one location to the next, as a result there is significant variation in the requirements for addressing issues of radon. Consult local building regulations to identify the relevant requirements.

There are a number of approaches to dealing with radon in buildings depending on the severity of exposure and relevant regulations. Passive measures include:

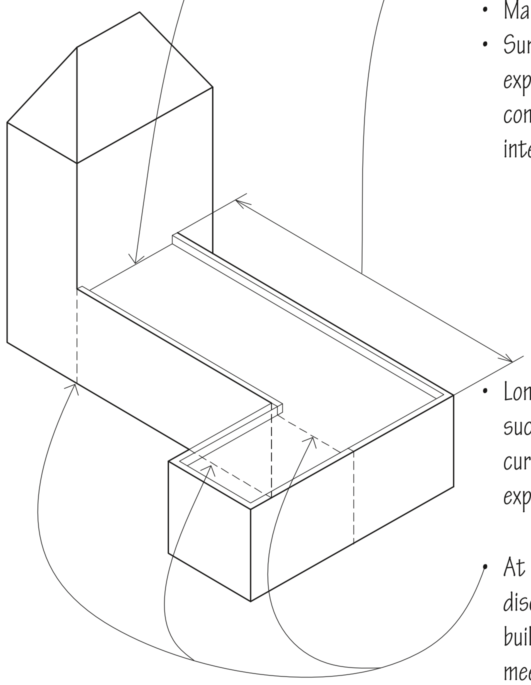
- Installation of a radon barrier below the ground-floor slab of the building (radon barriers of sufficient grade can also act as a damp-proof membrane)
- Installation of radon barrier with a radon sump and connecting pipework and passive vent to allow for venting of any collecting gas to the atmosphere

In some cases, the radon sump and pipework may be connected to a blanking cap at ground level for future connection to a vent stack if high levels of radon are detected.

Where active measures are necessary, the passive vent stack is fitted with a permanently running fan to continuously vent the radon sump.



Radon Barrier & Sump



- Where a new building adjoins an existing structure
- Long surface areas; maximum length without expansion joints:
- Steel, concrete or built-up roofing – 30–60 m
- Masonry – 6–12 m
- Surfaces with severe solar exposure require expansion or control joints at more frequent intervals
- Long, linear building elements, such as fascias, gravel stops and curtain-wall framing also require expansion joints
- At horizontal and vertical discontinuities in the massing of a building, such as where a low mass meets a taller mass, or at wings and intersections

Location of Movement Joints

All building materials expand and contract in response to normal changes in temperature. Some also swell and shrink with changes in moisture content, while others deflect under loading. Joints must be constructed to allow this movement to occur in order to prevent distortion, cracking or breaks in the building materials. Movement joints should provide a complete separation of material and allow free movement while, at the same time, maintaining the weathertightness of the construction.

Types of Movement Joints

- Expansion joints are continuous, unobstructed slots constructed between two parts of a building or structure permitting thermal or moisture expansion to occur without damage to either part. Expansion joints can often serve as control and isolation joints. See 5.25 for expansion joints in brick masonry walls, 7.49, 7.50 for horizontal expansion joints in masonry veneer walls and 10.04 for expansion joints in internal plastering
- Control joints are continuous grooves or separations in concrete ground slabs and concrete masonry walls to form a plane of weakness and thus regulate the location and amount of cracking resulting from drying shrinkage, thermal stresses or structural movement. See 3.19 for control joints in concrete ground slabs and 5.25 for control joints in concrete masonry walls
- Isolation joints divide a large or geometrically complex structure into sections so that differential movement or settlement can occur between the parts. At a smaller scale, an isolation joint can also protect a non-structural element from the deflection or movement of an abutting structural member

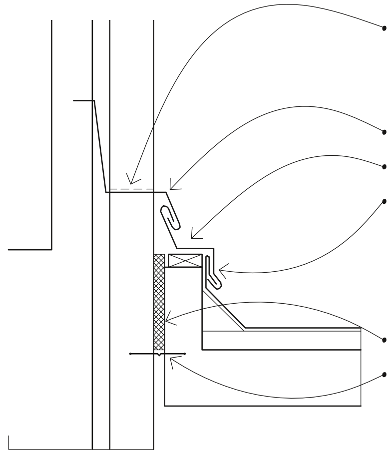
Coefficients of Linear Expansion

Per Unit Length Per 1 Degree Change in Temperature (°K)

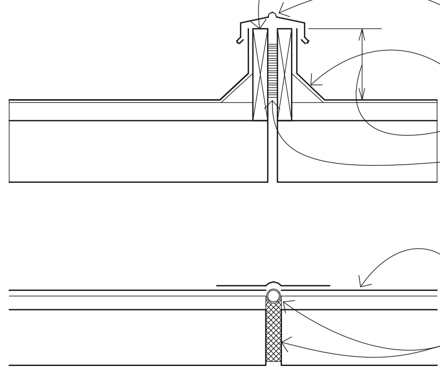
	$\times 10^{-6}$		$\times 10^{-6}$		$\times 10^{-6}$
Aluminium	22.5	Parallel to timber grain:		Brick masonry	5.50
Brass	19.0	Fir	4.0	Concrete	9.80
Bronze	18.0	Maple	6.5	Granite	7.90
Copper	17.0	Oak	5.0	Limestone	8.0
Iron, cast	10.5	Pine	6.5	Marble	14.0
Iron, wrought	11.5	Perpendicular to grain:		Plaster	13.0
Lead	28.0	Fir	57.5	Slate	10.5
Nickel	13.0	Maple	48.5	Steel, stainless	17.5
Steel, carbon	13.0	Oak	54.0	Glass	9.0
		Pine	34.0		

The width of an expansion joint depends on the building material and the temperature range involved. It varies from 6 to 25 mm or more, and should be calculated for each specific situation.

- The coefficient of surface expansion is approximately twice the linear coefficient
- The coefficient of volume expansion is approximately three times the linear coefficient



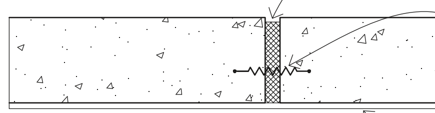
Wall and Roof Juncture



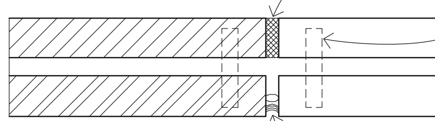
Flat Roof

These expansion joint details, although general in nature, have the following elements in common:

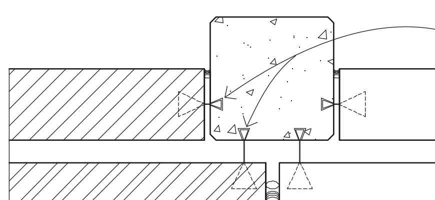
- A joint that creates a complete break through the structure, which is then usually filled with a compressible material
- A weatherstop that may be in the form of an elastic joint sealant, a flexible waterstop embedded within the construction or a flexible membrane over flat roof joints



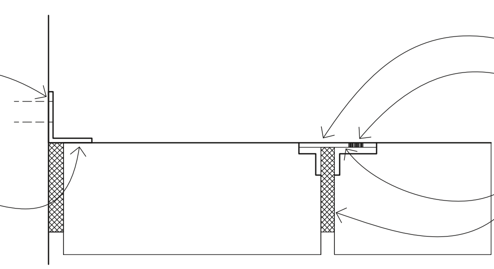
Concrete Foundation Wall



Masonry Cavity Wall

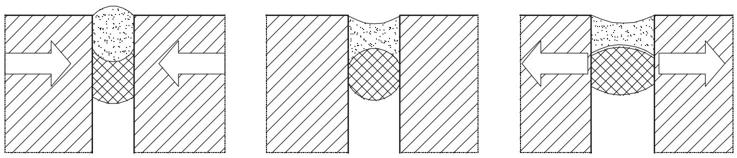


Column and Wall Juncture



Expansion Joint Covers

To provide an effective seal against the passage of water and air, a joint sealant must be durable, resilient and have both cohesive and adhesive strength. Sealants can be classified according to the amount of extension and compression they can withstand before failure.



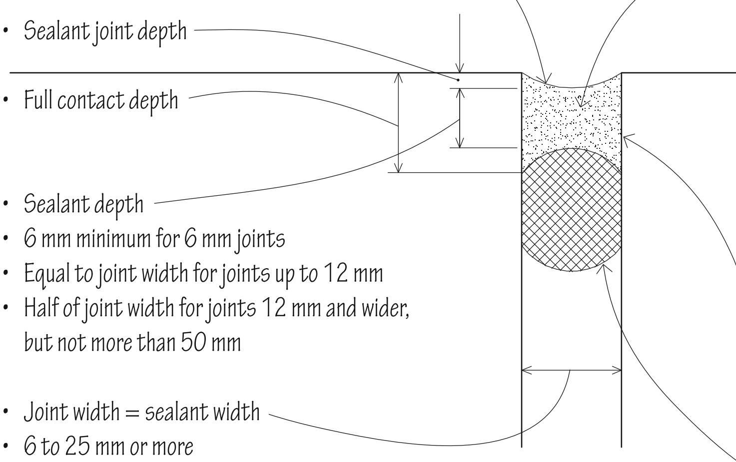
- Compressed
- As installed
- Elongated

Joint Movement

Low-Range Sealants
- Movement capability of +/- 5%
- Oil-based or acrylic compounds
- Often referred to as caulking and used for small joints where little movement is expected

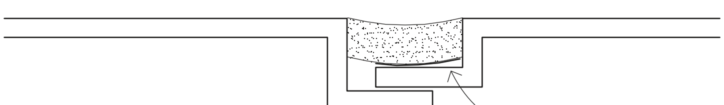
Medium-Range Sealants
- Movement capability of +/- 5% to +/-10%
- Butyl rubber, acrylic or neoprene compounds
- Used for non-working, mechanically fastened joints

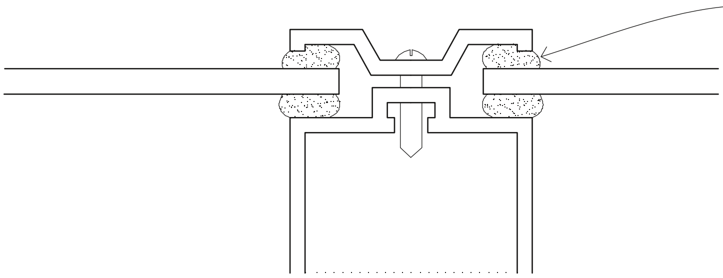
High-Range Sealants
- Movement capability of +/- 12% to +/-25%
- Polymercaptans, polysulfides, polyurethanes and silicones
- Used for working joints subject to a significant amount of movement, such as those in curtain walls



- Joints should be tooled to ensure full contact with and adhesion to substrate
- Sealant joint depth
- Full contact depth
- Sealant depth
- 6 mm minimum for 6 mm joints
- Equal to joint width for joints up to 12 mm
- Half of joint width for joints 12 mm and wider, but not more than 50 mm
- Joint width = sealant width
- 6 to 25 mm or more
- Width depends on the joint spacing, expected temperature range, anticipated movement due to wind or structural displacement and the movement capability of the sealant

- The substrate must be clean, dry and compatible with the sealant material
- A primer may be required to improve the adhesion of a sealant to the substrate
- The joint filler controls the depth of the sealant contact with the joining parts. It should be compressible and be compatible with but not adhere to the sealant. It may be in the form of a rod or tubing of polyethylene foam, polyurethane foam, neoprene or butyl rubber

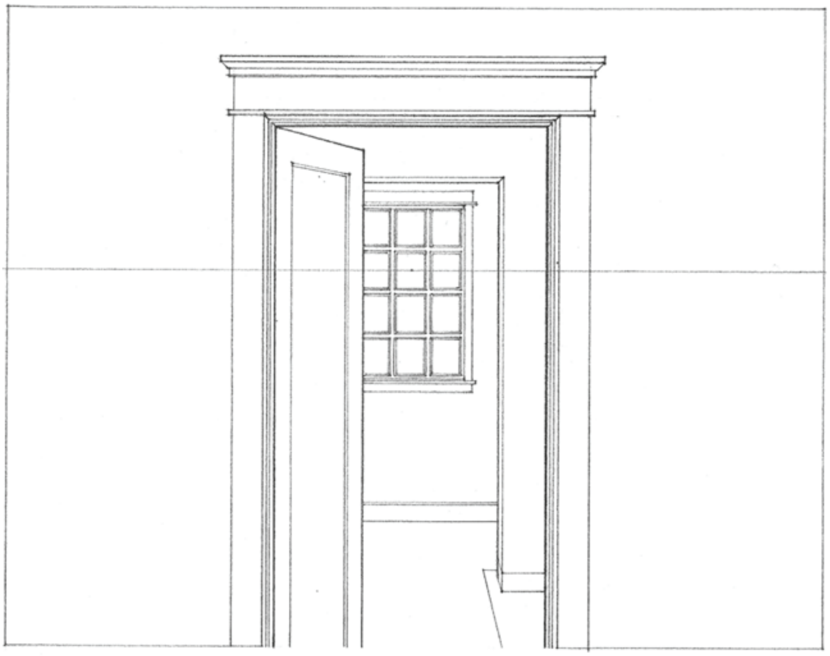


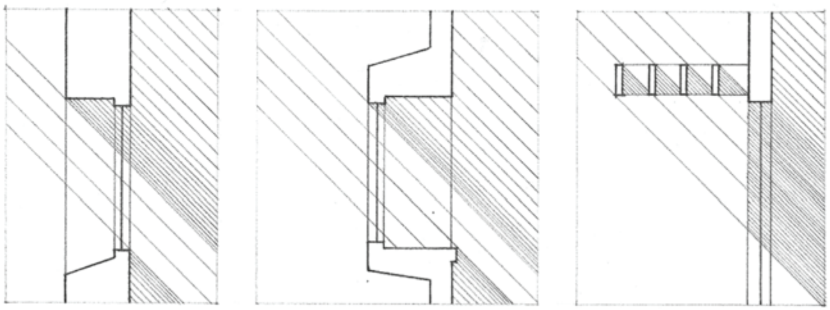


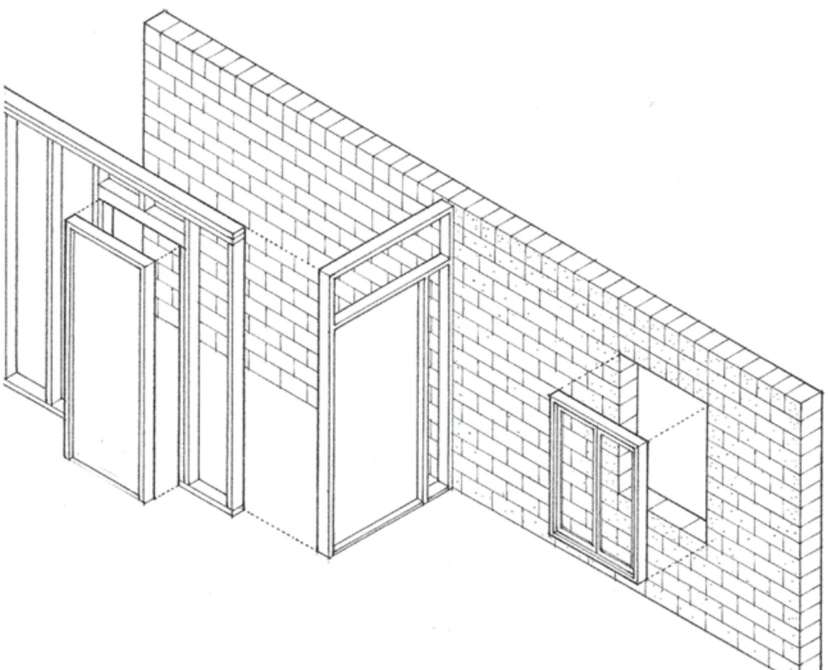
- When there is insufficient depth for a compressible filler, a bond breaker, such as polyethylene tape, is required to prevent adhesion between the sealant and the bottom of the joint recess
- Most sealants are viscous liquids that cure after being applied with a hand-operated or power gun. These are referred to as gunnable sealants. Some lap joints, however, are difficult to seal with gunnable sealants. These joints may require instead a pre-formed solid polybutene or polyisobutylene tape sealant that is held in place under compression

8

DOORS & WINDOWS







Doors and doorways provide access from the outside into the interior of a building as well as passage between interior spaces. Doorways should therefore be large enough to move through easily and accommodate the moving of furnishings and equipment. They should be located so that the patterns of movement they create between and within spaces are appropriate to the uses and activities housed by the spaces.

Exterior doors should provide weathertight seals when closed and maintain the approximate thermal insulation value of the exterior walls they penetrate. Interior doors should offer the desired degree of visual and acoustic privacy. All doors should be evaluated for their ease of operation, durability under the anticipated frequency of use, security provisions, and the light, ventilation and view they may offer. Further, there may be building regulation requirements for fire resistance, emergency egress and safety glazing that must be satisfied.

There are many types and sizes of windows, the choice of which affects not only the physical appearance of a building, but also the natural lighting, ventilation, view potential and spatial quality of the building's interior spaces. As with exterior doors, windows should provide a weathertight seal when closed. Window frames should have low thermal conductivity or be constructed to interrupt the flow of heat. Window glazing should retard the transmission of heat and control solar radiation and glare.

Because door and window units are normally factory-built, their manufacturers may have standard sizes and corresponding rough-opening requirements for the various door and window types. The size and location of doors and windows should be carefully planned so that adequate rough openings with properly sized lintels can be built into the wall systems that will receive them.

From an exterior point of view, doors and windows are important compositional elements in the design of building facades. The manner in which they punctuate or divide exterior wall surfaces affects the massing, visual weight, scale and articulation of the building form.

Door Types

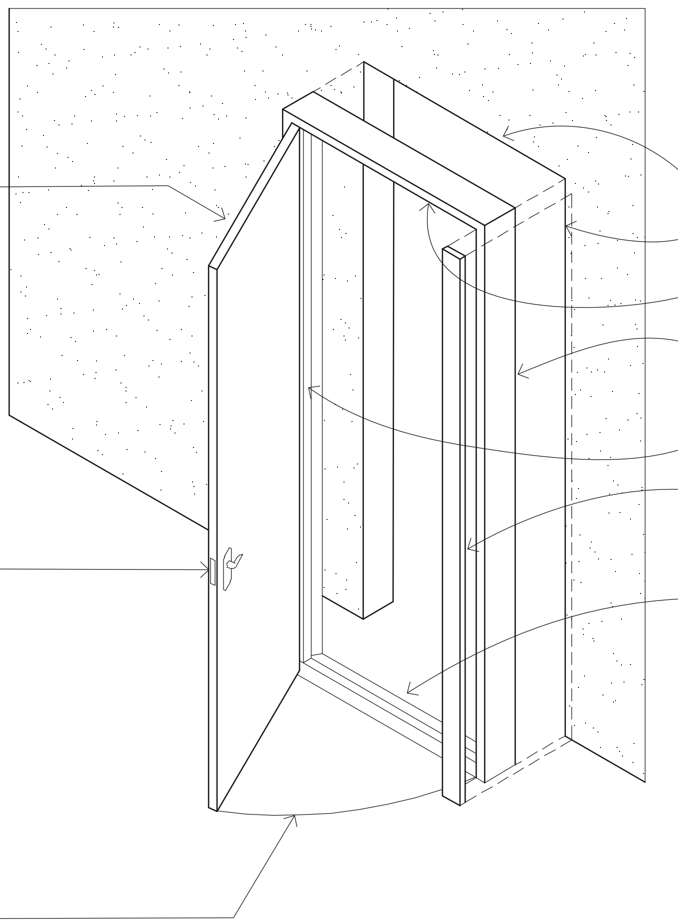
- Hollow metal doors and frames; see 8.05–8.07
- Timber doors and frames; see 8.08–8.10

Door Hardware

- Door hardware includes the metal fastenings and fittings required for the operation of a door, such as hinges, lock sets and closers; see 8.17–8.21

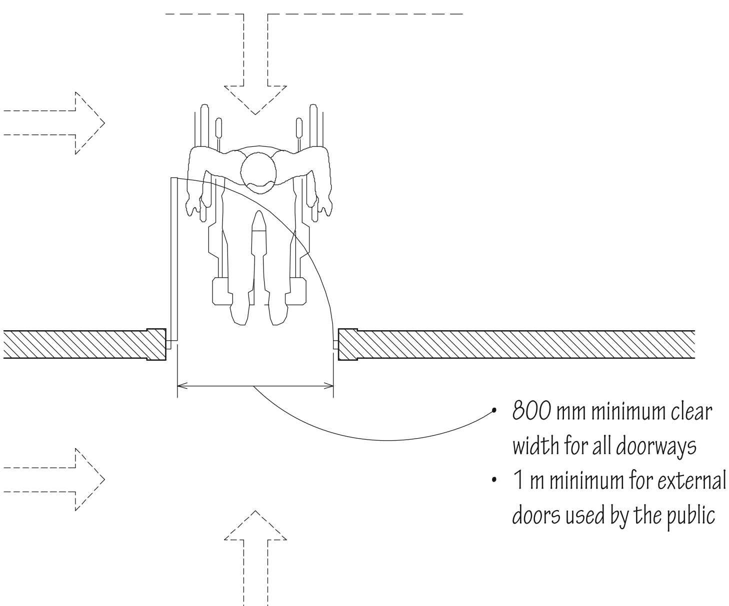
Door Operation

- See 8.04



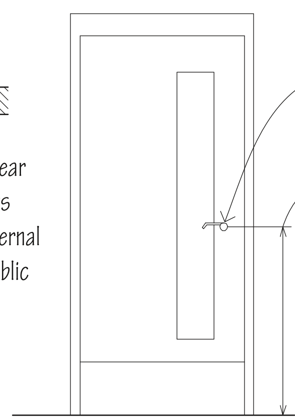
- The detailing of a door frame establishes the appearance of a doorway. Depending on the thickness of the wall construction, a door frame may be set within the structural opening or overlap its edges
- Structural opening is the wall opening into which a door frame is fitted
- Head is the uppermost member of a door frame
- Jamb refers to either of the two side members of a door frame
- Stop is the projecting part of a door frame against which a door closes
- Architrave is the trim that finishes the joint between a door frame and its rough opening
- Threshold is the sill of a doorway, covering the joint between two flooring materials or providing weather protection at an exterior door
- British Standards code of practice 8300 requires a threshold if provided should be no higher than 15 mm and bevelled. Consult local building regulations for specific guidance
- Saddle is a raised piece of flooring between the jambs of a doorway, to which a door fits closely to prevent its binding when opened

Door Frames



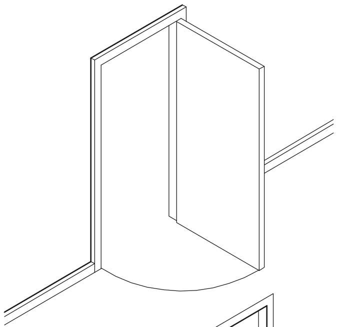
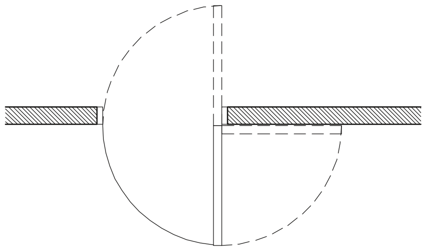
- 800 mm minimum clear width for all doorways
- 1 m minimum for external doors used by the public

Minimum Clearance at Doorways



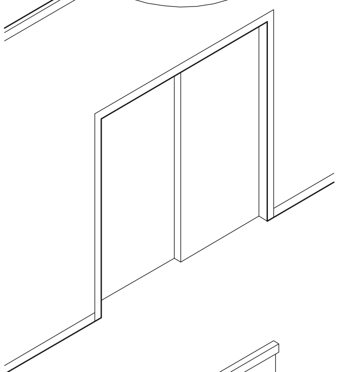
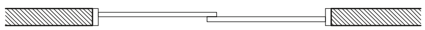
- Operating hardware should be easy to grasp with one hand without tight pinching or twisting of the wrist
- 900 mm height to centre of door handle above floor recommended, consult local regulations for maximum and minimum dimensions
- Entrance and lobby doors should incorporate vision panels to prevent accidents

BS 8300:2009 Design of Buildings and their Approaches to Meet the Needs of Disabled People

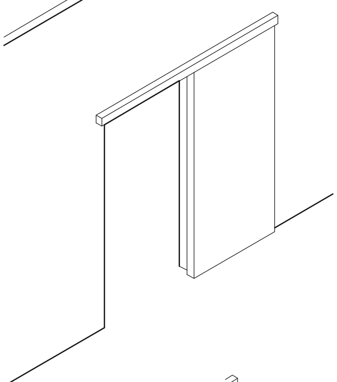
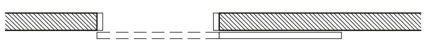
Swinging • Exterior and interior use

- Door normally turns on hinges about a side jamb when pushed or pulled, but may also be pivoted from head jamb and threshold
- Requires space around doorway for door swing; check clearance required
- Most convenient operation for entry and passage
- Most effective door type for thermal and acoustic insulation and for weather resistance; can be fire-rated

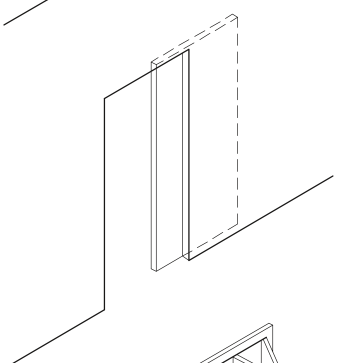
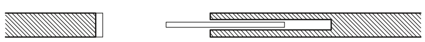
Bypass Sliding • Exterior and interior use

- Doors slide on overhead track and along guides or a track on the floor
- Requires no operating space but is difficult to seal against weather and sound
- Offers access only through 50% of doorway width
- Used on exterior as sliding glass doors
- Used in interiors primarily for visual screening

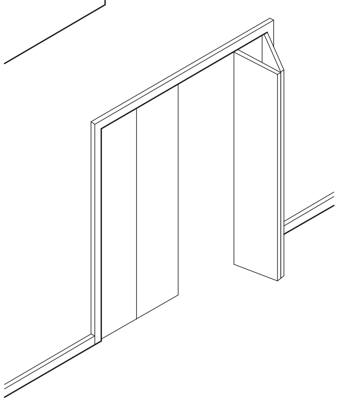
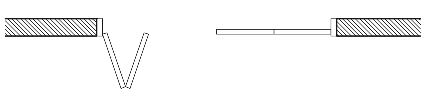
Surface Sliding • Exterior and interior use

- Similar to a bypass sliding door but provides access through full width of doorway
- No operating space required but is difficult to weatherproof
- Door is surface-hung on an exposed overhead track

Pocket Sliding • Interior use

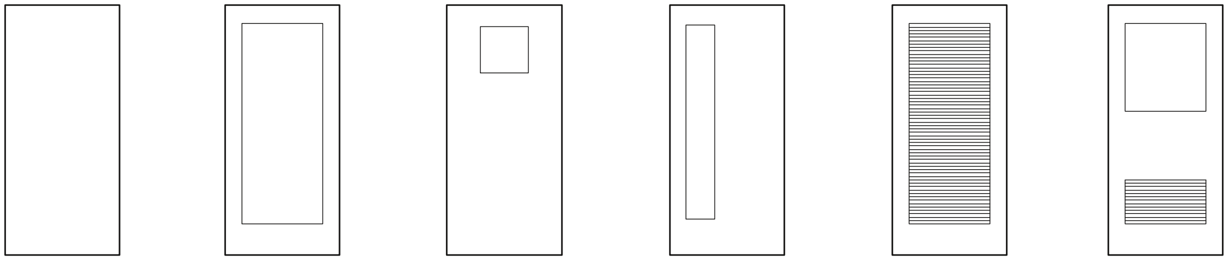
- Door slides on an overhead track into and out of a recess within the width of a wall
- Doorway has a finished appearance when fully open
- Often used where a normal door swing would interfere with the use of a space

Folding • Exterior and interior use

- Hinged door panels fold flat against one another when opened
- Bi-fold doors divide into two parts, require little operating space and are used primarily as a visual screen to enclose closet and storage spaces or to create a large opening to an outdoor space
- Accordion doors are multi-leafed doors that are used primarily to subdivide interior spaces. They are hung from an overhead track and open by folding back in the manner of an accordion

- See 8.16 for revolving doors

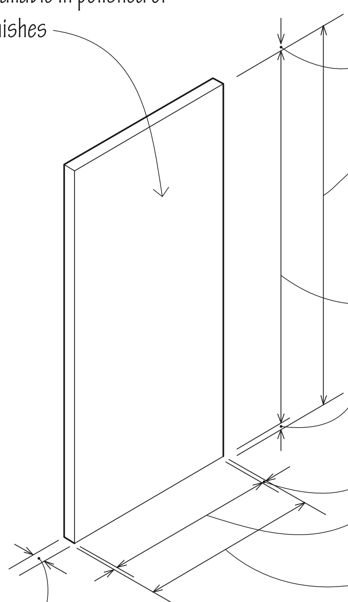


- Flush
- Glazed
- Vision
- Narrow light
- Full-louvred
- Vision/louvred

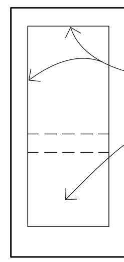
Door Designs

Door Finishes
- Primed or galvanised for painting
- Baked enamel paint
- Vinyl clad
- Stainless-steel or aluminium skins are available in polished or textured finishes

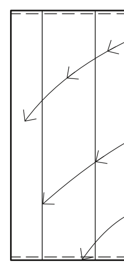
Door Construction
- Hollow metal doors have face sheets of 0.8–1.0 mm steel bonded to a steel channel frame and reinforced with channels, a honeycomb structure or a rigid plastic-foam core



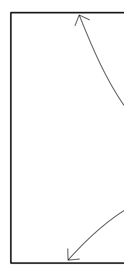
- 3 mm
- Nominal height = frame opening; 2000–2400 mm
- Net height
- 20 mm +/– ; varies with finish flooring
- 3 mm on both sides
- Net width
- Nominal width = frame opening; 725–1200 mm
- Door thickness 35–45 mm



Rail-and-Stile Construction
- Tubular stiles and rails
- Infill may be flush or recessed panel, glass or louvres



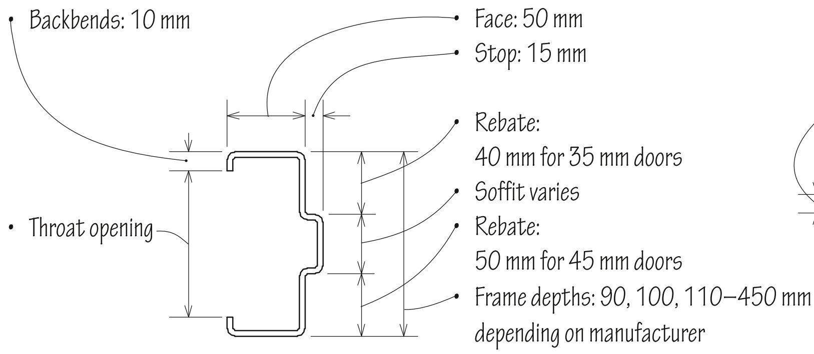
Rail Panel Construction
- Hinge and lock stiles connected to wide centre panel
- Exposed vertical interlocking welded seams
- Inverted channel at top and bottom



Flush Construction
- No visible seams on face
- Pan or enclosed grid construction
- Flush or recessed at top and bottom

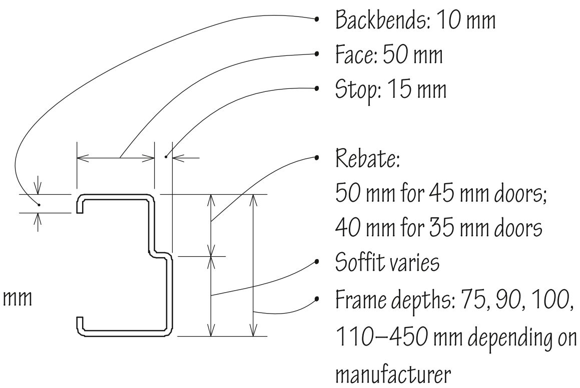
- Fire-door assemblies, consisting of a fire-resistant door, door frame and hardware, are required to protect openings in fire-rated walls; see 2.07
- Door frame and hardware must have a fire-resistance rating similar to that of the door
- Door must be self-latching and be equipped with closers

8.06 HOLLOW METAL DOOR FRAMES

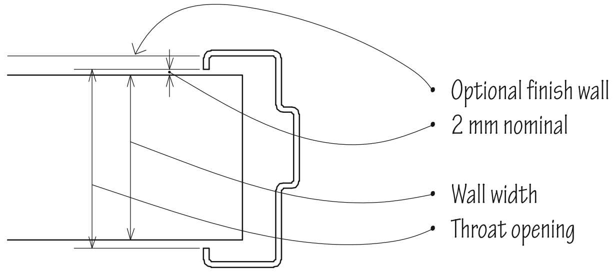


Standard Double-Rebate Frame

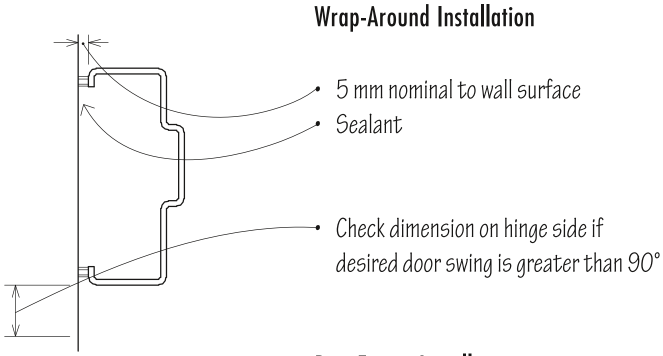
- 1.2–2.0 mm standard thickness
- Standard finish: factory-primed for painting
- Frame profiles vary with manufacturer
- Frames are morticed and reinforced to receive hinges, strike and closer



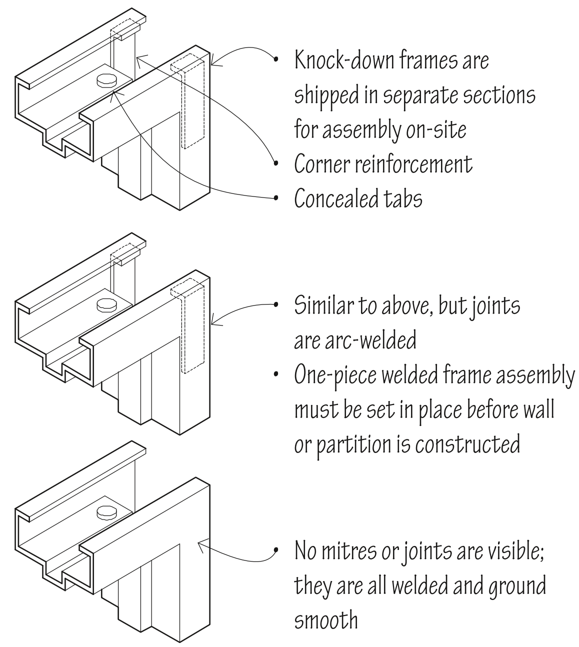
Single Rebate Frame



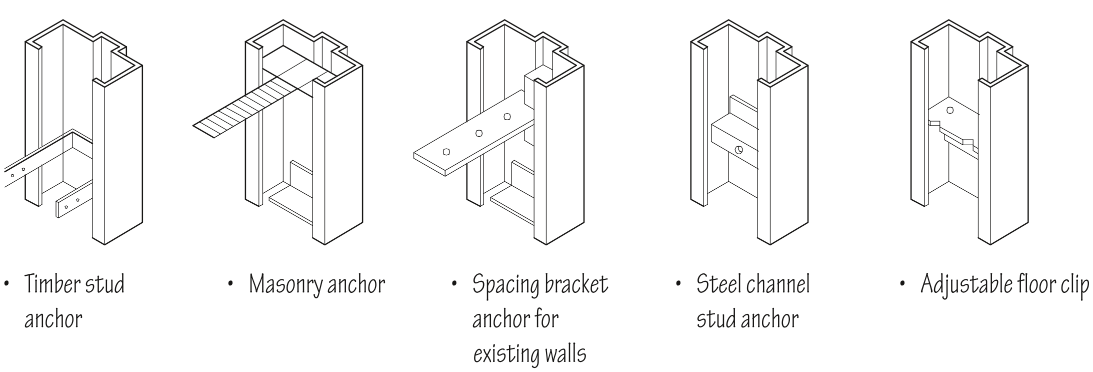
Wrap-Around Installation



Butt Frame Installation

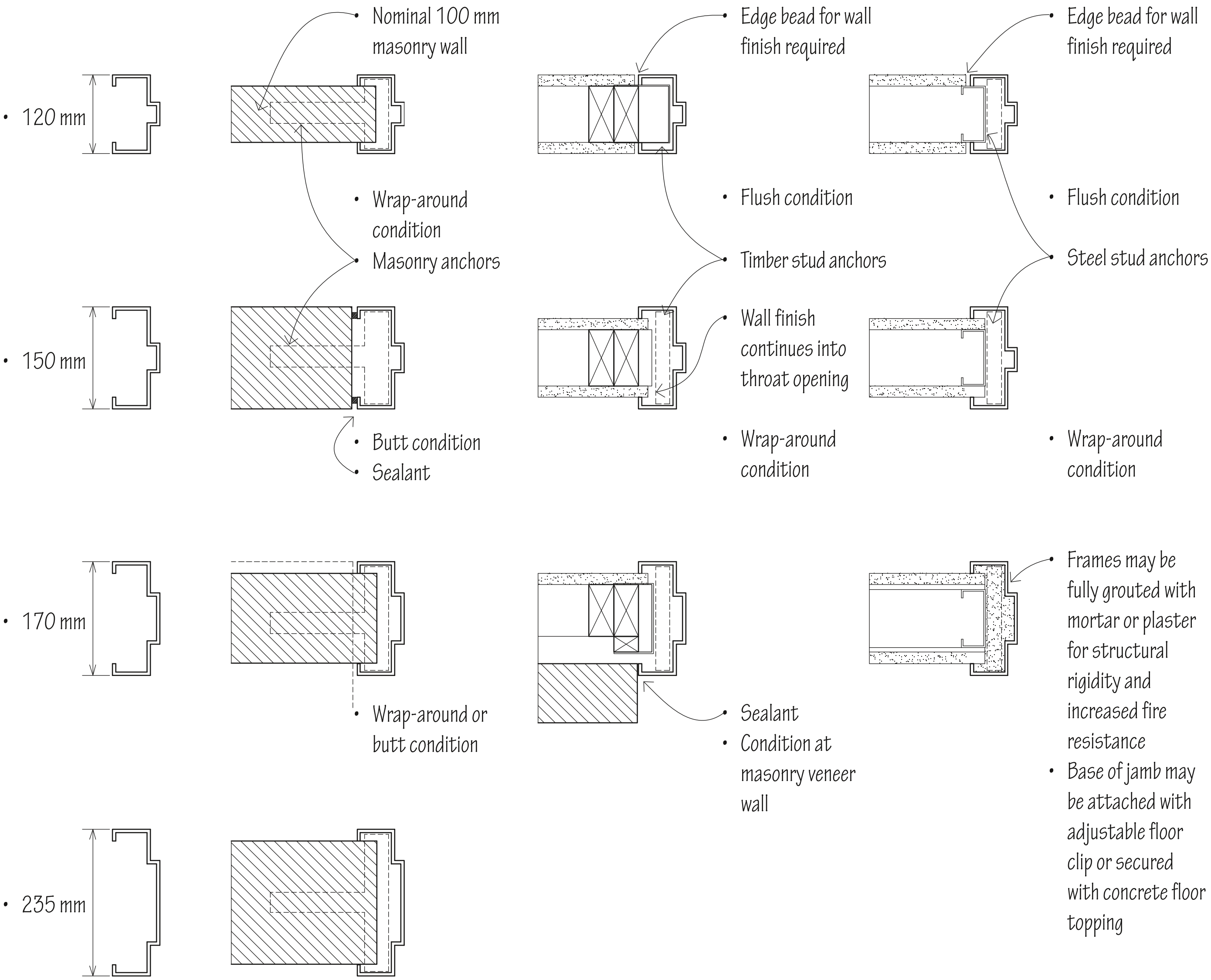


Corner Construction



Door-Frame Anchors

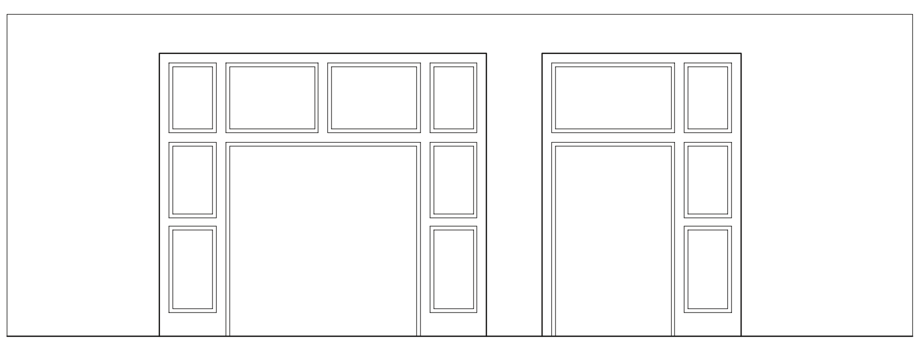
- Minimum of three anchors required per jamb



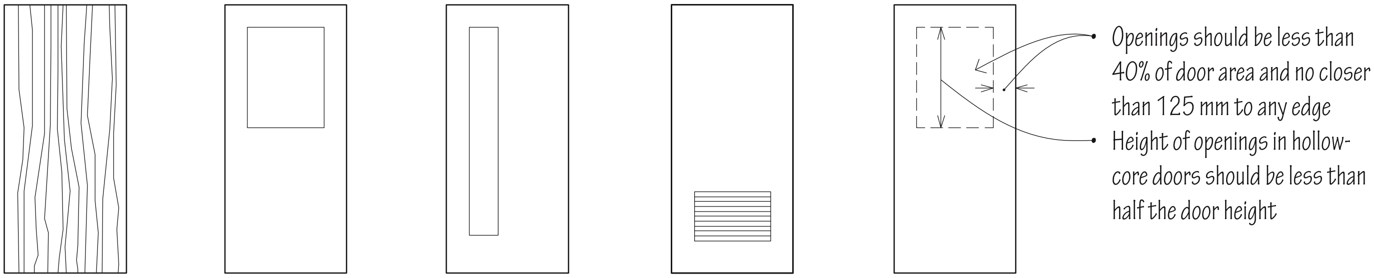
Frame Sizes **Masonry Walls** **Timber Stud Walls** **Steel Stud Walls**

Standard hollow-metal frame components may be utilised to create architectural entrances incorporating a combination of transoms, side lights and borrowed lights:

- Maximum door size: 1200 x 2400 mm
- Minimum jamb depth: 95 mm
- Consult manufacturer for details

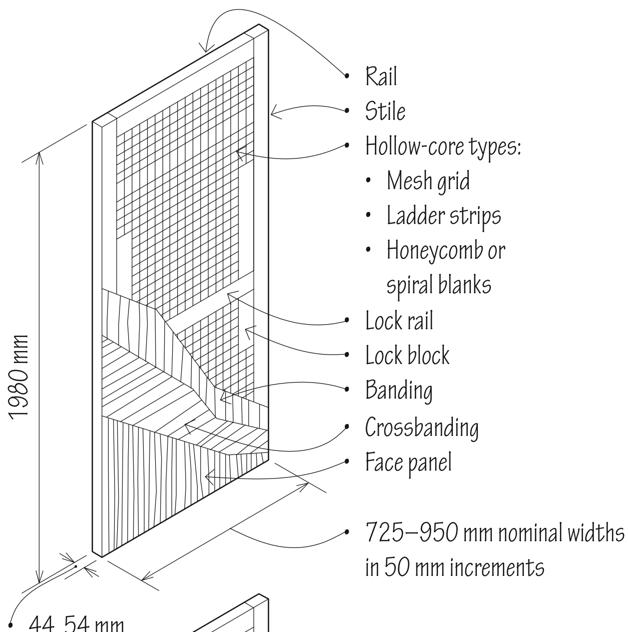


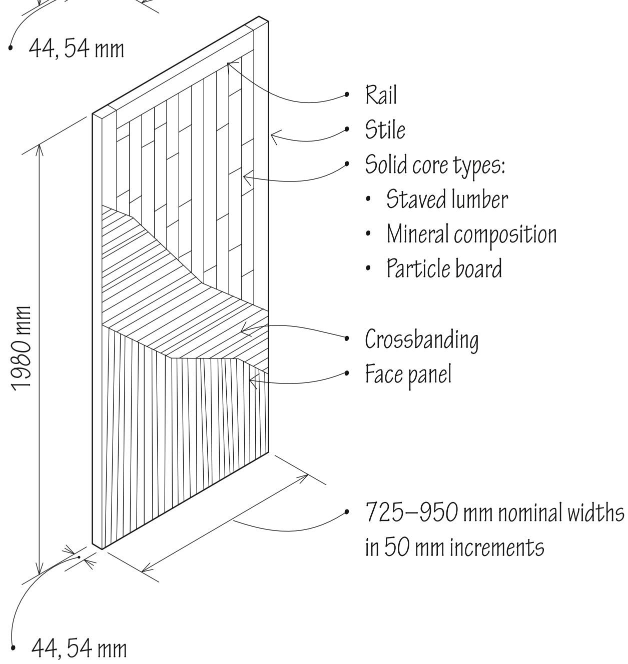
Hollow-Metal Stick Systems



• Flush door
• Flush door with glass inserts
• Flush door with louvred insert

Door Designs





Hollow-Core Doors

Hollow-core doors have a framework of stiles and rails encasing an expanded honeycomb core of corrugated fibreboard or a grid of interlocking horizontal and vertical timber strips. They are lightweight but have little inherent thermal or acoustic insulation value. While intended primarily for interior use, they may be used for exterior doors if bonded with waterproof adhesives.

Solid-Core Doors

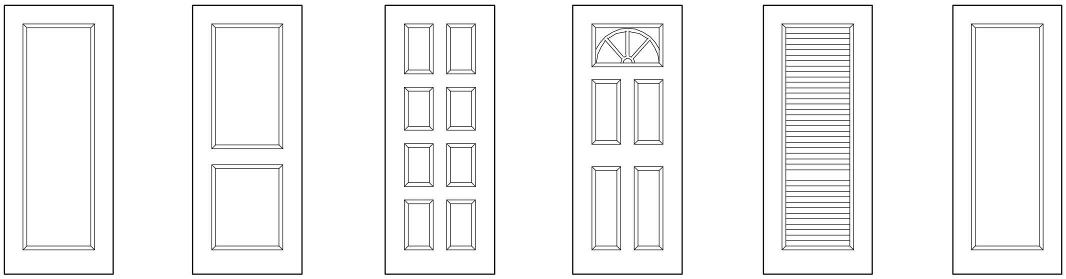
Solid-core doors have a core of bonded timber blocks, particle board or a mineral composition. Of these, the bonded timber core is the most economical and widely used. The mineral composition core is lightest but has low screw-holding strength and cut-outs are difficult. Solid-core doors are used primarily as exterior doors, but they may also be used wherever increased fire resistance, sound insulation or dimensional stability is desired.

Grades and Finishes

- Flush doors can be provided fully or partially finished
- Partially finished doors are primed and ready for a finish to be applied allowing flexibility. Partially finished doors are generally of paint grade requiring a paint finish
- Fully finished doors come pre-finished with a paint or varnish finish applied in factory conditions, ensuring a high-quality finish
- High-pressure plastic laminates may be bonded to the face panels
- Flush doors may also be factory-finished partially with a seal coat or completely including prefitting and premachining for hinges and lock sets

Special Doors

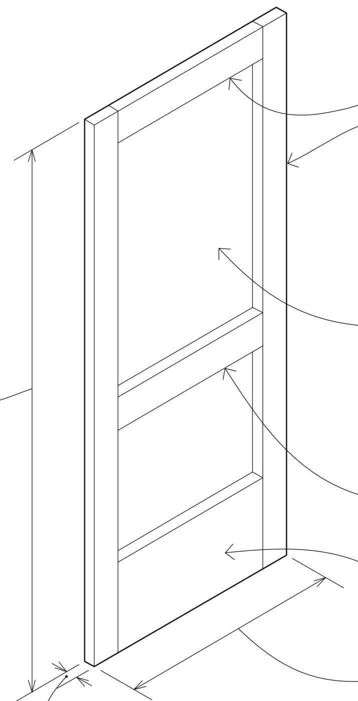
- Fire-rated doors are classified as FD30, FD30S, FD60, FD60S, FD90 or FD90S
- The number refers to the rated integrity of the door in minutes
- 'S' at the end of the classification refers to the inclusion of smoke barrier around the door edge
- Intumescent strips are used around door edges to enhance resistance to the passage of fire



- Panel
- Various panel designs are available
- Panel
- Panel
- Panel with sash
- Louvred
- French door
- French door with divided lights

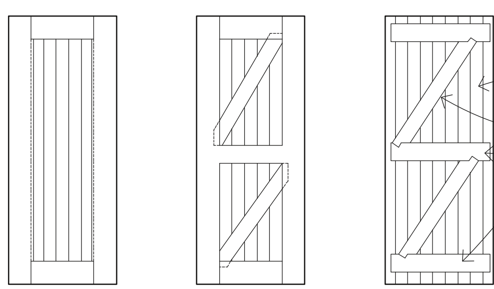
Door Designs

Timber rail-and-stile doors consist of a framework of vertical stiles and horizontal rails that hold solid wood or plywood panels, glass lights or louvres in place. The stiles and rails may be solid softwood or veneered hardwood.



Framed, ledged and braced doors consist of vertical board sheathing nailed at right angles to cross strips or ledgers. Diagonal bracing is nailed between and notched into the ledgers.

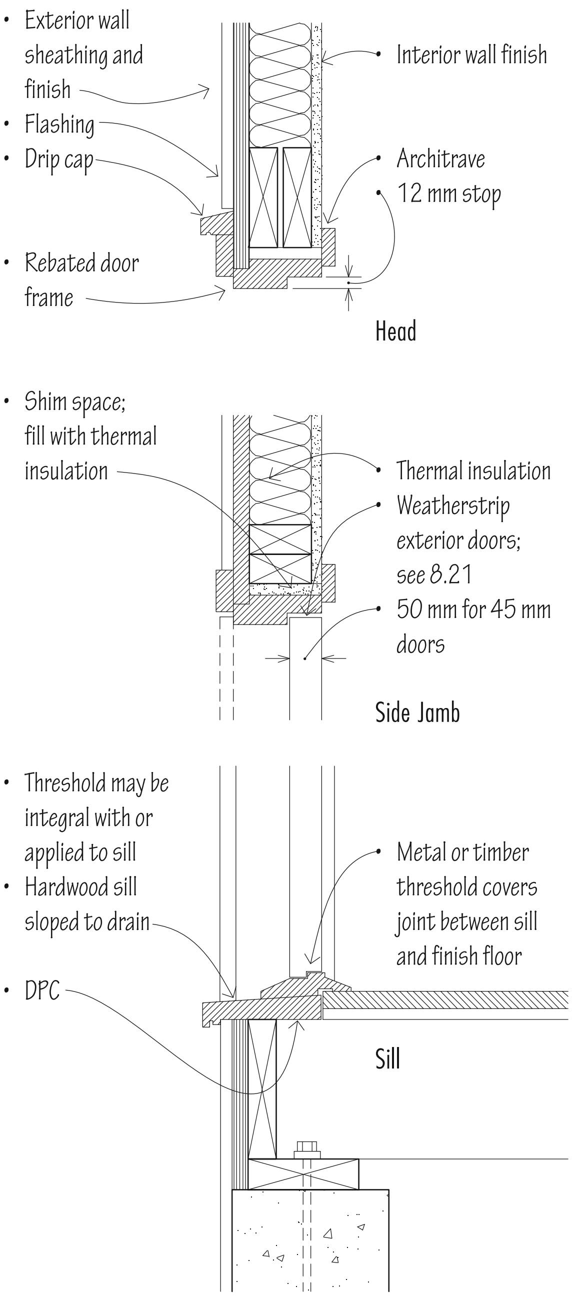
- Used primarily for economy in rough construction or to achieve a specific aesthetic
- Tongue-and-groove sheathing is recommended for weathertightness
- Subject to expansion and contraction with changes in moisture content



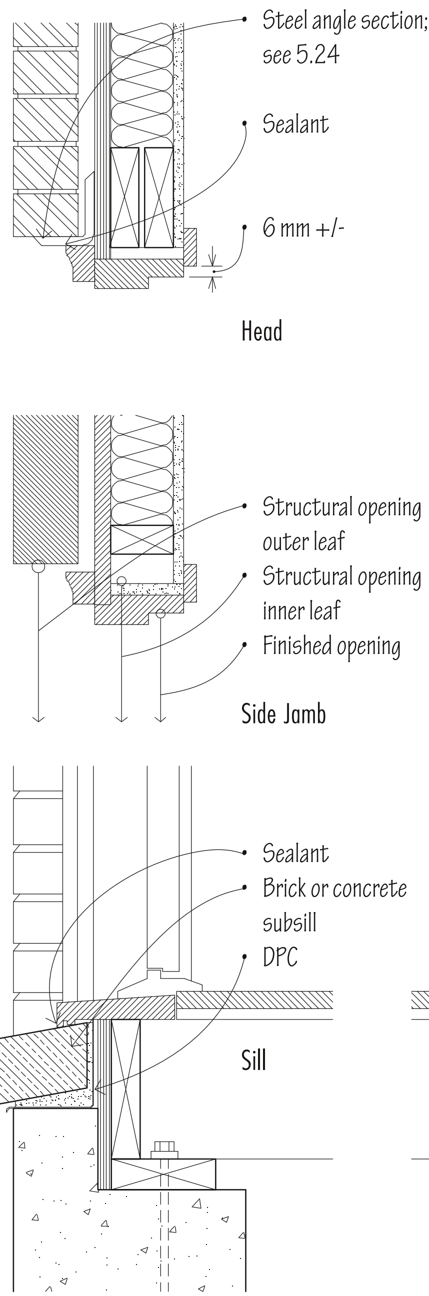
Framed & Sheathed

Framed, Braced & Sheathed

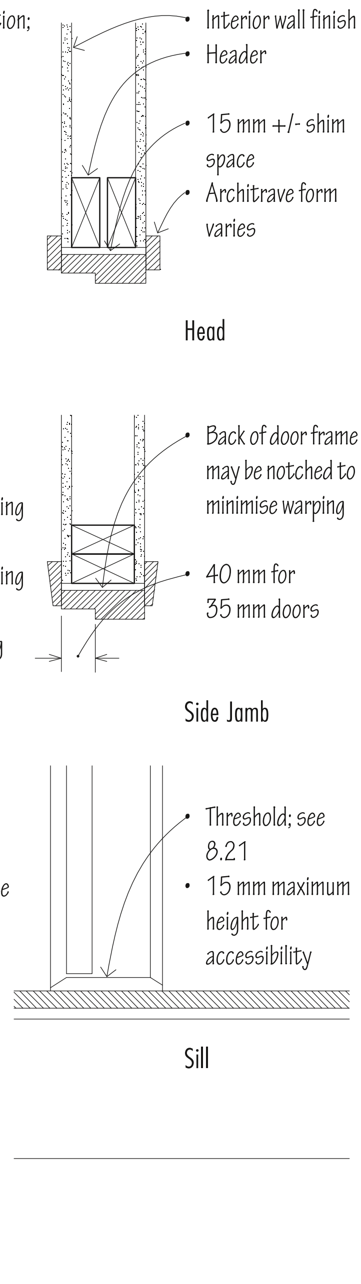
Braced & Sheathed



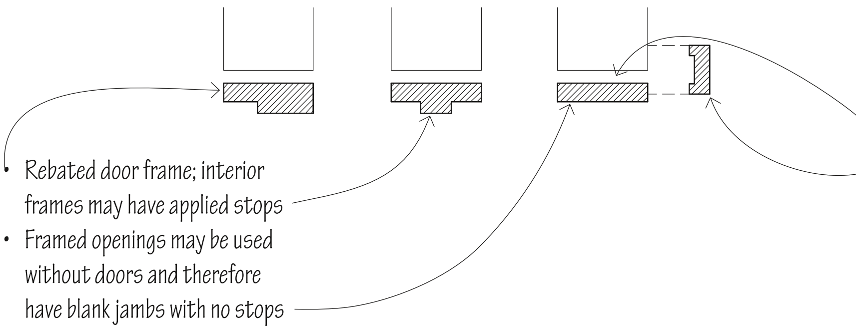
Exterior Door • Stud Wall



Exterior Door • Masonry Veneer Wall

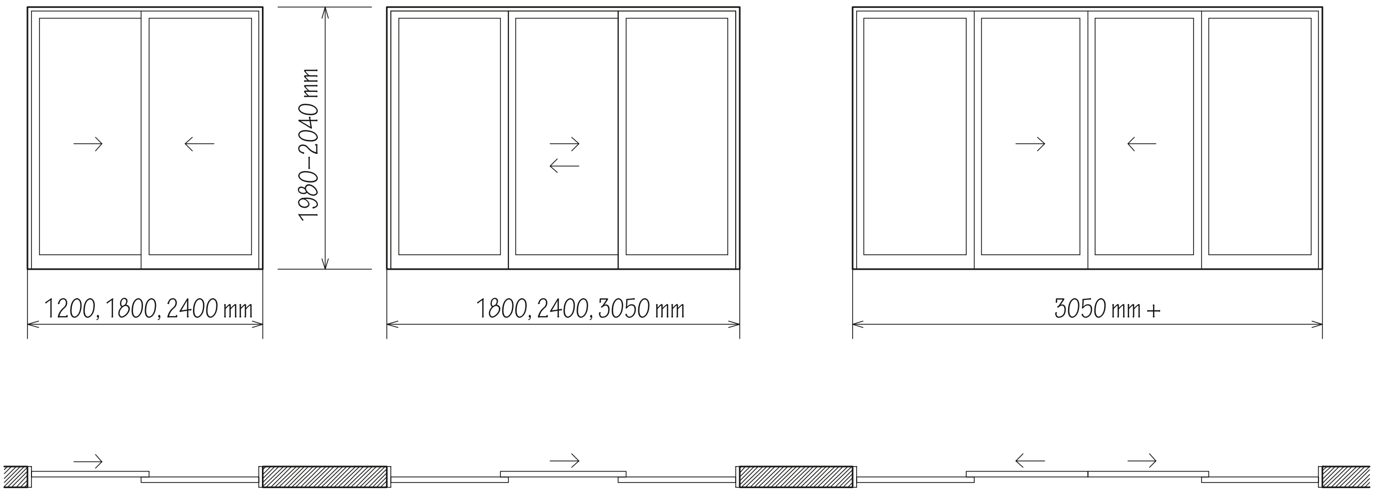


Interior Door • Stud Wall



General Notes

- Most door manufacturers offer doors that are prehung in a door frame; some doors are also available pre-finished and pre-fitted with all necessary hardware and casing trim
- 15 mm shim space allows door frame to be plumbed
- Internal architrave finishes the joint between a door frame and its structural opening
- Head and side jamb conditions are usually similar so that the profile of the casing trim may continue around the doorway



• Dimensions are standard; consult manufacturer for standard sizes, required structural openings, glazing options and installation details
• As a guide, add 25–75 mm to nominal width for structural openings depending on construction methods and ease of adjustment

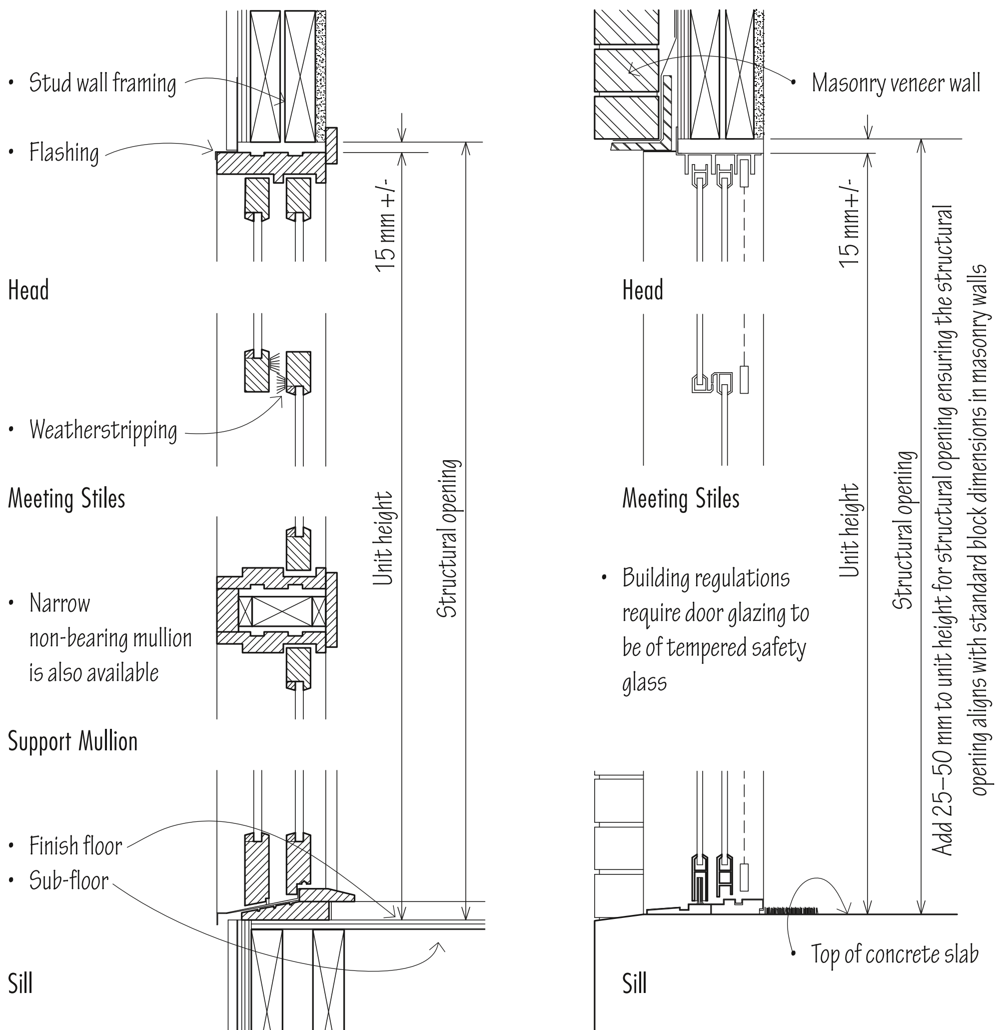
Typical Sizes

Sliding glass doors are available with timber, aluminium or steel frames. Timber frames may be treated with preservative, primed for painting, or clad in aluminium to form a composite door. Metal frames are available in a variety of finishes, with thermal breaks and integral windproof mounting fins.

• Sliding glass doors are manufactured as standard units complete with operating hardware and weatherstripping

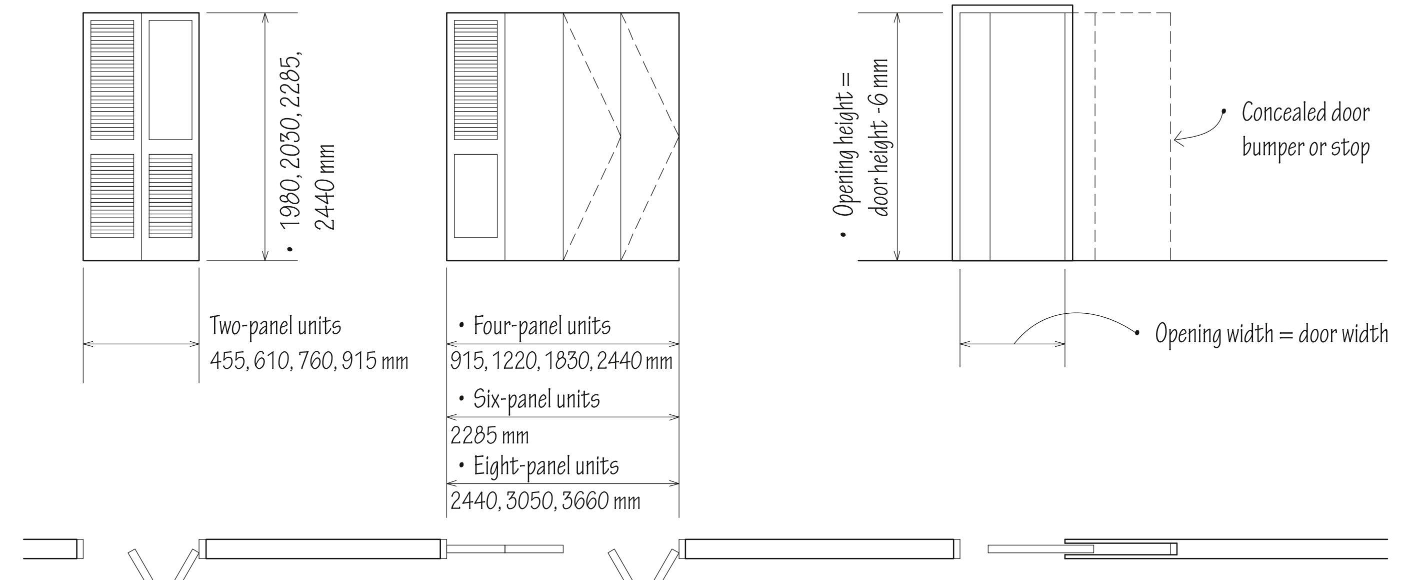
Accessibility Guideline

• Thresholds for exterior residential sliding doors should be no higher than 15 mm



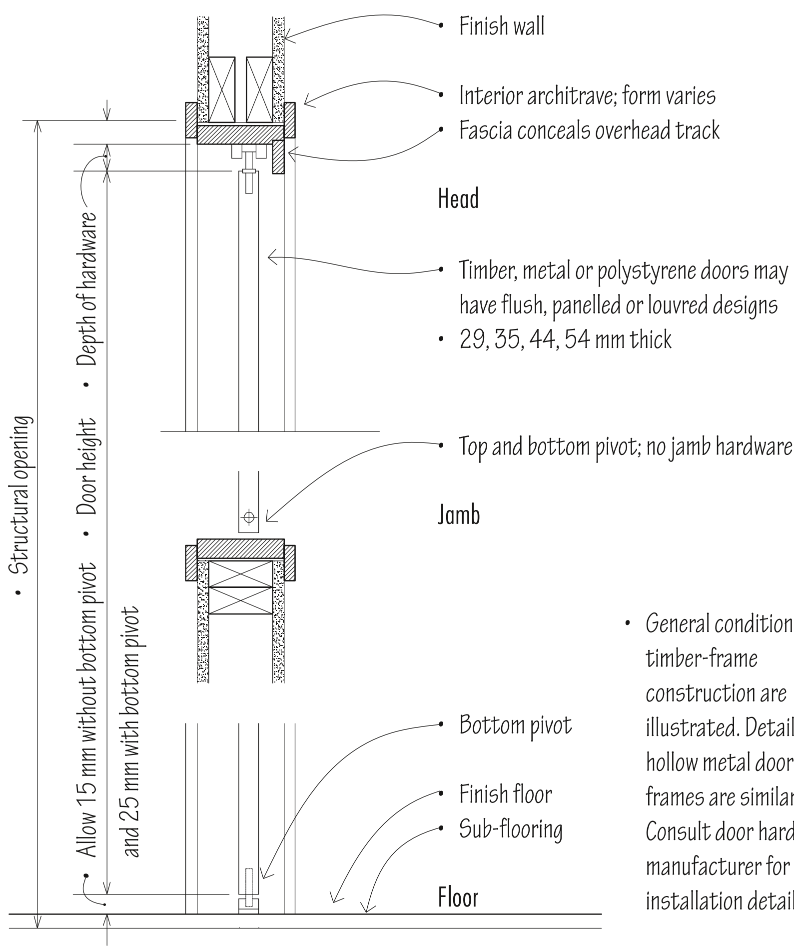
Timber Sliding Door **Metal Sliding Door**

• Hatched sections are normally supplied by door manufacturer
• Thermal insulation and airtightness measures excluded for clarity

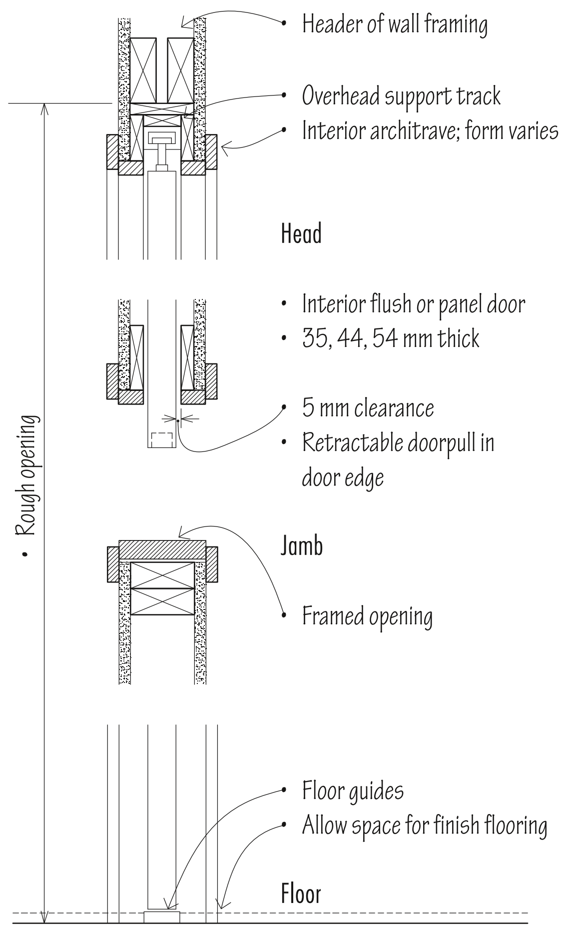


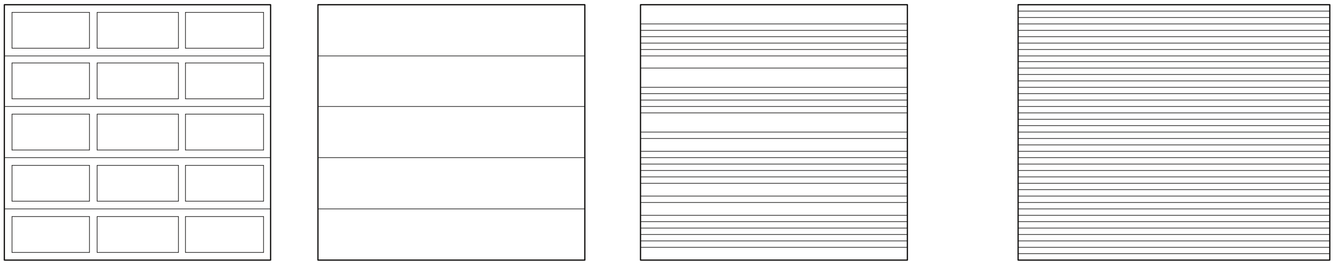
Folding Doors

Pocket Sliding Door



• General conditions for timber-frame construction are illustrated. Details for hollow metal doors and frames are similar. Consult door hardware manufacturer for installation details

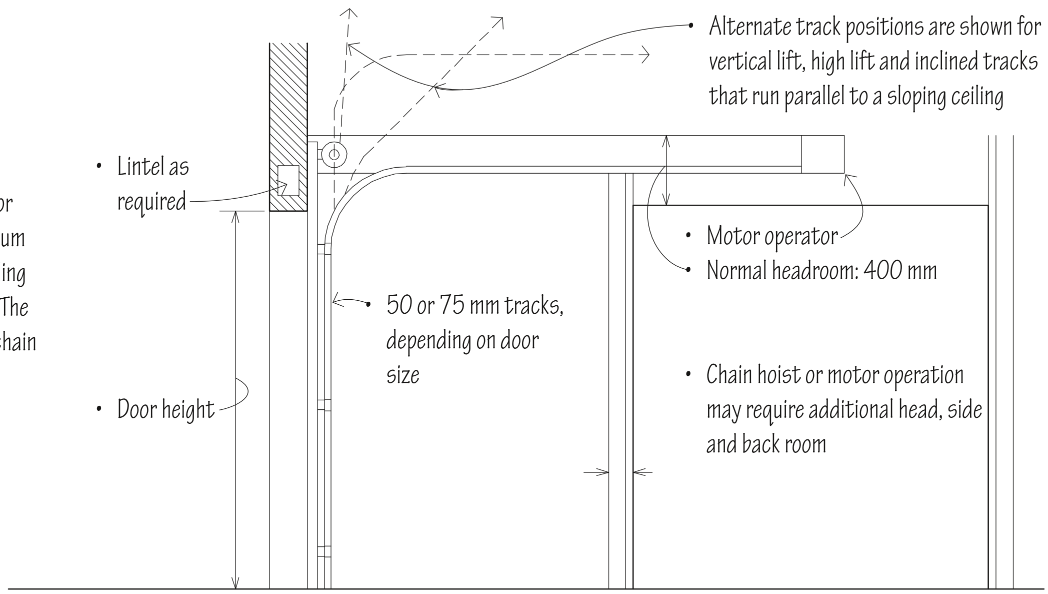




- Timber or aluminium panel-door
- Timber or steel flush doors
- Steel or fibreglass ribbed doors
- Overhead sectional doors are available up to 3000 high and 7500 mm wide
- Steel or aluminium slatted sections
- Roller shutter doors are available up to 10 m high and 8 m wide

Overhead Doors

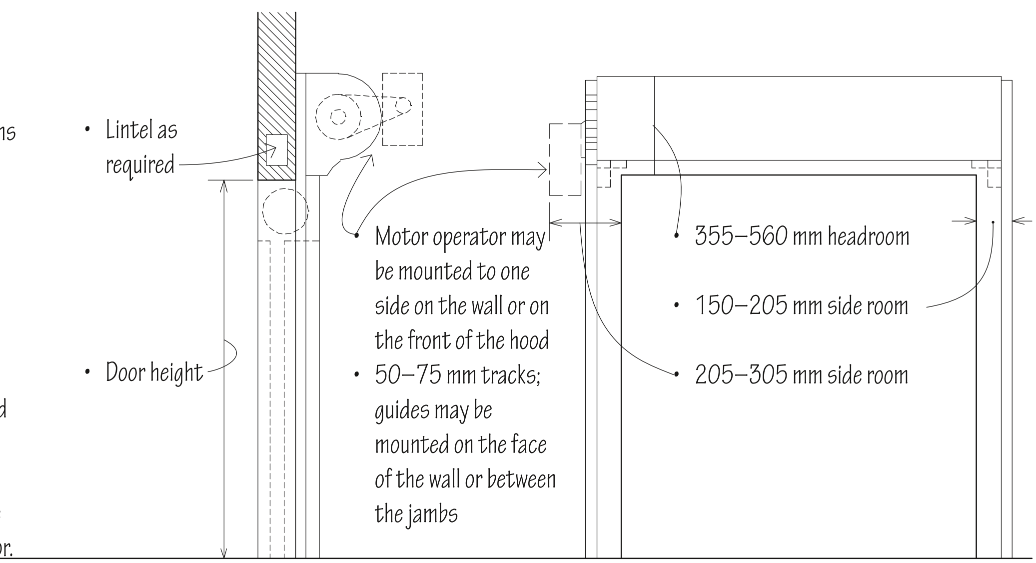
Overhead doors are constructed of one or several sections of timber, steel, aluminium or fibreglass and open by swinging or rolling up to a position above the door opening. The door may be operated manually, or by a chain hoist or electric motor.



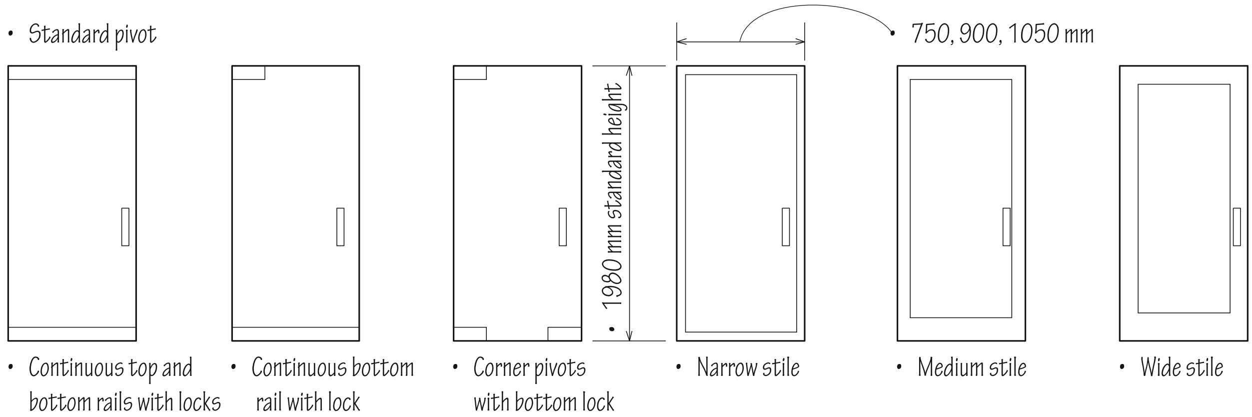
- Both overhead and roller shutter doors are available with vision panels, pass-through sections, thermal insulation and other options. Consult the door manufacturer for available sizes, designs and installation requirements

Roller Shutter Doors

Roller shutter or rolling doors consist of horizontal, interlocking metal slats guided by a track on either side and opened by coiling about an overhead drum at the head of the door opening. The door may be operated by a chain hoist or electric motor.



8.14 GLASS ENTRANCE DOORS



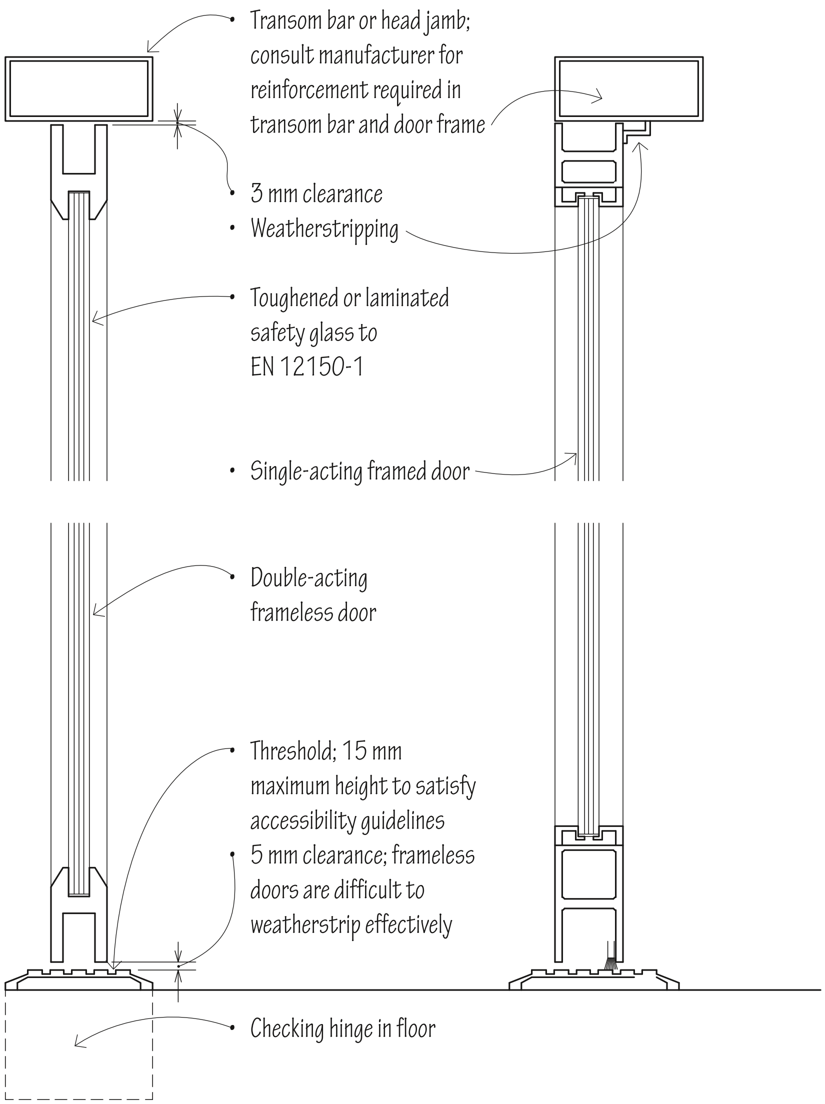
Frameless Doors

Framed Doors

Glass Doors

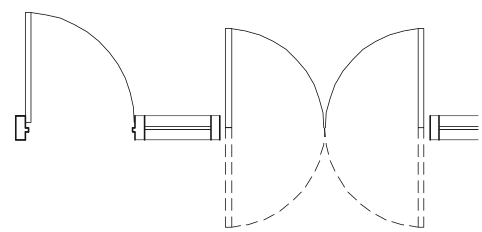
Glass doors are constructed of laminated or tempered glass, with or without rails or stiles, and used primarily as entrance doors.

- Consult the building regulations for requirements when used as an emergency exit door
- Consult manufacturer for sizes, glazing options and frame requirements

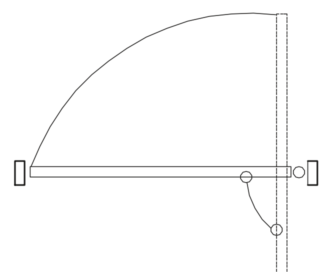


Frameless Door Section

Framed Door Section



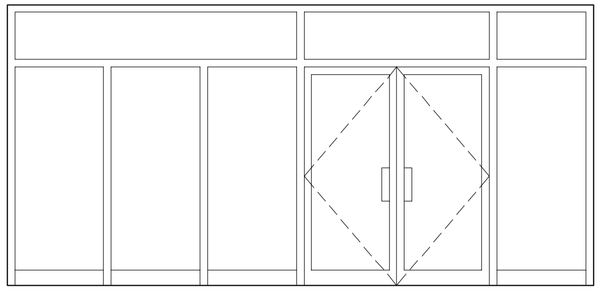
- Door may be offset in frame to swing in one direction only or be centre-hung for double-acting operation

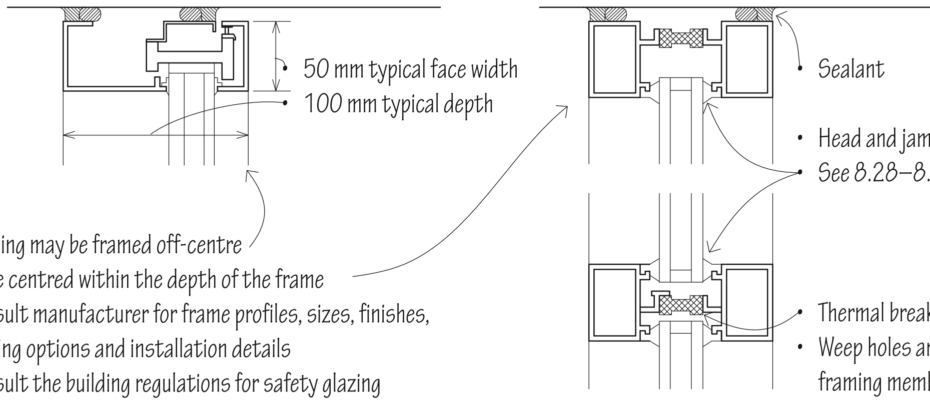


- Pivoted doors are carried on and swing about on a centre or offset pivot, as distinguished from one hung on hinges
- Balanced doors are pivoted doors that are partially counterbalanced for easier opening and closing
- Automatic doors open at the approach of a person or vehicle when activated by a radio transmitter, electric eye or other device

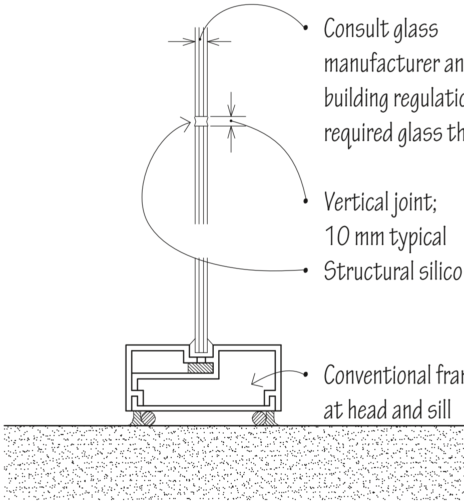
EN 12150-1: 2010. Glass in Building. Thermal Toughened Soda Lime Silicate Safety Glass

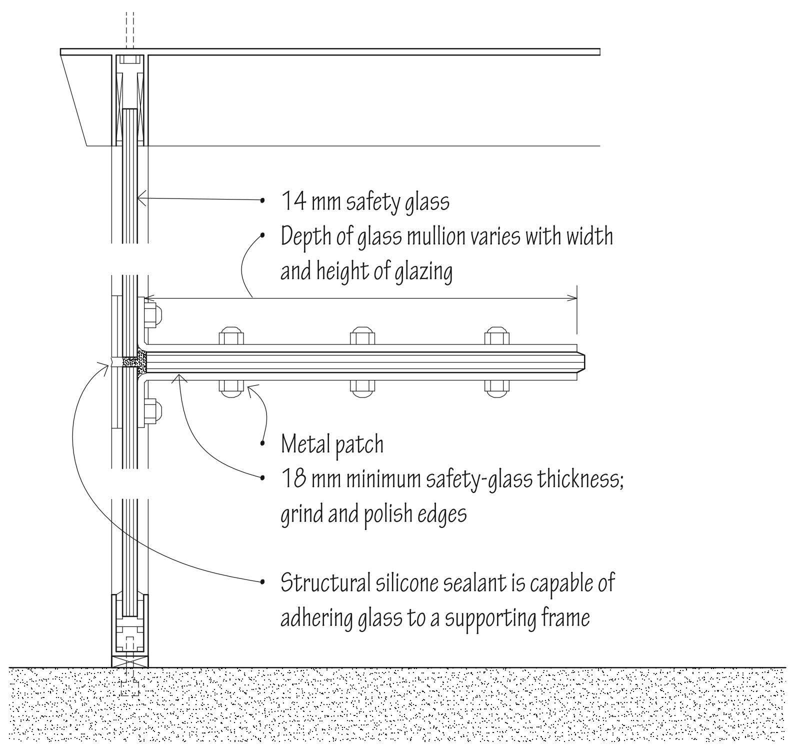
Shopfronts are coordinated systems of extruded metal frames, glass panels, glass entrance doors and hardware fittings. The size and spacing of the mullions are determined by the glass strength and thickness and the wind load on the wall plane.





All-glass wall systems utilise glass mullions and structural silicone sealant to support the glazing. The thickness of the glass mullions is related to the width and height of the glass panels and the wind load on the wall plane. Consult glass manufacturer for sizing and installation requirements.

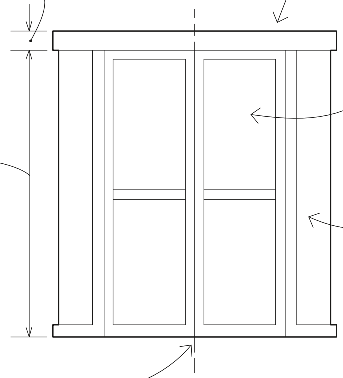




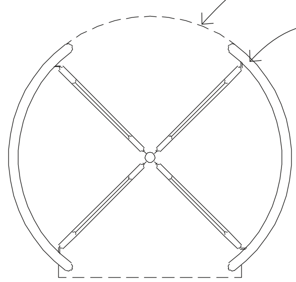
• Butt-joint glazing is a glazing system in which the glass panes or units are supported at the head and sill in a conventional manner, with their vertical edges being joined with a structural silicone sealant without mullions

• Glass mullion system is a glazing system in which sheets of tempered glass are suspended from special clamps, stabilised by perpendicular stiffeners of tempered glass, and joined by a structural silicone sealant and by metal patch plates at corners and edges. See 7.23 for structural glazing

- 50–100 mm
- 2040 and 2300 mm
- Top and bottom pivots



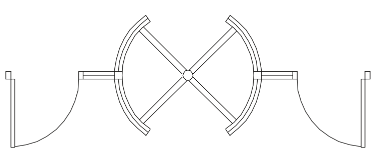
- Soffit includes provision for ceiling lights; may be glazed with safety glass
- Door leaves of safety glass with aluminium, stainless-steel or bronze frames
- Enclosure may be of metal or of safety glass
- Heating and/or cooling source may be integral with or adjacent to enclosure



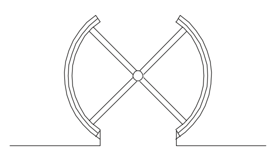
- Line of soffit may be curved or straight
- Weather seal is provided by rubber and felt sweeps along the stiles and top and bottom rails of door leaves

Revolving doors consist of three or four leaves that rotate about a central, vertical pivot within a cylindrically shaped vestibule. Used typically as entrance doors in large commercial and institutional buildings, revolving doors provide a continuous weather seal, eliminate draughts and hold heating and cooling losses to a minimum while accommodating traffic up to 2000 persons per hour.

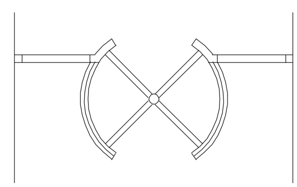
- 1890 mm diameter for general use; 2200 mm or larger diameter for high traffic areas
- An optional speed control automatically aligns doors at quarter points when not in use and turns wings 3/4 of a revolution at walking speed when activated by slight pressure
- Some revolving doors have leaves that automatically fold back in the direction of egress when pressure is applied, providing a legal passageway on both sides of the door pivot
- Some building regulations require adjacent hinged doors for emergency exits



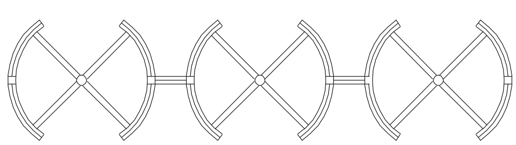
- Enclosure flanked by hinged doors



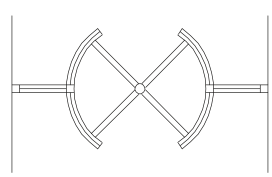
- Enclosure set within a wall plane



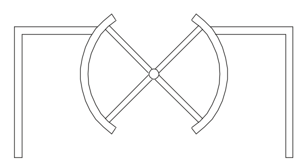
- Enclosure projecting from side lights



- Bank of enclosures with side lights between



- Side lights centred on enclosure



- Enclosure set back within a wall recess

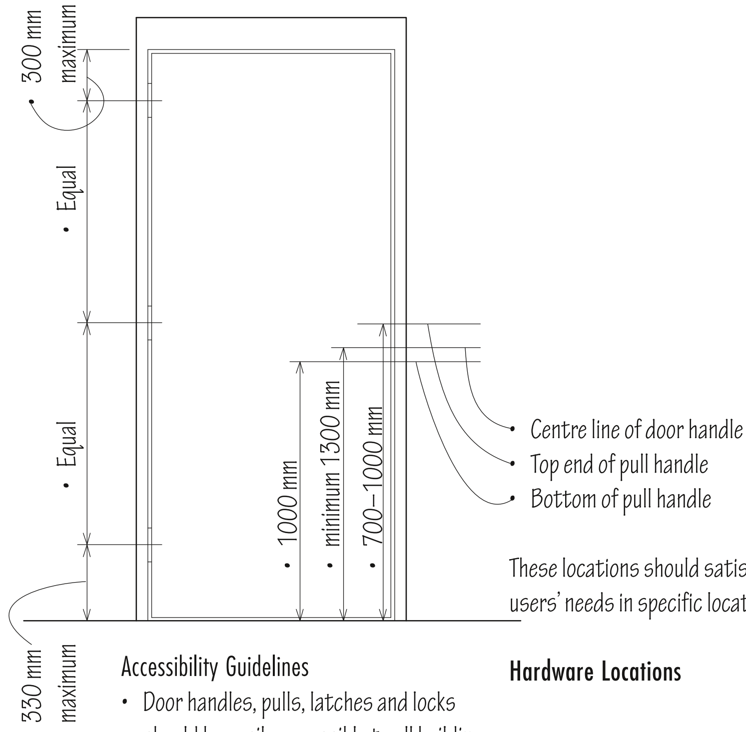
Revolving Door Layouts

Finish door hardware for doors include the following items:

- Lock sets incorporating locks, latches and bolts, a cylinder and stop works, and operating trim
- Hinges
- Closers
- Panic hardware
- Push and pull bars and plates
- Kick plates
- Door stops, holders and bumpers
- Thresholds
- Weatherstripping
- Door tracks and guides

Hardware selection factors:

- Function and ease of operation
- Recessed or surface-mounted installation
- Material, finish, texture and colour
- Durability in terms of anticipated frequency of use and possible exposure to weather or corrosive conditions



These locations should satisfy the users' needs in specific locations.

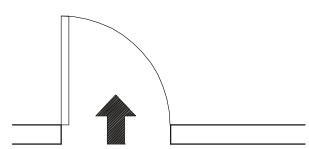
Hardware Locations

Accessibility Guidelines

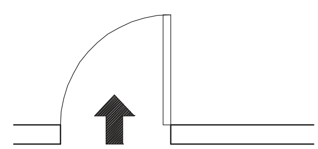
- Door handles, pulls, latches and locks should be easily accessible to all building users. Consult local building regulations for specific requirements
- Hardware should be mounted within the reach ranges specified in A.03

Door Hand Conventions

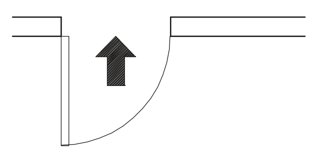
Door hand conventions are used in specifying door hardware such as lock sets and closers. The terms right and left assume a view from the exterior of the building or room to which the doorway leads.



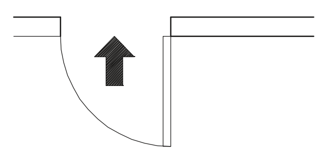
- Left hand (LH)
- Door opens inward; hinges on left



- Right hand (RH)
- Door opens inward; hinges on right

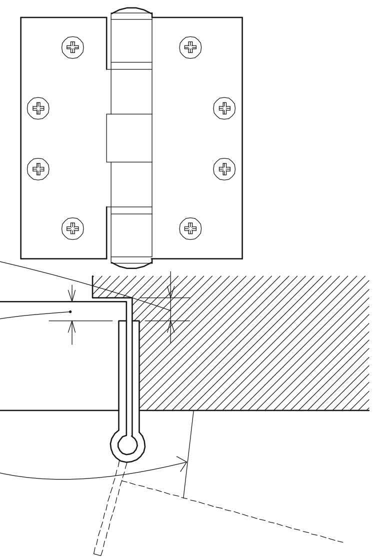


- Left hand reverse (LHR)
- Door opens outward; hinges on left



- Right hand reverse (RHR)
- Door opens outward; hinges on right

- The pin in the knuckle may be removable (loose) so that a door can be unhung by separating the two leaves or fixed (non-rising). Self-locking pins which cannot be removed when the door is closed are also available for security



- 15 mm for doors up to 44 mm thick
- 12 mm for doors up to 44 mm thick
- Check clearance required for surrounding trim

Hinge Size and Classification

- Hinges are available in a range of sizes and are specified depending on door size, mass and clearance required
- Fire-rated doors require at least three hinges

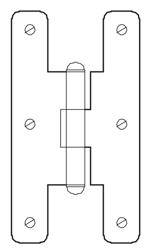
- EN 1935 sets out an eight-digit code for the classification of door furniture:
  - Category of use (light to severe)
  - Durability
  - Test door mass
  - Suitability for fire/smoke door usage
  - Safety
  - Corrosion resistance
  - Security
  - Hinge grade

Butt Hinges

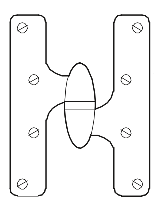
Butt hinges are composed of two plates or leaves joined by a pin and secured to the abutting surfaces of timber and hollow metal doors and door jambs.

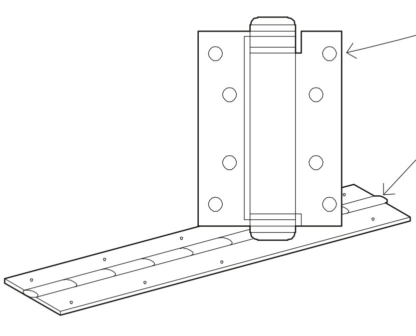
- Full-mortice hinges have both leaves fully morticed into the abutting surfaces of a door and door jamb so that only the knuckle is visible when the door is closed
- Template hinges are mortice hinges manufactured to fit the recess and match the arrangement of holes of hollow metal doors and frames; non-template hinges are used for timber doors
- Half-mortice hinges have one leaf morticed into the edge of a door and the other surface-mounted to the door frame
- Half-surface hinges have one leaf morticed into a door frame and the other surface-mounted to the face of the door
- Full-surface hinges have two leaves surface-mounted to the adjacent faces of a door and door frame

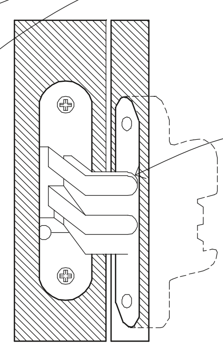
Special-Purpose Hinges



- Parliament hinges have T-shaped leaves and a protruding knuckle so that a door can stand away from the wall when fully opened
- Olive knuckle hinges have a single, pivoting joint and an oval-shaped knuckle
- Spring hinges contain coiled springs in their barrels for closing a door automatically
- Double-acting hinges permit a door to swing in either direction, and are usually fitted with springs to bring the door to a closed position after opening
- Piano hinges are long, narrow hinges that run the full length of the two surfaces to which their leaves are joined
- Invisible hinges consist of a number of flat plates rotating about a central pin, with shoulders morticed into the door edge and door frame so as to be concealed when closed
- Floor hinges are used with a mortice pivot at door head to enable a door to swing in either direction; may be provided with a closer mechanism

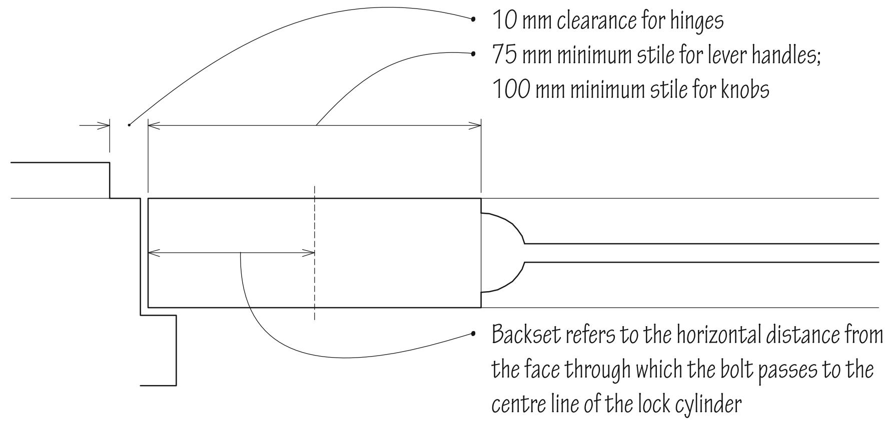


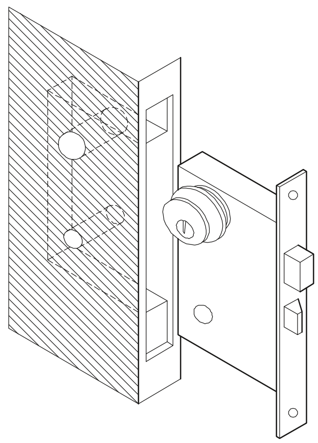




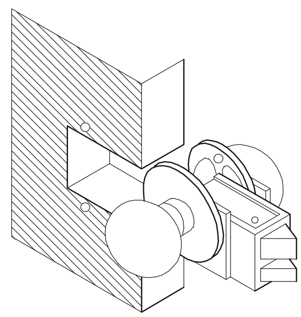
EN 1935:2002. Door Hardware – Single Axis Hinges – Requirements and Test Methods

Lock sets are manufactured assemblies of parts making up a complete locking system, including knobs, plates and a locking mechanism. Described below are the major types of lock sets: mortice locks, unit and integral locks, and cylinder locks. Consult hardware manufacturer for lock-set functions, installation requirements, trim designs, dimensions and finishes.

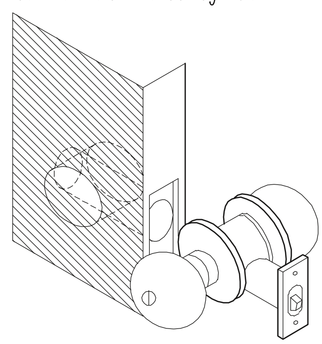




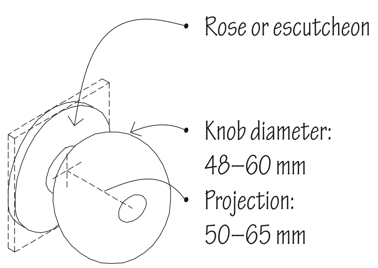
Mortice Lock
- Mortice lock is housed within a mortice cut into a door edge so that the lock mechanism is covered on both sides
- Lock is concealed except for a faceplate at the door edge, knobs or levers, a cylinder and operating trim



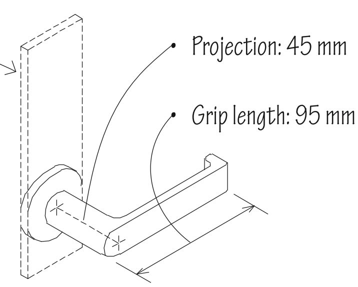
Unit and Integral Locks
- Unit lock is housed within a rectangular notch cut into the edge of a door
- Integral lock fits into a mortice cut into the edge of a door
- Unit and integral locks combine the security advantages of a mortice lock with the economy of a cylinder lock



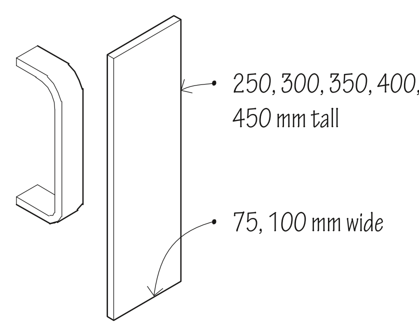
Cylinder Lock
- Cylinder lock is housed within two holes bored at right angles to each other, one through the lock stile of a door and the other in the door edge
- Cylinder locks are relatively inexpensive and easy to install



Door Knobs
- Rose refers to a round or square ornamental plate surrounding the shaft of a door knob at the face of a door
- Escutcheon is a protective or ornamental plate that may be substituted for a rose
- Door knobs can be difficult to grasp for those with arthritis and limited manual dexterity

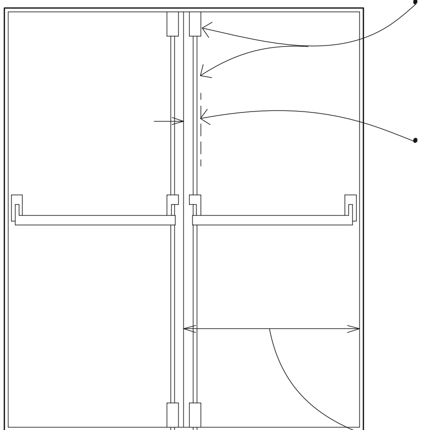


Lever Handles
- Lever-operated mechanisms, push-type mechanisms and U-shaped handles are generally easier for people with disabilities to grasp

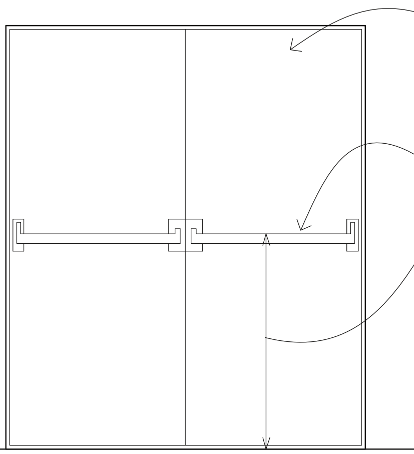


Pull Handles and Push Plates

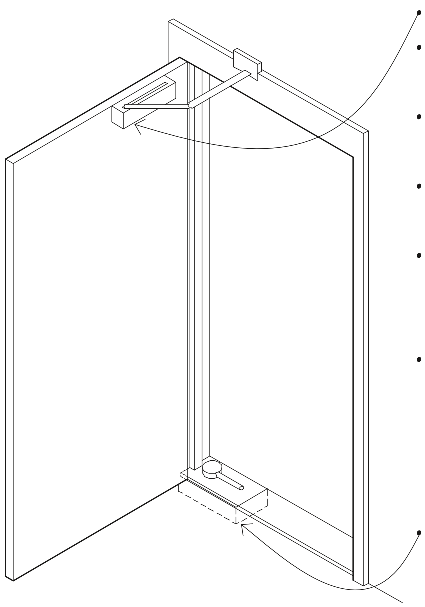
Accessibility Guidelines (see BS 8300)
- Door handles, pulls, latches and locks should be easy to grasp with one hand without tight grasping, pinching or twisting of the wrist
- The force required for pushing open or pulling open a door should be no greater than 30 N for the first 30° of opening



Exposed Vertical Rod



Concealed Lateral Latching



Panic Hardware

Panic hardware is a door-latching assembly that disengages when pressure is applied on a horizontal bar that spans the interior of an emergency exit door at waist height. The push bar should extend across at least one-half the width of the door leaf on which it is installed.

- Building regulations require the use of panic hardware on emergency egress doors in certain building occupancies. Consult the applicable building regulations for details
- The width, direction of swing and location of required exit doors are also regulated by the building regulations according to the use and occupancy load of a building

EN 1125 classifies panic and emergency-exit devices by a nine-digit code similar to that of door hinges (see 8.18). Emergency exits are generally operated by a push or touch bar and are alarmed along and linked into the building's fire alarm.

Accessibility Guideline (BS 8300)

- The force required for pushing open or pulling open a door should be no greater than 30 N for the first 30º of opening

Door Closers

Door closers are hydraulic or pneumatic devices that automatically close doors quickly but quietly. They help reduce the shock a large, heavy or heavily used door would otherwise transmit upon closing to its frame, hardware and surrounding wall.

- Building regulations require doors along escape routes or protected areas to be fitted with automatic door closers to ensure integrity; see 2.07

EN 1125: 2008. Building Hardware. Panic Exit Devices Operated by a Horizontal Bar, For Use on Escape Routes. Requirements and Test Methods

Weatherstripping

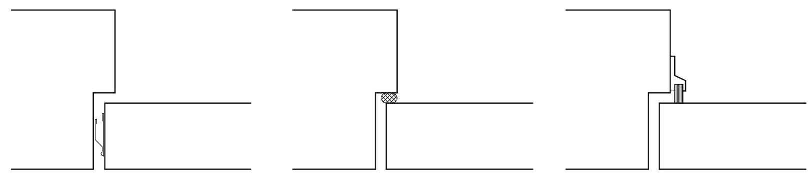
Weatherstripping consists of metal, felt, vinyl, or foam rubber strips, placed between a door or window sash and its frame, to provide a seal against wind-blown rain and reduce the infiltration of air and dust.

- Weatherstripping may be fastened to the edge or face of a door, or to the door frame and threshold
- The weatherstripping material should be durable under extended use, non-corrosive and replaceable

Basic types of weatherstripping include:

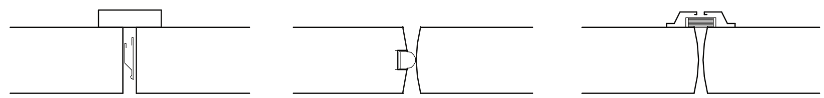
- Spring-tensioned strip of aluminium, bronze, or stainless or galvanised steel
- Vinyl or neoprene gaskets
- Foam plastic or rubber strips
- Woven pile strips

- Weatherstripping is often supplied and installed by the manufacturer of sliding glass doors, glass entrance doors, revolving doors and overhead doors



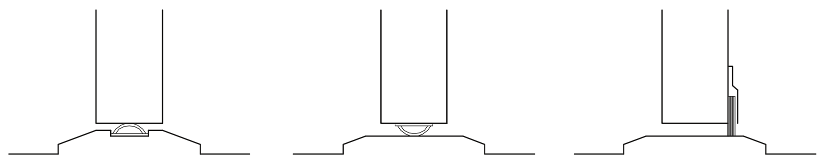
- Metal spring strip
- Foam rubber or felt
- Vinyl or rubber

Weatherstripping Door Jambs

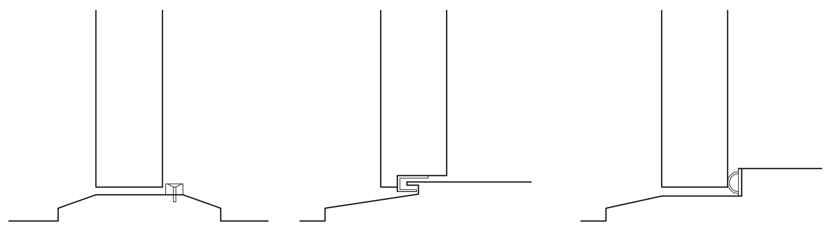


- Metal spring strip
- Vinyl gasket
- Vinyl gaskets

Weatherstripping Meeting Stiles



- Vinyl gasket
- Vinyl gasket
- Applied sweep



- Bumper strip
- Interlocking J-hook
- Vinyl insert

Weatherstripping Door Thresholds

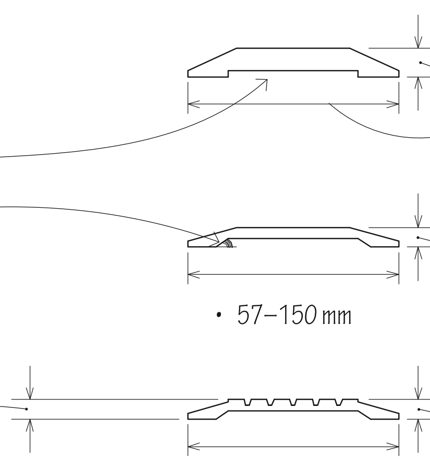
Thresholds

Thresholds cover the joints between two flooring materials at doorways and serve as a weather barrier at exterior sills.

- Thresholds usually have recessed undersides to fit snugly against the flooring or sill
- When installed at exterior sills, joint sealant is used for a tight seal
- Metal thresholds may be cast or covered with abrasive material to provide a non-slip surface

Accessibility Guideline (see BS 8300)

- Thresholds should be no higher than 15 mm with bevelled edges



- Wood: hardwood grade for maximum wear
- Width and height varies

- Plain brass, bronze or aluminium
- 57–150 mm
- 6, 8, 12, 15 mm

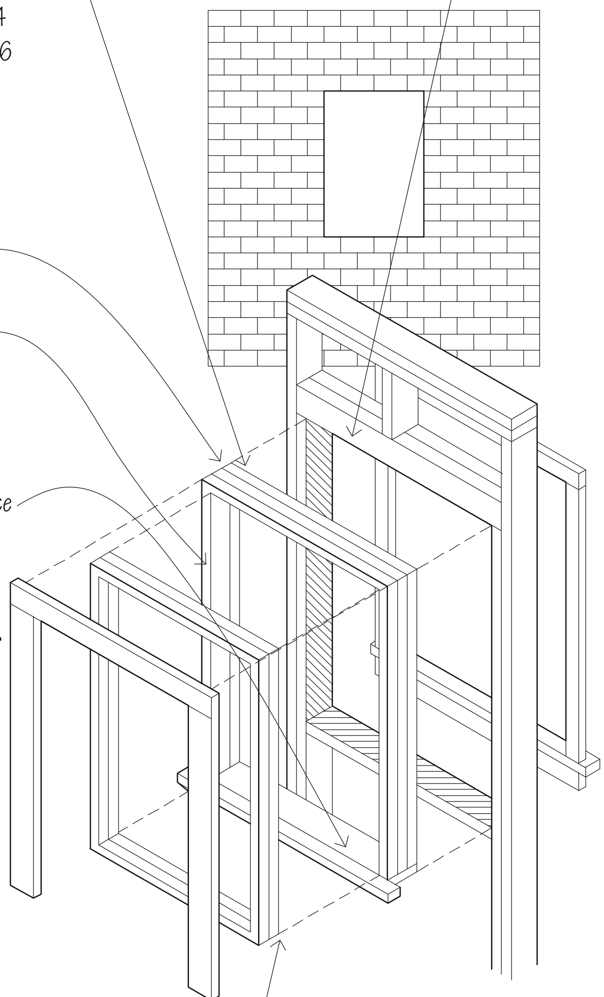
- Fluted steel, aluminium or bronze
- 75–180 mm
- 6, 8, 12, 15 mm

8.22 WINDOW ELEMENTS

Window Frame
- Metal window frames; see 8.24
- Timber window frames; see 8.26

- Head is the uppermost member of a window frame
- Jamb is either of the two side members of a window frame

- Sill is the horizontal member beneath a door or window opening, having an upper surface sloped to shed rainwater
- Subsill is an additional sill fitted to a window frame to cause rainwater to drip further away from a wall surface

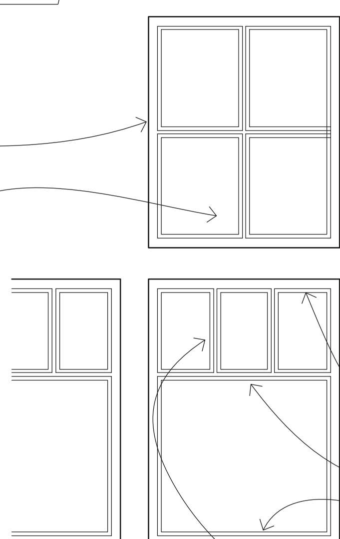


Structural Opening
- Consult window manufacturer for required structural opening. Space is required at the top, sides and bottom for levelling and shimming of the window unit while ensuring weather- and air-tightness can be achieved

Building Regulations Requirements

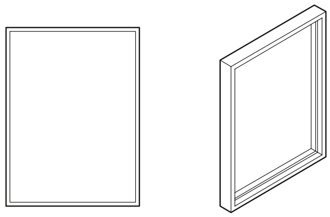
In selecting a window unit, review the building regulation requirements for:
- Natural light and ventilation of habitable spaces
- Thermal insulation value of the window assembly
- Structural resistance to wind loads
- Clear opening of any operable window that serves as an emergency exit; such windows are typically required to have a clear unobstructed opening area of minimum 0.33 m^2 in area and have a minimum clear width of 450 mm, a minimum clear height of 450 mm, and the bottom of the openable area should be no more than 1100 mm above the finished floor level (see Part M of the UK Building Regulations, Approved Documents)
- Safety glazing is required in any glazed window element within 800 mm of finished floor level and within 1500 mm of finished floor level in a door
- Type and size of glazing allowable in fire-rated walls and corridors

Sash and Glazing
- Sash refers to the fixed or movable framework of a window in which panes of glass are set. Its section profile varies with material, manufacturer and type of operation
- Pane is one of the divisions of a window, consisting of a single unit of glass set in a frame
- Glazing refers to the panes or sheets of glass set in the sashes of a window. Single glazing offers little resistance to heat flow. Double glazing is required to comply with building regulation U-values; using triple glazing is an option if better U-values are required; see 8.30
- Just as important as the thermal performance rating of a window is its weathertightness. Operating sash should be weather-stripped against wind-blown rain and air infiltration. The joint between the window frame and the surrounding wall should be sealed and have a windbreak built into the detail. See 7.43 for airtightness details and window openings



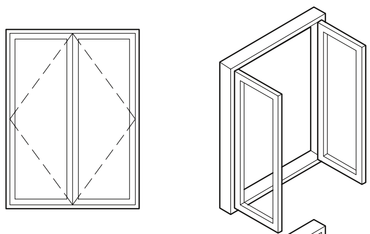
Accessibility Guidelines (see BS 8300)
- Windows that require operation by occupants in accessible spaces should have adequate clear floor space for manoeuvring a wheelchair, be within reach, and be operable with one hand without requiring tight grasping, pinching or twisting of the wrist

- Rails are the horizontal members framing a window sash
- Top rail
- Transoms are the horizontal members separating glazing
- Bottom rail
- Mullion is a vertical member separating a series of windows or doorways



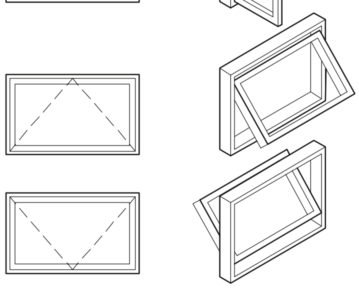
Fixed • 0% ventilation

- Fixed windows consist of a frame and stationary sash
- When used in conjunction with operable window units, the thickness of the fixed sash should approximate the cross-sectional dimension of the operating sashes



Side Hung • 100% ventilation

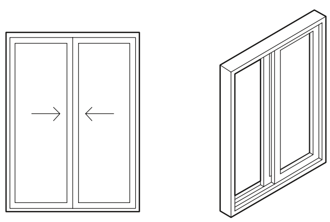
- Side-hung or casement windows have operating sashes that are side-hinged and usually swing outward
- When open, the sash is able to direct ventilation
- The inner end of the sash may slide along a track on the sill or jamb as the sash swings outward
- A pair of sashes may close on a mullion or have a floating astragal to close on each other



Top or Bottom Hung • 100% ventilation

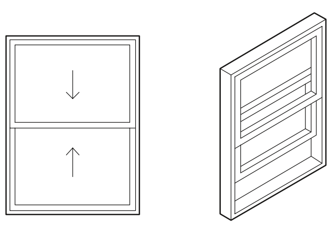
- Top-hung windows have operating sashes that swing outward on hinges attached to the top of their frames
- Bottom-hung windows have operating sashes that swing inward on hinges attached to the bottom of their frames
- When open, the sash is able to direct ventilation
- The sashes may be stacked vertically with sashes closing on each other or on meeting stiles

LEED EQ Credit 2: Increased Ventilation
LEED EQ Credit 8: Daylight & Views
BREEAM HEA 01: Visual Comfort



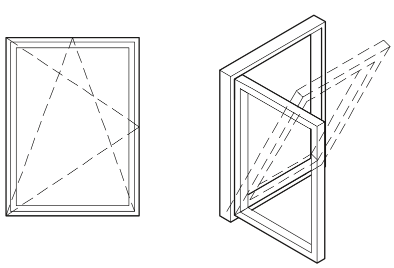
Sliding • 50% ventilation

- A sliding window has two or more sashes, of which at least one slides along horizontal grooves or tracks



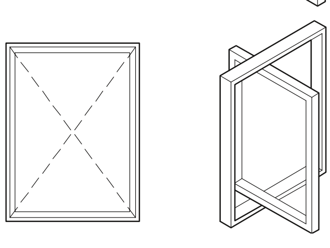
Sliding Sash • 50% ventilation

- Sliding sash windows, traditionally used in Georgian or Victorian buildings, have two vertically sliding sashes, each in separate grooves or tracks, closing different parts of the window
- The sashes are held in the desired position by means of counterweights, pre-tensioned springs or friction



Tilt & Turn • 100% ventilation

- Tilt and turn windows feature a locking mechanism that allows them to be operated like an inward-opening bottom-hung window or side-hung casement (inward opening)
- Tilt and turn windows offer the advantage of being able to be cleaned from inside the building



Pivoting • 100% ventilation

- Pivoting windows have sashes that rotate 90° or 180° about a vertical or horizontal axis at or near their centres

- Aluminium window frames may have equal or unequal legs, depending on the nature of the wall construction
- The fin created by unequal legs can serve as a windbreak for the joint between the window unit and the wall construction. The fin may also be used for securing the frame to the supporting structure
- Sealant is required to weatherproof joints between the window frame and the wall construction

- Head, jamb and sill sections are usually similar in profile

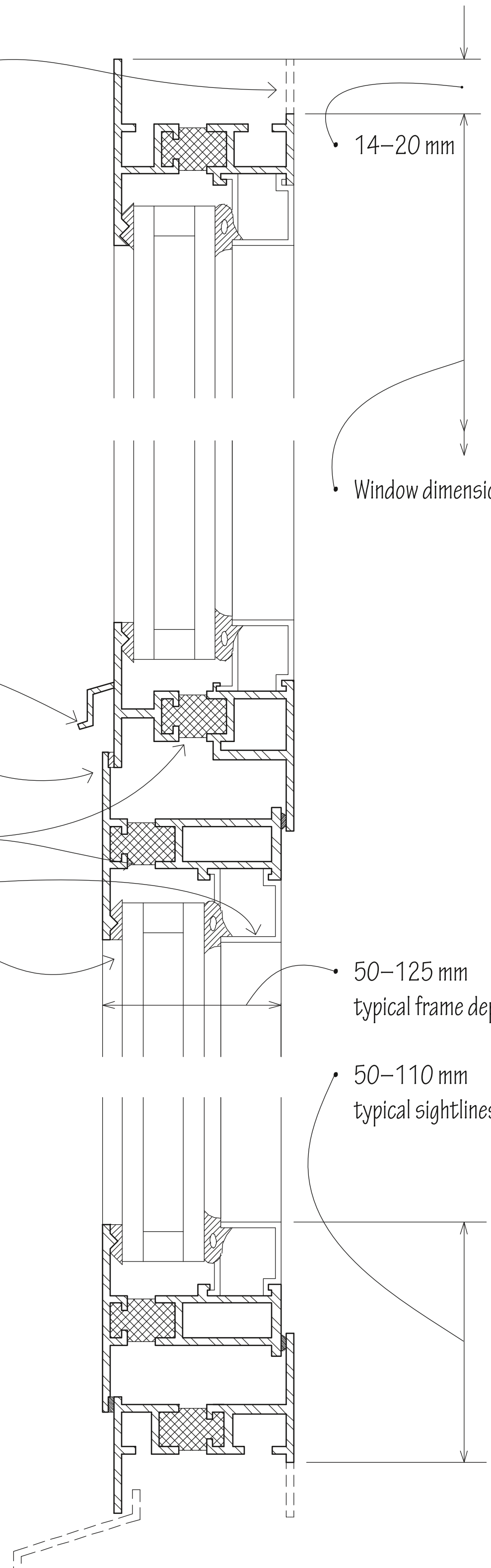
- Drips are required for horizontal members at the heads of ventilating sashes that are flush with the exterior face of the wall

- Weatherstripping is set into integral grooves in the frame and sash sections

- Thermal breaks

- Snap-in glazing bead
- See 8.28–8.29 for glazing systems

- Because aluminium is susceptible to galvanic action, anchoring materials and flashing should be aluminium or a material compatible with aluminium, such as stainless steel or galvanised steel. Dissimilar metals, such as copper, should be insulated from direct contact with the aluminium by a waterproof, non-conductive material, such as neoprene or coated felt. For more information on galvanic action, see 12.09
- Concealed aluminium in contact with concrete or masonry should also be protected by a coating of bituminous or aluminium paint or by a zinc chromate primer

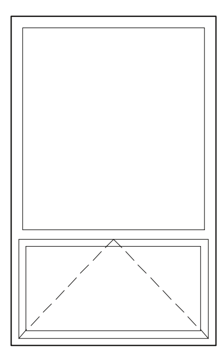


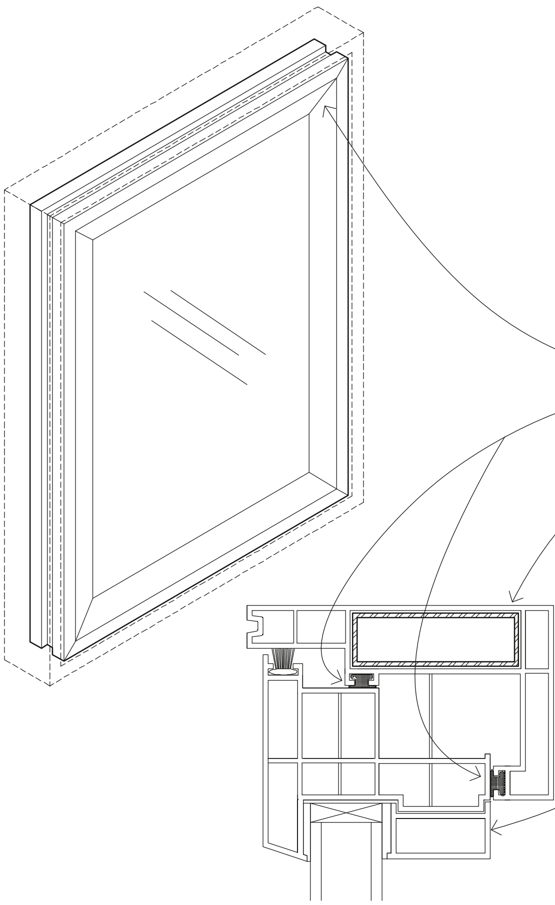
Metal windows are generally fabricated of aluminium or steel. Shown on this and the following page are typical sections for aluminium, steel, uPVC and composite windows. Because window frame and sash sections vary greatly from one manufacturer to the next, refer to the manufacturer's literature for:

- Large-scale details of frame and sash profiles
- Alloy, weight and thickness of sections
- Thermal performance of window assembly
- Resistance to corrosion, water pressure, air infiltration and wind loading
- Glazing methods and options
- Finishes available
- Structural openings required

Aluminium Windows

Aluminium window frames are relatively low in cost, lightweight and corrosion-resistant, but because they are such efficient conductors of heat, synthetic rubber or plastic thermal breaks are required to interrupt the flow of heat from the warm to the cool side of the frame. Aluminium frames may have anodised, baked-enamel or fluoropolymer resin finishes.





Unplasticised polyvinyl chloride (uPCV) windows and doors offer a low-maintenance and cost-effective alternative to timber-frame or metal windows. Sunlight can degrade and discolour the uPVC over time.

uPVC frames are similar in configuration to metal frame windows. uPVC manufacturers offer a range of frame configurations. Contact the window manufacturer for structural opening and installation requirements.

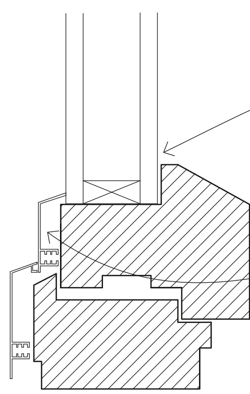
- Heat-welded corner joint
- EPDM gasket
- Larger sections are reinforced with galvanised-steel sections
- Clip in place internal glazing bead

Unplasticised Polyvinyl Chloride (uPVC) Windows

Common RAL Numbers

White	9010
Black	9011
Light grey	9022
Dark grey	9023
Blue	5005
Yellow	1026
Green	6001
Brown	8017

Source: www.ralcolor.com



Composite window systems generally incorporate a timber-frame window with a cladding of aluminium. The aluminium cladding minimises the necessary maintenance on the system offering protection to the timber. The timber offers improved thermal resistance over unbroken metal frames.

- Timber-framed double-glazed unit
- Aluminium cladding 2 mm

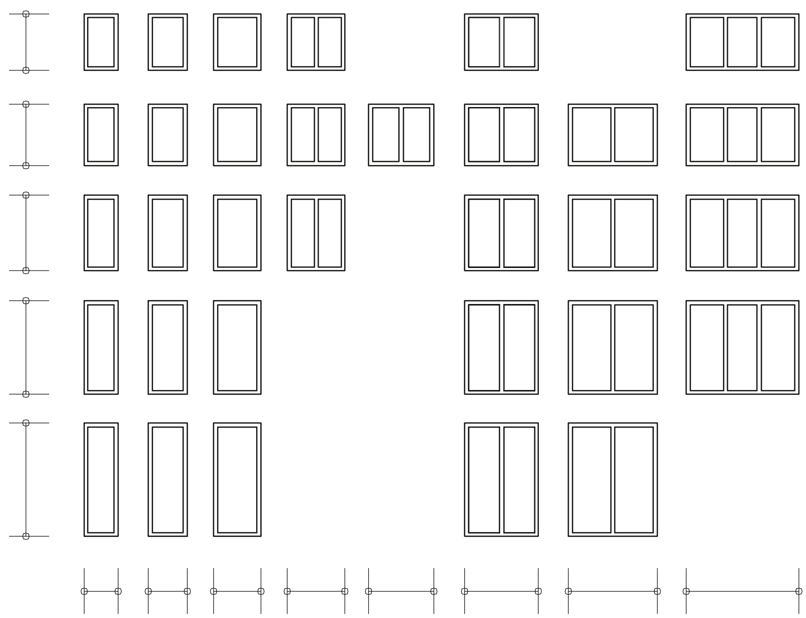
The aluminium cladding can be finished with a polyester powder coat (PPC) finish to a specified RAL number offering a great deal of flexibility.

Composite Windows

8.26 TIMBER WINDOWS

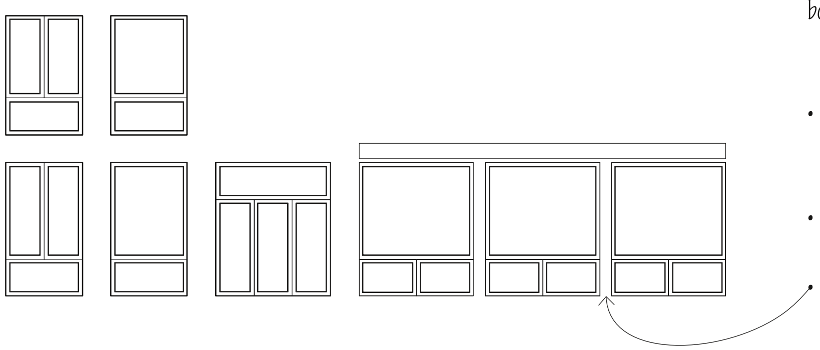
Timber frames are thicker than aluminium or steel frames, but they are also more effective as thermal insulators. The frames are usually of kiln-dried, clear, straight-grain wood, factory-treated with a water-repellent preservative. The wood may be stained, painted or primed for painting on-site. To minimise the need for maintenance, the majority of timber frames are now clad with vinyl or bonded to acrylic-coated aluminium sections that require no painting.

Most standard timber windows are manufactured with similar details. The exact profile and dimensions of the window frame and opening sections vary with the type of window operation and from manufacturer to manufacturer. Each manufacturer, however, usually has large-scale 1:10 or 1:5 details that can be used to work out specific window installations.

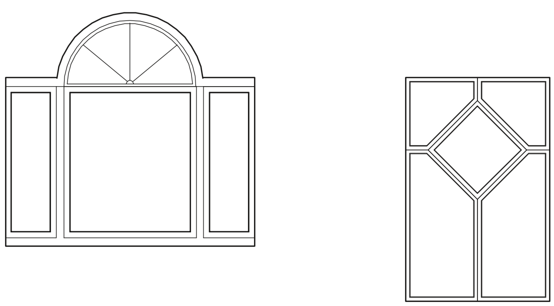


- Consult window manufacturer for standard window sizes and clear/structural openings required. Manufacturers will often fabricate custom sizes, shapes and configurations

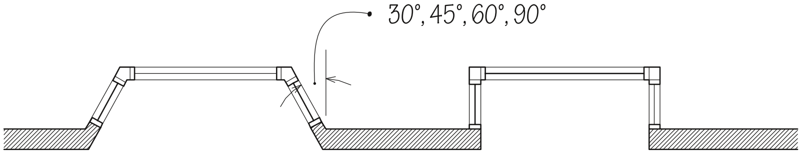
Window manufacturers offer various combinations of both fixed and venting units to cover large openings.



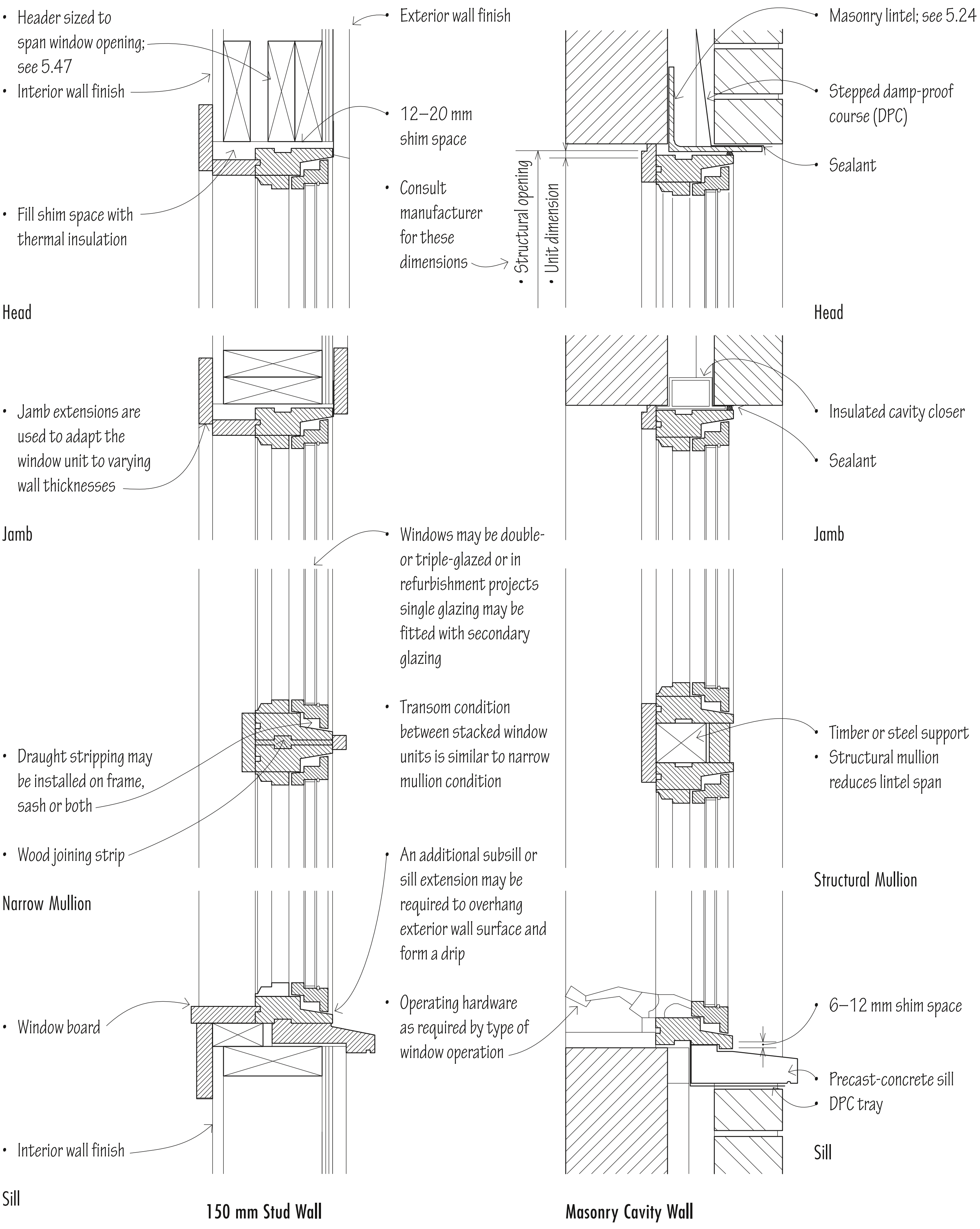
- Window units may be stacked vertically or be banked side by side
- Structural supporting mullions may be used to reduce the span of the lintel above
- Reinforcement may be required when four windows meet at a common corner, often in the form of a structural steel section or timber post



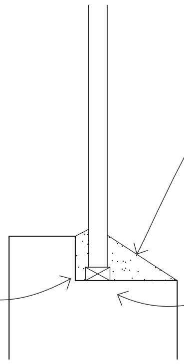
- Special shapes are available from many manufacturers



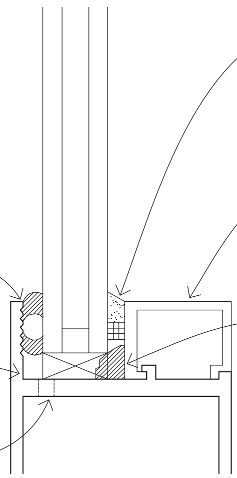
- Angled or box bay windows



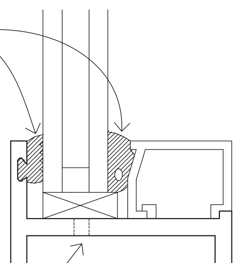
*Insulation omitted for clarity



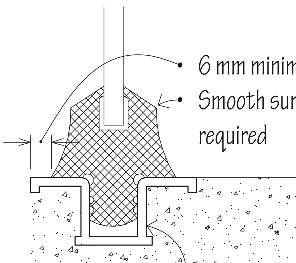
- A bedding of putty or glazing compound is laid in the rebate of a window sash to give a pane of glass an even backing
- Face putty is the putty or glazing compound formed on the exterior side of a glass pane
- Metal glazier's points hold a glass pane in a wood sash until the face putty has hardened



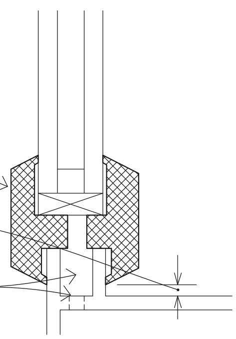
- Glazing tape is a pre-formed ribbon of synthetic rubber, such as butyl or polyisobutylene, having adhesive properties and used in glazing to form a watertight seal between glass and frame
- Setting block
- Weep hole
- Cap bead or sealant is an adhesive liquid of synthetic rubber injected into the joint between a glass pane or unit and a window frame, curing to form a watertight seal
- Glazing bead or stop is the timber moulding or metal section secured against the edge of a glass pane or unit to hold it in place
- Heel bead is an adhesive liquid of synthetic rubber injected between a glass pane or unit and a glazing bead, curing to form an airtight seal



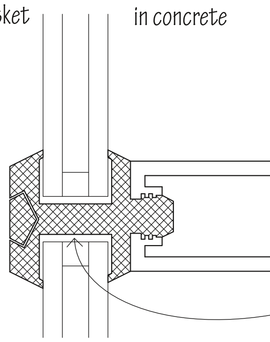
- Compression gaskets are pre-formed strips of synthetic rubber or plastic compressed between a glass pane or unit and a window frame to form a watertight seal and cushion for the glass
- Weep hole



- 6 mm minimum
- Smooth surface required
- Reglet-type gasket
- Plastic reglet in concrete



- Structural gasket with lockstrip
- 3 mm minimum
- Weep holes



- 3 mm maximum edge clearance on all sides
- Mullion-supported gasket for multiple or divided openings

Glazing

Traditionally small glass panes in domestic buildings may be set in a rebated frame, held in place with glazier's points, and sealed with a bevelled bead of putty or glazing compound.

- Putty is a compound of whiting and linseed oil, of doughlike consistency when fresh, used in securing window panes or patching woodwork defects
- Glazing compound is an adhesive compound used as putty, formulated so as not to become brittle with age

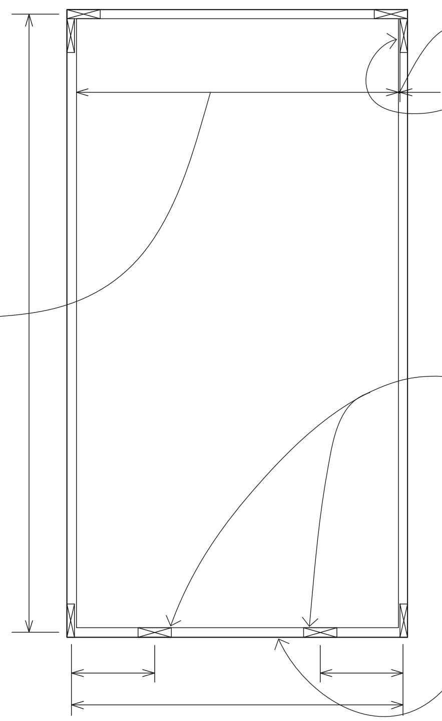
More recent glazing methods involve setting of glass in a window frame with a compression gasket instead of glazing tape or a liquid sealant.

Structural Gaskets

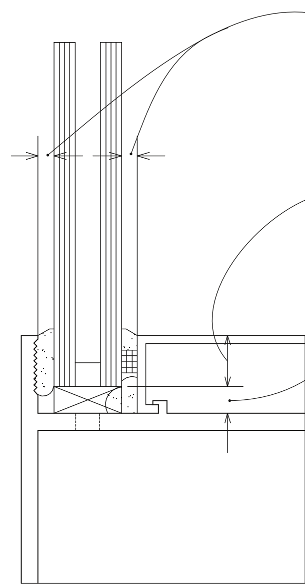
Structural gaskets are pre-formed of synthetic rubber or other elastomeric material to secure a glass pane or unit in a window frame or opening. The gaskets are held in compression by forcing a keyed locking strip into a groove in the gasket. They require smooth contact surfaces and a frame or opening with exacting dimensional tolerances and true plane alignment. The glass must be supported on at least two sides by the frame or a supported gasket.

Both wet- and dry-glazing systems should allow the glass unit to float in its opening and be cushioned with a resilient glazing material. There should be no direct contact between the glass and the perimeter frame. The perimeter frame itself must support the glass against wind pressure or suction, and be strong enough that structural movements and thermal stresses are not transferred to the glass.

- Glass size is the size of a glass pane or unit required for glazing an opening, allowing for adequate edge clearances

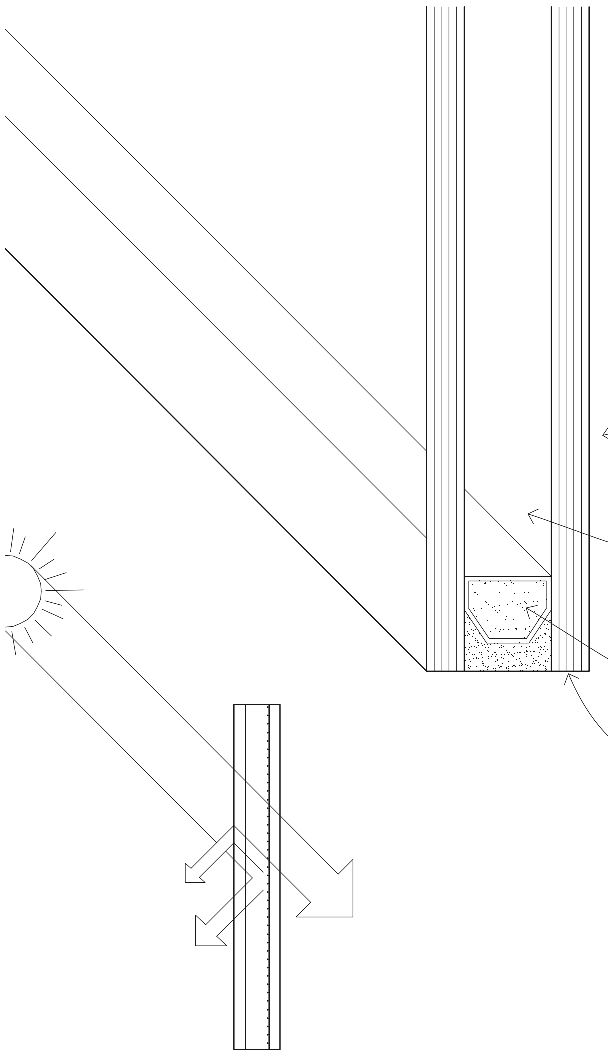


- Limit deflection to 1/175 of span
- 3 mm clearance
- Edge blocks of synthetic rubber are placed between the side edges of a glass pane or unit and a frame to centre it, maintain a uniform width of sealant and limit lateral movement caused by building vibrations or thermal expansion or contraction; 100 mm minimum length
- Setting blocks of lead or synthetic rubber are placed under the lower edge of a glass pane or unit to support it within a frame; two per panel at quarter points
- Setting blocks should be as wide as glass thickness and 25 mm per 0.09 m^2 of glass area in length; 100 mm minimum
- Minimum of two 6–10 mm Ø weep holes in glazing pocket



- Face clearance is the distance between the face of a glass pane or unit and the nearest face of its frame or stop, measured normal to the plane of the glass
- Bite is the amount of overlap between the edge of a glass pane or unit and a window frame, stop or lock-strip gasket
- Edge clearance is the distance between the edge of a glass pane or unit and a window frame, measured in the plane of the glass

8.30 GLAZING UNITS



Glazed units consist of two or more sheets of glass separated by a hermetically sealed air space to provide increased thermal insulation and restrict condensation.

- Spacer-edge units are constructed with two sheets of glass separated around the edges by a hollow metal or organic rubber spacer and hermetically sealed with an organic sealant, such as butyl rubber
- The 12–24 mm space between the two glass sheets may be filled with dehydrated air at atmospheric pressure, or for improved thermal efficiency, with an inert gas such as argon or krypton
- A desiccant (chemical dehumidifier) in the spacer absorbs any residual moisture in the air space
- The glass may be from 4 to 12 mm thick
- For improved thermal efficiency, tinted, reflective or low-emissivity (low-e) glass may be used; see table below
- Triple-glazed units improve thermal performance and may feature warm edge spacer of foam or thermoplastic or silicone-based materials
- High-performance units may also feature insulated frames

- When referring to the thermal performance of windows a centre of pane or entire unit U-value may be quoted, it should be noted that depending on installation thermal bridges may be introduced; see 7.36–7.37
- The low-emissivity coating on one or both sheets of glass reflects much of the incident radiant energy while admitting most of the visible light
- For safety glazing, the glass may be annealed, tempered or laminated

- See 12.16 for other glass products

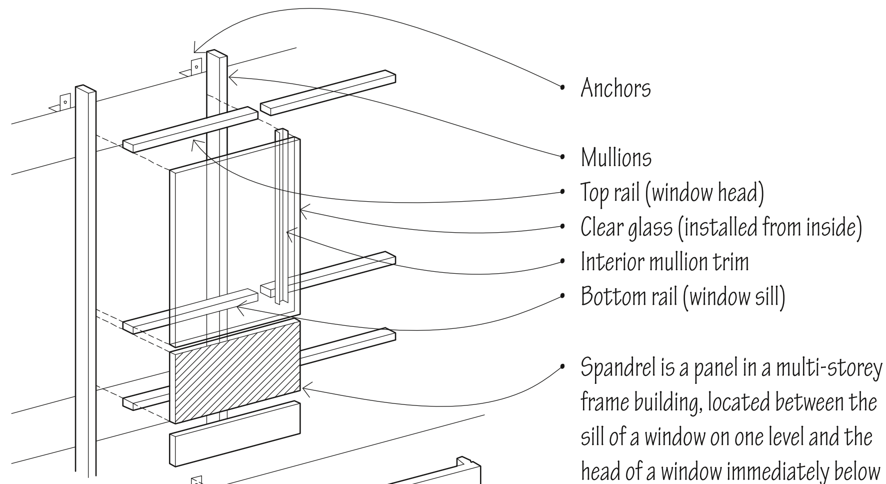
G-value is a factor representing the percentage of solar transmission through the window on a scale of 0–1. With 0 representing 0% and 1, 100%.

*Insulating Glass Type	G-Value	U-Value
clear + clear 4-16-4	0.75	2.2
clear + clear 4-16-4		2.0
clear + low-e 4-24-4	0.72	1.8
clear + low-e + argon 4-24-4		1.4–1.6
triple + low-e + argon 4-16-4-16-4	0.64	0.8–1.2

*Assuming timber window frames

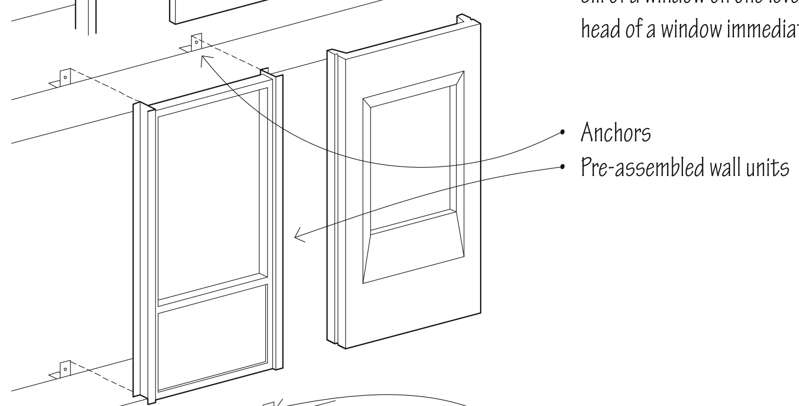
LEED EA Credit 1: Optimize Energy Performance
BREEAM ENE 01: Reduction of CO_2 Emissions

Glazed curtain walls are exterior non-load-bearing walls consisting of vision glass or opaque spandrel panels supported by metal framing. They may be categorised according to their method of assembly.



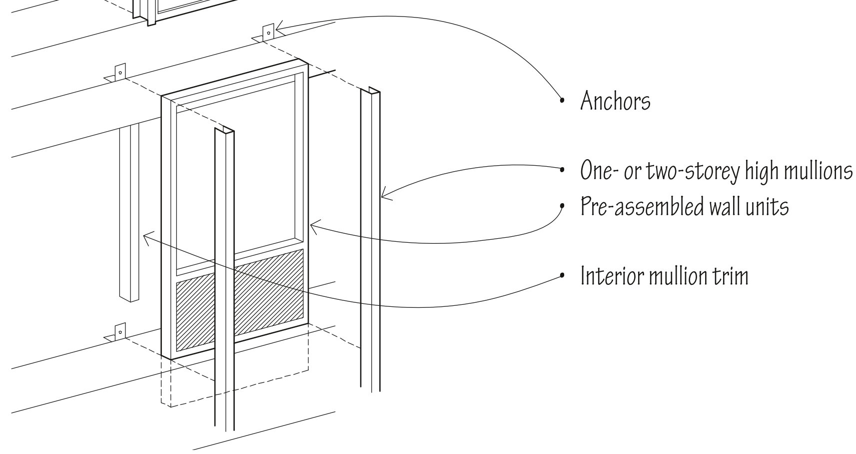
Stick Systems

The stick system consists of tubular metal mullions and rails or transoms assembled piece by piece on-site to frame vision glass and spandrel units. It offers relatively low shipping and handling costs and can be adjusted more readily than other systems to on-site conditions.



Unit Systems

Unit systems consist of pre-assembled, framed wall units which may be pre-glazed or glazed after installation. Shipping bulk is greater than with the stick system, but less on-site labour and erection time is required.



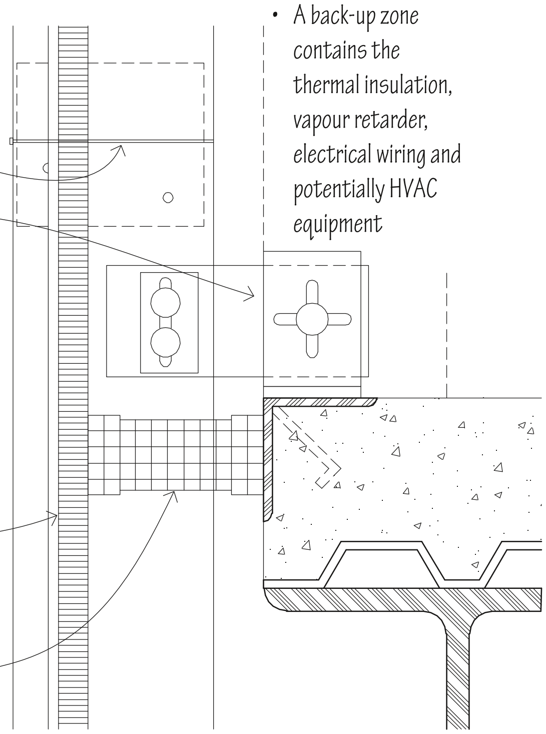
Unit-and-Mullion Systems

In the unit-and-mullion system, one- or two-storey high mullions are installed before pre-assembled wall units are lowered into place behind the mullions. The panel units may be full-storey height, pre-glazed or unglazed, or may be separate vision glass and spandrel units.

- See 7.20–7.22 for general conditions and requirements of curtain-wall construction

8.32 GLAZED CURTAIN WALLS

- Mullion sections are spliced with the lower mullion fixed to an internal spline and the upper mullion slipping down over the spline so that it is free to move
- Angle anchors; see 7.22
- All anchors and fasteners must be detailed to guard against galvanic action
- Infill panel or spandrel glass with an opaque glass produced by fusing a ceramic frit to the interior surface of tempered or heat-strengthened glass
- A continuous fire-stop is secured between the wall and the edge of each floor slab or deck to prevent the spread of fire

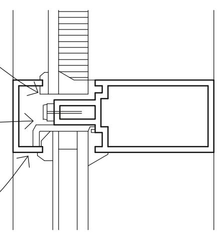


- A back-up zone contains the thermal insulation, vapour retarder, electrical wiring and potentially HVAC equipment

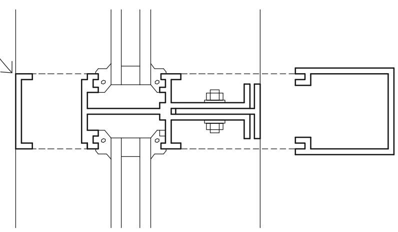
These details illustrate typical conditions of glazed curtain-wall construction. When using standard fabricated wall systems, there is no need for extensive detailing except when components are modified. Things to note include:

- Overall wall pattern
- Type of glazing
- Type, size and location of any operable window sash
- Type and finish of infill or spandrel panels
- Perimeter, corner and anchorage conditions

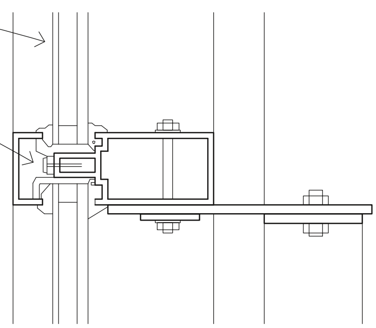
- See 7.21 for pressure-equalised design of curtain-wall frames
- Metal frames should have thermal breaks
- Horizontal rails are provided with weep holes for drainage

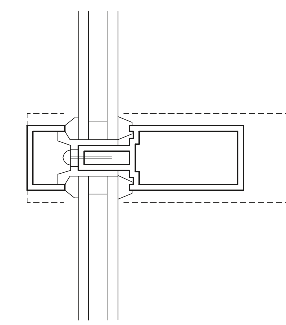


- Snap-on covers may be used to conceal fasteners, provide uninterrupted profiles and permit variations in metal finishes

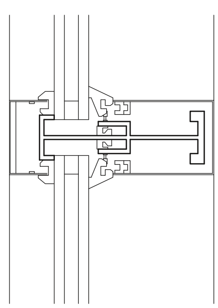


- Glazed unit
- Glass may be glazed from the outside using pressure bars or structural gaskets; see 8.29 and 8.31





- For high-rise applications, interior glazing is more convenient and economical. It is accomplished by means of fixed exterior gaskets and interior wedge-shaped gaskets; snap-on covers conceal the inner frame and fasteners
- Some curtain-wall systems may be glazed from either the outside or the inside of the building

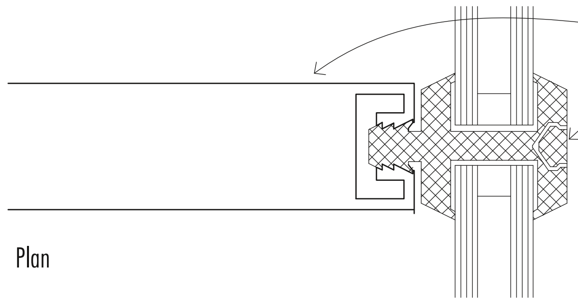


- The required size, strength and stiffness of the curtain-wall frame are determined by the loads the frame must carry – primarily lateral wind loads and relatively light gravity loads. Consult the manufacturer for the structural capacity of the curtain-wall assembly, as well as its resistance to water and air infiltration

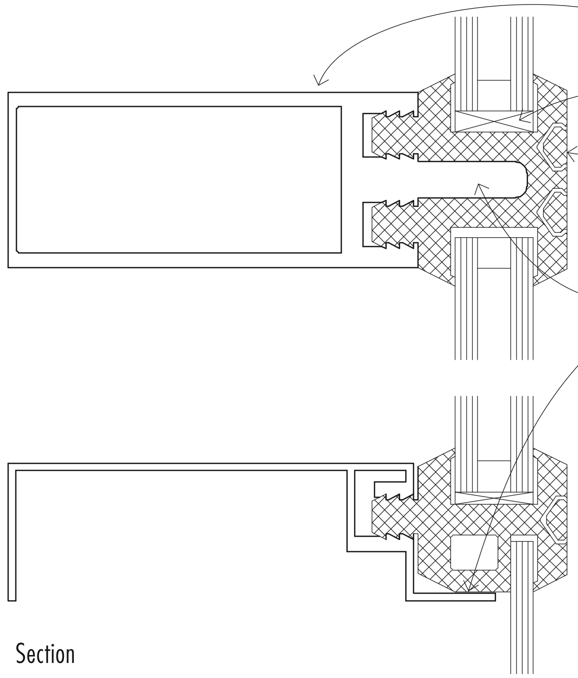
A curtain-wall system may utilise structural gaskets to glaze both fixed glass units and spandrel panels. The supporting frame members should be of the same thickness as the insulating glass unit to ensure balanced support.

When stacking glazed units vertically, the weight of the upper glass units can introduce stresses into the lower glass units. For this reason, the transom rather than the gaskets should provide the necessary support for the glazing.

See 8.28 for more information on glazing with structural gaskets.



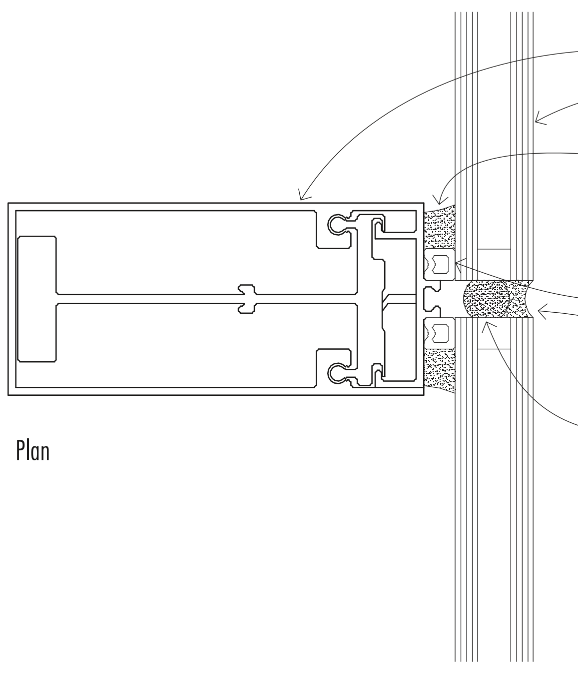
Plan



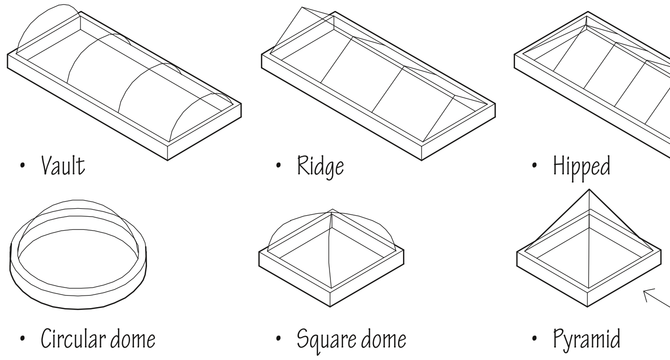
Section

Flush Glazing

Flush glazing is a glazing system in which the metal framing members are set entirely behind the glass panes or units to form a flush exterior surface. The glazed units adhere to the framing with a structural silicone sealant; the silicone sealant transfers wind and other loads from the glass to the metal curtain-wall frame without mechanical fastenings. The design should allow for easy maintenance and replacement of broken glass units. Factory-glazing is preferred for better quality control. Consult manufacturer for details.



Plan

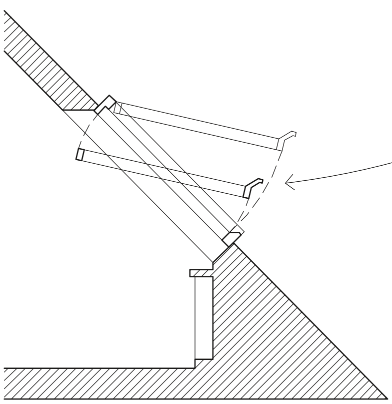


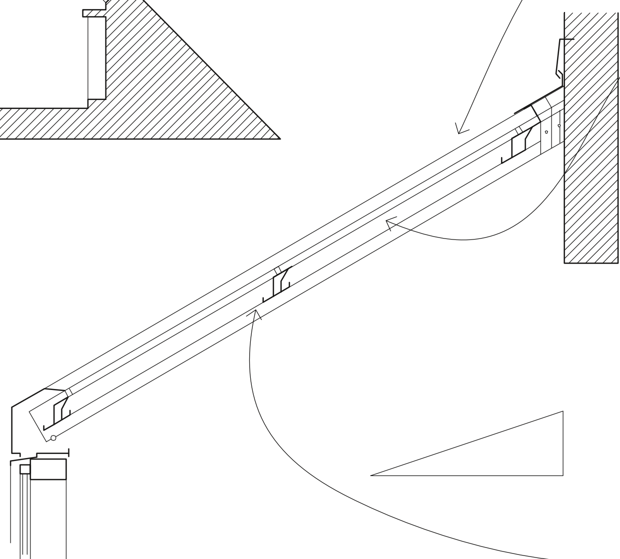
Skylight Forms

Glazed openings in a roof allow daylight to enter an interior space from above. This efficient and cost-effective source of lighting can be in place of or in addition to the normal daylighting from windows. Careful consideration, however, should be paid to the control of brightness and glare, which may require the use of louvres, shades or reflector panels. Horizontal and south-facing skylights also increase solar heat gain in the winter, but in the summer, shading may again be required to prevent excessive heat gain.

Glazed openings may be constructed using the following elements:

- Skylights are metal-framed units pre-assembled with glass or plastic glazing and flashing. They are available in stock sizes and shapes but may also be custom-fabricated
- Roof lights are standard timber windows designed for installation in a sloping roof. These windows either pivot or swing open for ventilation and cleaning. They are typically 600–1200 mm wide and 900–1850 mm high and available with shades, blinds and electric operators
- Sloped glazing systems are glazed curtain walls engineered to serve as pitched glass roofs

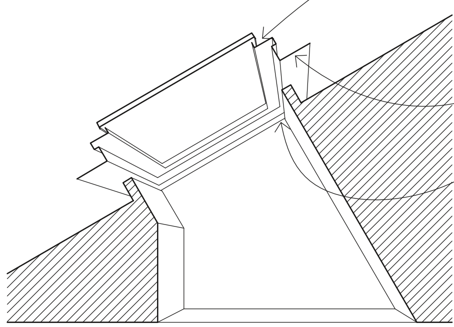




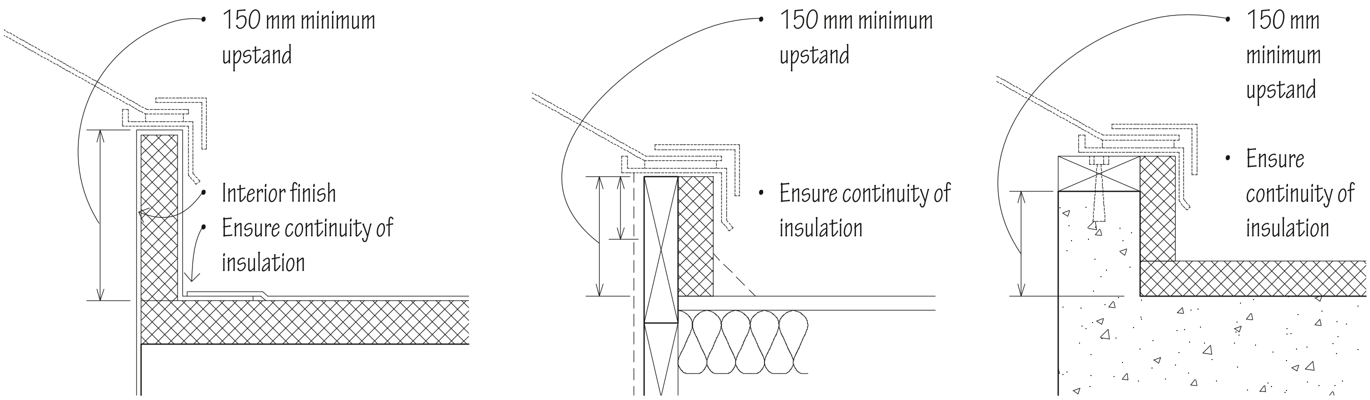
- Units may be of acrylic or polycarbonate plastic or of wired, laminated, heat-strengthened or fully tempered glass

- Care should be taken with detailing around rooflights to ensure a weather- and airtight finish. In most construction types, thermal bridges can be difficult to avoid with roof glazing due to the required upstand. See 7.36 and 7.37 for more information on thermal bridging

- The frames for skylights and sloped glazing systems should incorporate an internal guttering system to collect and drain infiltrating water and condensation through weep holes to the exterior
- Roof flashing
- Skylights set at an angle of less than 45° require a kerb at least 100 mm high to elevate the skylight above the surrounding roof surface. This kerb may be built on-site or be an integral part of the skylight unit

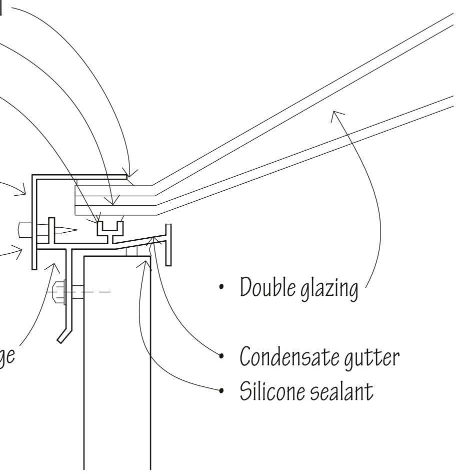


- Skylight units require a framed roof opening; both the supporting roof structure and the skylight units must be engineered to carry the anticipated roof loads

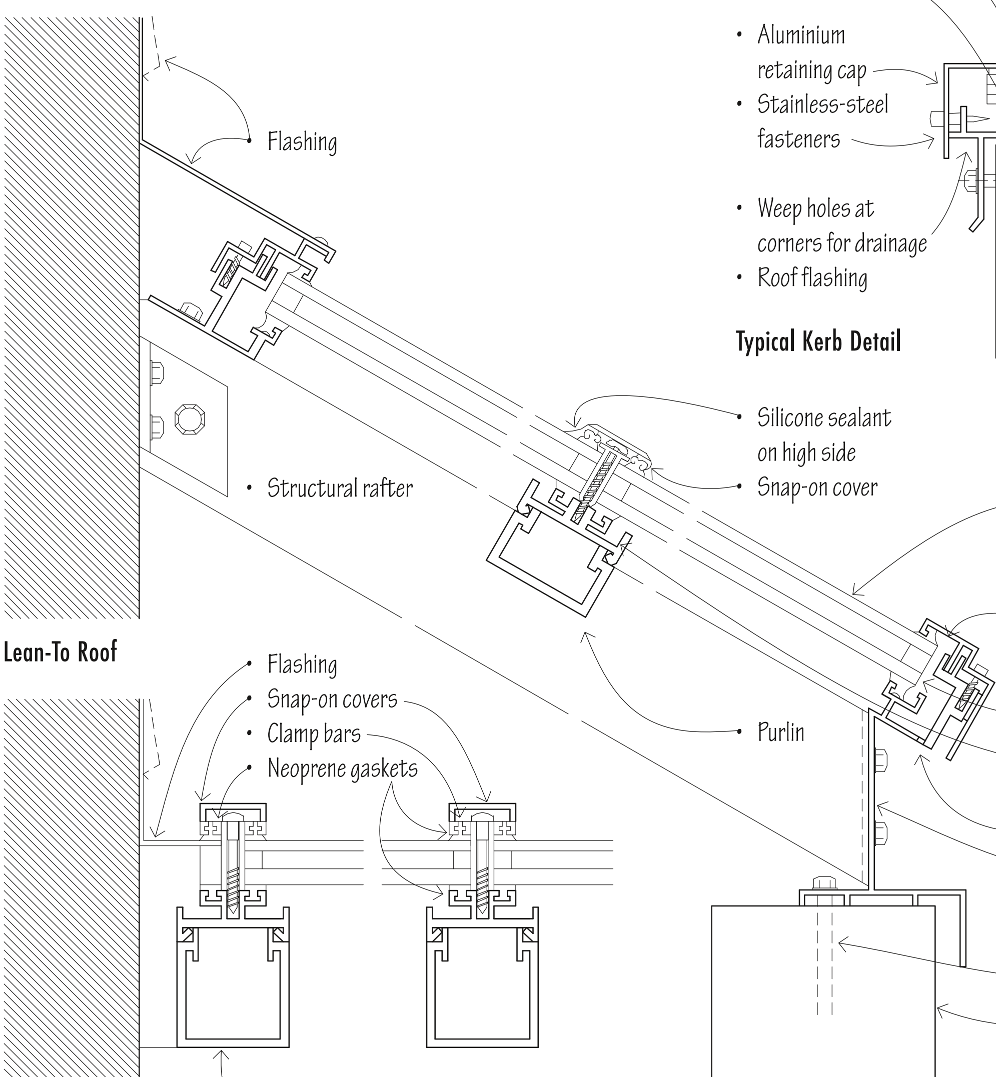


Aluminium
Wood
Concrete

Upstand Types



Typical Kerb Detail



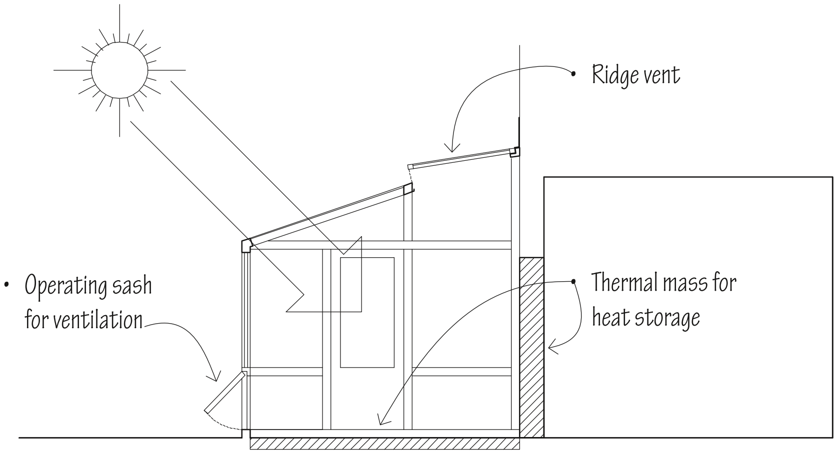
Lean-To Roof

End Wall and Typical Rafter

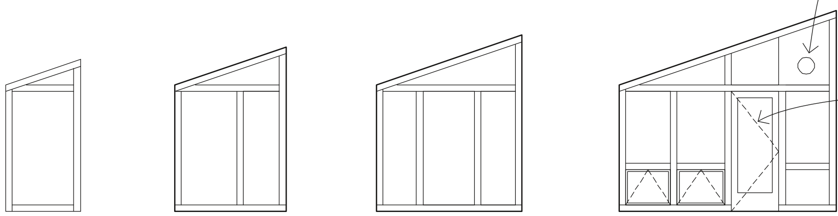
Sill or Eaves

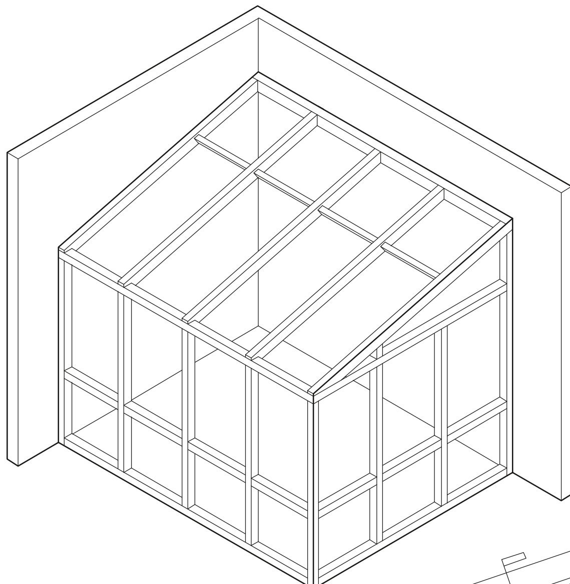
*Insulation omitted for clarity

A sunspace is a glass-enclosed porch or room adjoining another living space and oriented to admit large amounts of sunlight. Sunspaces are often used in passive solar design in conjunction with a thermal mass of masonry, rock or concrete to store the solar heat gain. Because of the possibility of overheating, provision should be made for shading and ventilation with operable windows and, if necessary, an exhaust fan.

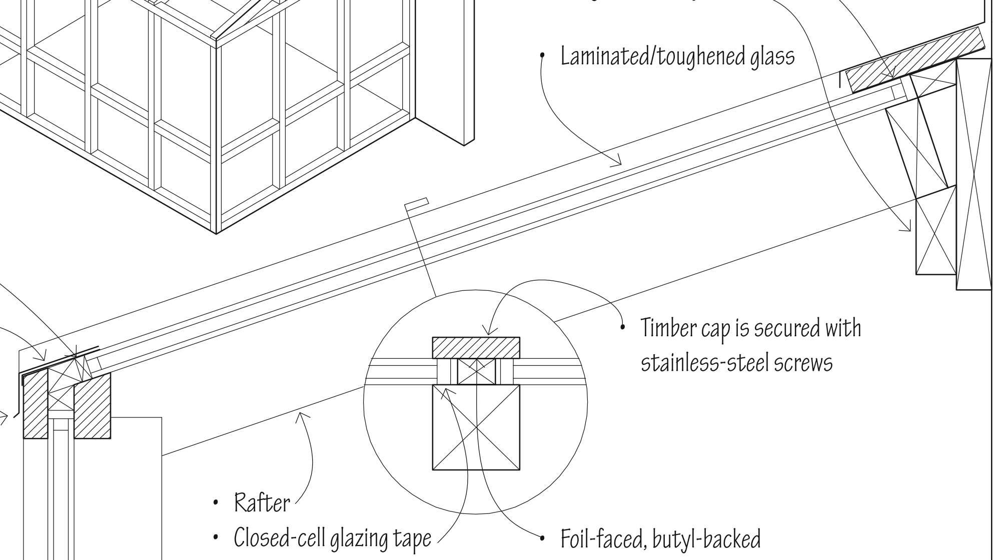


- Sunspaces and greenhouses are available as manufactured systems with timber or metal frames, complete with glazing and flashing
- A ventilating fan can be mounted on the roof or in either of the gable ends
- Insulating shades and blinds follow the slope of the roof and can be operated manually or by remote control
- French or sliding doors can be located in either of the gable ends



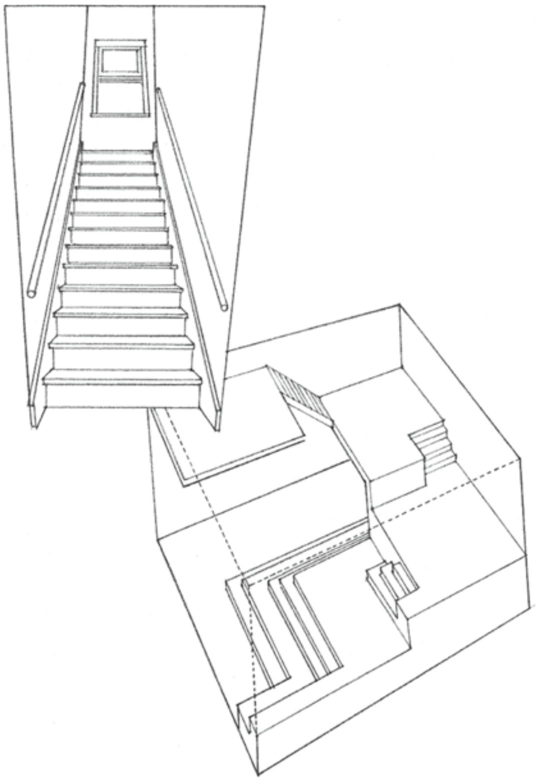


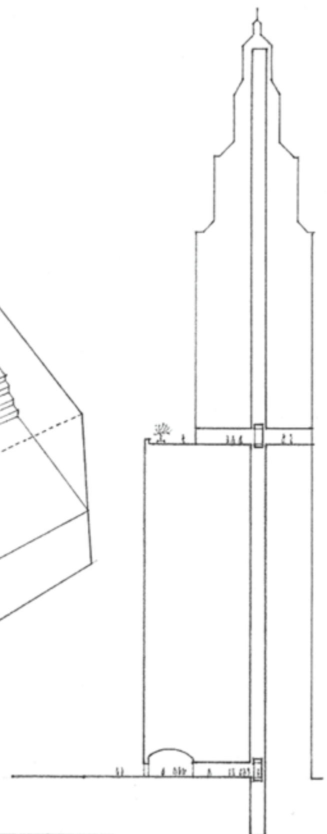
- The details in the lower half of 8.35 characterise the construction of metal-framed glazed structures. Shown below are typical details for a timber-framed sunspace or solarium



9

SPECIAL CONSTRUCTION

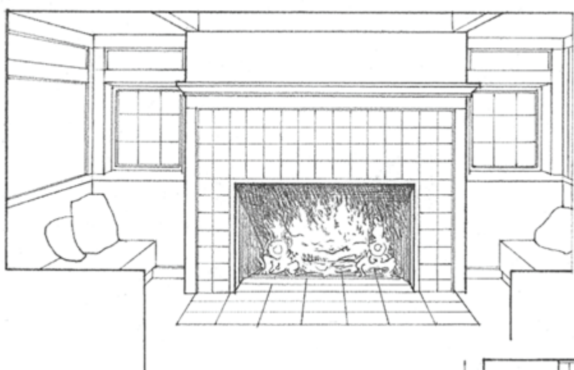


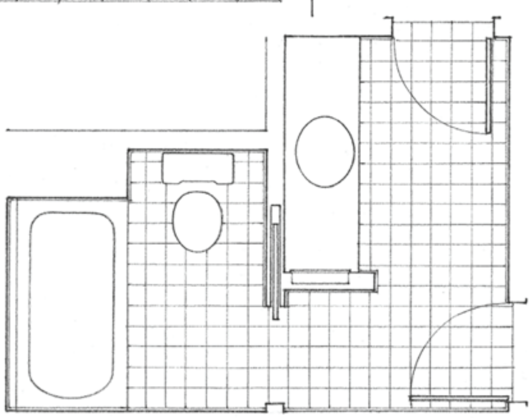


This chapter discusses those elements of a building that have unique characteristics and that therefore should be considered as separate entities. While not always affecting the exterior form of a building, they do influence the internal organisation of spaces, the pattern of the structural system, and in some cases, the layout of heating, plumbing and electrical systems.

Stairs provide means for moving from one level to another and are therefore important links in the overall circulation scheme of a building. Whether punctuating a two-storey volume or rising through a narrow shaft, a stairway takes up a significant amount of space. The landings of a stairway should be logically integrated with the structural system to avoid overly complicated framing conditions. Safety and ease of travel are, in the end, the most important considerations in the design and placement of stairs.

Multi-storey buildings require elevators to move people, equipment and goods from one floor to another. For accessibility to multi-storey public and commercial facilities by persons with disabilities, building regulations mandate their installation. An alternative to elevators is the escalator, which can move a large number of people efficiently and comfortably between a limited number of floors.





Fireplaces and wood-burning stoves are sources of heat and visual points of interest for any interior space. The placement and size of a fireplace or stove in a room should be related to the scale and use of the space. Both fireplaces and stoves must be located and constructed to draw properly. The damper and flue sizes should correspond to the size and proportions of the firebox and precautions should be taken against fire hazards and heat loss. Room-sealed appliances are preferable as combustion air is not drawn from the room, additionally it should be noted that most of the useful heat from a fireplace will be lost up the flue.

Kitchens and bathrooms are unique areas of a building that demand the careful integration of plumbing, electrical and heating/ventilating systems with the functional and aesthetic requirements of the spaces. These areas also require special fixtures and equipment, as well as durability, ease of maintenance, and sanitary surfaces and finishes.

The dimensions of risers and treads in a stairway should be proportioned to accommodate our body movement. Their pitch, if steep, can make ascent physically tiring as well as psychologically forbidding, and can make descent precarious. If the pitch of a stairway is shallow, its treads should be deep enough to fit our stride.

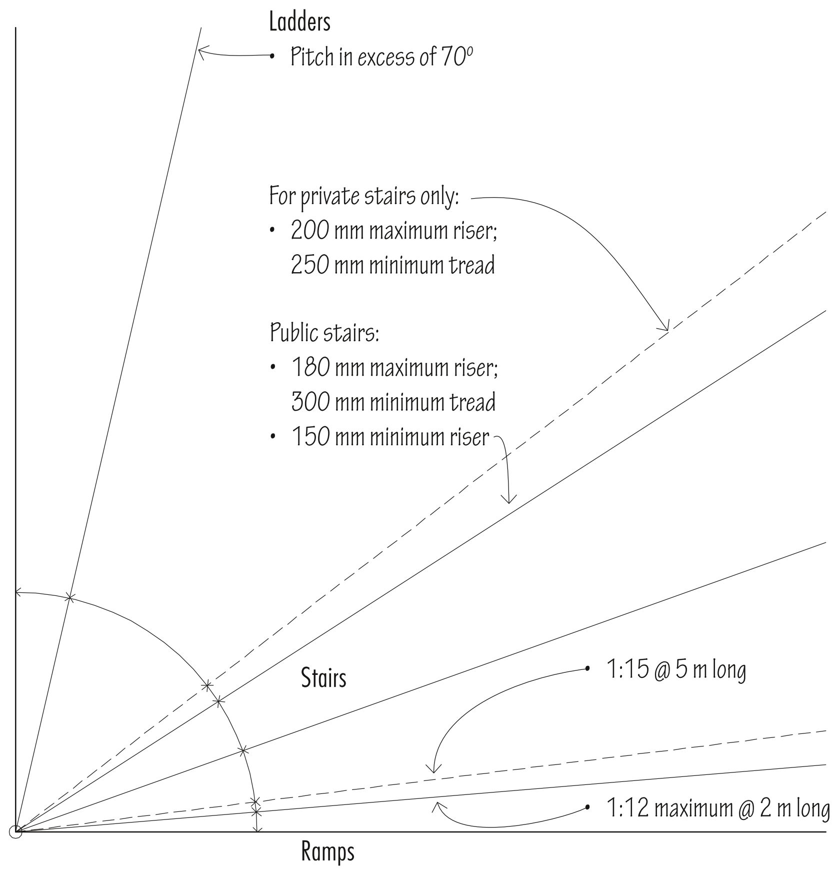
Building regulations (see Approved Document K in the UK) regulate the minimum and maximum dimensions of risers and treads; see 9.04–9.05. For comfort, the riser and tread dimensions can be proportioned according to the following formula (within the maximum and minimum riser and thread dimensions allowed):

- 2x rise (mm) + going (mm) = 550–700 mm

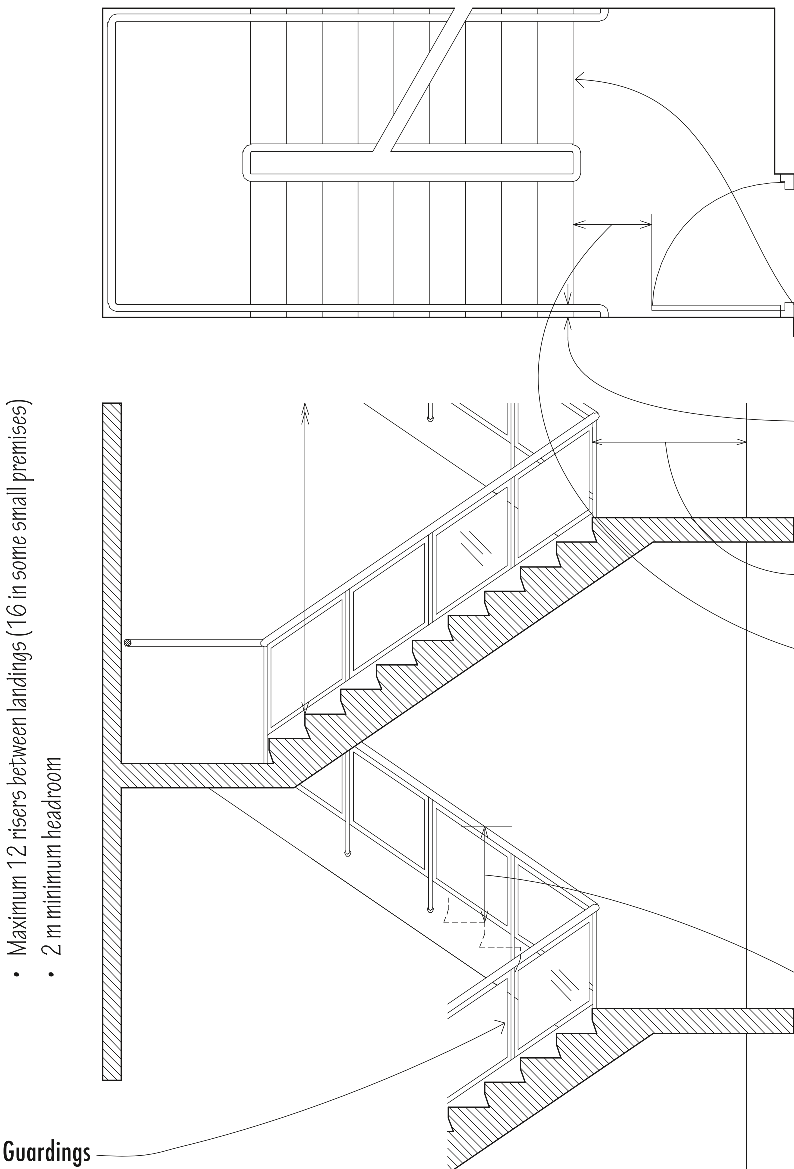
Exterior stairs are generally not as steep as interior stairs, especially where dangerous conditions such as snow and ice exist.

For safety, all risers and goings in a flight of stairs should be uniform. In practice this can be difficult to achieve and building regulations may allow a variation of +/- 1% for rise and going in private stairs with +/-1.5% variation in the going of public stairs. Consult the building regulations to verify the dimensional guidelines outlined on this and the following page.

- The actual riser and tread dimensions for a set of stairs are determined by dividing the total rise or floor-to-floor height by the desired riser height. The result is rounded off to arrive at a whole number of risers. The total rise is then redivided by this whole number to arrive at the actual riser height
- This riser height must be checked against the maximum and minimum riser height allowed by the building regulations
- Once the actual riser height is fixed, the tread run can be determined by using the riser: going proportioning formula
- Since in any flight of stairs, there is always one fewer tread than the number of risers, the total number of treads and the total going can be easily determined



9.04 STAIR REQUIREMENTS



Stairway design is strictly regulated by the building regulations, especially when a stairway is an essential part of an emergency egress system. Because an accessible stairway should also serve as a means of egress during an emergency, the accessibility requirements illustrated on the next page are similar to those of an emergency egress stairway.

Stairway Width

- The occupant density, which is based on the purpose group and the floor area served, determines the required width of an exit stairway. Consult the building regulations for details
- 1 m minimum width for public stairs; 1.1 m minimum for fire-fighting stairs
- Handrails may project a maximum of 75 mm into the required width

Landings

- Landings should be at least as wide as the stairway they serve and have a minimum length equal to the stair width, measured in the direction of travel
- A door can open across the landing at the bottom of the stairs but a clear space of 400 mm must be maintained
- Door should swing in the direction of egress to aid escape

Handrails

- Handrails are required on both sides of the stair. Some building regulations allow exceptions for stairs in individual dwelling units
- Handrails should be 900–1000 mm above the pitch of the stairs (900–1100 mm at landings)
- Handrails should be continuous without interruption by a newel post or other obstruction
- Handrails should be provided to the bottom two steps in all public buildings. The ends should return smoothly to a wall or walking surface, or continue to the handrail of an adjacent stair flight without blocking any access routes. Where a staircase is more than 1m wide handrails will be required on both sides; where more than 1800 mm wide further division will be required (consult local building regulations)
- See the next page for detailed handrail requirements
- Consult building regulations for specific local requirements

Guardings

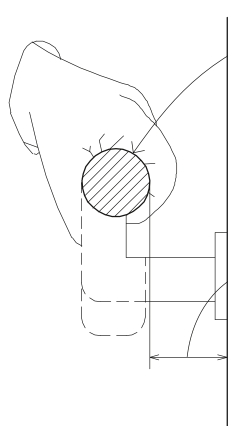
- Guardings are required to protect the open or glazed sides of stairways, ramps, porches and unenclosed floor and roof openings
- Guarding must be provided to stairs where there is a drop of 600 mm or more
- Guarding protecting the open or glazed side of a stairway may have the same height as the handrails
- A 100 mm sphere must not be able to pass through any opening in the guarding and the guarding should not be easily climbable by children
- Guardings should be able to withstand a concentrated load applied non-concurrently to their top rails in both vertical and horizontal directions. Consult the building regulations for detailed requirements

Treads, Risers and Nosings

- A minimum of three risers per flight is recommended to prevent tripping and may be required by the building regulations
- See the next page for detailed tread, riser and nosing requirements
- See 9.03 for tread (going) and riser (rise) proportions

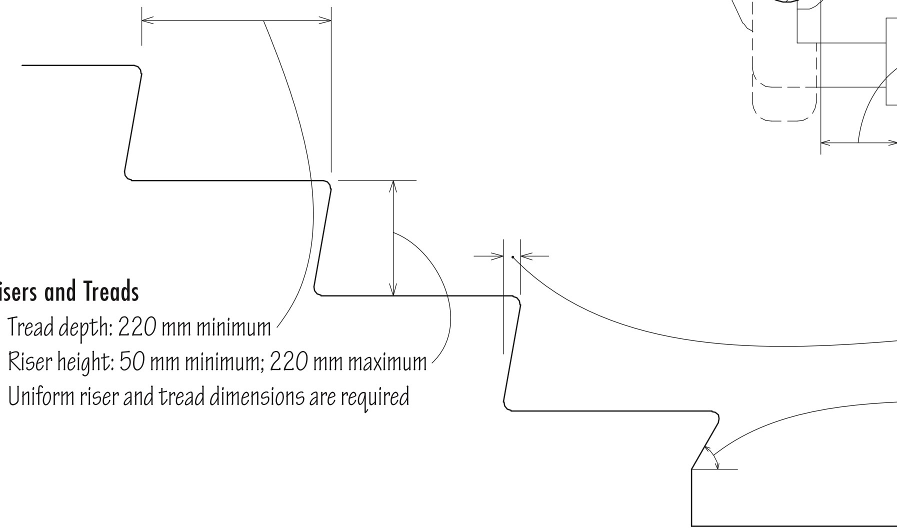
Accessibility Guidelines

Accessible stairs should also serve as a means of egress during an emergency, or lead to an accessible area of refuge where people who are unable to use stairs may remain temporarily in safety to await assistance during an emergency evacuation.



Handrails

- Handrails should be free of sharp or abrasive elements and have a circular cross section with a diameter of 40–45 mm; other shapes are allowable if they provide equivalent graspability and have a minimum radius of 15 mm
- 60–75 mm minimum clearance between handrail and wall



Risers and Treads

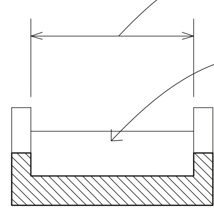
- Tread depth: 220 mm minimum
- Riser height: 50 mm minimum; 220 mm maximum
- Uniform riser and tread dimensions are required

Nosings

- 25 mm maximum protrusion
- Risers can be sloped or the undersides of the nosings should have an angle from the horizontal

Ramps

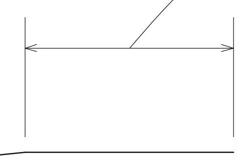
Ramps provide smooth transitions between the floor levels of a building. To have comfortable low slopes, they require relatively long runs. They are typically used to accommodate a change in level along an accessible route or to provide access for wheeled equipment. Short, straight ramps act as beams and may be constructed as timber, steel or concrete floor systems. Long or curvilinear ramps are usually of steel or reinforced concrete.



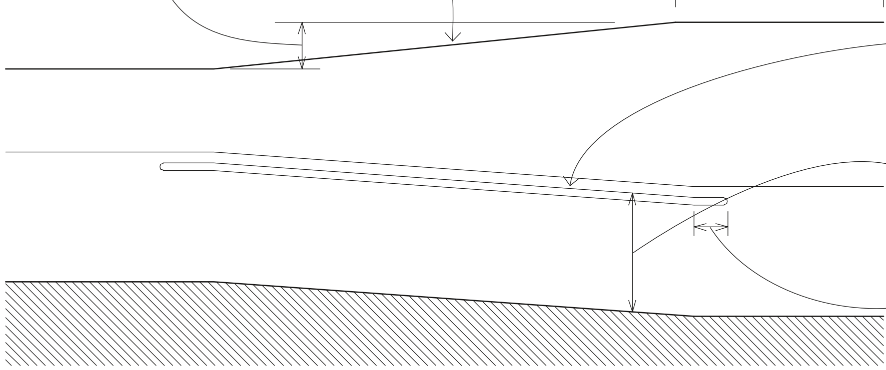
- 950 mm recommended minimum clear width between kerbs or guardings
- Ramp surface should be stable, firm and slip-resistant
- Guardings are required in the same manner to stairs

Landings

- Ramps should have level landings at each end with a length at least equal to the width of the ramp



- 1:20 maximum slope at 10 m length
- 500 mm maximum rise between landings (333 mm at 1:15, 166 mm at 1:12)

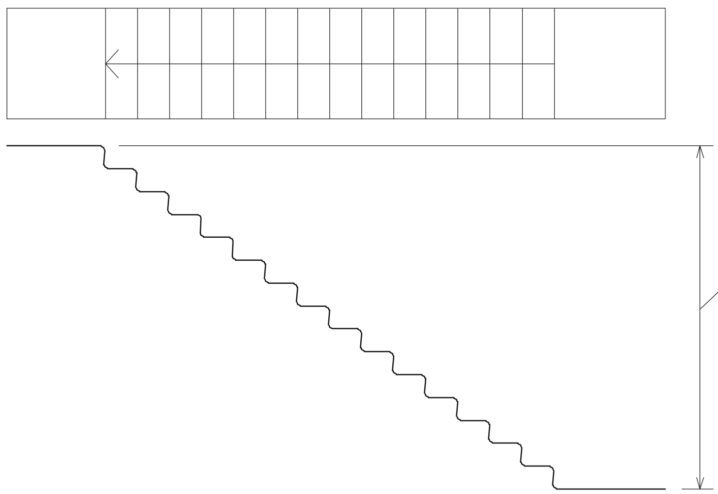


Handrails

- Ramps having a rise greater than 600 mm require a handrail on at least one side. Ramps less than 1m wide require a handrail only on one side, wider ramps require handrails on both sides
- Handrail requirements are the same as for stairways
- Extend handrails at least 300 mm horizontally beyond the top and bottom of ramp runs

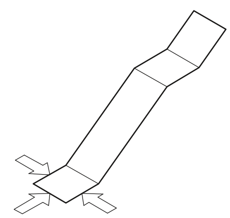
See local building regulations for further details

9.06 STAIR PLANS

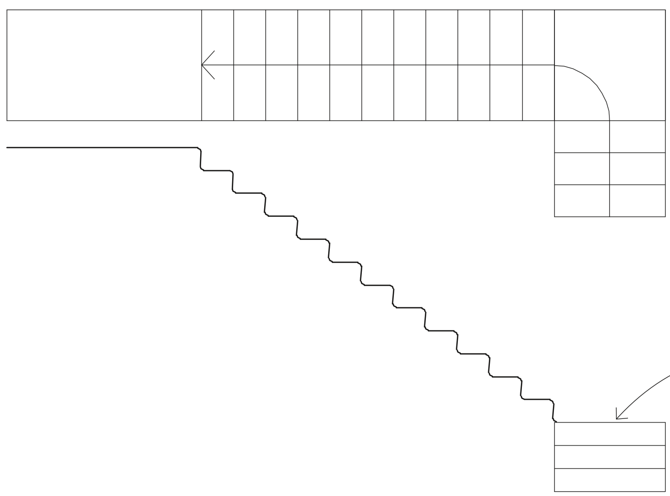


Straight-Run Stair

- A straight-run stair extends from one level to another without turns or winders
- Building regulations generally limit the vertical rise between landings to 16 risers

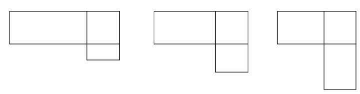


- A stairway may be approached or departed either axially or perpendicular to the stair run

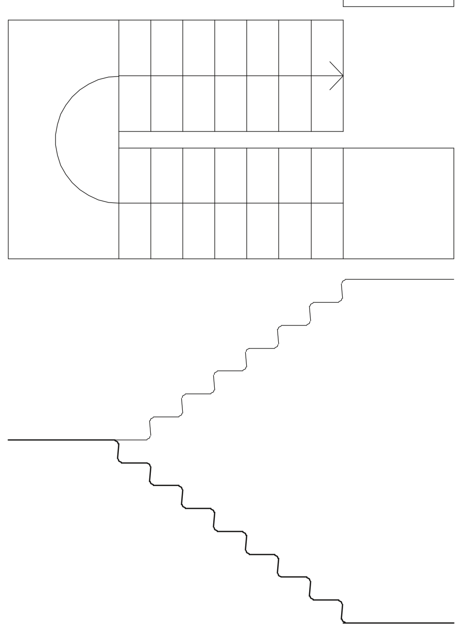


Quarter-Turn Stair

- A quarter-turn or L-shaped stair makes a right-angled turn in the path of travel
- The two flights connected by an intervening landing may be equal or unequal, depending on the desired proportion of the stairway opening

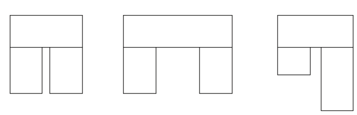


- Landings that are below normal eye level and provide a place to rest or pause are inviting



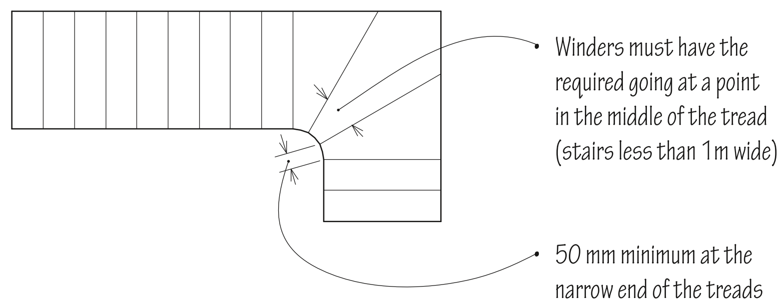
Dog-Leg Stair

- A dog-leg stair turns 180° or through two right angles at an intervening landing
- A dog-leg stair is more compact than a single straight-run stair
- The two flights connected by the landing may be equal or unequal, depending on the desired proportion of the stairway opening



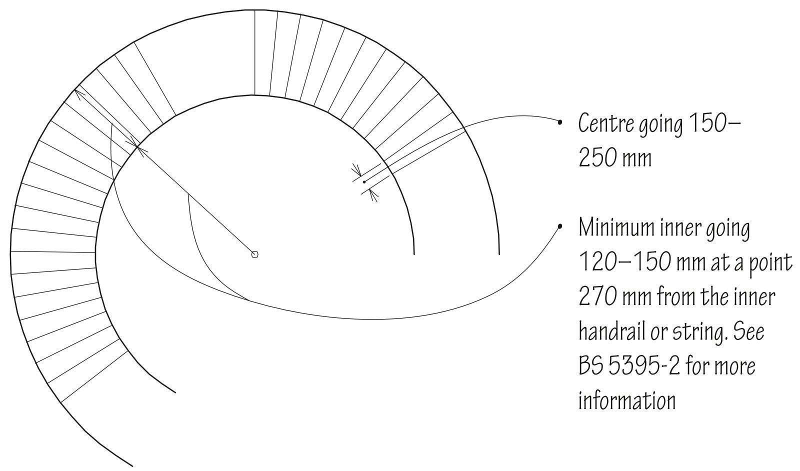
Winding Stair

- A winding stair is any stairway constructed with winders, as a circular or spiral stair. Dog-leg and half-landing stairs may also use winders rather than a landing to conserve space when changing direction
- Winders can be hazardous since they offer little foothold at their interior corners. Building regulations generally restrict the use of winders to private stairs within individual dwelling units



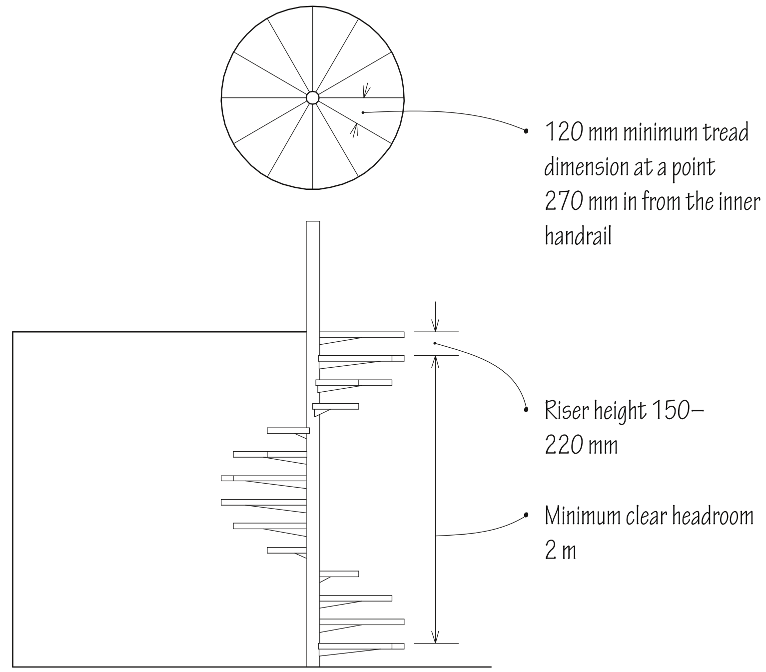
Helical Stair

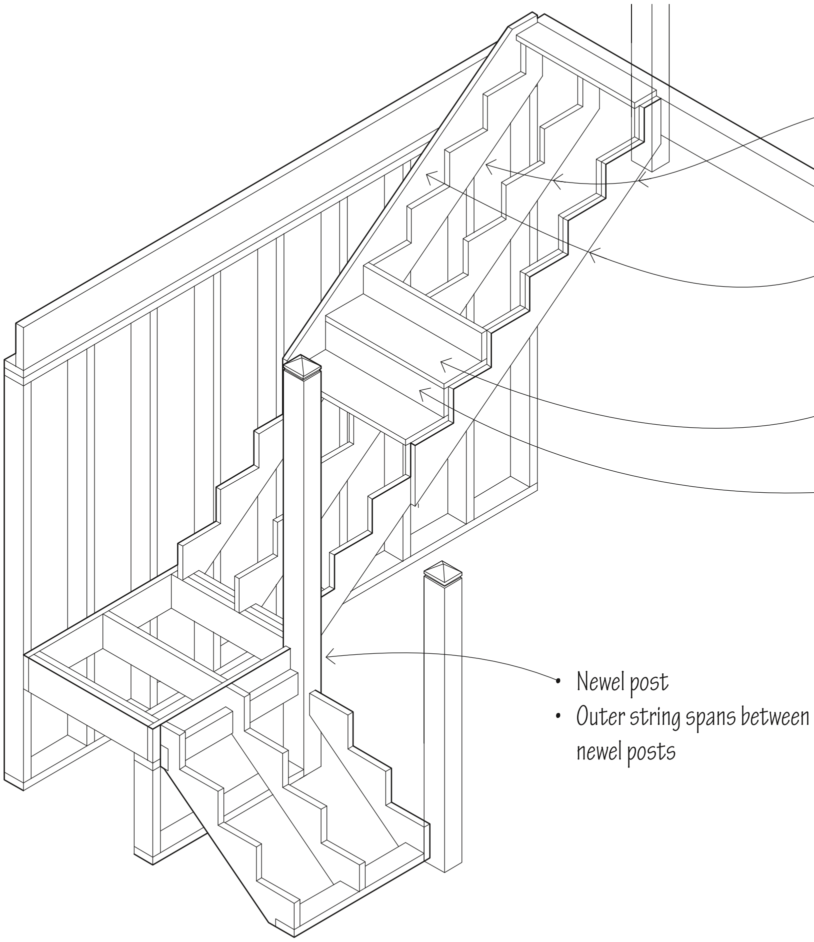
- A helical stair has a circular plan configuration



Spiral Stair

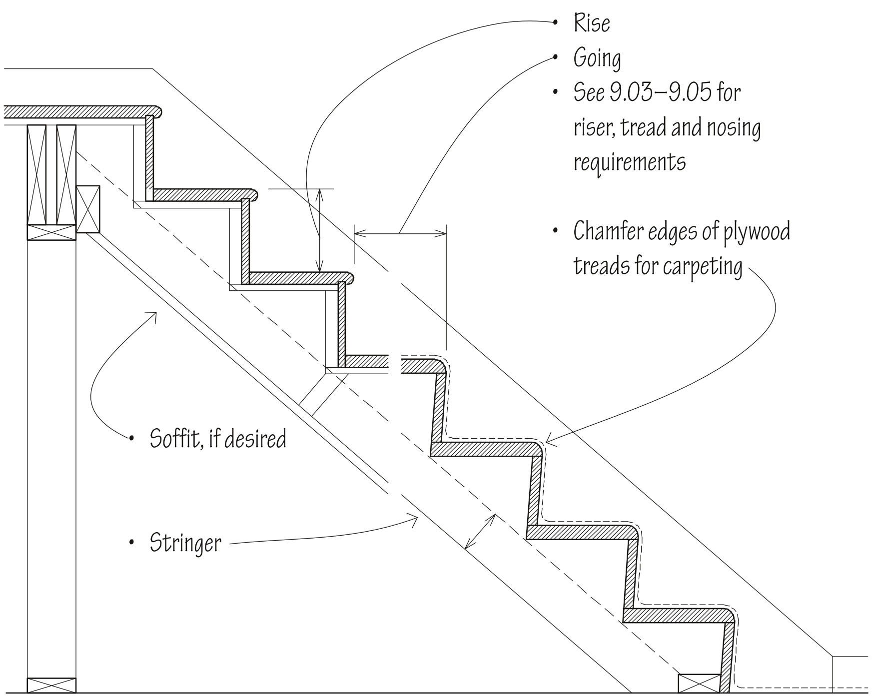
- A spiral stair consists of wedge-shaped treads winding around and supported by a central post
- Spiral stairs occupy a minimum amount of floor space, but building regulations may restrict their use
- See 9.12 for typical dimensions



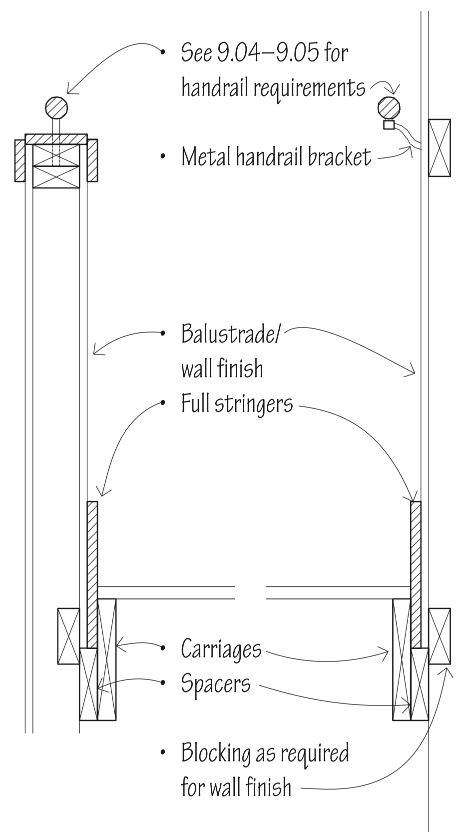


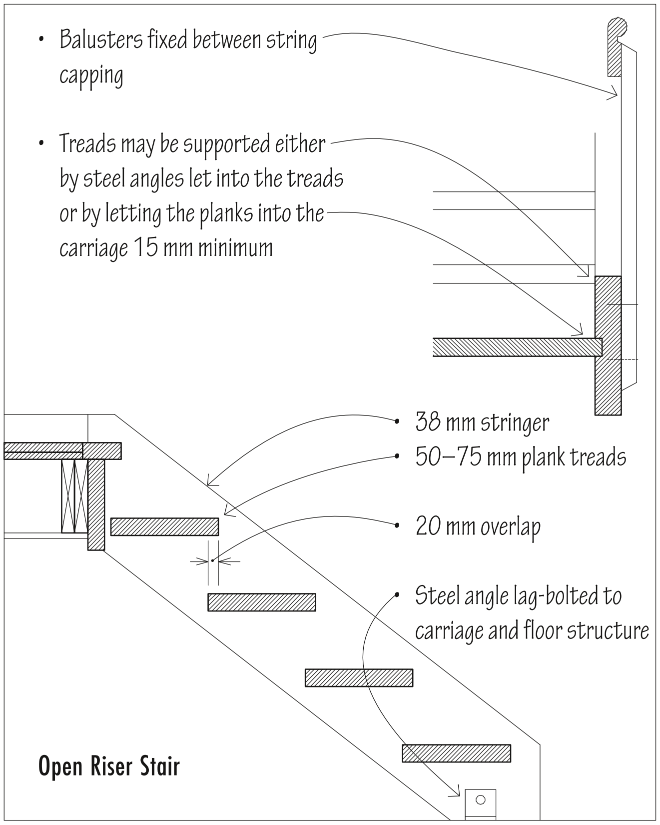
A timber stair is constructed of the following elements:

- Stringers are the principal inclined beams supporting the treads and risers of a flight of stairs. The number and spacing of stringers required for a stairway depend on the spanning capability of the tread material
- Stringers are the sloping finish members running alongside a staircase, against which the risers and treads terminate
- Treads are the footways that span the distance between the supporting carriages and result in a 'going' of a given dimension
- Risers are the vertical boards that close off the stair space and help make the construction rigid; some stairs have open risers



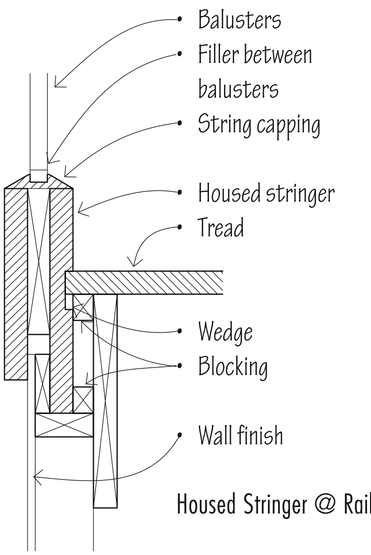
Closed-Riser Stair



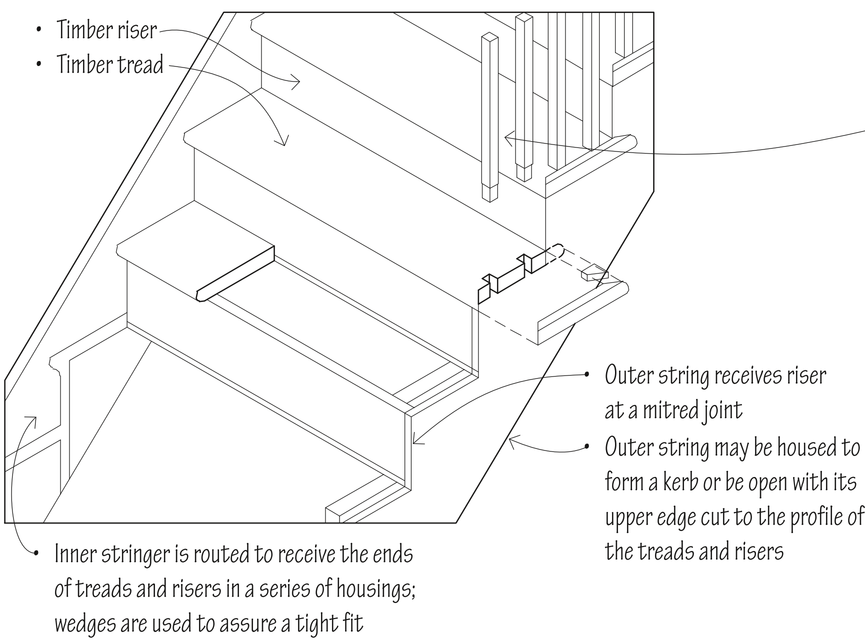


Open Riser Stair

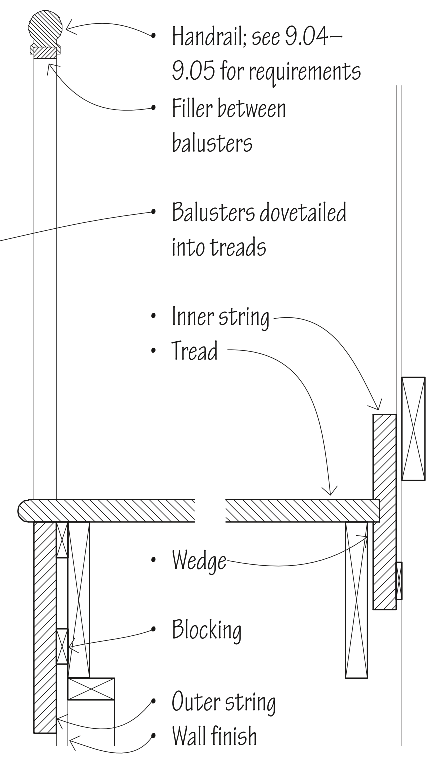
• A box stair has a housed string on both sides so that it may be more or less completely finished before being set in its final location



Housed Stringer @ Rail



Closed-Riser Stair with Housed Stringer

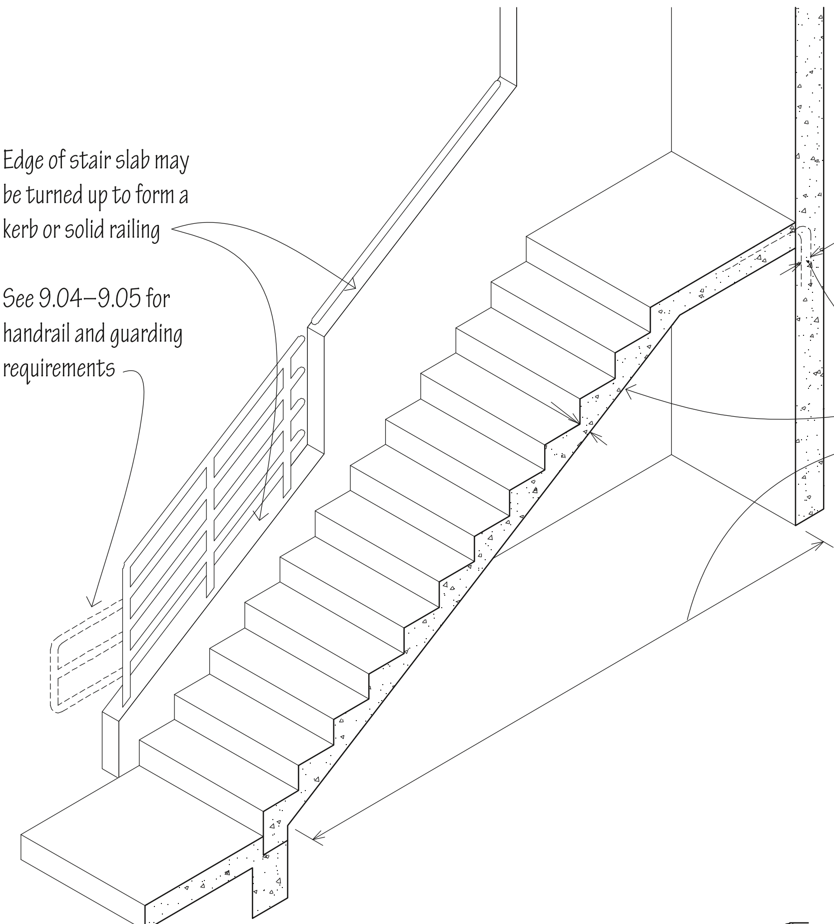


Open Stringer @ Rail

9.10 CONCRETE STAIRS

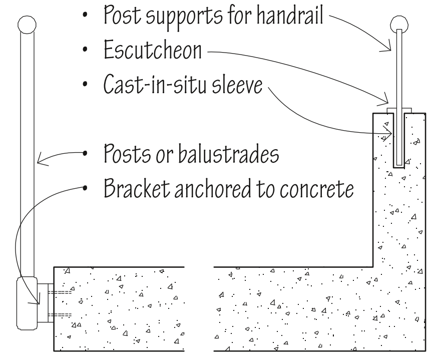
A concrete stair is designed as an inclined, one-way reinforced slab with steps formed on its upper surface. If the stair is constructed after the floor beam or wall supports, it acts as a simple beam. If it is cast with the beam or slab supports, it is designed as a continuous beam. Concrete stairs require careful analysis of load, span and support conditions; consult a suitably qualified engineer for final design requirements.

- Edge of stair slab may be turned up to form a kerb or solid railing
- See 9.04–9.05 for handrail and guarding requirements



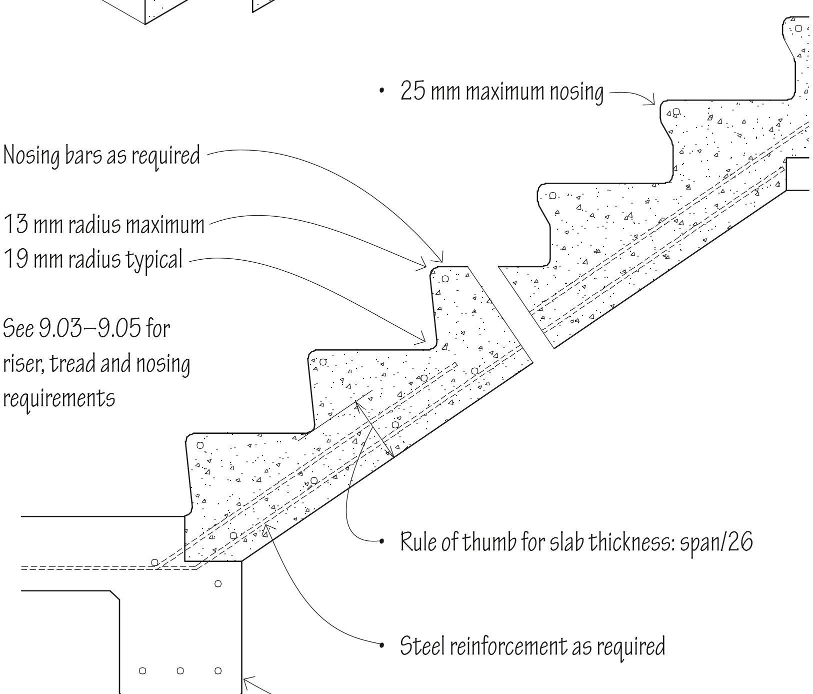
- 100 mm minimum bearing
- Stair slab thickness; rule of thumb: span/26
- Span is equal to the horizontal distance between the slab supports

- Post supports for handrail
- Escutcheon
- Cast-in-situ sleeve
- Posts or balustrades
- Bracket anchored to concrete



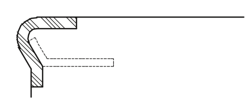
- Handrail supports may be anchored to the top of the stair slab or low wall, or to the edge of the stair slab

- 25 mm maximum nosing
- Nosing bars as required
- 13 mm radius maximum
- 19 mm radius typical
- See 9.03–9.05 for riser, tread and nosing requirements

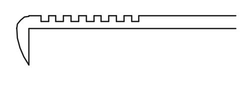


- Rule of thumb for slab thickness: span/26
- Steel reinforcement as required
- Beam support

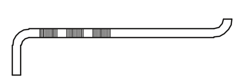
Longitudinal Section



- Cast-metal nosing with abrasive finish



- Metal, rubber or vinyl tread with grooved surface



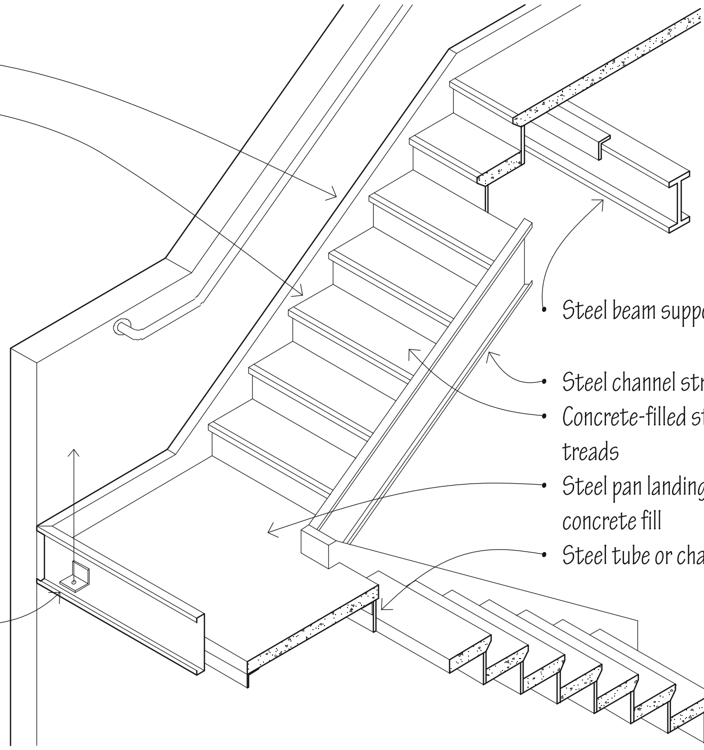
- Stone tread with abrasive strips

- Stairs require slip-resistant nosings and treads

Steel stairs are analogous in form to timber stairs.

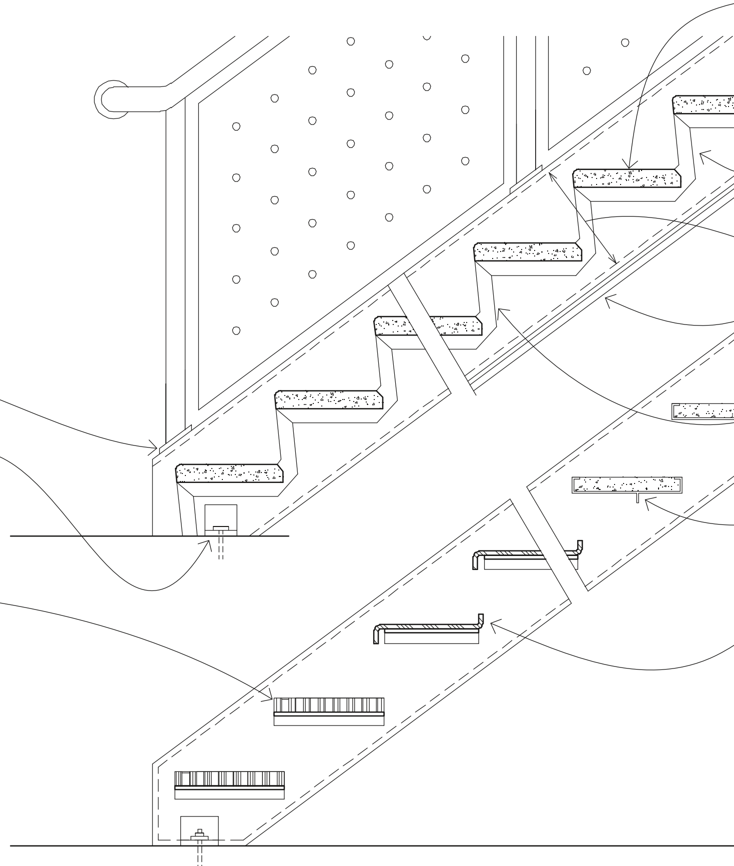
- Steel channel sections serve as stringers
- Stair treads span the distance between the stringers
- Treads may consist of concrete-filled steel pans, bar grating or flat plates with a textured top surface

- Pre-engineered and prefabricated steel stairs are available



- Steel beam support
- Steel channel stringer
- Concrete-filled steel pan treads
- Steel pan landing with concrete fill
- Steel tube or channel support

- Steel channel may rest on a bearing plate on masonry, or be hung on threaded rods from the floor structure above

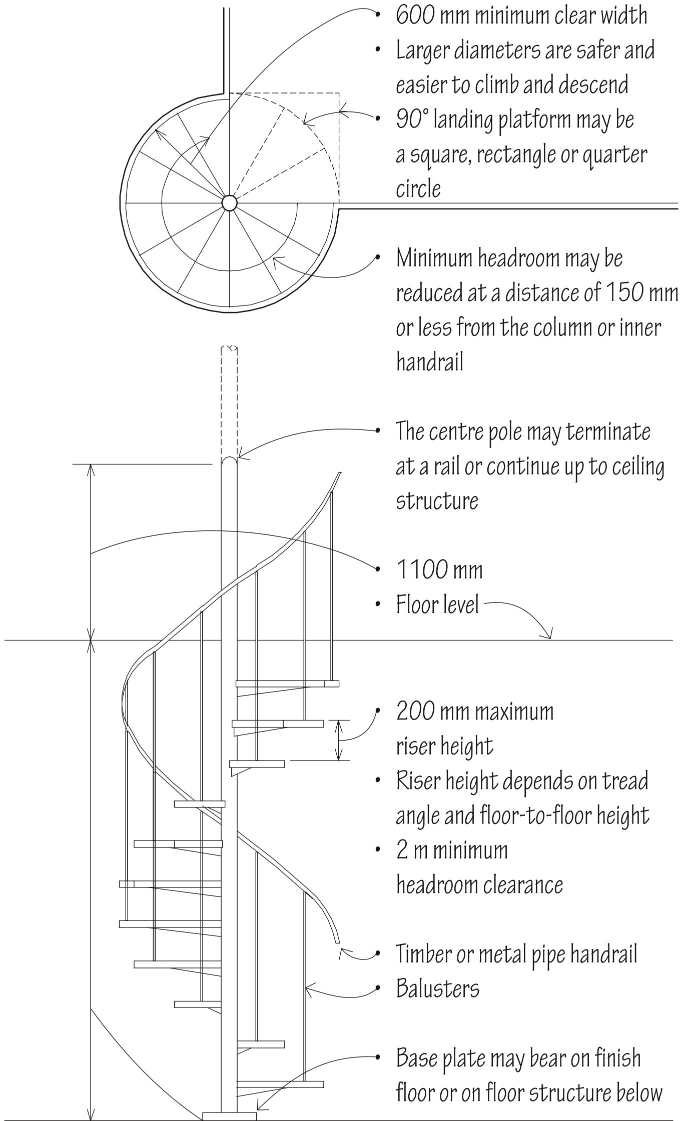


- See 9.04–9.05 for building regulation requirements and accessibility guidelines for handrails and guardings
- Site weld
- Clip angle with anchor bolts secures each stringer to the floor structure
- Steel pan treads with 50 mm minimum concrete fill
- Form of pan varies; consult manufacturer
- 32 x 32 x 3 mm angle supports
- Steel channel stringer; 250 mm minimum
- Plasterboard soffit supported on furring channels

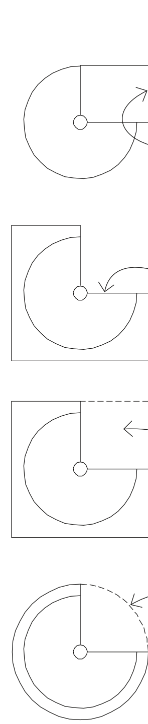
Closed Risers

- Bar grating treads
- Nosing may consist of a chequered plate, closely spaced bars or an angle with an abrasive strip
- Timber and precast-concrete treads are also available
- Steel pans with concrete fill welded to channel stringer
- Flat plate treads with textured top surfaces
- Open riser should not allow a sphere of 100 mm ø to pass through

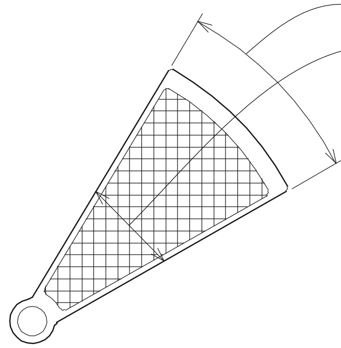
Open Risers



Plan and Elevation



Stair Connections



Stair Treads

Representative Sizes and Dimensions of Spiral Stairs*

Tread angle	No of treads in 360°	Riser Height	Headroom (min)
22½°	16	180 mm	2135 mm
27°	13	190–200 mm	2055 mm

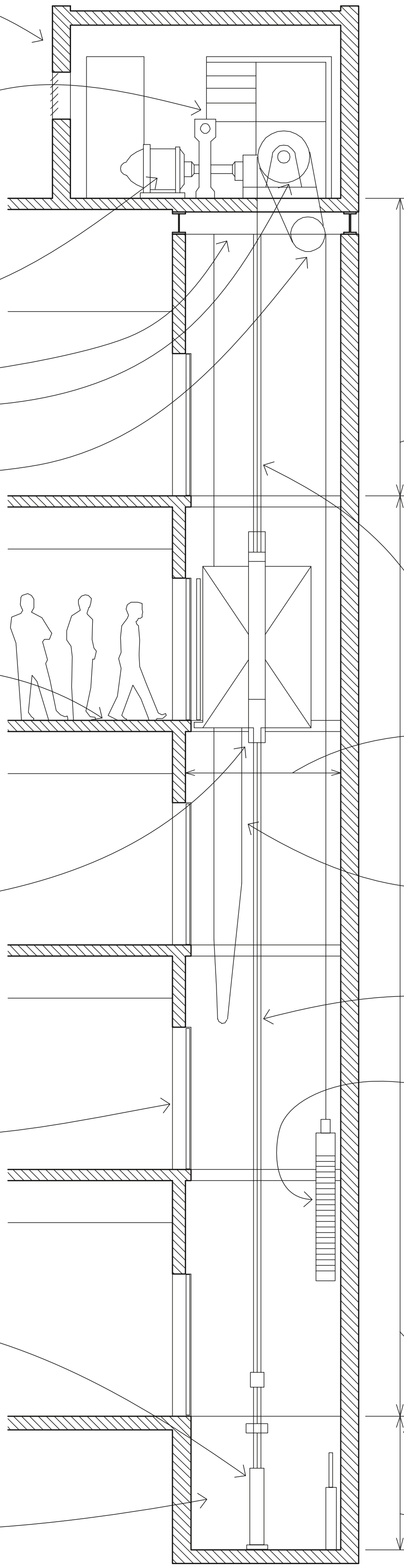
*Consult manufacturer's literature to verify these dimensional guidelines. See BS 5395 for more information

Stair Diameter	Well Opening	Landing Size	Width Pole to Rail	Centre Pole/ Base Plate Diameter
1525 mm	1625 mm	815 mm	660 mm	100/305 mm
1625 mm	1725 mm	865 mm	710 mm	100/305 mm
1830 mm	1930 mm	965 mm	815 mm	100/305 mm
1930 mm	2030 mm	1015 mm	865 mm	100/305 mm
2235 mm	2335 mm	1170 mm	1015 mm	150/305 mm
2440 mm	2540 mm	1270 mm	1115 mm	150/305 mm

Elevators travel vertically to carry passengers, equipment and goods from one level of a building to another. The two most common types are electric elevators and hydraulic elevators.

Electric Elevators

Electric elevators consist of a car that is mounted on guide rails, supported by hoisting cables and driven by electric hoisting machinery in a penthouse. Geared traction elevators are capable of speeds up to 1.75 m/s and are suitable for medium-rise buildings. Gearless traction elevators are available with speeds up to 6 m/s and typically serve high-rise buildings.



- A machine room houses lift machinery located on the rooftop
- A control panel contains switches, buttons and other equipment for regulating the hoisting machinery
- The hoisting machinery for raising and lowering an elevator car consists of a motor-generator set, traction machine, speed governor, brake, driving sheave, and gears, if used
- Heavy steel machine beams support the hoisting machinery for an elevator
- Driving sheave is the hoisting pulley
- Idle sheave tightens and guides the hoisting cables of the elevator system
- Landing is the portion of a floor adjacent to an elevator hoistway, used for the receiving and discharge of passengers or goods
- Elevator car safety is a mechanical device for slowing down and stopping an elevator car in the event of excessive speed or free fall, activated by a governor and clamping the guide rails by a wedging action
- Elevator doors between a well and an elevator landing are normally closed except when an elevator car is stopped at the landing; 2100 and 2400 mm heights are typical
- Buffer is the piston or spring device that absorbs the impact of a descending elevator car or counterweight at the extreme lower limit of travel
- Elevator well is the portion of the shaft that extends from the level of the lowest landing to the floor of the hoistway

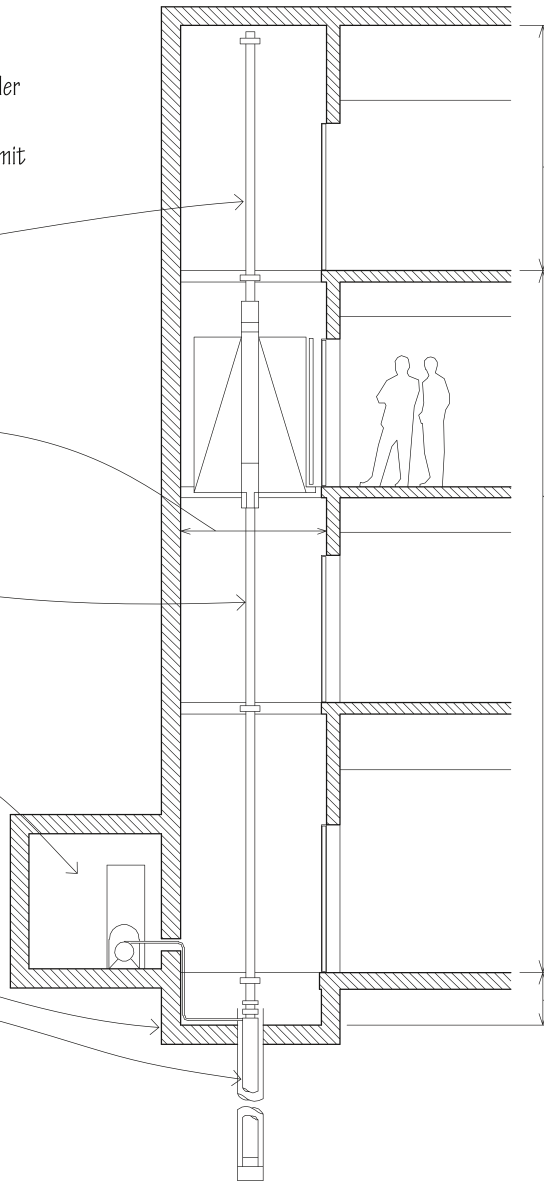
- 4875–6095 mm
- Top floor
- Hoisting cable is one of the wire cables or ropes used for raising and lowering an elevator car
- Well is the vertical enclosed space for the travel of one or more elevators
- Travelling cable is one of the electric cables connecting an elevator car to a fixed electrical outlet in the hoistway
- Guide rails are the vertical steel tracks controlling the travel of an elevator car or counterweight; they are secured to each floor with support brackets
- Counterweights are rectangular cast-iron blocks mounted in a steel frame to counterbalance the load placed on the hoisting machine by an elevator car
- A limit switch automatically cuts off current to an electric motor when an elevator car has passed a given point
- Rise or travel is the vertical distance covered by an elevator car from the lowest to the highest landings of the hoistway
- Bottom floor
- 1500–3500 mm

9.14 ELEVATORS

Hydraulic Elevators

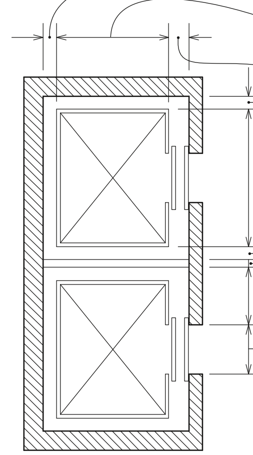
Hydraulic elevators consist of a car supported by a piston that is moved by or moves against a fluid under pressure. Rooftop housing is not required, but the hydraulic elevator's lower speed and piston length limit its use to buildings up to six storeys in height.

- Guide rail
- Well of fire-resistant construction must extend to the underside of a fire-resistant roof
- Hydraulic piston
- Machine room houses the hoisting machinery, control equipment and sheaves for raising and lowering an elevator car; a location at or near the bottom landing is preferred
- Elevator well
- Piston cylinder well; depth equals rise or travel + 1200–2100 mm
- These dimensional guidelines are for preliminary planning only. Consult the elevator manufacturer for specific sizes, capacities and dimensional and structural support requirements



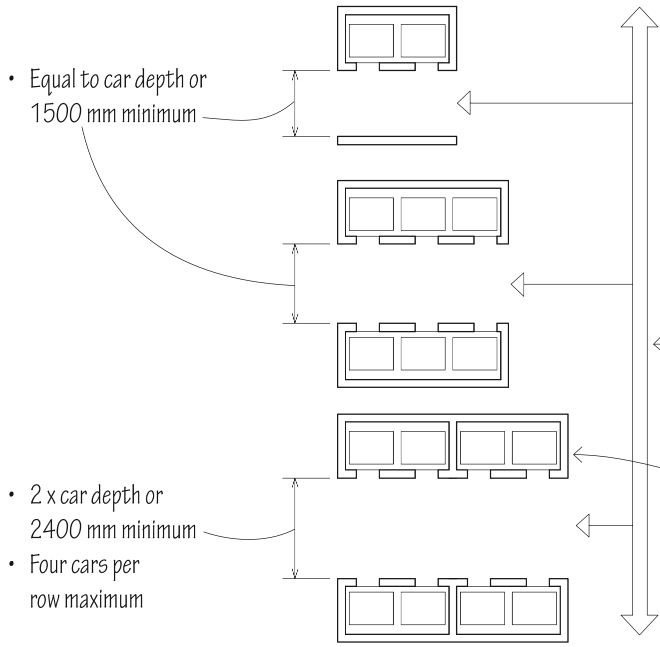
ISO 4190 classifies lifts according to their usage:

- Class I: Transport of persons
- Class II: Persons and goods
- Class III: Healthcare purposes
- Class IV: Transport of goods
- Class V: Service lift
- Class VI: High-speed lifts



Elevator Car Dimensions

ISO 4190-1: 2010 Lift Installation



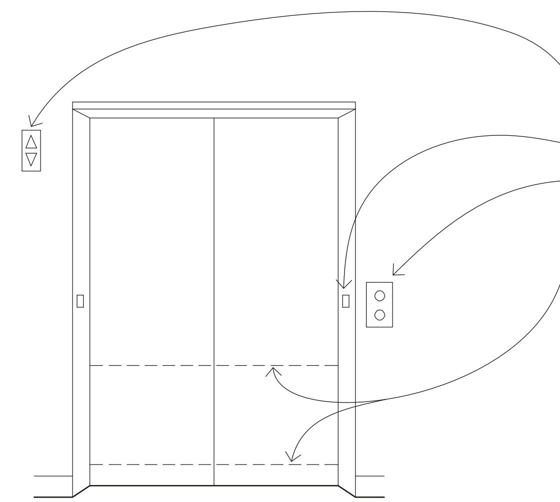
Elevator Layout

The type, size, number, speed and arrangement of elevators are determined by:

- Type of occupancy
- Amount and tempo of traffic to be carried
- Total vertical distance of travel
- Round-trip time and speed desired

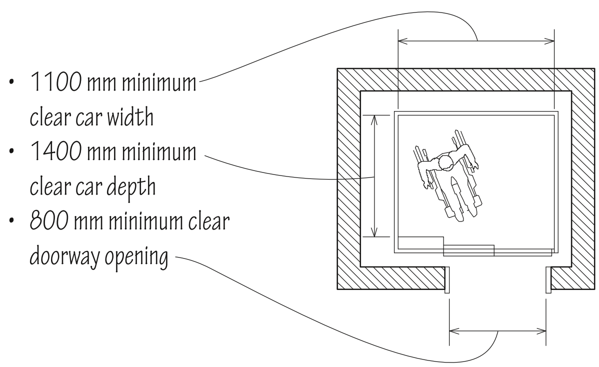
- Banks or rows of elevators in a high-rise building are controlled by a common operating system and respond to a single call button
- Elevators should be centrally located near the main entrance to a building and be easily accessible on all floors, but also be placed off the main circulation path
- Two or more wells are required for four or more elevators

- Consult elevator manufacturer for recommended type, size, layout, controls, and installation requirements and details
- Consult the building regulations for structural requirements and shaft requirements for fire separation, ventilation and soundproofing



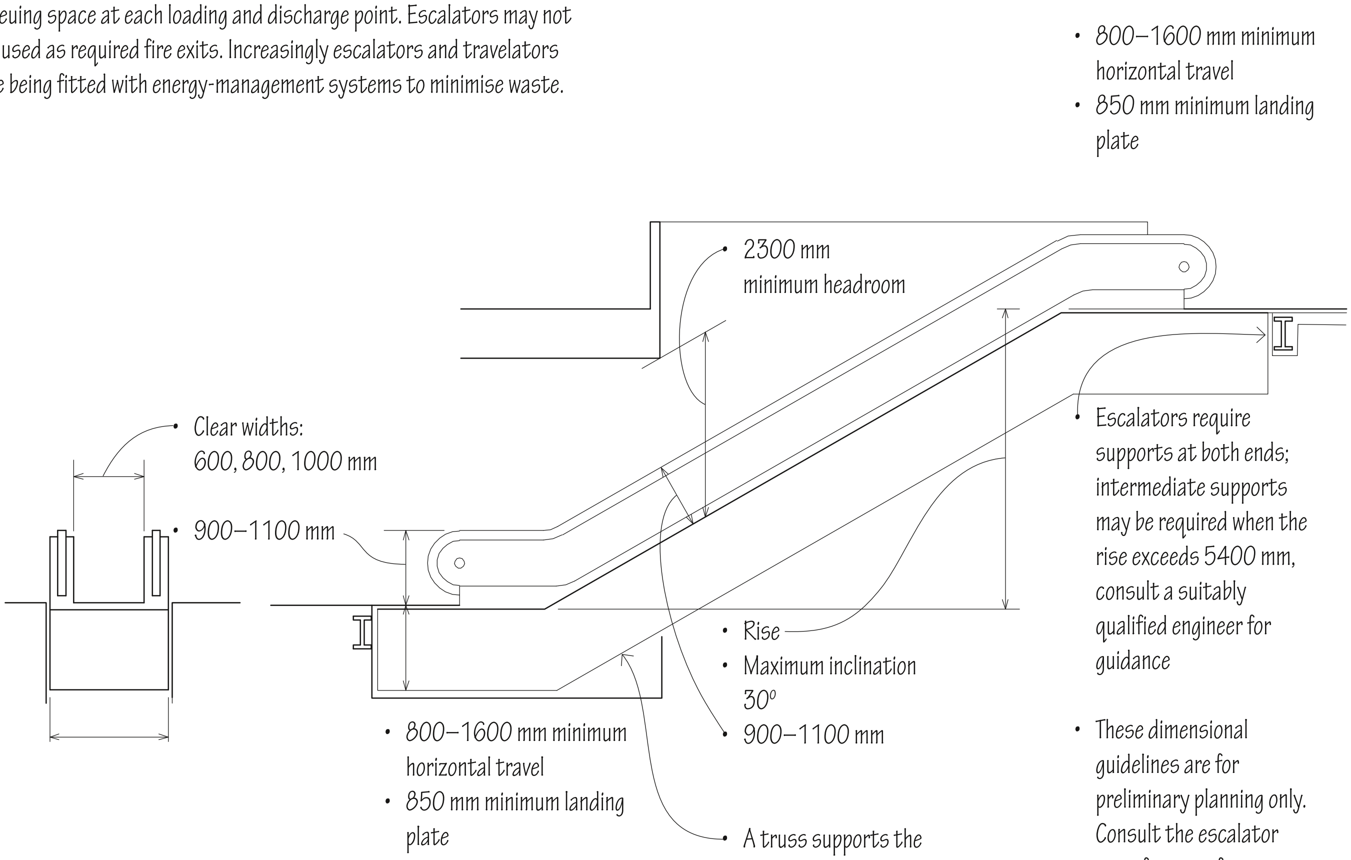
Accessibility Guidelines

- Visible and audible call signals should be provided inside and outside the lift
- Sign showing storey with braille and tactile lettering
- Call buttons for requesting an elevator should be centred between 900 and 1100 mm above the floor in each elevator lobby
- Elevator doors should be provided with an automatic reopening device if the door becomes obstructed by an object or person



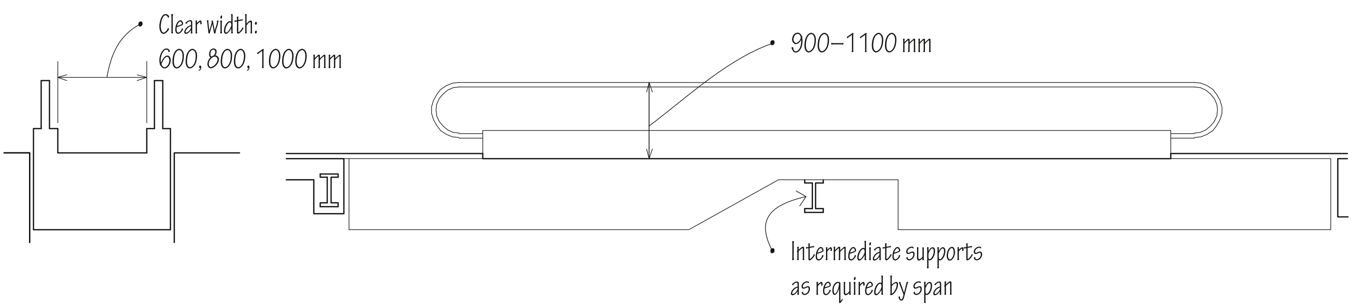
9.16 ESCALATORS

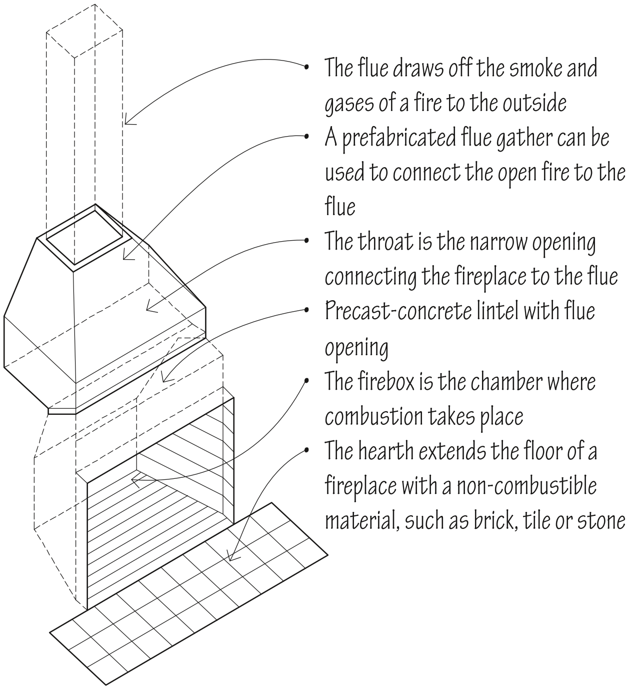
Escalators are power-driven stairways consisting of steps attached to a continuously circulating belt. They can move a large number of people efficiently and comfortably between a limited number of floors; six floors are a practical limit. Because escalators move at a constant speed, there is practically no waiting period, but there should be adequate queuing space at each loading and discharge point. Escalators may not be used as required fire exits. Increasingly escalators and travelators are being fitted with energy-management systems to minimise waste.



• These dimensional guidelines are for preliminary planning only. Consult the escalator manufacturer for specific sizes, capacities and dimensional and structural support requirements

• Moving walkways or travelators are power-driven, continuously moving surfaces, similar to a conveyor belt, used for carrying pedestrians horizontally or along low inclines

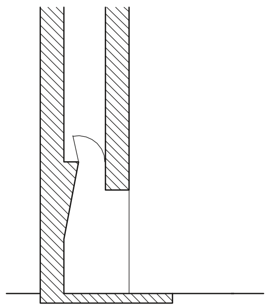




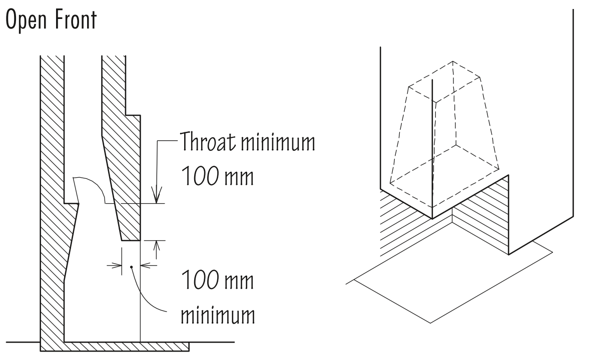
A fireplace is a framed opening in a chimney to hold an open fire. It must be designed and constructed to:

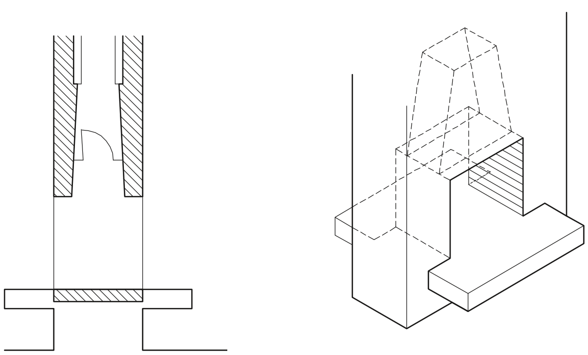
- Sustain the combustion of fuel
- Draw properly to carry smoke and other combustive by-products to the outside
- Radiate the maximum amount of heat comfortably into the room
- Ensure proper distances from combustible materials

Thus the dimensions and proportions of a fireplace and its flue, and the arrangement of its components, are subject to the laws of nature and the requirements of the building regulations.



Open Front





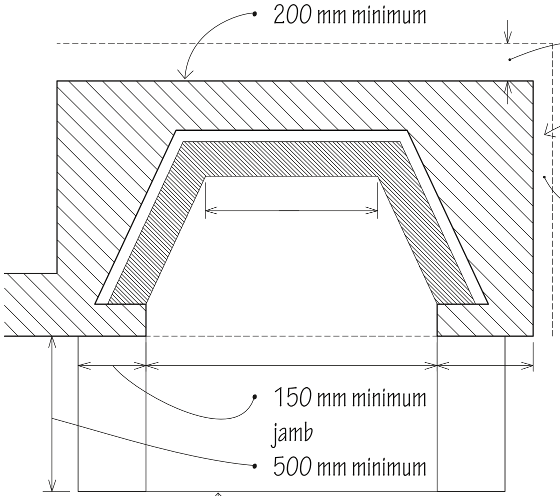
Open Front and Back

Types of Fireplaces

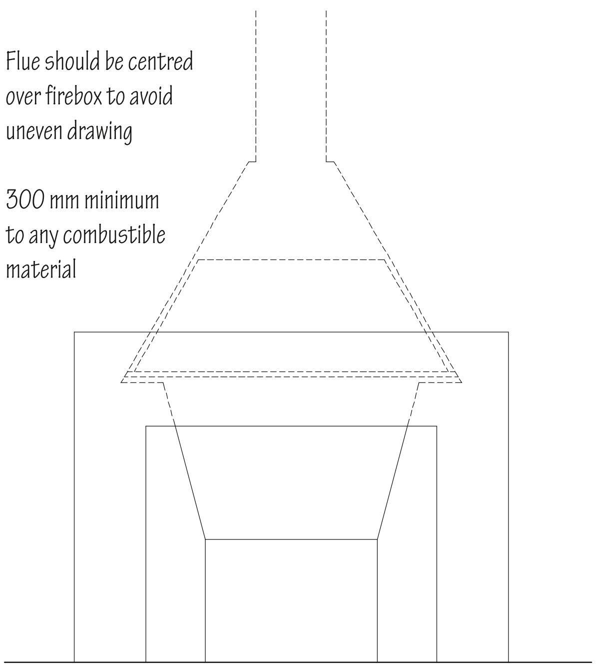
Traditional open fireplaces have been found to be an inefficient mechanism for providing space heating with only 40–50% of useful heat generated being used in the room. As a result room-sealed appliances are favoured.

- Open fireplace, combustion air drawn from the room with ventilation provided to allow for combustion air
- Room-sealed appliance, combustion air drawn from a dedicated supply

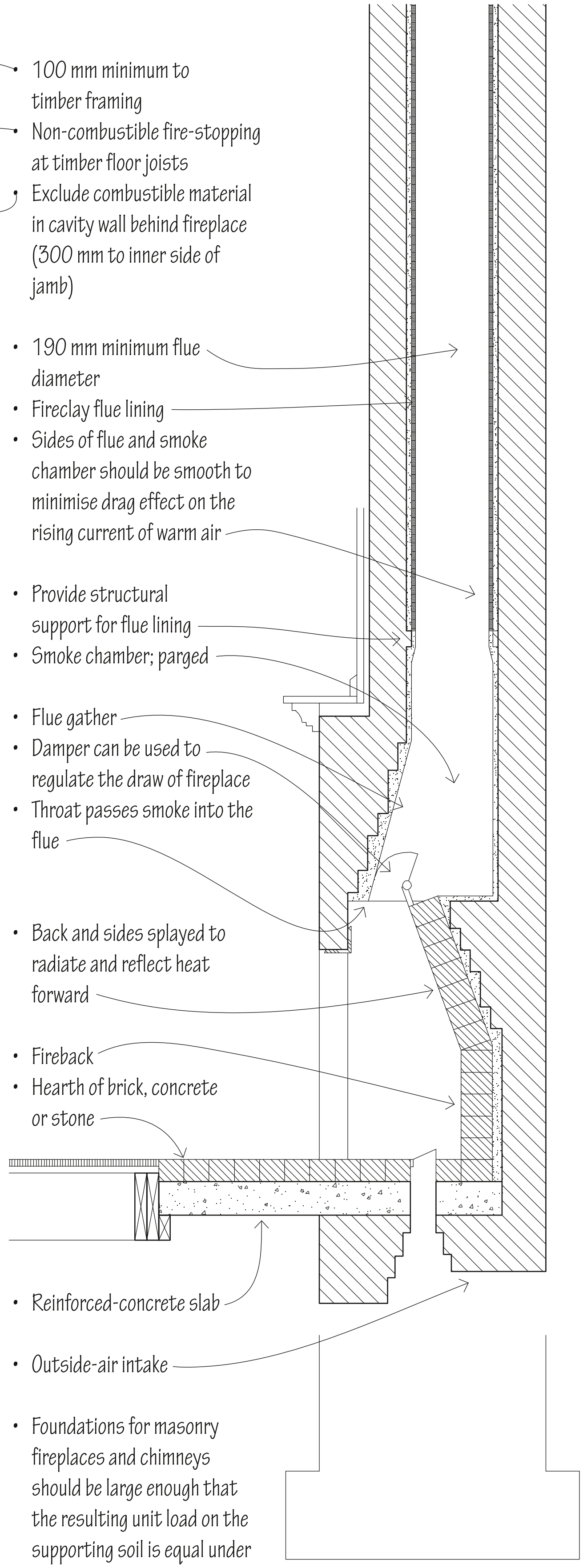
9.18 FIREPLACE REQUIREMENTS



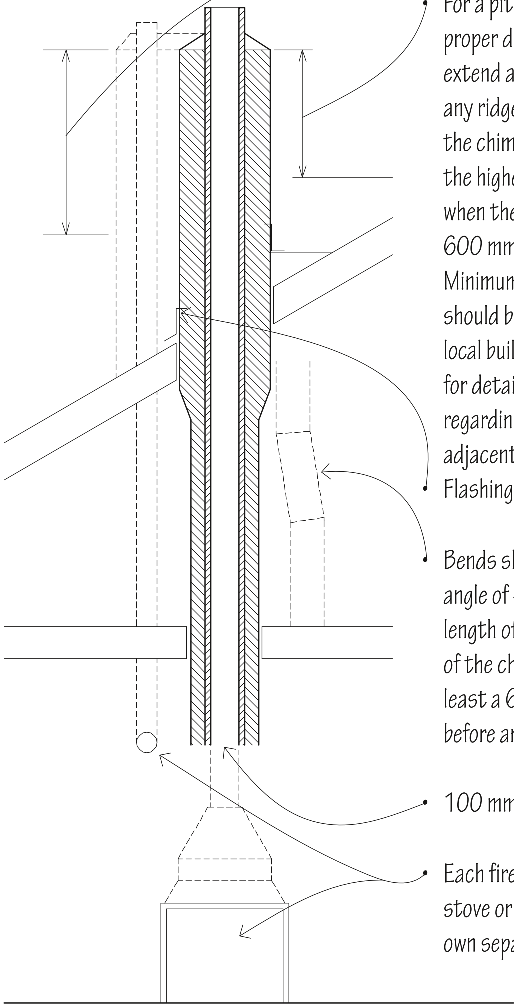
Fireplace Plan



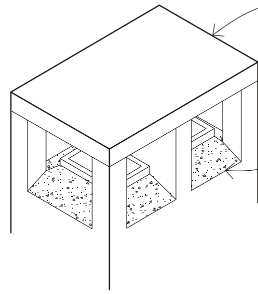
Fireplace Elevation



Fireplace Section

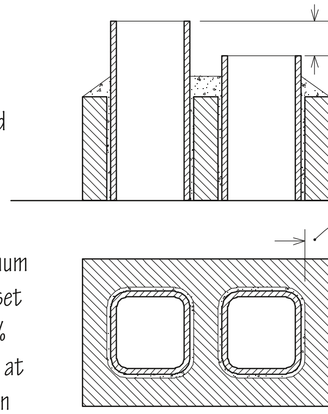


- 1 m minimum above flat roof
- For a pitched roof to ensure proper draw, chimney should extend at least 600 mm above any ridge within 600 mm of the chimney or 1 m above the highest point of contact when the ridge is more than 600 mm from the chimney. Minimum total flue height should be 4.5 m. Consult local building regulations for detailed requirements regarding roof openings and adjacent buildings
- Flashing
- Bends should have a maximum angle of 45°, maximum offset length of no more than 20% of the chimney length, with at least a 600 mm vertical run before any offset
- 100 mm minimum
- Each fireplace, wood-burning stove or furnace requires its own separate flue



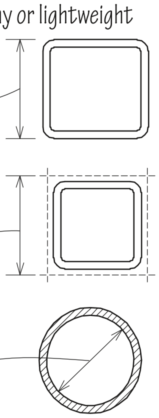
- Chimney pot or stone/precast-concrete cap
- Reinforced-cement wash to drain rainwater

Chimney Hood



- Flue lining stands free of surrounding masonry; lining should have close fitting joints and be left smooth on the inside
- 100 mm minimum; 200 mm when to adjoining dwelling
- Consult building regulations and specialist guidelines for chimney requirements of high-heat appliances such as incinerators

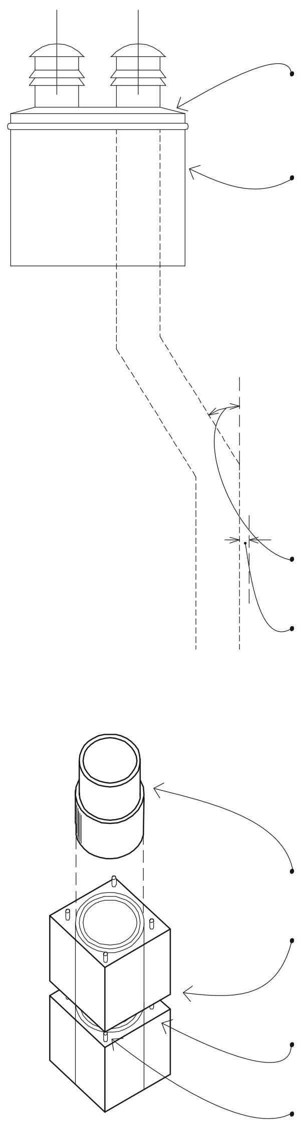
- Flue linings are smooth-surfaced units of heat-resistant fire clay or lightweight concrete

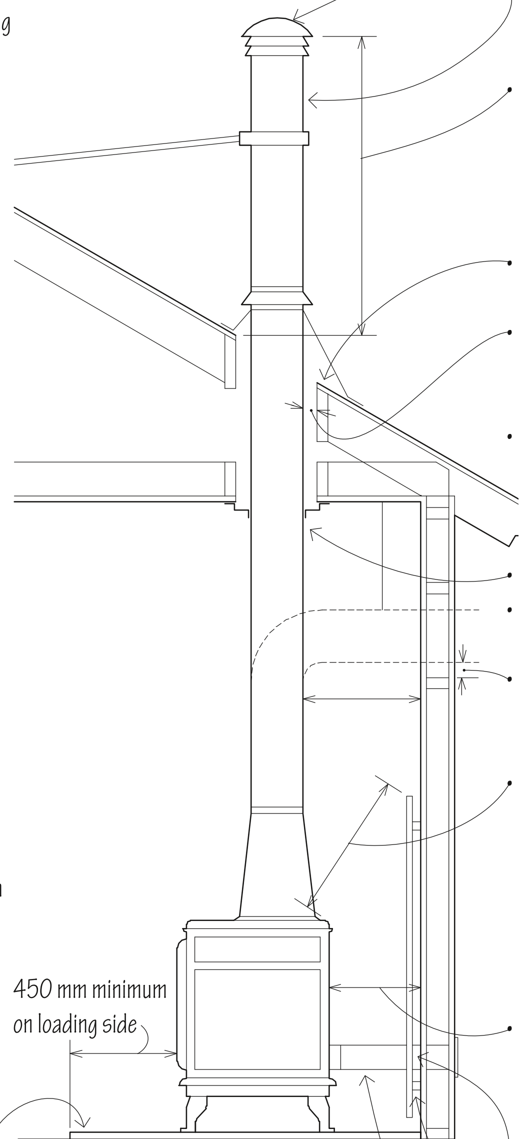


- Rectangular flues
- Modular flues
- Circular flues

Minimum Flue Sizes
- 500 x 550 mm fireplace openings; minimum 200 mm diameter
- Fireplace openings in excess of 500 x 550 mm; 15% of total face area but not less than 200 mm diameter

Prefabricated fireplaces and wood-burning stoves should have a declared efficiency tested against relevant European Standards.





• Verify installation details and requirements with stove manufacturer and building regulations

• Appliances with outputs greater than 75kW require the provision of permanent ventilation

Prefabricated Systems

Wood-Burning Stove

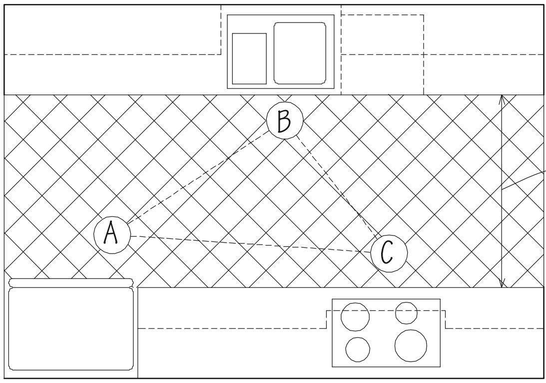
These plans illustrate the basic types of kitchen layouts. They can be readily adapted to various structural or spatial situations, but they are all based on a work triangle that connects the three major kitchen centres:

(A) Refrigerator centre for receiving and preparing food
(B) Sink centre for food preparation and clean up
(C) Cooker/hob centre for cooking and serving

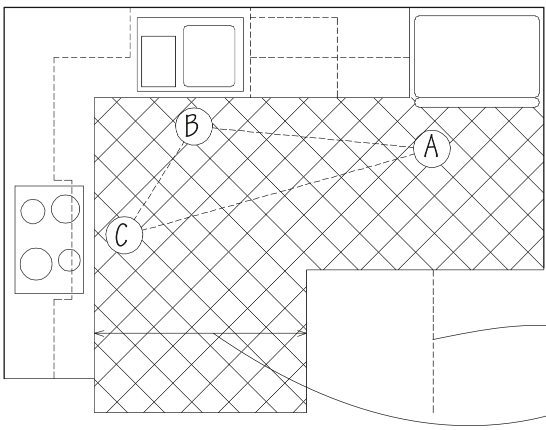
The sum of the sides of the triangle should be not more than 6600 mm nor less than 3300 mm.

Additional factors to consider in laying out a kitchen space include:

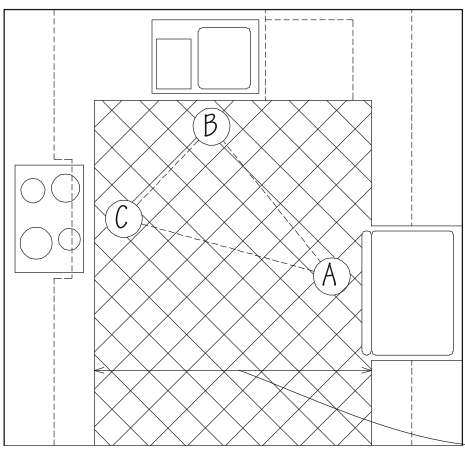
- Amount of counter space and work surfaces required
- Type and quantity of under-counter and overhead storage required
- Requirements for natural light, views and ventilation
- Type and degree of access desired
- Degree of enclosure envisioned for the space
- Integration of electrical, plumbing and mechanical systems



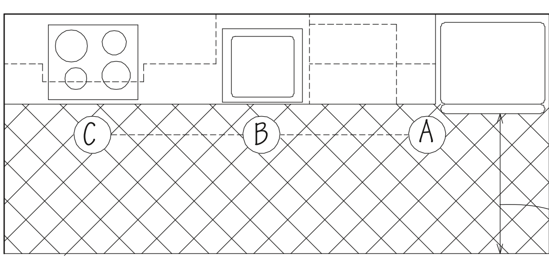
Parallel Walls



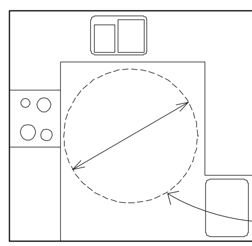
L-Shape



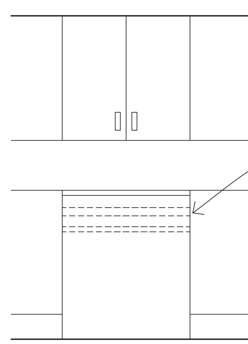
U-Shape



Single Wall



- Provide a 1500 mm minimum diameter space for turning a wheelchair in U-shaped kitchens to be used by wheelchair users
- Consult local building regulations for specific requirements

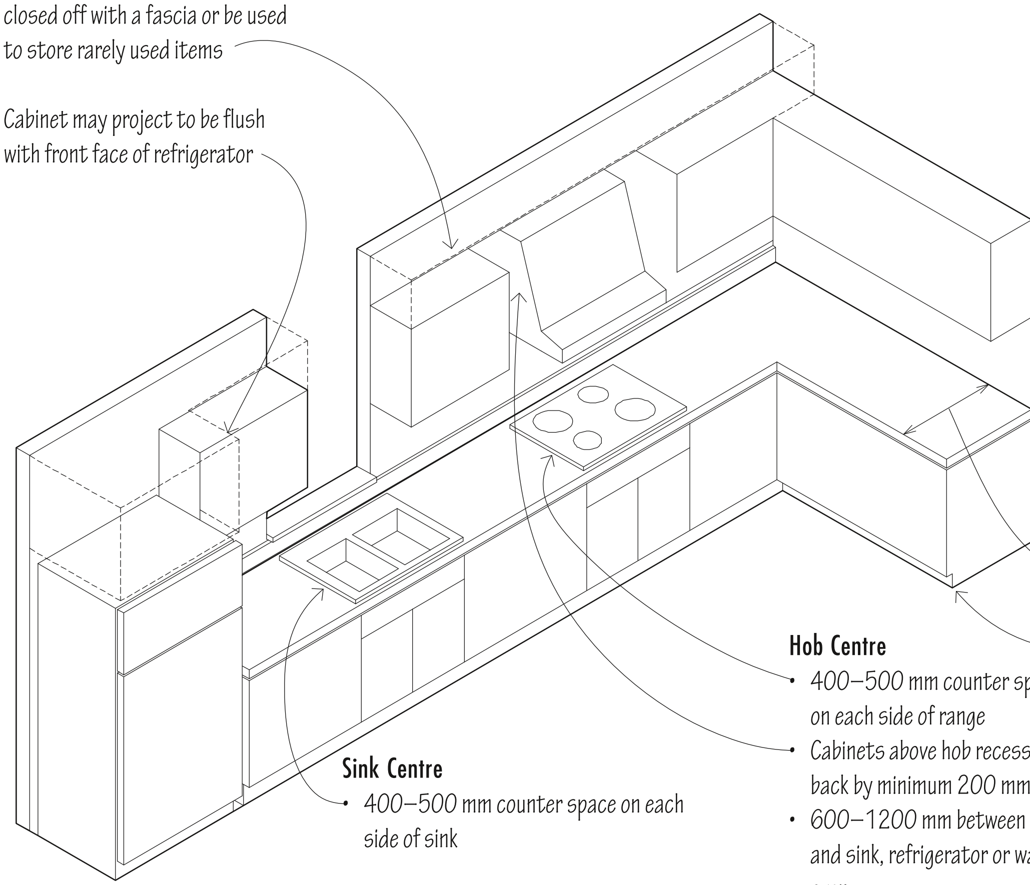


- Provide counter space and units at an appropriate level to ensure accessibility
- See also A.03 for general accessibility requirements

Accessibility Guidelines

9.22 KITCHEN DIMENSIONS

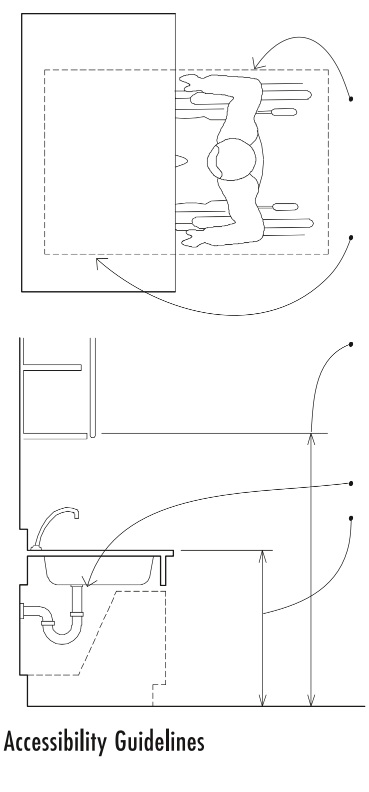
- Space above cabinets may be closed off with a fascia or be used to store rarely used items
- Cabinet may project to be flush with front face of refrigerator



- 450 mm minimum clearance above counter
- 950 mm typical counter height
- 600 mm typical counter depth
- 100 mm recessed plinth

Hob Centre
- 400–500 mm counter space on each side of range
- Cabinets above hob recessed back by minimum 200 mm
- 600–1200 mm between hob and sink, refrigerator or wall oven

Sink Centre
- 400–500 mm counter space on each side of sink



Accessibility Guidelines

- 760 x 1200 mm minimum clear floor space should be provided at sink, accessible work surface and all appliances
- Clear floor space may extend up to 480 mm under the sink, accessible work surface or appliance
- At least one shelf of all cabinets mounted above work counters should be no more than 1200 mm above the floor
- 150 mm maximum depth of bowl
- Rim of sink and surrounding counter should be adjustable in height from 700 to 900 mm, or be fixed at a height of 850 mm

See local regulations for detailed guidance

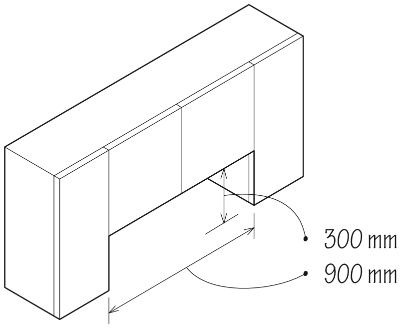
Appliances

Verify appliance dimensions when planning a kitchen layout. For preliminary planning purposes, the following range of widths can be used:
- Hob: 840–1100 mm
- Refrigerator: 600–1500 mm
- Dishwasher: 600 mm
- Sink: 800–1200 mm

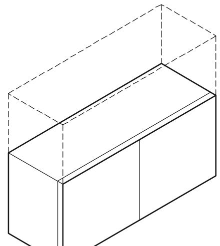
- Counter dimensions should be coordinated with standard cabinet sizes; see 9.23

Kitchen cabinets may be constructed of timber or enamelled steel. Timber cabinets usually have hardwood frames and plywood or particle-board panels with plastic laminate, hardwood veneer or lacquer finishes.

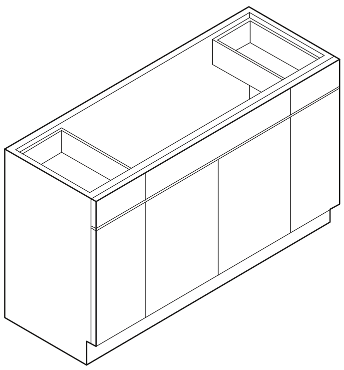
Prefabricated kitchen cabinets are manufactured in industry standard sizes. There are three basic types of units: base units, wall units and special units. Consult manufacturer for available sizes, finishes, hardware and accessories.



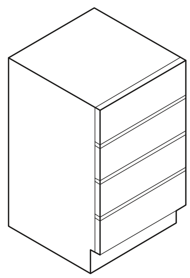
Combination Wall Unit
- For use over sinks
- 1400–2100 mm long
- 750 mm high



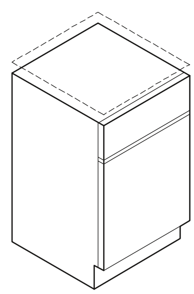
Basic Wall Unit
- 400–1200 mm long in 75 mm increments
- 300–750 mm high



Sink Base Unit

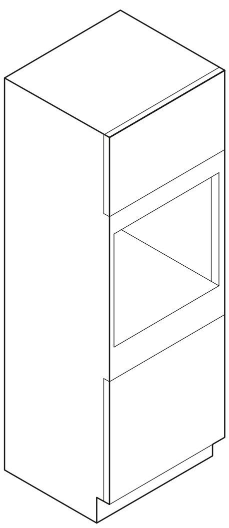


Drawer Unit
- 400–600 mm wide

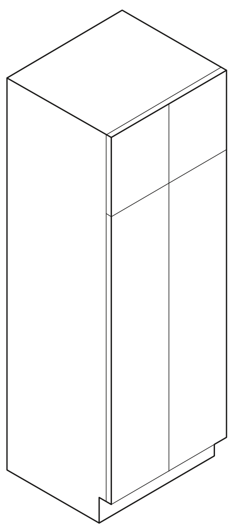


Basic Base Unit
- 400–600 mm wide for one-door units
- 600 mm deep

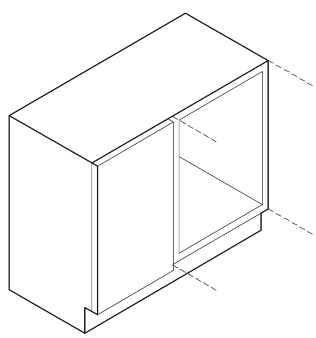
- 870–910mm tall base units with counters up to 38 mm thick
- Base units for bathroom vanities are 870 mm high and 430 mm deep



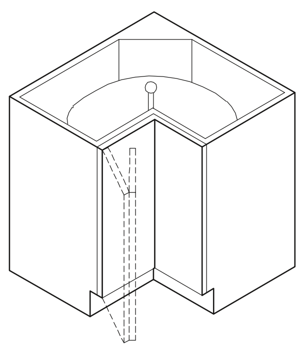
Wall Oven Unit
- 600 mm wide
- 2300 mm tall



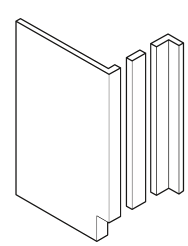
Utility Closet or Pantry Unit
- 300 and 600 mm depths



Base Corner Unit
- 800–1200 mm long



Base Corner Unit
- 1000–1200 mm long



- Finished end and filler panels are available

Ventilation

- A natural ventilation system or continuous mechanical ventilation system may be employed to provide background ventilation
- Purge ventilation can be provided to the kitchen by means of an opening window section. The opening section should provide a clear ventilation area of at least $^1/_{20}$ of the floor area

Cooker may be ventilated by a hood with an exhaust fan:

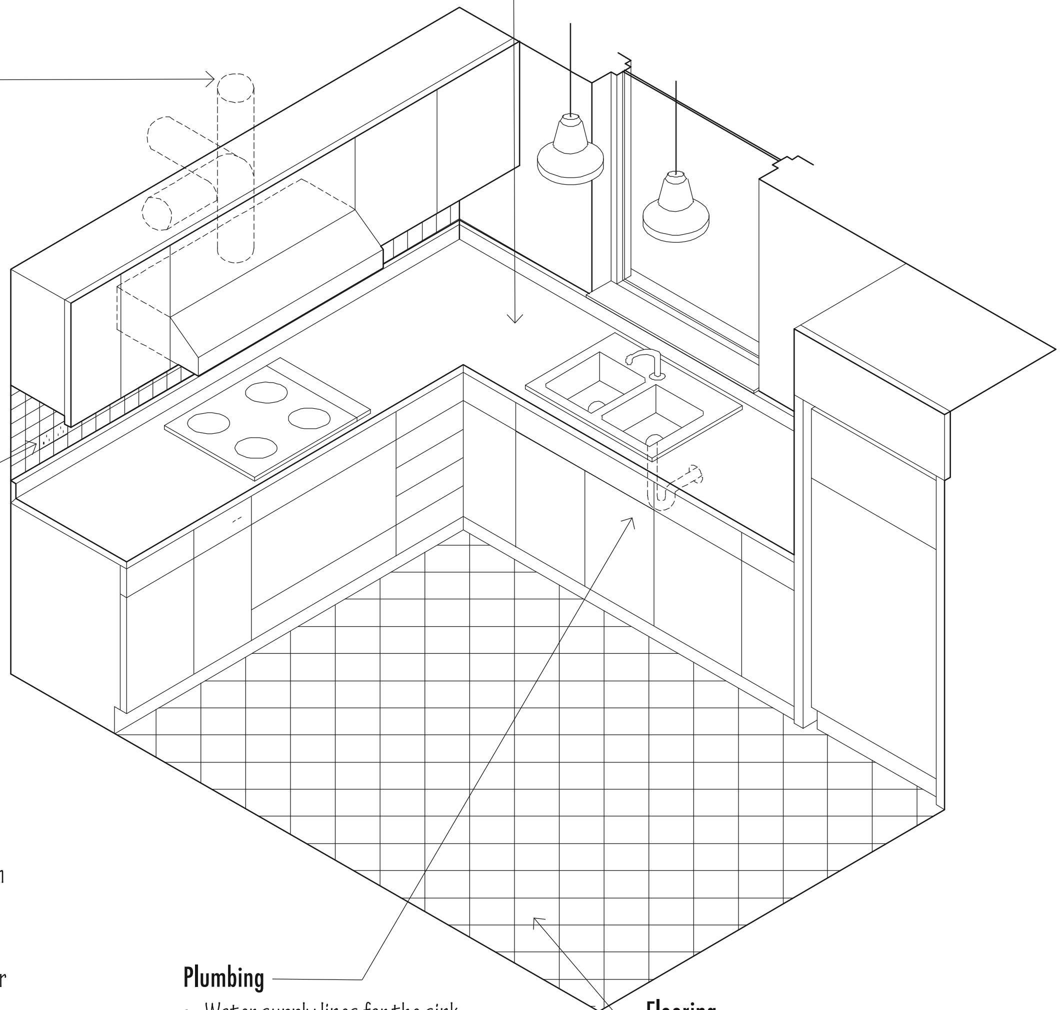
- Vertically through roof
- Directly through exterior wall
- Horizontally to outside through soffit above wall cabinets
- Alternatively, where it is not possible to connect externally, a recirculating fan with a filter may be used

Counter Surfaces

- The counter surface may be plastic laminate, butcher block, ceramic tile, marble or granite, synthetic stone, concrete or stainless steel
- Provide a heat-resistant surface next to the range

Lighting

- Provide natural light by means of exterior glazed openings with an area not less than 20% of the floor area
- In addition to general area lighting, task lighting may be required over each of the work centres and over counters



Electrical

- A dedicated circuit for small appliances should be provided to the kitchen with outlets at least 150 mm above the counter. These circuits should be protected by a residual current device (RCD) and miniature circuit breaker (MCB)
- Single-outlet circuits are required for permanently installed appliances such as electric hobs and ovens
- Separate circuits are also required for appliances such as the refrigerator and washing machine

Plumbing

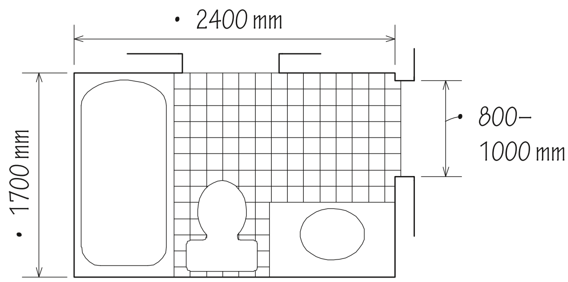
- Water supply lines for the sink and dishwasher are required
- Waste lines for the sink, waste disposal unit and dishwasher are required
- See 11.23–11.29

Heating

- Underfloor heating may be utilised due to the limited availability of wall space

Flooring

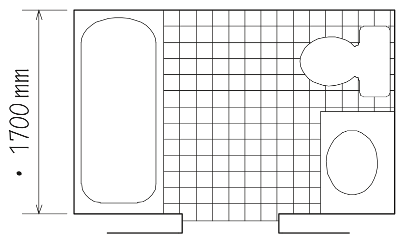
- Flooring should be slip-resistant, durable, easy to maintain and resistant to water and grease

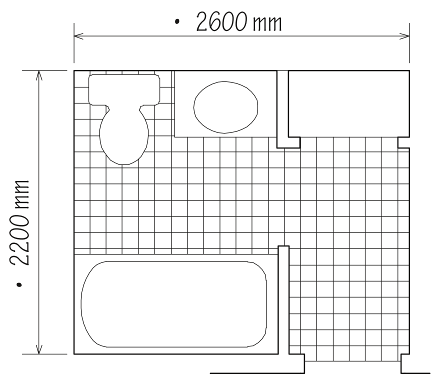


These bathroom plans illustrate basic layouts and relationships, which can be adjusted to suit specific situations. Fixture spacing and clearances are important for safe and comfortable movement within a bathroom space. Recommended dimensions can be perceived through the study of these plans and the drawings on the following page. The overall dimensions of a bathroom will vary according to the actual sizes of the fixtures used.

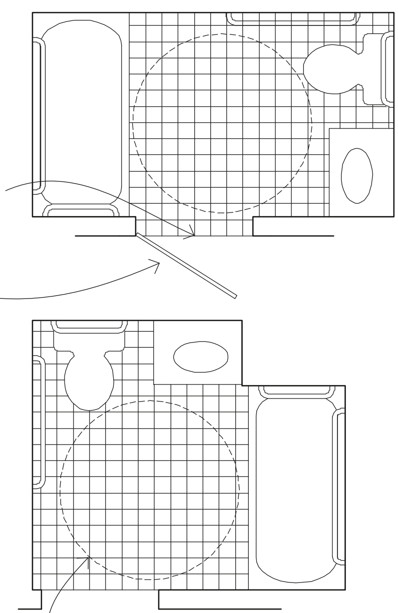
The layout of bathrooms and other washroom facilities should also take into account the:

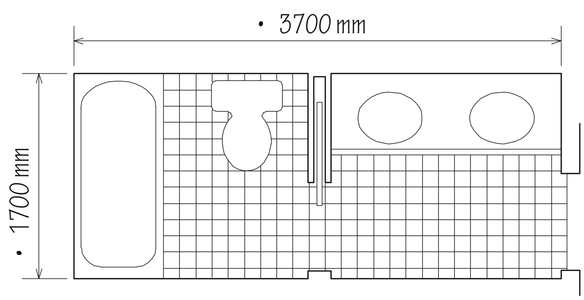
- Space for and locations of accessories such as towel bars, mirrors and storage cabinets
- Number of plumbing walls required and the location of stacks, vents and horizontal runs

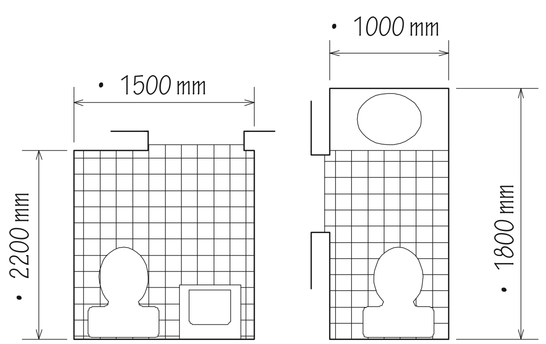


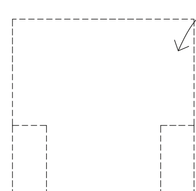


- Doorway should have a minimum clear opening width of 800–1000 mm depending on approach and configuration
- Door should not swing into the required clear floor space









- Wheelchair-accessible bathrooms are required to allow for manoeuvring and a clear 1500 x 1500 mm turning circle for a wheelchair. Facilities for the ambulant disabled should include a 750 mm space clear of any door swing or sanitary fittings
- Wheelchair-accessible toilets are required to allow for manoeuvring and transfer space around the WC
- In domestic buildings, facilities accessible to the ambulant disabled should be provided on the ground floor
- See 9.27–9.28 for accessible fixture requirements
- See A.03 for general accessibility guidelines

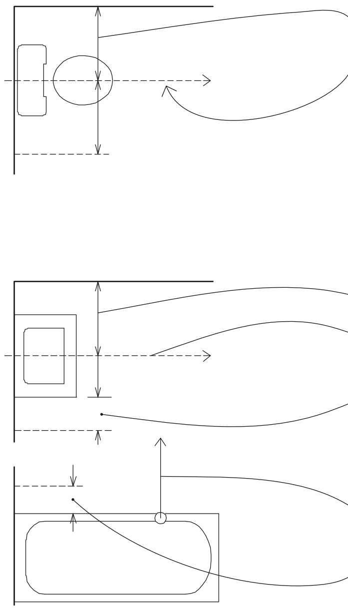
Accessibility Guidelines

9.26 PLUMBING FIXTURES

The range of fixture dimensions given below is for preliminary planning purposes only. Consult the fixture manufacturer for actual dimensions of specific models.

Plumbing fixtures may be made of the following materials:

- Water closets, urinals and bidets: vitreous china
- Lavatories, bathtubs and utility sinks: vitreous china, enamelled cast iron, enamelled steel
- Shower receptacles: terrazzo, enamelled steel
- Shower enclosures: enamelled steel, stainless steel, ceramic tile, fibreglass
- Kitchen sinks: enamelled cast iron, enamelled steel, stainless steel

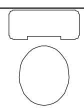
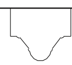
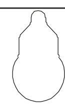


Water Closet
- 500 mm to side wall
- 750 mm minimum to opposite wall from edge of fixture

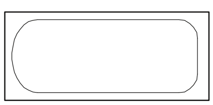
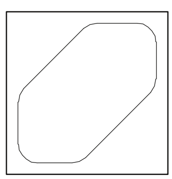
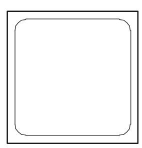
Lavatory
- 550 mm to side wall; 400 mm minimum
- 750 mm to opposite wall from edge of fixture
- 150 mm to fixture; 50 mm minimum

Bathtub
- 900 mm to opposite wall
- 200 mm to fixture; 50 mm minimum

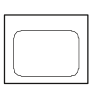
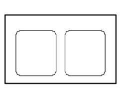
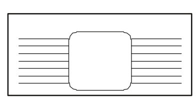
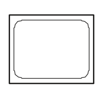
Fixture Clearances

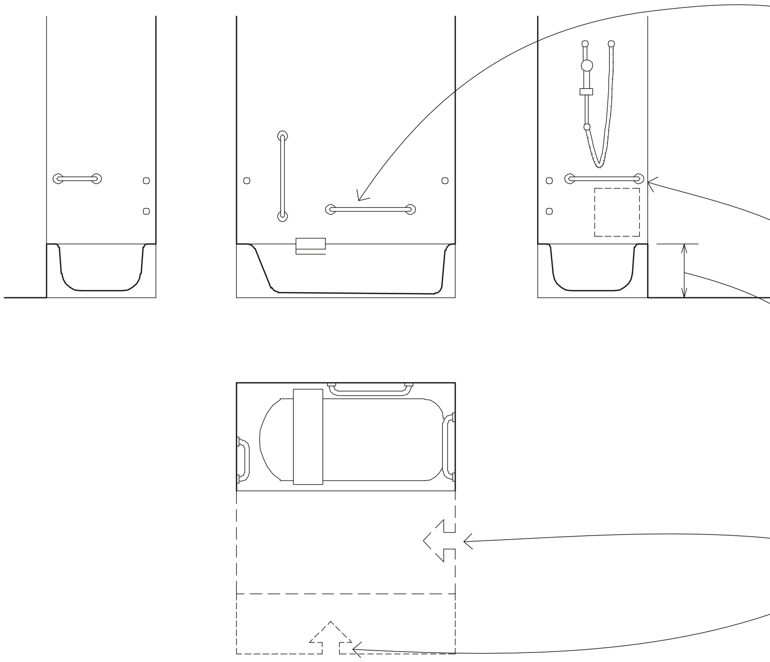
	Water Closet	Urinal	Bidet
Width	510–610 mm	455 mm	355 mm
Depth	560–735 mm	305–610 mm	760 mm
Height	510–710 mm	610 mm rim height	355 mm

	Bathtub	Square Bathtub	Shower
Width	1500–1800 mm	1120–1400 mm	800–1400 mm
Depth	760–815 mm	1120–1400 mm	800–1400 mm
Height	305–510 mm	30–400 mm	1800–2000 mm

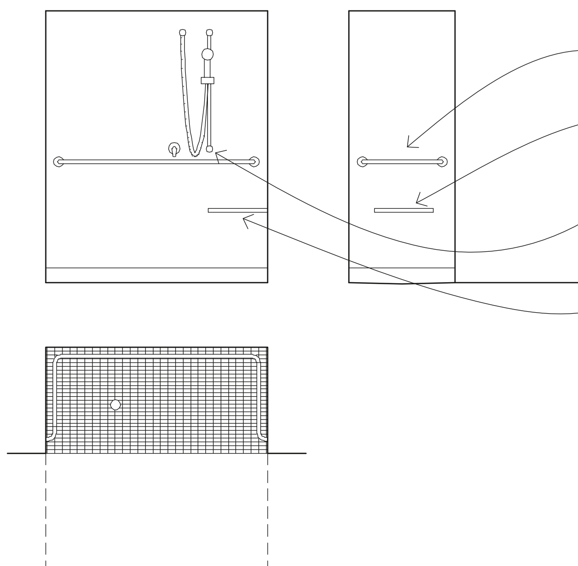
	Single-Bowl Sink	Double-Bowl Sink	Sink with Drainboards	Utility Sink
Width	330–840 mm	710–1170 mm	1200–2200 mm	560–1220 mm
Depth	330–600 mm	405–600 mm	540–650 mm	450–560 mm
Height	205–305 mm	205–255 mm	205 mm	600–800 mm



Bathtubs

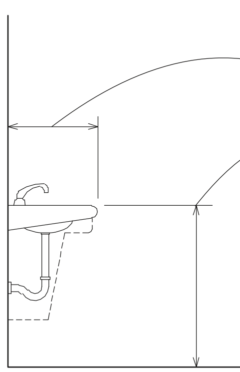
- A horizontal grab rail should be provided 75–100 mm above the top line of the bath. Where installed for wheelchair accessibility, the rail should extend a minimum of 250 mm beyond the head of the bath to overlap with any transfer seat provided. A 500 mm tall vertical grab rail should also be provided at a distance of 600 mm from the end wall and 200 mm above the top of the bath
- Additional grab rails should be provided where showering facilities are provided
- In non-dwellings an alarm pull cord should be provided
- Rim of tub should be (450–480 mm) above the floor
- Diameter or width of grab bars should be 32–35 mm with 50–60 mm space between the grab bar and the wall

- A 1500 x 1500 mm turning space should be provided in wheelchair-accessible bathrooms



Showers

- Horizontal shower rail
- Tilt up shower seat
- Vertical shower rod 500 mm from adjacent wall and allowing for adjustable shower-head height of 1050–1850 mm
- Shower controls 750–1000 mm above finished floor level



Sinks

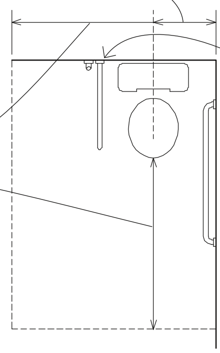
- 450 mm maximum extension from wall
- 720–800 mm rim height of sink above the floor
- 600 mm vertical grab rails each side of mirror in wheelchair-accessible bathrooms and shower rooms

- Consult local building regulations for more detailed guidance

9.28 ACCESSIBLE FIXTURES

Water Closets

- Water closets should be mounted adjacent to a wall or partition. The distance from the centre line of the water closet to the wall or partition should be 500 mm
- Top of toilet seat should be 480 mm above the floor
- 1200 mm minimum clear floor space in front of water closet and 1000 mm from the centre line of the water closet on the side not adjacent to a wall

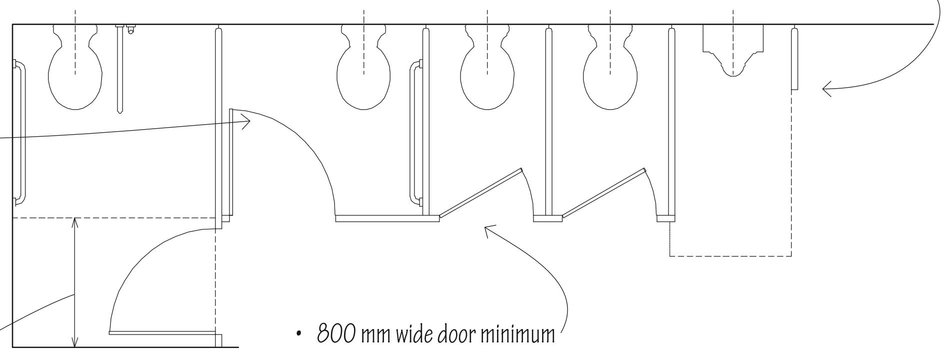


- Grab bars should be mounted in a horizontal position 680 mm above the floor, on the side wall closest to the water closet
- Diameter or width of grab bars should be 32–35 mm with 50–60 mm space between the grab bar and the wall
- Drop-down grab rail provided 320 mm from the centre line of the WC
- Vertical grab rail provided beside drop-down rail and at a distance of up to 470 mm from the centre line of the WC

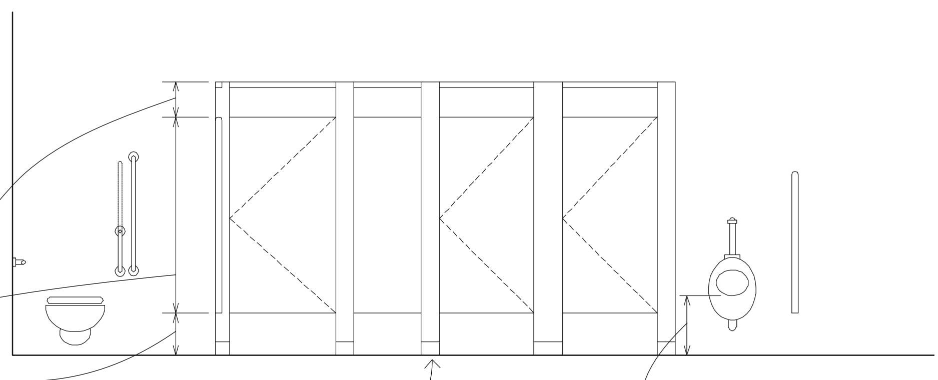
Toilet Cubicles

- Wheelchair-accessible toilet cubicles should be at least 1500 mm wide and 2200 mm deep
- Grab bars should be mounted in a horizontal position 680 mm above the floor on the side wall closest to the water closet with a drop-down rail opposite, see details above
- Ambulatory-accessible cubicles should be at least 850 mm wide, 1500 mm deep, and provided with grab bars on both sides of the stall

- Screen walls should not extend beyond rim of urinal



- 800 mm wide door minimum



- 300 mm
- 1475 mm
- 300 mm

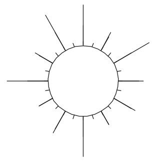
- Toilet partitions may be floor-mounted, wall-hung, or suspended from the overhead ceiling structure
- Metal partitions may have baked-enamel, porcelain-enamel or stainless-steel finishes
- Plastic laminate, tempered glass and marble panels are also available

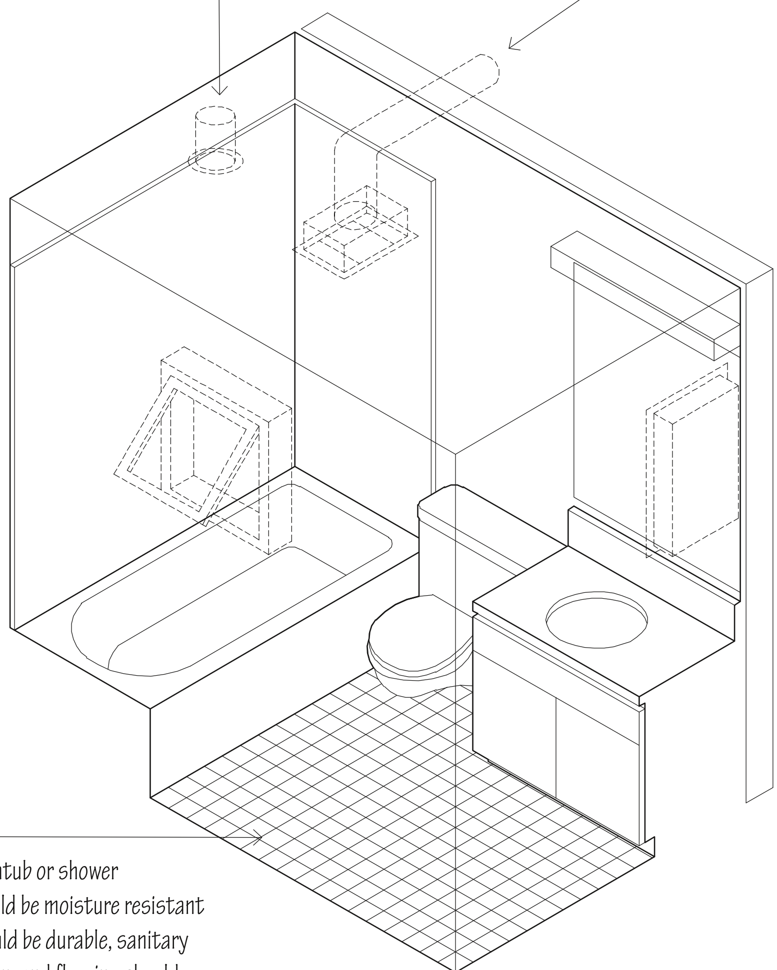
Urinals

- Stall type or wall-hung urinals should have a rim not more than 500 mm above the floor

Lighting

- Natural lighting by means of exterior glazed openings is always desirable
- A single overhead light fixture is usually not sufficient; auxiliary lighting may be required over the bath or shower and over the lavatory or sink
- The light fixture over the bath or shower should be resistant to water vapour





Finishes

- Backing for bathtub or shower enclosures should be moisture resistant
- All finishes should be durable, sanitary and easy to clean, and flooring should have a non-slip surface

Heating

- Heating may be supplied by underfloor heating, a hot towel rail, traditional radiators or a warm-air supply system

Ventilation

- Bathrooms require either natural or mechanical ventilation in order to purge the room of stale air and supply fresh air
- Provide natural purge ventilation by means of openable windows with a clear opening area not less than 1/20 of the floor area
- A mechanical ventilating system may be employed in lieu of natural ventilation
- The ventilating fan should be located close to the shower and high on an exterior wall opposite the bathroom door. It should be connected directly to the outside and be capable of providing an extract rate of 15l/s. The point of discharge should be at least 900 mm away from any opening that allows outside air to enter the building. Alternatively passive stack ventilation may be used with a humidity sensitive grill

Electrical

- Electrical services within a bathroom are closely controlled, generally no sockets or switches other than pull cords and shaving outlets can be provided within the bathroom
- Light fittings must be rated in accordance with the bathroom zone (Zone 0, 1, 2 ,3) which they are installed in; see BS EN 7671
- All convenience outlets should be protected by a dedicated residual current device (RCD); see 11.32

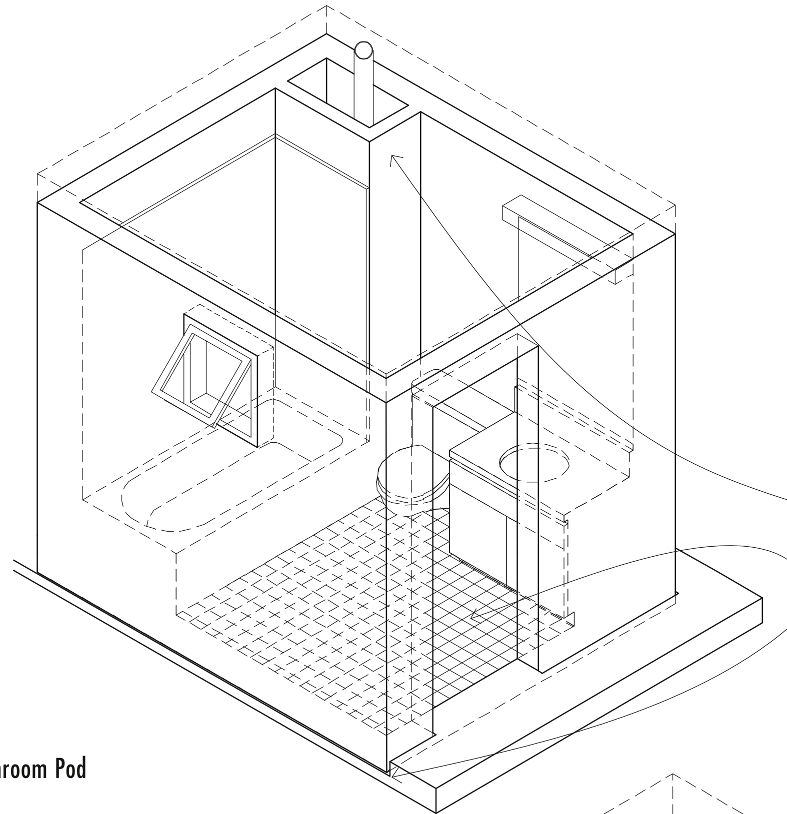
Plumbing

- Allowance should be made around bathrooms to accommodate the required water supply, waste lines and vents
- See 11.24–11.28

- Space is required for accessories such as a medicine cabinet, mirror, towel bars, toilet-roll holder and soap dish
- Storage space is required for towels, linen and cleaning supplies

Bathroom or kitchen pods are a form of volumetric prefabrication increasingly used in developments with high levels of repetition, such as hotels and multi-residential buildings.

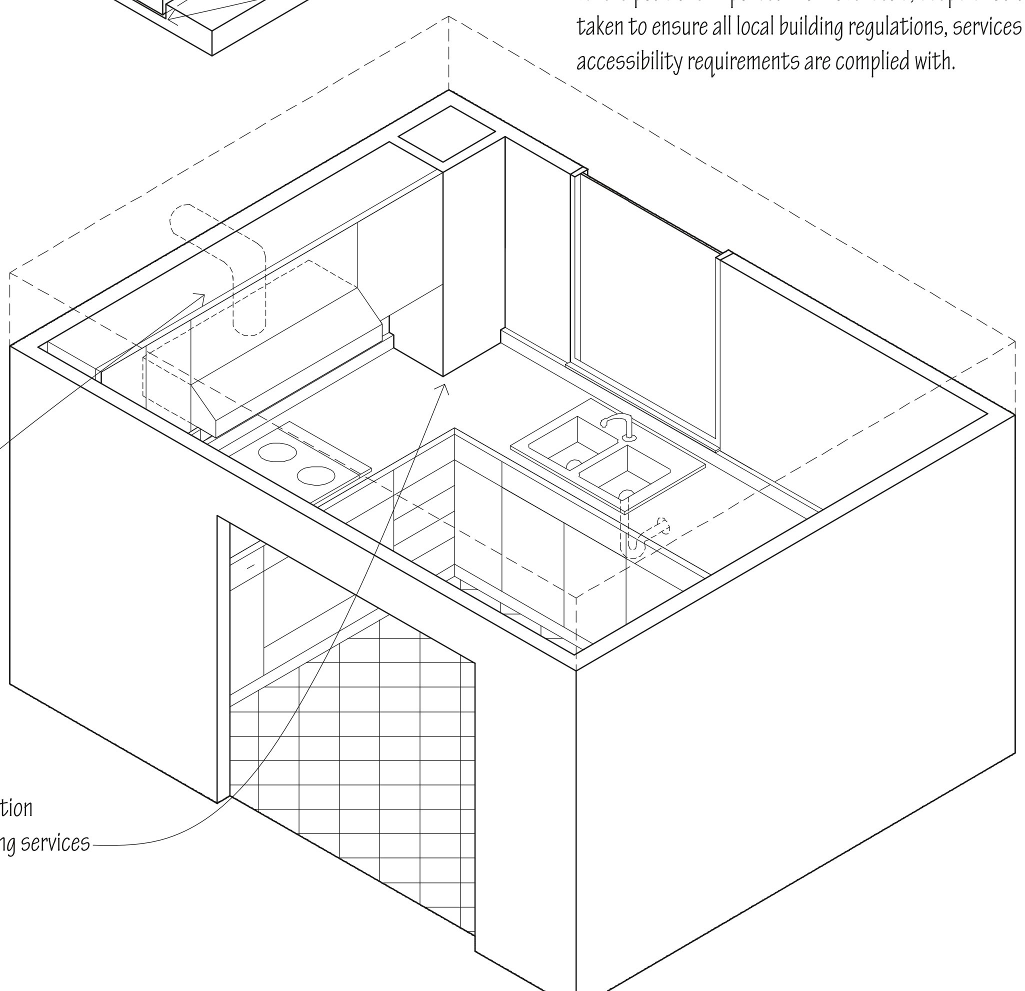
Pods can be of steel-frame, precast-concrete or timber construction and offer high levels of quality control as finishing takes place in factory conditions. Pods are fabricated in a factory and transported to site for installation where they are craned into position. Care must be taken after installation to avoid damage during the construction process. Great care must be paid to sequencing and coordination to avoid delays. A delay in pod deliveries could impact upon the installation of floors as they cannot be installed at a later date.



- Service voids provided to coincide with service runs within the building
- Tiling and sanitary fittings installed prior to transportation
- Floor screed recessed to allow for level access
- Typical concrete pod floor depth 50 mm

Bathroom Pod

Where pods are imported from overseas, steps should be taken to ensure all local building regulations, services and accessibility requirements are complied with.



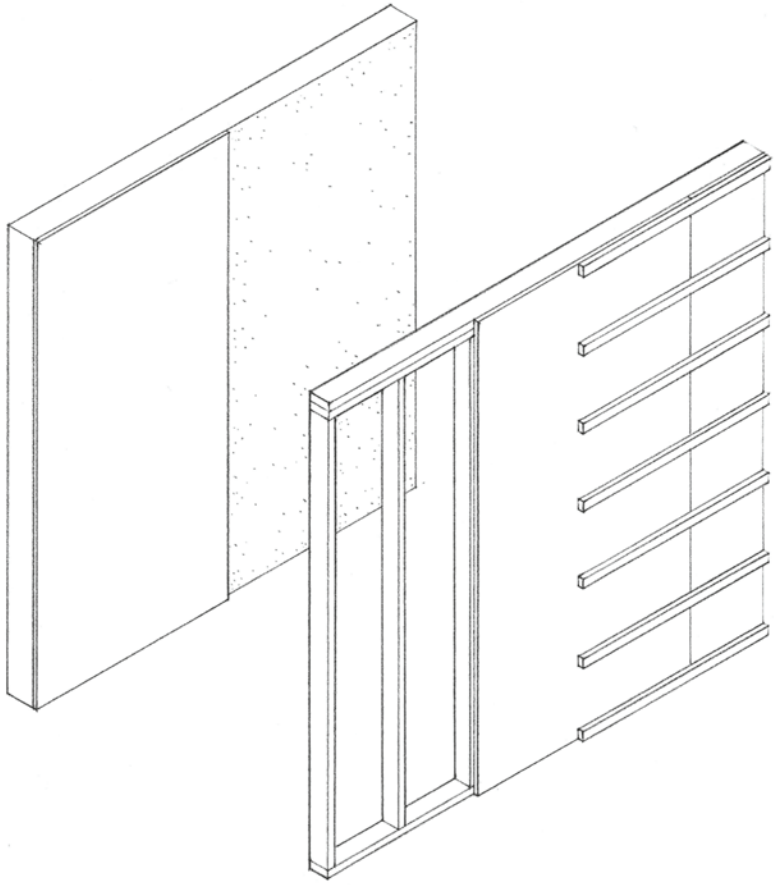
- Extract fan ready for connection
- Zone for connection of building services

Kitchen Pod

10

FINISH WORK

10.02 FINISH WORK

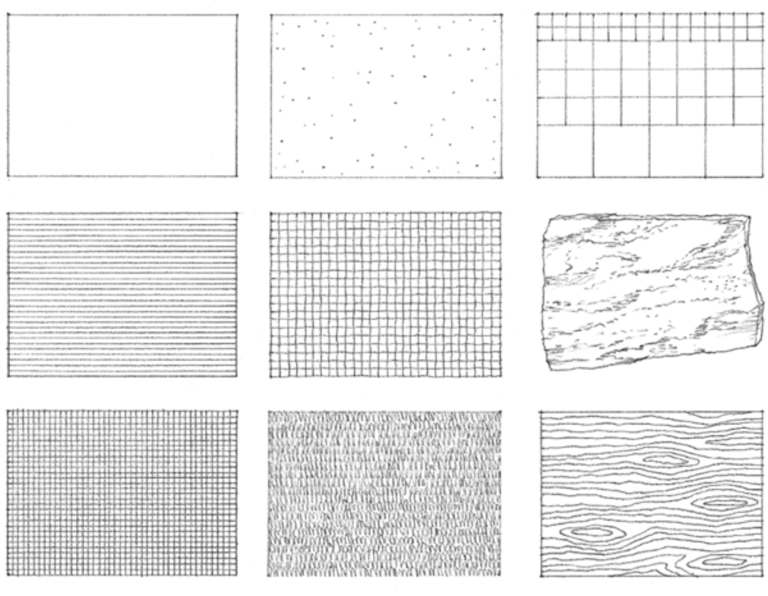


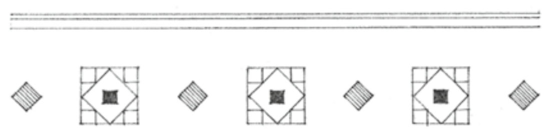
This chapter illustrates the major materials and methods used to finish the interior wall, ceiling and floor surfaces of a building. Interior walls should be resistant to wear and be cleanable; floors should be durable, comfortable and safe to walk on; ceilings should be relatively maintenance-free.

Because exterior wall surfaces, such as render and timber cladding, must serve effectively as barriers against the penetration of water into the interior of a building, they are covered in Chapter 7 along with roof coverings.

Rigid finish materials capable of spanning short distances may be applied to a supporting grid of linear members. More flexible finish materials, on the other hand, require a solid, rigid backing. Additional technical factors to consider include the acoustic qualities, fire resistance, and thermal insulation value of a finish material.

Surface finishes have a critical influence on the aesthetic qualities of a space. In the selection and use of a finish material, we should carefully consider its colour, texture and pattern, and the way it meets and joins with other materials. If a finish material has modular characteristics, then its unit dimensions can be used to regulate the dimensions of a wall, floor or ceiling surface.





BREEAM MAT 01: Life Cycle Impacts
LEED EQ Credit 4: Low-Emitting Materials

Plaster refers to any of various mixtures applied in a pasty form to the surfaces of walls or ceilings in a plastic state and allowed to harden and dry. The most common type of plaster used in construction is gypsum plaster, which is made by mixing calcined gypsum with water, fine sand or lightweight aggregate, and various additives to control its setting and working qualities. Gypsum plaster is a durable, relatively lightweight and fire-resistant material that can be used on any wall or ceiling surface that is not subject to moist or wet conditions. Portland cement plaster, also known as render, is used on exterior walls and in areas subject to wet or moist conditions; see 7.32–7.33.

- Plaster is applied in layers, the number of which depends on the type and strength of base used

Two-Coat Plaster

- Plaster is applied in two coats, a basecoat followed by a finish coat

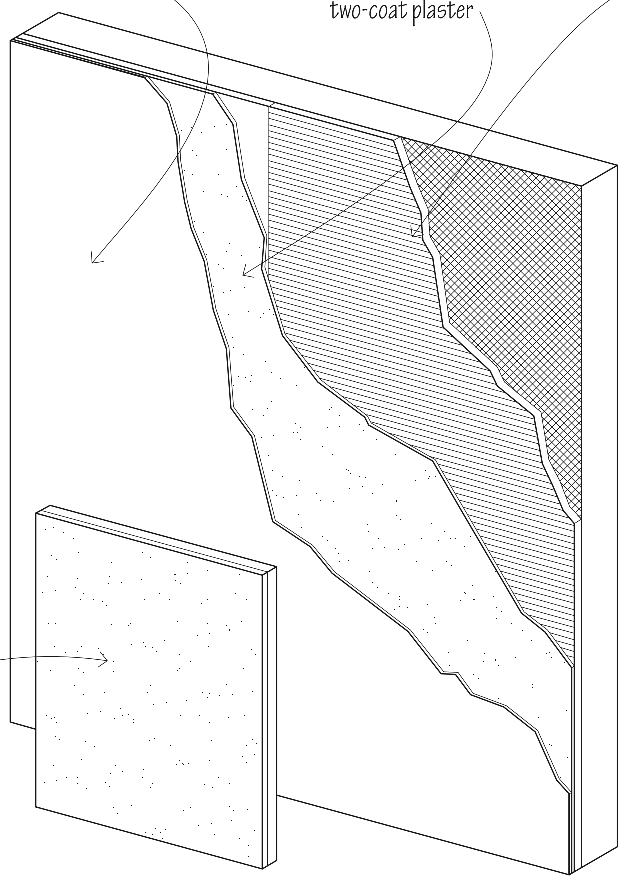
Three-Coat Plaster

- Plaster is applied in three successive coats, a scratch coat followed by a brown coat and a finish coat

- Finish coat is the final coat of plaster, serving either as a finished surface or as a base for decoration

- Brown coat is a roughly finished, levelling coat of plaster, either the second coat in three-coat plaster or the base coat in two-coat plaster

- Basecoat refers to any plaster coat applied before the finish coat
- Scratch coat is the first coat in three-coat plaster, which must adhere firmly to the base and be raked to provide a better bond for the second or brown coat



- Hardwall plaster provides a dense finish with high levels of impact resistance

- Gauging plaster is a specially ground gypsum plaster for mixing with lime putty, formulated to control the setting time and counteract shrinkage in a finish coat of plaster

- Thin or skim-coat plaster is a ready-mixed gypsum plaster applied as a very thin, one-coat finish over a plasterboard base

- Acoustic plaster is a low-density plaster containing vermiculite or other porous material to enhance its ability to absorb sound

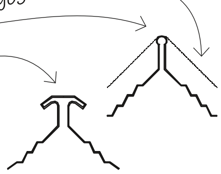
- Moulding plaster, consisting of very finely ground gypsum and hydrated lime, is used for ornamental plasterwork

- Lime-based plaster is used in renovation projects and traditional buildings. It is a mix of hydraulic lime, sand and water and was traditionally reinforced with horse hair

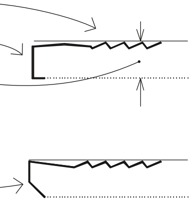
- The most commonly used plasters come ready-mixed requiring only the addition of water or water and sand depending on the mix. This reduces the preparation time required on-site
- Neat plaster is a gypsum basecoat plaster having no admixture except hair or other fibre, used for on-the-job mixing with aggregates
- Ready-mixed plaster is a mill-prepared plaster mix of calcined gypsum and an aggregate, such as perlite or vermiculite. It requires only the addition of water
- The addition of perlite or vermiculite reduces the weight and increases the thermal and fire resistance of the plaster

- The final appearance of a plaster surface depends on both its texture and its finish. It may be trowelled to produce a smooth, non-porous finish, floated to a sandy, lightly textured finish, or sprayed on for a rougher finish. The finish may be painted; smooth finishes will accept textile or paper wallcoverings

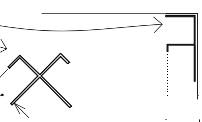
- Corner beads reinforce external angles of plasterwork and plasterboard surfaces
- 32 to 86 mm expanded flanges
- 3 mm radius
- 19 mm radius bullnose
- Flexible corner beads may be bent for curved edges



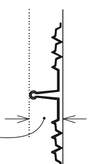
- Casing beads reinforce the edges of plasterwork and plasterboard surfaces
- 80 mm expanded flange
- Square end
- 13, 16, 19, 22 mm depths
- Square end with 6 mm 45° break



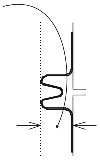
- A variety of mouldings create reveals at the corners and edges of plasterwork
- F-reveal
- Corner mould
- 19 mm

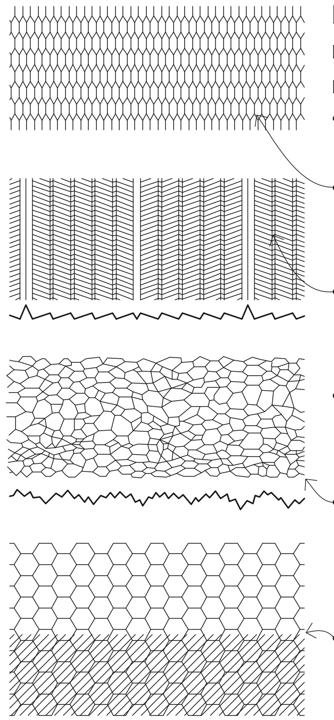


- Base screeds separate a plastered surface from another material
- 13, 19, 22 mm depths



- Gypsum plaster expands slightly as it hardens, requiring expansion joints to control cracking
- 13, 19, 22 mm depths

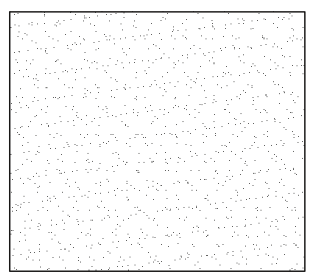




Metal Lath

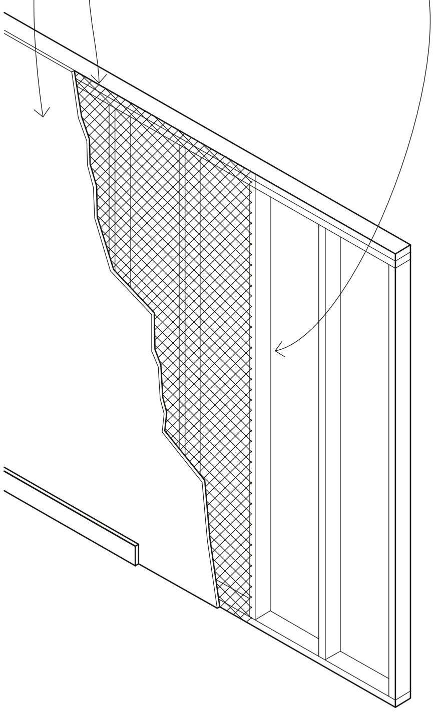
Metal lath is a plaster base fabricated of expanded metal or of wire fabric, galvanised or coated with a rust-inhibiting paint for corrosion resistance.

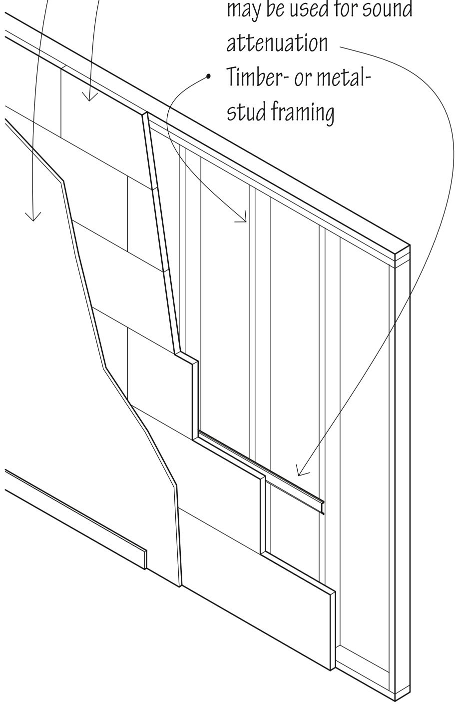
- The weight and strength of the metal lath used is related to the spacing and rigidity of its supports
- Expanded metal lath is fabricated by slitting and expanding a sheet of steel alloy to form a stiff network with diamond-shaped openings
- Rib lath is an expanded-metal lath havig V-shaped ribs to provide greater stiffness and permit wider spacing of the supporting framing members
- Self-centring lath is a rib lath used over steel joists as formwork for concrete slabs, or as lathing in solid plaster partitions
- Self-furring lath is expanded-metal, welded-wire or woven-wire lath that is dimpled to space itself from the supporting surface, creating a space for the keying of plaster or render
- Paper-backed lath is expanded-metal or wire lath having a backing of perforated or building paper, used as a base for ceramic-tile and exterior-rendered walls



Trim Accessories

Various accessories made of galvanised steel or zinc alloy are used to protect and reinforce the edges and corners of plaster surfaces. These trim accessories also serve as grounds that help the plasterer level the finish coat and bring it up to the proper thickness. For this reason, all grounds should be securely fastened to their supports and installed straight, level and plumb. Timber grounds may be used where a nailable base is required for the addition of wood trim.



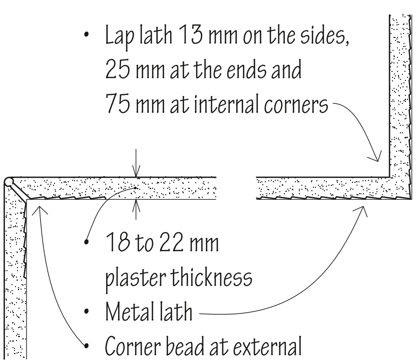


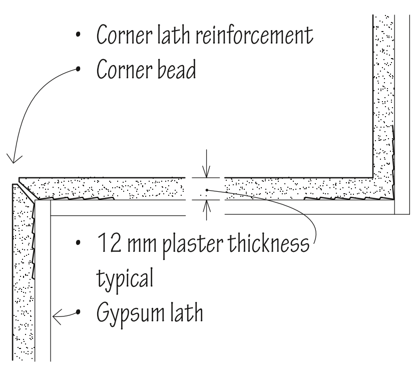
Plaster over Metal Lath

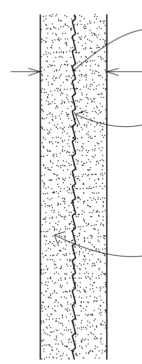
- Three-coat plaster is applied over metal lath
- Timber or metal studs are spaced at 400 or 600 mm centres. The frame should be sturdy, rigid, plane and level; deflection should be limited to 1/360 of the support spacing
- The long dimension or ribs of the lath are laid across the supports

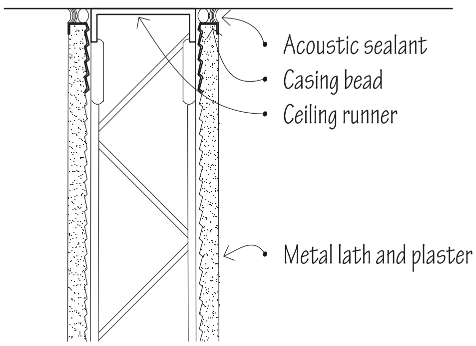
Skim over Plasterboard

- Thin-coat plaster can also be applied as a 2–4 mm thick one-coat finish over a gypsum plasterboard
- Supports may be spaced at 400 or 600 mm centres
- The long dimension of the lath is laid across the supports; ends of lath should bear on a support or be supported by sheet metal clips

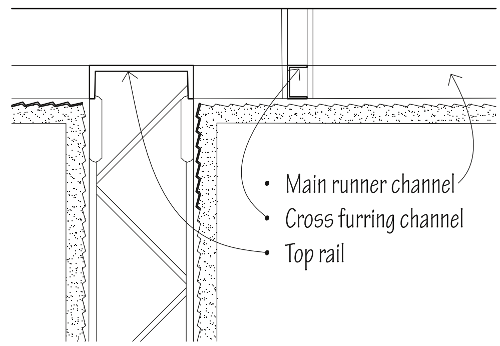




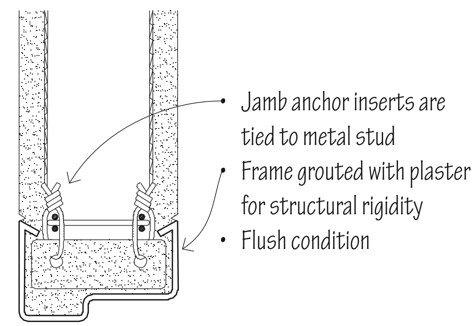




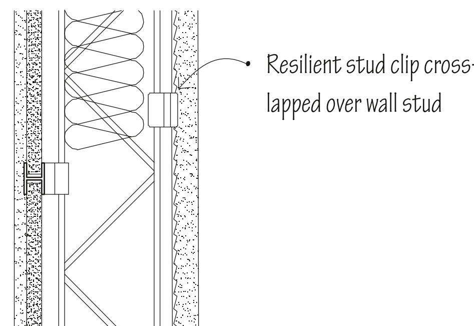
Ceiling Detail



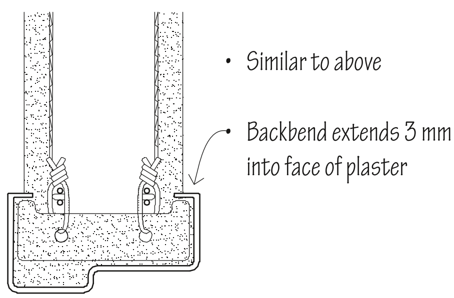
Ceiling Detail



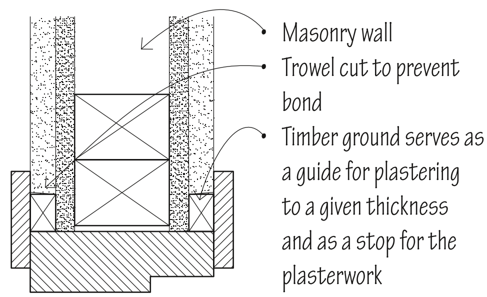
Metal Door Frame



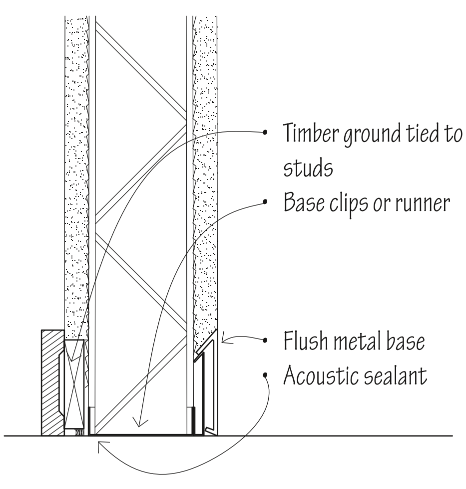
Acoustic Wall Treatment

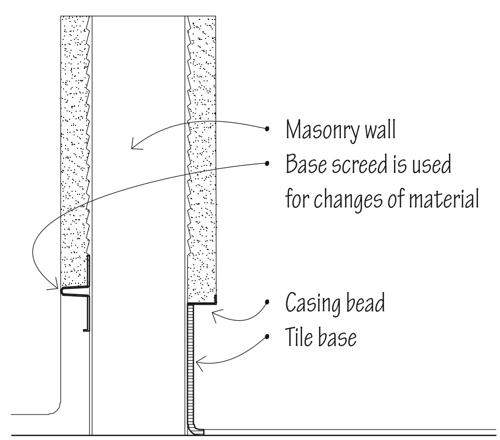


Metal Door Frame

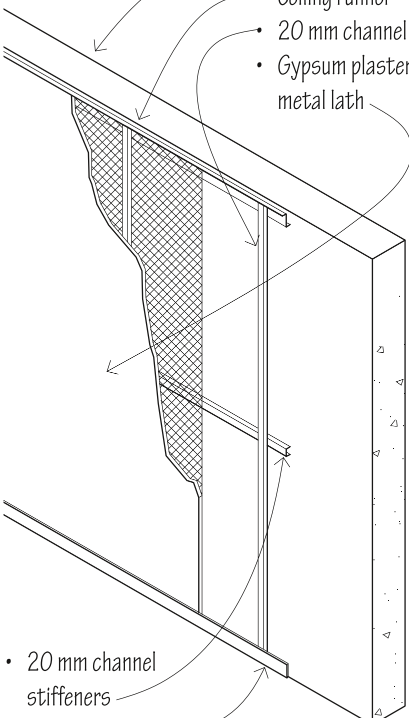


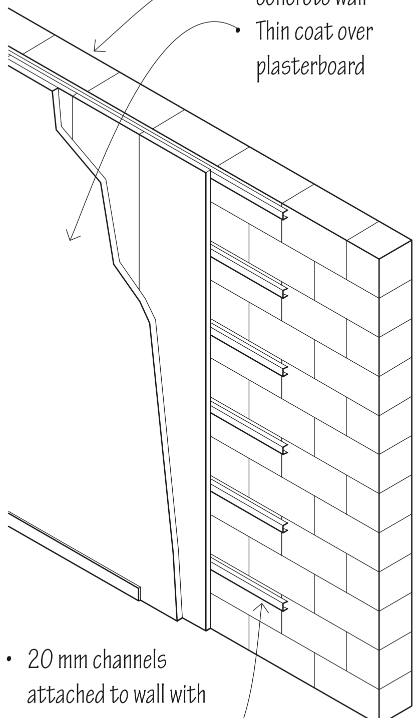
Timber Door Frame

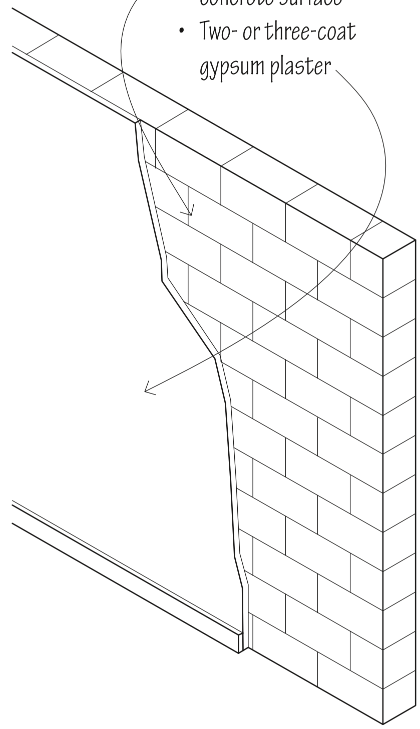




Alternative Base Details







Plaster over Furring

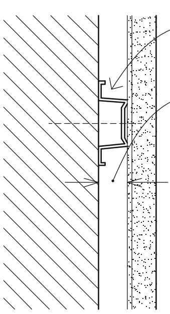
Plaster should be applied over lath and furring when:

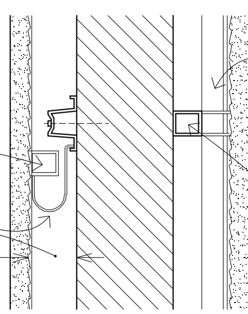
- The masonry surface is not suitable for direct application
- The possibility exists that moisture or condensation might penetrate the wall
- Additional air space or space for insulating material is required
- A resilient wall surface is desired for acoustic treatment of the space

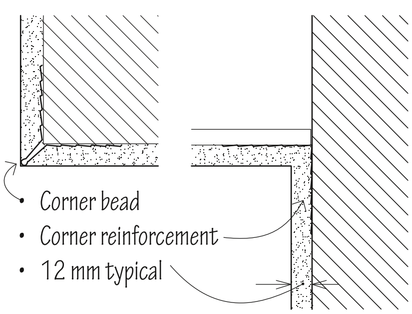
- Timber or metal furring may be applied vertically or horizontally
- Plaster requires either metal lath or plasterboard over the furring; the application and support spacing are similar to the examples shown on 10.06

Direct Application

- Two-coat plaster, 12 mm thick, is normally applied directly over masonry
- Plaster may be applied directly to brick, clay tile or concrete masonry if the surface is sufficiently rough and porous to allow for a good bond
- A bonding agent is required when applying plaster directly to dense, non-porous surfaces such as concrete

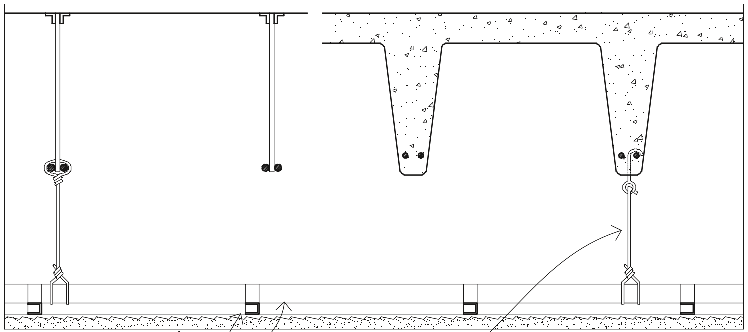




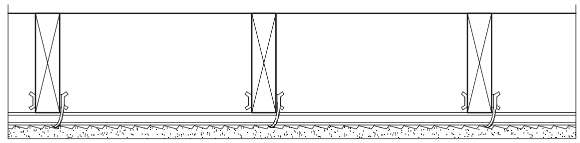


- Furring may be attached to the wall with resilient clips for acoustic treatment and independent movement between the plaster and masonry

- Horizontal channel stiffeners may be required for vertical furring that is installed away from the wall

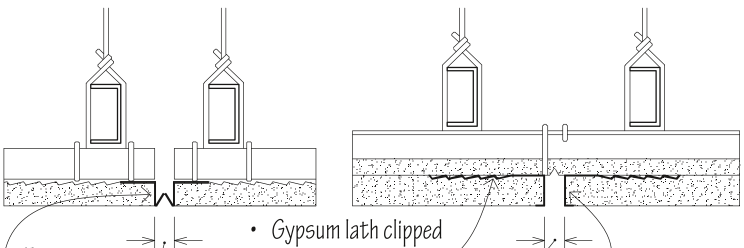


- Hanger wire
- 45 mm main runner channels spaced at up to 600 mm centres
- 25 mm channels tied to the main runners
- Metal lath tied to furring at 150 mm centres



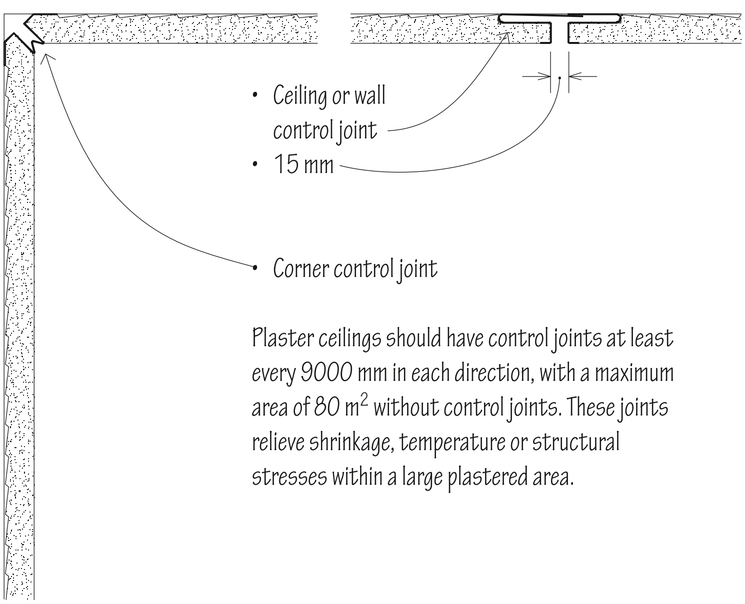
Joint-free suspended ceiling can be installed using lath and plaster or more commonly a plasterboard and skim finish; see 10.11.

If lath is nailed directly to the underside of joists, the plaster is subject to cracking due to wood shrinkage. Even when furring is used, deflection of the supporting members should be limited to 1/360 of their span. Suspending the plaster ceiling allows it to move independently of the supporting floor or roof structure and also provides a concealed space for mechanical and light systems.



- Expansion joint
- 15 mm

- Gypsum lath clipped to channels
- 10 mm
- Casing beads

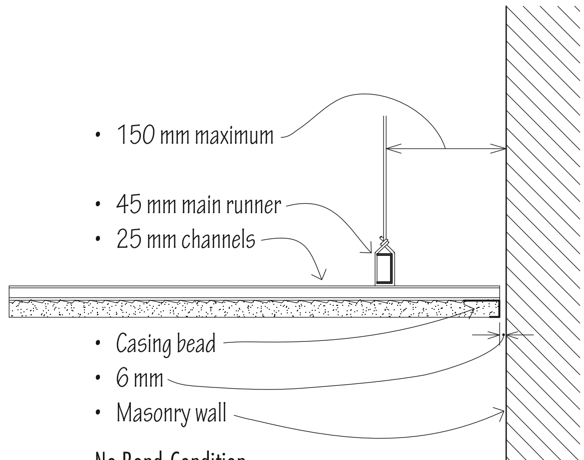


- Ceiling or wall control joint
- 15 mm

- Corner control joint

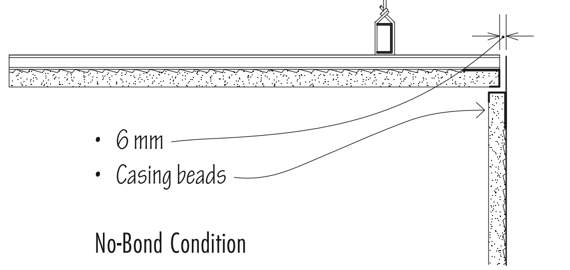
Plaster ceilings should have control joints at least every 9000 mm in each direction, with a maximum area of 80 m^2 without control joints. These joints relieve shrinkage, temperature or structural stresses within a large plastered area.

Control Joints



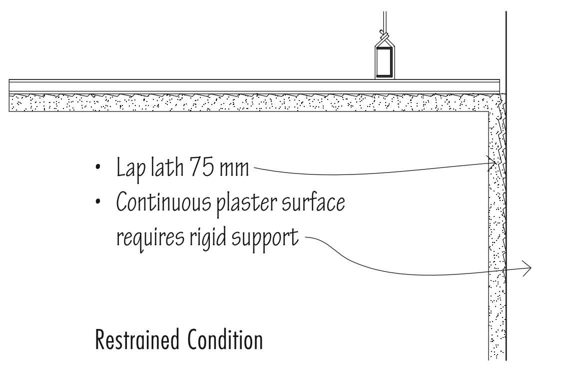
- 150 mm maximum
- 45 mm main runner
- 25 mm channels
- Casing bead
- 6 mm
- Masonry wall

No-Bond Condition



- 6 mm
- Casing beads

No-Bond Condition



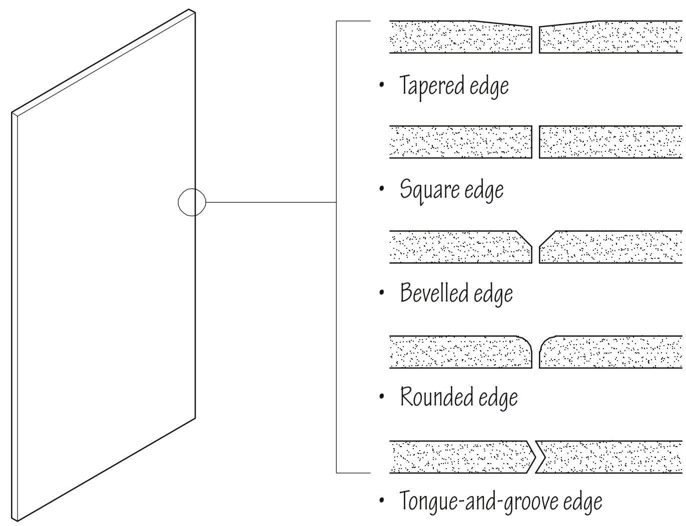
- Lap lath 75 mm
- Continuous plaster surface requires rigid support

Restrained Condition

Wall and Ceiling Joints

Plasterboard is a sheet material used for covering walls. It consists of a gypsum core surfaced and edged to satisfy specific performance, location, application and appearance requirements. It has good fire resistance and dimensional stability. In addition, its relatively large sheet size makes it an economical material to install. Gypsum wallboard is often referred to as drylining because of its low moisture content, and little or no water is used in its application to interior walls or ceilings.

Plasterboard may have different edge conditions. Square edge boards are used for textured finishes. Most commonly, however, plasterboard has a tapered edge. The tapered edge allows the joints to be taped and filled to produce strong, invisible seams. Plasterboard thus can form smooth surfaces that are monolithic in appearance and that can be finished by painting or applying a paper, vinyl or fabric wallcovering.



Types of Plasterboard

Types of Edges

Regular Wallboard
- Tapered edge
- 900 or 1200 mm wide, 2400–3000 mm long
- 9.5 mm board used in low-impact areas generally in domestic construction, 12.5 mm used in general conditions in single layer or double layer to meet fire requirements. 15 mm board is used in high impact areas or to meet acoustic, fire or thermal requirements

Impact Resistant
- Tapered edge
- 15 mm thick
- 1200 mm wide, 2400–3000 mm long
- High-density plasterboard used in areas subject to heavy usage

Foil-Backed Board
- Square or tapered edge
- 9.5, 12.5, 15 mm thick
- 900 or 1200 mm wide, 2400–3000 mm long
- Aluminium-foil backing serves as a vapour retarder and as a reflective thermal insulator when the foil faces a 25 mm minimum dead air space

Moisture-Resistant Board
- Tapered or square edge
- 12.5, 15 mm thick
- 1200 mm wide, 2400–3000 mm long
- Used as a base for ceramic or other non-absorbent tile in high-moisture areas

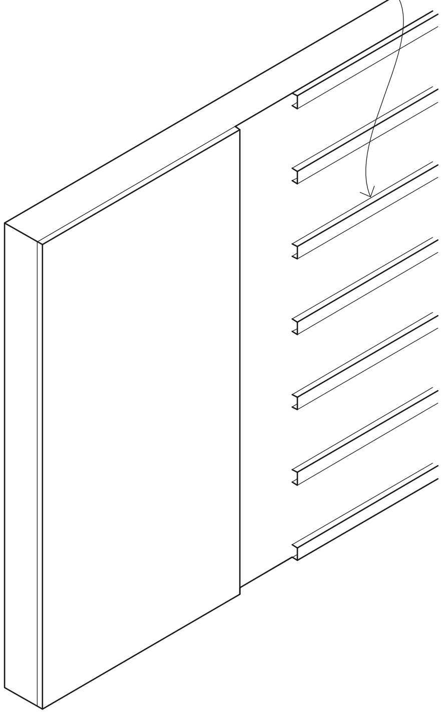
Thermal Boards
- Square or tongue-and-groove edge
- 22–100 mm thick
- 900 or 1200 mm wide, 2400–3000 mm long
- Wallboard adhered to a rigid insulation to provide an insulating plasterboard for use in drylining

Sound-Block Board
- Tapered edge
- 12.5, 15 mm thick
- 900 or 1200 mm wide, 2400–3000 mm long
- Has a higher density core for use where more sound insulation is required. Available variants combine moisture-resistant additives to provide additional moisture resistance

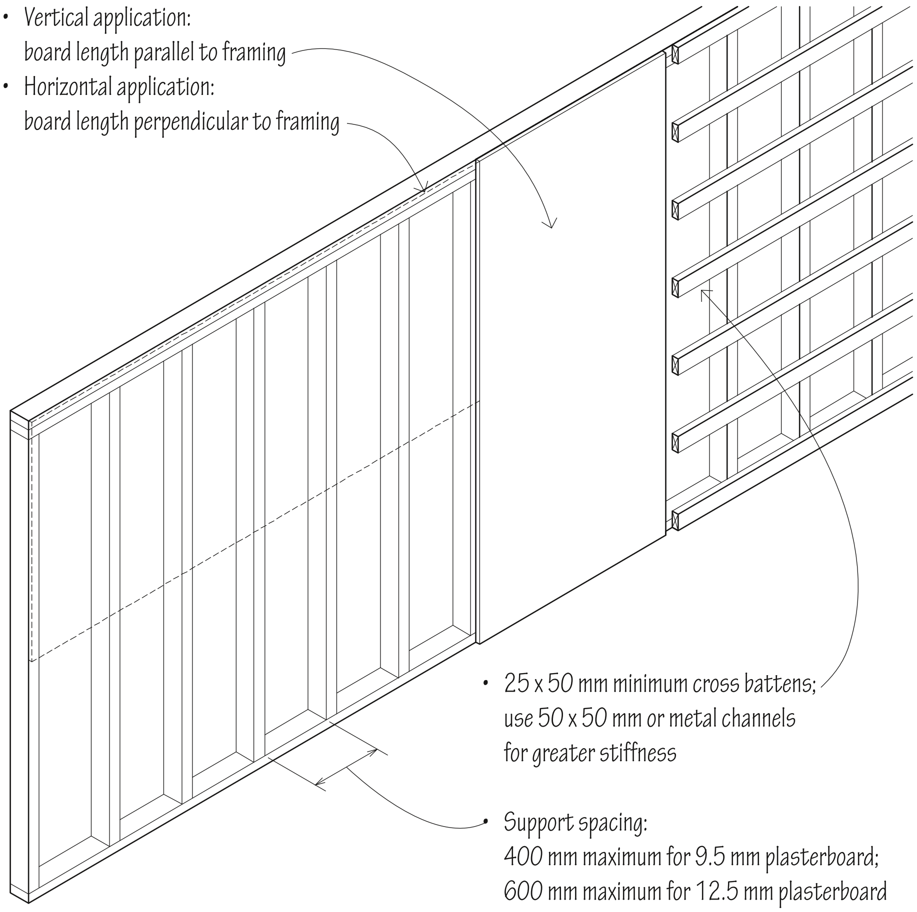
Fire-Resistant Board
- Square or tapered edge
- 12.5, 15, 19 mm thick
- 900, 1200 mm wide, 2400–3000 mm long
- Used in areas where increased fire performance is required. Specific fire-resistant boards are available to be used in high-impact areas or as protection to structural steel

10.10 PLASTERBOARD APPLICATION

- Exterior and below-grade masonry or concrete walls require furring before the application of plasterboard to eliminate the capillary transfer of water and to minimise condensation on interior wall surfaces



- Vertical application: board length parallel to framing
- Horizontal application: board length perpendicular to framing



- 25 x 50 mm minimum cross battens; use 50 x 50 mm or metal channels for greater stiffness

- Support spacing: 400 mm maximum for 9.5 mm plasterboard; 600 mm maximum for 12.5 mm plasterboard

Masonry or Concrete Base

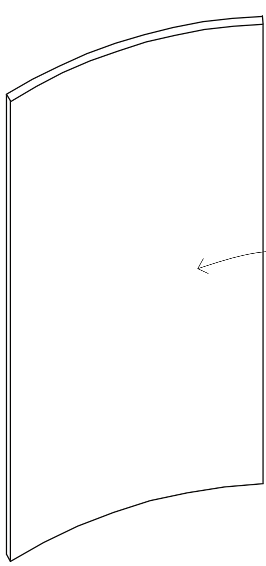
Plasterboard may be applied to above-grade masonry or concrete walls whose surfaces are dry, smooth, even and free of oil or other parting materials.

Stud Wall Base

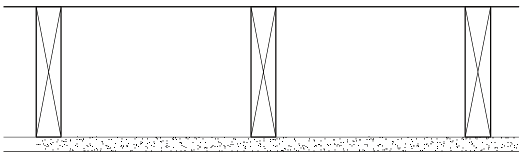
Plasterboard may be fastened directly to timber- or metal-stud framing that is structurally sound and rigid enough to prevent buckling or cracking of the plasterboard. The face of the frame should form a flat and even plane.

Horizontal application is preferred for greater stiffness if it results in fewer joints. Butt-end joints, which should be kept to a minimum, must fall over a support.

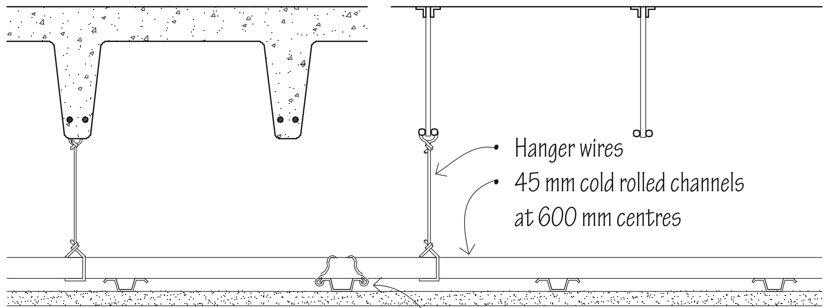
Timber or metal cross battens are required when:
- The frame or masonry base is not sufficiently flat and even
- The framing supports are spaced too far apart
- Additional space for thermal or acoustic insulation is desired
- The use of resilient furring channels is needed to improve the acoustic performance of the assembly



- Plasterboard can be bent and attached to a curving line of studs. Consult the board provider for the maximum bending

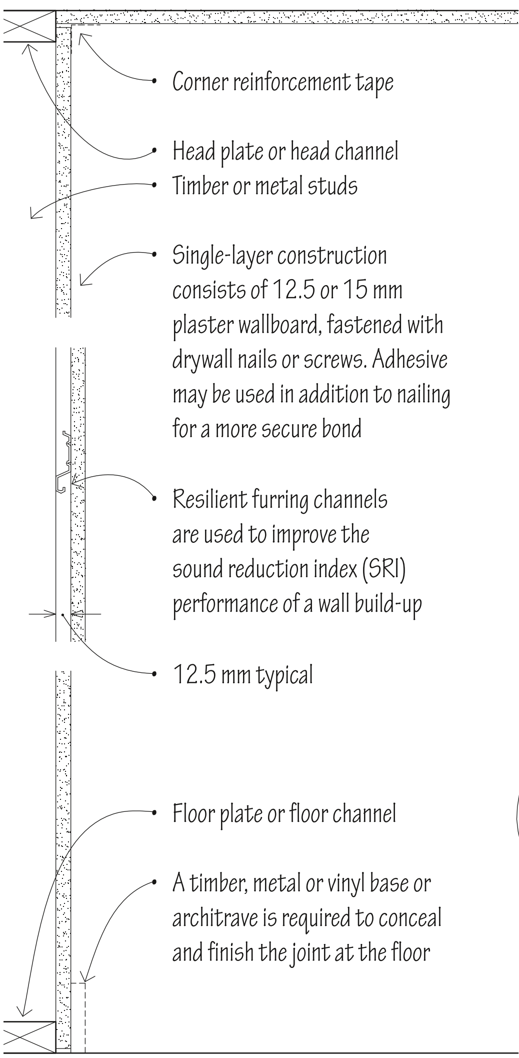


Plasterboard may be fastened directly to the undersides of joists at 400 mm centres. The deflection of the floor or roof structure should be limited to 1/240 of its span. For improved resistance to sound transmission, and when attaching the plasterboard to concrete or steel joists, resilient channels at 400 or 600 mm centres are used. For fire resistance, fire rated board can be used; see A.10–A.11 for fire ratings of various wall and ceiling assemblies.

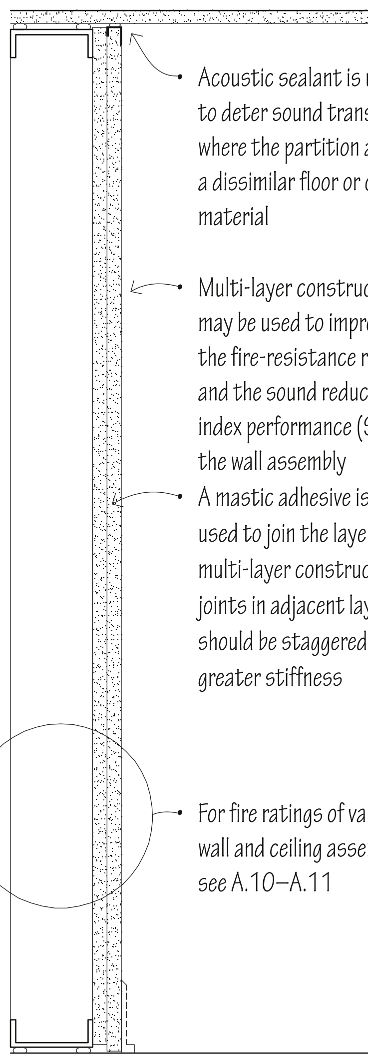


- Hanger wires
- 45 mm cold rolled channels at 600 mm centres
- Plasterboard may also be supported by a grid of channels and hung as a suspended ceiling
- 25 mm metal channels at 400 mm centres, clipped or tied to main channels
- 2.5 or 15 mm plasterboard

Ceilings

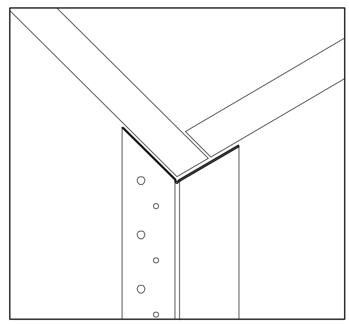


- Corner reinforcement tape
- Head plate or head channel
- Timber or metal studs
- Single-layer construction consists of 12.5 or 15 mm plaster wallboard, fastened with drywall nails or screws. Adhesive may be used in addition to nailing for a more secure bond
- Resilient furring channels are used to improve the sound reduction index (SRI) performance of a wall build-up
- 12.5 mm typical
- Floor plate or floor channel
- A timber, metal or vinyl base or architrave is required to conceal and finish the joint at the floor

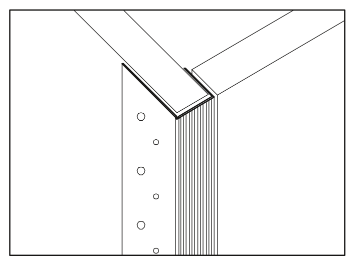


- Acoustic sealant is used to deter sound transmission where the partition abuts a dissimilar floor or ceiling material
- Multi-layer construction may be used to improve both the fire-resistance rating and the sound reduction index performance (SRI) of the wall assembly
- A mastic adhesive is often used to join the layers in multi-layer construction; joints in adjacent layers should be staggered for greater stiffness
- For fire ratings of various wall and ceiling assemblies, see A.10–A.11

Walls



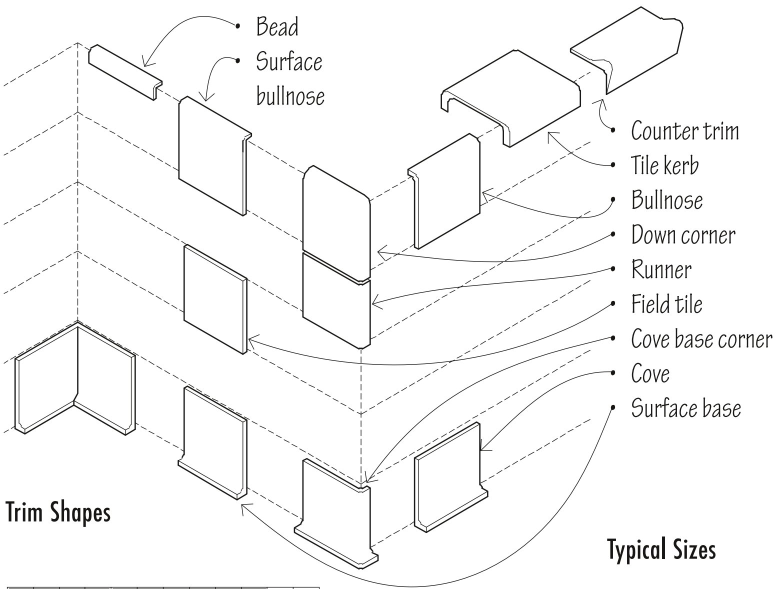
- Corner bead



- Metal edge trim
- Various profiles are available

- External corners and exposed edges should be protected against damage by metal corner beads and edge trims. Metal-trim accessories require finishing with a joint compound

Edges



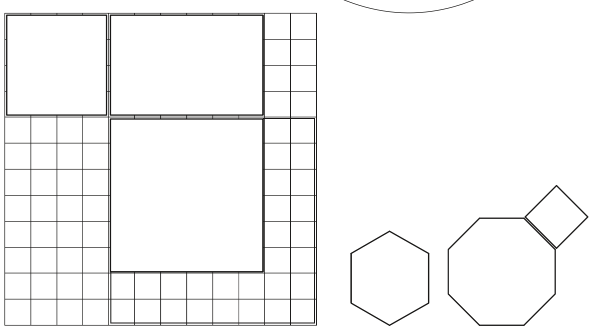
Trim Shapes

Ceramic tiles are relatively small, modular surfacing units made of clay or other ceramic material. The tiles are fired in a kiln at very high temperatures. The result is a durable, tough, dense material that is water-resistant, difficult to stain and easy to clean; its colours generally do not fade.

Ceramic tile is available glazed or unglazed. Glazed tile has a face of ceramic material fused into the body of the tile, and may have glossy, matte or crystalline finishes in a wide range of colours. Unglazed tiles are hard and dense, and derive their colour from the body of the clay material. These colours tend to be more muted than those of glazed tiles.

Typical Sizes

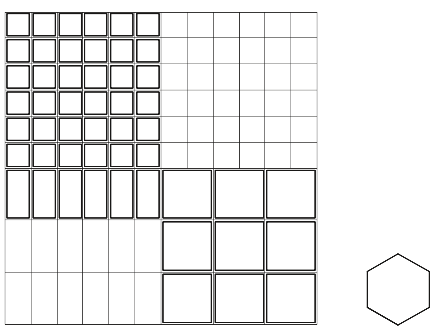
Types of Ceramic Tile



- 6–8 mm thick
- 10 x 100 mm
- 100 x 148 mm
- 148 x 148 mm
- 200 x 200 mm
- 35 mm square
- 110 mm octagon
- 125 mm hexagon

Glazed Wall Tile

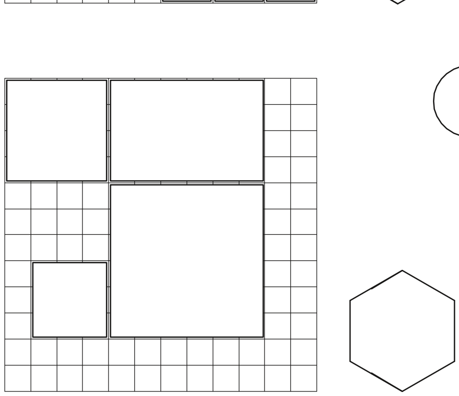
Glazed wall tile has a non-vitreous body and a bright, matte or crystalline glaze, used for surfacing interior walls and light-duty floors. Exterior tiles are weatherproof and frostproof, and can be used for both exterior and interior walls.



- 6–8 mm thick
- 25 x 25 mm
- 25 x 50 mm
- 50 x 50 mm
- 25 and 50 mm hexagons

Ceramic Mosaic Tile

Ceramic mosaic tile has a porcelain or natural clay body, glazed for surfacing walls or unglazed for use on both floors and walls. Porcelain tiles have bright colours, while natural clay tiles have more muted colours. To facilitate handling and speed installation, small tiles are usually faced with paper or backed with mesh to form 300 x 300 mm or 300 x 600 mm sections with the proper tile spacing.



- 10, 12, 16, 19 mm thick
- 75 x 75 mm
- 100 x 100 mm
- 100 x 150 mm
- 150 x 150 mm
- 200 x 200 mm
- 150 and 200 mm hexagons

Quarry and Paver Tiles

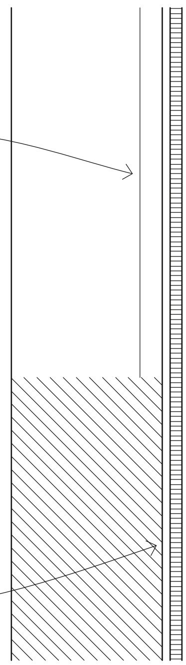
Quarry tile is an unglazed floor tile of natural clay or porcelain. The tiles are impervious to dirt, moisture and stains, and resistant to freezing and abrasion. Pavers are similar in composition to ceramic mosaic tiles but thicker and larger. They are weatherproof and can be used on floors subjected to heavy-duty loads.

- Consult tile manufacturer for exact sizes, shapes, colours, glazes and slip resistance

Thin Set

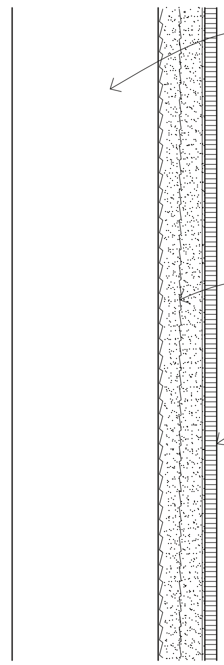
In the thin-set process, ceramic tile is bonded to a continuous, stable backing with a thin coat of dry-set mortar, latex-portland cement mortar, epoxy mortar or an organic adhesive.

- Thin-set installations require a solid, dimensionally stable backing of gypsum plaster, plasterboard or plywood
- In wet areas around bathtubs and showers, use 12.5 mm thick moisture-resistant or tile backer board and set the tile with latex-portland cement or dry-set mortar
- Masonry surfaces should be clean, sound and free of efflorescence. When dry-set or latex-portland cement mortar is used to set the tile, the surface should be keyed to ensure a good bond

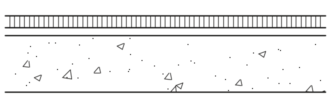


Thick Set

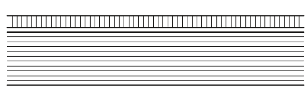
In the thick-set process, ceramic tile is applied over a bed of portland cement mortar. This relatively thick bed allows for accurate slopes and true planes in the finished work. The mortar bed is also not affected by prolonged contact with water.



- Suitable backings for cement mortar bed installations include brick or concrete-block masonry, monolithic concrete, plywood, gypsum plaster and plasterboard. Open-stud framing and furring can also be used with metal lath
- The setting bed, which is a field mix of portland cement, sand, water and sometimes hydrated lime, is 10–12 mm thick on walls
- Tiles may be laid with a 2 mm bond coat of neat portland cement or dry-set mortar while the mortar bed is still plastic, or set with a 3–6 mm coat of latex-portland cement after the mortar bed is fully cured

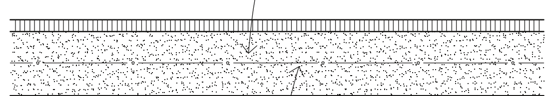


- Floor finishes are assigned a slip resistance. Throughout Europe there are a range of test methods and classifications used depending on the region, however there is not yet a harmonised European standard. The German standard DIN 51130 assigning R values is widely adopted. R9 is generally the minimum acceptable standard for use in floor tiles depending on use and location



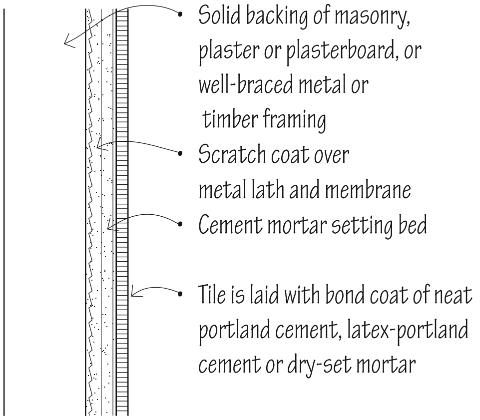
- Concrete slabs should be smooth, level and properly reinforced and cured; a levelling topping can be used if required

- Setting bed is 15–70 mm thick on floors depending on substrate, requirement for falls and bedding

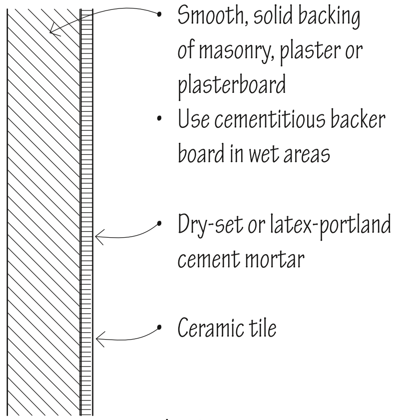


- Suitable floors for cement mortar bed installations include properly reinforced and cured concrete slabs and structurally sound plywood sub-flooring
- Maximum deflection of the floor under full load should be limited to 1/360 of the span

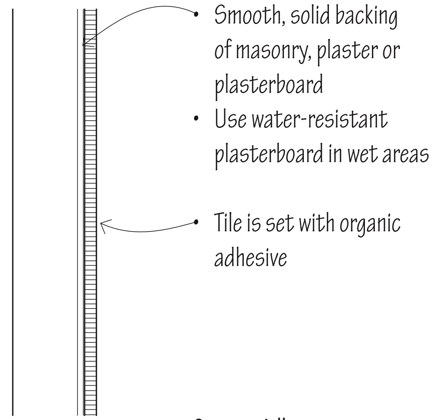
- A membrane isolates the mortar bed from damaged or unstable backings and allows some independent movement of the supporting construction to occur
- The mortar bed should be reinforced with metal lath or mesh whenever it is backed by a membrane



Cement Mortar

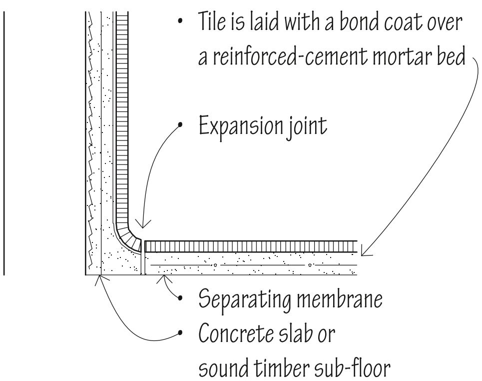


Thin-Set Mortar

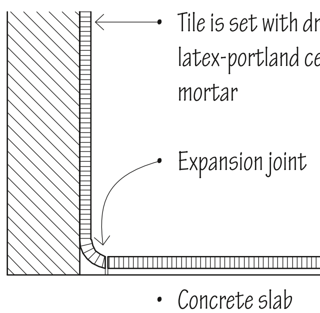


Organic Adhesive

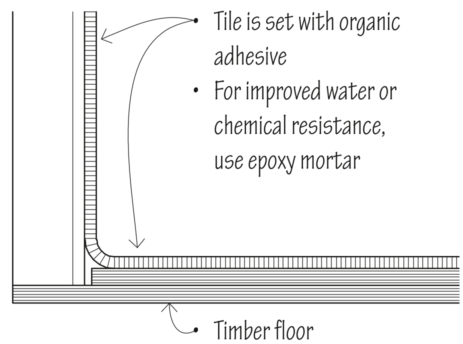
Interior Wall Applications



Cement Mortar

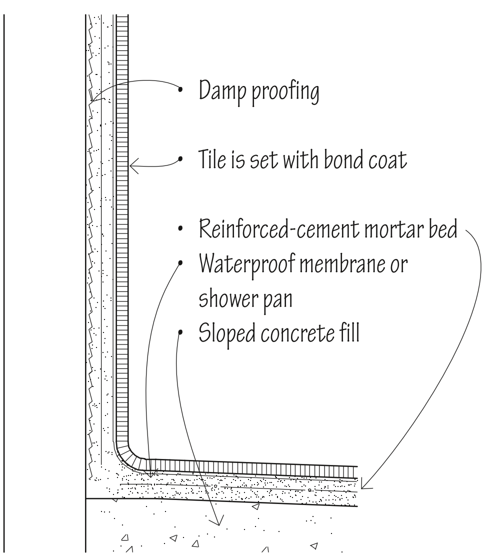


Thin-Set Mortar

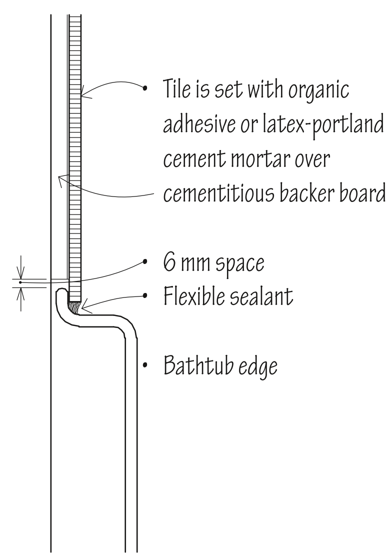


Organic Adhesive

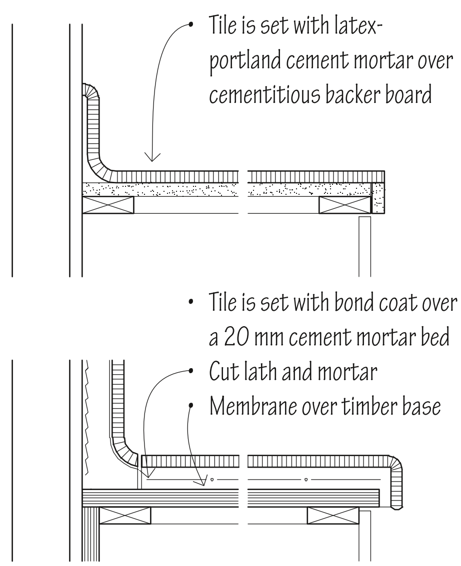
Interior Floor Applications



Ceramic-Tile Shower



Tile Tub Enclosure

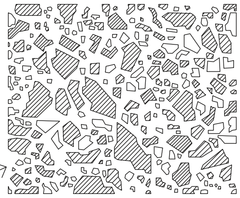


Tile Counters

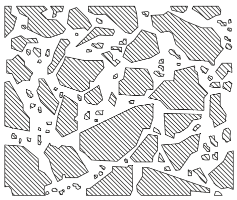
Terrazzo is a mosaic floor or paving composed of marble or other stone chips, set in a cementitious or resinous matrix and ground and polished when dry. It provides a dense, extremely durable, smooth flooring surface whose mottled colouring is controlled by the size and colours of the aggregate and the colour of the binder.

Terrazzo Finishes

- Standard terrazzo is a ground and polished terrazzo finish consisting mainly of relatively small stone chips



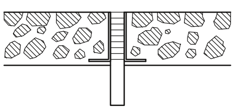
- Venetian terrazzo is a ground and polished terrazzo finish consisting mainly of large stone chips, with smaller chips filling the spaces between



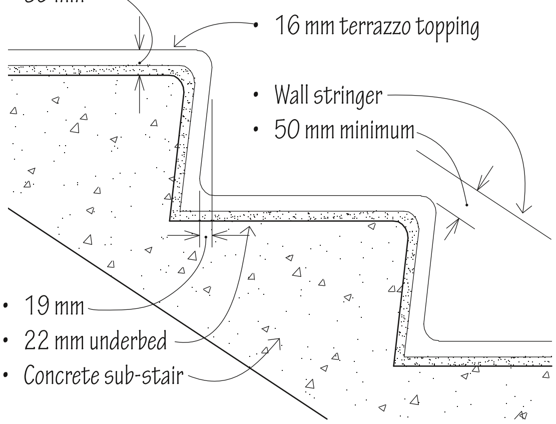
Metal or plastic-tipped divider strips are used:

- To localise shrinkage cracking
- To serve as construction joints
- To separate the different colours of a floor pattern
- To act as decorative elements

- Expansion joints are required over isolation or expansion joints in the sub-floor. They consist of a pair of divider strips separated by a resilient material such as neoprene

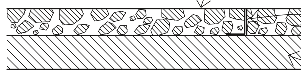


- 38 mm



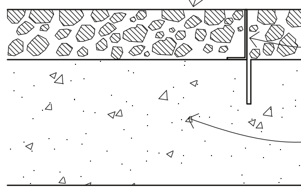
- 19 mm
- 22 mm underbed
- Concrete sub-stair

Terrazzo Stair



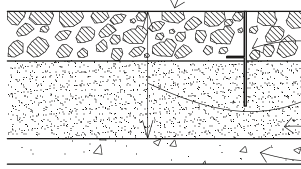
- 6 to 13 mm resinous topping
- Divider strip at all control joints
- Timber, metal or concrete sub-floor

Thin-Set Terrazzo



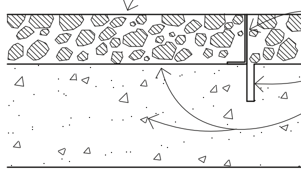
- 16 mm or thicker portland-cement topping
- Divider strips at 4570–6095 mm centres at column lines, and over floor beams; avoid narrow proportions
- Rough-finished concrete slab; 90 mm minimum

Monolithic Terrazzo



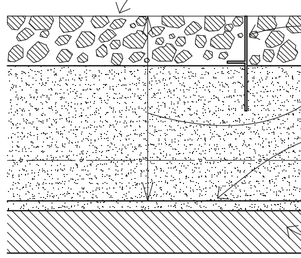
- 16 mm or thicker portland-cement topping
- Divider strips at 1830 mm centres maximum
- 45 mm minimum overall
- Mortar underbed
- Rough-finished concrete slab

Bonded Terrazzo



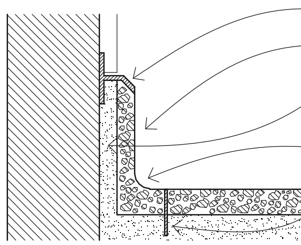
- 16 mm or thicker portland-cement topping
- Divider strips as per monolithic terrazzo
- Saw-cut control joint
- Smooth-finished slab with a chemical bonding agent if the concrete surface is too smooth for a mechanical bond

Chemically Bonded Terrazzo



- 15 mm or thicker portland-cement topping
- Divider strips at 1830 mm centres maximum
- 64 mm minimum overall
- Reinforced-mortar underbed
- Isolation membrane over 6 mm bed of sand to control cracking when structural movement is expected
- Sub-floor

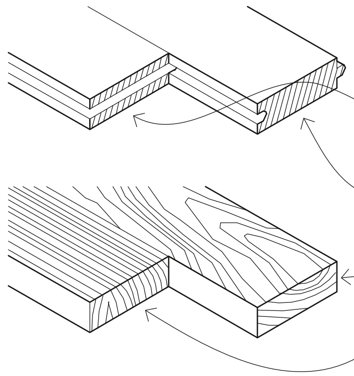
Sand-Cushion Terrazzo



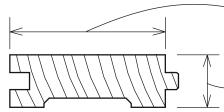
- Base bead
- 10 mm terrazzo
- Underbed thickness may vary to create recessed, flush or projecting base conditions
- 25 to 38 mm radius
- Divider strip

Terrazzo Base

TIMBER FLOORING

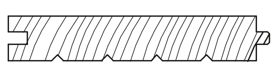


- Strips are matched to form tongue-and-groove joints along sides and ends
- Hollow or scratch back allows edges to bear firmly on the sub-floor surface
- Flat grain, plain sawn
- Edge or vertical grain, quarter sawn



- Widths: 75–200 mm
- Thicknesses:
  - Laminate: 8, 10, 12 mm
  - Engineered: 14, 22 mm
  - Solid: 12, 19 mm

There are three main methods of laying timber flooring elements (see 10.17):
- Floating
- Fixed
- Glued



Timber flooring combines durability and wear resistance with comfort and warmth. Durable, hard, close-grained species of both hardwood and softwood are used for flooring. Common species of hardwood flooring include oak, maple, birch and cherry. Common species of softwood flooring include pine and douglas fir. Bamboo is a relatively fast-growing grass product that qualifies as a renewable resource.
(LEED MR Credit 6: Rapidly Renewable Materials)

Timber flooring is available as laminates, engineering timber, solid timber or block flooring.

Laminate Timber Flooring

Laminate flooring consists of a clear protective wear course over a thin decorative layer adhered to an MDF substrate and backing layer. Laminate floors offer a less costly alternative to engineered or solid timber floors while providing a wide range of decorative finishes.

Engineered Timber

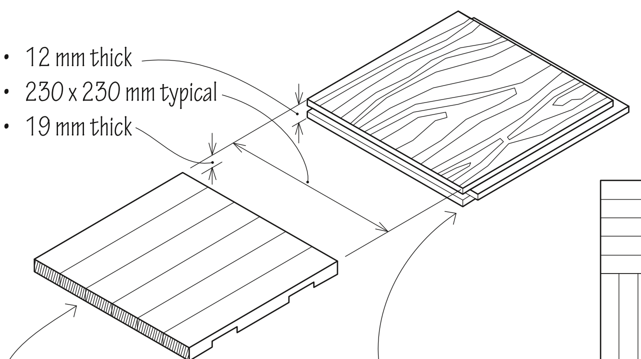
Engineered-timber floors consist of a solid-timber facing normally 5–6 mm thick, adhered to a plywood base or a wear layer on a softwood-based core on a backing layer. Engineered-timber flooring offers cost savings over solid-timber flooring while providing greater dimensional stability.

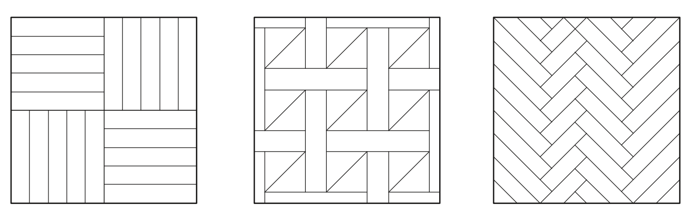
Solid Timber

Solid-timber floors consist of planks of solid timber machined to standard sizes and profiles. To avoid cupping in solid floors, a ratio of width to depth not in excess of 4:1 is recommended.

Block Flooring

Block flooring is composed of square units pre-assembled at the mill and usually installed with mastic over a timber sub-floor or concrete slab.





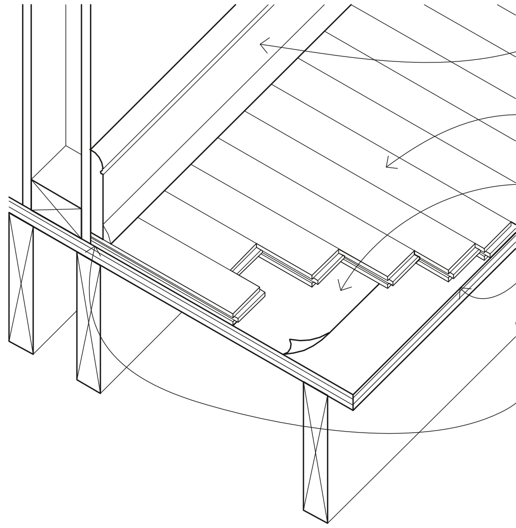
- Unit blocks are made by joining short lengths of strip flooring edgewise. The blocks are usually tongued on two adjoining sides and grooved on the other two to ensure proper alignment in setting
- Laminated blocks are made by bonding three or more wood veneers with a moisture-resistant adhesive for dimensional stability. The blocks are usually tongued on two opposing sides and grooved on the other two to ensure proper alignment in setting
- Slat block flooring is made by assembling narrow slats or fingers of hardwood into larger units with various parquet designs. The blocks are typically 13 mm thick and 150, 300 or 500 mm square. They may be prefinished or unfinished and have square edges or grooved-and-splined edges

Timber flooring requires a wood sub-floor or a base of spaced timber battens. Plywood or panel sub-floors, integral parts of a timber-joist floor system, may be laid over other floor systems as well to receive the timber flooring. Treated timber battens are usually required over concrete slabs to receive a timber sub-floor or the finish timber flooring. This is especially important to protect the flooring from dampness when it is installed on concrete slabs on or below grade.

Timber flooring requires a clean, dry, smooth, flat surface such as a plywood sub-floor or underlay. While block tiles can be applied to the surface of a dry concrete slab, it is best, especially in basements, to lay the flooring over a plywood sub-floor and a vapour barrier set on treated timber sleepers.

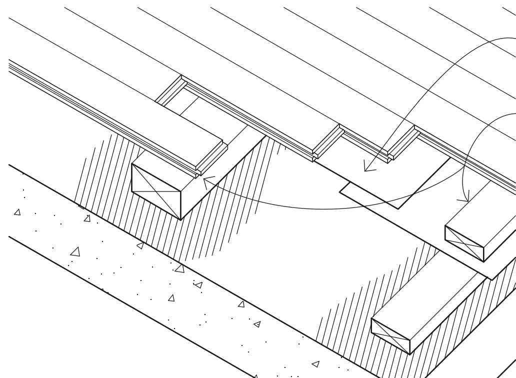
Timber flooring will shrink and swell as its moisture content changes with variations in atmospheric humidity. It should not be installed until the building is enclosed, permanent lighting and the heating plant are installed, and all building materials are dry. The timber flooring should be stored for several days in the space where it will be installed to allow the flooring to become acclimatised to the interior conditions. As the flooring is installed, space should be provided along the perimeter for ventilation and expansion of the flooring.

To provide a level surface and insulation against impact noise, a felt or wood-fibre based flooring underlay should be used, specific underlays are available for laminate, engineering and solid timber flooring.



Timber Flooring over Timber Sub-Flooring

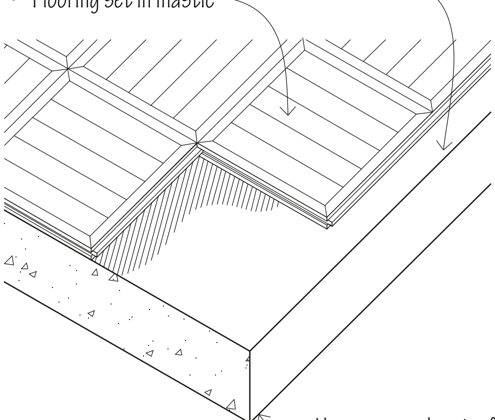
Floating floor panels interlock with each other but are not fixed to the substrate.



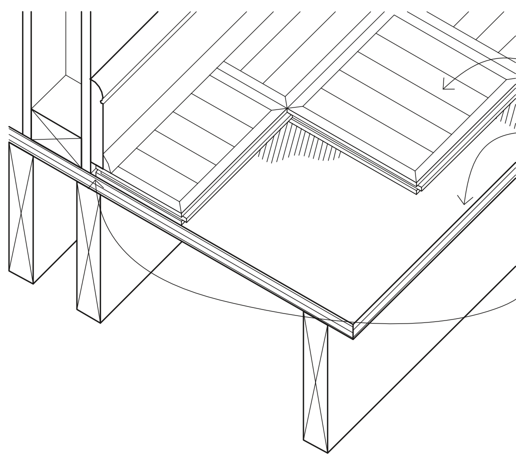
Timber Flooring over Concrete Slab

Glued flooring components are adhered directly to the floor below.

Fixed flooring elements are nailed to the battens or joists below.

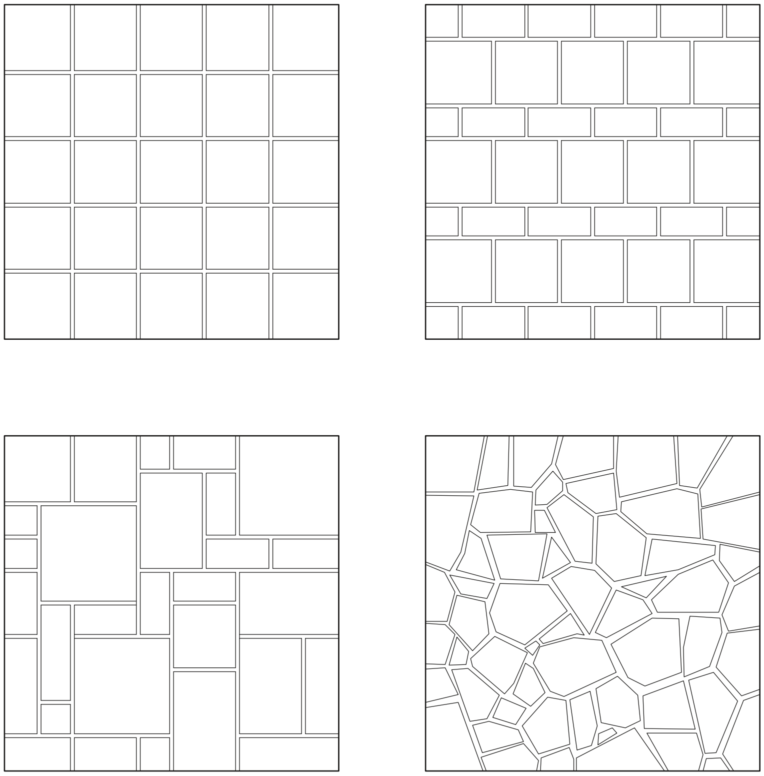


Block Flooring over Timber Sub-Flooring



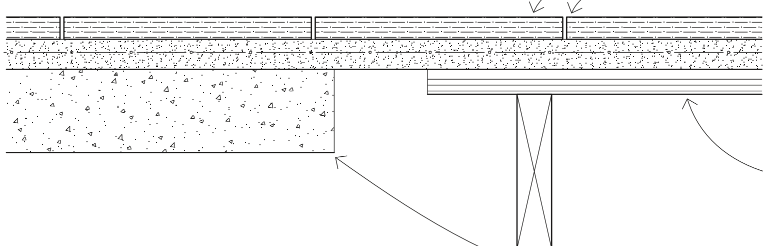
Block Flooring over Concrete Slab

10.18 STONE FLOORING

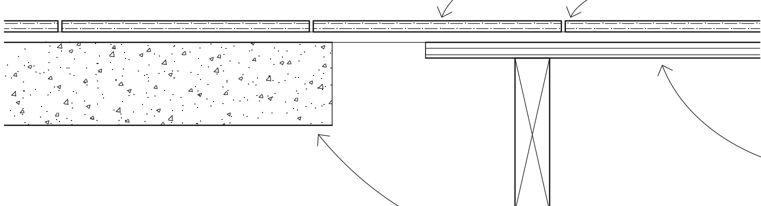


Stone flooring may consist of sandstone, limestone, polished marble or granite, or split-face slate. Consideration should be given to the colour and texture of the stone finish, its abrasion- and slip-resistance, as well as the additional dead load the stone will impose on the floor structure. Stone flooring 12 mm thick applies a load in the region of 35–40kg/m^2.

The tiles or slabs may be laid in regular or irregular patterns over a portland-cement mortar bed in a manner similar to the installation of ceramic-tile flooring. Thin stone flooring may also be applied using the thin bedding; see 10.13.



- Cut-stone flooring units vary in thickness from 12 to 50 mm
- Portland-cement grout
- 30–50 mm portland-cement mortar bed with wire-mesh reinforcement
- Waterproof membrane or cementitious backer board over plywood sub floor
- Concrete slab

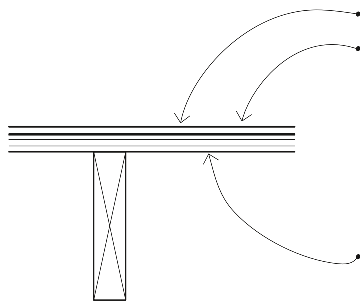


- Thin stone units from 6 to 12 mm thick
- Acrylic latex grout; some thin stone units may be set with tight joints
- Bond coat of latex-portland cement mortar; 6 mm minimum
- Plywood sub-floor or cementitious backer board over plywood sub-floor
- Concrete slab

Resilient flooring materials provide an economical, relatively dense, non-absorbent flooring surface that is durable and easy to maintain. Their degree of resilience enables them to resist permanent indentation and contributes to their quietness and comfort underfoot. How comfortable a resilient floor covering is, however, depends not only on its resilience but also on its backing and the hardness of the supporting substrate.

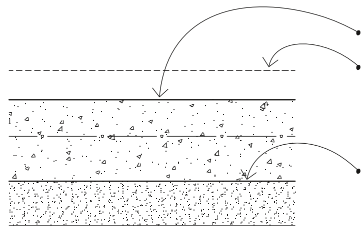
None of the resilient flooring types is superior in all respects. Listed below are the types that perform well in specific areas.

- Resilience and quietness: cork tile, rubber tile, homogeneous vinyl tile
- Resistance to indentation: homogeneous vinyl tile, vinyl sheet, cork tile with vinyl coating
- Stain resistance: rubber tile, homogeneous vinyl tile, vinyl composition tile, linoleum
- Alkali resistance: cork tile with vinyl coating, vinyl sheet, homogeneous vinyl tile, rubber tile
- Grease resistance: vinyl sheet, homogeneous vinyl tile, cork tile with vinyl coating, linoleum
- Durability: homogeneous vinyl tile, vinyl sheet, vinyl composition tile, rubber tile
- Ease of maintenance: vinyl sheet, homogeneous vinyl tile, vinyl composition tile, cork tile with vinyl coating



Timber Sub-Floors

- Surface must be smooth, firm, clean and dry
- Double-layer timber floor consists of hardboard (high-density fibreboard) underlay at least 6 mm thick or sanded plywood underlay at least 10 mm thick, laid with the face grain perpendicular to floor joists or to flooring boards
- Single-layer timber floor consists of combination sub-floor/underlay panels at least 16 mm thick, laid with the face grain perpendicular to floor joists or to flooring boards

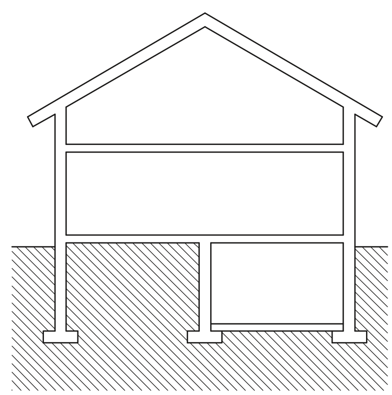


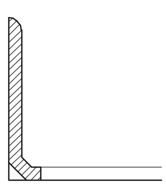
Concrete Sub-Floors

- Surface must be smooth, dense, clean and dry
- Provide a 50–75 mm reinforced-concrete topping over precast slabs
- For concrete slabs on or below grade, provide a damp-proof/waterproofing membrane of an appropriate gauge

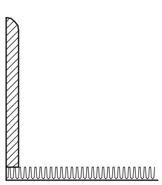
BREEAM MAT 01: Life-Cycle Impacts
LEED EQ Credit 4.1: Low-Emitting Materials, Adhesives & Sealants

Flooring Type	Components	Thickness	Sizes	
Vinyl sheet	vinyl resins with fibre back		2–4 mm	1800 to 4500 mm wide
Homogeneous vinyl tile	vinyl resins	2–3 mm	250 x 250 mm 300 x 300 mm	
Vinyl composition tile	vinyl resins with fillers	0.8–2 mm	250 x 250 mm 300 x 300 mm	
Cork tile	raw cork and resins	3.2–8 mm	150 x 150 mm 300 x 300 mm	
Cork tile w/ vinyl coating	raw cork, vinyl resins	3.2–8 mm	250 x 250 mm 300 x 300 mm	
Rubber tile	rubber compound	2.5–4.5 mm	250 x 250 mm 300 x 300 mm	
Linoleum sheet	linseed oil, cork, rosin	2.5 mm	1800 mm wide	
Linoleum tile	linseed oil, cork, rosin	2.5 mm	250 x 250 mm 300 x 300 mm	

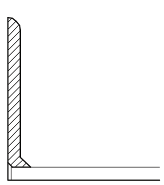




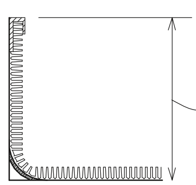
- Butt cove for resilient flooring



- Straight base for carpeted floors



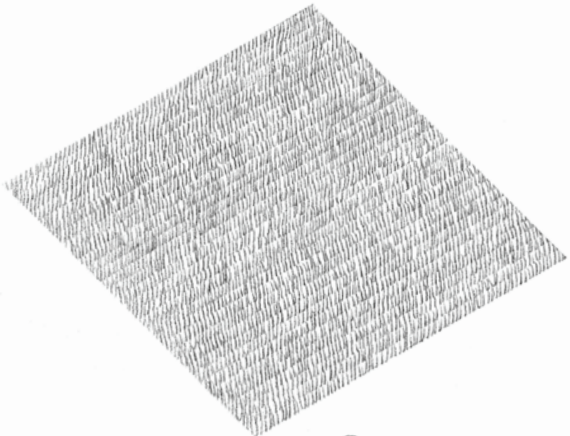
- Top-set cove for any flooring type



- Cove and cap strips
- 65, 100, 150 mm typical heights

- Various resilient flooring accessories are available for use as wall bases, stair nosings and treads, and thresholds

10.20 CARPETING



Carpeting provides floors with both visual and textural softness, resilience and warmth in a wide range of colours and patterns. These qualities, in turn, enable carpeting to absorb sound, reduce impact noise and provide a comfortable and safe surface to walk on. As a group, carpeting is also fairly easy to maintain.

Carpeting is normally installed wall to wall, covering the entire floor of a room. It can be laid directly over a sub-floor and underlay pad, obviating the need for a finish floor. It can also be laid over an existing floor.

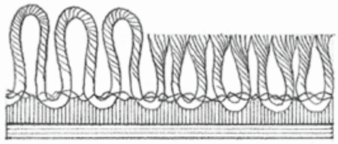
Carpet Fibres

- Nylon: predominant face fibre; excellent wearability; soil and mildew resistant; anti-static properties achieved through the use of conductive filaments
- Polypropylene (olefin): good resistance to abrasion, soil and mildew; used extensively in outdoor carpeting
- Wool: excellent resilience and warmth; good soil, flame and solvent resistance; cleanable
- Acrylic: approximates wool in appearance; good crush resistance; moisture and mildew resistant
- Polyester: combines look of wool with durability of nylon; good soil and abrasion resistance; low cost
- Cotton: not as durable as other face fibres, but softness and colourability used to advantage in flat-woven rugs

- Plastic fibres are a source of gases harmful to the respiratory system; some also yield toxic fumes when burned. Select carpets, carpet adhesives and carpet pads that comply with the European Construction Products Directive and carry a CE mark. It is recommended that rooms containing carpets be ventilated with open doors and windows for 48 to 72 hours after installation

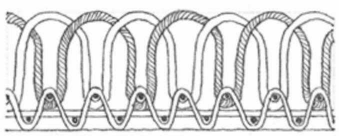
- BREEAM HEA 09: Volatile Organic Compounds
- LEED IEQ Credit 4.3: Low-Emitting Materials, Carpet Systems

Carpet Construction

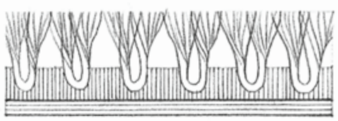


- Tufted carpet is made by mechanically stitching pile yarn through a primary fabric backing and bonding the yarn with latex to a secondary backing. The majority of carpet produced today is tufted

- Woven carpet is made by simultaneously interweaving the backing and pile yarns on a loom. Woven carpet is longer wearing and more stable than tufted carpet, but it is more expensive to produce

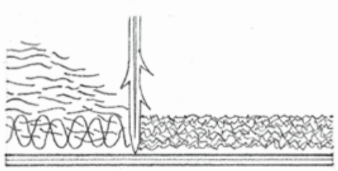


- Knitted carpet is made by looping the backing, stitching and pile yarns with three sets of needles

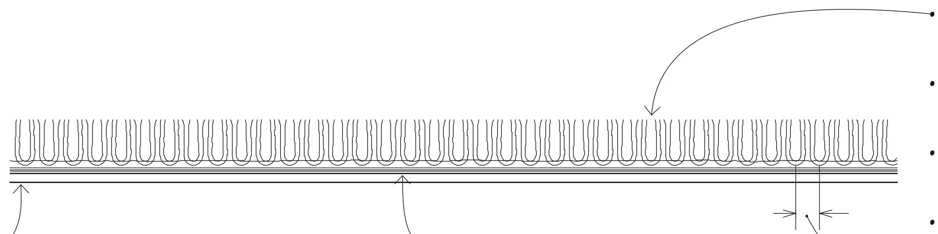


- Fusion-bonded carpet is made by heat-fusing face yarns to a vinyl backing supported by other materials

- Flocked carpet is made by propelling short strands of pile fibre electrostatically against an adhesive-coated backing



- Needle-punched carpet is made by punching carpet fibres back and forth through a woven polypropylene sheet with barbed needles to form a felted fibre mat



- Pile refers to the upright tufts of yarn forming the surface of a carpet
- Pile weight is the average weight of pile yarn in a carpet, stated in ounces per square yard
- Pile density is the weight of pile yarn per unit volume of carpet, stated in ounces per cubic yard
- Pitch is the crosswise number of tuft-forming pile yarns in a 685 mm width of woven carpet
- Gauge is the spacing of tufts across the width of a tufted or knitted carpet, expressed in millimetres

- Carpet pad is a pad of cellular rubber, felted animal hair or jute, over which carpet is installed to increase resilience and comfort, improve durability of the carpet and reduce impact sound transmission

- Backing is the foundation material securing the pile yarns of a carpet and providing it with stiffness, strength and dimensional stability

Carpet Terminology

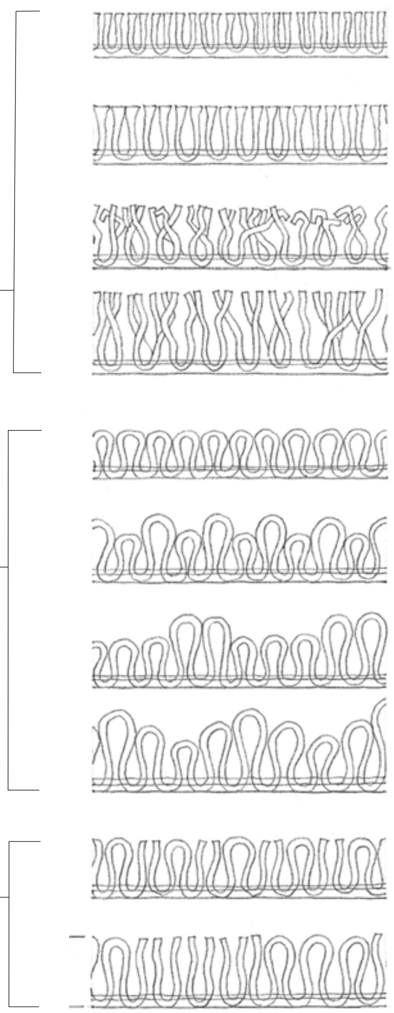
Carpet Textures

After colour, texture is the prime visual characteristic of a carpet. The various carpet textures available are a result of the pile construction, pile height and the manner in which the carpet is cut. There are three major groups of carpet textures – cut pile, loop pile and a combination of cut and loop pile.

- Cut pile is created by cutting each loop of pile yarn, producing a range of textures from informal shags to short, dense velvets

- Loop pile is created by weaving, tufting or knitting the pile yarn into loops. Loop pile is tougher and more easily maintained than cut pile but is less versatile in colour and pattern

- Combination loop and pile adds a degree of warmth to all-loop pile. It can be produced in tufted and woven constructions

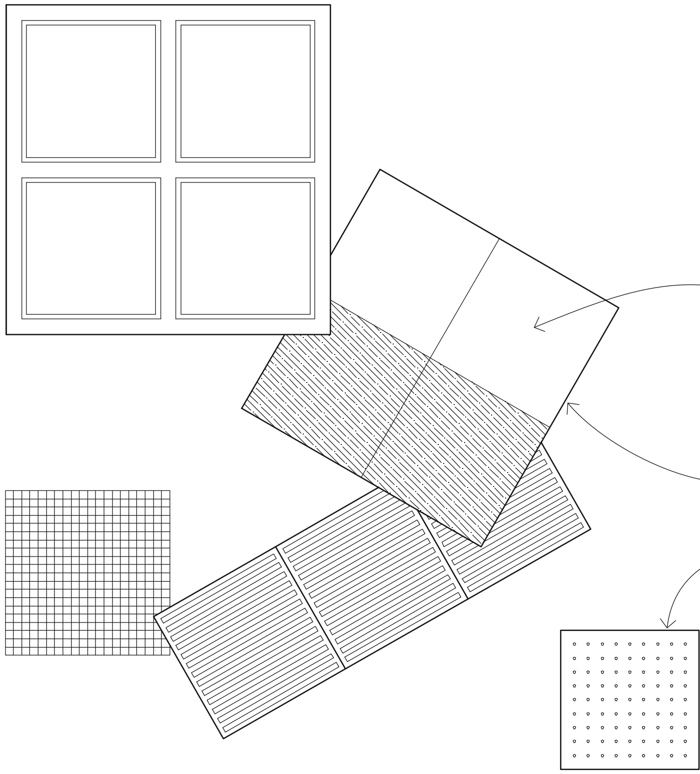


- Plush: smooth cut pile; cut yarn ends blend; called velvet plush when dense pile is cut closely
- Saxony plush: texture between plush and shag; thicker yarn
- Twist or frieze; heavier, rougher texture than plush; twist set into yarn
- Shag: heavily textured surface created by long, twisted yarns
- Level loop: looped tufts are at the same height; very sturdy; little textural variation
- Ribbed loop: creates directional, ribbed or corrugated texture
- Hi-lo loop: adds another dimension to the loop texture
- Multi-level loop: capable of producing sculptured patterns
- Cut and loop: cut and uncut loops alternate in a uniform fashion; adds a degree of softness and warmth to loop texture; symmetrical geometric figures may be created by cut rows

Accessibility Guidelines

- Securely attach carpet to a firm underlay
- Carpet should have a level cut pile, level loop, textured loop, or cut-and-loop texture, with a maximum pile height of 15 mm
- Fasten and trim all exposed edges to the floor surface
- Check local regulations for further guidance

10.22 ACOUSTIC CEILING TILES



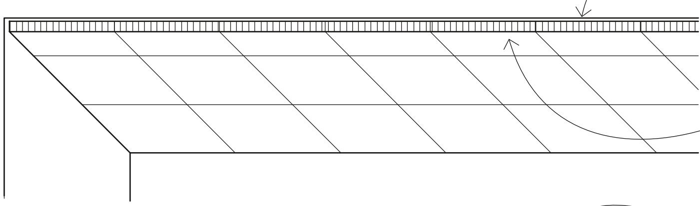
Acoustic ceiling tiles are made in various sizes and textures from a soft, sound-absorbing material, such as cork, mineral fibre or fibreglass. These modular units have perforated, patterned, textured or fissured faces that allow sound to penetrate into the fibre voids. Because of their light weight and low density, the tiles can be easily damaged. To improve their resistance to humidity, impact and abrasion, the tiles may be factory-painted or have a ceramic, plastic, steel or aluminium facing.

- Acoustic ceiling tiles are manufactured in 300 x 300 mm, 600 x 600 mm and 600 x 1200 mm modules. Tiles based on 500, 750, 1200 and 1500 mm dimensions are also available

- Typical tile thicknesses: 19, 20, 22 mm
- Tiles may have square, bevelled, rebated or tongue-and-groove edges

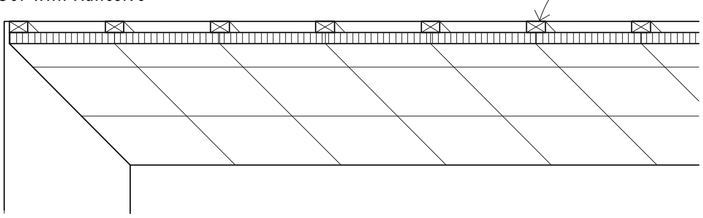
- Metal pan tiles consist of a steel or aluminium pan having a perforated face and containing a separate layer of sound-absorbing material

Consult the ceiling tile manufacturer for:
- Sizes, patterns and finishes
- Weighted sound absorption coefficient
- Fire rating
- Light-reflectance value
- Suspension-system details



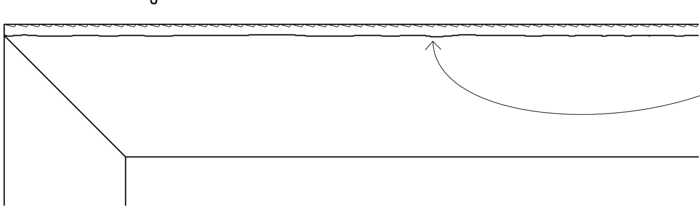
Set with Adhesive

- A solid backing such as concrete, plaster or plasterboard is required
- Tiles are set with a special adhesive that allows a true, flat plane to be maintained even though there may be slight irregularities in the base surface



Fastened to Furring

- 25 x 75 mm furring strips at 300 mm centres are used when the base surface is not flat enough or is otherwise unsuitable for the adhesive application of the ceiling tiles. Cross furring and shims may also be required to establish a flat, level base
- Tiles should be backed with building paper to provide a draught-tight ceiling surface



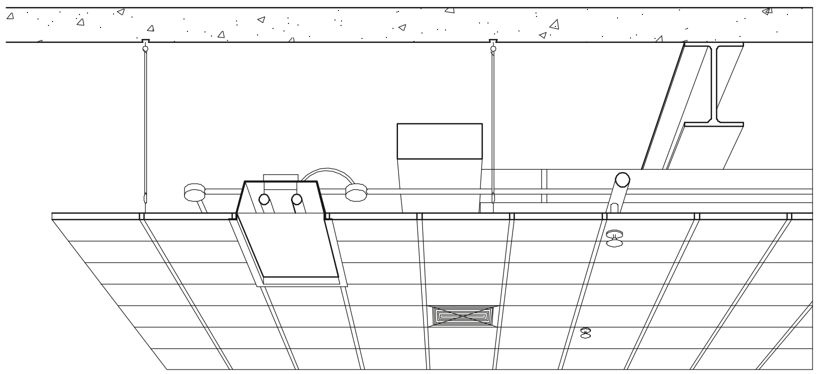
Sprayed On

- Acoustic material of mineral or cellulose fibres mixed with a special binder may be sprayed directly onto hard surfaces such as concrete or plasterboard. The material can also be sprayed onto metal lath, which provides better sound absorption and permits curved or irregular ceiling shapes to be formed

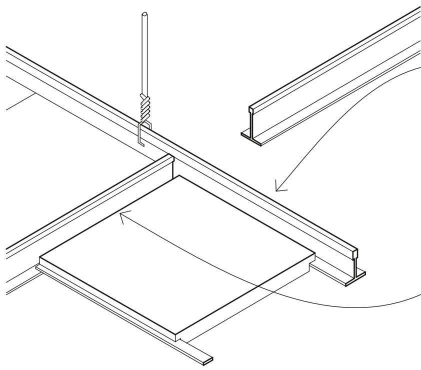
Direct Application of Acoustic Ceilings

ISO 11654: Acoustics – Sound Absorbers for Use in Buildings

Acoustic ceiling tiles can be suspended from an overhead floor or roof structure to provide a concealed space for mechanical ductwork, electrical conduit and plumbing lines. Light fixtures, sprinkler heads, fire-detection devices and sound systems can be recessed into the ceiling plane. The ceiling membrane can be fire-rated and provide fire protection for the supporting floor and roof structure. Thus, the ceiling system is able to integrate the functions of lighting, air distribution, acoustic control and fire protection.

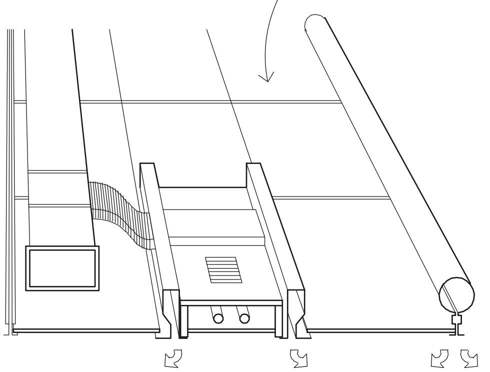


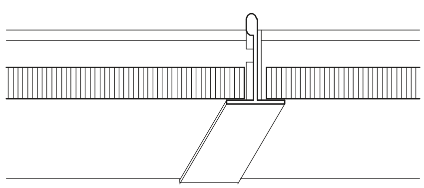
Although the suspension systems of each manufacturer may vary in their details, they all consist of a grid of main channels or runners, cross tees and splines. This grid, suspended from the overhead floor or roof structure, may be exposed, recessed or fully concealed. In most suspension systems, the acoustic tiles are removable for replacement or for access into the ceiling space.



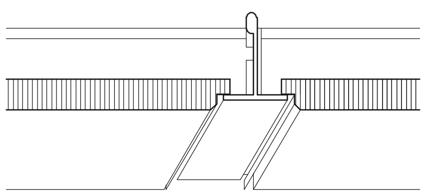
- Main runners are the principal supporting members of a suspended-ceiling system, usually consisting of sheet-metal tees or channels suspended by hanger wires from the overhead structure
- Cross tees are the secondary supporting members, usually consisting of sheet-metal tees carried by the main runners

Integrated ceiling systems incorporate acoustic lighting and air-handling components into a unified whole. The suspension systems, which typically form a 1500 x 1500 mm grid, may support either flat or coffered acoustic panels. Air-handling components may be integral parts of modular luminaires and disperse conditioned air along the edges of the fixtures, or be integrated into the suspension system and diffuse conditioned air through long, narrow slots between the ceiling panels.

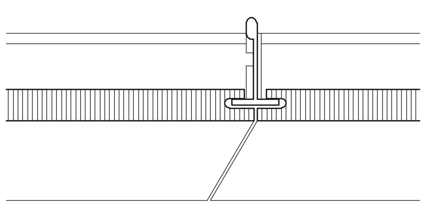




- Exposed-grid suspension systems support the acoustic tiles with inverted tees

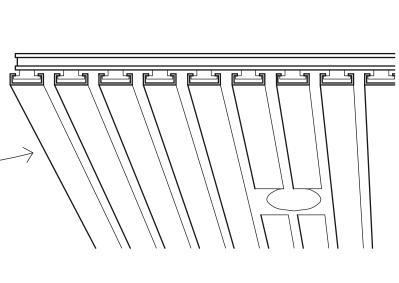


- Recessed-grid suspension systems support acoustic tiles within rebated joints



- Concealed-grid suspension systems are hidden within kerfs cut into the edges of the acoustic tiles

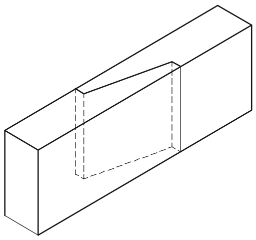
Linear metal ceilings consist of narrow anodised aluminium, painted steel or stainless-steel strips. The slots between the spaced strips may be open or closed. Open slots permit sound to be absorbed by a backing of batt insulation in the ceiling space. Linear metal ceiling systems usually incorporate modular lighting and air-handling components.



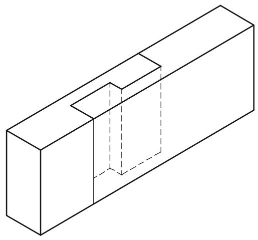
The strength and rigidity of ordinary timber framing are more important than its appearance because it is normally covered with a finish surface. In finish trim, cabinetwork and furniture work, however, the appearance of a timber joint becomes just as important as its strength. Small-scale work requires more sophisticated and refined joints that present a clean appearance.

Timber joints can express the manner in which the members are connected, or they can be relatively inconspicuous. In either case, they must remain tight. If they open due to the shrinkage or structural movement of the wood, they become both weaker and more noticeable.

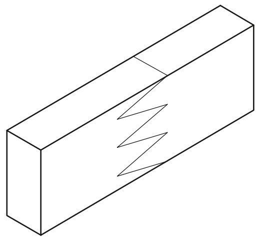
In designing and constructing a timber joint, it is important to understand the basic nature of the compressive, tensile, shear forces acting on the joint, and to comprehend their relationship to the direction of the wood grain; see 12.11.



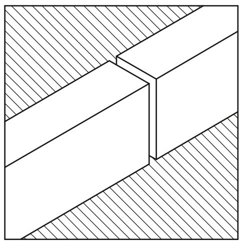
• Scarf joint



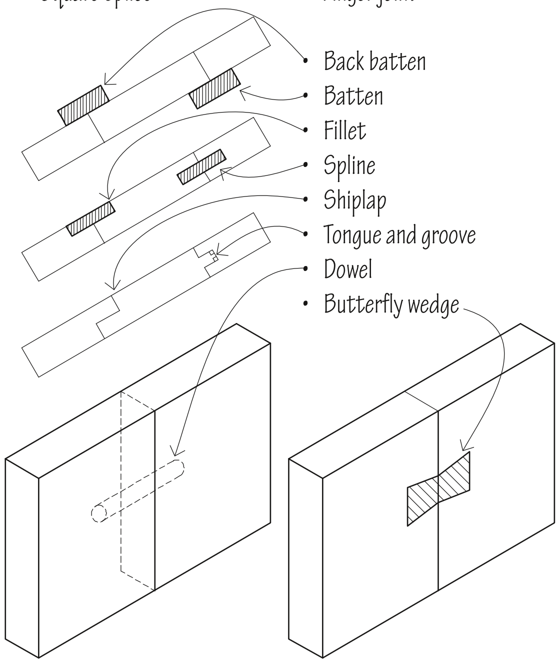
• Square splice

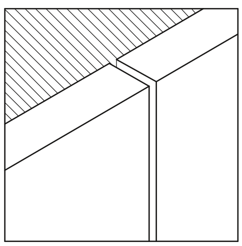


• Finger joint



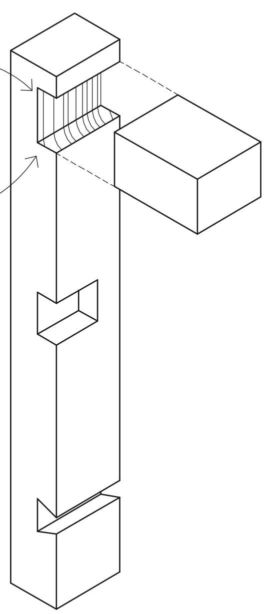
End Joints



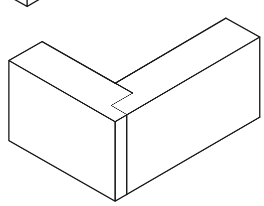


Edge Joints

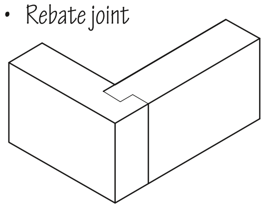
• Housing joint
• Housing is a rectangular groove cut in a member to receive the end of another



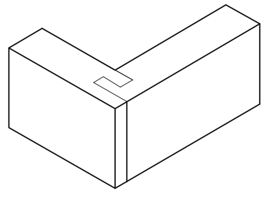
• Dovetail joint



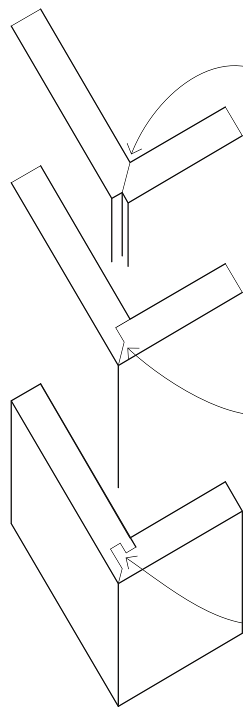
• Rebate joint



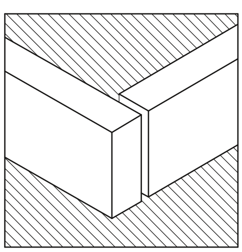
• Housing and rebate



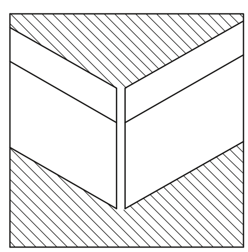
• Housing, tongue and rebate



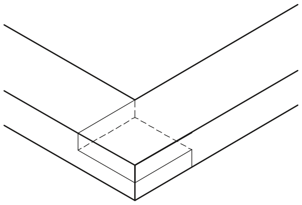
• Mitre joint is made by cutting each of the butting surfaces to an angle equal to half the angle of junction
• Shoulder mitre has a raised surface to limit motion between the joined parts
• Tongued mitre



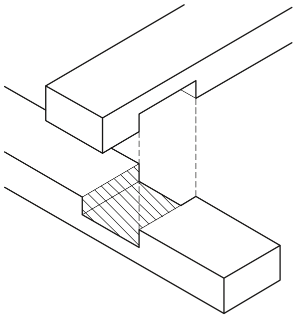
Angle Joints



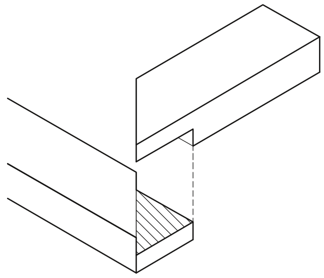
Mitre Joints



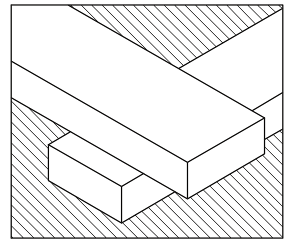
• End lap



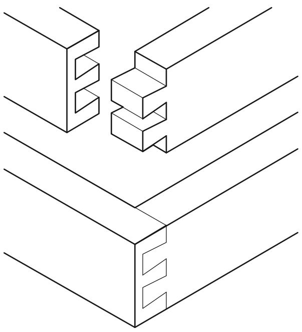
• Cross lap



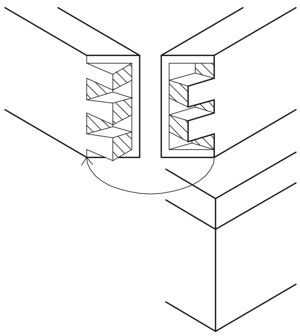
• Mitred halving



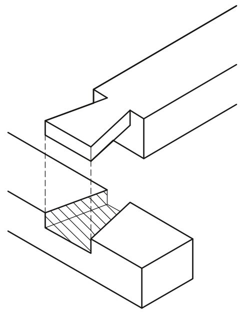
Lap Joints



• Lap or half-blind dovetail

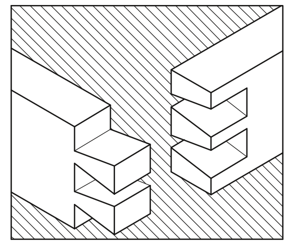


• Secret dovetail or blind mitre



• Dovetail halving

• Halving refers to cutting away half of each member at the place of joining so that a flush surface results



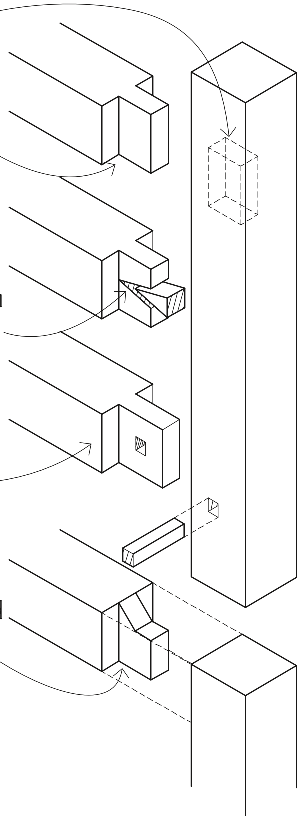
Dovetail Joints

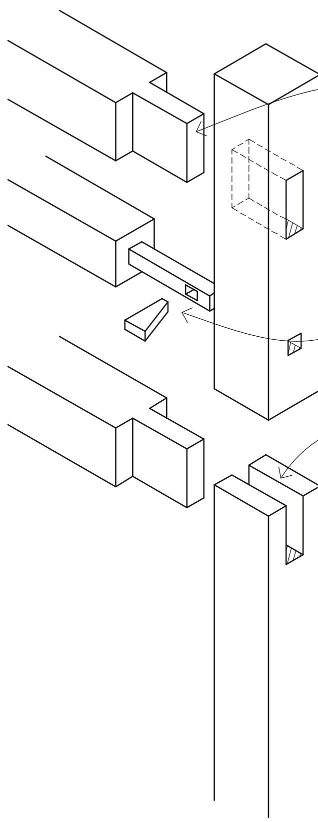
• Blind mortice and stub tenon

• Foxtail wedge spreads and secures a stub tenon when driven into a blind mortice

• Pinned joint

• Haunched tenon is strengthened by a bevelled shoulder at a blind joint

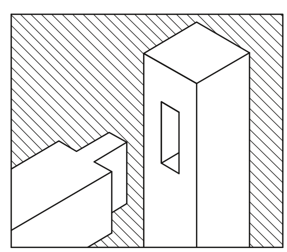




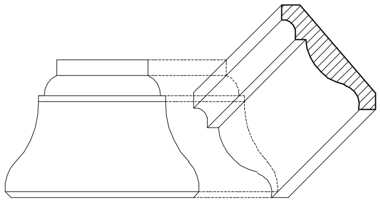
• Through tenon

• Keyed joint

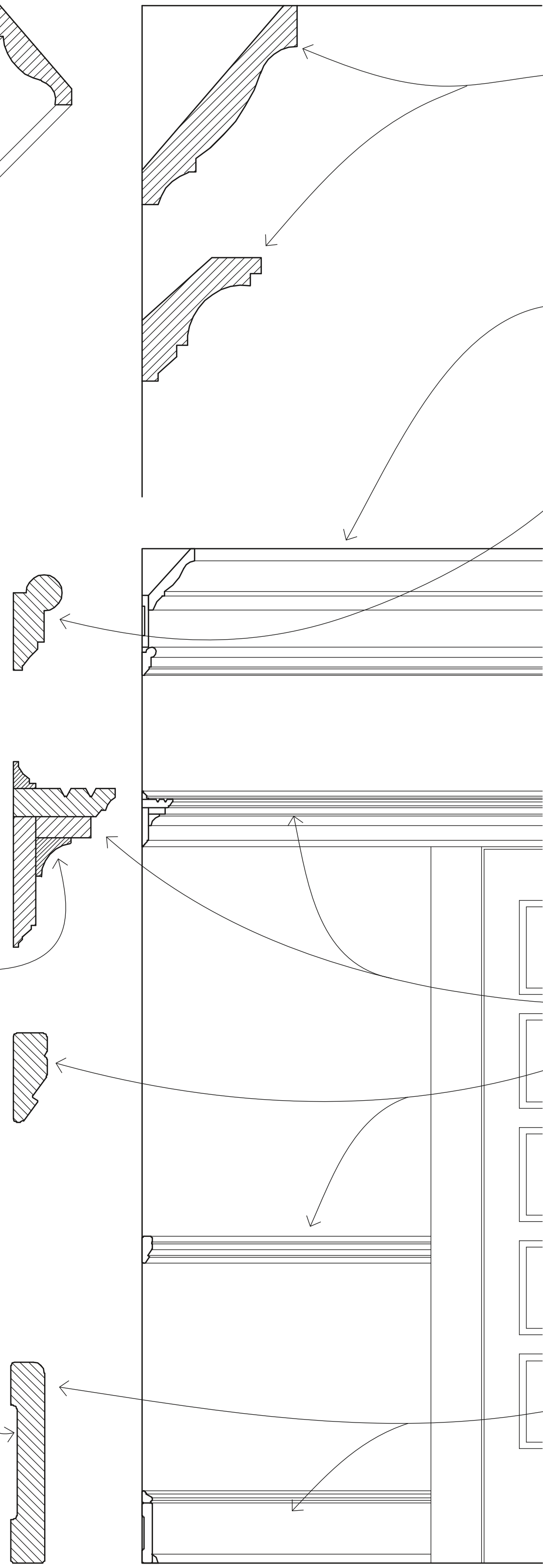
• Open or slip mortice



Mortice-and-Tenon Joints



- A coped or scribed joint is used where shaped mouldings meet at an interior angle. It is made by square-cutting one moulding against the wall surface and then undercutting the other moulding to the profile of the first
- Mitred joints are used to join mouldings at exterior angles



- Crown mouldings terminate the top of a wall or built-up cornice

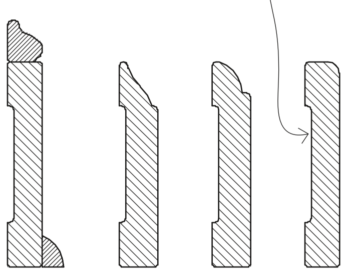
Cornice
- Cornice is a moulded projection that crowns a wall or divides it horizontally for compositional purposes. It may be formed simply with a crown moulding or be built up with a number of mouldings
- Picture rail is a horizontal moulding near a ceiling from which pictures can be suspended with cord and hooks. It is often integrated with a cornice

- Frieze is a decorative band along the top of an interior wall, immediately below the cornice

- Cove mouldings ease the transition between meeting surfaces

Rails
- Moulded capping is a narrow shelf fixed along a wall and grooved to hold plates for ornament or display
- Dado rail is a horizontal moulding on an interior wall, placed to prevent the backs of chairs from rubbing against and damaging the wall surface

- Relieved back reduces the tendency for a wide trim piece to cup and allows it to fit neatly against a surface

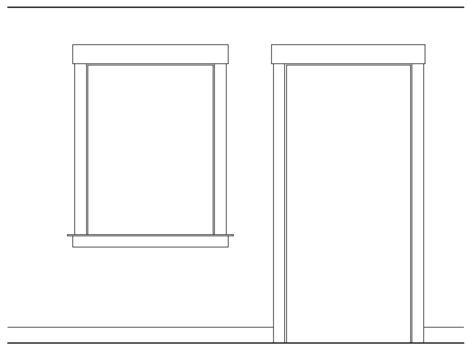


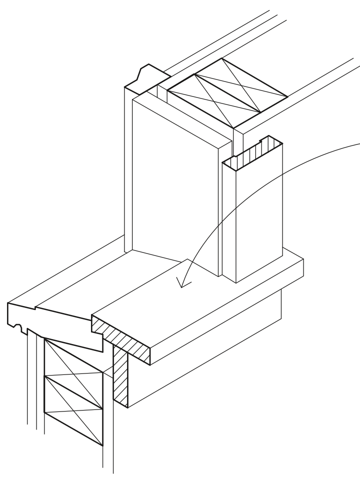
Skirtings
- Skirtings conceal and finish the joints where side walls meet the floor. They may be a single moulding or incorporate a cap moulding and base shoe

For use as trim, a variety of stock wood mouldings are available at joinery shops. They vary in section, length and species of wood. They can be used singly or be combined to form more complex sections. In addition to these stock sections, timber mouldings can be milled to custom specifications.

The type of wood used for trim depends on the type of finish to be applied to the woodwork. For painted finishes, the wood should be close-grained, smooth and free of pitch streaks or other imperfections. If the woodwork is to receive a transparent or natural finish, the wood should have a uniform colour, an attractive figure and a degree of hardness.

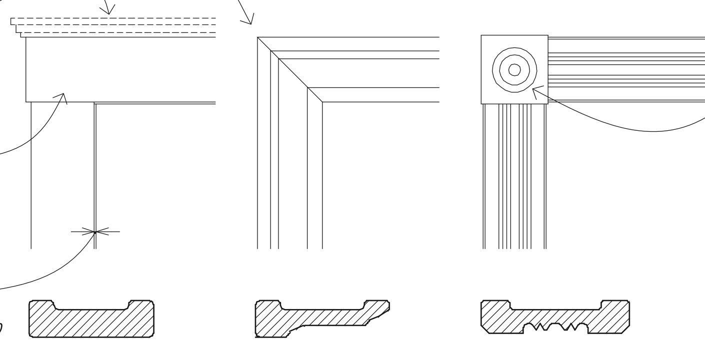
Interior trim is normally applied after the finish walls, ceiling and flooring are in place. Although decorative in nature, interior trim also serves to conceal, finish and perfect the joints between interior materials.





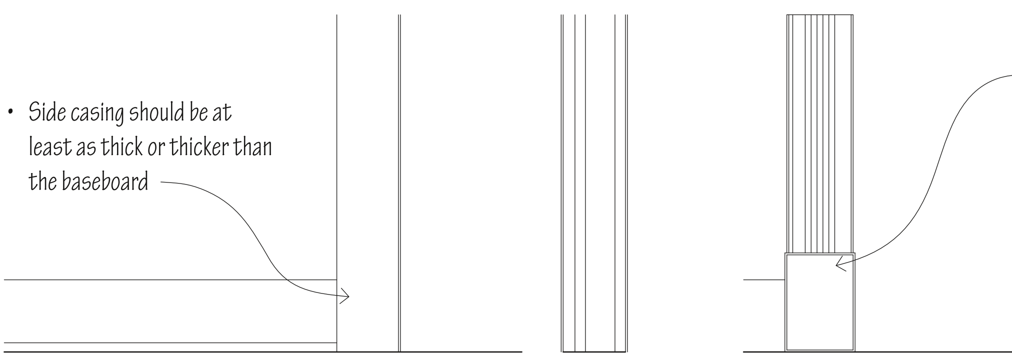
- Window sill refers to the horizontal ledge formed by the stool at the base of a window opening. The sill may be cut to fit between the jambs of a window or door opening or extend beyond the jamb casings

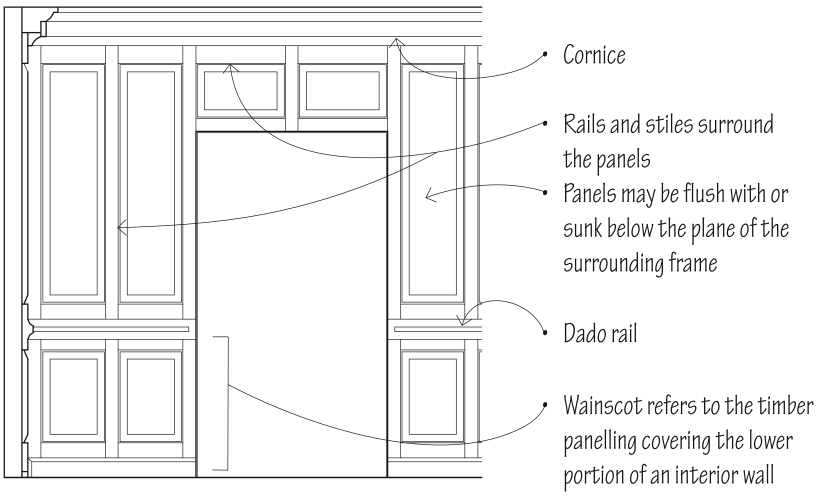
- Shaped mouldings must join at a mitred joint
- Cap moulding may terminate the head of a window or doorway
- Jamb or side casing butts into a square-cut head casing, especially when the head casing is thicker than the side casing



- A corner block can be used to join more complex casing sections
- The term architrave refers to the casing that surrounds a window or doorway, especially when it is continuous with the same profile
- 6 to 10 mm reveal typical; reveal refers to the part of a jamb that is not covered by a window or door casing

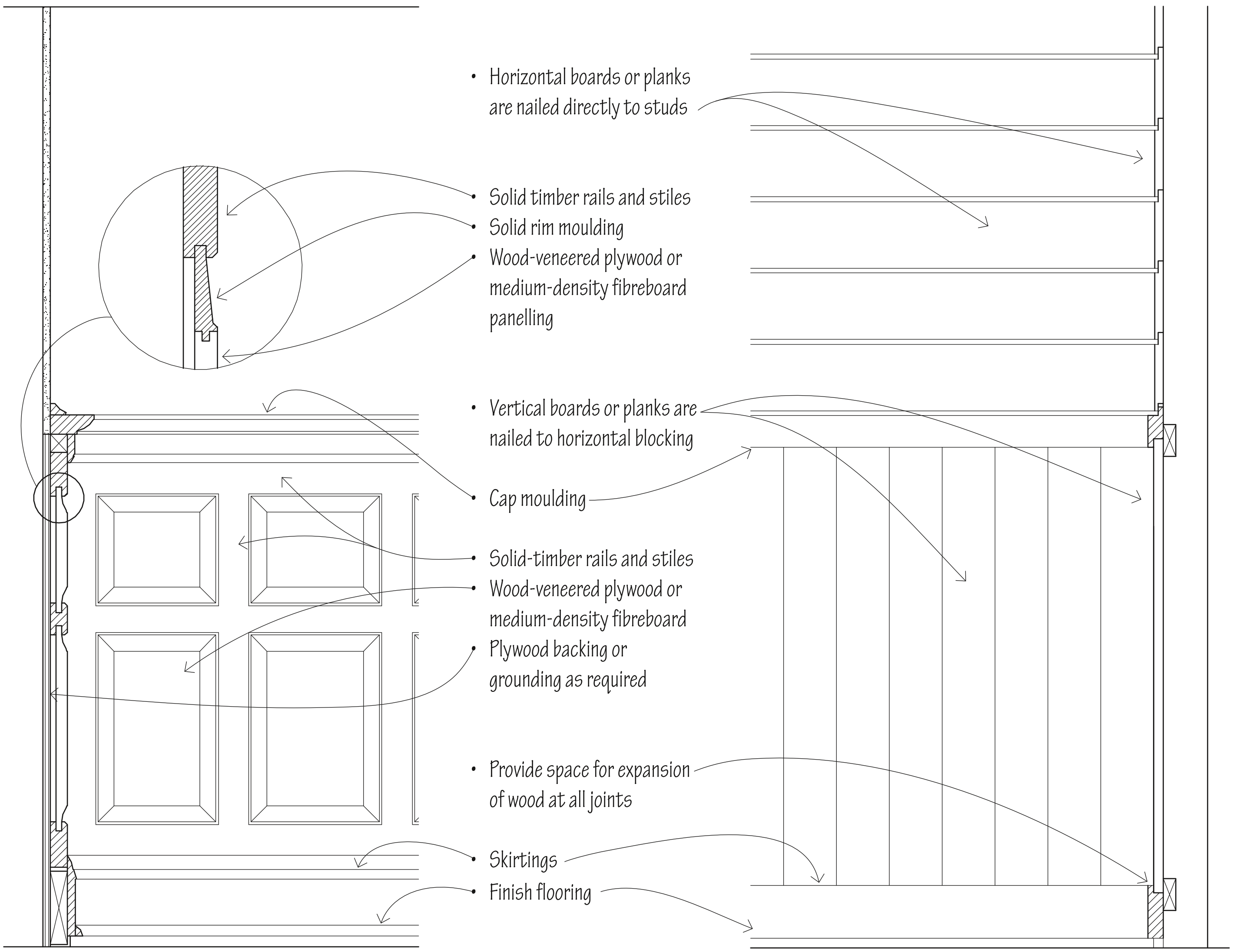
- Side casing should be at least as thick or thicker than the baseboard
- A plinth block may be used to terminate a jamb casing above the floor





Interior timber panelling may consist of veneer-faced panels applied directly to wood or metal framing, or grounding or furring. Furring is required over masonry or concrete walls. Furring may also be used over frame walls when improved thermal-insulation properties, greater acoustic isolation or additional wall depths are desired. The panels are normally fastened with nails or screws although adhesives can be used for greater rigidity. The final appearance of the panelled wall will depend on the treatment of the joints and the grain or figure of the timber panels.

Solid timber planks may also be used for interior panelling. The planks may have square cut, tongue-and-groove or shiplap edges. The resulting wall pattern and texture will depend on the plank width, orientation, spacing and joint details.

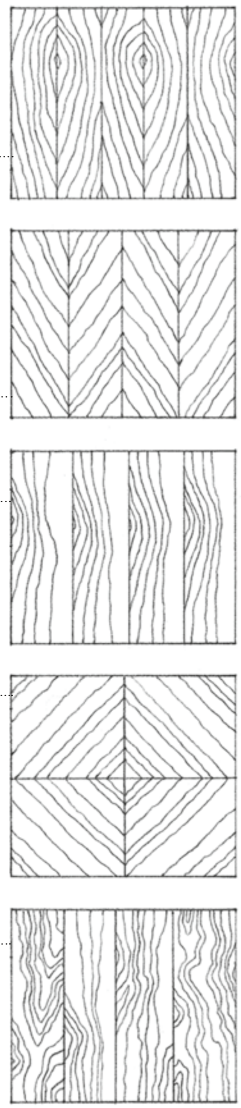


Decorative plywood panels are available with hardwood or softwood face veneers for use as wall panelling, cabinetwork and furniture work. The panels are typically 1200 x 2400 mm and available in 6, 10, 12 and 18 mm thicknesses.

Matching Patterns

The appearance of naturally finished plywood panelling depends on the species of wood used for the face veneer and the way in which the sheets of veneer are arranged so as to emphasise the colour and figure of the wood.

- Book matching arranges veneers from the same flitch alternately face up and face down to produce symmetrical mirror images about the joints between adjacent sheets
- Herringbone matching is book matching in which the figures in adjacent sheets slope in opposite directions
- Slip matching arranges adjacent sheets of veneer from the same flitch side by side without turning so as to repeat the figure
- Diamond matching arranges four diagonally cut sheets of a veneer to form a diamond pattern about a centre
- Random matching arranges veneers to intentionally create a casual, unmatched appearance



Hardwood and Softwood Classification

European Standards classify plywood veneers according to the quality surface appearance (see EN 635);

- E, I, II, III & IV. E relating to limited defects to IV relating to the maximum level of defects allowed

and backing (EN 636):

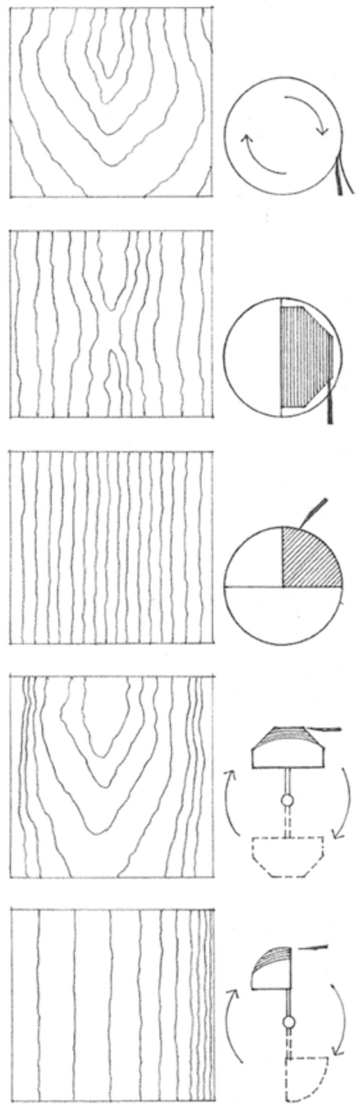
- Bending strength F3 to F80 (in length and width) and
- Bending modulus E5 to E140 (in length and width)

and service class (ENV 1995)

- Class I: Dry Conditions
- Class II: Humid Conditions
- Class III: Exterior Usage

Grain Figures

Figure refers to the natural pattern on a sawn-wood surface produced by the intersection of annual rings, knots, burls, rays and other growth characteristics. Different figures may be produced by varying the way in which a wood veneer is cut from a log.



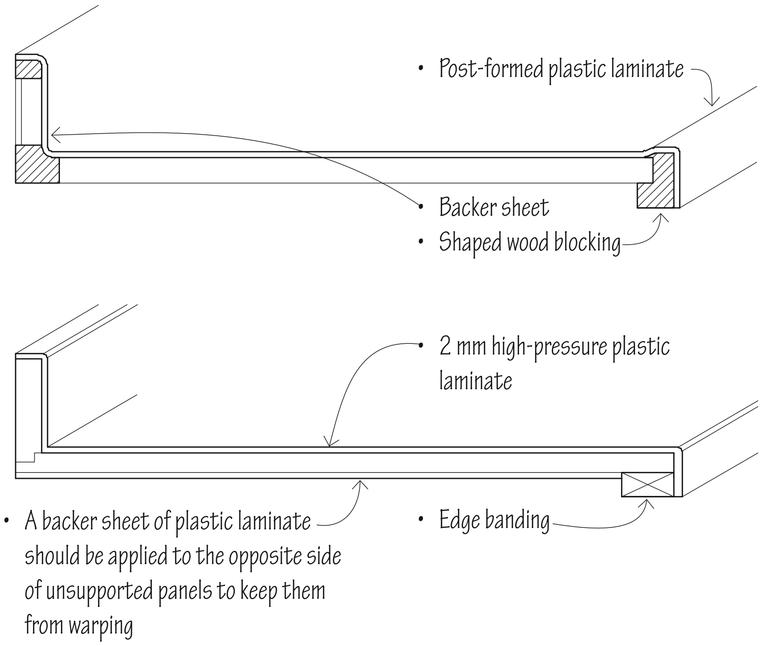
- Rotary cutting against the edge of a knife in a lathe produces a continuous veneer with a variegated ripple figure
- Flat or plain slicing of a half-log parallel to a line through its centre produces a variegated wavy figure
- Quarter slicing of a log perpendicular to the annual rings produces a series of straight or varied stripes in the veneer
- Half-round slicing of a flitch mounted off-centre in the lathe, slightly across the annual rings, produces characteristics of both rotary cutting and flat slicing
- Rift cutting is the slicing of oak and similar species perpendicular to the conspicuous, radiating rays so as to minimise their appearance

BREEAM MAT 03: Responsible Sourcing of Materials
LEED EQ Credit 4.4 Low-Emitting Materials: Composite Wood & Agrifiber Products

10.30 PLASTIC LAMINATE

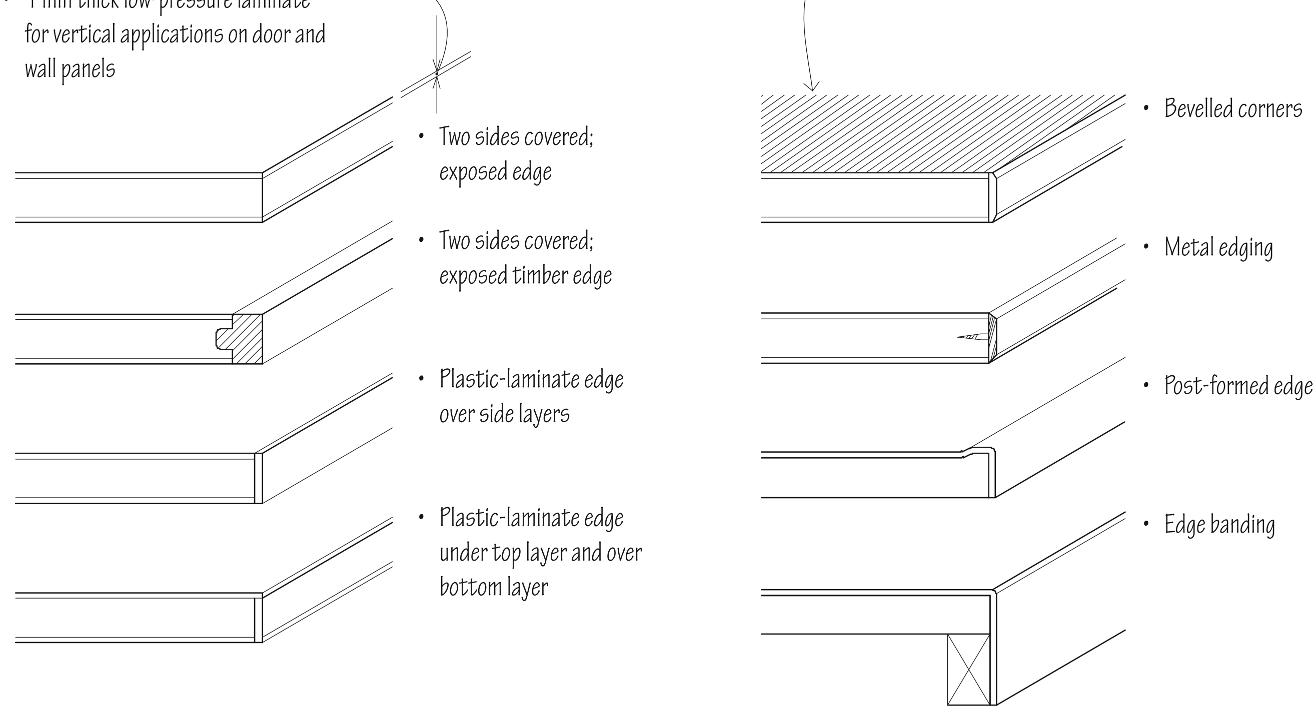
Plastic laminate is a hard surfacing material consisting of superposed layers of kraft paper, foil, printed paper, timber veneer or fabric impregnated with melamine and phenolic resins, fused together under heat and pressure. Plastic laminates provide a durable, heat- and water-resistant surface covering for counters, furniture, doors and wall panels. They may be applied to smooth plywood, hardboard, particle board and other common core materials. They may be bonded with contact adhesive in the field or with thermosetting adhesive, under pressure, in the shop.

- High-pressure laminate is moulded and cured in the range of pressures from 84 to 140 kg/m^2, and used for surfacing counters and tabletops
- Low-pressure laminate is moulded and cured with a maximum pressure of 28 kg/m^2, and used in vertical and low-wear applications
- Formica® is a trademark for a brand of plastic laminate
- Plastic-laminate surfaces with tight rolls and bends should be post-formed during manufacture and bonded with thermosetting adhesive. Post-formed plastic laminate 1.2 mm thick may be bent to a radius as small as 19 mm. Plastic-laminate edge banding may be bent to a radius of 75 mm or smaller if heated
- A wide range of colours and patterns is available in glossy, satin, low-glare or textured finishes



Plastic-Laminate Counters

- 2 mm thick high-pressure laminate for horizontal applications on counters and tabletops
- 1 mm thick low-pressure laminate for vertical applications on door and wall panels



Edge Treatments for Plastic-Laminate-Faced Panels

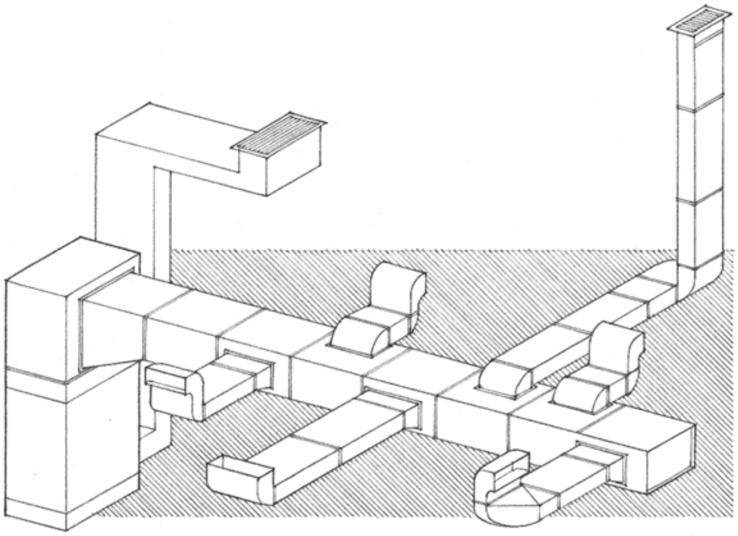
Formica® is the registered trademark of The Diller Corporation

BREEAM MAT 03: Responsible Sourcing of Materials
EQ Credit 4.1: Low-Emitting Materials, Adhesives & Sealants

11

MECHANICAL & ELECTRICAL SYSTEMS

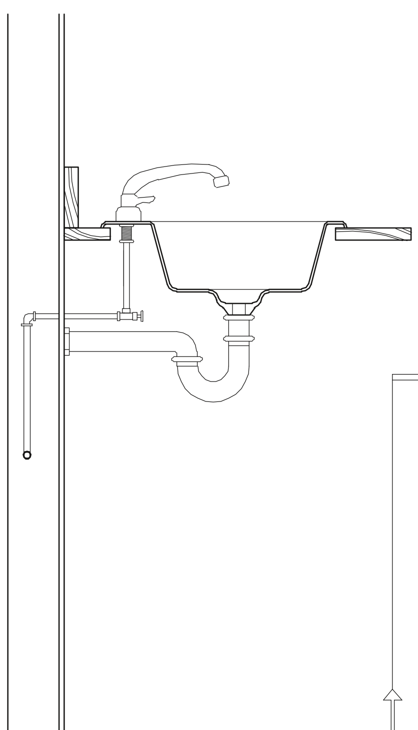
11.02 MECHANICAL & ELECTRICAL SYSTEMS

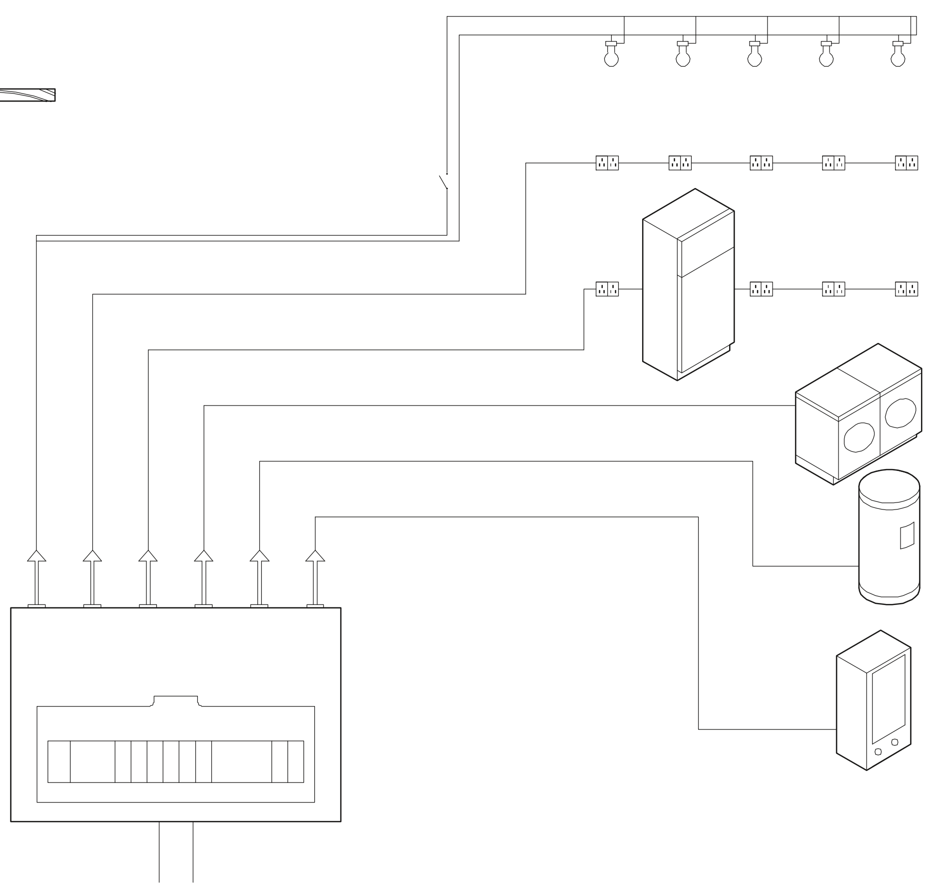


This chapter discusses the mechanical and electrical systems that are required to maintain the necessary conditions of environmental comfort, health and safety for the occupants of a building. The intent is not to provide a complete design manual but to outline those factors that should be considered for the successful operation of these systems and their integration with other building systems.

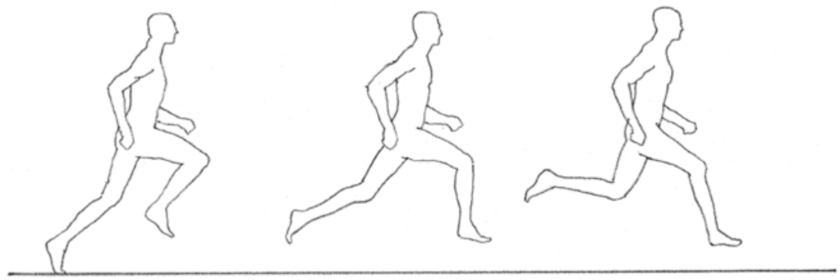
Heating, ventilating and air-conditioning systems condition the interior spaces of a building for the environmental comfort of the occupants. A potable water supply is essential for human consumption and sanitation. The efficient disposal of fluid waste and organic matter is necessary in order to maintain sanitary conditions within a building and in the surrounding area. Electrical systems furnish light and in some cases heat for a building's occupants, and power to run its machines.

These systems require a significant amount of space. Because much of the hardware is normally hidden from view – within concealed construction spaces or special rooms – the layouts of these systems should be carefully integrated with each other as well as with the structural and enclosure systems of the building.





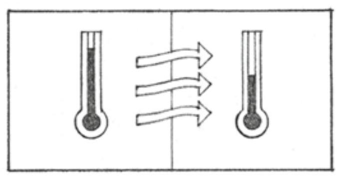
At rest, the human body produces about 117 W. Moderate activities like walking can raise this amount to 220 W, while strenuous activities can cause the body to generate up to 351 W. Thermal comfort is achieved when the human body is able to dissipate the heat and moisture it produces by metabolic action in order to maintain a stable, normal body temperature. In other words, thermal equilibrium must exist between the body and its environment.



The human body loses or transfers heat to the surrounding air and surfaces in the following ways.

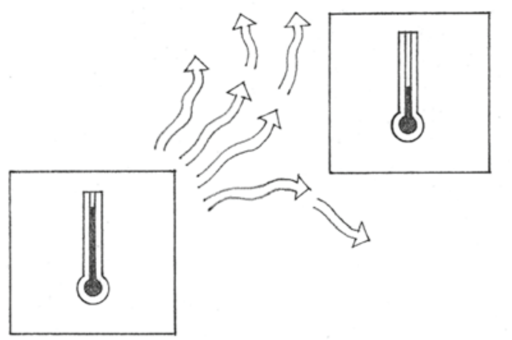
Conduction

- Conduction is the transfer of heat from the warmer to the cooler particles of a medium or of two bodies in direct contact, occurring without perceptible displacement of the particles themselves
- Conduction accounts for a very small portion of the total heat loss from the body



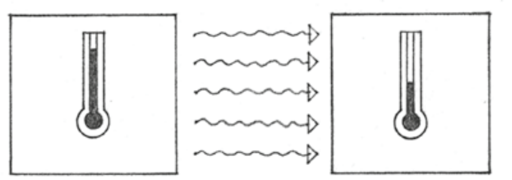
Convection

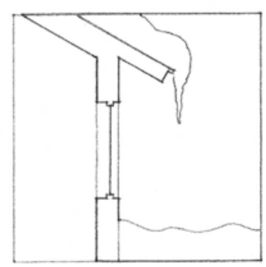
- Convection is the transfer of heat by the circulatory motion of the heated parts of a liquid or gas owing to a variation in density and the action of gravity. In other words, the body gives off heat to the surrounding cooler air
- A large differential between air and skin temperature and increased air motion induces more heat transmission by convection



Radiation

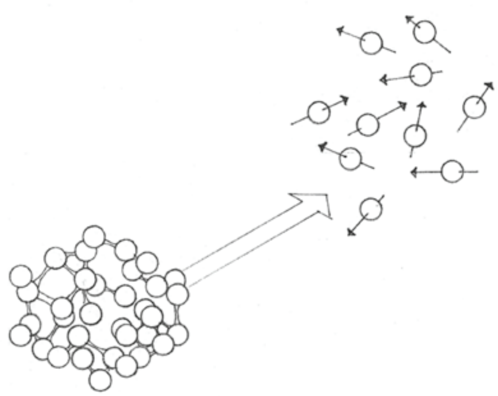
- Radiation is the process by which heat energy in the form of electromagnetic waves is emitted by a warm body, transmitted through an intervening space, and absorbed by a cooler body. No air motion is required for the transfer of heat
- Light colours reflect while dark colours absorb heat; poor reflectors make good radiators
- Radiant heat cannot travel around corners and is not affected by air motion



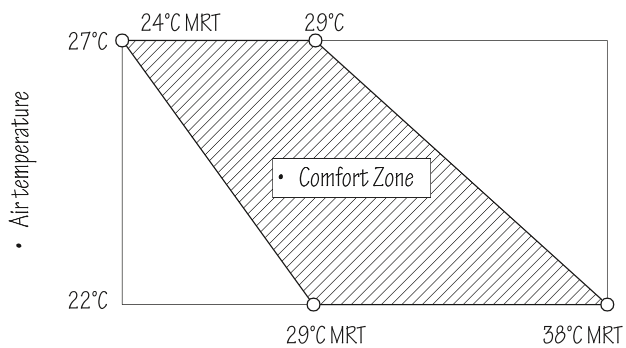


Evaporation

- Heat is required for the evaporative process of converting body moisture into a vapour
- Heat loss by evaporation increases with air motion
- Evaporative cooling is especially beneficial when high air temperatures, humidity and activity levels exist

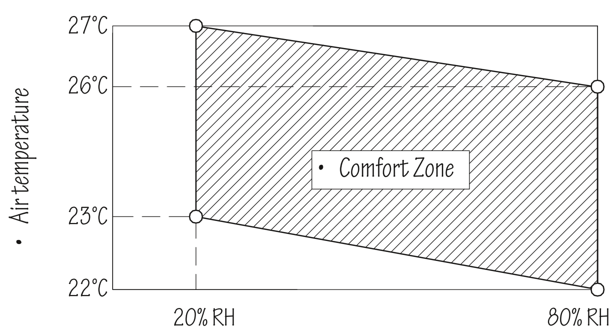


Factors affecting human comfort include air temperature, relative humidity, mean radiant temperature, air motion, air purity, sound, vibration and light. Of these, the first four are of primary importance in determining thermal comfort. Certain ranges of air temperature, relative humidity, mean radiant temperature and air motion have been judged to be comfortable by a majority of people. These comfort zones are described by the following graphs of the interaction between the four primary thermal-comfort factors. Note that a specific level of comfort for any individual is a subjective judgement of these thermal-comfort factors and will vary with prevailing and seasonal variations in climate as well as the age, health, clothing and activity of the individual.



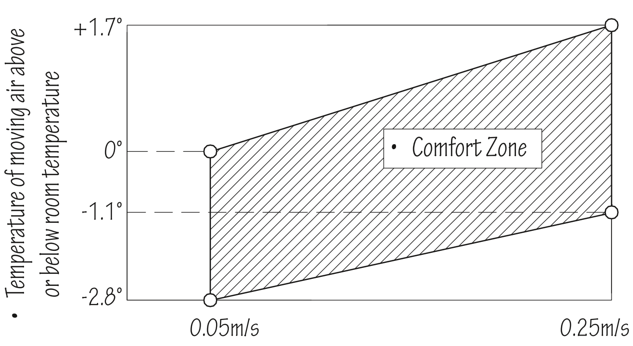
Air Temperature and Mean Radiant Temperature

- Mean radiant temperature (MRT) is important to thermal comfort since the human body receives radiant heat from or loses heat by radiation to the surrounding surfaces if their MRT is significantly higher or lower than the air temperature. See diagram on following page
- The higher the MRT of the surrounding surfaces, the cooler the air temperature should be
- MRT has about 40% more effect on comfort than air temperature
- In cold weather, the MRT of the interior surfaces of exterior walls should not be more than 2.8°C below the indoor air temperature



Air Temperature and Relative Humidity

- Relative humidity (RH) is the ratio of the amount of water vapour actually present in the air to the maximum amount that the air could hold at the same temperature, expressed as a percentage
- The higher the relative humidity of a space, the lower the air temperature should be
- Relative humidity is more critical at high temperatures than within the normal temperature range
- Low humidity (<20%) can have undesirable effects such as the build-up of static electricity and the drying out of wood; high humidity can cause condensation problems



Air Temperature and Air Velocity

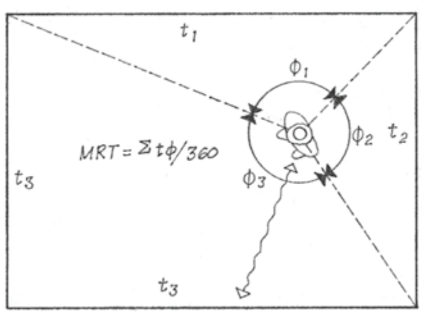
- Air velocity (V) increases heat loss by convection and evaporation
- The cooler the moving air stream is, relative to the room air temperature, the less velocity it should have
- Air velocity should range between 0.05 and 0.25 metres per second (m/s); higher velocities can cause draughty conditions
- Air motion is especially helpful for cooling evaporation in hot, humid weather

LEED EQ Credit 7: Thermal Comfort

A psychrometer is an instrument for measuring atmospheric humidity, consisting of two thermometers, the bulb of one being dry and the bulb of the other being kept moist and ventilated so that the cooling that results from evaporation makes it register a lower temperature than the dry one, with the difference between the readings being a measure of atmospheric humidity. Psychrometric charts relate the wet-bulb and dry-bulb readings from a psychrometer to relative humidity, absolute humidity and dew point. Mechanical engineers use psychrometric charts to determine the amount of heat that must be added or removed by an HVAC system to achieve an acceptable level of thermal comfort in a space.

- Effective temperature represents the combined effect of ambient temperature, relative humidity and air motion on the sensation of warmth or cold felt by the human body, equivalent to the dry-bulb temperature of still air at 50% relative humidity that induces an identical sensation

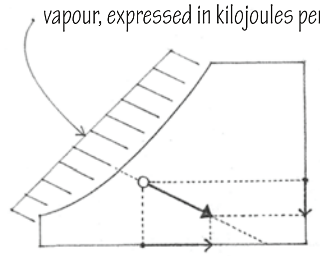
- Dew point is the temperature at which air becomes saturated with water vapour, warm air can carry more water vapour than cool air



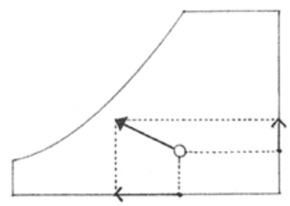
- Mean radiant temperature (MRT) is the sum of the temperatures of the surrounding walls, floor and ceiling of a room, weighted according to the solid angle subtended by each at the point of measurement

- Adiabatic heating is a rise in temperature occurring without the addition or removal of heat, as when excess water vapour in the air condenses and the latent heat of vaporisation of the water vapour is converted to sensible heat in the air

- Enthalpy is a measure of the total heat contained in a substance, equal to the internal energy of the substance plus the product of its volume and pressure. The enthalpy of air is equal to the sensible heat of the air and the water vapour present in the air plus the latent heat of the water vapour, expressed in kilojoules per kilogram (kJ/kg) of dry air



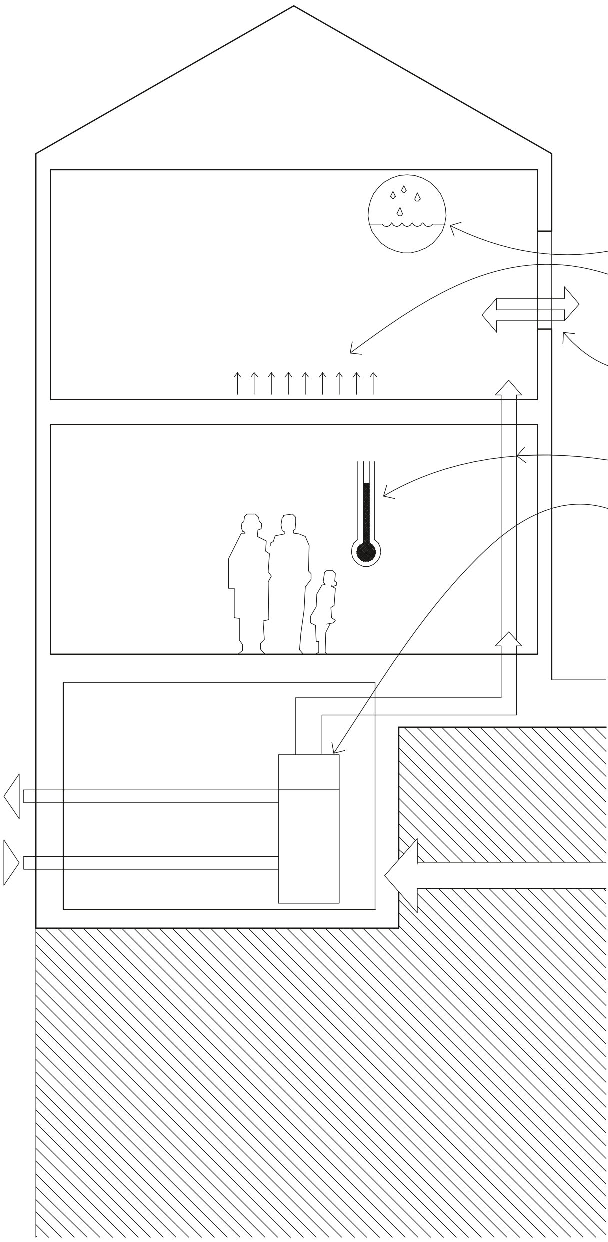
- Evaporative cooling is a drop in temperature occurring without the addition or removal of heat, as when moisture evaporates and the sensible heat of the liquid is converted to latent heat in the vapour



The predicted mean vote (PMV) is used to predict the mean response of a large group of people, taking into account a range of parameters that impact upon human comfort (such as clothing level, activity, humidity, air temperature and mean radiant temperature), the combination of which constitutes thermal comfort. The PMV works on the principle that people experience thermal comfort in different ways, what is comfortable for one person may be too warm or too cold for another. Many factors can influence this feeling of comfort such as metabolism, climatic conditions the subject is familiar with and perception of control over the environment. The variables associated with comfort are input into a mathematical formula (as outlined in EN ISO 7730) to calculate the PMV. The closer the answer is to zero, the smaller the predicted percentage dissatisfied (PPD). A positive result indicates the perception of being too warm and a negative result a perception of being too cold, the further away from zero the more severe the discomfort.

The overall goal of PMV and PPD is to aid designers in producing internal environments that result in optimum levels of thermal comfort. PMV has been used to identify thermal comfort zones such as those noted on page 11.04.

LEED EQ Credit 7: Thermal Comfort
BREEAM HEA 03: Thermal Comfort



The siting, orientation and construction assemblies of a building should aim to optimise heat loss and gain throughout the heating and cooling seasons. Any excessive heat loss or heat gain must be balanced by passive energy systems or by mechanical heating and cooling systems in order to maintain conditions of thermal comfort for the occupants of a building. While heating and cooling to control the air temperature of a space is perhaps the most basic and necessary function of a mechanical system, attention should be paid to the other three factors that affect human comfort – relative humidity, mean radiant temperature and air motion.

- Relative humidity can be controlled by introducing water vapour through humidifying devices, or removing it by ventilation
- The mean radiant temperature of room surfaces can be raised by using radiant-heating panels or lowered by radiant cooling
- Air motion can be controlled by natural or mechanical ventilation

Heating and Cooling

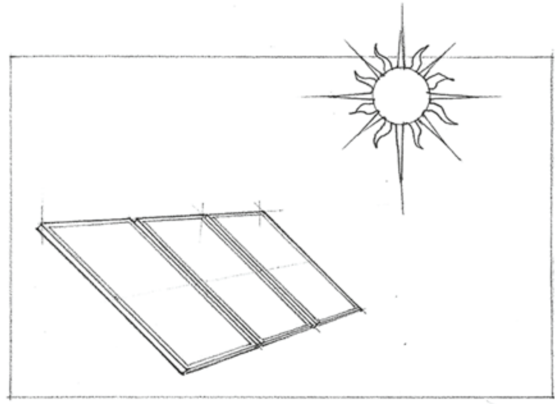
- Air temperature is controlled by the supply of a fluid medium – warm or cool air, or hot or chilled water – to a space
- Furnaces heat air; boilers heat water or produce steam; electric heaters employ resistance to convert electric energy into heat. See 11.16 for cooling systems
- The size of heating and cooling equipment required for a building is determined by the heating and cooling loads anticipated; see 11.09

The traditional fossil fuels – gas, oil and coal – continue to be the most commonly used to produce the energy for heating and cooling buildings. Natural gas burns cleanly and does not require storage or delivery except through a pipeline. Oil is also an efficient fuel choice, but it requires delivery by trucks to storage tanks located in or near the point of utilisation. Coal is rarely used for heating in new residential construction, but may be found in existing residential buildings.

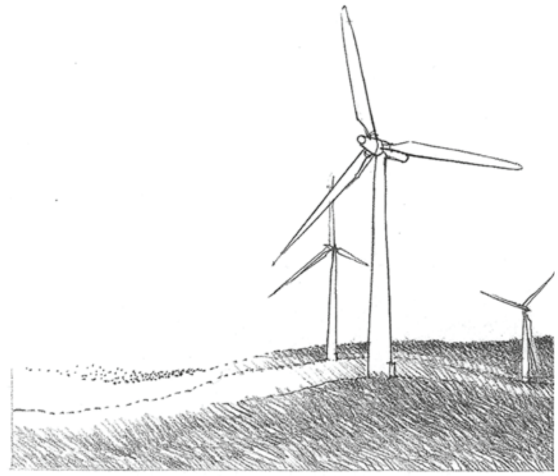
Electricity is a clean energy source requiring no combustion or fuel storage at the site. It is also a compact system, being distributed through small wires and utilising relatively small and quiet equipment. However, the cost to electrically heat or cool a building can be prohibitive and most electric power must be generated by utilising other sources of energy – nuclear fission or the burning of fossil fuels – to drive turbines. Nuclear energy, despite continuing concerns with the safety of its installations and the disposal of nuclear waste material, may still become an important source of power. A small percentage of turbines are driven by flowing water (hydropower), wind and the gases produced by burning natural gas, oil and coal.

LEED EA Credit 1: Optimize Energy Performance
BREEAM ENE 01: Reduction of CO_2 Emissions

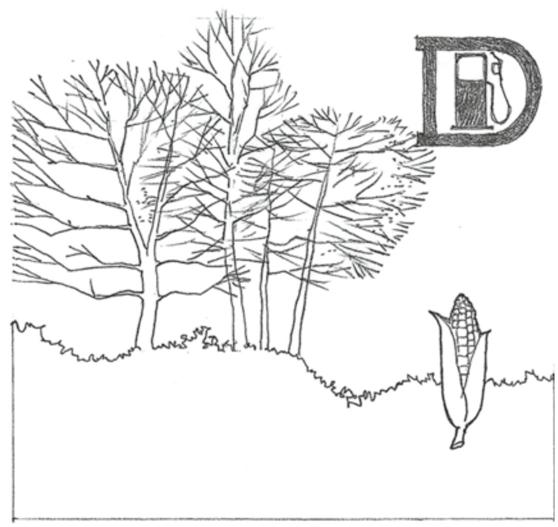
Of increasing concern are the uncertain cost and availability of conventional energy sources, the impact of energy extraction and production on environmental resources, and the burning of greenhouse-gas-emitting fossil fuels (see 1.07). In Europe more than 40% of all energy consumption and two-thirds of all greenhouse gas emissions are as a result of buildings. Consequently the design professions, construction industry and government bodies are exploring strategies for reducing the energy consumption of buildings and evaluating alternative, renewable sources of energy including solar, wind, biomass (carbon neutral), hydrogen, hydropower, ocean and geothermal.



Solar Energy
Solar energy can be used directly for passive heating, daylighting, hot-water heating and generating electricity with photovoltaic (solar cell) systems. The conversion efficiency is low with present technology but some systems may be able to produce enough electricity to allow off-grid operation or to sell the extra electricity back to the grid. Businesses and industry can employ larger-scale applications of solar technology for pre-heating ventilation air, solar-process heating and solar cooling. Service providers and power plants are also taking advantage of the sun's energy in concentrating solar-power systems to produce electricity on a larger scale. These large-scale systems require sizeable installations as well as a means of storing the electricity when the sun is not available to produce it.



Wind Power
Wind power is the process by which a turbine converts the kinetic energy of wind flow into mechanical power that a generator can use to produce electricity. The technology consists of blades, sails or hollow drums that catch the flow of winds and rotate, causing a shaft connected to a generator to turn. Small wind turbines can be used to pump water and power homes and telecommunication dishes; some can be connected to the power grid or be combined with a photovoltaic (solar-cell) system. For commercial-scale sources of wind energy, a large number of wind turbines are usually built close together to form a wind farm. Like solar power, wind power is dependent upon location and weather and can be intermittent; the electricity generated when the wind is blowing cannot be stored without a storage medium such as lithium-ion batteries. The best sites for wind farms are often remote and distant from where the electricity is needed. Additional concerns include the aesthetics of wind turbines, noise and the potential for birdkill which can sometimes make planning permission difficult to obtain. Of the range of renewable energy being used in Europe, wind power represents a high proportion of the overall renewable-energy mix.



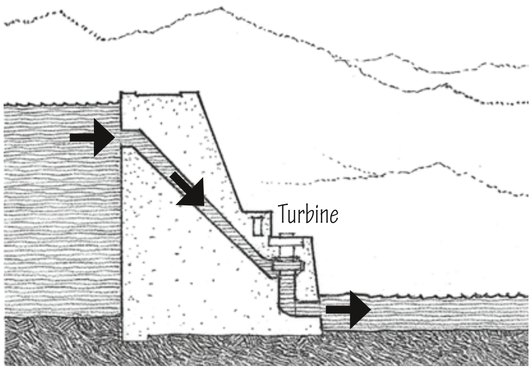
Biomass Energy
Biomass, the organic matter that makes up plants, can be used to produce electricity, transportation fuels and chemicals that would otherwise be made from fossil fuels. Properly harvested wood is one example of a natural and sustainable biomass, but its burning can create air pollution and harm indoor air quality. Wood-burning appliances should meet local environmental regulations for emissions. Wood pellets made from wood by-products burn cleanly and should be considered as an alternative. Other viable sources of biomass include food crops, such as corn for ethanol and soy beans for biodiesel, grassy and woody plants, residues from forestry or agriculture, and the organic component of municipal and industrial wastes.

Biomass is considered to be a carbon-neutral fuel because its burning does not release more carbon dioxide than that captured in its own growth and released by its natural biodegradation. The conversion process of biomass into fuel, however, can be energy negative if more energy is required for the conversion process than is obtained from the product itself. Using grain such as corn also precludes it from being used as food for humans or livestock.

H_2

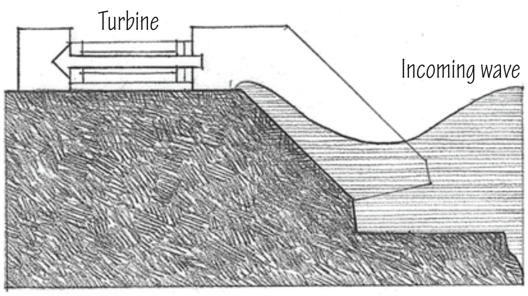
Hydrogen
Hydrogen is the most abundant element on earth and can be found in many organic compounds as well as water. While it does not occur naturally as a gas, once separated from another element, hydrogen can be burned as a fuel or used by fuel cells to electrochemically combine with oxygen to produce electricity and heat, emitting only water vapour in the process. Because hydrogen has very high energy for its weight, but very low energy for its volume, new technology is needed to more efficiently store and transport it.

LEED EA Credit 2: On-Site Renewable Energy
LEED EA Credit 6: Green Power
BREEAM ENE 04: Low and Zero Carbon Technologies



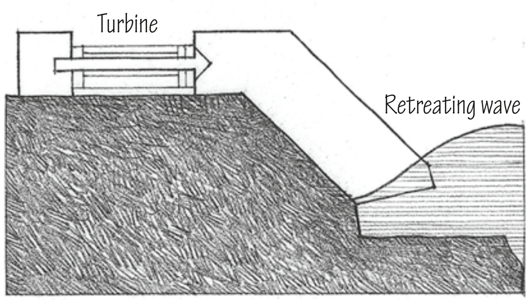
Hydropower

Hydroelectric power, or hydropower, is created and controlled by the damming of rivers. As the water stored behind a dam is released at high pressure, its kinetic energy is transformed into mechanical energy and used by turbine blades to generate electricity. Because the water cycle is an endless, constantly recharging system, hydropower is considered a clean, renewable energy source, but hydropower plants can be impacted by drought. Benefits of hydropower include flood control and the recreational opportunities afforded by the reservoirs created by dams. Disadvantages include very significant installation costs, loss of farmland, disruption of fish migration and uncertain effects on riparian habitats and historical sites.



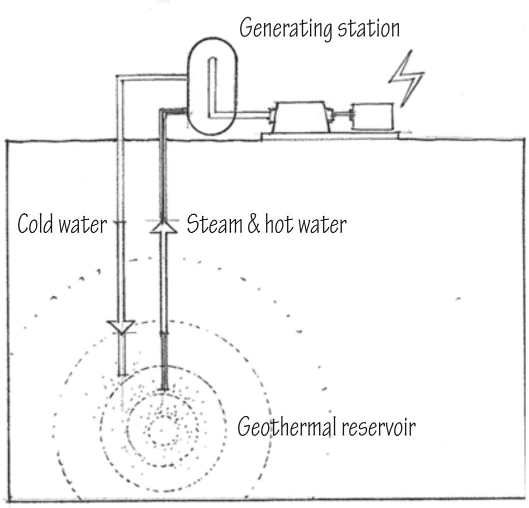
Ocean Energy

Covering more than 70% of the earth's surface, the ocean can produce thermal energy from the sun's heat and mechanical energy from its tides and waves. Ocean Thermal Energy Conversion (OTEC) is a process for generating electricity from the heat energy stored in the earth's oceans. The process works best in tropical coastal areas, where the surface of the ocean is warm and the depths are cold enough to create a modest temperature differential. OTEC utilises this temperature differential to run a heat engine – pumping warm surface-seawater through a heat exchanger where a low-boiling-point fluid, such as ammonia, is vaporised, with the vapour expanding to rotate a turbine connected to a generator. Cold deep-seawater – pumped through a second heat exchanger – condenses the vapour back into a liquid, which is then recycled through the system. Because its conversion efficiency is very low, an OTEC plant would have to be vast and move an enormous amount of water while anchored in the deep open ocean subject to storms and corrosion.



Similar to more conventional hydroelectric dams, the tidal process utilises the natural motion of the tides to fill reservoirs, which are then discharged through electricity-producing turbines. Because seawater has a much higher density than air, ocean currents carry significantly more energy than wind currents. Utilising tidal power requires a high tide and special coastline conditions present in several locations throughout Europe including Scotland, Spain, Turkey, Norway, France, Italy and Sweden. Tidal power offers the distinct advantage of predictability which can be one of the main drawbacks of wind and solar power. Damming estuaries would have considerable environmental impact, affecting both sea-life migration and fisheries.

Wave energy can be converted into electricity through both offshore and onshore systems. Offshore systems are situated in deep water and use either the bobbing motion of the waves to power a pump or the funnelling of waves through internal turbines on floating platforms to create electricity. Onshore wave-power systems are built along shorelines to extract the energy in breaking waves by utilising the alternating compression and depressurisation of an enclosed air column to drive turbines. The potential energy of waves can be effectively harvested in only certain areas of the world, such as the west coast of Ireland and Scotland, Denmark, Norway, Portugal and Sweden. Careful site selection is the key to keeping the environmental impacts of wave-power systems to a minimum, preserving scenic shorefronts, and avoiding altering flow patterns of sediment on the ocean floor.



Geothermal Energy

Geothermal energy – the earth's internal heat – can yield warmth and power for a variety of uses without burning fuels, damming rivers or harvesting forests. The shallow ground near the earth's surface (at approximately 2 m depth) maintains a relatively constant temperature of 10°–15°C, heat that can be used to provide direct heating and cooling in homes and other buildings. Steam, heat or hot water from deeper geothermal reservoirs can provide the force that spins turbine generators to produce electricity. The used geothermal water is then returned down an injection well into the reservoir to be reheated, to maintain pressure and to sustain the reservoir.

Calculating heat loss in cold weather and heat gain in hot weather is necessary to size the heating and cooling equipment required for a building. It takes into account the differential between desired indoor air temperature and outdoor temperature, the daily temperature range, the solar orientation and thermal resistance of wall, window and roof assemblies, and the use and occupancy of inhabited spaces. The more heat loss and heat gain can be reduced by the siting, layout and orientation of a building, the less energy will be consumed by smaller heating and cooling equipment. Other energy-conscious design strategies include utilising thermal insulation and thermal mass to effectively control the transmission of heat through building assemblies; making wise choices in selecting energy-efficient HVAC systems, water heaters, appliances and lighting systems; and employing 'smart' systems to control thermal conditions and lighting.

LEED EA Credit 1: Optimize Energy Performance
ENE 01: Reduction of CO_2 Emissions

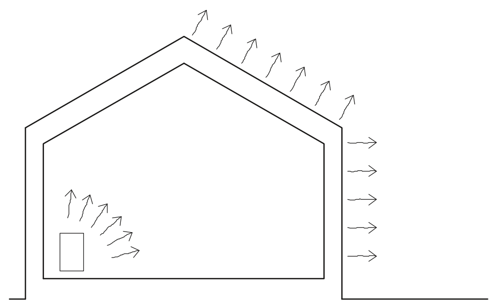
Heating Load

- Heating load is the hourly rate of net heat loss in an enclosed space, expressed in Btu (British thermal units) per hour and used as the basis for selecting a heating unit or system. Alternatively, in Europe heating load is measured in kW (kilowatts)
- Btu is the quantity of heat required to raise the temperature of 1 lb (0.4 kg) of water 1°F. A kW is 1000 watts, a watt is one joule per second, a joule being the SI unit of energy
- Degree-day is a unit that represents the difference over time between outdoor air temperature and the balance point temperature for the building. It is used to compute heating and cooling loads, size HVAC systems and calculate yearly fuel consumption
- The balance point temperature is the point at which for a given space no additional space heating or cooling is required to maintain comfort. When the external temperature is below the balance point this will result in heating degree-days

Cooling Load

- Cooling load is the hourly rate of heat gain in an enclosed space, expressed in Btu per hour or kW and used as the basis for selecting an air-conditioning unit or cooling system
- Cooling degree-day is used in estimating energy requirements for air conditioning and refrigeration
- Energy-efficiency rating is an index of the efficiency of a refrigerating unit, expressing the amount of heat removed per watt of electrical energy input

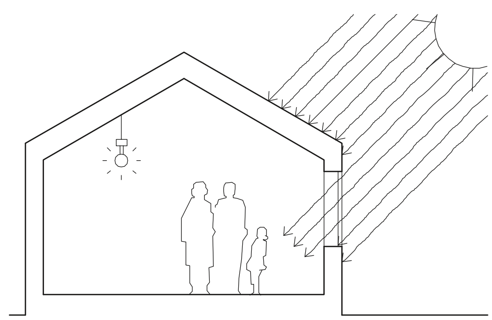
- For more detailed information on the calculation of heating and cooling loads, refer to the guidance offered by the Chartered Institution of Building Services Engineers (CIBSE)



Heat Loss

The primary sources of heat loss in cold weather are:

- Convection, radiation and conduction of heat through exterior wall, window and roof assemblies to the outside, and through floors over unheated spaces
- Infiltration of air through cracks in exterior construction, especially around windows and doorways



Heat Gain

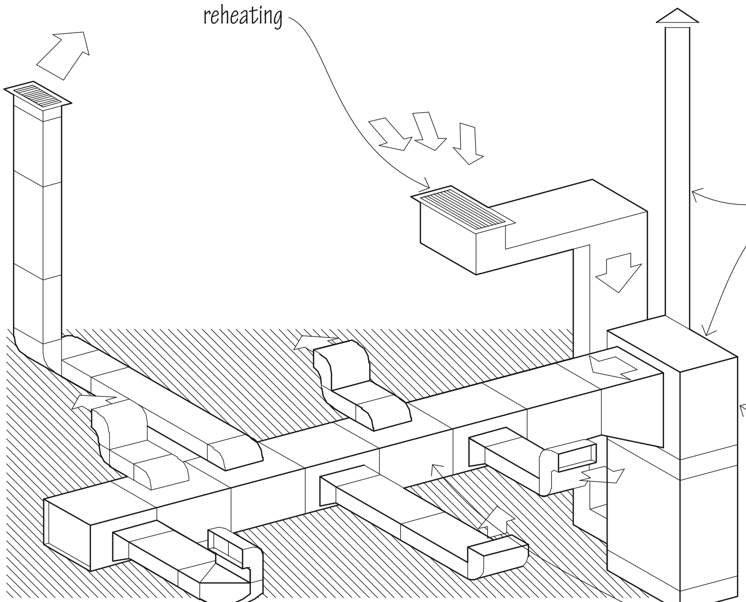
Sources of heat gain in warm or hot weather include:

- Convection, radiation and conduction through exterior wall, window and roof assemblies when outdoor temperatures are high; varies with the time of day, the solar orientation of the assemblies and the effect of thermal lag
- Solar radiation on glazing; varies with solar orientation and the effectiveness of any shading devices used
- Building occupants and their activities
- Lighting and other heat-producing equipment
- Ventilation of spaces that may be required to remove odours and pollutants
- Latent heat, requiring energy to condense the moisture in warm air so that the relative humidity in a space will not be excessive

11.10 FORCED WARM-AIR HEATING

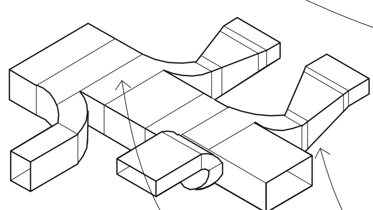
Forced warm air is an indirect system for heating by means of air heated in a gas, oil or electric furnace and distributed by a fan through ductwork to diffusers in inhabited spaces. It is a versatile system used for heating commercial and other small buildings. Forced warm air was in the past widely utilised in domestic buildings, but this has now largely been superseded by wet-heating systems; see 11.11.

- Cold-air return conveys cool air back to the furnace for reheating

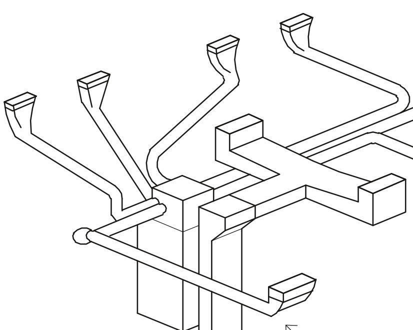


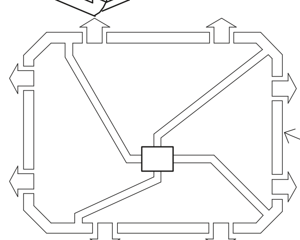
- Extended plenum system is a perimeter heating system in which a main duct conveys warm air to a number of branch ducts, each serving a single floor diffuser

- Gas and oil furnaces require combustion air and a vent by which products of combustion are carried to the outside. Oil furnaces also require a fuel storage tank. Electric furnaces do not require a flue or combustion air
- Filtering, humidifying and dehumidifying devices can be incorporated into the system
- Cooling may be provided by an outdoor compressor and condensing unit that supplies cold refrigerant to evaporator coils in the main supply ductwork
- Fresh-air ventilation is usually provided by natural means



- Plenum is the chamber at the top of a furnace from which ducts of sheet metal or fibreglass emerge to conduct heated or conditioned air to the inhabited spaces of a building
- Leaders are the ducts that convey warm air from a furnace to a stack or branch duct
- Stacks convey warm air from a leader vertically to a diffuser on upper floors
- Gathering refers to a tapered section of a duct forming a transition between two sections, one of which has a greater area than the other
- Boot is a duct fitting forming a transition between two sections that vary in cross-sectional shape
- A manifold has several outlets for making multiple connections





- Perimeter heating distributes warm air to diffusers placed in or near the floor along exterior walls
- Perimeter loop system consists of a loop of ductwork, usually embedded in a concrete ground slab, for distributing warm air to each floor diffuser
- Perimeter radial system uses a leader from a centrally located furnace to carry warm air directly to each floor diffuser

Self-contained direct warm-air heating systems incorporating a furnace, fan, diffuser and dedicated flue are commercially available. They can be a room-sealed appliance, taking combustion air from outside the heated space, or open flue, taking combustion air from the heated space itself.

Direct System

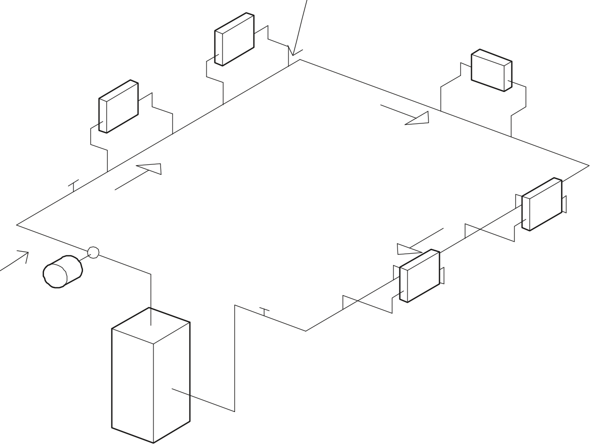
In a direct heating system, fuel is burned and heat output directly at the location it is needed. This offers easy control for a single space, a fireplace or stove is an example of direct heating.

Indirect System

Indirect systems burn fuel at a central location and distribute the resulting heating through air or water transferred to an output device such as a radiator. Indirect systems offer greater levels of control and efficiency at a building scale.

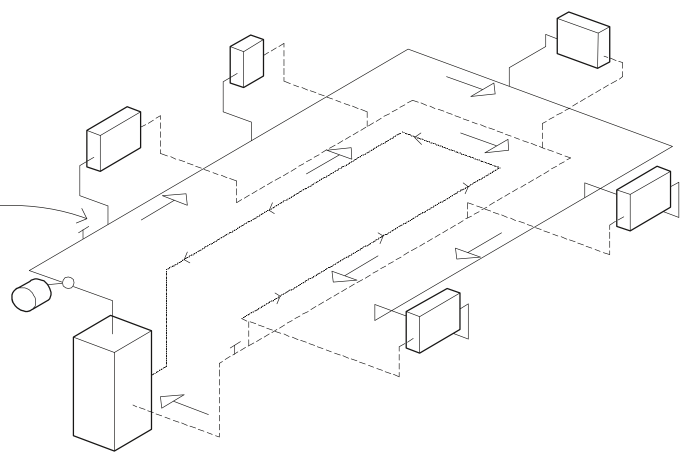
Hot-water heating is a system for heating a building by means of water heated in a boiler and circulated by a pump through pipes to radiators or convectors. In large cities and building complexes, hot water generated at a central boiler plant may be available via underground pipelines. Known as district heating, this system eliminates the need for boilers in each building. Additionally, district heating may be able to use waste heat from one location as useful heat at another location.

- Venturi tees induce the flow of water from a return branch into the supply main

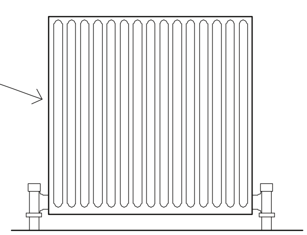


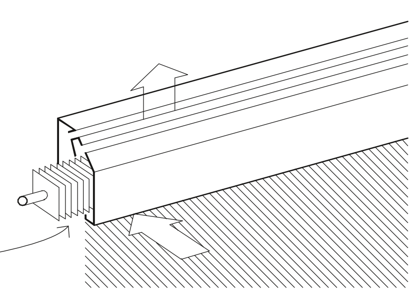
- Boiler is a closed vessel or arrangement of vessels and tubes in which water is heated. The heat may be supplied by the combustion of gas or oil, or by electric-resistance coils. Safety relief valves on boilers open when activated by a vapour pressure above a predetermined level, allowing the vapour to escape until its pressure is reduced to a safe or acceptable level

- One-pipe system is a hot-water heating system in which a single pipe supplies hot water from a boiler to each radiator or convector in sequence
- One-pipe systems need careful design and commissioning to ensure the system is in balance
- If not properly balanced, the last radiator on the system may not receive enough hot water to heat the relevant space to the required temperature



- Two-pipe system is a hot-water heating system in which one pipe supplies hot water from a boiler to the radiators or convectors and a second pipe returns the water to the boiler
- A two-pipe system is now more common than a one-pipe system as it offers greater consistency

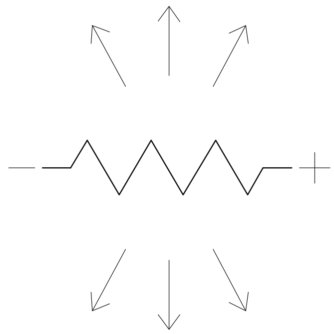




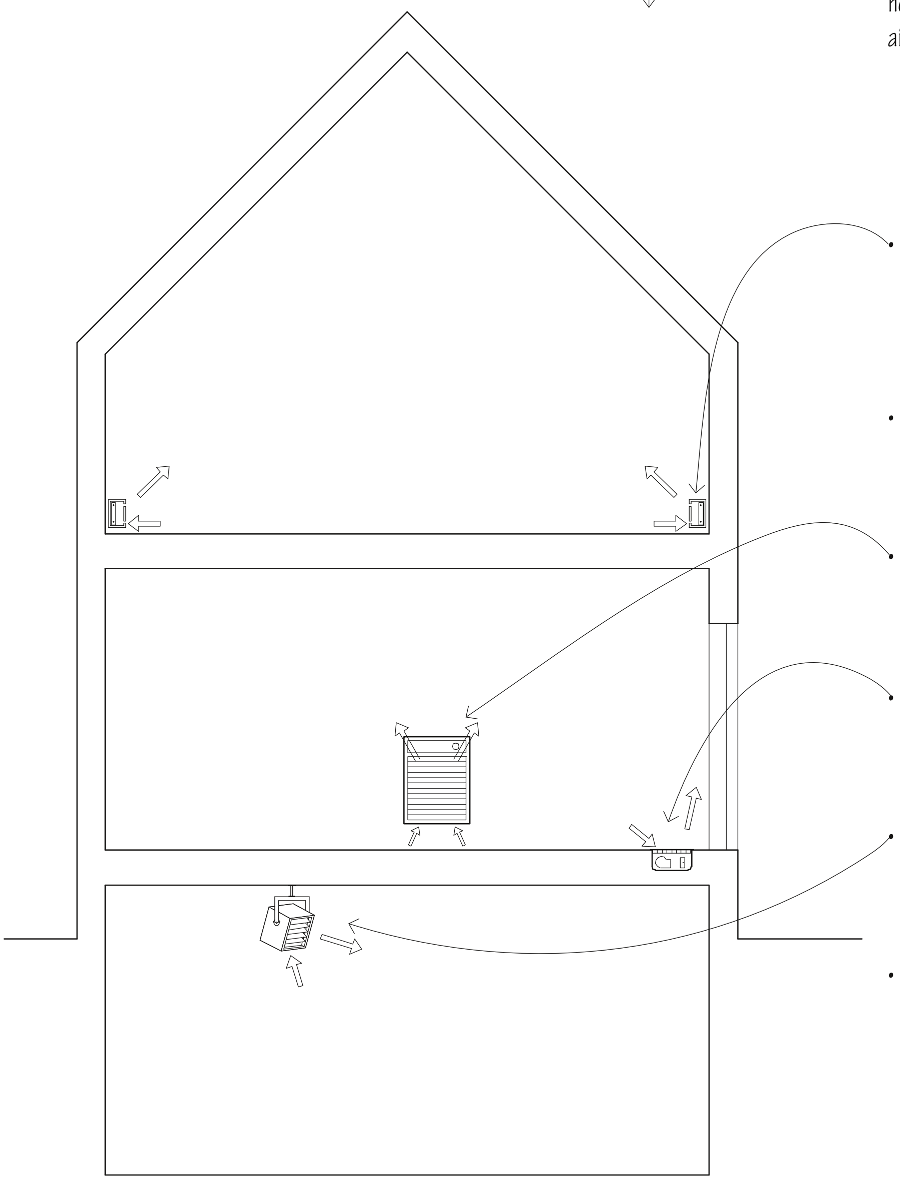
- Radiators consist of a series or coil of pipes through which hot water passes. The heated pipes warm a space primarily by convection but with a proportion of radiation. Convectors, on the other hand, are heating units in which air is heated by contact with fin-tubes and circulates by convection
- Fin-tube convectors are skirting convectors having horizontal tubes with closely spaced vertical fins to maximise heat transfer to the surrounding air. Cool room air is drawn in from below by convection, heated by contact with the fins and discharged at the top

Comparative Calorific Values of Energy Sources

Fuel	Calorific Value
Coal	27 MJ/kg
Oil	36 MJ/l
Natural Gas	40 MJ/kg
Electricity	1 watt = 3.41 Btu/hr



Electric heating is more accurately described as electric-resistance heating. Resistance is the property of a conductor by virtue of which the passage of current is opposed, causing electric energy to be converted into heat. Electric-resistance heating elements may be exposed to the air stream in a furnace or ductwork in a forced warm-air heating system or provide the heat for a boiler in a wet-heating system. More direct means of heating with electric energy involve housing the resistance wires or coils in space-heating units. While compact and versatile, these electric-resistance heaters have no provision for controlling humidity and air quality.

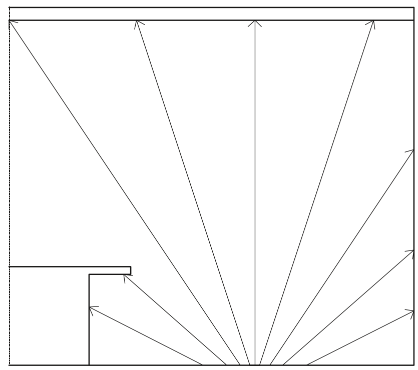


- Electric-resistance heating elements may be housed in baseboard convection units installed around the perimeter of a room. Room air is heated by resistance coils as it circulates through the units by convection
- Electric unit heaters utilise a fan to draw in room air and pass it over resistance-heating coils before blowing it back into the room
- Wall-unit heaters are available surface-mounted or recessed for use in bathrooms, kitchen and other small rooms
- Fully-recessed floor-unit heaters known as trench heaters are typically used where a window or curtain wall is carried down to the floor line
- Industrial-unit heaters are housed in metal cabinets with directional outlets and designed to be suspended from a ceiling or roof structure
- Quartz heaters have resistance-heating elements sealed in quartz-glass tubes that produce infrared radiation in front of a reflective backing

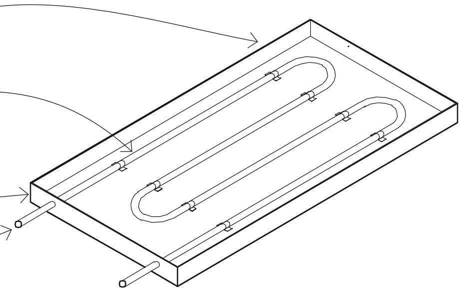
Radiant-heating systems utilise heated ceilings (this can sometimes be combined with the lighting and ventilation system of the building in a composite system), floors and sometimes walls, as radiating surfaces. The heat source may be pipes or tubing carrying hot water or electric-resistance heating cables embedded within the ceiling, floor or wall construction. The radiant heat is absorbed by surfaces and objects in the room, re-radiates from the warmed surfaces, and raises the mean radiant temperature (MRT) as well as the ambient temperature in the space.

Floor installations are effective in warming concrete slabs and are often used in domestic situations (as low-temperature heating systems often coupled with suitable renewable-energy technologies). In non-residential and commercial situations, however, ceiling installations are sometimes preferred because ceiling constructions have less thermal capacity and can respond faster. Ceiling panels can also be heated to a higher surface temperature than floor slabs. In both electric and hot-water radiant systems, the installations are completely concealed except for thermostats or balancing valves.

Because radiant panel-heating systems cannot respond quickly to changing temperature demands, they may be supplemented with perimeter convector units. For complete air conditioning, separate ventilating, humidity control and cooling systems are required.



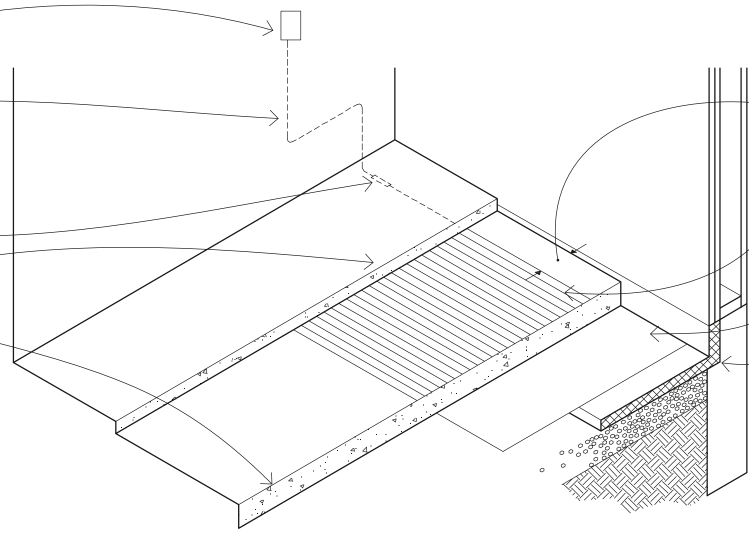
Radiant heat:
- Travels in a direct path
- Cannot travel around corners and may therefore be obstructed by physical elements within the space such as furniture
- Cannot counteract cold downdraughts along exterior glass areas
- Is not affected by air motion



Radiant-Heating Panel (Wet)

- Pre-assembled radiant-heating panels are commercially available. They may be used with modular, suspended ceiling systems or to heat specific areas of a space
- Chilled beams offer radiant cooling, other multi-service devices are available and can offer heating and cooling. They are often integrated with lighting, fire protection or ventilation and can be an architectural feature

Ceiling Installation

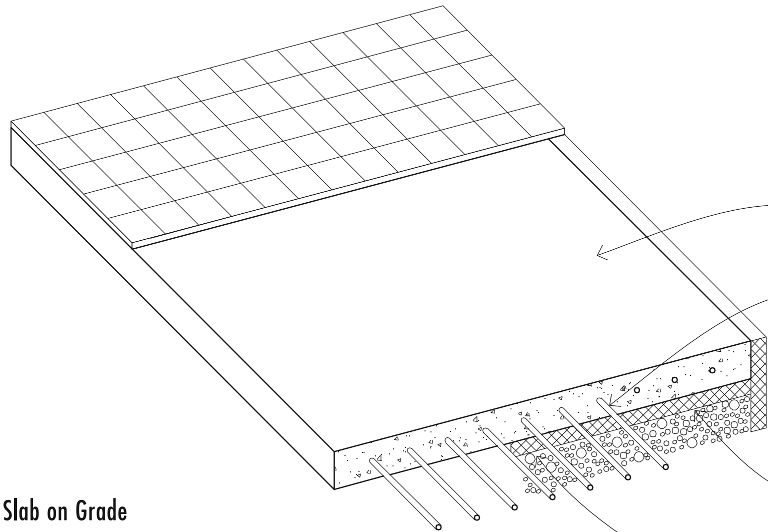


Electric Radiant-Heating (Dry)

Floor Installation

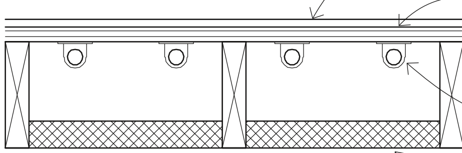
11.14 RADIANT HEATING

Liquid radiant-heating systems circulate warm water through metal or plastic pipes either encased in a concrete slab that serves as a thermal mass or secured to the underside of sub-flooring with a conductive diffusion plate. The supply water may be heated in a boiler, heat pump, solar collector or geothermal system. In response to the thermostat setting, a control valve adjusts the supply water temperature by mixing it with the circulating water from the pipe loops.



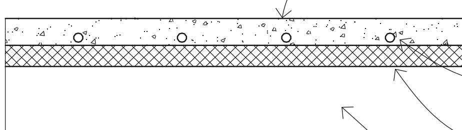
Slab on Grade

- Concrete slab on grade
- Metal pipes or plastic tubing completely embedded in concrete slab and spaced at 150–450 mm centres; closer spacings are used where more warmth is needed
- 40 mm minimum cover
- Rigid insulation along the edge and around the perimeter of the slab
- Damp-proof membrane (under insulation unless otherwise advised)



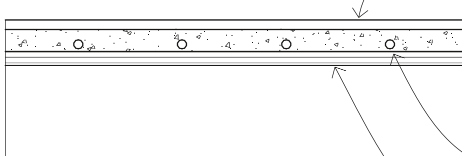
Raised Timber Floor

- Finish flooring
- Sub-floor
- Heating pipes or tubing secured to the underside of the sub-flooring with a conductive diffusion plate
- Thermal insulation as required



Existing Concrete Slab

- Cementitious floor screed; 25 mm minimum cover
- Heating pipes or tubing
- Floor insulation serves as a thermal break
- Existing concrete slab



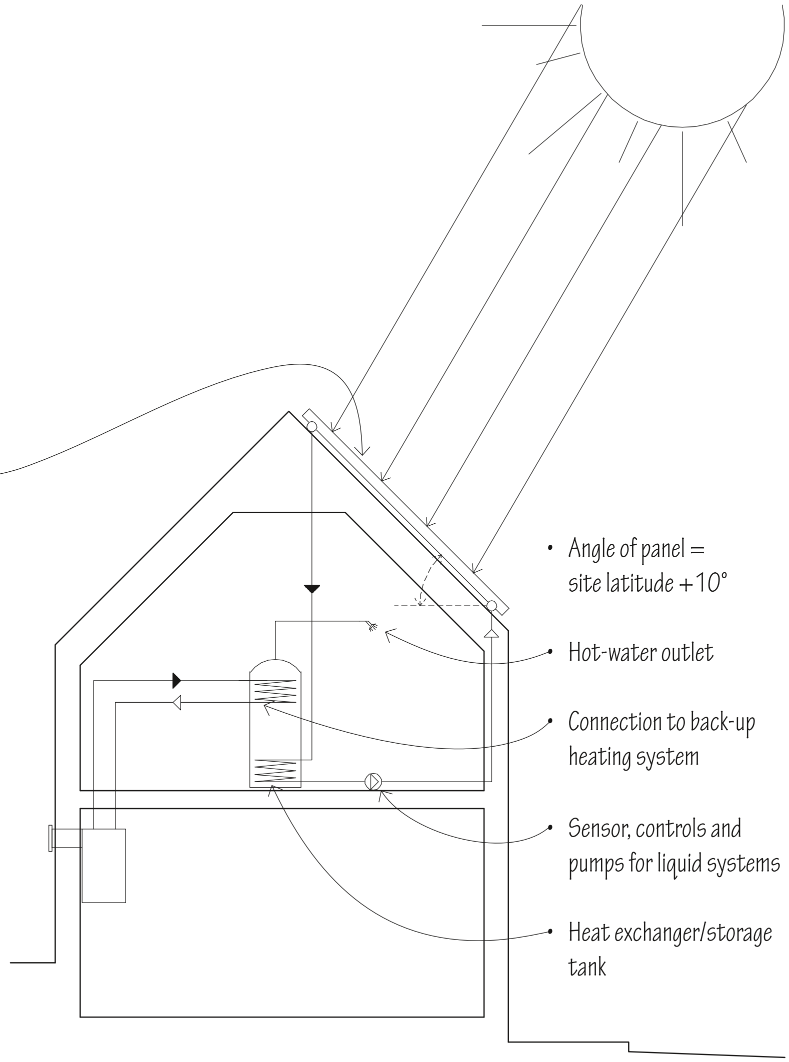
Timber First Floor

- Finish flooring
- Cementitious floor screed; 25 mm minimum cover
- Heating pipes or tubing run perpendicular to joist framing
- Existing sub-flooring; 19 mm minimum
- Existing joists

Active solar-energy systems absorb, transfer and store energy from solar radiation for building heating and cooling. They normally consist of the following components:

- Solar collector panels
- Circulation and distribution system for the heat transfer medium
- Heat exchanger and storage facility

In most cases, solar thermal panels are used to provide hot water for showering etc. but not for space heating. If used with space heating a suitable low temperature heat distribution system such as underfloor heating should be used. Generally, however, where a solar thermal system would provide enough water at a suitable temperature for space heating, the space heating is not required at that time (during the summer).



Solar Collector Panels

- The solar collector panels should be oriented within 20° of true south and not be shaded by nearby structures, terrain or trees. The required collector surface area depends on the heat-exchange efficiency of the collector and heat-transfer medium, and the heating and cooling load. When providing hot water in a domestic situation current recommendations are for approximately 1 m^2 per building occupant

Heat-Transfer Medium

- The heat-transfer medium may be water or other liquid (air may also be used in some circumstances). It carries the collected heat energy from the solar panels to the heat exchange equipment or to a storage utility for later use
- Liquid systems use pipes for circulation and distribution. An anti-freeze solution provides freeze protection; a corrosion-retarding additive is required for aluminium pipes

Storage Facility

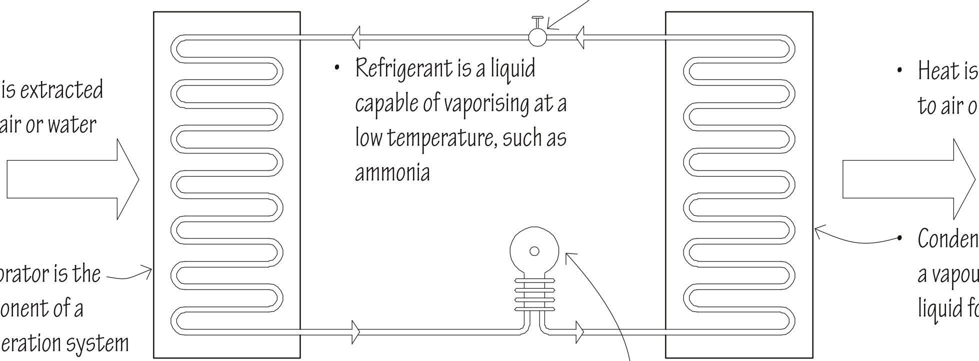
- An insulated storage facility holds heat for use at night or on overcast days. It may be in the form of a tank filled with water or other liquid medium, or a bin of rocks or phase-change salts for air systems
- In most domestic situations an insulated hot-water storage tank is used, which may be combined with the existing domestic hot-water heating system
- A back-up heating system is recommended
- The heat-distributing components of the solar-energy system are similar to those of conventional systems
- For an active solar-energy system to be efficient, the building itself must be thermally efficient and well insulated. Its siting, orientation and window openings should take advantage of the seasonal solar radiation

- See 1.19–1.21 for passive solar design

Compressive Refrigeration

Compressive refrigeration is a process in which cooling is effected by the vaporisation and expansion of a liquid refrigerant.

- Expansion valve reduces the pressure and evaporation temperature of a refrigerant as it flows to the evaporator

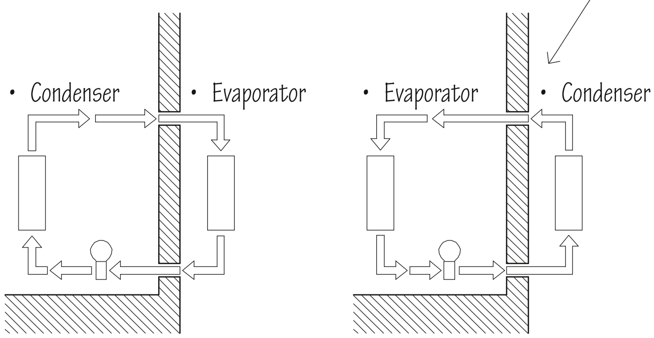


- Heat is extracted from air or water
- Evaporator is the component of a refrigeration system in which the refrigerant absorbs heat from a cooling medium and changes from a liquid to a vapour or gas
- Refrigerant is a liquid capable of vaporising at a low temperature, such as ammonia
- Compressor reduces the volume and increases the pressure of a vapour or gas
- Heat is released to air or water
- Condenser reduces a vapour or gas to liquid form

Air-Source Heat Pumps

Heat pumps are electrically powered heating and cooling units. For cooling, the normal compressive refrigeration cycle is used to absorb and transfer excess heat to the outdoors. For heating, heat energy is drawn from the outdoor air (or the ground or water in ground-source and water-source heat pumps respectively) by reversing the cooling cycle and switching the heat exchange functions of the condenser and evaporator.

Air-source heat pumps are most efficient in moderate climates where heating and cooling loads are almost equal. In freezing temperatures, a heat pump requires an electric resistance heater to keep the outdoor coils from freezing. It should be noted that for heating supply when the heat is most needed, the efficiency of the system will be at it lowest.

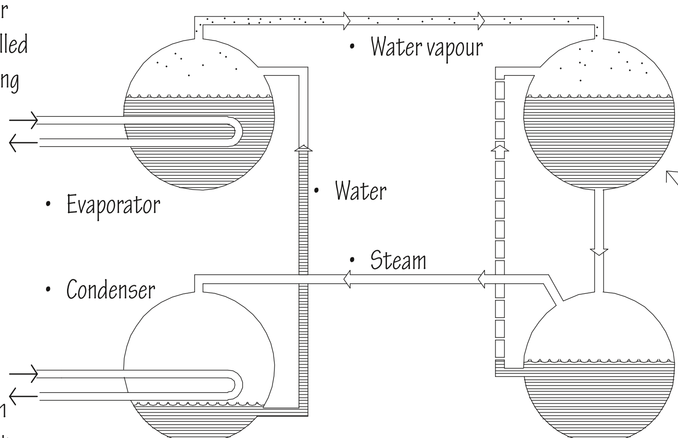


Winter Heating

Summer Cooling

Absorption Refrigeration

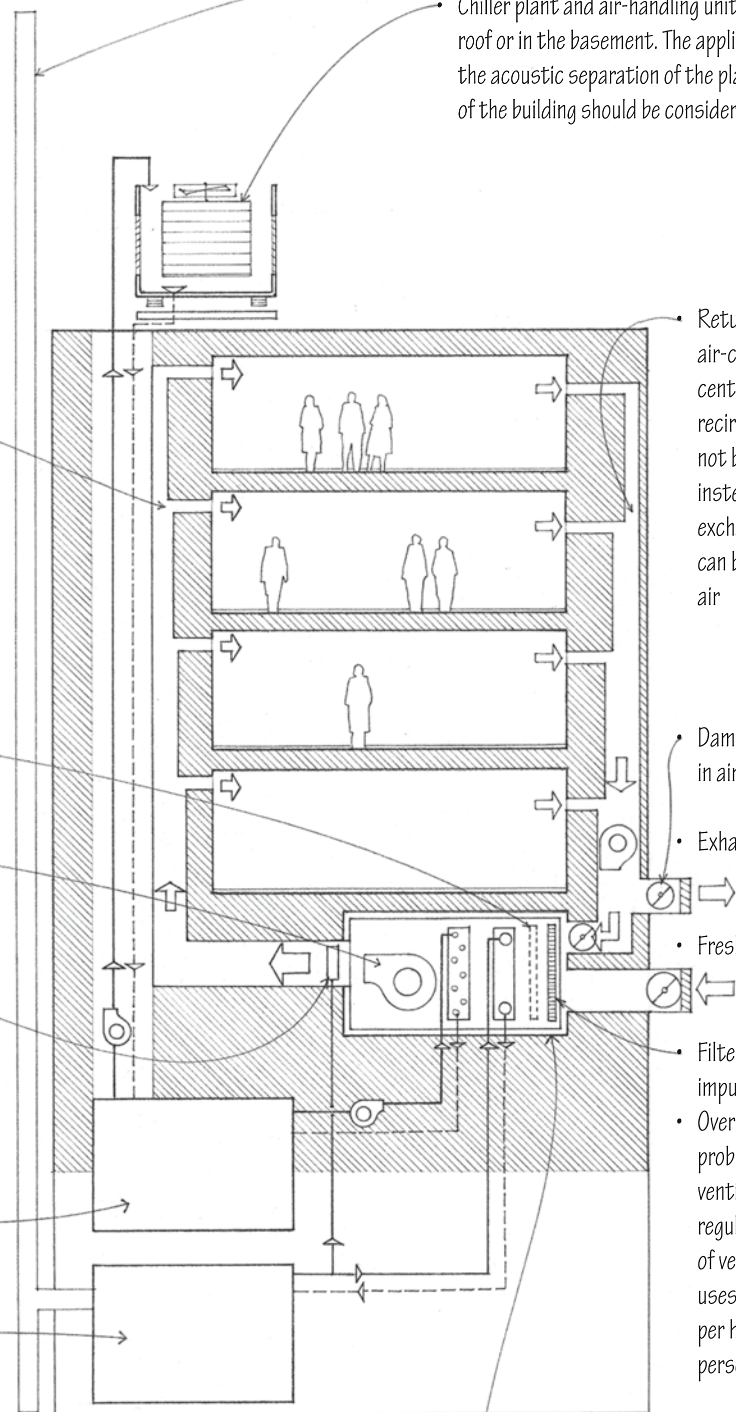
Absorption refrigeration uses an absorber and a generator instead of a compressor to transfer heat and produce cooling.



- Heat is extracted by means of a heat exchanger to produce chilled water for cooling
- Waste heat is extracted from the steam as it condenses before returning to the evaporator
- Absorber uses a saline solution to draw water vapour from the evaporator, cooling the remaining water in the process
- Generator uses a heat source to remove excess water vapour from the saline solution

Heating, ventilating and air-conditioning (HVAC) systems simultaneously control the temperature, humidity, purity, distribution and motion of the air in the interior spaces of a building.

- Chimney exhausts flue gases from the burning of fuel
- Chiller plant and air-handling units may be located on the roof or in the basement. The applied load of the plant and the acoustic separation of the plant from the structure of the building should be considered

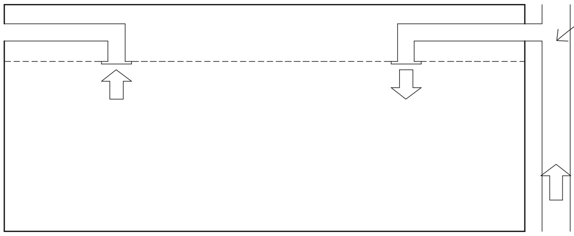


- Heating and cooling energy can be distributed by air, water or a combination of both; see 11.18–11.20
- Pre-heaters heat air that is below 0°C to a temperature slightly above freezing, in advance of other processing
- Blowers supply air at a moderate pressure, as to supply forced draughts in a HVAC system
- Humidifiers maintain or increase the amount of water vapour in the supply air
- Chilled water plant, powered by electricity or gas, delivers chilled water to the air-handling equipment for cooling, and pumps condenser water to the cooling tower for the disposal of heat
- Boilers produce hot water. They require fuel (gas or oil) and an air supply for combustion. Oil-fired boilers also need an on-site storage tank. Electric boilers, which may be feasible if electricity costs are low, eliminate the need for combustion air and a chimney. If hot water or steam can be supplied by a central plant, district heating may be viable and an individual boiler is not required

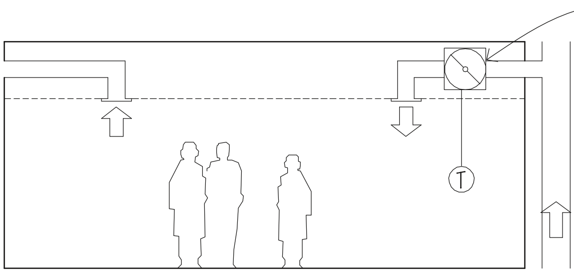
- Return air is conveyed from an air-conditioned space back to the central plant for processing and recirculation. Ideally return air will not be directly recirculated but instead passed through a heat exchanger where warmth or coolth can be passed to the fresh incoming air
- Dampers regulate the draught in air ducts, intakes and outlets
- Exhaust air
- Fresh air
- Filters remove suspended impurities from the air supply
- Over half of indoor air-quality problems result from inadequate ventilation and filtration. Building regulations specify the amount of ventilation required for certain uses and occupancies in air changes per hour or in litres per second per person

- Plant rooms contain the air-handling equipment in large buildings. A plant room should be located to minimise the distance conditioned air must travel to the furthest air-conditioned space. Individual plant rooms can also be distributed to serve individual zones of a building or be located on each floor to minimise vertical duct runs
- Air-handling units contain the fans, filters and other components necessary to treat and distribute conditioned air

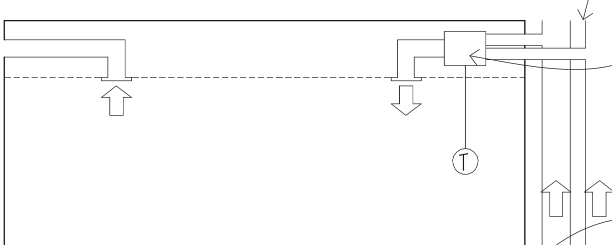
All-Air Systems



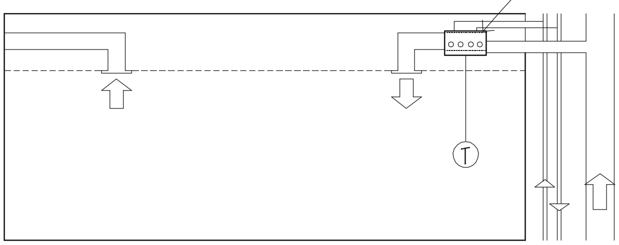
- A single-duct, constant-air-volume (CAV) system delivers conditioned air at a constant temperature through a low-velocity duct system to the served spaces
- In a single-zone system, a master thermostat regulates the temperature for the entire building
- In a multi-zone system, separate ducts from a central air-handling unit serve each of a number of zones



- A single-duct, variable-air-volume (VAV) system uses dampers at the terminal outlets to control the flow of conditioned air according to the temperature requirements of each zone or space



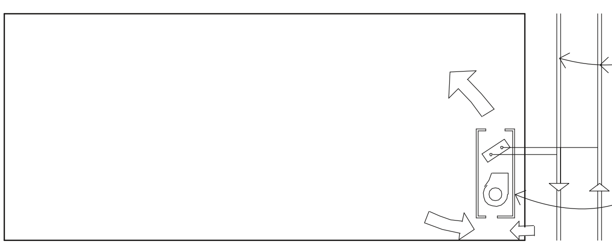
- A dual-duct system uses separate ducts to deliver warm air and cool air to mixing boxes, which contain thermostatically controlled dampers
- The mixing boxes proportion and blend the warm and cold air to reach the desired temperature before distributing the blended air to each zone or space
- This is usually a high-velocity system to reduce duct sizes and installation space



- A terminal reheat system offers more flexibility in meeting changing space requirements. It supplies air at about 12°C to terminals equipped with electric or hot-water reheat coils, which regulate the temperature of the air being furnished to each individually controlled zone or space

All-Water Systems

- Pipes, which require less installation space than air ducts, deliver hot or chilled water to fan-coil units in the served spaces

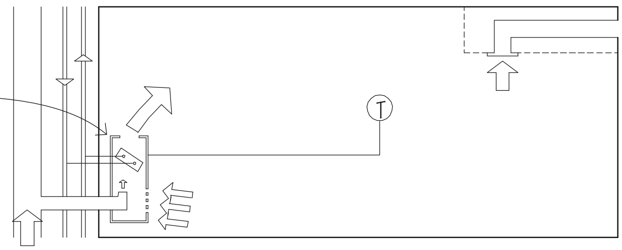


- A two-pipe system uses one pipe to supply hot or chilled water to each fan-coil unit and another to return it to the boiler or chilled water plant
- Fan-coil units contain an air filter and a centrifugal fan for drawing in a mixture of room air and outside air over coils of heated or chilled water and then blowing it back into the space

- A four-pipe system uses two separate piping circuits — one for hot water and one for chilled water — to provide simultaneous heating and cooling as needed to the various zones of a building
- Ventilation is provided through wall openings, by infiltration, or by a separate duct system

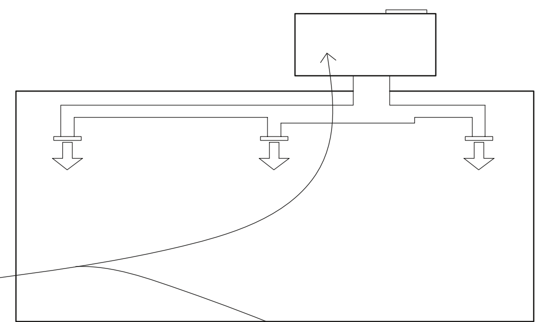
Air-Water Systems

- Air-water systems use high-velocity ducts to supply conditioned primary air from a central plant to each zone or space, where it mixes with room air and is further heated or cooled in induction units
- The primary air draws in room air through a filter and the mixture passes over coils that are heated or chilled by secondary water piped from a boiler or chilled-water plant
- Local thermostats control water flow over the coils to regulate air temperature

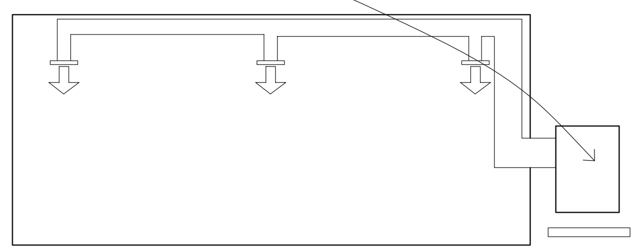


Packaged Systems

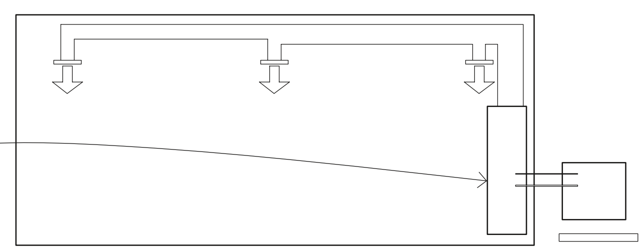
- Packaged systems are self-contained, weatherproof units incorporating a fan, filters, compressor, condenser and evaporator coils for cooling. For heating, the unit may operate as a heat pump or contain auxiliary heating elements. Packaged systems are powered by electricity or by a combination of electricity and gas



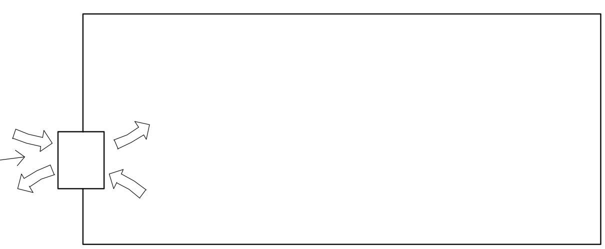
- Packaged systems may be mounted as a single piece of equipment on the roof or on a concrete pad alongside an exterior wall of a building
- Rooftop packaged units may be placed at intervals to serve long buildings
- Packaged systems with vertical shafts that connect to horizontal branch ducts can serve buildings up to four or five storeys in height



- Split-packaged systems consist of an outdoor unit incorporating the compressor and condenser and an indoor unit that contains the cooling and heating coils and the circulating fan; insulated refrigerant tubing and control wiring connect the two parts



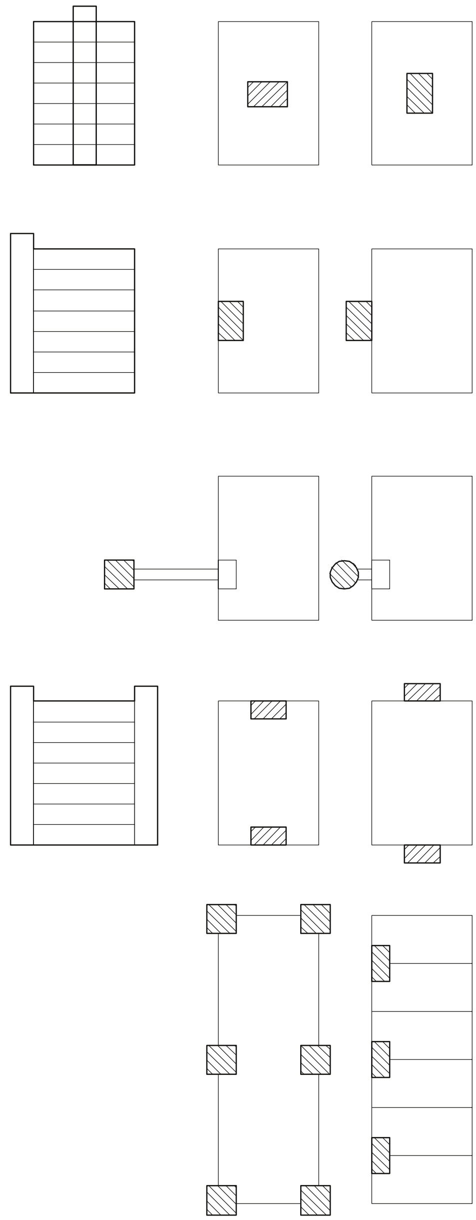
- Small terminal units may be mounted directly below a window or in openings cut into the exterior wall of each served space



11.20 HVAC SYSTEMS

Factors to consider in the selection, design and installation of a heating, ventilation and air-conditioning (HVAC) system include:

- Performance, efficiency and both the initial and life costs of the system
- Fuel, power, air and water required and the means for their delivery and storage; some equipment may require direct access to the outdoors
- Flexibility of the system to service different zones of a building, which may have different demands because of use or site orientation. Decentralised or local systems are economical to install, require short distribution runs and allow each space or zone to have individual temperature control, while central systems are generally more energy-efficient, easier to service and offer better control of air quality
- Type and layout of the distribution system used for the heating and cooling media. To minimise friction loss, ductwork and piping should have short, direct runs with a minimum of turns and offsets
- Space requirements for the mechanical equipment and the distribution system. The heating, ventilating and air-conditioning equipment of a building can often occupy 10% to 15% of the area of a building; some pieces of equipment also require space or a zone for access, service and maintenance. Air duct systems require more space than either pipes carrying hot or chilled water or wiring for electric-resistance heating. Ductwork should therefore be carefully laid out to be integrated with the structure and spaces of a building, as well as with its plumbing and electrical systems
- Access required for service and maintenance
- Construction requirements for the enclosure of the mechanical plant, fire resistance, and noise and vibration control
- Structural requirements imposed by the weight of the equipment
- Degree of visibility, whether concealed within the construction or exposed to view. If ductwork is to be left exposed, the layout should have a visually coherent order and be coordinated with the physical elements of the space (eg, structural elements, lighting fixtures, surface patterns)
- Ability to adapt the system easily to any change of use or occupancy



- A single core is often used in high-rise office buildings to leave a maximum amount of unobstructed rentable area
- Central locations are ideal for short runs and efficient distribution patterns

- Placing the core along an edge leaves an unobstructed floor space but occupies a portion of the daylit perimeter

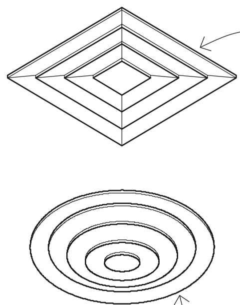
- Detached cores leave a maximum amount of floor space but require long service runs and cannot serve as lateral bracing

- Two cores may be symmetrically placed to reduce service runs and to serve effectively as lateral bracing, but the remaining floor area loses some flexibility in layout and use

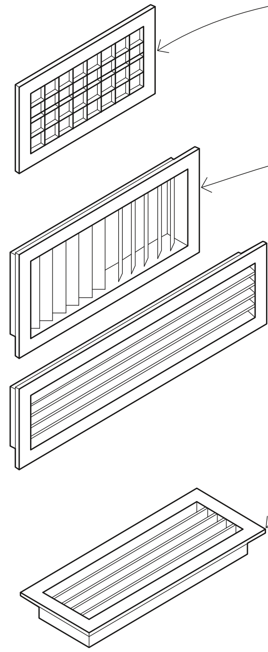
- Multiple cores are often used in broad, low-rise buildings in order to avoid long horizontal runs
- The cores may be dispersed to better serve spaces or zones that have different demands and load requirements
- In apartment buildings and other structures housing repetitive units, the cores may be situated between the units or along circulation spaces

- The service core or cores of a building house the vertical distribution of mechanical and electrical services, elevator shafts and exit stairways. These cores must be coordinated with the structural layout of columns, bearing walls, and shear walls or lateral bracing as well as with the desired patterns of space, use and activity. Shown above are some basic ways in which we can lay out the service cores of a building

Air for heating, cooling and ventilating is supplied through registers and diffusers. They should be evaluated in terms of their air-flow capacity and velocity, pressure drop, noise factor and appearance.

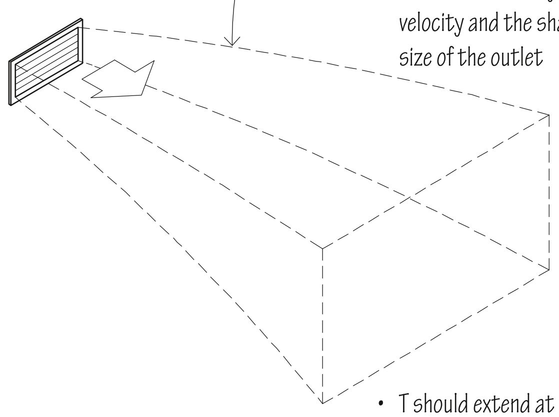


- Diffusers have slats at different angles for deflecting warm or conditioned air from an outlet in various directions
- Ceiling diffusers discharge low-velocity air in a spreading pattern
- Diffusers may be round, square or linear, or be in the form of perforated ceiling tiles

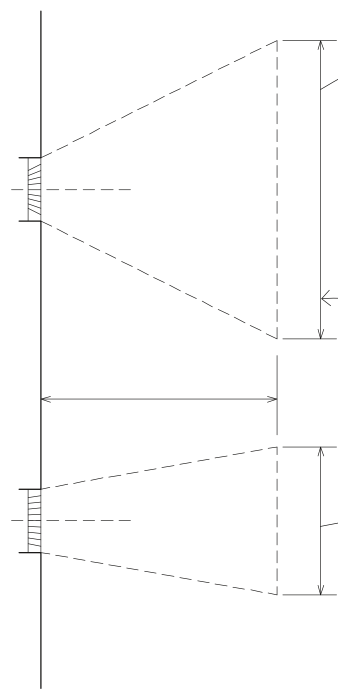


- Grills are simply gratings or perforated screens for covering and protecting an opening
- Dampers control the flow of warm or conditioned air from an outlet, composed of a grill with a number of parallel blades that may be adjusted so as to overlap and close the opening
- Floor dampers are used to control heat loss and condensation along exterior windows and walls

Air-supply outlets should be located to distribute warm or cool air to the occupied areas of a space comfortably, without noticeable draughts, and without stratification. The throw distance and spread or diffusion pattern of the supply outlet should be carefully considered along with any obstructions that might interfere with the air distribution.

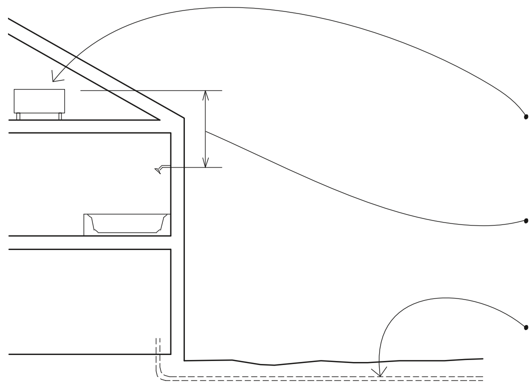


- Throw (T) is the distance a projected air stream travels from an outlet to a point where its velocity is reduced to a specified value. It is determined by the air velocity and the shape and size of the outlet
- T should extend at least 3/4 of the depth of a space



- Spread (S) is the extent to which a projected air stream diffuses at the end of the throw
- The spacing of outlets should be approximately equal to the extent of their spread
- Fan-shaped throw; S = T
- Straight throw; S = T/3

11.22 WATER SUPPLY



Water is utilised in a building in the following ways:

- Water is consumed by drinking, cooking and washing
- HVAC systems circulate water for heating and cooling, and maintaining a desirable level of humidity
- Fire-protection systems store water for extinguishing fires

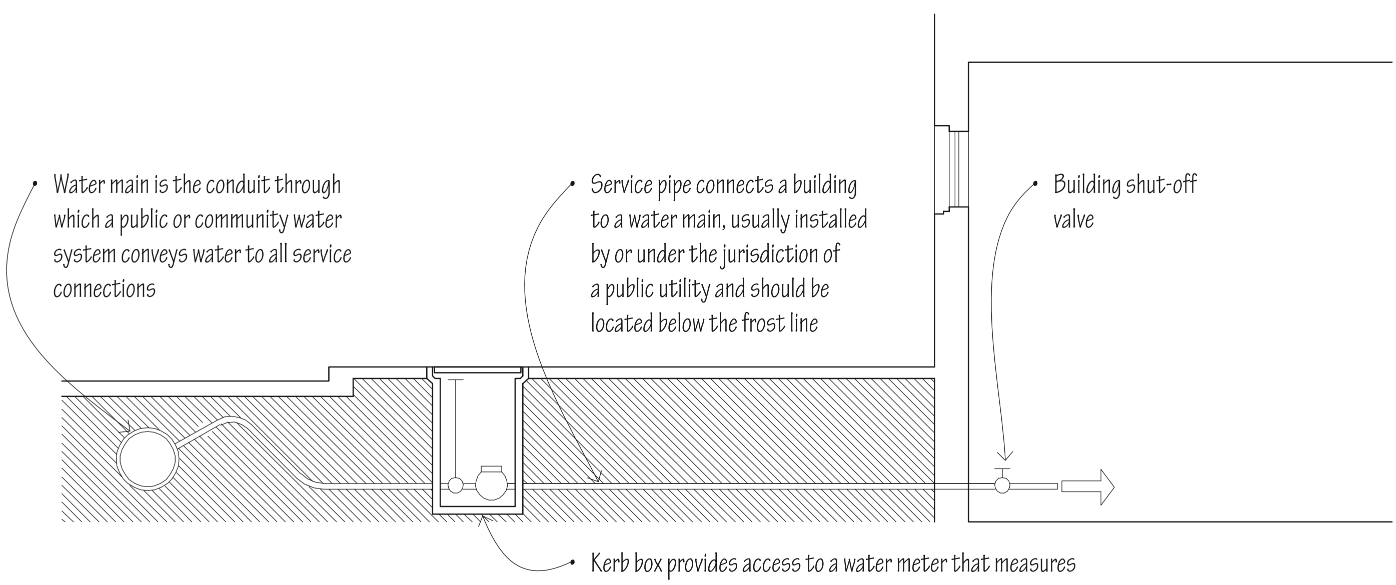
Water must be supplied to a building in the correct quantity, and at the proper flow rate, pressure and temperature, to satisfy the above requirements. For human consumption, water must be potable – free of harmful bacteria – and palatable. To avoid the clogging or corrosion of pipes and equipment, water may have to be treated for hardness or excessive acidity.

- Water wells should be located up slope from and at least 50 m from potential sources of contamination such as building sewers, septic tanks and sewage-disposal fields, and should be accessible to permit the removal of the well casings or pump for maintenance or repair
- Check local environmental regulations that govern private water supply

Private Well

If water is supplied by a public utility provider, there can be no direct control over the quantity or quality of water supplied until it reaches the building site. If a public water system is not available, then either drilled or bored wells or rainwater storage tanks are required. Water is normally stored in a building at high level to provide gravity feed to outlets, where sufficient pressure exists direct feed to the outlets may be used in combination with an on-demand water-heating system.

Well water, if the source is deep enough, is usually pure, cool and free of discoloration and taste or odour problems. A sample should be checked for bacteria and chemical content by the local environmental agency before a well is put into operation.

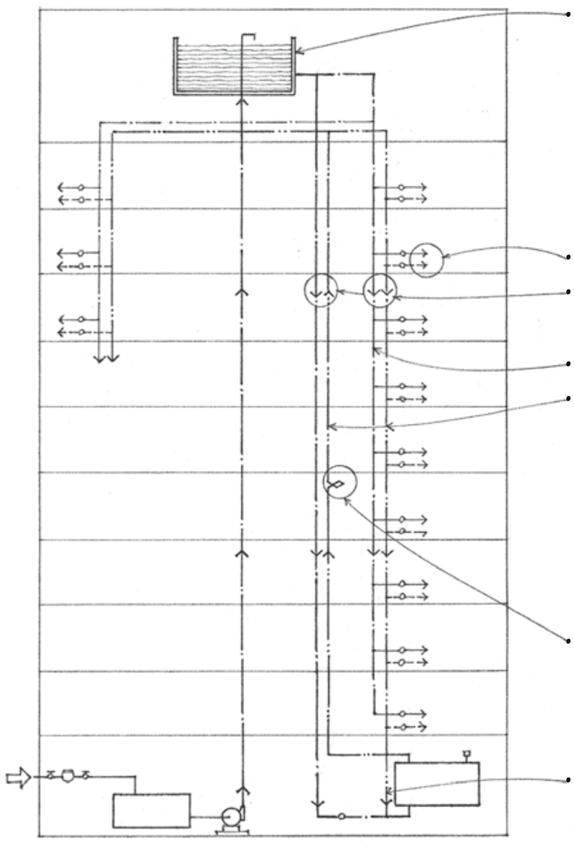


Public Water Supply

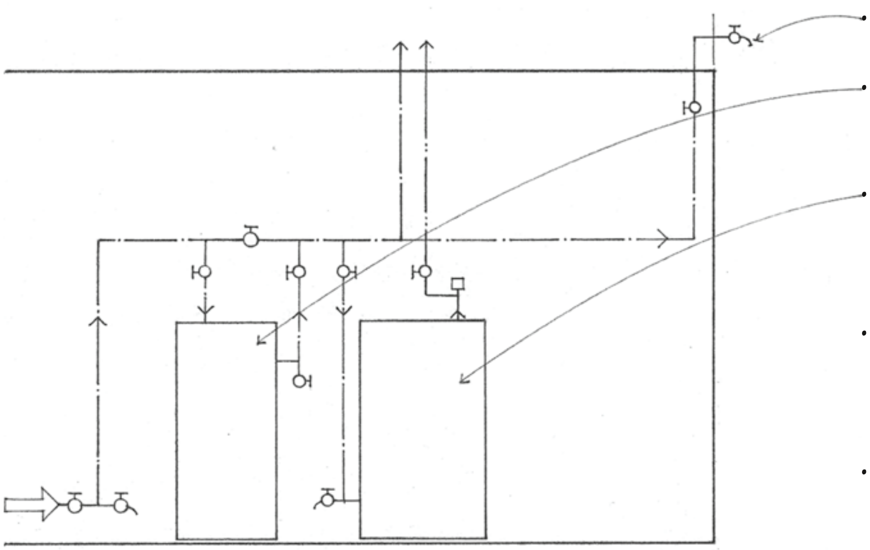
Water-supply systems operate under pressure. The service pressure of a water-supply system must be great enough to absorb pressure losses due to vertical travel and friction as the water flows through pipes and fittings, and still satisfy the pressure requirement of each plumbing fixture. Public water systems usually supply water at a minimum of 1 bar (100 kPa), although there can be significant variation across locations and 3 bar (300 kPa) is typical.

For most mains water supply, upfeed distribution is feasible for low-rise buildings up to six storeys in height. For taller buildings, or where the water service pressure is insufficient to maintain adequate fixture service, water is pumped up to an elevated or rooftop storage tank for gravity downfeed. Part of this water is often used as a reserve for fire-protection systems.

There must be sufficient pressure at each fixture to ensure its satisfactory operation. Fixture pressure requirements vary from 0.1 to 2 bar (10 to 200 kPa). Too much pressure is as undesirable as insufficient pressure. Water-supply pipes are therefore sized to use up the differential between the service pressure, allowing for the pressure loss due to vertical lift or hydraulic friction, and the pressure requirement for each fixture. If the supply pressure is too high, pressure reducers or regulators may be installed on plumbing fixtures.



- Gravity downfeed system sets a water source at a height sufficient to maintain adequate supply pressure throughout the water distribution system
- Branch lines
- Risers
- Cold-water supply
- Hot-water supply; hot water circulates by virtue of its natural rising action. In long, low-rise buildings, pumps may be required for hot-water circulation and distribution
- Expansion vessels permit thermal expansion to occur in long runs of hot-water piping
- Hot-water return line to heater or storage tank in two-pipe systems

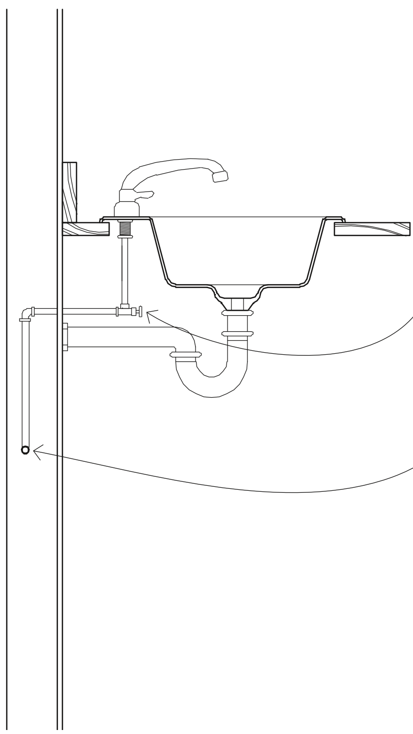


- Upfeed system distributes water from a water main or an enclosed storage tank under pressure from compressed air

- Exterior outlets should be frostproof in cold climates
- Water softener removes calcium and magnesium salts from hard water by ion exchange; hard water can clog pipes, corrode boilers and inhibit the sudsing action of soap
- Water heaters are electric or gas appliances for heating water to a temperature between 50°C and 60°C and storing it for use. Safety pressure-relief valves are required for all water heaters
- An alternative to standard water heaters is a gas-fired combination boiler that heats water at the time and point of use. This system is energy-efficient and requires no space for a storage tank, but does need a flue for the boiler
- Another option is a solar water-heating system able to satisfy the typical hot-water needs of a household in some sunny climates. In temperate climates, solar water-heating systems can effectively serve as a pre-heating system backed up by a standard water-heating system

- The pressure loss due to hydraulic friction depends on the diameter of the supply pipe, the distance of water flow and the number of valves, tees and elbow fittings through which the water passes. Runs should be short, straight and as direct as possible

Maximum pressure required at any fixture [0.1–2 bar (10–200 kPa)]
\+ Pressure loss through water meter
\+ Pressure loss due to static head or vertical lift
\+ Pressure loss by hydraulic friction in pipe runs and fittings
= Water service pressure



- Fixture shut-off valve controls the flow of water at each fixture; additional valves can be installed to isolate one or more fixtures from the water-supply system for repair and maintenance
- Branch supply line
- If a water-supply pipe must be located in an exterior wall, it should be placed on the warm side of the wall insulation

Water-supply lines may be of copper, galvanised steel or plastic. Copper piping is commonly used for water-supply lines because of its corrosion resistance, strength, low friction loss and small outside diameter. Plastic pipes are lightweight, easily joined, produce low friction and do not corrode, but not all types are suitable for carrying potable water. Polybutylene (PB), polyethylene (PE), polyvinyl chloride (PVC) and chlorinated polyvinyl chloride (CPVC) pipes may be used for cold-water supply lines; only PB and CPVC are suitable for hot-water lines (consult local building regulations for confirmation of acceptable materials).

Water branch pipes are sized according to the number and types of plumbing fixtures served and pressure losses due to hydraulic friction and static head, taking into account the required flow rate.

The water-supply system can usually be accommodated within floor and wall construction spaces without too much difficulty. It should be coordinated with the building structure and other systems, such as the parallel but bulkier sanitary drainage system.

Water-supply pipes should be supported at least every storey vertically and every 1800 to 3600 mm horizontally depending on the pipe diameter. Adjustable hangers can be used to ensure proper pitch along horizontal runs for drainage.

Cold-water pipes should be insulated to prevent heat flow into the water from the warmer surrounding air. Hot-water pipes should be insulated against heat loss and preferably should be no closer than 150 mm to parallel cold-water pipes.

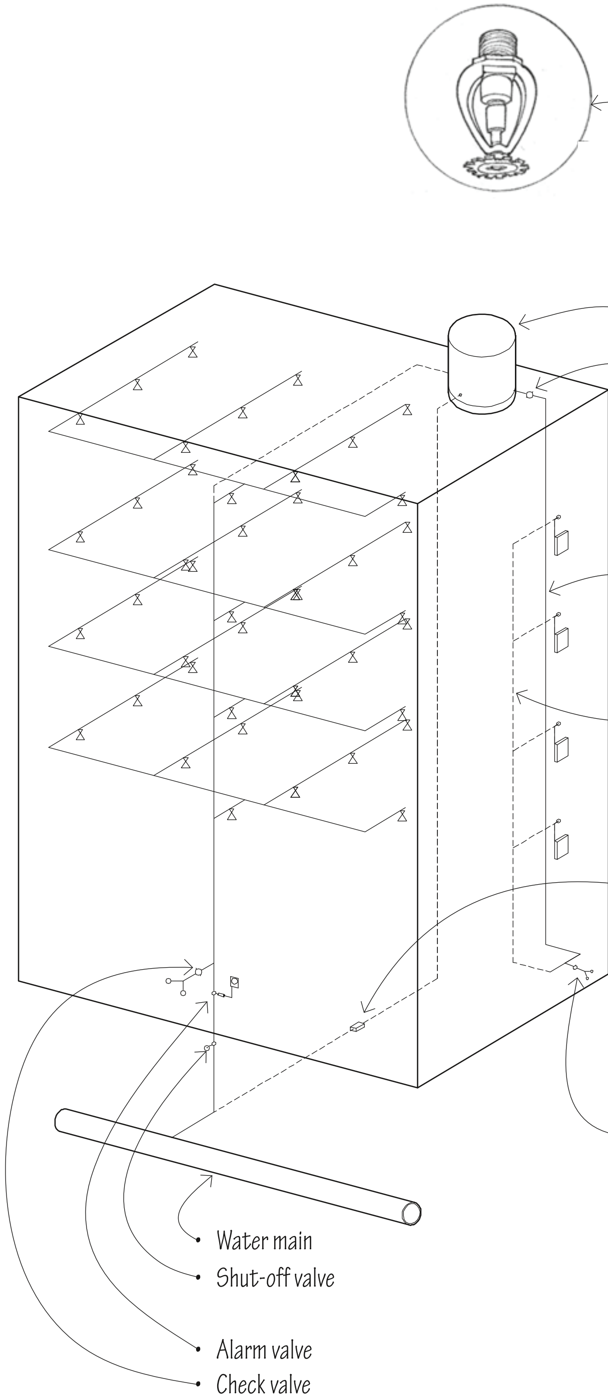
In very cold climates, water pipes in exterior walls and unheated buildings can freeze and rupture. Provision should be made for their drainage to a low point in the system.

Fire-alarm systems are installed in a building to automatically sound an alarm when activated by a fire-detection system. The fire-detection system may consist of heat sensors such as thermostats, or smoke detectors that are activated by products of combustion. Most regions require the installation and hard-wiring of smoke detectors in residential units. Refer to national building regulations or fire-protection organisations for recommendations concerning the type and placement of heat and smoke detectors.

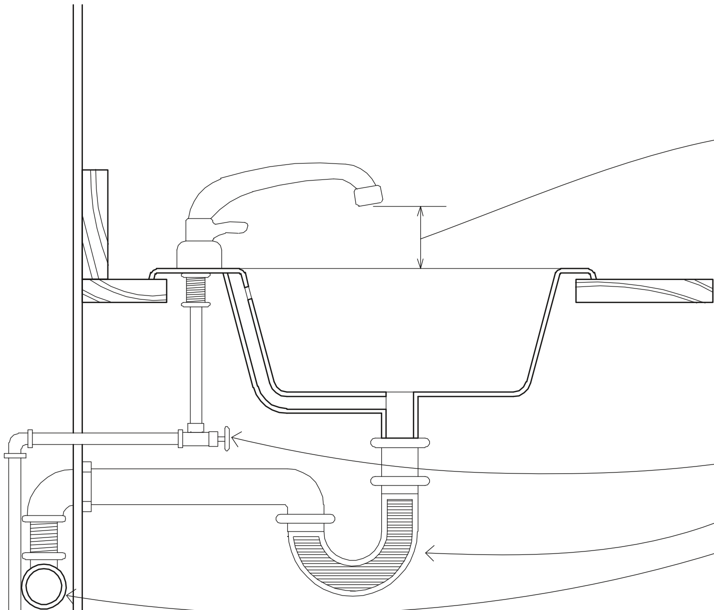
In large commercial and institutional buildings where public safety is an issue, building regulations often require a fire-suppression (sprinkler) system. Some regulations may require the installation of fire-sprinkler systems in multi-family housing also.

Fire-sprinkler systems consist of pipes that are located in or below ceilings, connected to a suitable water supply and supplied with valves or sprinkler heads made to open automatically at a certain temperature. The two major types of sprinkler systems are wet-pipe systems and dry-pipe systems.

- Wet-pipe systems contain water at sufficient pressure to provide an immediate, continuous discharge through sprinkler heads that open automatically in the event of a fire
- Dry-pipe systems contain pressurised air that is released when a sprinkler head opens in the event of fire, allowing water to flow through the piping and out of the opened nozzle. Dry-pipe systems are used where the piping is subject to freezing
- Pre-action systems are dry-pipe sprinkler systems through which water flow is controlled by a valve operated by fire-detection devices more sensitive than those in the sprinkler heads. Pre-action systems are used when an accidental discharge would damage valuable materials
- Deluge systems have sprinkler heads open at all times, through which water flow is controlled by a valve operated by a heat-, smoke- or flame-sensing device



Plumbing fixtures receive water from a supply system and discharge the liquid waste into a sanitary drainage system. They should be of a dense, smooth, non-absorbent material, and be free of concealed fouling surfaces. Some building regulations mandate the use of water-efficient fixtures and valves in order to conserve water resources.

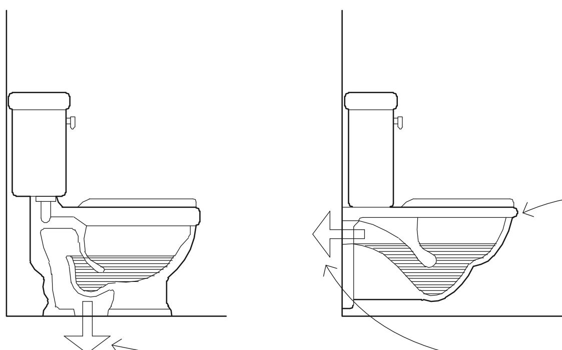


- Air gap is the clear vertical distance between the spout of a tap or other outlet of a supply pipe and the flood level of a receptacle. Sinks and baths may include an overflow that directs waste water back to the waste pipe when the overflow level is reached. Air gaps are required to prevent back-siphonage of used or contaminated water from a plumbing fixture into a pipe supplying potable water due to negative pressure in the pipe
- Shut-off valve
- Trap with water seal
- To soil and vent pipe

LEED WE Credit 3: Water Use Reduction
BREEAM WAT 04: Water Efficient Equipment

Traps

An essential feature of the sanitary drains from plumbing fixtures is a trap, a U-shaped or S-shaped section of drainpipe in which waste water remains. This waste water forms a seal that prevents the passage of sewer gas without affecting the normal flow of waste water or sewage through it.



- Every plumbing fixture requires a trap
- Fixtures should have sufficient water flow to periodically clean out their traps and prevent sediment from collecting
- Traps are cast into water closets

- Wall outlet for wall-hung water closets
- Floor outlet for other types of water closets

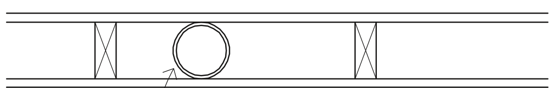
- Waterless urinals do not require water for flushing or feature a traditional trap, they prevent smells from sewer gas by using a one-way valve or oil-based barrier and filter cartridge

- See 9.26 for typical sizes of plumbing fixtures

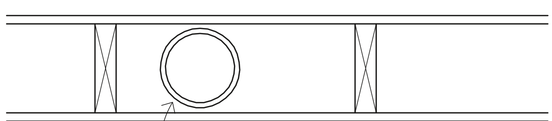
The water-supply system terminates at each plumbing fixture. After water has been drawn and used, it enters the sanitary drainage system. The primary objective of this drainage system is to dispose of fluid waste and organic matter as quickly as possible.

Since a sanitary drainage system relies on gravity for its discharge, its pipes are much larger than the water-supply lines, which are under pressure. Drainage lines are sized according to their location in the system and the total number and types of fixtures served. Always consult the local building regulations for allowable pipe materials, pipe sizing, and restrictions on the length and slope of horizontal runs and on the types and number of turns allowed.

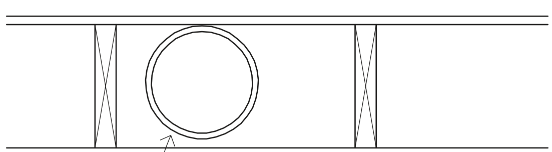
Drainage lines may be of cast iron or plastic. Cast iron, the traditional material for drainage piping, may have hubless or bell-and-spigot joints and fittings. The two types of plastic pipe that are suitable for drainage lines are polyvinyl chloride (PVC) and acrylonitrile-butadiene-styrene (ABS). Some building regulations also permit the use of galvanised steel or copper pipes.



100 mm stud wall
- 75 mm ø hubless cast-iron or plastic pipe
- 50 mm ø bell-and-spigot cast-iron pipe



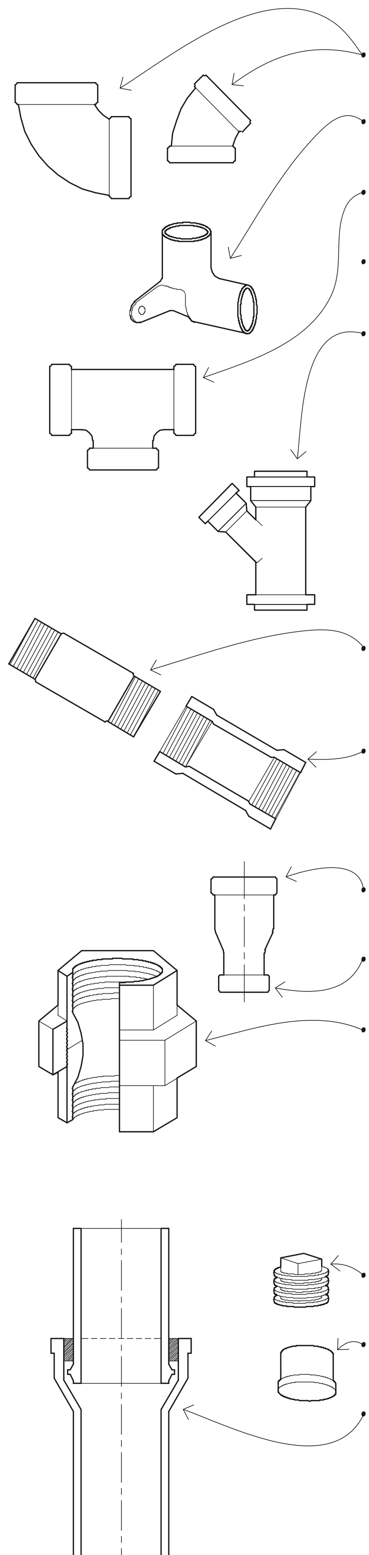
150 mm stud wall
- 125 mm ø hubless cast-iron or plastic pipe
- 75 mm ø bell-and-spigot cast-iron pipe



200 mm stud wall
- 150 mm ø hubless cast-iron or plastic pipe
- 125 mm ø bell-and-spigot cast-iron pipe

Maximum Pipe Sizes

- When plumbing is enclosed within a partition wall, the wall should be deep enough to accommodate branch lines, fixture run-outs and air chambers. Alternatively plumbing can be accommodated in dedicated ducts and risers



- Elbows have an angled bend usually 45°or 90°
- Drop elbow has lugs for attachment to a wall or joist
- Tees are T-shaped pipe fittings for making three-way joints
- Drop tee has lugs for attachment to a wall or joist
- Wyes are Y-shaped pipe fittings for joining a branch pipe with a main, usually at a 45° angle
- Nipples are short lengths of pipe with threads on each end, used for joining couplings or other pipe fittings
- Couplings are short lengths of pipe having each end threaded on the inside, used for joining two pipes of the same diameter
- Increaser is a coupling increasing in diameter at one end
- Reducer is a coupling decreasing in diameter at one end
- Unions connect two pipes neither of which can be turned, consisting of two internally threaded end pieces that are tightened around the pipe ends to be joined, and an externally threaded centrepiece, which draws the two end pieces together as it is rotated
- Plugs are externally threaded fittings for closing the end of a pipe
- Caps are internally threaded fittings for enclosing the end of a pipe
- Bell-and-spigot pipe joints are made by fitting the end (spigot) of one pipe into the enlarged end (bell) of another pipe and sealing with a caulking compound or a compressible ring

Pipe Fittings

11.28 SANITARY-DRAINAGE SYSTEMS

The layout of the sanitary drainage system should be as direct and straightforward as possible to prevent the deposit of solids and clogging.

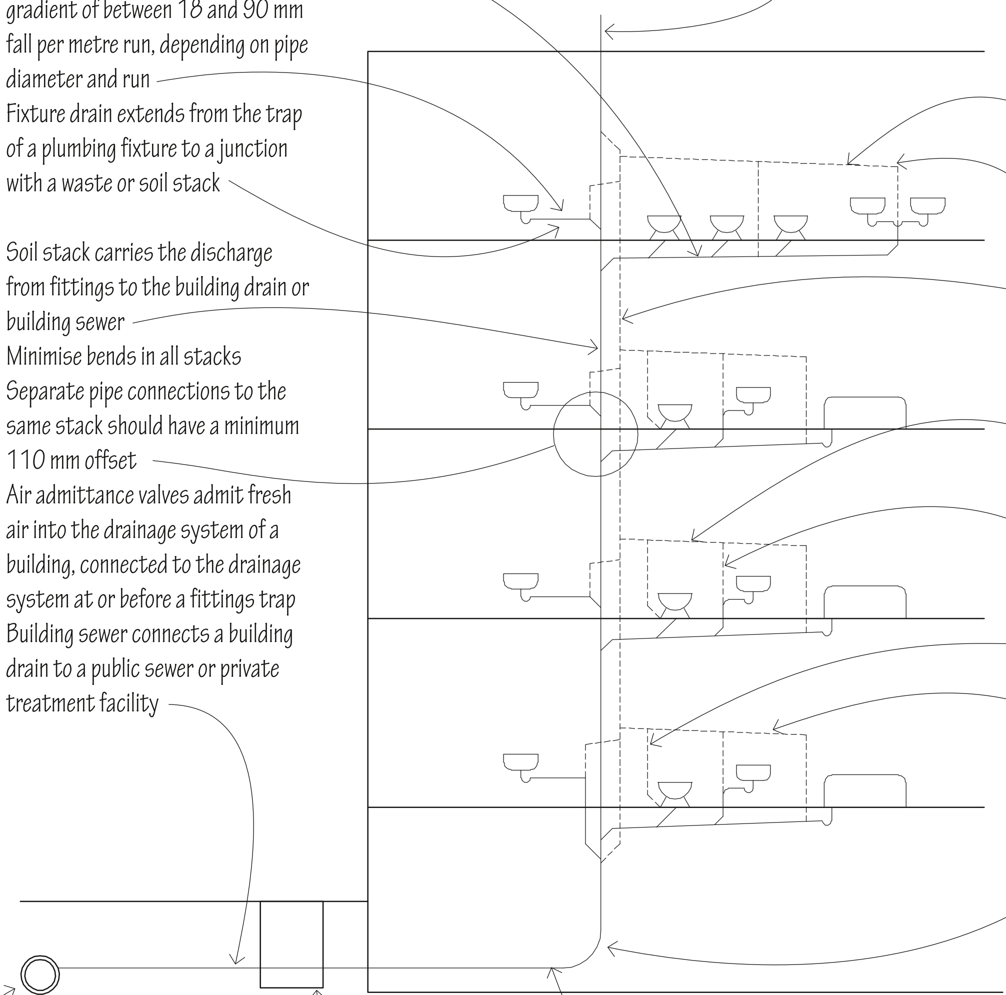
- Stack vent is an extension of a soil stack above the highest horizontal drain connected to the stack; open stacks should extend at least 900 mm above any opening in the building

Vents

The vent system permits septic gases to escape to the outside and supplies a flow of fresh air into the drainage system to protect trap seals from siphonage and back pressure. A single-stack system can be used where the fixtures are close to the stack. Alternatively secondary ventilation stacks can be provided.

- Branch drain connects one or more fixtures to a stack
- Horizontal drain lines should have a gradient of between 18 and 90 mm fall per metre run, depending on pipe diameter and run
- Fixture drain extends from the trap of a plumbing fixture to a junction with a waste or soil stack

- Soil stack carries the discharge from fittings to the building drain or building sewer
- Minimise bends in all stacks
- Separate pipe connections to the same stack should have a minimum 110 mm offset
- Air admittance valves admit fresh air into the drainage system of a building, connected to the drainage system at or before a fittings trap
- Building sewer connects a building drain to a public sewer or private treatment facility



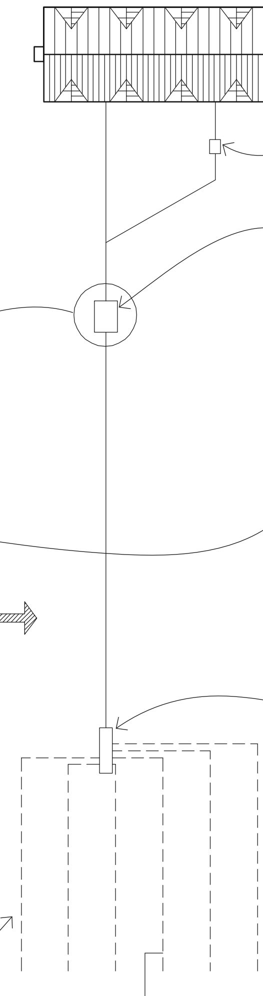
- Loop vent is a circuit vent that loops back and connects with a stack vent instead of a vent stack
- Common vent serves two fixture drains connected at the same level
- Vent stack is a vertical vent installed primarily to provide circulation of air to or from any part of a drainage system
- Branch vent connects one or more individual vents with a vent stack or soil stack
- Continuous vent is formed by a continuation of the drain line to which it connects
- Back vent is installed on the sewer side of a trap
- Circuit vent serves two or more traps and extends from in front of the last fixture connection of a horizontal branch to the vent stack
- Large radius bend to bottom of the stack
- Ground-floor appliances may connect into a stub stack (a short soil stack) where certain criteria are met. Consult local building regulations for confirmation of specific requirements

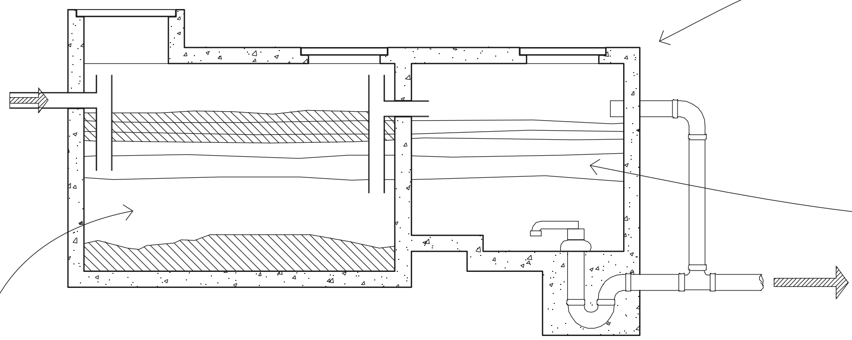
- Foul sewers convey only the sewage from plumbing fixtures and exclude rain and surface water; surface-water sewers convey rainfall drained from roofs and paved surfaces; combined sewers carry both sewage and surface water

- Inspection chamber or manhole

- Building drain is the lowest part of a drainage system that receives the discharge from stacks inside the walls of a building and conveys it by gravity to the sewer
- Building surface-water drains convey only rainwater or similar discharge to a building surface-water sewer, which in turn leads to a public surface water sewer, combined sewer or other point of disposal

Foul-water sewers usually convey sewage from plumbing fixtures to a public facility for treatment and disposal. When this is not possible, a private sewage-disposal system is required. Its type and size depend on the number of fixtures served and the permeability of the soil as determined by a percolation test. Sewage-disposal systems must be designed by appropriately qualified and experienced engineers and must be approved and inspected by the environment agency before being put into use. Consult the building and health regulations for specific requirements.



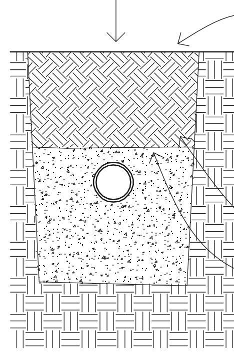


- Precast-concrete grease trap optional
- Septic tank
- Locate septic tank at least 7 m from habitable parts of buildings and drainage field at least 50 m away from wells, 10 m from streams and 15 m from buildings
- The dosing chamber of a large septic tank employs siphonic action to automatically discharge a large volume of effluent when a predetermined quantity has accumulated
- Distribution box is equipped with baffles to direct effluent to various parts of the disposal field
- Drainage field
- Distribution pipes should run perpendicular to slope

A septic tank is a covered watertight tank for receiving the foul water from a building, separating out the solid organic matter, which is decomposed and purified by anaerobic bacteria, and allowing the clarified liquid to discharge for final disposal.

The liquid effluent, which is about 70% purified, may flow into one of the following systems:

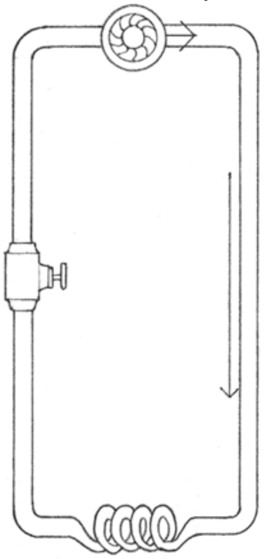
- A drainfield or percolation area is an open area containing an arrangement of irrigation pipes through which effluent from a septic tank may seep or leach into the surrounding soil
- A reed bed (or other wetland) treatment system consists of a gravel bed around the roots of suitable plants which purifies the wastewater as it progresses through the bed



- Irrigation pipes in a drain field should be separated by at least 2 m; the perforated distribution pipes should be bedded in coarse aggregate
- Backfill
- Geotextile layer

- Greywater refers to the wastewater from sinks, baths, showers and dishwashers, which can be treated and recycled for such uses as toilet flushing and irrigation. Greywater systems should be used in conjunction with other water-conservation strategies, such as specifying water-efficient fixtures and capturing rainwater and surface run-off in cisterns and reservoirs for use in landscaping

BREEAM WAT 01: Water Consumption; WAT 04: Water Efficient Equipment
LEED WE Credit 2: Innovative Wastewater Technologies



Hydraulic Analogy to Electric Circuit

The electrical system of a building supplies power for lighting, heating and the operation of electrical equipment and appliances. This system must be installed according to the building and electrical regulations in order to operate safely, reliably and effectively. All electrical equipment should meet appropriate standards. Consult the Institution of Engineering and Technology wiring regulations for specific requirements in the design and installation of any electrical system within the UK. The European Committee for Electrotechnical Standardization CENELEC is working towards harmonised European standards in this area.

Electrical energy flows through a conductor because of a difference in electrical charge between two points in a circuit.

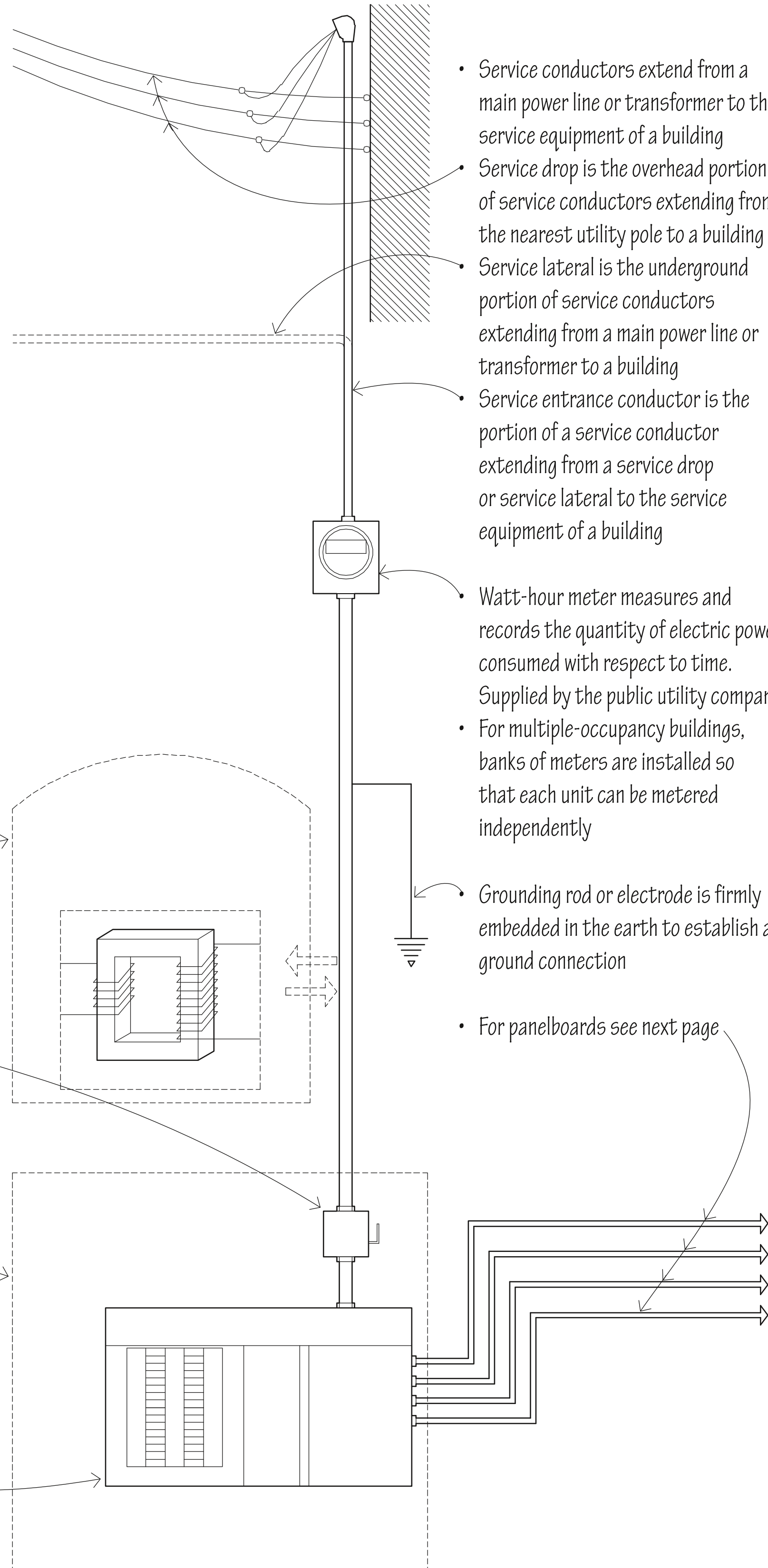
- Volt (V) is the SI unit of electromotive force, defined as the difference of electric potential between two points of a conductor carrying a constant current of one ampere, when the power dissipated between the points is equal to one watt
- Ampere (A) is the basic SI unit of electric current, equivalent to a flow of one coulomb per second or to the steady current produced by one volt applied across a resistance of one ohm
- Watt (W) is the SI unit of power, equal to one joule per second or to the power represented by a current of one ampere flowing across a potential difference of one volt
- Ohm is the SI unit of electrical resistance, equal to the resistance of a conductor in which a potential difference of one volt produces a current of one ampere. Symbol: Ω

Power is usually supplied to a building by the electrical utility company. A large installation may use its own transformer to step down from a more economical, higher supply voltage to the service voltage. Generator sets may be required to supply emergency electrical power for exit lighting, alarm systems, elevators, telephone systems, fire pumps and medical equipment in hospitals.

- Most domestic installations in Europe will be 230 V, single-phase installations
- Larger commercial buildings may require 400 V, three-phase installations
- Some large commercial and industrial buildings may require high-voltage supplies (11kV). This type of installation is likely to incur higher installation and operating costs

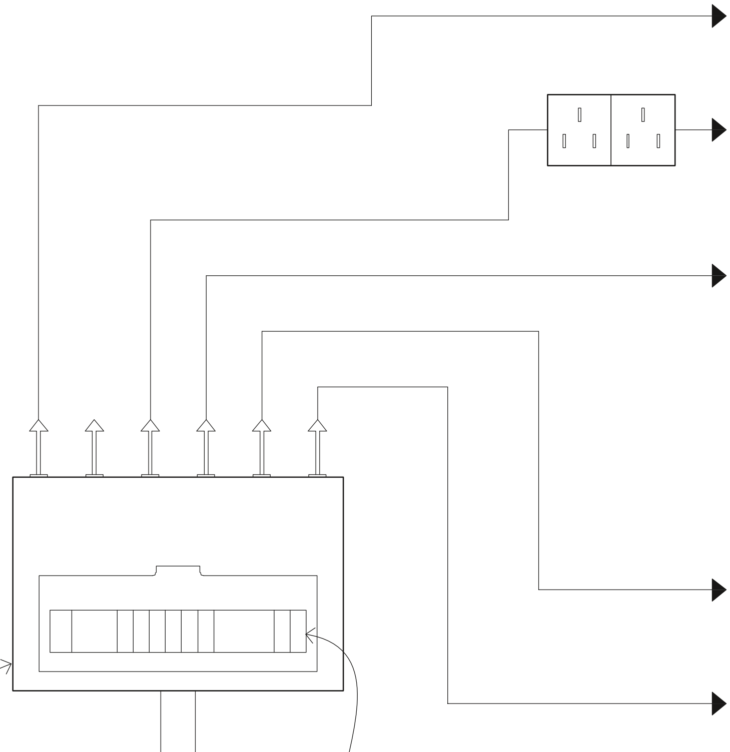
The public utility company should be notified of the estimated total electrical load requirements for a building during the planning phase to confirm service availability and to coordinate the location of the service connection and meter.

The service connection may be overhead or underground. Overhead service is less expensive, easily accessible for maintenance, and can carry high voltages over long runs. Underground service is more expensive but is used in high load-density situations such as urban areas. The service cables are run in pipe conduit or raceways for protection and to allow for future replacement. Direct burial cable may be used for residential service connections.



- Service conductors extend from a main power line or transformer to the service equipment of a building
- Service drop is the overhead portion of service conductors extending from the nearest utility pole to a building
- Service lateral is the underground portion of service conductors extending from a main power line or transformer to a building
- Service entrance conductor is the portion of a service conductor extending from a service drop or service lateral to the service equipment of a building
- Watt-hour meter measures and records the quantity of electric power consumed with respect to time. Supplied by the public utility company
- For multiple-occupancy buildings, banks of meters are installed so that each unit can be metered independently
- Grounding rod or electrode is firmly embedded in the earth to establish a ground connection
- For panelboards see next page

- A transformer is used by medium-sized and large buildings to step down from a high-supply voltage to the service voltage. To reduce costs, maintenance, noise and heat problems, a transformer may be placed on an outdoor pad. If located within a building, the local supplier is likely to have a number of key criteria relating to ventilation, access and location that should be met. Location criteria for dry-type transformers used in small- and medium-sized buildings may be less stringent than those of oil-filled transformers although they are likely to be more expensive
- The service switch is the main disconnect for the entire electrical system of a building, except for any emergency power systems
- The service equipment includes a mains disconnect switch and secondary switches, fuses and circuit breakers for controlling and protecting the electric power supply to a building
- The mains distribution board is a panel on which are mounted switches, overcurrent devices, metering instruments and busbars for controlling, distributing and protecting a number of electric circuits. It should be located as close as possible to the service connection to minimise voltage drop and for wiring economy



Once the electrical power requirements for the various areas of a building are determined, wiring circuits must be laid out to distribute the power to the points of utilisation.

- Branch circuits are the portions of an electrical system extending from the final overcurrent device protecting a circuit to the outlets served by the circuit. Each branch circuit is sized according to the amount of load it must carry. About 20% of its capacity is reserved for flexibility, expansion and safety. To avoid an excessive drop in voltage, a branch circuit should not exceed 30 m in length

- General-purpose circuits supply current to a number of outlets for lighting and appliances
- Receptacles in wet locations, such as in bathrooms, should be protected by a residual current device (RCD). An RCD is a circuit breaker that senses currents caused by ground faults and instantaneously shuts off power before damage or injury can occur

- Appliance circuits supply current to one or more outlets specifically intended for appliances
- Individual circuits supply current only to a single piece of electrical equipment

- Load requirements for lighting fixtures and electrically powered appliances and equipment are specified by their manufacturer. The design load for a general-purpose circuit, however, depends on the number of receptacles served by the circuit and how they are used

- Separate wiring circuits are required for the sound and signal equipment of telephone, cable, intercom, security or fire alarm systems
- Telephone systems should have their outlets located and wired during construction. Large installations also require a service connection, terminal enclosures, riser spaces, etc, similar to electrical systems. Large systems are usually designed, furnished and installed by a telecommunications company
- Cable television systems may receive their signals from an outdoor antenna or satellite dish, a cable company or a closed-circuit system

- Panelboards control, distribute and protect a number of similar branch circuits in an electrical system. In large buildings, they are located in electrical closets close to the load ends of circuits. In residences and small installations, the panelboard is combined with the switchboard to form a consumer unit

- Circuit breakers are switches that automatically interrupt an electric circuit to prevent excess current from damaging apparatus in the circuit or from causing a fire. A circuit breaker may be reclosed and reused without replacement of any components

- Miniature circuit breakers (MCB) are used mainly in domestic situations where they have replaced traditional fuses. Often referred to as trip switches, when a circuit is overloaded, they 'trip' into a position breaking the circuit

Metals, offering little resistance to the flow of electric current, make good conductors. Copper is most often used. The various forms of conductors – wire, cable and busbars – are sized according to their safe current-carrying capacity and the maximum operating temperature of their insulation. They are identified according to:

- Current-carrying capacity
- Number and size of conductors
- Type of insulation

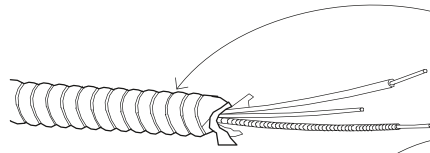
A conductor is covered with insulation to prevent its contact with other conductors or metal, and to protect it against heat, moisture and corrosion. Materials with a high resistance to the flow of electric current, such as rubber, plastics, porcelain and glass, are commonly used to insulate electrical wiring and connections.

Conduit provides support for wires and cables and protects them against physical damage and corrosion. Metal conduit also provides a continuous grounded enclosure for the wiring. For fireproof construction, rigid metal conduit, electrical metallic tubing or flexible metal conduit can be used. For framed construction, armoured or non-metallic sheathed cable is used. Plastic tubing and conduits are most commonly used for underground wiring.

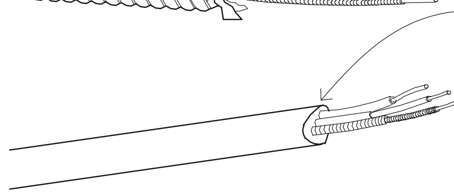
Being relatively small, conduit can be easily accommodated in most construction systems. Conduit should be adequately supported and laid out as directly as possible. Regulations generally restrict the radius and number of bends a run of conduit may have between junction or outlet boxes. Coordination with a building's mechanical and plumbing systems is required to avoid conflicting paths.

Electrical conductors are often run within the raceways of cellular steel decking to allow for the flexible placement of power, signal and telephone outlets in office buildings. Flat conductor cable systems are also available for installation directly under carpet tiles.

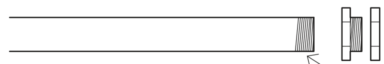
For exposed installations, special conduit, raceways, troughs and fittings are available. As with exposed mechanical systems, the layout should be visually coordinated with the physical elements of the space.



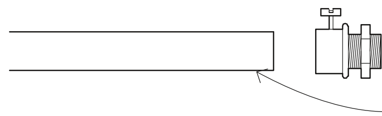
- Armoured cable consists of two or more insulated conductors protected by a flexible, helically wound metal wrapping



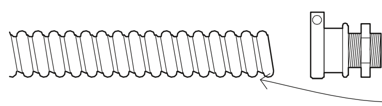
- Non-metallic sheathed cable, also called Romex cable, consists of two or more insulated conductors enclosed in a non-metallic, moisture-resistant, flame-retardant sheath
- Mineral-insulated cable consists of a tubular copper sheath containing one or more conductors embedded in a highly compressed, insulating refractory mineral



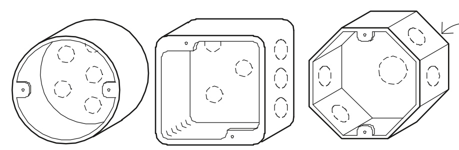
- Rigid metal conduit is heavy-walled steel tubing joined by screwing directly into a threaded hub with lock nuts and bushings



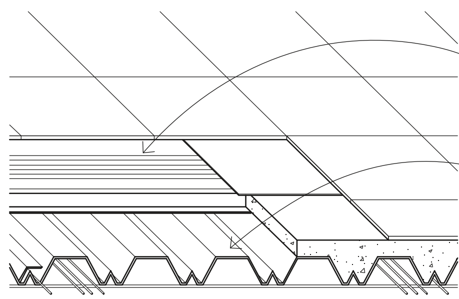
- Electrical metallic tubing is thin-walled, steel tubing joined by compression or set-screw couplings



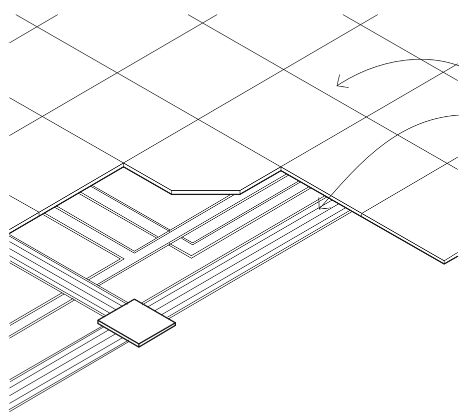
- Flexible metal conduit is a helically wound metal conduit, used for connections to motors or other vibrating equipment



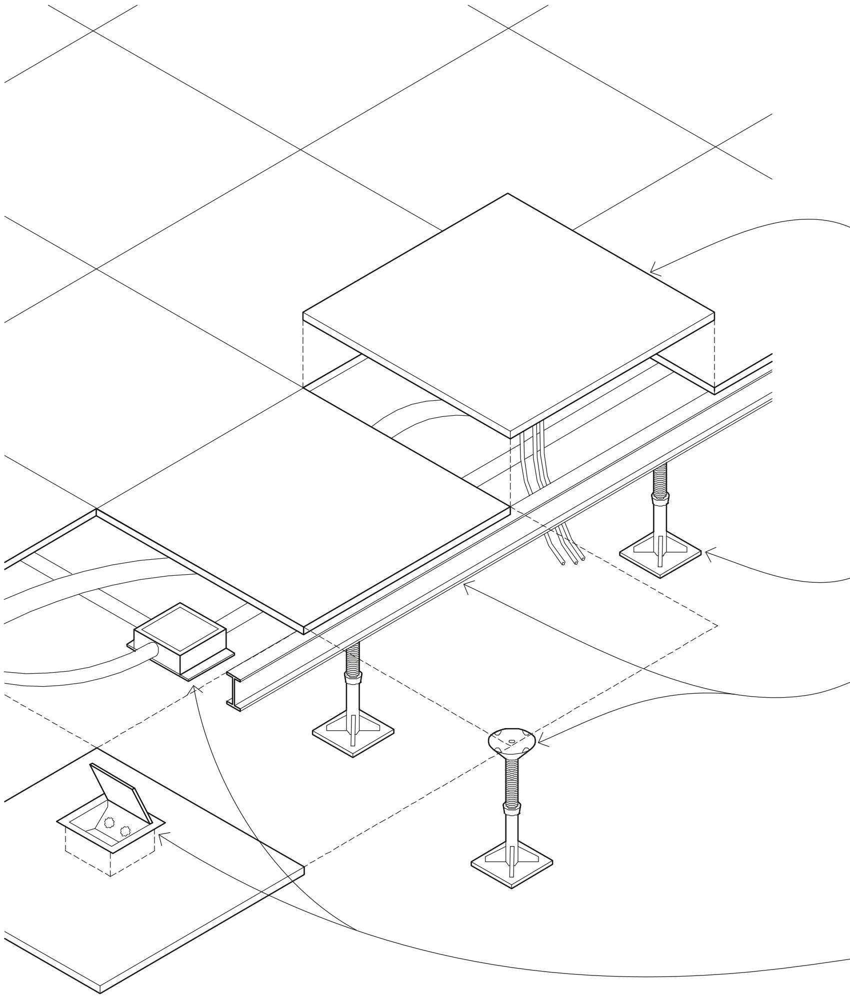
- Junction boxes are enclosures for housing and protecting electric wires or cables that are joined together in connecting or branching electric circuits



- Trench header perpendicular to raceways
- Floor outlets are located on a preset module
- Cellular steel floor decking



- Carpet squares
- 1, 2 or 3 circuit flat conductor cables with low-profile outlets

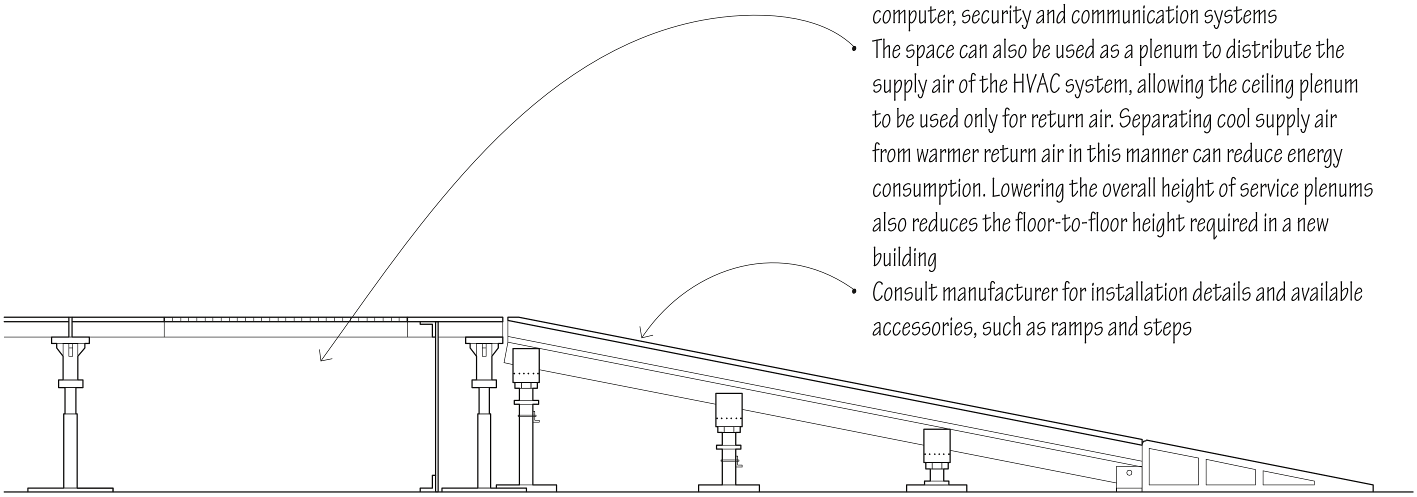


Raised access-floor systems are typically used in office spaces, hospitals, laboratories, computer rooms and television and communication centres to provide accessibility and flexibility in the placement of desks, workstations and equipment. Equipment can be moved and reconnected fairly easily with modular wiring systems.

- Raised access-floor systems consist essentially of removable and interchangeable floor panels supported on adjustable pedestals to allow free access to the space beneath. The floor panels are typically 600 mm square and constructed of steel, aluminium, a wood core encased in steel or aluminium, or lightweight reinforced concrete. The panels may be finished with carpet tile, vinyl tile or high-pressure laminate; fire-rated and electrostatic-discharge-control coverings are also available

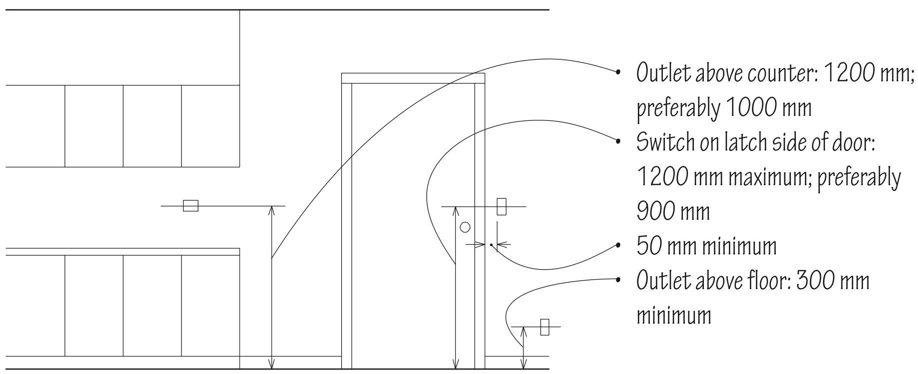
- The pedestals are adjustable to provide void heights from as little as 50 mm to 1 m or more, typical void heights range from 300 to 500 mm
- Systems using stringers have greater lateral stability than stringerless systems; seismic pedestals are available to meet building regulation requirements in relevant geographical zones for lateral stability
- Uniformly distributed design loads range from 5 to 25 kN/m^2, but are available up to 50 kN/m^2 to accommodate heavier loadings

- The underfloor space is used for the installation of electrical conduit, junction boxes and the cables for computer, security and communication systems
- The space can also be used as a plenum to distribute the supply air of the HVAC system, allowing the ceiling plenum to be used only for return air. Separating cool supply air from warmer return air in this manner can reduce energy consumption. Lowering the overall height of service plenums also reduces the floor-to-floor height required in a new building
- Consult manufacturer for installation details and available accessories, such as ramps and steps



Lighting fixtures, wall switches and convenience outlets are the most visible parts of an electrical system. Switches and sockets should be located for convenient access, and coordinated with visible surface patterns. Wall plates for these devices may be of metal, plastic or glass, and are available in a variety of colours and finishes.

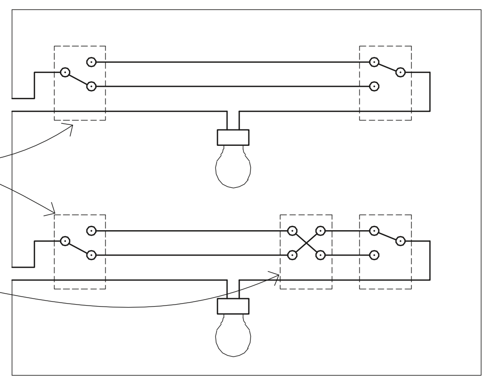
The design load for a general-purpose circuit depends on the number of outlets served by the circuit and how they are used.



Heights of Switches and Outlets

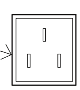
Switches

- A switch has a lever or knob that moves through a small arc and causes the contacts to open or close an electric circuit
- Three-way switch is a single-pole, double-throw switch used in conjunction with another to control lights from two locations
- Four-way switch is used in conjunction with two three-way switches to control lights from three locations
- Dimmer is a rheostat or similar device for regulating the intensity of an electric light without appreciably affecting spatial distribution

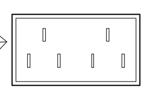


Receptacles

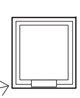
- Single-gang sockets have a single receptacle



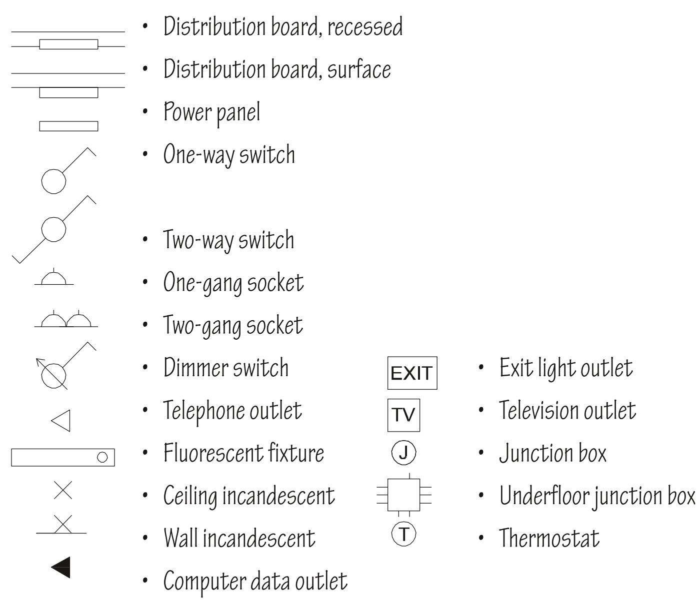
- Two-gang sockets are usually mounted on a wall and house two receptacles for portable lamps or appliances



- Sockets may be switched so that individual outlets can be isolated
- Outdoor receptacles should have a water-resistant cover

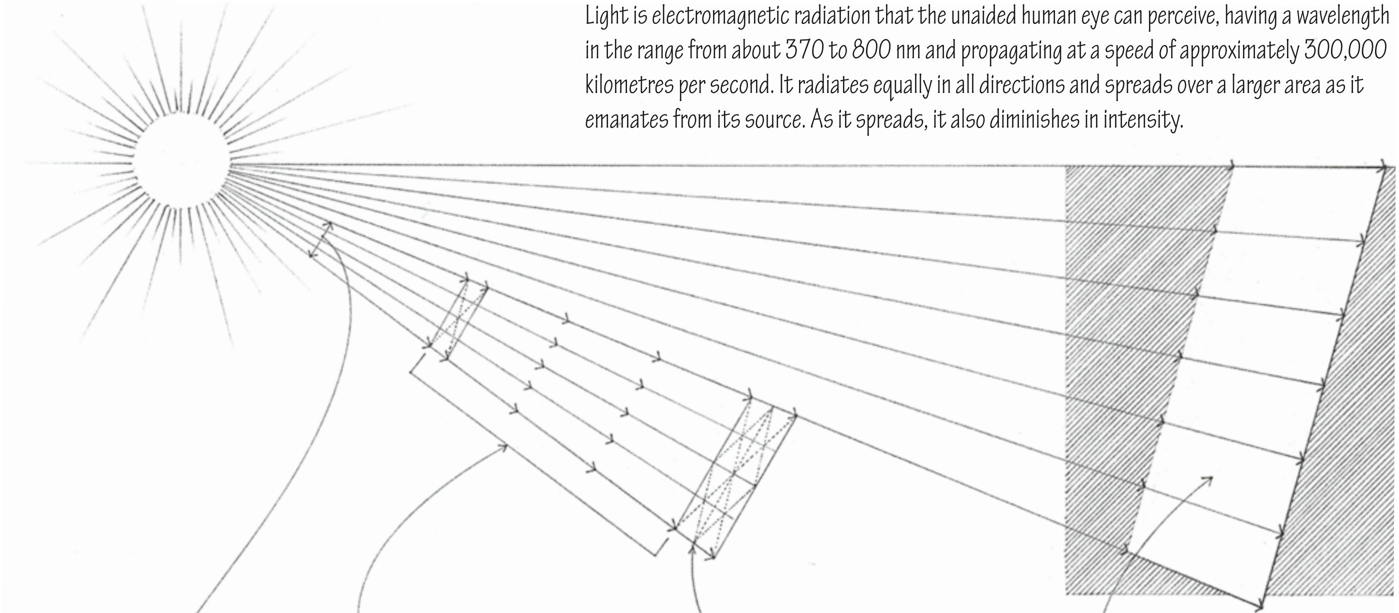


- In all wet locations, receptacles should be protected by a residual current device (RCD)



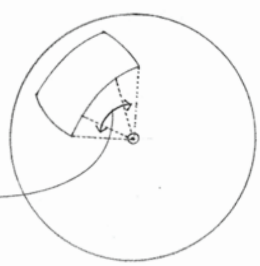
Typical Electrical Plan Symbols

Light is electromagnetic radiation that the unaided human eye can perceive, having a wavelength in the range from about 370 to 800 nm and propagating at a speed of approximately 300,000 kilometres per second. It radiates equally in all directions and spreads over a larger area as it emanates from its source. As it spreads, it also diminishes in intensity.



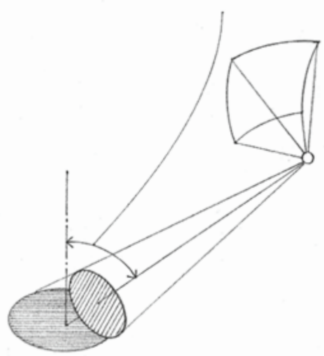
- Luminous intensity is the luminous flux emitted per unit solid angle by a light source, expressed in candelas
- Candela is the basic SI unit of luminous intensity, equal to the luminous intensity of a source that emits monochromatic radiation of frequency 540 x 1012 hertz and that has a radiant intensity of 1/683 watt per steradian
- A steradian is a solid angle at the centre of a sphere subtending an area on the surface equal to the square of the radius of the sphere

- Luminous flux is the rate of flow of visible light per unit time, expressed in lumens
- Lumen is the SI unit of luminous flux, equal to the light emitted in a solid angle of one steradian by a uniform point source having an intensity of one candela



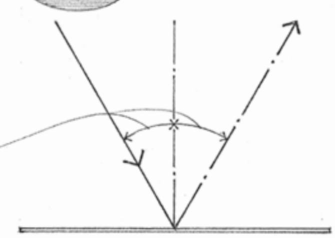
- Inverse square law states that the illumination produced on a surface by a point source varies inversely as the square of the distance of the surface from the source
- Cosine law states that the illumination produced on a surface by a point source is proportional to the cosine of the angle of incidence

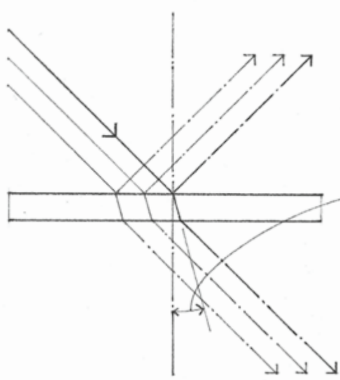
- Illumination is the intensity of light falling at any given place on a lighted surface, equal to the luminous flux incident per unit area and expressed in lumens per unit of area
- Lux is the SI unit of illumination, equal to one lumen per square metre



- Reflectance is the ratio of the radiation reflected by a surface to the total incident on the surface
- Absorptance is the ratio of the radiation absorbed by a surface to the total incident on the surface
- Transmittance is the ratio of the radiation transmitted through and emerging from a body to the total incident on it, equivalent to one minus the absorptance

- Law of reflection is the principle that when light is reflected from a smooth surface, the angle of incidence is equal to the angle of reflection, and the incident ray, the reflected ray, and the normal to the surface all lie in the same plane





- Angle of refraction is the angle that a refracted ray makes with a normal to the interface between two media at the point of incidence

Light reveals to our eyes the shape, texture and colour of objects in space. An object in its path will reflect, absorb or allow the light striking its surface to pass through. Luminance is the quantitative measure of brightness of a light source or an illuminated surface, equal to the luminous intensity per unit projected area of the source or surface viewed from a given direction.

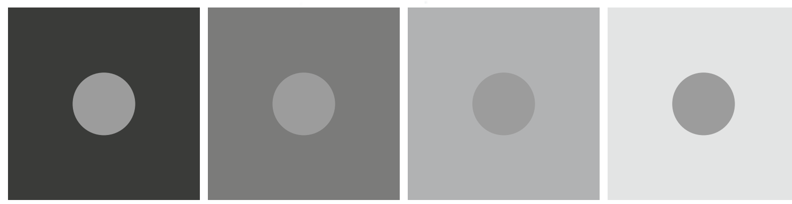
Brightness is the sensation by which an observer is able to distinguish between differences in luminance. Visual acuity increases with object brightness. Of equal importance is the ratio of the luminance of an object being viewed and that of its background. To discern shape and form, some degree of contrast or brightness ratio is required. Contrast is especially critical for visual tasks that require discrimination of shape and contour. For seeing tasks requiring discrimination of texture and detail, less contrast is desirable since our eyes adjust automatically to the average brightness of a scene. When the contrast or brightness ratio is too high, glare can result.

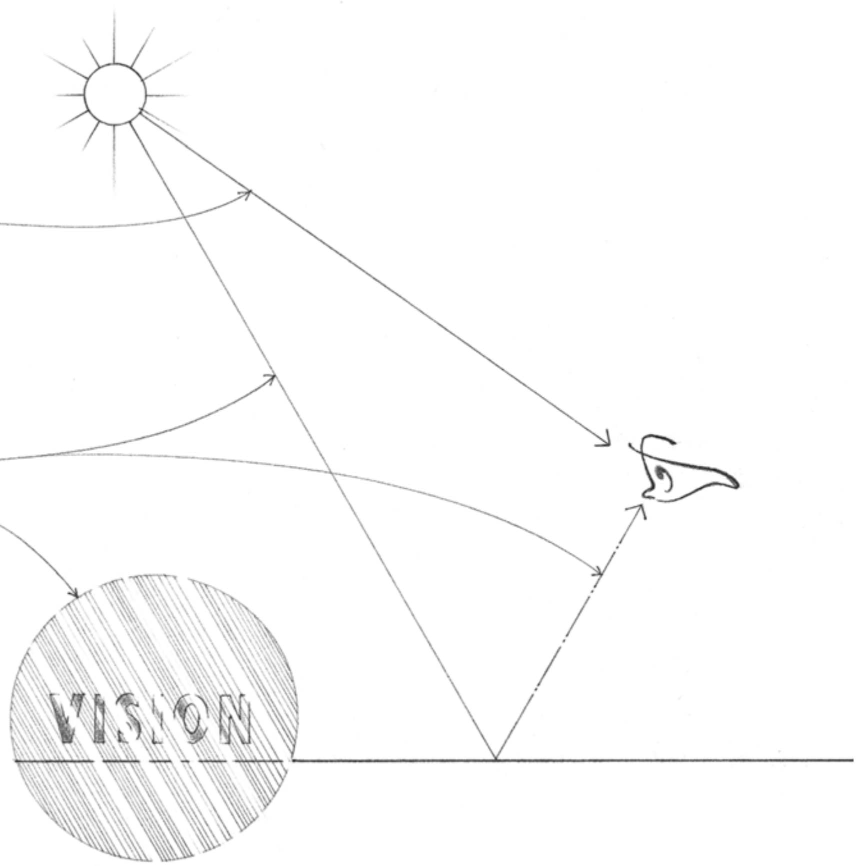
Glare is the sensation produced by any brightness within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss of visibility. There are two types of glare: direct and reflected.

- Direct glare results from a high brightness ratio or an insufficiently shielded light source in the visual field
- Strategies to control or minimise glare include using shielded luminaires to cut off direct view of lamps and using luminaires with diffusers or lenses that lower their brightness levels

- Reflected or indirect glare results from the specular reflection of a light source within the visual field
- A specific type of reflected glare is veiling reflectance, which occurs on a task surface and reduces the contrast necessary for seeing details
- To prevent veiling reflectance, locate the light source in such a way that incident light rays are reflected away from the observer

- A candela is the SI unit of luminous intensity
- Luminance or brightness is measured in candela per square metre cd/m^2
- Brightness is affected by both colour and texture. Shiny, light-coloured surfaces reflect more light than dark, matte or rough-textured surfaces, even though both surfaces may receive the same amount of illumination



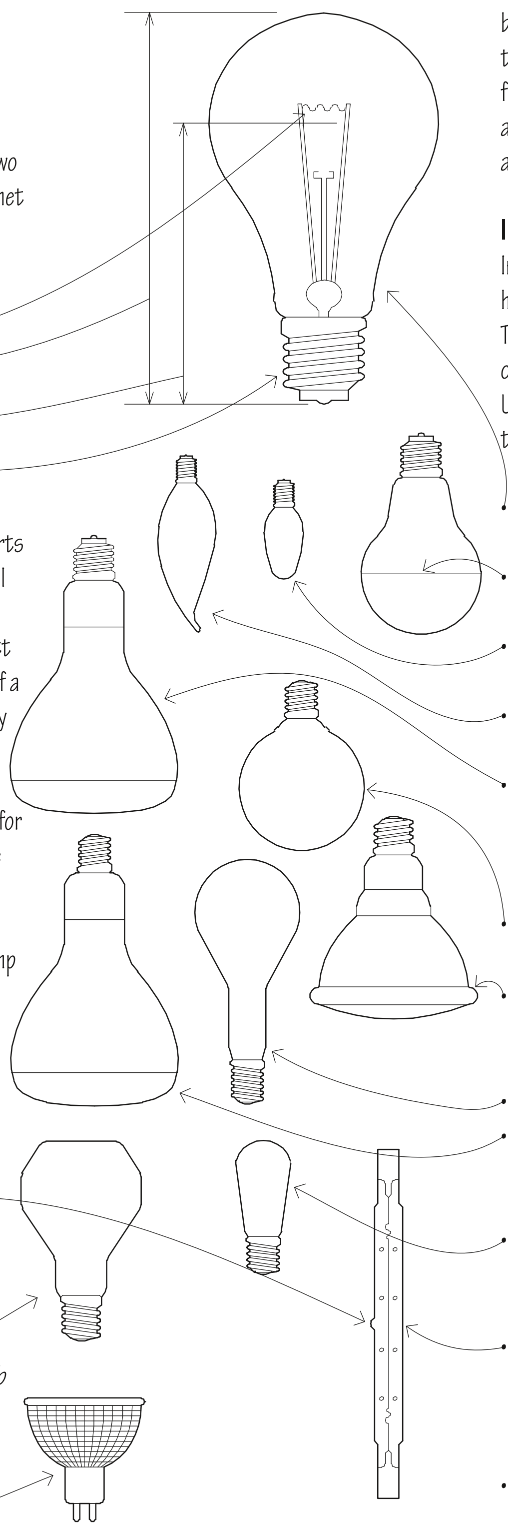


- Bulb is the glass housing of an incandescent lamp, filled with an inert gas mixture, usually of argon and nitrogen, to retard evaporation of the filament. Bulbs can be specified according to a number of criteria including: the shape, designated by a letter; the base type, designated by two letters (ES=Edison Screw, BC=Bayonet Cap, size may also be noted); and efficiency on a scale of A to G

- Filament
- Overall length
- Centre length
- Lamp base

- Efficacy is a measure of the effectiveness with which a lamp converts electric power into luminous flux, equal to the ratio of flux emitted to power input and expressed in lumens per watt
- Rated life is the average life in hours of a given type of lamp, based on laboratory tests of a representative group under controlled conditions
- Extended-service lamps are designed for reduced energy consumption and a life longer than the conventionally set value for its general class
- Three-way lamp is an incandescent lamp having two filaments so that it can be switched to three successive degrees of illumination

- T bulb: a tubular, quartz bulb for tungsten-halogen lamps
- TB bulb: a quartz bulb for tungsten-halogen lamps similar in shape to the A bulb but having an angular profile
- MR bulb: a multi-faceted reflector bulb for tungsten-halogen lamps, having highly polished reflectors arranged in discrete segments to provide the desired beam spread



Artificial light is natural light that is produced by manufactured elements. The quantity and quality of light produced differ according to the type of lamp used. The light is further modified by the housing that holds and energises the lamp. There are three major types of artificial light sources – incandescent, fluorescent and high-intensity discharge (HID) lamps. For accurate, current data on lamp sizes, wattages, lumen output and average life, consult the lamp manufacturer.

Incandescent Lamps

Incandescent lamps contain a filament that gives off light when heated to incandescence by the passage of an electric current. They provide point sources of light, have low efficacy, render colour well, and are easy to dim with rheostats. The European Union is in the process of phasing out incandescent bulbs due to their low energy efficiency (average efficiency E–G).

- A bulb: standard rounded shape for general-service incandescent lamps
- A/SB bulb: A bulb having a hemispherical, reflective silver bowl opposite the lamp base to decrease glare
- C bulb: cone-shaped bulb for low-wattage, decorative incandescent lamps
- CA bulb: candle-flame shaped bulb for low-wattage, decorative incandescent lamps
- ER bulb: ellipsoidal reflector bulb for incandescent lamps, having a precisely formed internal reflector that collects light and redirects it into a dispersed pattern at some distance in front of the light source
- G bulb: globe-shaped bulb for incandescent lamps, having a low brightness for exposed use
- PAR bulb: parabolic aluminised reflector bulb for incandescent and HID lamps, having a precisely formed internal reflector and a lensed front to provide the desired beam spread
- PS bulb: pear-shaped bulb for large incandescent lamps
- R bulb: reflector bulb for incandescent and HID lamps, having an internal reflective coating and either a clear or frosted glass front to provide the desired beam spread
- S bulb: straight-sided bulb for low-wattage, decorative incandescent lamps

- Tungsten-halogen lamps have a tungsten filament and a quartz bulb containing a small amount of halogen that vaporises on heating and redeposits any evaporated tungsten particles back onto the filament
- IR lamp is a tungsten-halogen lamp having an infrared dichroic coating for reflecting infrared energy back to the filament, raising lamp efficiency and reducing radiant heat in the emitted light beam

Discharge lamps produce light by the discharge of electricity between electrodes in a gas-filled glass enclosure. The two major types of discharge lamps are fluorescent lamps and a variety of high-intensity-discharge lamps.

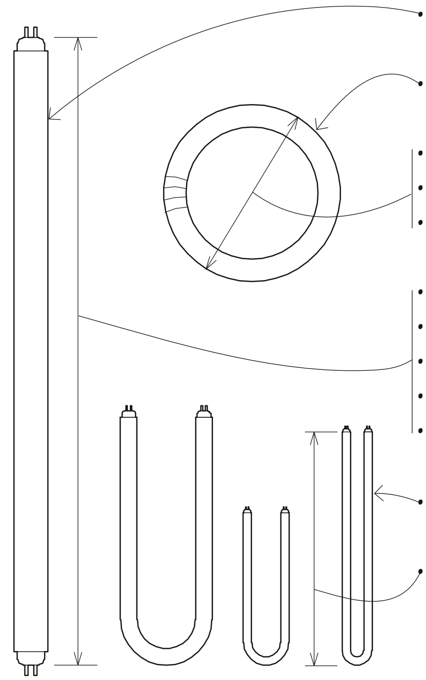
Fluorescent Lamps
Fluorescent lamps are tubular discharge lamps in which light is produced by the fluorescence of phosphors coating the inside of the tube. They provide linear sources of light and have an efficacy of 50–80 lumens per watt. Their ability to render colour varies.

- Ballasts maintain the current through a fluorescent or high-intensity-discharge lamp at the desired constant value
- Pre-heat lamps require a separate starter to pre-heat the cathodes before opening the circuit to the starting voltage
- Rapid-start lamps are designed to operate with a ballast having a low-voltage winding for continuous heating of the cathodes, which allows the lamps to be started more rapidly than a pre-heat lamp
- Instant-start lamps are designed to operate with a ballast having a high-voltage transformer to initiate the arc directly without any pre-heating of the cathodes
- High-output lamps are rapid-start fluorescent lamps designed to operate on a current of 800 milliamperes, resulting in a corresponding increase in luminous flux per unit length of lamp
- Very-high-output lamps are designed to operate on a current of 1500 milliamperes, providing a corresponding increase in luminous flux per unit length of lamp

- Compact fluorescent lamps are any of various small, improved-efficiency fluorescent lamps having a single, double or U-shaped tube, and often an adapter for fitting an incandescent lampholder

High-Intensity Discharge Lamps
High-intensity discharge (HID) lamps are discharge lamps in which a significant amount of light is produced by the discharge of electricity through a metallic vapour in a sealed glass enclosure. HID lamps combine the form of an incandescent lamp with the efficacy of a fluorescent.

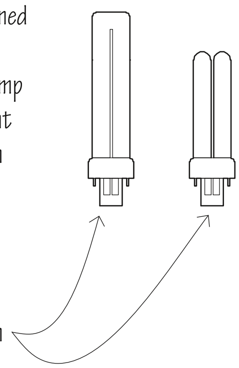
- Mercury lamps produce light by means of an electric discharge in mercury vapour
- Metal-halide lamps are similar in construction to a mercury lamp, but have an arc tube to which various metal halides are added to produce more light and improve colour rendering
- High-pressure sodium (HPS) lamps produce a broad spectrum of golden-white light by means of an electric discharge in sodium vapour

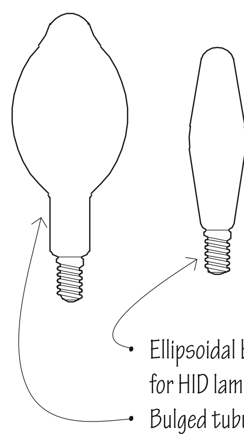


- T bulb: tubular bulb for fluorescent and HID lamps
- Circline lamp: doughnut-shaped fluorescent lamp for circular luminaires
- 210 mm 22W
- 305 mm 32W
- 405 mm 40W

- 455 mm 15W
- 610 mm 20W
- 915 mm 30W
- 1220 mm 40W
- 2440 mm 75W

- U-bent lamp: U-shaped fluorescent lamp for square or rectangular luminaires
- 570 mm 40W





- Ellipsoidal bulb for HID lamps
- Bulged tubular bulb for HID lamps
- HID lamps are also available in B and T shapes

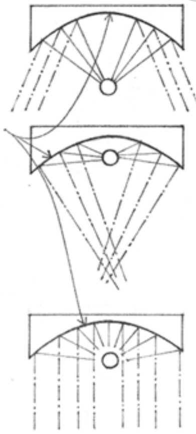
Light and Colour
The spectral distribution of artificial light varies with the type of lamp. For example, an incandescent bulb produces a yellow-white light while a cool-white fluorescent produces a blue-white light. The spectral distribution of a light source is important because if certain wavelengths of colour are missing, then those colours cannot be reflected and will appear to be missing in any surface illuminated by that light.

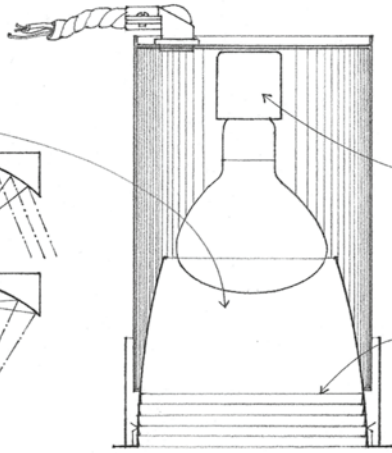
- Colour rendering index is a measure of the ability of an electric lamp to render colour accurately when compared with a reference light source of similar colour temperature. A tungsten lamp operating at a colour temperature of 3200K, noon sunlight having a colour temperature of 4800K, and average daylight having a colour temperature of 7000K, all have an index of 100 and are considered to render colour perfectly

11.40 LUMINAIRES

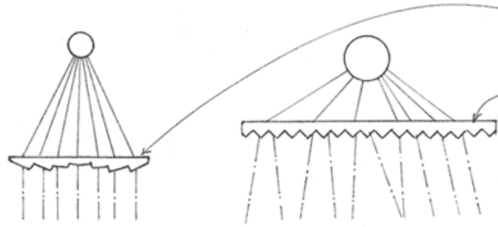
A luminaire, also commonly called a lighting fixture, consists of one or more electric lamps with all of the necessary parts and wiring for positioning and protecting the lamps, connecting the lamps to a power supply and distributing the light.

- Reflectors control the distribution of light emitted by a lamp
- Parabolic reflectors spread, focus or collimate (make parallel) the rays from a light source, depending on the location of the source
- Elliptical reflectors focus the rays from a light source

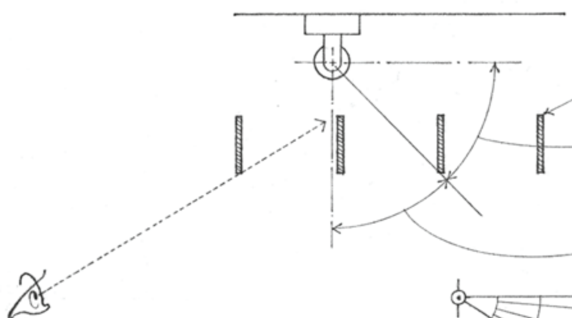




- Lamp holder mechanically supports and makes the electrical contact with a lamp
- Ridged baffles are a series of circular ridges for reducing the brightness of a light source at an aperture

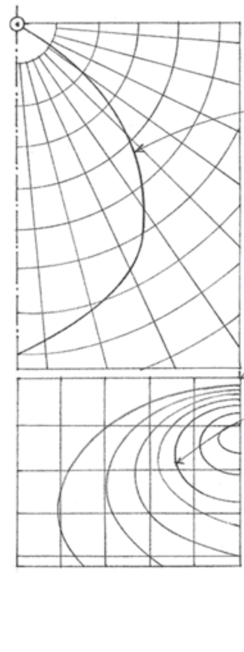


- Lenses of glass or plastic have two opposite surfaces either or both of which are curved. They are used in luminaires to focus, disperse or collimate the emitted light
- Fresnel lenses have concentric, prismatic grooves to concentrate light from a small source
- Prismatic lenses have a multi-faceted surface with parallel prisms to redirect the rays from a light source



- Baffles are louvred devices for shielding a light source from view at certain angles. They may consist of a series of parallel fins or form an eggcrate pattern
- Shielding angle is the angle between a horizontal line through the light centre and the line of sight at which the lamp first becomes visible
- Cut-off angle is the angle between a vertical axis and the line of sight at which the lamp first becomes visible

- In order to evaluate problems with direct glare, the visual comfort probability factor was developed. It rates the likelihood that a lighting system will not cause direct glare, expressed as the percentage of people who may be expected to experience visual comfort when seated in the least-favourable visual position



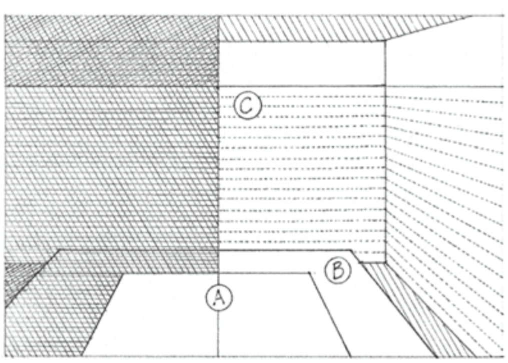
- Light distribution curve is a polar plot of the luminous intensity emitted by a lamp, luminaire or window in a given direction from the centre of the light source, measured in a single plane for a symmetrical light source, and in a parallel, perpendicular and sometimes a 45° plane for an asymmetrical source
- Isochart plots the pattern of illumination produced on a surface by a lamp or luminaire
- Isolux line is a line through all points on a surface where the level of illumination is the same
- Luminaire efficiency is the ratio of luminous flux emitted by a luminaire to the total flux emitted by the lamps in the luminaire

The primary purpose of a lighting system is to provide sufficient illumination for the performance of visual tasks. Recommended levels of illumination for certain tasks specify only the quantity of light to be supplied. How this amount of light is supplied affects how a space is revealed or how an object is seen.

Diffused light emanates from broad or multiple light sources and reflecting surfaces. The flat, fairly uniform illumination minimises contrast and shadows and can make the reading of textures difficult.

Directional light, on the other hand, enhances our perception of shape, form and texture by producing shadows and brightness variations on the surfaces of the objects illuminated.

While diffused lighting is useful for general vision, it can be monotonous. Some directional lighting can help relieve this dullness by providing visual accents, introducing variations in luminance and brightening task surfaces. A mix of both diffused and directional lighting is often desirable and beneficial, especially when a variety of tasks are to be performed.



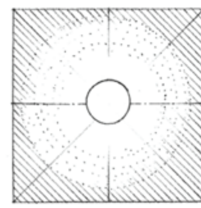
- As noted by CIBSE Guide F, the uniformity over a task area and its surrounding area (A–B) should not be less than 0.8 (ratio of minimum illuminance to average)
- The surrounding area (C) should be illuminated to at least 1/3 of the value of the immediate surrounding area (B)

Artificial-Lighting Uniformity

Recommended Illumination Levels

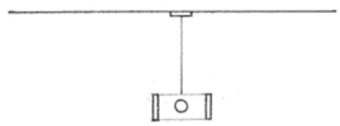
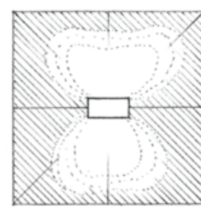
Task Difficulty	Lux
Casual (dining)	200
Ordinary (reading)	500
Moderate (drawing)	750
Difficult (sewing)	2000
Severe (surgery)	3000

Luminaires may be categorised according to the percentage of light emitted above and below a horizontal plane. The actual light distribution of a specific luminaire is determined by the type of lamp, lens and reflector housing used. Consult the luminaire manufacturer for polar curves.

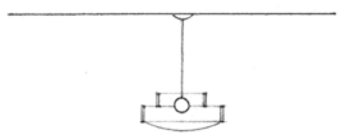
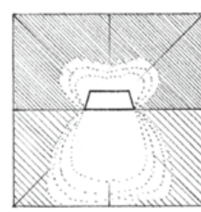
General Diffuse

- 40–60%
- 40–60%

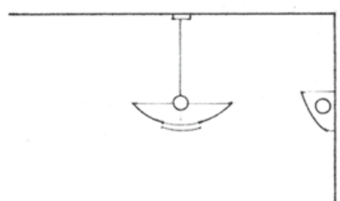
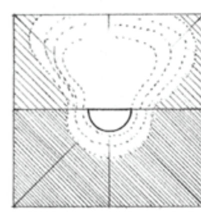
Direct-Indirect

- 40–60%
- 40–60%

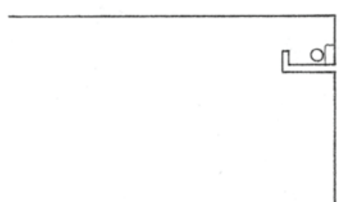
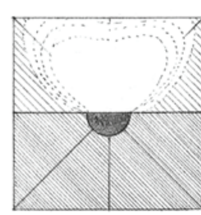
Semi-Direct

- 10–40%
- 60–90%

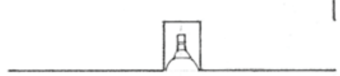
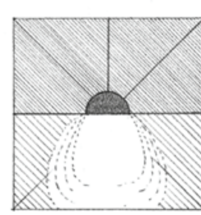
Semi-Indirect

- 60–90%
- 10–40%

Indirect

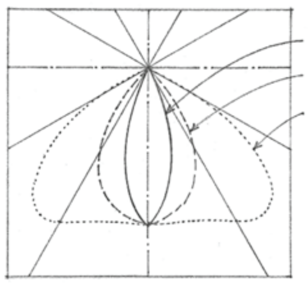
- 90–100%
- 0–10%

Direct

- 0–10%
- 90–100%

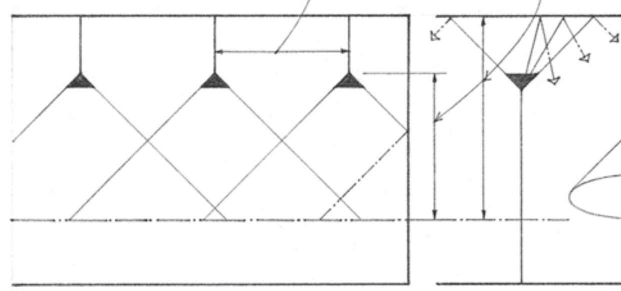
- Beam spread is the angle of a light beam that intersects the light distribution curve at points where the luminous intensity equals a stated percentage of a maximum reference intensity



SC = 0.5
SC = 1.0
SC = 1.5

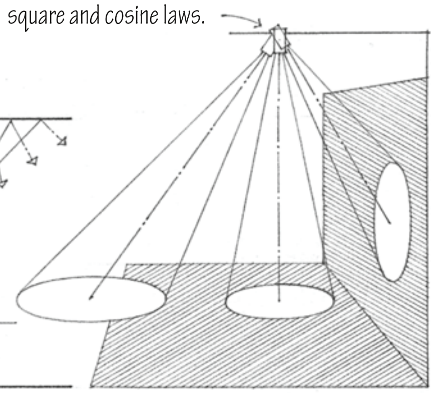
Spacing criteria is a formula for determining how far apart luminaires may be installed for uniform lighting of a surface or area, based on mounting height.

- Spacing criteria (SC) = Spacing (S)/Mounting Height (MH)

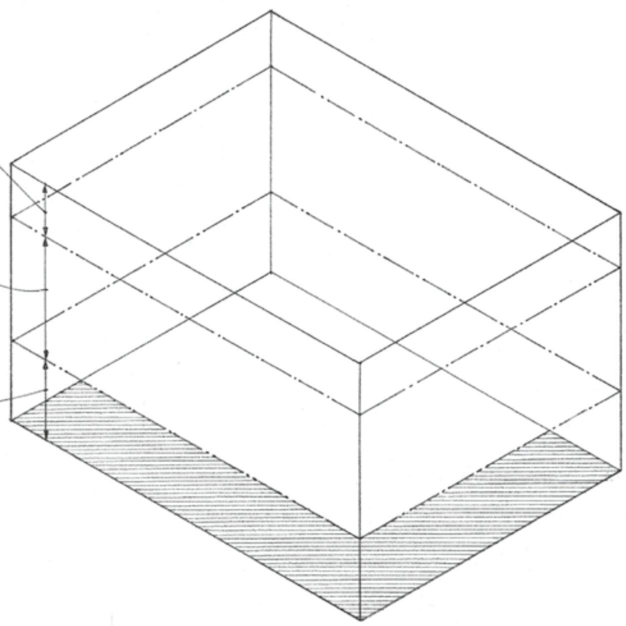


- S/MH ratios are calculated and supplied by the luminaire manufacturer

The point method is a procedure for calculating the illumination produced on a surface by a point source from any angle, based on the inverse square and cosine laws.



- Ceiling cavity is formed by a ceiling, a plane of suspended luminaires and wall surfaces between these two planes
- Room cavity is formed by a plane of luminaires, the work plane and the wall surfaces between these two planes
- Floor cavity is formed by the work plane, the floor and the wall surfaces between these two planes



- Room-cavity ratio is a single number derived from the dimensions of a room cavity for use in determining the coefficient of utilisation
- Coefficient of utilisation (CU) is the ratio of the luminous flux reaching a specified work plane to the total lumen output of a luminaire, taking into account the proportions of a room and the reflectances of its surfaces

- Light loss factor is any of several factors used in calculating the effective illumination provided by a lighting system after a given period of time and under given conditions
- Recoverable light loss factors (RLLF) may be recovered by relamping or maintenance

The lumen method, also called the zonal-cavity method, is a procedure for determining the number and types of lamps, luminaires or windows required to provide a uniform level of illumination on a work plane, taking into account both direct and reflected luminous flux.

- Work plane is the horizontal plane at which work is done and on which illumination is specified and measured, usually assumed to be 800 mm above the floor

- Lamp lumen depreciation represents the decrease in luminous output of a lamp during its operating life, expressed as a percentage of initial lamp lumens
- Luminaire dirt depreciation represents the decrease in luminous output of a luminaire resulting from the accumulation of dirt on its surfaces, expressed as a percentage of the illumination from the luminaire when new or clean
- Room surface dirt depreciation represents the decrease in reflected light resulting from the accumulation of dirt on a room's surfaces, expressed as a percentage of the light reflected from the surfaces when clean
- Non-recoverable light loss factor (NRLLF) is any of several permanent light loss factors that take into account the effects of temperature, voltage drops or surges, ballast variations and partition heights

- Average maintained illuminance = $$\frac{\text{initial lamp lumens* x CU x RLLF x NRLLF}}{\text{work area}}$$

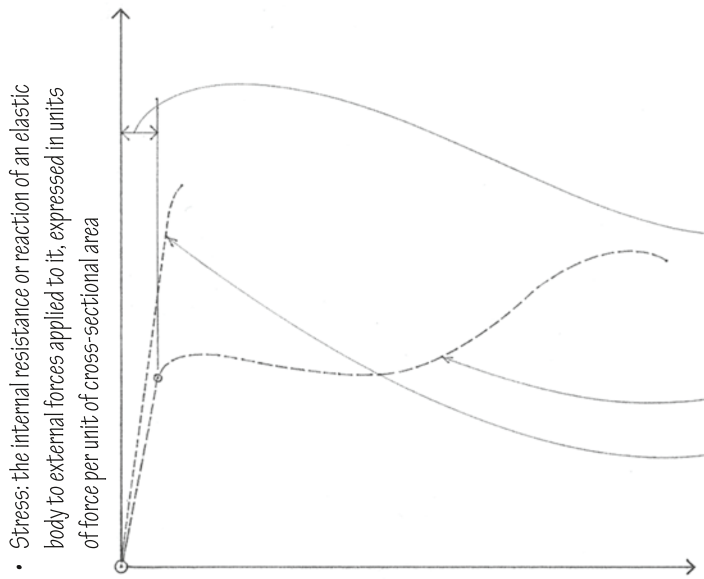
* Initial lamp lumens = lumens per lamp x lamps per luminaire

LEED EQ Credit 6.1: Controllability of Lighting Systems

12

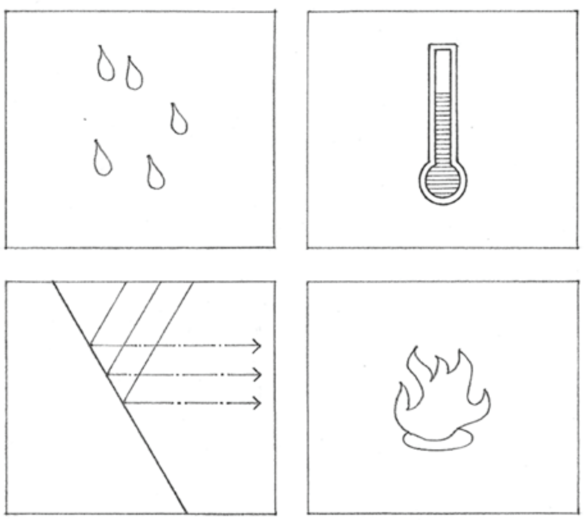
NOTES ON MATERIALS

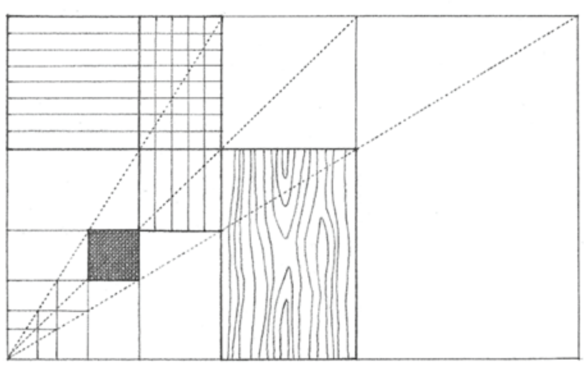
12.02 BUILDING MATERIALS



• Strain: the deformation of a body under the action of an applied force, equal to the ratio of the change in size or shape to the original size or shape of a stressed element

Young's Modulus of Elasticity: rate of stress to strain





This chapter describes the major types of building materials, their physical properties and their uses in building construction. The criteria for selecting and using a building material include those listed below.

- Each material has distinct properties of strength, elasticity and stiffness. The most effective structural materials are those that combine elasticity with stiffness
- Elasticity is the ability of a material to deform under stress – bend, stretch or compress – and return to its original shape when the applied stress is removed. Every material has its elastic limit beyond which it will permanently deform or break
- Materials that undergo plastic deformation before actually breaking are termed ductile
- Brittle materials, on the other hand, have low elastic limits and rupture under loads with little visible deformation. Because brittle materials have less reserve strength than ductile materials, they are not as suitable for structural purposes
- Stiffness is a measure of the force required to push or pull a material to its elastic limit. A material's stiffness, along with the stiffness of its cross-sectional shape, are important factors when considering the relationship between span and deflection under loading

- The dimensional stability of a material as it responds to changes in temperature and moisture content affects the manner in which it is detailed and constructed to join with other materials
- The resistance of a material to water and water vapour is an important consideration when it is exposed to weather or used in moist environments
- The thermal conductivity or resistance of a material must be assessed when it is used in constructing the exterior envelope of a building

- A material's transmission, reflection or absorption of visible light and radiant heat should be evaluated when the material is used to finish the surfaces of a room
- The density or hardness of a material determines its resistance to wear and abrasion, its durability in use and the costs required to maintain it

- The ability of a material to resist combustion, withstand exposure to fire, and not produce smoke and toxic gases, must be evaluated before using it as a structural member or an interior finish

- The colour, texture and scale of a material are obvious considerations in evaluating how it fits within the overall design scheme
- Many building materials are manufactured in standard shapes and sizes. These standard dimensions, however, may vary slightly from one manufacturer to the next. They should be verified in the planning and design phases of a building so that unnecessary cutting or wasting of material can be minimised during construction

The evaluation of building materials should extend beyond their functional, economic and aesthetic aspects and include assessing the environmental consequences associated with their selection and use. This examination, called a life-cycle assessment, encompasses the extraction and processing of raw materials, the manufacturing, packaging and transport of the finished product to the point of use, maintaining the material in use, the possible recycling and reuse of the material, and its final disposal. The focus of the assessment can be on energy or carbon and other greenhouse gas emissions or both. Other environmental impacts such as pollution of water courses should be considered. Various databases are available, some are 'cradle to gate' (assessment from raw material until it leaves the factory gate), some are 'cradle to grave' (full life-cycle assessment).

- Embodied energy includes all of the energy expended during the life cycle of a material

Embodied Energy in Building Materials*

Material	Energy Content MJ/kg
Sand	0.081
Wood	10.00
Aluminium	155.00
Concrete	0.75
Plasterboard	6.75
Brickwork	3.0
Cement	4.5
Glass	15.0
Steel	20.10
Lead	25.21
Copper	42.00

*Selected data from: Hammond and Jones, 2011

- Raw materials
- Energy
- Water

Acquisition of Raw Materials

- What impact does the extraction, mining or harvesting process have on health and the environment?
- Is the material renewable or non-renewable?
- Non-renewable resources include metals and other minerals
- Renewable resources, such as timber, vary in their rate of renewal; their rate of harvest should not exceed their rate of growth

Processing, Manufacturing and Packaging

- How much energy and water is required to process, manufacture and package the material or product?

Transport and Distribution

- Is the material or product available regionally or locally, or does it have to be transported a long distance?

Construction, Use and Maintenance

- Does the material perform its intended function efficiently and effectively?
- How does the material affect the indoor air quality and energy consumption of a building?
- How durable is the material or product and how much maintenance is required for its upkeep?
- What is the material's useful life?

Disposal, Recycling and Reuse

- Usable products

+

- How much waste and how many toxic by-products result from the manufacture and use of the material or product?

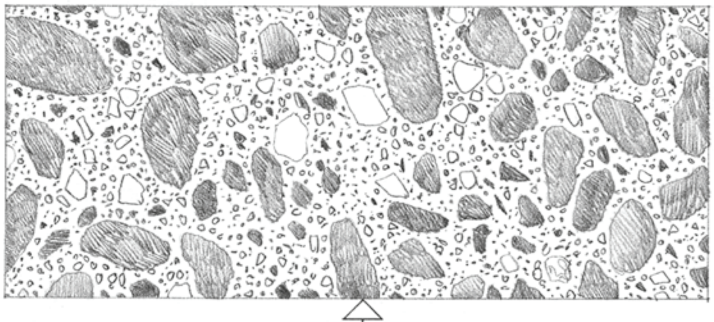
- Waterborne effluents
- Atmospheric emissions
- Solid wastes
- Other environmental releases

Life-Cycle Inventory

Evaluating the choice of a building material is a complex matter that cannot be reduced to a simple formula yielding a precise and valid answer with certainty. For example, using less of a material with a high energy content may be more effective in conserving energy and resources than using more of a lower-energy material. Using a higher-energy material that will last longer and require less maintenance, or one that can be recycled and reused, may be more compelling than using a lower-energy material. The Building Research Establishment's (BRE) Green Guide to Specification takes into account a wide range of environmental impacts and assigns a corresponding rating.

Reduce, reuse and recycle best summarise effective strategies to achieve sustainability.

- Reduce building size through more efficient layout and use of spaces
- Reduce construction waste. BREEAM WST 01: Construction Waste Management; LEED MR Credit 2: Construction Waste Management
- Specify products that use raw materials more efficiently. LEED MR Credit 5: Regional Materials
- Substitute plentiful resources for scarce resources. LEED MR Credit 6: Rapidly Renewable Materials
- Reuse building materials from demolished buildings. BREEAM WST 02: Recycled Aggregates; LEED MR Credit 3: Materials Reuse
- Rehabilitate existing buildings for new uses. LEED MR Credit 1: Building Reuse
- Recycle new products from old. BREEAM MAT 01: Life Cycle Impacts; LEED MR Credit 3: Materials Reuse



Concrete is made by mixing cement and various mineral aggregates with sufficient water to cause the cement to set and bind the entire mass. While concrete is inherently strong in compression, steel reinforcement is required to handle tensile and shear stresses. It is capable of being formed into almost any shape with a variety of surface finishes and textures. In addition, concrete structures are relatively low in cost and inherently fire-resistant. Concrete's liabilities include its weight – 2400 kg/m^3 for normal reinforced concrete – and the forming or moulding process that is required before it can be placed to set and cure, and a significant environmental impact in production.

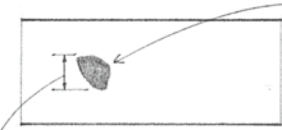
Cement

- Portland cement is a hydraulic cement made by burning a mixture of clay and limestone in a rotary kiln and pulverising the resulting clinker into a very fine powder. EN 197 identifies five main cement types depending on the constituent parts. These are further subdivided depending on variables in the make-up of the cement
- CEM I: normal portland cement
- CEM II: portland-composite cement
- CEM III: blast furnace cement
- CEM IV: pozzolanic cement
- CEM V: composite cement

Cement is further classified according to clinker content, early compressive strength and compressive strength after 28 days. Early strength is indicated by a letter N: normal early strength; or R: high early strength. The strength after 28 days is indicated in MPa with 32.5, 42.5 and 52.5 standard compressive strengths.

Water

- The water used in a concrete mix must be free of organic material, clay and salts; a general criterion is that the water should be fit for drinking
- Cement paste is a mixture of cement and water for coating, setting and binding the aggregate particles together in a concrete mix



- Generally maximum aggregate size is 40 mm but 6–10 or 20 mm aggregates are more common

Lightweight Concrete

- Structural lightweight concrete, made with expanded shale or slate aggregate, has a unit weight from 1362 to 1840 kg/m^3 and compressive strength comparable to that of normal concrete
- Insulating concrete, made with perlite aggregate or a foaming agent, has a unit weight of less than 960 kg/m^3 and low thermal conductivity

Aggregate

- Aggregate refers to any of various inert mineral materials, as sand and gravel, added to a cement paste to make concrete. Because aggregate represents from 60% to 80% of the concrete volume, its properties are important to the strength, weight, fire-resistance and resistance to abrasion of the hardened concrete. Aggregate should be hard, dimensionally stable and free of clay, silt and organic matter that can prevent the cement matrix from binding the particles together
- Fine aggregate consists of sand having a particle size smaller than 6 mm
- Coarse aggregate consists of crushed stone, gravel or blast-furnace slag having a particle size larger than 6 mm
- The maximum size of coarse aggregate in reinforced concrete is limited by the size of the section and the spacing of the reinforcing bars

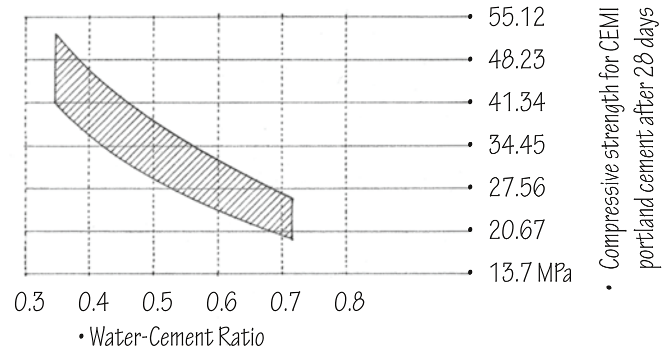
Admixtures

Admixtures may be added to a concrete mix to alter its properties or those of the hardened product.

- Air-entraining agents disperse microscopic, spherical air bubbles in a concrete mix to increase workability to improve resistance of the cured product to the cracking induced by freeze-thaw cycles or the scaling caused by de-icing chemicals, and in larger amounts, to produce lightweight, insulating concrete
- Accelerators hasten the setting and strength development of a concrete mix, while retarders slow the setting of a concrete mix in order to allow more time for placing and working the mix
- Surface-active agents, or surfactants, reduce the surface tension of the mixing water in a concrete mix, thereby facilitating the wetting and penetrating action of the water or aiding in the emulsifying and dispersion of other additives in the mix
- Water-reducing agents, or superplasticisers, reduce the amount of mixing water required for the desired workability of a concrete or mortar mix. Lowering the water-cement ratio in this manner generally results in increased strength
- Colouring agents are pigments or dyes added to a concrete mix to alter or control its colour

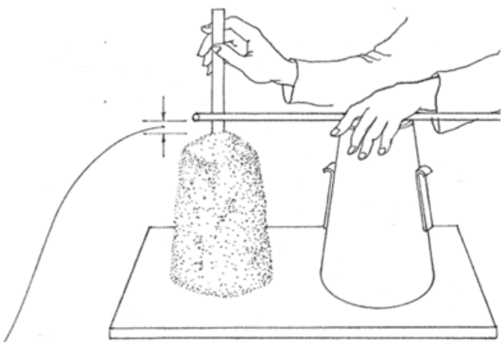
Water-Cement Ratio

Water-cement ratio is the ratio of mixing water to cement in a unit volume of a concrete mix, expressed by weight as a decimal fraction. The water-cement ratio controls the strength, durability and watertightness of hardened concrete. According to Abrams' law, formulated by DA Abrams in 1918 from experiments at the Lewis Institute in Chicago, the compressive strength of concrete is inversely proportional to the ratio of water to cement. If too much water is used, the concrete mix will be weak and porous after curing. If too little water is used, the mix will be dense but difficult to place and work. For most applications, the water-cement ratio should range from 0.40 to 0.60.



Concrete is normally specified according to the compressive strength it will develop within 28 days after placement (7 days for high-early-strength concrete).

- Slump test is a method for determining the consistency and workability of freshly mixed concrete by measuring the slump of a test specimen, expressed as the vertical settling, in mm, of a specimen after it has been placed in a slump cone, tamped in a prescribed manner and the cone is lifted
- Lab-based compressive-strength testing generally uses a 150 x 150 mm cube or 100–300 mm diameter cylinder of concrete samples taken from site and subjected to destructive or non-destructive testing to determine the compressive strength of the material



Steel Reinforcement

Because concrete is relatively weak in tension, reinforcement consisting of steel bars, strands or wires is required to absorb tensile, shearing and sometimes the compressive stresses in a concrete member or structure. Steel reinforcement is also required to tie vertical and horizontal elements, reinforce the edges around openings, minimise shrinkage cracking and control thermal expansion and contraction. All reinforcement should be designed by a suitably qualified engineer.

- Reinforcing bars are steel sections hot-rolled with ribs or other deformations for better mechanical bonding to concrete. The bar number refers to its diameter in millimetres – for example, a 6 bar is 6 mm in diameter.
- Welded-wire fabric consists of a grid of steel wires or bars welded together at all points of intersection. The fabric is designated by the size of the grid in mm followed by a number indicating the wire size; see 3.18 for typical sizes

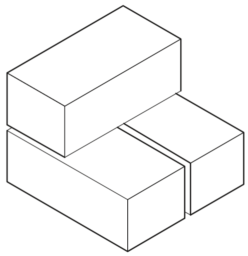
- Reinforcing steel must be protected by the surrounding concrete against corrosion and fire. Minimum requirements for cover and spacing are specified by Eurocode 2: Design of Concrete Structures according to the concrete's exposure and the size of the coarse aggregate and steel used

Standard Reinforcing Bars

Nominal Dimensions

Diameter mm	Cross-Sectional Area mm^2	Mass Per Metre kg
6	28.3	0.222
10	78.5	0.617
12	113	0.888
16	201	1.58
20	314	2.47
25	491	3.85
32	804	6.31
40	1257	9.86

- Common brick, also called building brick, is made for general building purposes and not specially treated for colour and texture
- Facing brick is made of special clays for facing a wall, often treated to produce the desired colour and surface texture
- Engineering bricks offer greater compressive strengths and lower water absorption rates to standard face or common bricks



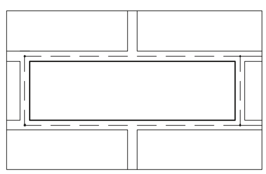
Clay Masonry Units

- Clay masonry units are classified according to their density with LD low density and HD high density

- Low-density units include interlocking thin-joint system clay units with honeycomb structures such as those on page 5.26. During manufacturing, clay is mixed with polystyrene which then vaporises during the firing of the unit

- High-density units include most standard brick units

- Efflorescence is a white, powdery deposit that forms on an exposed masonry or concrete surface, caused by the leaching and crystallisation of soluble salts from within the material. Reducing moisture absorption is the best assurance against efflorescence



- The actual dimensions of brick units vary due to shrinkage during the manufacturing process. The nominal dimensions given on page 5.29 include the thickness of the mortar joints, typically 8–10 mm

- See 5.29 for modular brick coursing and 5.30 for masonry bonding patterns

Masonry refers to building with units of various natural or manufactured products, such as brick, stone or concrete block, usually with the use of mortar as a bonding agent. The modular aspect (ie, uniform sizes and proportional relationships) of unit masonry distinguishes it from most of the other building materials discussed in this chapter. Because unit masonry is structurally most effective in compression, the masonry units should be laid up in such a way that the entire masonry mass acts as an entity.

Brick

Brick is a masonry unit of clay, formed into a rectangular prism while plastic and hardened by firing in a kiln or drying in the sun.

- Soft-mud process refers to forming brick by moulding relatively wet clay having a moisture content of 20–30%
- Sandstruck brick is formed in the soft-mud process with a mould lined with sand to prevent sticking, producing a matte-textured surface. Bricks formed using this process can be more irregular in size than units using alternative methods
- Waterstruck brick is formed in the soft-mud process with a mould lubricated with water to prevent sticking, producing a smooth, dense surface
- Stiff-mud process refers to forming brick and structural tile by extruding stiff but plastic clay having a moisture content of 12–15% through a die and cutting the extrusion to length with wires before firing
- Dry-press process refers to forming brick by moulding relatively dry clay having a moisture content of 5–7% under high pressure, resulting in sharp-edged, smooth-surfaced bricks

Brick Grades

EN 771 designated bricks to one of three grades depending on their durability and suitability to various exposures based on their frost resistance. This designation will determine the suitability of the brick for use in a range of areas within the building:

- F0 Limited Exposure: bricks generally not suitable for external use

- F1 Moderate Resistance: generally not suitable in areas within contact of the ground or areas that may be subject to severe exposure. Can generally be used in most above-ground situations excluding sills or any areas that may be subject to continuous wetting

- F2 Frost Resistance: can be used in most areas of the building including those areas in contact with the ground and subject to continuous wetting

EN 771 further grades bricks according to their soluble salt content which can lead to sulphate attach in certain situation. Category S0 has no requirement and is intended for bricks in protected areas. Categories S1 and S2 set specific requirements.

EN 771: Specification for Masonry Units

Concrete Masonry

Concrete blocks are precast of portland cement, fine aggregate and water, moulded into various shapes to satisfy various construction conditions. The availability of these types varies with locality and manufacturer.

- Autoclaved aerated concrete blocks are a lightweight block offering greater insulating values with a density of 300–1000 kg/m^3
- Lightweight block is made from concrete with a density of 650–1500 kg/m^3
- Dense block is made from concrete with a density from 1800 to 2100 kg/m^3

Compressive Strength

Manufacturers must declare the compressive strength of their concrete blocks expressed as N/mm^2.

- Autoclaved aerated concrete blocks: 3.6–5.2
- Lightweight block: 3.6–7.3
- Dense block: up to 30–40

Thermal Conductivity (W/mK)

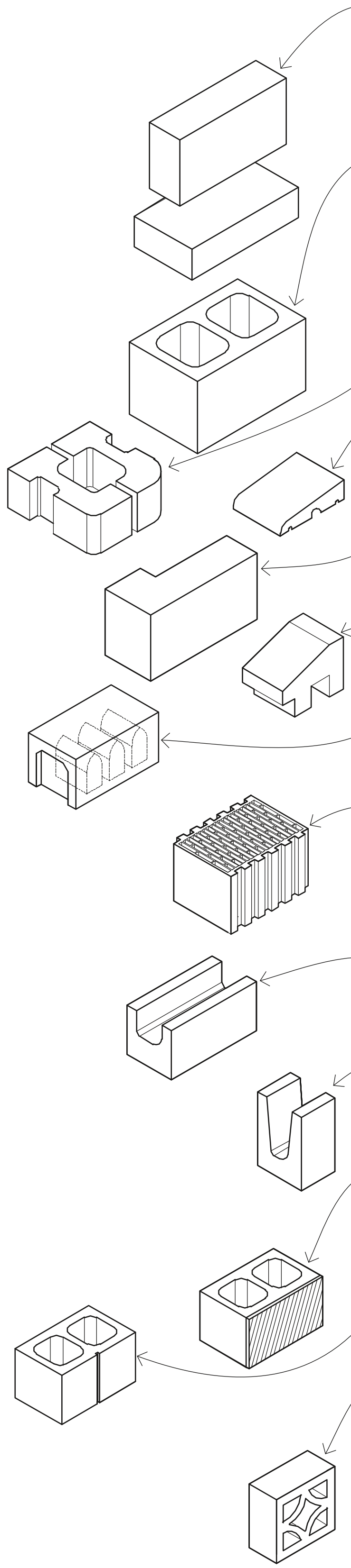
- Autoclaved aerated concrete blocks: 0.12–0.19
- Lightweight block: 0.18–0.25
- Dense block: 1.20–1.70

Groupings

Eurocode 6 categorises masonry units into groups based on the percentage of voids in the unit. Groups I and II cover the most common units in use.

- Group I: solid blocks without major voids
- Group II: blocks incorporating hollow sections such as standard hollow blocks

- Concrete brick or coursing brick is a solid rectangular concrete masonry unit usually identical in size to a modular clay brick



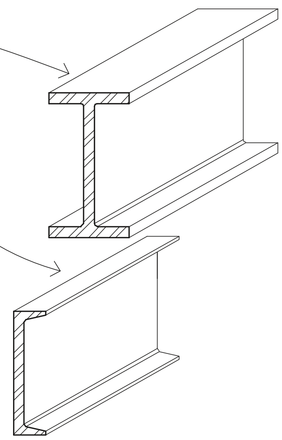
- Standard solid blocks are 100 x 215 x 440 mm and can be laid on edge to create a 100 mm leaf or 'on the flat' to create a 215 mm leaf
- Hollow blocks incorporate hollow sections than can be filled with insulating material or left void. More recently similar shape blocks of insulating material have been used as part of an ICF system; see 5.10
- Pier blocks are used in constructing a plain or reinforced-masonry pier
- Coping blocks are used in constructing the top or finishing course of a masonry wall
- Cavity closer blocks are traditionally used in cavity walls to close the cavity. Insulated cavity closers are now preferable
- Sill blocks have a wash to shed rainwater from a sill
- Cap blocks have a solid top for use as a bearing surface in the finishing course of a foundation wall
- Cellular blocks contain one or more cells that do not fully penetrate the block (unlike hollow blocks). If a fill material is used these blocks can help increase sound absorption
- Bond-beam blocks have a depressed section in which reinforcing steel can be placed for embedment in grout
- Lintel blocks have a U-shaped section in which reinforcing steel can be placed for embedment in grout
- Faced blocks have a special ceramic, glazed or polished face
- Scored blocks have one or more vertical grooves that simulate raked joints
- Screen blocks, used especially in tropical architecture, have a decorative pattern of transverse openings for admitting air and excluding sunlight

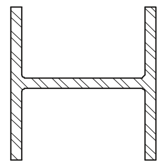
Eurocode 6: Design of Masonry Structures

12.08 STEEL

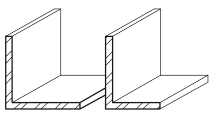
Steel refers to any of various iron-based alloys having a carbon content less than that of cast iron and more than that of wrought iron, and having qualities of strength, hardness and elasticity varying according to composition and heat treatment. Steel is used for light and heavy structural framing, as well as a wide range of building products such as windows, doors, hardware and fastenings. As a structural material, steel combines high strength and stiffness with elasticity. Measured in terms of weight to volume, it is probably the strongest low-cost material available. Although classified as an non-combustible material, steel becomes ductile and loses its strength when subject to temperatures over 520°C. When used in buildings requiring fire-resistant construction, structural steel must be coated, covered or enclosed with fire-resistant materials; see A.10. Because it is normally subject to corrosion, steel must be painted, galvanised or chemically treated for protection against oxidation.

- I-beam
- Channel

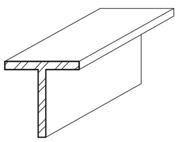




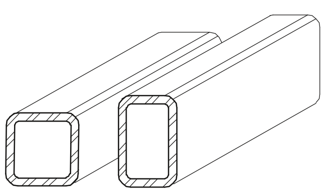
- Equal angle



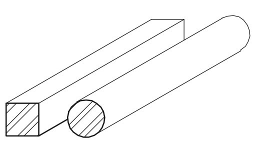
- T shape

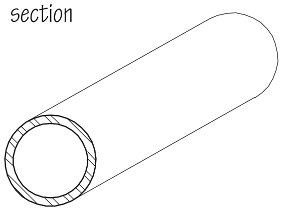


- Square or rectangular hollow section



- Circular hollow section





- Bars (square, round and flat)

Steel Standards

- European Standards (EN 10027) specify steel grades according to minimum yield strength such as S275 which has a corresponding minimum yield strength of 275 MPa

- Mild or soft steel is a low-carbon steel containing from 0.15% to 0.25% carbon
- Medium steel is a carbon steel containing from 0.25% to 0.45% carbon; most structural steel is medium-carbon steel
- Hard steel is a high-carbon steel containing from 0.45% to 0.85% carbon
- Spring steel is a high-carbon steel containing 0.85–1.8% carbon

- Carbon steel is unalloyed steel in which the residual elements, such as carbon, manganese, phosphorus, sulphur and silicon, are controlled. Any increase in carbon content increases the strength and hardness of the steel but reduces its ductility and weldability

- Stainless steel contains a minimum of 10.5% chromium, sometimes with nickel, manganese or molybdenum as additional alloying elements, so as to be highly resistant to corrosion
- High-strength low-alloy steel is a low-carbon steel containing less than 2% alloys in a chemical composition specifically developed for increased strength, ductility and resistance to corrosion
- Weathering steel is a high-strength, low-alloy steel that forms an oxide coating when exposed to rain or moisture in the atmosphere; this coating adheres firmly to the base metal and protects it from further corrosion. Structures using weathering steel should be detailed to prevent the small amounts of oxide carried off by rainwater from staining adjoining materials
- Tungsten steel is an alloy steel containing 10–20% tungsten for increased hardness and heat retention at high temperatures

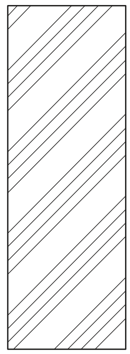
- Alloy steel refers to a carbon steel to which various elements, such as chromium, cobalt, copper, manganese, molybdenum, nickel, tungsten or vanadium, have been added in a sufficient amount to obtain particular physical or chemical properties

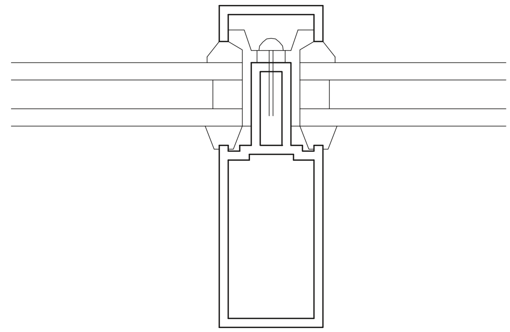
Other ferrous metals used in building construction include:

- Cast iron, a hard, brittle, non-malleable iron-based alloy containing 2.0–4.5% carbon and 0.5–3% silicon, cast in a sand mould and machined to make many building products, such as piping, grating and ornamental work
- Malleable cast iron, which has been annealed by transforming the carbon content into graphite or removing it completely
- Wrought iron, a tough, malleable, relatively soft iron that is readily forged and welded, having a fibrous structure containing approximately 0.1% carbon and a small amount of uniformly distributed slag
- Galvanised iron, which is coated with zinc to prevent rust

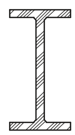
Non-ferrous metals contain no iron. Aluminium, copper and lead are non-ferrous metals commonly used in building construction.

Aluminium is a ductile, malleable, silver-white metallic element that is used in forming many hard, light alloys. Its natural resistance to corrosion is due to the transparent film of oxide that forms on its surface; this oxide coating can be thickened to increase corrosion resistance by an electrical and chemical process known as anodising. During the anodising process, the naturally light, reflective surface of aluminium can be dyed a number of warm, bright colours. Care must be taken to insulate aluminium from contact with other metals to prevent galvanic action. It should also be isolated from alkaline materials such as wet concrete, mortar and plaster.

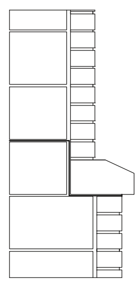




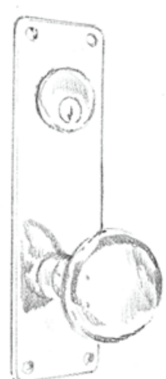
Aluminium is widely used in extruded and sheet forms for secondary building elements such as windows, doors, roofing, flashing, trim and hardware. For use in structural framing, high-strength aluminium alloys are available in shapes similar to those of structural steel. Aluminium sections may be welded, bonded with adhesives or mechanically fastened.



Copper is a ductile, malleable metallic element that is widely used for electrical wiring, water piping and in the manufacture of alloys, such as bronze and brass. Its colour and resistance to corrosion also make it an excellent roofing and flashing material. However, copper will corrode aluminium, steel, stainless steel and zinc. It should be fastened, attached or supported only with copper or carefully selected brass fittings. Contact with red cedar in the presence of moisture will cause premature deterioration of the copper.



Brass refers to any of various alloys consisting essentially of copper and zinc, used for windows, railings, trim and finish hardware. Alloys that are brass by definition may have names that include the word bronze, as architectural bronze.



Lead is a heavy, soft, malleable, bluish-gray metallic element used for flashing, sound isolation and radiation shielding. Although lead is the heaviest of the common metals, its pliability makes it desirable for application over uneven surfaces. Lead dust and vapours are toxic.

Galvanic Action

Galvanic action can occur between two dissimilar metals when enough moisture is present for electric current to flow. This electric current will tend to corrode one metal while plating the other. The severity of the galvanic action depends on how far apart the two metals are on the galvanic series table.

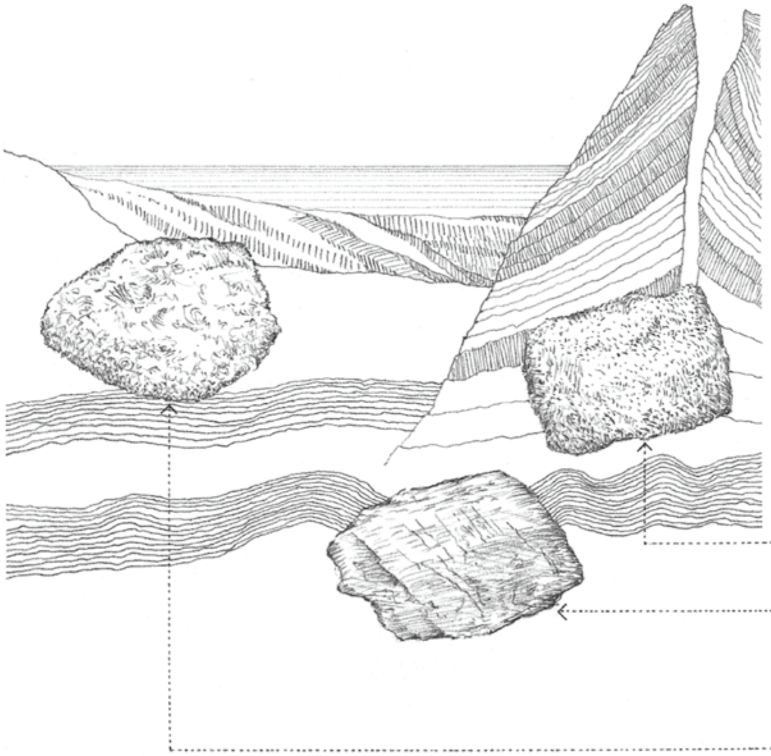
- Gold, platinum — Most noble
- Titanium — Cathode (+)
- Silver
- Stainless steel
- Bronze
- Copper
- Brass
- Nickel
- Tin
- Lead
- Cast iron
- Mild steel
- Aluminium
- Cadmium
- Zinc — Anode (−)
- Magnesium — Least noble

- Current flows from positive to negative

Galvanic Series

- The galvanic series lists metals in order from most noble to least noble
- Noble metals, such as gold and silver, resist oxidation when heated in air and solution by inorganic acids
- The metal that is lower on the list is sacrificial and corrodes when enough moisture is present for electric current to flow
- The further apart two metals are on the list, the more susceptible the least noble one is to corrosive deterioration

12.10 STONE

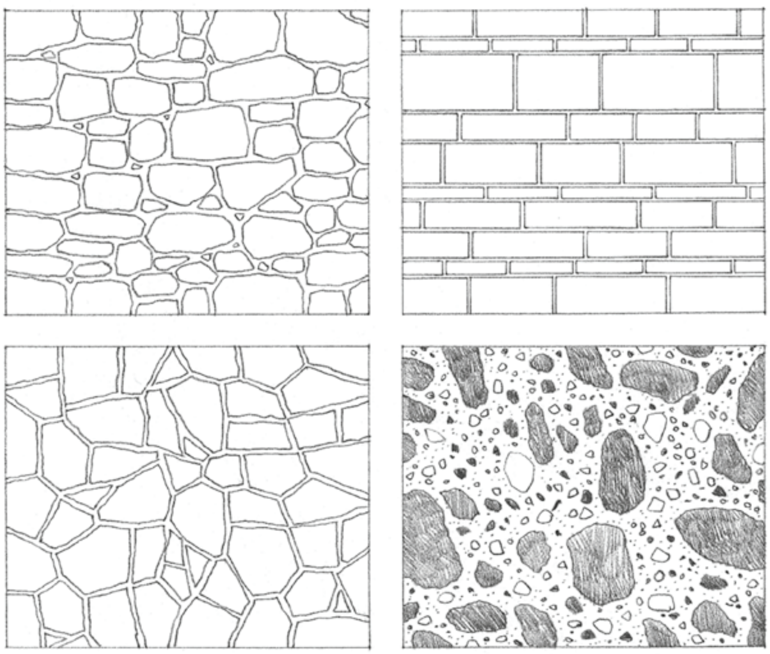


Stone is an aggregate or combination of minerals, each of which is composed of inorganic chemical substances. To qualify as a construction material, stone should have the following qualities:

- Strength: most types of stone have more than adequate compressive strength. The shear strength of stone, however, is usually about $^{1}/_{10}$ of its compressive strength
- Hardness: hardness is important when stone is used for flooring, paving and stair treads
- Durability: resistance to the weathering effects of rain, wind, heat and frost action is necessary for exterior stonework
- Workability: a stone's hardness and grain texture must allow it to be quarried, cut and shaped
- Density: a stone's porosity affects its ability to withstand frost action and staining
- Appearance: appearance factors include colour, grain and texture

Stone may be classified according to geological origin into the following types:

- Igneous rock, such as granite, obsidian and malachite, is formed by the crystallisation of molten magma
- Metamorphic rock, such as marble and slate, has undergone a change in structure, texture or composition due to natural agencies, such as heat and pressure, especially when the rock becomes harder and more crystalline
- Sedimentary rock, such as limestone, sandstone and shale, is formed by the deposition of sediment by glacial action



As a load-bearing wall material, stone is similar to masonry. Although stone masonry is not necessarily uniform in size, it is laid with mortar and used in compression. Almost all stone is adversely affected by sudden changes in temperature and should not be used where a high degree of fire resistance is required.

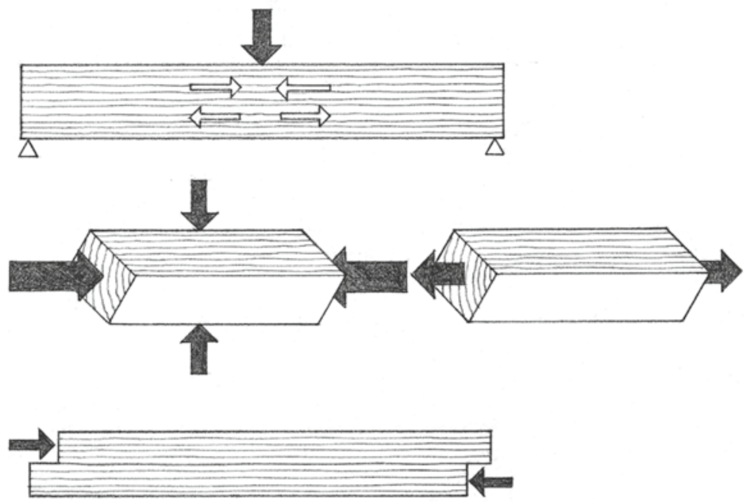
Stone is used in construction in the following forms:

- Rubble consists of rough fragments of broken stone that have at least one good face for exposure in a wall
- Cut stone is quarried and squared stone of a specified size, used commonly for wall panels, cornices, copings, lintels and flooring or coursed walls
- Flagstone refers to flat stone slabs used for flooring and horizontal surfacing
- Crushed stone is used as aggregate in concrete products

- See 5.35 for types of stone masonry

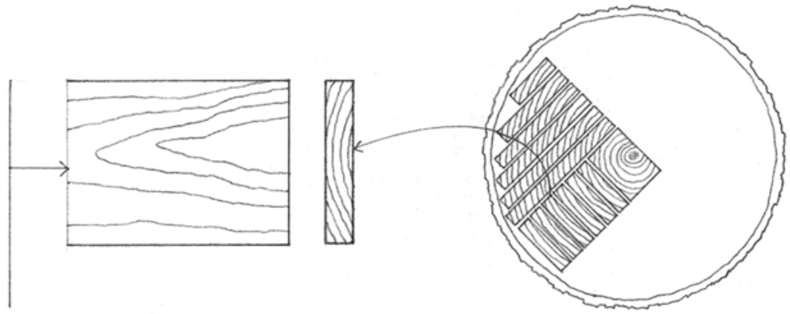
As a construction material, wood is strong, durable, light in weight and easy to work. In addition, it offers natural beauty and warmth to sight and touch. Although it has become necessary to employ conservation measures to ensure a continued supply, wood is still used on construction in many and varied forms.

There are two major classes of wood — softwood and hardwood. These terms are not descriptive of the actual hardness, softness or strength of a wood. Softwood is the wood from any of various predominantly evergreen, coniferous trees, such as pine, fir, hemlock and spruce, used for general construction. Hardwood is the wood from a broad-leaved flowering tree, such as cherry, maple or oak, typically used for flooring, panelling, furniture and interior trim.



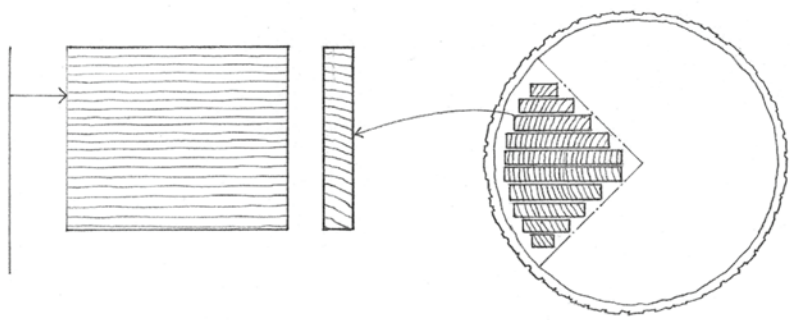
The manner in which a tree grows affects its strength, its susceptibility to expansion and contraction, and its effectiveness as an insulator. Tree growth also affects how pieces of sawn wood may be joined to form the structure and enclosure of a building.

Grain direction is the major determining factor in the use of wood as a structural material. Tensile and compressive forces are best handled by wood in a direction parallel to the grain. Typically, a given piece of wood will withstand 1/3 more force in compression than in tension parallel to its grain. The allowable compressive force perpendicular to its grain is only about 1/5 to 1/2 of the allowable compressive force parallel to the grain. Tensile forces perpendicular to the grain will cause the wood to split. The shear strength of wood is greater across its grain than parallel to the grain. It is therefore more susceptible to horizontal shear than to vertical shear.



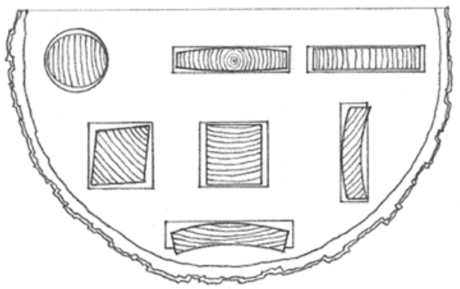
The manner in which timber is cut from a log affects its strength as well as its appearance. Crown-sawing a squared log into boards with evenly spaced parallel cuts results in flat grain timber that:

- May have a variety of noticeable grain patterns
- Tends to twist and cup, and wears unevenly
- Tends to have raised grain
- Shrinks and swells less in thickness, more in width

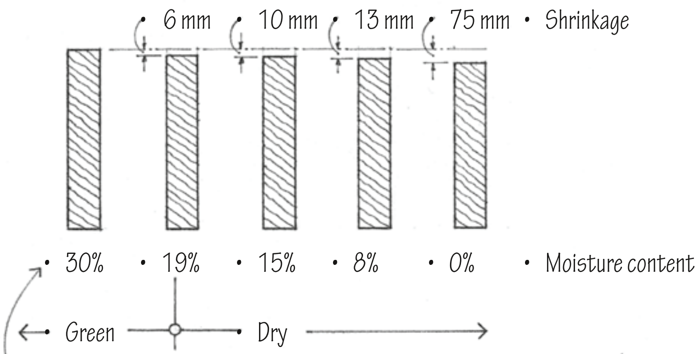


Quarter-sawing logs approximately at right angles to the annual rings results in edge or vertical grain timber that:

- Has more even grain patterns
- Wears more evenly with less raised grain and warping
- Shrinks and swells less in width, more in thickness
- Is less affected by surface checks
- Results in more waste in cutting and is more expensive



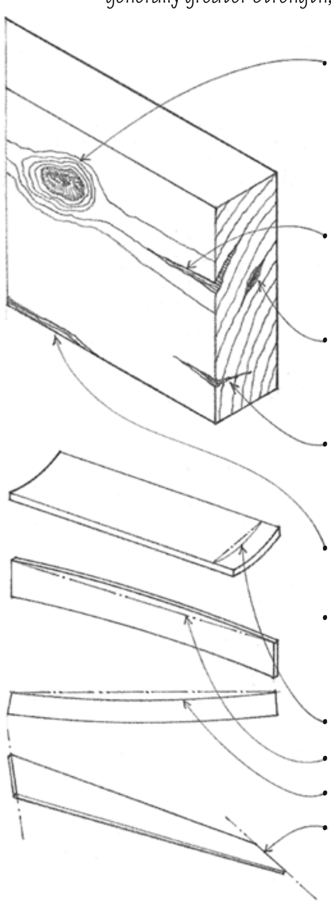
To increase its strength, stability and resistance to fungi, decay and insects, wood is seasoned – dried to reduce its moisture content – by air-drying or kiln-drying under controlled conditions of heat, air circulation and humidity. It is impossible to completely seal a piece of wood to prevent changes in its moisture content. Below a moisture content of about 30%, wood expands as it absorbs moisture and shrinks as it loses moisture. This possibility of shrinkage and swelling must always be taken into account when detailing and constructing wood joints, both in small- and large-scale work.



- Fibre saturation point is the stage at which the cell walls are fully saturated but the cell cavities are void of water, ranging from a moisture content of 25–32% for commonly used species. Further drying results in shrinkage and generally greater strength, stiffness and density of the wood

Shrinkage tangential to the wood grain is usually twice as much as radial shrinkage. Vertical grain timber shrinks uniformly while plain-sawn cuts near a log's perimeter will cup away from the centre. Because the thermal expansion of wood is generally much less than volume changes due to changes in moisture content, moisture content is therefore the controlling factor.

Wood is decay-resistant when its moisture content is under 20%. If installed and maintained below this moisture-content level, wood will usually not rot. Species that are naturally resistant to decay-causing fungi include redwood, cedar, bald cypress, black locust and black walnut. Insect-resistant species include redwood, eastern red cedar and bald cypress.



- Knots are hard nodes of wood that occur where branches join the trunk of a tree, appearing as circular, cross-grained masses in a piece of sawn timber. In the structural grading of a wood piece, knots are restricted by size and location
- Shakes or fissures are separations along the grain of a wood piece, usually between the annual rings, caused by stresses on a tree while standing or during felling
- Resin pockets are well-defined openings between the annual rings of a softwood, containing or having once contained solid or liquid resin
- Checks are lengthwise separations of wood across the annual rings, caused by uneven or rapid shrinkage during the seasoning process
- Wane is the presence of bark or absence of wood at a corner or along an edge of a piece
- Warping is usually caused by uneven drying during the seasoning process or by a change in moisture content
- Cup is a curvature across the face of a wood piece
- Bow is a curvature along the length of a wood piece
- Spring is a curvature along the edge of a wood piece
- Twist results from the turning of the edges of a wood piece in opposite directions

Preservative treatments are available to further protect wood from decay and insect attack. Of these, pressure treatment is the most effective, especially when the wood is in contact with the ground. There are three types of preservatives:

- Water-borne preservatives leave the wood clean, odourless and readily paintable; preservatives do not leach out when exposed to weather
- Oil-borne preservatives may colour the wood, but treated wood is paintable; pentachlorophenol is highly toxic
- Creosote treatment leaves wood with coloured, oily surfaces; odour remains for a long period; used especially in marine and saltwater installations

Defects affect the grading, appearance and use of wood members. They may also affect a wood's strength, depending on their number, size and location. Defects include the natural characteristics of wood, such as knots, shakes and pitch pockets, as well as the effects of manufacturing, such as checks and warping.

European Standards (see EN 14081-1:2005) grade softwood and hardwood timber products according to a series of strength classes designated by the bending strength of the timber. Each grade sets out a number of parameters within each class relating to strength, stiffness and density which must be met.

Softwood strength classes include:
- C14, C16, C18, C20, C22, C24, C27, C30, C35, C40, C45 & C50

Hardwood strength classes include:
- D18, D24, D30, D35, D40, D50, D60 & D70

Timber is specified by species and grade. Each piece of timber is graded for structural strength and appearance. Structural timber may be graded visually by trained inspectors according to quality-reducing characteristics that affect strength, appearance or utility, or by a machine that flexes a test specimen, measures its resistance to bending, calculates its modulus of elasticity, and electronically computes the appropriate stress grade, taking into account such factors as the effects of knots, slope of grain, density and moisture content.

- Each piece of timber has a grademark indicating the assigned stress grade, grading authority, moisture-content condition at time of grading, species or species group and the standard which the timber has been graded against

- A dry-graded timber is one where the mean moisture content of the timber when tested is less than 20%. This offers the advantage of greater dimensional stability as 'wet-graded' timber is likely to shrink to a greater extent

- When timber is intended for use in wet areas or is greater than 100 mm thick it should be wet graded

- Floor joists for domestic use are generally C16 or C24

- Boards: less than 50 mm thick and 50 mm or more wide are generally non-structural and graded for appearance rather than strength and used as siding, sub-flooring and interior trim

- Dimension timber: from 50 to 100 mm thick and 50 mm or more wide, is generally graded for strength rather than appearance, and used for general construction

- Structural timber: dimension timber and timbers graded either by visual inspection or mechanically on the basis of strength and intended use

Wood is a renewable and natural material used at every stage of the construction process. When procuring any wood product for a construction project, care should be taken to ensure it is responsibly and sustainably sourced. As noted by TRADA (www.trada.co.uk), in Europe certified softwoods are readily available and easily sourced, certified topical hardwoods however can be more difficult to source.

There are several third-party certification schemes that guarantee wood is sourced sustainably and legally.
The most widely recognised schemes include:

- The Forest Stewardship Council (FSC)
- The Programme for the Endorsement of Forest Certification (PEFC)
- Canadian Standards Association (CSA)
- Sustainable Forestry Initiative (SFI)

BREEAM MAT 03: Responsible Sourcing of Materials
LEED MR Credit 7: Certified Wood 1

Timber-panel products are less susceptible to shrinking or swelling, require less labour to install, and make more efficient use of wood resources than solid wood products. The following are the major types of timber panel products.

Oriented Strand Board

- Oriented strand board (OSB) is a non-veneered timber-panel product commonly used for sheathing and as sub-flooring, made by bonding layers of long, thin wood strands under heat and pressure using a waterproof adhesive. The surface strands are aligned parallel to the long axis of the panel, making the panel stronger along its length. Boards are available from 6 to 25 mm in thickness

European Standards (EN 300) identify four classes of OSB depending on intended use and the conditions at the location they are to be installed in:

- OSB 1: general purpose for use in internal dry conditions for non-load-bearing uses
- OSB 2: for use in dry conditions and load-bearing uses
- OSB 3: for use in humid conditions and load-bearing uses
- OSB 4 : heavy duty load-bearing and used in humid conditions

Plywood

- Plywood is made by bonding veneers together under heat and pressure, usually with the grain of adjacent plies at right angles to each other and symmetrical about the centre ply

- European Standards (EN 636) classify plywood according to a number of key criteria which must correspond to the markings on the panel, these include:

- Condition of use
  1 – dry condition
  2 – humid condition
  3 – external use

- Intended application
  S – structural
  G – general

- Formaldehyde release class (E1, E2 or external use)
- Bending strength

Medium-Density Fibreboard

MDF consists of softwood and hardwood fibres combined with synthetic resins, water and adhesives to produce a wood-based panel for a range of uses. MDF generally uses urea formaldehyde resins making it unsuitable for external, humid or wet conditions, although alternatives with greater resistance to moisture are available.

MDF is generally classified according to density;

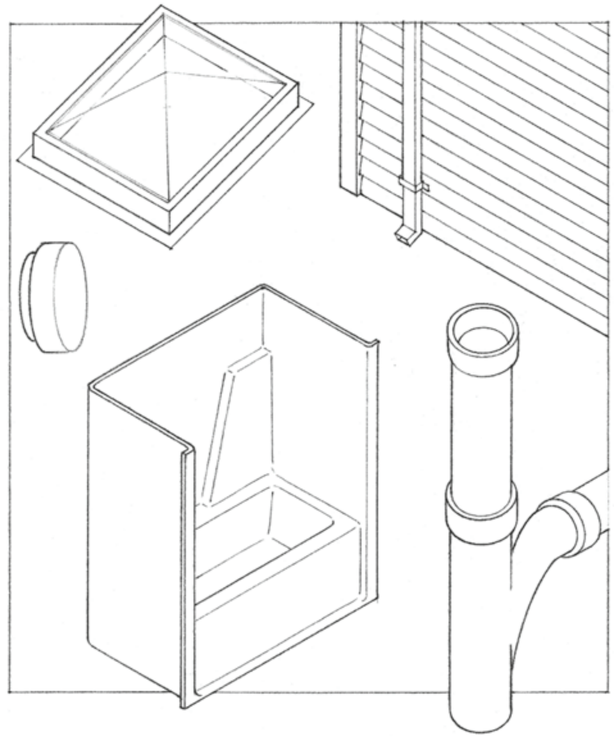
- H – high density: 800kg/m^3 or more
- L – low density: 650kg/m^3 or less
- UL – ultra low density: 550kg/m^3 or less

European Standards (EN 622) identifies four classes of MDF depending on the intended use:

- MDF – general internal non-structural for internal uses
- MDF.H – internal non-structural applications in humid conditions
- MDF.LA – internal structural application in dry conditions
- MDF.HLS – internal structural application in humid conditions

Further classification is made depending on the use of the board designated with a letter representing the use; such as RW for roofs and walls.

Plastics are any of the numerous synthetic or natural organic materials that are mostly thermoplastic or thermosetting polymers of high molecular weight and that can be moulded, extruded or drawn into objects, films or filaments. As a class, plastics are tough, resilient, lightweight and resistant to corrosion and moisture. Many plastics also emit gases harmful to the respiratory system and release toxic fumes when burned.



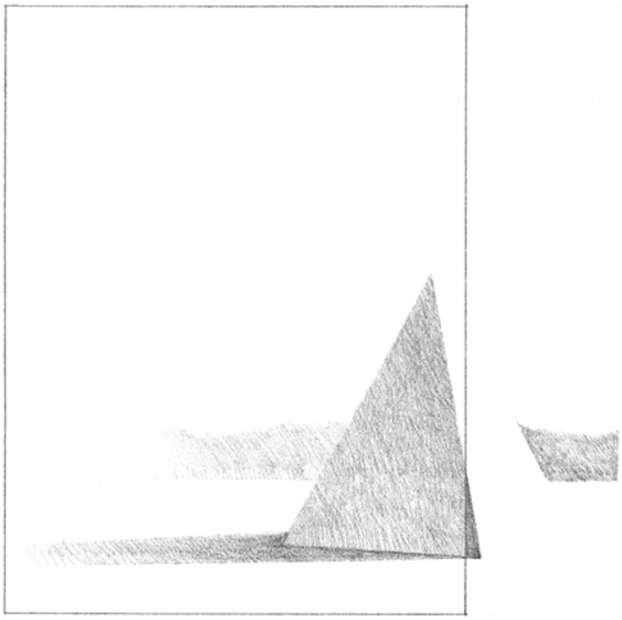
While there are many types of plastics with a wide range of characteristics, they can be divided into two basic categories:

- Thermosetting plastics go through a pliable stage, but once they are set or cured, they become permanently rigid and cannot be softened again by reheating
- Thermoplastics are capable of softening or fusing when heated, without a change in any inherent properties, and of hardening again when cooled

In the table below are listed the plastics that are commonly used in construction and their primary uses.

Thermosetting Plastics	Uses
Epoxies (EP)	Adhesives and surface coatings
Melamines (MF)	High-pressure laminates, moulded products, adhesives, coatings
Phenolics (PF)	Electrical parts, laminates, foam insulation, adhesives, coatings
Polyesters	Fibreglass-reinforced plastics, skylights, plumbing fixtures, films
Polyurethanes (UP)	Foam insulation, sealants, adhesives, coatings
Silicones (SI)	Waterproofing, lubricants, adhesives, synthetic rubber

Thermoplastics	Uses
Acrylonitrile-butadiene-styrene (ABS)	Pipes and pipe fittings, door hardware
Acrylics (Polymethylmethacrylate – PMMA)	Glazing, adhesives, caulking, latex paints
Cellulosics (Cellulose acetate-butyrate – CAB)	Pipes and pipe fittings, adhesives
Nylons (Polyamides – PA)	Synthetic fibres and filaments, hardware
Polycarbonates (PC)	Safety glazing, lighting fixtures, hardware
Polyethylene (PE)	Damp-proofing, vapour retarder, electrical insulation
Polypropylene (PP)	Pipe fittings, electrical insulation, carpeting fibres
Polystyrene (PS)	Lighting fixtures, foam insulation
Vinyls (Polyvinyl chloride – PVC)	Flooring, siding, gutters, window frames, insulation, piping

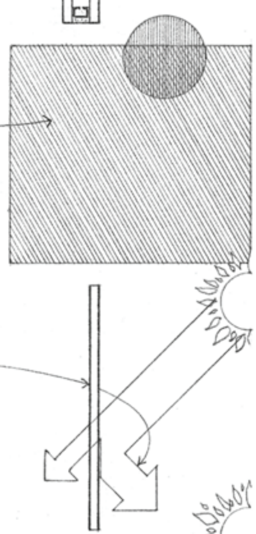


Glass is a hard, brittle, chemically inert substance produced by fusing silica together with a flux and a stabiliser into a mass that cools to a rigid condition without crystallisation. It is used in building construction in various forms. Foamed or cellular glass is used as rigid, vapourproof thermal insulation. Glass fibres are used in textiles and for material reinforcement. In spun form, glass fibres form glass wool, which is used for acoustic and thermal insulation. Glass block is used to control light transmission, glare and solar radiation. Glass, however, is used most commonly to glaze the window and skylight openings of buildings.

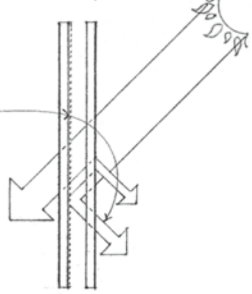
The three major types of flat glass are the following:

- Sheet glass is fabricated by drawing the molten glass from a furnace (drawn glass), or by forming a cylinder, dividing it lengthwise, and flattening it (cylinder glass). The fire-polished surfaces are not perfectly parallel, resulting in some distortion of vision. To minimise this distortion, glass should be glazed with the wave distortion running horizontally
- Plate glass is formed by rolling molten glass into a plate that is subsequently ground and polished after cooling. Plate glass provides virtually clear, undistorted vision
- Float glass is manufactured by pouring molten glass onto a surface of molten tin and allowing it to cool slowly. The resulting flat, parallel surfaces minimise distortion and eliminate the need for grinding and polishing. Float glass is the successor to plate glass and accounts for the majority of flat-glass production

- Glazed units consist of two or more sheets of glass separated by a hermetically sealed air space to provide thermal insulation and restrict condensation; glazed units have a cavity of 6–24 mm. A larger cavity can offer greater sound and thermal insulation



- Solar control glass consists of glazed units with a coating of metal oxide to reduce the amount of heat entering a building. Solar control glass can be used to limit solar gain and the incidence of glare through a heavily glazed facade. The use of solar control glass may reduce the overall daylight factor achieved depending on the daylight transmission of the glazed unit used. Iron oxide gives the glass a pale blue-green tint; cobalt oxide and nickel impart a greyish tint; selenium infuses a bronze tint

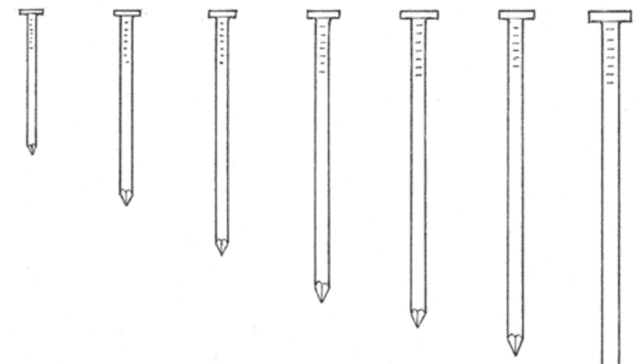


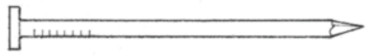
- Low-emissivity (low-e) glass transmits visible light while selectively reflecting the longer wavelengths of radiant heat, produced by depositing a low-e coating either on the glass itself or over a transparent plastic film suspended in the sealed air space of glazed units

Other types of glass include the following:

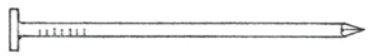
- Annealed glass is cooled slowly to relieve internal stresses
- Heat-strengthened glass is annealed glass that is partially tempered by a process of reheating and sudden cooling. Heat-strengthened glass has about twice the strength of annealed glass of the same thickness
- Tempered glass is annealed glass that is reheated to just below the softening point and then rapidly cooled to induce compressive stresses in the surfaces and edges of the glass and tensile stresses in the interior. Tempered glass has three to five times the resistance of annealed glass to impact and thermal stresses but cannot be altered after fabrication. When fractured, it breaks into relatively harmless pebble-sized particles
- Laminated or safety glass consists of two or more plies of flat glass bonded under heat and pressure to interlayers of polyvinyl butyral resin that retains the fragments if the glass is broken. Security glass is laminated glass that has exceptional tensile and impact strength
- Wired glass is flat or patterned glass with a square or diamond wire mesh embedded within it to prevent shattering in the event of breakage or excessive heat. Wired glass is considered a safety glazing material and may be used to glaze fire doors and windows
- Patterned glass has a linear or geometric surface pattern formed in the rolling process to obscure vision or to diffuse light
- Obscure glass has one or both sides acid-etched or sandblasted to obscure vision. Either process weakens the glass and makes it difficult to clean
- Spandrel glass is an opaque glass for concealing the structural elements in curtain-wall construction, produced by fusing a ceramic frit to the interior surface of tempered or heat-strengthened glass

• 40 mm • 50 mm • 65 mm • 75 mm • 85 mm • 90 mm • 100 mm





- Common nails • For general construction 25–150 mm

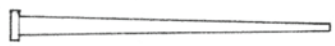


- Box nails • For light construction 25–125 mm

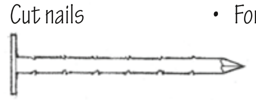
- Casing nails • For finish work 25–125 mm

- Panel pins • For cabinetry 25–100 mm

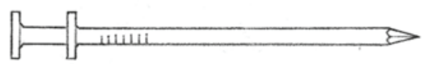
- Flooring nails • For fastening floorboards



- Cut nails • For wood flooring

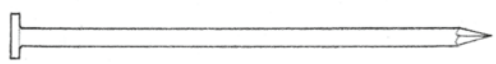


- Roofing nails • For fastening shingles

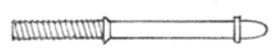


- Duplex-headed nails • For temporary structures

- Masonry nails • For hammering into concrete or masonry

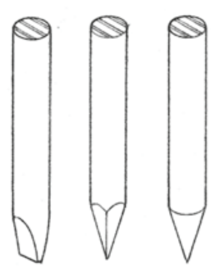


- Spikes • For fastening heavy timbers



- Power-driven studs • For driving into concrete or steel

- Drywall nails • For fixing plasterboard



Nails are straight, slender pieces of metal having one end pointed and the other enlarged and flattened for hammering into wood or other building materials as a fastener.

Material

- Nails are usually of mild steel, but may also be of aluminium, copper, brass, zinc or stainless steel
- Tempered, high-carbon steel nails are used for greater strength in masonry applications
- The type of metal used should be compatible with the materials being secured to avoid loss of holding power and prevent staining of the materials

Length and Diameter of the Shank

- When ordered in bulk nails are specified by the weight of quantity required, type and length x diameter of their shank
- Nails range in length from 25 mm long to about 200 mm long and shank diameters from about 1.2 to 8 mm
- Nail length should be about 3 x thickness of the material being secured
- Large diameter nails are used for heavy work while lighter nails are used for finish work; thinner nails are used for hardwood rather than for softwood

Form of the Shank

- For greater gripping strength, nail shafts may be serrated, barbed, threaded, fluted or twisted
- Nail shafts may be cement-coated for greater resistance to withdrawal, or be zinc-coated for corrosion resistance

Nail Heads

- Flat heads provide the largest amount of contact area and are used when exposure of the heads is acceptable
- The heads of panel pins are only slightly larger than the shaft and may be tapered or cupped. Coupled with a narrow shaft this can reduce the risk of splitting and make the nail less visible
- Double-headed nails are used for easy removal in temporary construction and concrete formwork

Nail Points

- Most nails have diamond-shaped points
- Sharp-pointed nails have greater holding strength but may split some woods; use blunt points for easily split woods

Power-Driven Fasteners

- Pneumatic nailers and staplers, driven by a compressor, are capable of fastening materials to wood, steel or concrete
- Powder-driven fasteners use gunpowder charges to drive a variety of studs into concrete or steel

12.18 SCREWS & BOLTS

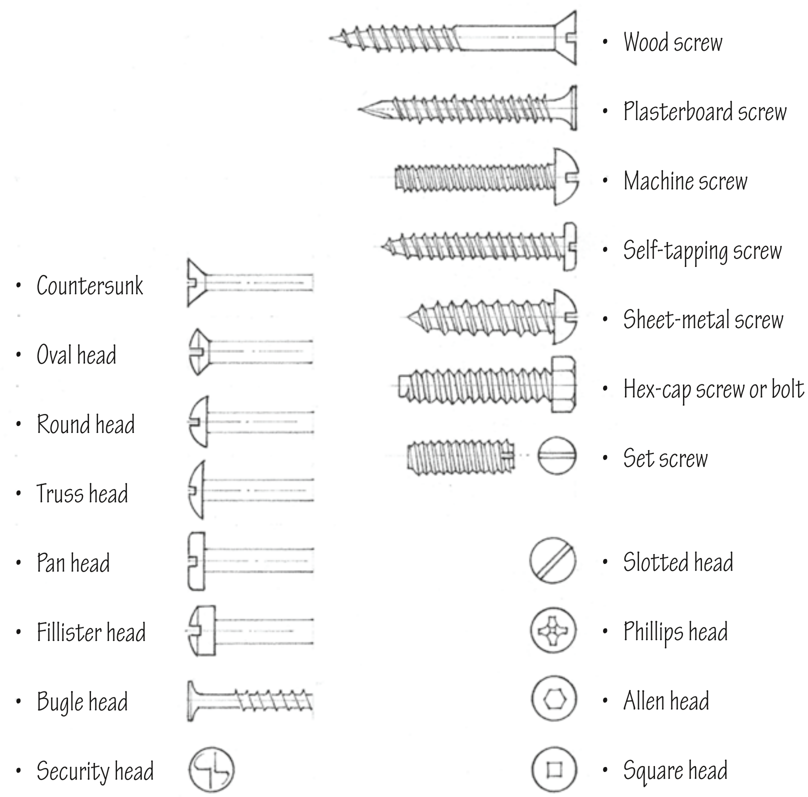
Screws

Screws are metal fasteners having tapered, helically threaded shanks and slotted heads, designed to be driven into wood or the like by turning, as with a screwdriver. Because of their threaded shafts, screws have greater holding power than nails, and are more easily removable. The more threads they have per mm, the greater their gripping strength. Screws are classified by use, type of head, material, length and diameter.

- Material: steel, brass, aluminium, bronze, stainless steel
- Lengths: 12–150 mm
- Diameters: up to 12 mm

The length of a wood screw should be about 3–4 mm less than the combined thickness of the boards being joined, with 1/2 to 2/3 of the screw's length penetrating the base material. Fine-threaded screws are generally used for hardwoods while coarse-threaded ones are used for softwoods.

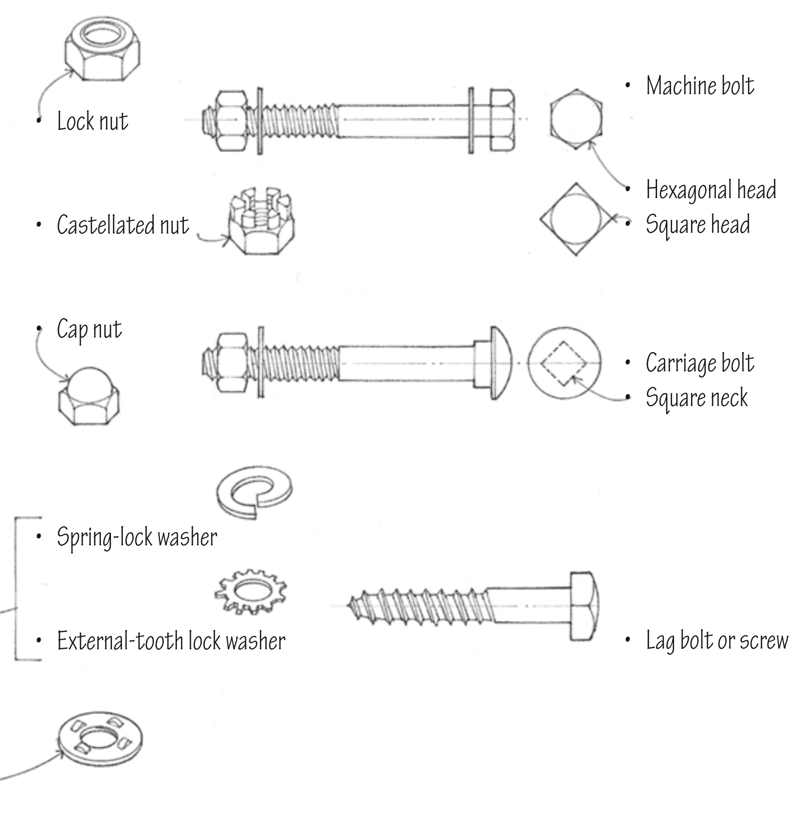
Holes for screws should be pre-drilled and be equal to the base diameter of the threads. Some screws, such as self-tapping and drywall screws, are designed to tap corresponding female threads as they are driven.

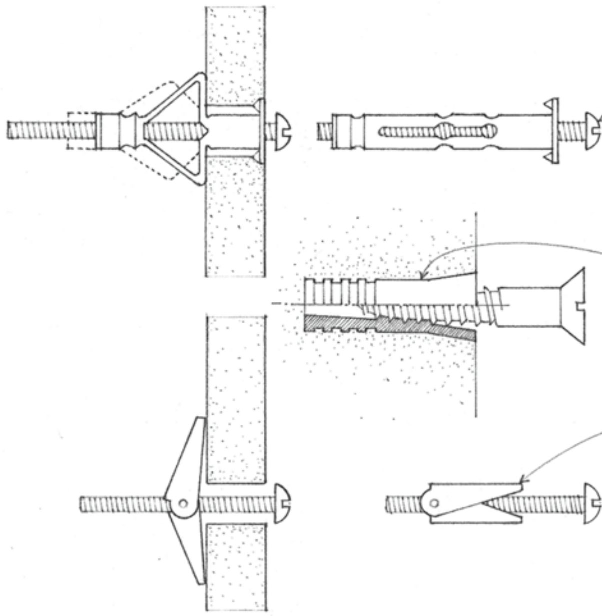


Bolts

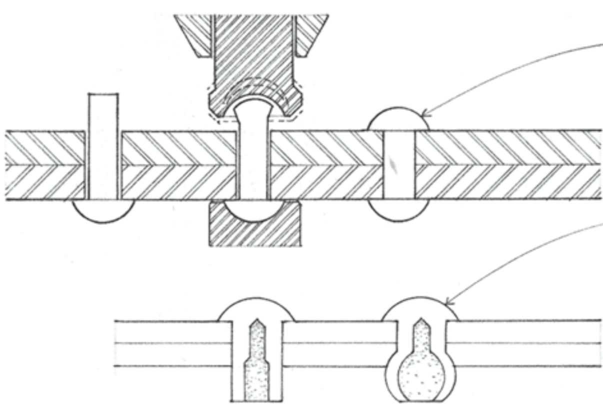
Bolts are threaded metal pins or rods, usually having a head at one end, designed to be inserted through holes in assembled parts and secured by a mating nut. Carriage bolts are used where the head may be inaccessible during tightening. Lag bolts or screws are used in areas inaccessible to the placement of a nut or where an exceptionally long bolt would be needed to penetrate a joint fully.

- Lengths: 75–760 mm
- Diameters: 6–32 mm
- Washers are perforated discs of metal, rubber or plastic, used under the head of a nut or bolt or at a joint to distribute pressure, prevent leakage, relieve friction or insulate incompatible materials
- Lock washers are specially constructed to prevent a nut from shaking loose
- Load-indicating washers have small projections that are progressively flattened as a bolt is tightened, the gap between the head or nut and the washer indicating the tension in the bolt
- High-strength friction grip bolts are widely used for connecting structural steel elements. Their high tensile strength minimises movement in the connected elements





- Expansion bolts are anchor bolts having a split casing that expands mechanically to engage the sides of a hole drilled in masonry or concrete
- Expansion shields are lead or plastic sleeves inserted into a pre-drilled hole and expanded by driving a bolt or screw into it
- Toggle bolts are used to fasten materials to plaster, plasterboard and other thin wall materials. They have two hinged wings that close against a spring when passing through a pre-drilled hole and open as they emerge to engage the inner surface of a hollow wall



- Rivets are metal pins that are used for permanently joining two or more structural steel members by passing a headed shank through a hole in each piece and hammering down the plain end to form a second head. Their use has been largely superseded by the less labour-intensive techniques of bolting or welding
- Explosive rivets, used when a joint is accessible from one side only, have an explosive-filled shank that is detonated by striking the head with a hammer to expand the shank on the far side of the hole

Adhesives

Adhesives are used to secure the surfaces of two materials together. Numerous types of adhesives are available, many of them being tailor-made for use with specific materials and under specified conditions. They may be supplied in the form of a solid, liquid, powder or film; some require a catalyst to activate their adhesive properties. Always follow the manufacturer's recommendations in the use of an adhesive. Important considerations in the selection of an adhesive include:

- Strength: adhesives are usually strongest in resisting tensile and shear stresses and weakest in resisting cleavage or splitting stresses
- Curing or setting time: this ranges from immediate bonding to curing times of up to several days
- Setting temperature range: some adhesives will set at room temperature while others require baking at elevated temperatures
- Method of bonding: some adhesives bond on contact while others require clamping or higher pressures
- Characteristics: adhesives vary in their resistance to water, heat, sunlight and chemicals, as well as their ageing properties

Common types of adhesives:

- Animal or fish glues are primarily for indoor use where temperature and humidity do not vary greatly; they may be weakened by exposure to heat or moisture
- White or polyvinyl glue sets quickly, does not stain and is slightly resilient
- Epoxy resins are extremely strong and may be used to secure both porous and non-porous materials; they may dissolve some plastics. Unlike other adhesives, epoxy glues will set at low temperatures and under wet conditions
- Resorcinol resins are strong, waterproof and durable for outdoor use, but they are flammable and their dark colour may show through paint
- Contact cement forms a bond on contact and therefore does not require clamping. It is generally used to secure large sheet materials such as plastic laminate

The purpose of a coating is to protect, preserve or visually enhance the surface to which it is applied. The principal types of coating are paints, stains and varnishes.

Paints

Paint is a mixture of a solid pigment suspended in a liquid vehicle and applied as a thin, usually opaque coating to a surface for protection and decoration.

- Primers are basecoats applied to a surface to improve the adhesion of subsequent coats of paint or varnish
- Sealers are basecoats applied to a surface to reduce the absorption of subsequent coats of paint or varnish, or to prevent bleeding through the finish coat

- Oil paints utilise a drying oil that oxidises and hardens to form a tough elastic film when exposed in a thin layer to air
- Alkyd paints have as a binder an alkyd resin, such as a chemically modified soy or linseed oil
- Latex paints have as a binder an acrylic resin that coalesces as water evaporates from the emulsion. Latex paints generally offer quicker drying time over alkyd or oil paints and give off less odour due to a lower level of volatile organic compounds (VOC)

- Epoxy paints have an epoxy resin as a binder for increased resistance to abrasion, corrosion and chemicals
- Rust-inhibiting paints and primers are specially formulated with anti-corrosive pigments to prevent or reduce the corrosion of metal surfaces
- Fire-retardant paints are specially formulated with silicone, polyvinyl chloride or other substance to reduce the flame-spread of a combustible material
- Intumescent coatings, when exposed to the heat of a fire, swell to form a thick insulating layer of inert foam that retards flame spread and combustion
- Heat-resistant paints are specially formulated with silicone resins to withstand high temperatures

- Pigment: a finely ground, insoluble substance suspended in a liquid vehicle to impart colour and opacity to the coating

+

- Vehicle: a liquid in which pigment is dispersed before being applied to a surface in order to control consistency, adhesion, gloss and durability

- Binder is the non-volatile part of a paint vehicle that bonds particles of pigment into a cohesive film during the drying process
- Solvent or thinner is the volatile part of a paint vehicle that ensures the desired consistency for application by brush, roller or spray

Stains

Stain is a solution of dye or suspension of pigment in a vehicle, applied to penetrate and colour a wood surface without obscuring the grain.

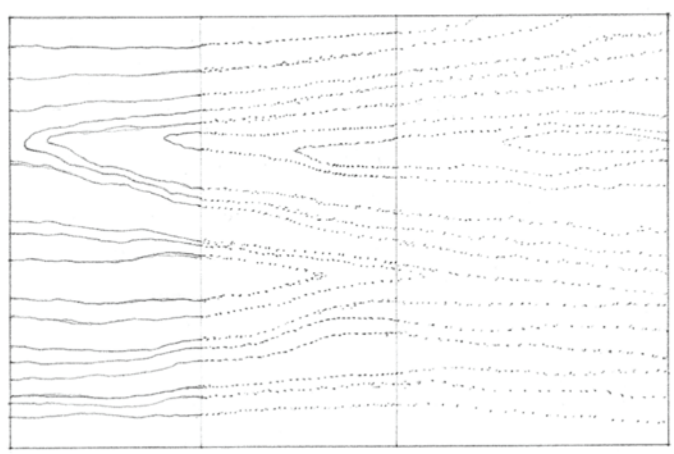
- Penetrating stains permeate a wood surface, leaving a very thin film on the surface
- Water stain is a penetrating stain made by dissolving dye in a water vehicle
- Spirit stain is a penetrating stain made by dissolving dye in an alcohol or spirit vehicle

- Pigmented or opaque stain is an oil stain containing pigments capable of obscuring the grain and texture of a wood surface
- Oil stain is made by dissolving dye or suspending pigment in a drying oil or oil varnish vehicle

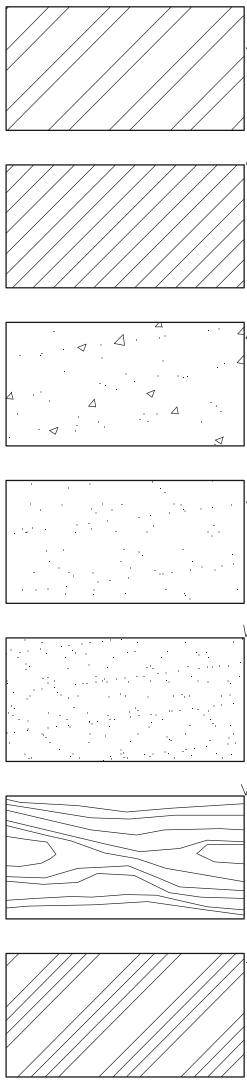
Varnishes

Varnish is a liquid preparation consisting of a resin dissolved in an oil (oil varnish) or in alcohol (spirit varnish), that when spread and allowed to dry forms a hard, lustrous, usually transparent coating.

- Marine varnish is a durable, weather-resistant varnish made from durable resins and linseed or tung oil
- Polyurethane varnish is an exceptionally hard, abrasion-resistant and chemical-resistant varnish made from a plastic resin of the same name
- Lacquer refers to any of various clear or coloured synthetic coatings consisting of nitrocellulose or other cellulose derivative dissolved in a solvent that dries by evaporation to form a high-gloss film
- Shellac is a spirit varnish made by dissolving purified lac flakes in denatured alcohol



All materials to receive paint or other coating must be properly prepared and primed to ensure adhesion of the coating to their surfaces and to maximise the life of the coating. In general, surfaces should be dry and free of contaminants, such as dirt, grease, moisture and mould. The following are recommendations for various materials:



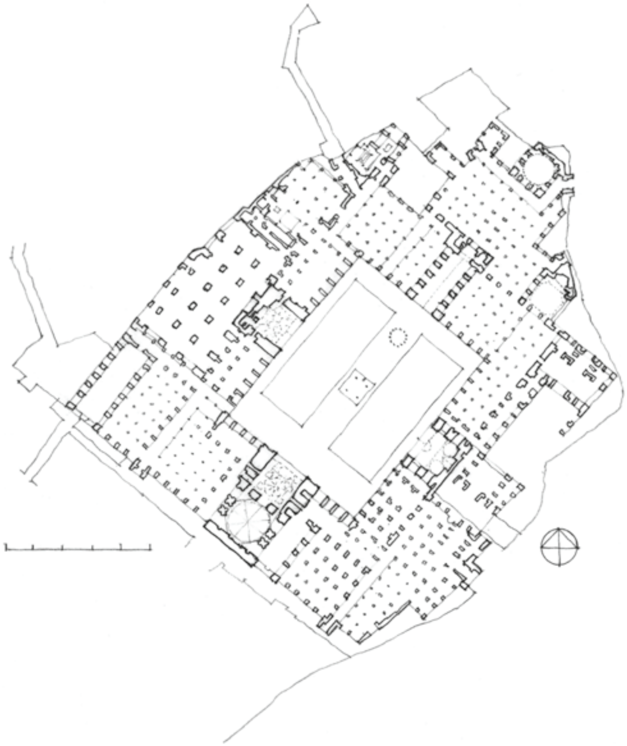
- Brick surface should have dirt, loose mortar, efflorescence and other foreign matter removed by wire brushing, air pressure or steam cleaning. Seal with a latex primer-sealer or a clear silicone water-repellent
- Concrete masonry should be thoroughly dry and free of dirt and loose or excess mortar. Porous surfaces may require a block filler or cement grout primer if the acoustic value of a rough surface is not important
- Concrete surface should be well-cured and free of dirt, form oils and curing compounds. Porous surfaces may require a block filler or cement grout primer. Prime grouted surfaces with a latex, alkyd or oil primer-sealer. Concrete surfaces may also be sealed with a clear silicone water-repellent
- Concrete floors should be free of dirt, wax, grease and oils, and should be etched with a muriatic acid solution to improve adhesion of the coating. Prime with an alkali-resistant coating
- Plasterboard surfaces should be clean and dry. Use a latex primer-sealer to avoid raising the fibres of the paper surface
- Plaster and rendered surfaces should be allowed to dry thoroughly and be completely cured. Prime with a latex, alkyd or oil primer-sealer. Fresh plaster should be primed with an alkali-resistant coating
- Wood should be clean, dry, well-seasoned timber. Knots and pitch stains should be sanded and sealed before priming. Surfaces to be painted should be primed or sealed to stabilise the moisture content of the wood and prevent the absorption of succeeding coats; stains and some paints may be self-priming. All nail holes, cracks and other small holes should be filled after the prime coat
- Old paint surfaces should be clean, dry and roughened by sanding or washing with a detergent solution
- Ferrous metal surfaces should be free of rust, metal burrs and foreign matter. Clean with solvents or by wire brushing, sandblasting, flame cleaning or pickling with acids. Prime with a rust-inhibitive primer
- Galvanised iron should have all grease, residue and corrosion removed with a solvent or chemical wash. Prime with a zinc oxide or portland cement paint. If weathered, galvanised iron should be treated as a ferrous metal

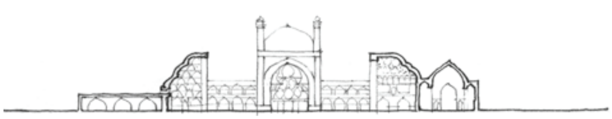
In addition to the surface preparation and priming required, other considerations in the selection of a coating include:

- Compatibility of the coating with the surface to which it is applied
- The method of application and drying time required
- Conditions of use and the required resistance to water, heat, sunlight, temperature variation, mildew, chemicals and physical abrasion
- The possible emission of harmful volatile organic compounds

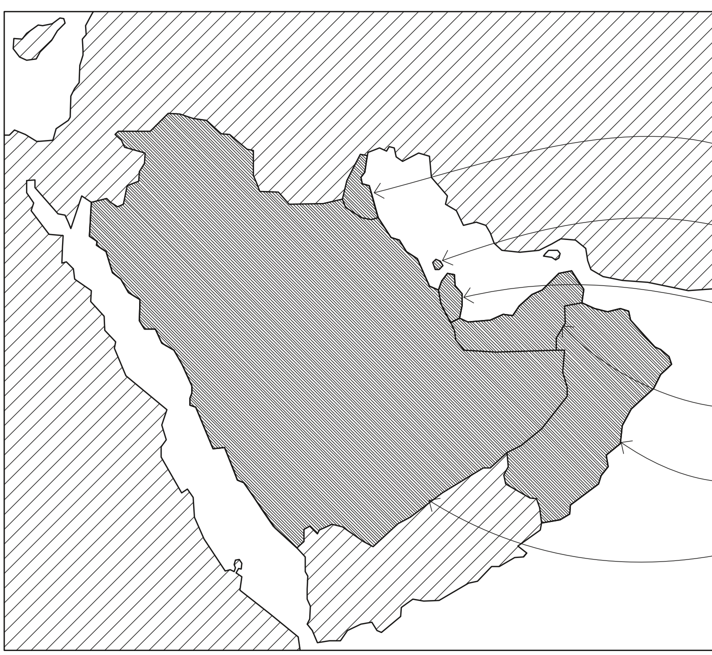
13

CONSTRUCTION IN THE MIDDLE EAST





The Great Mosque of Isfahan, Iran. Extract from Ching et al (2011), *A Global History of Architecture*



Taking in south-western Asia and northern Africa, the Middle East stretches from the Mediterranean Sea to Pakistan across the Arabian Peninsula. Given the geographic, cultural, political and economic diversity of the region, there is a wide range of construction methods used. This chapter aims to consider some of the main factors influencing construction in the Middle East. To provide specific focus, it concentrates on member states of the Gulf Cooperation Council (GCC), which share some similarities in topography, climate, traditional construction techniques and regulatory frameworks.

Traditionally the building regulations and standards in the region were, for historic reasons, influenced by US, UK, Russian or former Soviet Union frameworks. More recently, country- or region-specific regulations have been developed to address the unique conditions in each area. See pages 13.06 & 13.07 for an outline of the current regulatory framework in the region.

Increasingly these regulations are being influenced by a drive towards the delivery of sustainable built environments. As a result, energy use, resource use, materials and waste reduction are of central importance to the emerging regulatory framework.

In this drive towards sustainability, much can be learned from the traditional design and construction methods used in the region. These construction methods react directly to climate and local resource availability and were often, as a result of necessity, low- or zero-energy solutions.

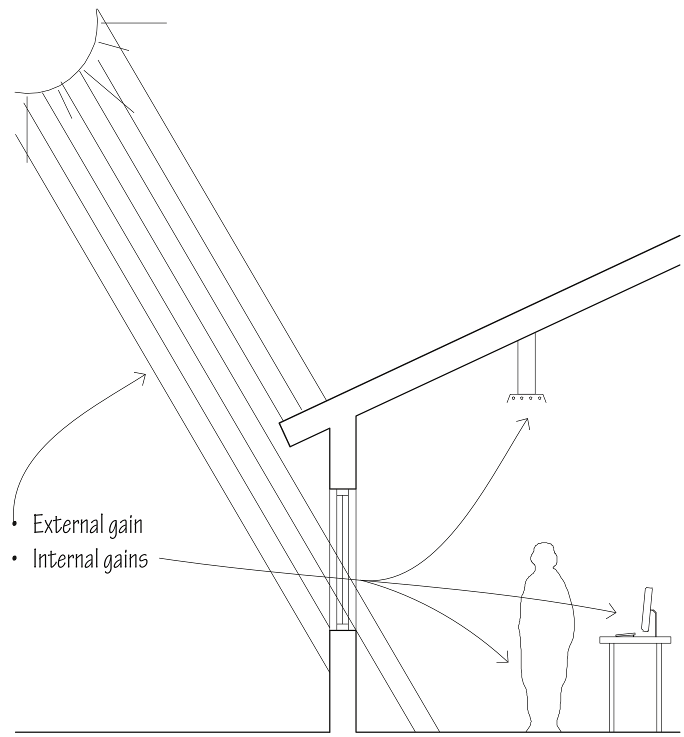
The following pages consider the above issues in greater detail, setting out the interactions between each and the resultant impact on the built environment.

Gulf Cooperation Council Member States:

- Kuwait
- Bahrain
- Qatar
- United Arab Emirates (UAE)
- Oman
- Kingdom of Saudi Arabia

Climate can have a significant impact on the ability of a building to provide comfortable internal environments in an efficient way (see 11.03–11.05), to aid this buildings must be designed in a manner that takes account of the prevailing climatic conditions. A heavily glazed unshaded building in a warm-dry climate will struggle to maintain thermal comfort without the use of artificial cooling. Indeed in some climatic conditions, it may not be possible to provide certain building types where thermal comfort can be maintained without comfort cooling. An appreciation and understanding of the climate a building operates in can significantly reduce the need for energy intensive heating and cooling. Many of the strategies discussed below are reflected in the traditional construction methods of the Middle East.

Country	Temperature (daily mean) Jan °C	July °C	Rainfall mm/yr
Bahrain	17	34	70
Kingdom of Saudi Arabia	14	36	75
Kuwait	14	37	105
Oman	22	34	95
Qatar	18	34	70
UAE	18	35	105



Cooling – External Gains/Internal Gains

Where a building is likely to require artificial cooling, great care must be taken to avoid unnecessary internal gains (such as heat gains from old lighting or computer systems or over occupancy) and external gains from solar radiation. A number of strategies can help to achieve this:

- Provide appropriate solar shading
- Reduce the ratio of glazed solid elements in the building fabric
- Locate glazed openings away from direct sunlight
- Specify efficient lighting systems or upgrade existing systems
- In large commercial buildings and industrial buildings consider the impact of gains from equipment

Water

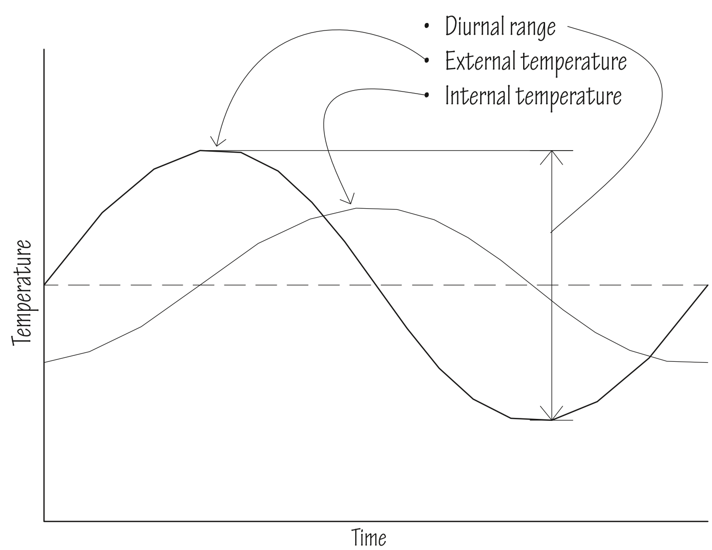
In a location with low relative humidity, where water readily evaporates, introducing water features near to or in a building or indeed introducing water directly into the incoming ventilation air can help to cool a space. When water evaporates or changes state from a liquid to a gas, an energy exchange must take place, it is this energy exchange that can help to cool a space.

Wind

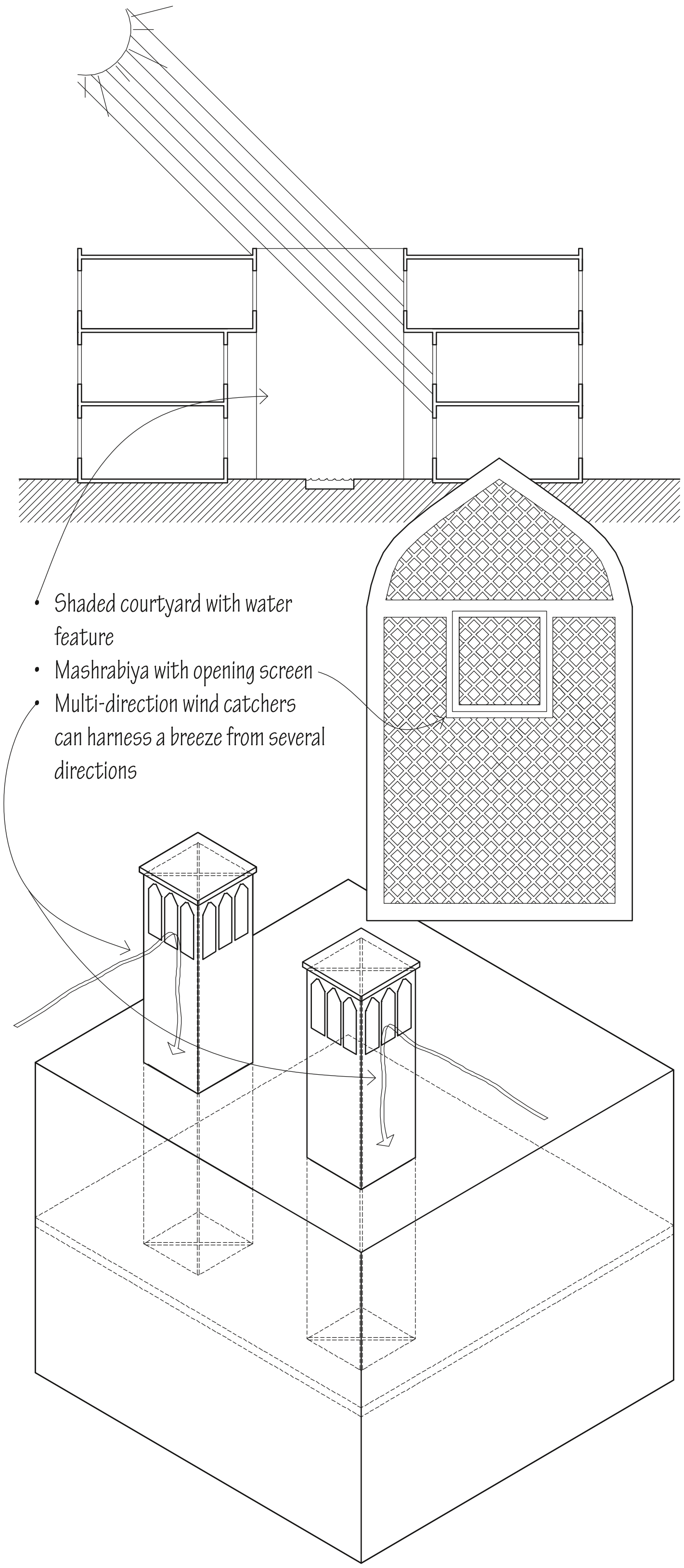
The prevailing wind can be used to aid comfort cooling within a building by orientating ventilation openings in the appropriate direction. This approach aims to replace the air in a space, warmed by internal gains, with cooler outside air (assuming outside air is sufficiently cool) driven by the pressure difference created by prevailing winds. In coastal locations or used in conjunction with a water feature, this cooling effect can be further enhanced by the use of evaporative cooling.

Diurnal Temperature

The diurnal temperature range refers to the extremes in temperature experienced in a particular location over a typical day. The bigger the gap between the highest daily temperature and the lowest daily temperature, the bigger the diurnal temperature range. Combined with high levels of thermal mass, this can be used to utilise a night-time cooling strategy where heat gains from the day, stored in the building's mass, are purged by cool night-time air. Such a strategy is sometimes referred to as free cooling. In Abu Dhabi (UAE), the diurnal temperature swing in summer can be 15°C.



13.04 TRADITIONAL CONSTRUCTION AND DESIGN



Traditionally, construction methods make use of materials that are available locally and use design strategies handed down through generations, These design strategies are likely to have evolved from necessity to react to the prevailing climatic conditions. Historically, and indeed to this day, in many regions the energy needed to artificially heat or cool a building may not be freely available. As such the building fabric can be viewed as a climatic filter. In cool or temperate climates, it must act to hold heat in, in a compact form. In hot and arid climates like many of those in the Middle East, external heat gains must be excluded from the building and heat in the building stored in thermal mass, again a compact form is often used. In hot and humid climates buildings must allow for high levels of shade and be open in form to allow for high levels of ventilation. A number of traditional design solutions widely used in the Middle East are outlined below.

Building Orientation & Shape

- Compact buildings
- Often with shaded internal courtyards

Earth Buildings

- Widely available construction material
- High levels of thermal mass to absorb heat from the day
- Deep window reveals to minimise solar gains

Evaporative Cooling

- Water features encourage evaporation in dry climates
- Used to cool ventilation air

Shading

- Minimises direct solar gains
- Often in the form of narrow streets between buildings
- Shaded transition zones can be introduced
- Can be combined with a range of design strategies

Courtyards

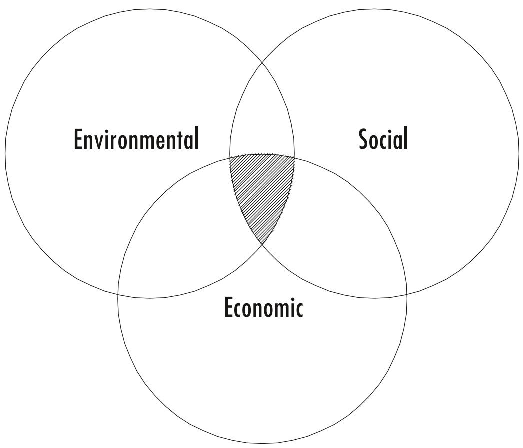
- Shaded courtyards provide cool ventilation air
- Combined with a water feature can aid evaporative cooling

Mashrabiya

- Screen of timber latticework
- Provides shading while allowing for ventilation
- Sometimes in a projecting bay

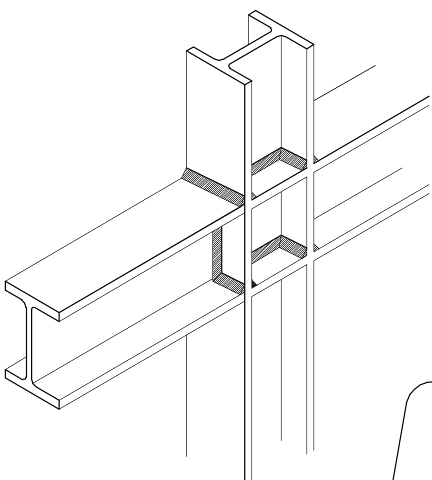
Wind Catchers

- Used to drive natural ventilation
- Draws cool air above ground level into the building
- In regions with a high diurnal range can be used in conjunction with thermally massive construction (earth buildings) to cool the building overnight



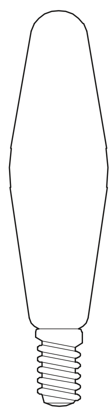
The requirement for buildings increasingly to be designed, constructed, maintained and operated in a sustainable manner has had a significant impact on construction practices in the Middle East. Such requirements in a region with a relatively extreme climate present a particular set of challenges but also opportunities not seen in other regions of the world. The configuration and orientation of a building along with the quality of construction and workmanship and the manner in which the building will be maintained and operated require the building to be considered in a holistic, whole-life manner. Generally, with new-build construction a fabric-first approach should be favoured.

- Configure the building and fabric to minimise unwanted heat gains
- Select appropriate, efficient and adaptable building services
- Consider the appropriate use of renewable-energy technologies

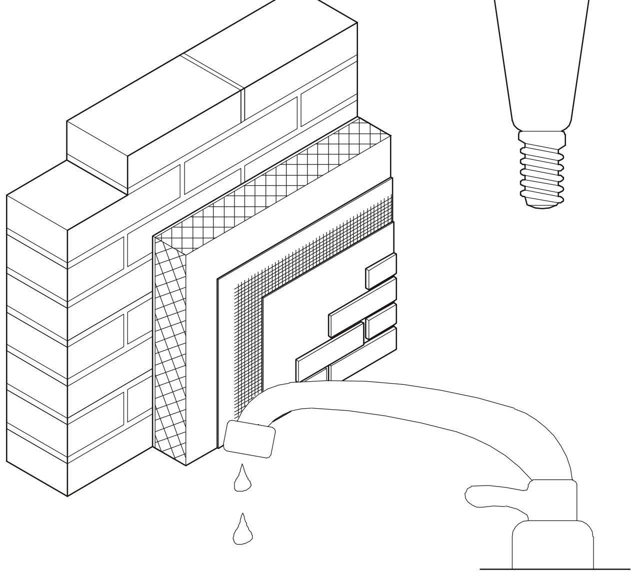


The quality of workmanship during the construction phase can have a significant impact on the overall performance of a building. Indeed poor-quality workmanship can often result in an energy performance gap between the design estimate and actual in-use performance. To ensure high-quality workmanship a number of strategies can be adopted.

- Introduce high levels of prefabrication to control workmanship
- Consider sequencing in relation to key aspects such as airtightness
- Work with the construction team to ensure awareness of the end goal and the impact of workmanship
- Introduce systematic checks and tests such as airtightness testing and thermal imaging surveys during the construction phase



Occupants and occupant behaviour can have a significant impact on the in-use performance of a building. With this in mind maintenance and operational issues should be considered early in the design process. A building may be well designed and constructed but, if occupants do not understand the design intention, building performance can be disappointing.



Energy
- Consider the items that consume the largest amounts of energy in the building and address this first
- Ensure all systems are fully commissioned to ensure efficent performance
- Consider renewable sources of energy

Materials
- Consider embodied energy; see 12.03
- Some materials that have high embodied energy may have secondary benefits justifying their use (such as the thermal mass of concrete)

Water
- Where annual rainfall is low, use efficient fixtures and fittings to minimise water use

Waste
- Separate waste streams to allow for recycling

International Standards

Historically the regulatory framework in the Middle East has been widely influenced by the regulations of the UK, Germany, the USA and Russia. As a result a wide range of regulations exist and are applied on the construction projects in the region.

British Standards

Produced by the British Standards Institute (BSI), British Standards cover a wide range of areas. They are technical standards that are largely referenced in building regulations.

- Part
- Number
- Year

• BS 8103-1:2011

German DIN Standards

The German Institute for Standardization produces a wide range of standards for use in Germany, although many have been adopted in other parts of Europe and indeed globally.

- DIN 4074-2 Building Timber for Wood Building Components; Quality Conditions for Building Logs (Softwood)
- DIN 4108-2 Thermal Protection and Energy Economy in Buildings – Part 2: Minimum Requirements

International Building Codes®

Since the early part of the last century, three major model codes have been developed for use in various parts of the US by the Building Officials and Code Administrators International, Inc (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Conference (SBCC). In 1994, these model-code groups merged to form the International Code Council (ICC) with the goal of developing a comprehensive and coordinated set of national model codes. In 2000, the ICC published the first edition of the *International Building Code®* (IBC).

Russian Federation

The national regulations and standards (similar to those set out above) of the Russian Federation are applied in a wide range of regions. SNiP indicates that the code relates to construction codes and regulations:

- SNiP 23.01.99: Building Climatology. Construction Norms and Regulations
- SNiP 2.03.01-84: Concrete and Concrete Reinforced Structures

GCC Region Specific Standards

In recent years a number of countries and regions have developed their own regulations. Although the regulations may be influenced by those outlined in the preceding paragraphs, they react to the specific requirements of the areas in question, taking into account the construction methods used, climate and traditions. Increasingly the emerging standards are being driven by a focus on the delivery of sustainable built environments. The following paragraphs consider the origins of some of the emerging standards, codes and regulations.

Bahrain

The new environmentally focused building codes for Bahrain are due to come into force in 2013. The codes aim to ensure the use of efficient building services while optimising the use of natural daylighting and the introduction of high levels of planting.

Qatar National Construction Standards

The Qatar National Construction Standards (QCS) address a wide range of issues relating to the construction process, workmanship and materials. They have been developed by the Qatar General Organization for Standards and Metrology and were revised in 2010 to place further emphasis on health and safety and environmental issues; see 13.07 for details of the Qatar Sustainability Assessment System.

The Abu Dhabi Building Code

The Department of Municipal Affairs in the Emirate of Abu Dhabi has adopted the ICC International Building Codes® which is used in conjunction with the Pearl Rating System; see 13.07.

Saudi Building Code

The building codes of the Kingdom of Saudi Arabia like those of Abu Dhabi are based on the ICC International Building Codes®.

Unified Building Code

The Gulf Cooperation Council (GCC) has been working to develop a unified construction code and environmental assessment methods.

Both BREEAM® and LEED® (see 1.05 & 1.06) have been widely applied in the Middle East. The BREEAM International Standard has been used in Qatar and allows for tailoring to the local conditions. With the emerging regulations in the region increasingly focused on sustainability, region-specific environmental assessment methodologies have also started to emerge.

Pearl Rating System

Developed by the Abu Dhabi Urban Planning Council under the Estidama initiative this assessment method aims to promote the adaptation of sustainable practices in the Emirate of Abu Dhabi. The rating system is similar in structure to that of BREEAM and LEED with a focus on environmental, economic, social and cultural issues divided into seven core sections:

- Integrated Development Process
- Natural Systems
- Livable Buildings
- Precious Water
- Resourceful Energy
- Stewarding Materials
- Innovating Practice

Ratings of 1–5 Pearls can be achieved with energy and water being given emphasis within the weighting of the credits available.

Pearl Rating System	Max Credit per Section*
Integrated Development Process	13
Natural Systems	12
Livable Buildings	37
Precious Water	43
Resourceful Energy	44
Stewarding Materials	28
Innovating Practice	03
*Depends on building type	

Qatar Sustainability Assessment System

The Qatar Sustainability Assessment System (QSAS) aims to address the specific requirements of Qatar for environmental performance. In a similar manner to the assessment methods previously mentioned, QSAS works on a credit-based system designed to address a wide range of building types in the construction and/or operation stage. QSAS is divided into categories designed around a number of environmental goals:

- Urban Connectivity
- Site
- Energy
- Water
- Material
- Indoor Environment
- Cultural and Economic Value
- Management and Operations

QSAS Category	Weighting %
Energy	24
Water	16
Indoor Environment	14
Culture & Economic Value	13
Site	09
Urban Connectivity	08
Material	08
Management & Operations	08

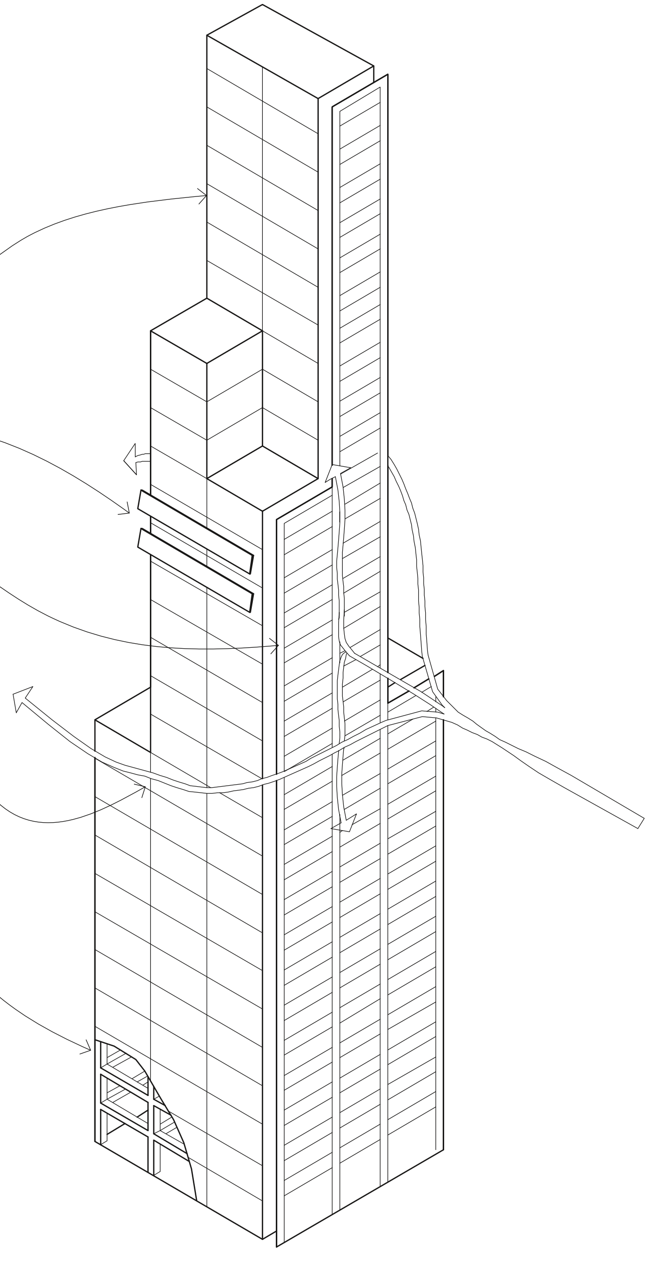
Global Sustainability Assessment System

The Qatar Sustainability Assessment System (QSAS) has now been renamed the Global Sustainability Assessment System (GSAS) as it has applications in the wider region and has been adopted by other GCC countries. The system is administered by the Gulf Organisation for Research and Development (GORD). www.gord.qa

13.08 CONSTRUCTION METHODS

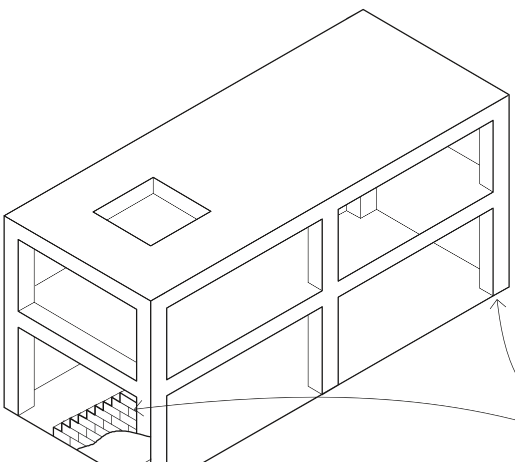
Construction in the Middle East is at the forefront of driving the technical limitations of the industry forward. This is particularly true in relation to tall buildings and increasingly sustainability standards. Additionally, architects and engineers internationally have been using the lessons learnt from traditional construction methods in the Middle East to influence emerging best practice in sustainable design. Methods founded in traditional construction, such as passive and evaporative cooling, wind catchers and thermal mass are now part of many sustainable design strategies.

- Highly glazed buildings can be energy intensive in hot-arid climates
- Building-integrated photovoltaics can be used to provide shading while generating electricity
- A double skin, if correctly configured and engineered, can be used to reduce heat gain, provide integrated shading and to help drive the building's ventilation system
- Tall buildings must be designed to take account of the impacts of high winds
- Concrete frame



Although construction standards generally in the Middle East have been improving and have driven the industry forward, a number of areas still need further development, these include:

- Thermal insulation
- Thermal bridging
- Airtightness
- Flashing details
- Fire regulations and materials



Materials

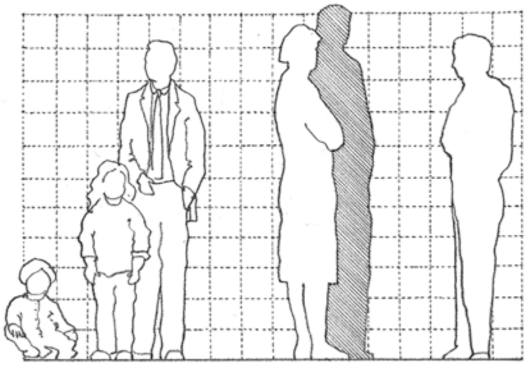
Tall buildings routinely use concrete as the main construction material as it offers availability, durability and workability. In the Middle East, concrete is also often used in low-rise buildings with domestic buildings frequently featuring a concrete frame with infill materials. Concrete is an energy-intensive material to produce, however its durability coupled with its thermal storage capacity can help to justify its use from an environmental perspective.

- Concrete frame
- Brick of block infill
- Render

A

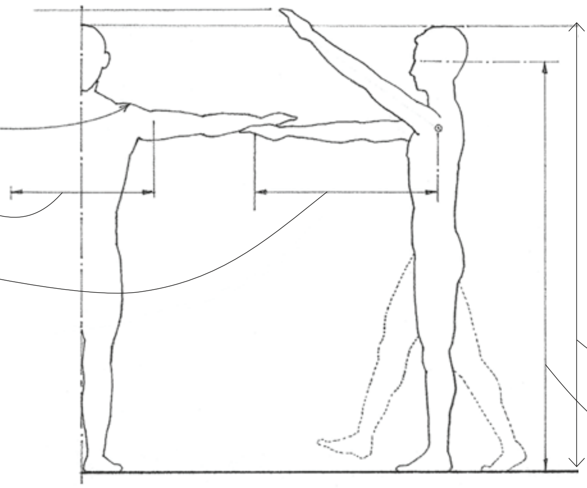
APPENDIX

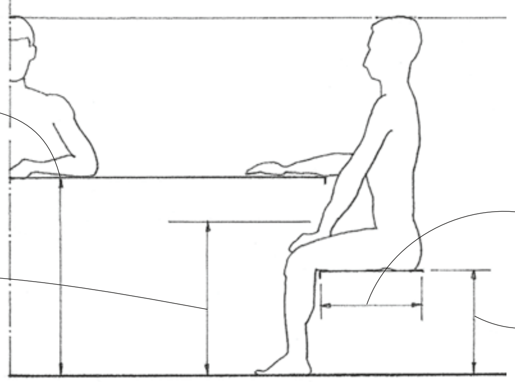
A.02 HUMAN DIMENSIONS

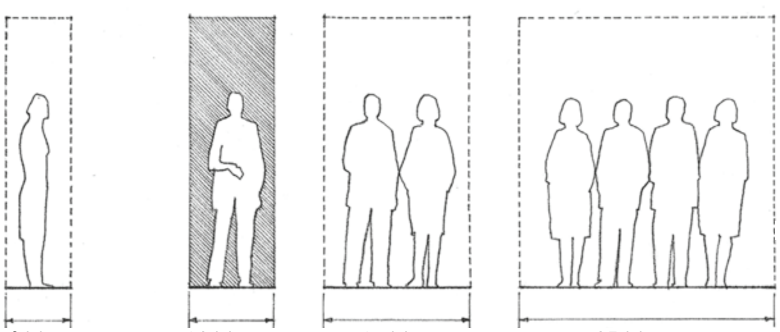


Our body dimensions, and the way we move through and perceive space, are prime determinants of the scale, proportions and spatial layout of a building. It should be noted that there is a difference between the structural dimensions of our bodies and those dimensional requirements that result from how we reach for something on a shelf, sit down at a table, walk down a stairway, or interact with other people. These functional dimensions will vary according to the nature of our activity and the social situation. The study of human dimensions is known as anthropometrics. Ergonomics concerns itself with how humans interact with the world around us, be it the screen height required to retain good posture or the ability of a hand to grip a handle.

Caution should always be exercised when using a set of dimensional tables or illustrations such as these. These are based on average measurements, which may have to be adjusted to satisfy specific user needs. Variations from the norm will always exist due to the differences between men and women, among various age and racial groups, and from one individual to the next.







• Corridors and passageways

The Metric Handbook provides design data considering anthropometrics or ergonomics, mainly focused on the UK but widely referred to throughout Europe.

Most regions in Europe have specific disability, equality and discrimination acts to provide a legal basis for inclusive design in the built environment, in the UK this is the Disability and Equality Act (2010). This legislation is interpreted in building regulations. The European disability strategy aims to make it easier for persons with disabilities to access and use public buildings and may in time result in a harmonised European Standard on accessibility.

The figures given on this and related pages are for guidance purposes only, consult local regulations for detailed guidance.

Facilities should be accessible to those confined to a wheelchair and the ambulatory.

- Accessible routes consist of walking surfaces with a maximum slope of 1:20, marked crossings at vehicular roadways, clear floor space at accessible elements, access aisles, ramps, kerb ramps and elevators
- Floor surfaces should be firm, stable and slip-resistant
- Avoid changes in level and the use of stairs
- Use ramps only where necessary

Facilities should be identifiable to the blind.

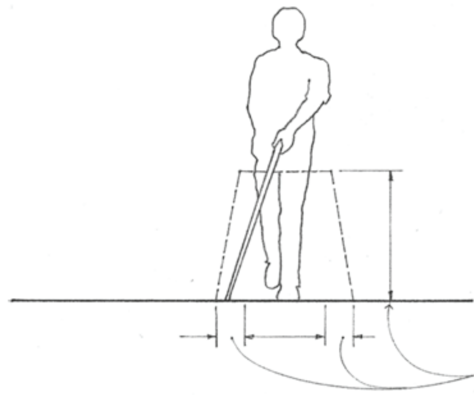
- Use raised lettering, audible warning signals and textured surfaces to indicate stairs or hazardous openings

Facilities should be usable.

- Circulation spaces should be adequate for comfortable movement
- All public facilities should have fixtures designed for use by persons with disabilities

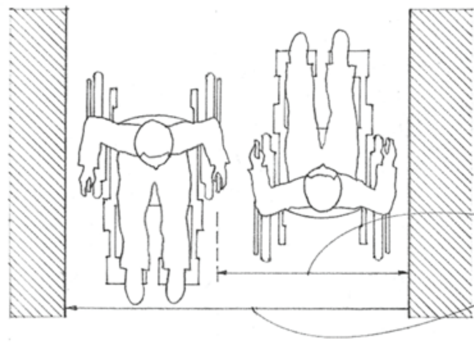
For Accessibility Guidelines for other building elements or components, see the following:

- Vehicular parking: 1.32
- Doors: 8.03
- Door hardware: 8.17, 8.19, 8.20
- Thresholds: 8.21
- Windows: 8.22
- Stairs and ramps: 9.05–9.09
- Elevators: 9.15
- Kitchens: 9.21–9.22
- Toilet and bathing facilities: 9.25
- Carpeting: 10.21

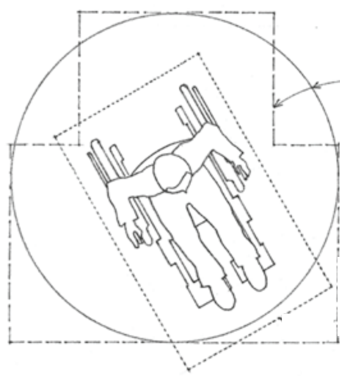


- Walking stick: 150 mm minimum to either side

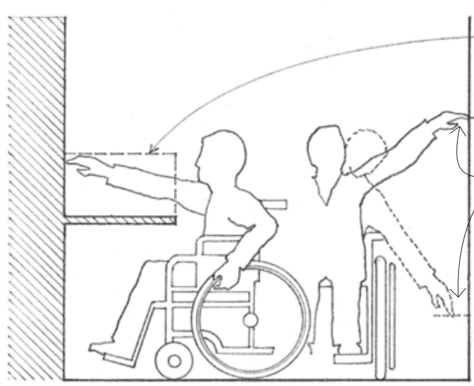
- Changes in level from 6 to 15 mm should be bevelled
- Changes in level greater than 15 mm must be ramped



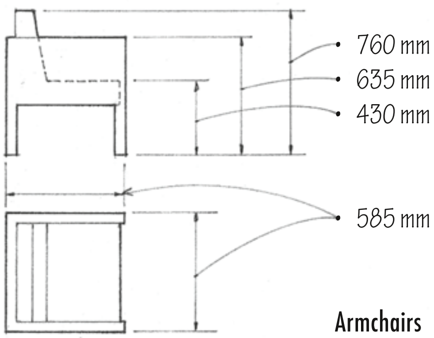
- 900 mm minimum clear width for passage
- 1800 mm minimum clear width for two wheelchairs to pass



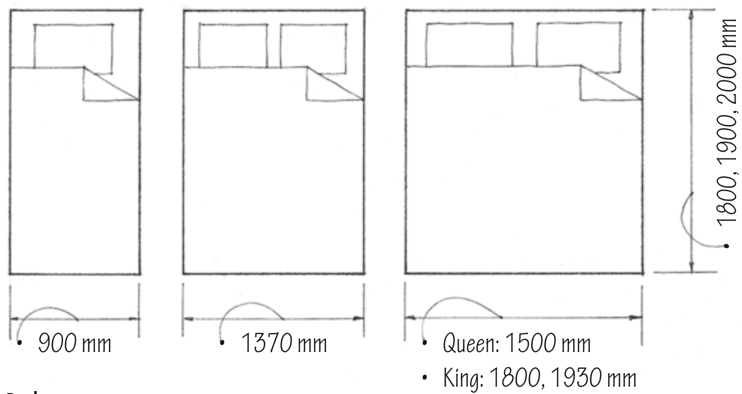
- 1500 mm minimum clear ø, or a T-shaped space with arms at least 1 m wide and 1.2 m long, to allow a wheelchair to turn



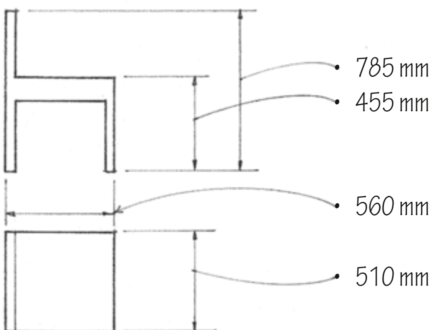
- Forward reach 1.3–1.4 m, oblique reach 1450–1590 mm, vertical reach 1570–1710 mm
- 1.3 m maximum and 400 mm minimum side reach above the floor



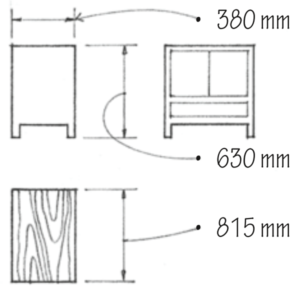
Armchairs



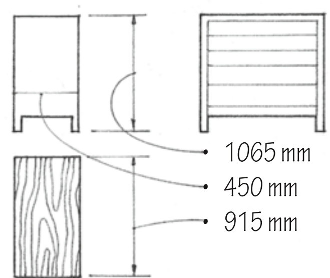
Beds



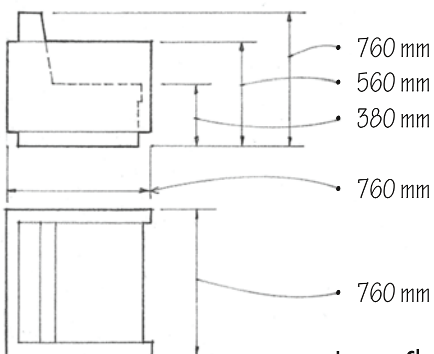
Side Chairs



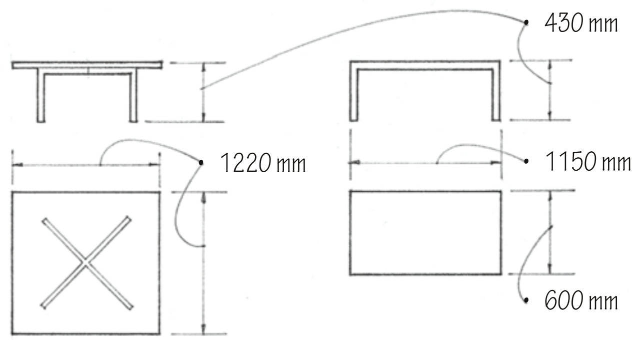
Night Tables



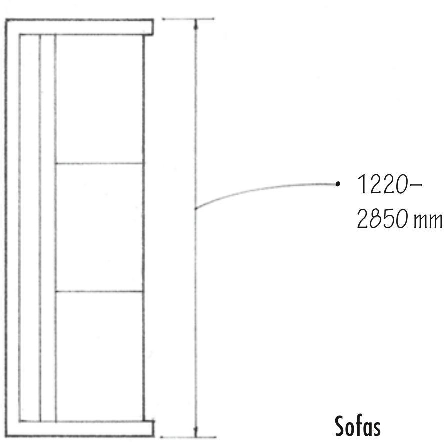
High Chests



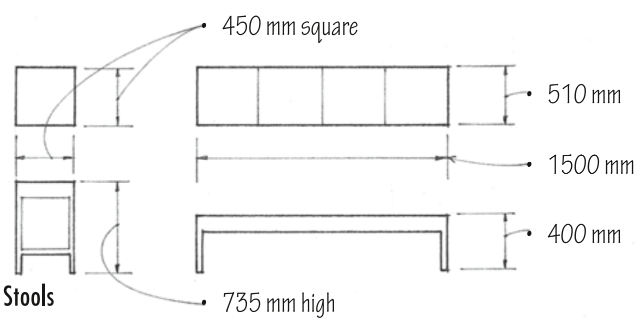
Lounge Chairs



Low Tables

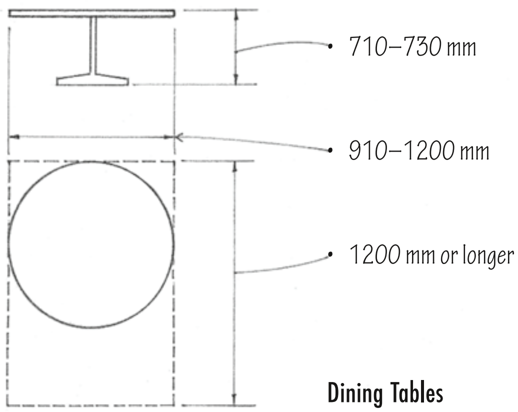


Sofas

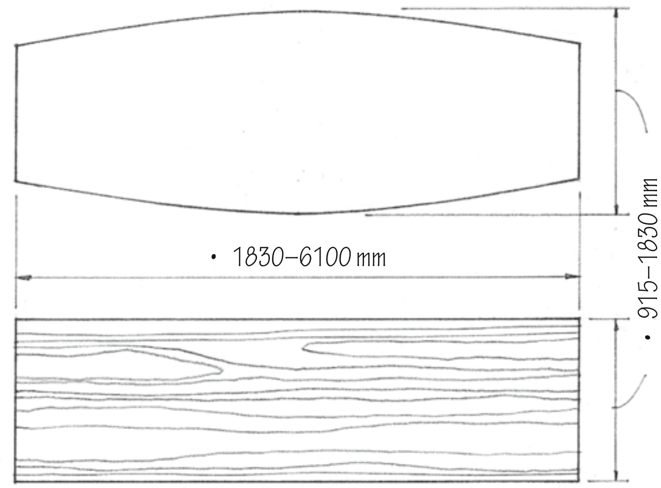


Stools

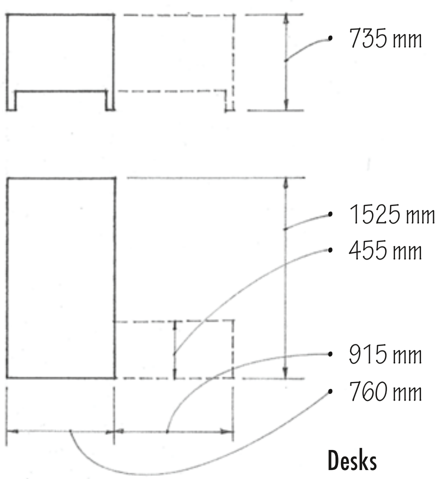
Benches



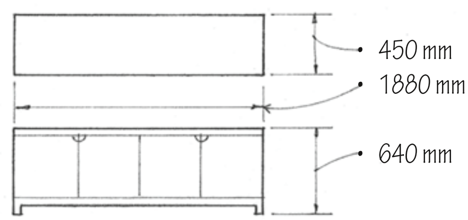
Dining Tables



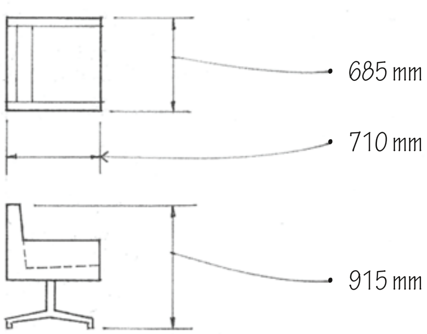
Conference Tables



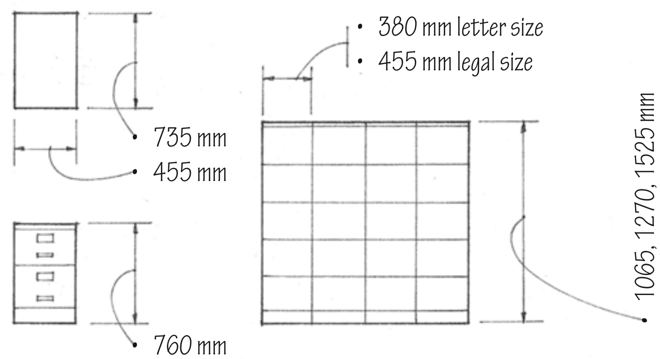
Desks



Sideboards



Swivel Chairs



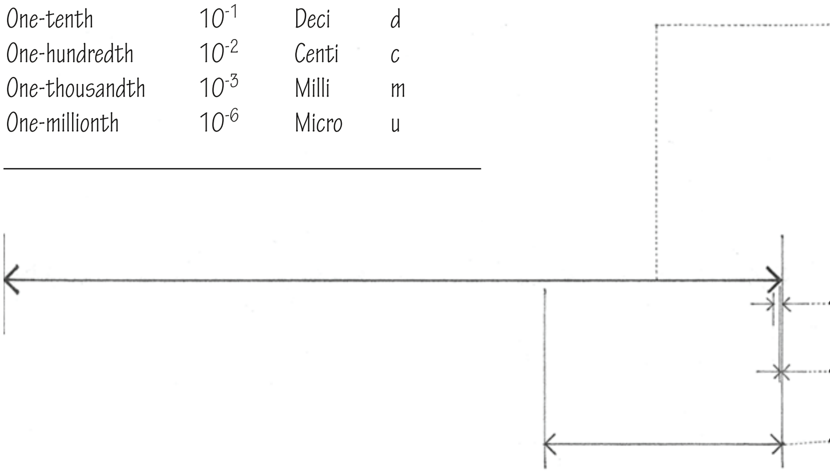
Filing Cabinets

- All dimensions are typical. Verify with furniture manufacturer
- Furniture may serve as space-defining elements, define circulation paths or be built-in or set as objects in space
- Selection factors include function, comfort, scale, colour and style

A.06 METRIC CONVERSION FACTORS

Factor	Multiples	Prefixes	Symbols
Thousand million	10^9	Giga	G
One million	10^6	Mega	M
One thousand	10^3	Kilo	k
One hundred	10^2	Hecto	h
Ten	10	Deca	da
One-tenth	10^{-1}	Deci	d
One-hundredth	10^{-2}	Centi	c
One-thousandth	10^{-3}	Milli	m
One-millionth	10^{-6}	Micro	u

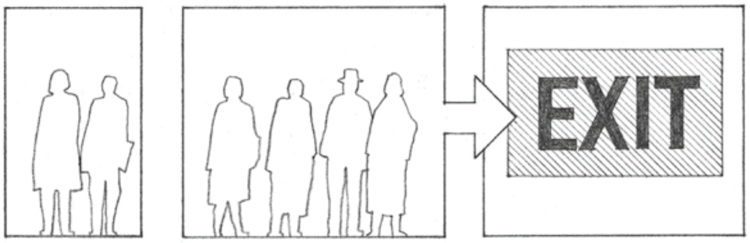
The International System of Units (SI), more commonly known as the metric system, is an internationally accepted system of coherent physical units, using the metre, gram, second, ampere, kelvin and candela as the basic units of the fundamental quantities of length, mass, time, electric current, temperature and luminous intensity. The metric system is universally used in science and mandatory for use in a large number of countries.



- The metre is the basic unit of length in the metric system, equivalent to 39.37 inches. It was originally defined as one ten-millionth of the distance from the equator to the pole measured on the meridian, later as the distance between two lines on a platinum-iridium bar preserved at the International Bureau of Weights and Measures near Paris, and now as $^1/_{299,972,458}$ of the distance light travels in a vacuum in one second
- A centimetre is equal to $^1/_{100}$ of a metre or 0.3937 inch. The centimetre is not recommended for use in construction
- A millimetre is equal to $^1/_{1000}$ of a metre or 0.03937 inch
- A foot, divided into 12 inches, is equal to 304.8 millimetres

Measurement	Imperial Unit	Metric Unit	Symbol	Conversion Factor
Length	mile	kilometre	km	1 mile = 1.609 km
	yard	metre	m	1 yard = 0.9144 m = 914.4 mm
	foot	metre	m	1 foot = 0.3048 m = 304.8 mm
		millimetre	mm	1 foot = 304.8 mm
	inch	millimetre	mm	1 inch = 25.4 mm
Area	square mile	sq kilometre	km^2	1 sq mile = 2.590 km^2
		hectare	ha	1 sq mile = 259.0 ha (1 ha = 10,000 m^2)
	acre	hectare	ha	1 acre = 0.4047 ha
		square metre	m^2	1 acre = 4046.9 m^2
	square yard	square metre	m^2	1 sq yard = 0.8361 m^2
	square foot	square metre	m^2	1 sq foot = 0.0929 m^2
		sq centimetre	cm^2	1 sq foot = 929.03 cm^2
	square inch	sq centimetre	cm^2	1 sq inch = 6.452 cm^2
Volume	cubic yard	cubic metre	m^3	1 cu yard = 0.7646 m^3
	cubic foot	cubic metre	m^3	1 cu foot = 0.02832 m^3
		litre	litre	1 cu foot = 28.32 litres (1000 litres = 1m^3)
		cubic decimetre	dm^3	1 cu foot = 28.32 dm^3 (1 litre = 1 dm^3)
	cubic inch	cubic millimetre	mm^3	1 cu inch = 16390 mm^3
		cubic centimetre	cm^3	1 cu inch = 16.39 cm^3
		millilitre	ml	1 cu inch = 16.39 ml
		litre	litre	1 cu inch = 0.01639 litre

Measurement	Imperial Unit	Metric Unit	Symbol	Conversion Factor
Mass	ton	kilogram	kg	1 ton = 1016.05 kg
	kip (1000 lb)	metric ton (1000 kg)	kg	1 kip = 453.59 kg
	pound	kilogram	kg	1 lb = 0.4536 kg
	ounce	gram	g	1 oz = 28.35 g
per length	pound/lf	kilogram/metre	kg/m	1 plf = 1.488 kg/m
per area	pound/sf	kilogram/metre^2	kg/m^2	1 psf = 4.882 kg/m^2
Mass density	pound/cu ft	kilogram/metre^3	kg/m^3	1 pcf = 16018 kg/m^3
Capacity	quart	litre	litre	1 qt = 1.137 litre
	pint	litre	litre	1 pt = 0.568 litre
	fluid ounce	cubic centimetre	cm^3	1 fl oz = 28.413 cm^3
Force	pound	Newton	N	1 lb = 4.488 N
				1 N = kg m/s^2
per length	pound/lf	Newton/metre	N/m	1 plf = 14.594 N/m
Pressure	pound/sf	Pascal	Pa	1 psf = 47.88 Pa
				1 Pa = N/m^2
	pound/sq in	kiloPascal	kPa	1 psi = 6.894 kPa
Moment	foot-pound	Newton-metre	Nm	1 ft-lb = 1.356 Nm
Mass	pound-feet	kilogram-metre	kg m	1 lb-ft = 0.138 kg m
Inertia	pound-feet^2	kilogram-metre^2	kg m^2	1 lb-ft^2 = 0.042 kg m^3
Velocity	miles/hour	kilometre/hour	km/h	1 mph = 1.609 km/h
	feet/minute	metre/minute	m/min	1 fpm = 0.3408 m/min
	feet/second	metre/second	m/s	1 fps = 0.3408 m/s
Volume rate of flow	cu ft/minute	litre/second	litre/s	1 ft^3/min = 0.4791 litre/s
	cu ft/second	metre^3/second	m^3/s	1 ft^3/sec = 0.02832 m^3/s
	cu in/second	millilitre/second	ml/s	1 in^3/sec = 16.39 ml/s
Temperature	°Fahrenheit	degree Celsius	°c	t °C = 5/9 (t °F – 32)
	°Fahrenheit	degree Celsius	°c	1 °F = 0.5556 °C
Heat	British thermal unit (Btu)	joule	J	1 Btu = 1055 J
		kilojoule	kJ	1 Btu = 1.055 kJ
flow	Btu/hour	watt	W	1 Btu/hr = 0.2931 w
conductance	Btu•in/sf•hr•degF	watt/metre^2 •degC	w/m^2 °C	1 Btu/ft^2 •hr •°F = 5.678 w/m^2• °C
resistance	ft^2•h•degF/Btu	metre^2 •degK/W	m^2 °C/W	1 ft^2•h•°F/Btu = 0.176 m^2•°C/W
refrigeration	ton	watt	W	1 ton = 3519 W
Power	horsepower	watt	W	1 hp = 745.7 W
		kilowatt	kW	1 hp = 0.7457 kW
Light	candela	candela	cd	Basic SI unit of luminous intensity
lux	lumen	lumen	lm	1 lm = cd steradian
illuminance	footcandle	lux	lx	1 FC = 10.76 lx
	lumen/sf	lux	lx	1 lm/ft^2 = 10.76 lux
luminance	footlambert	candela/metre^2	cd/m^2	1 fL = 3.426 cd/m^2



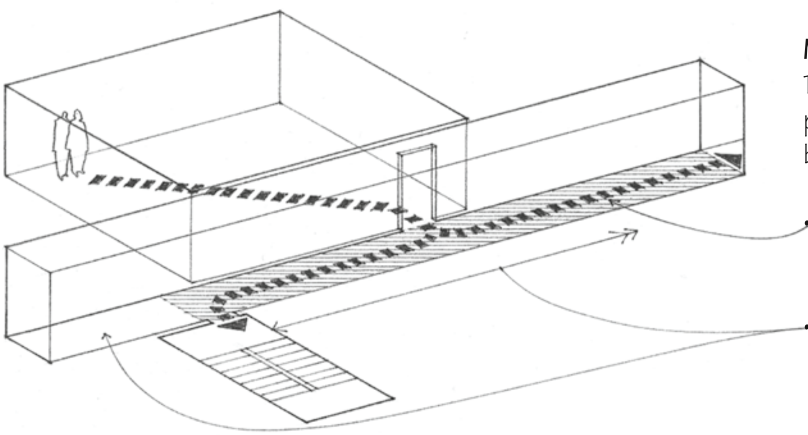
- Occupant density is the total number of persons that may occupy a building or portion thereof at any one time, determined by dividing the floor area assigned to a particular use by the square metres per occupant permitted in that use. Building regulations use occupant density to establish the required number and width of exits for a building

Building regulations specify:
- The fire-resistance ratings of materials and construction required for a building, depending on its location, use and occupancy, and size (height and area per floor); see 2.06–2.07
- The fire alarm, sprinkler and other protection systems required for certain uses and occupancies; see 11.25
- The required means of egress for the occupants of a building in case of a fire. A means of egress must provide safe and adequate access from any point in a building to protected exits leading to a place of refuge. There are three components to an egress system: exit access, exits and exit discharge

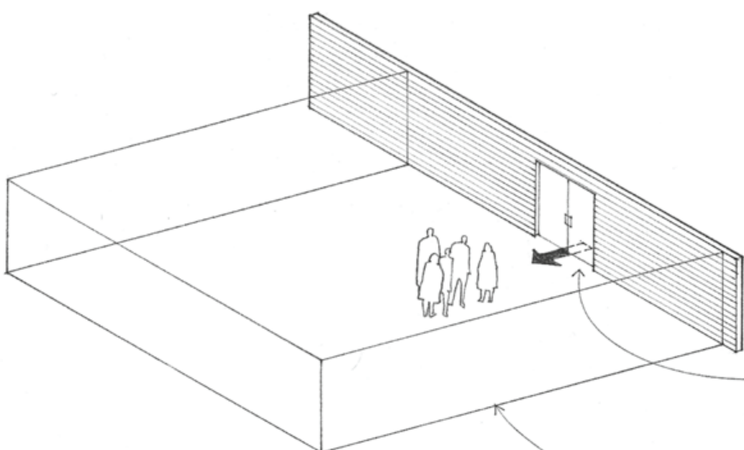
These requirements are intended to control the spread of fire and to allow sufficient time for the occupants of a burning building to exit safely before the structure weakens to the extent that it becomes dangerous. Consult the building regulations for specific requirements.

Means of Escape

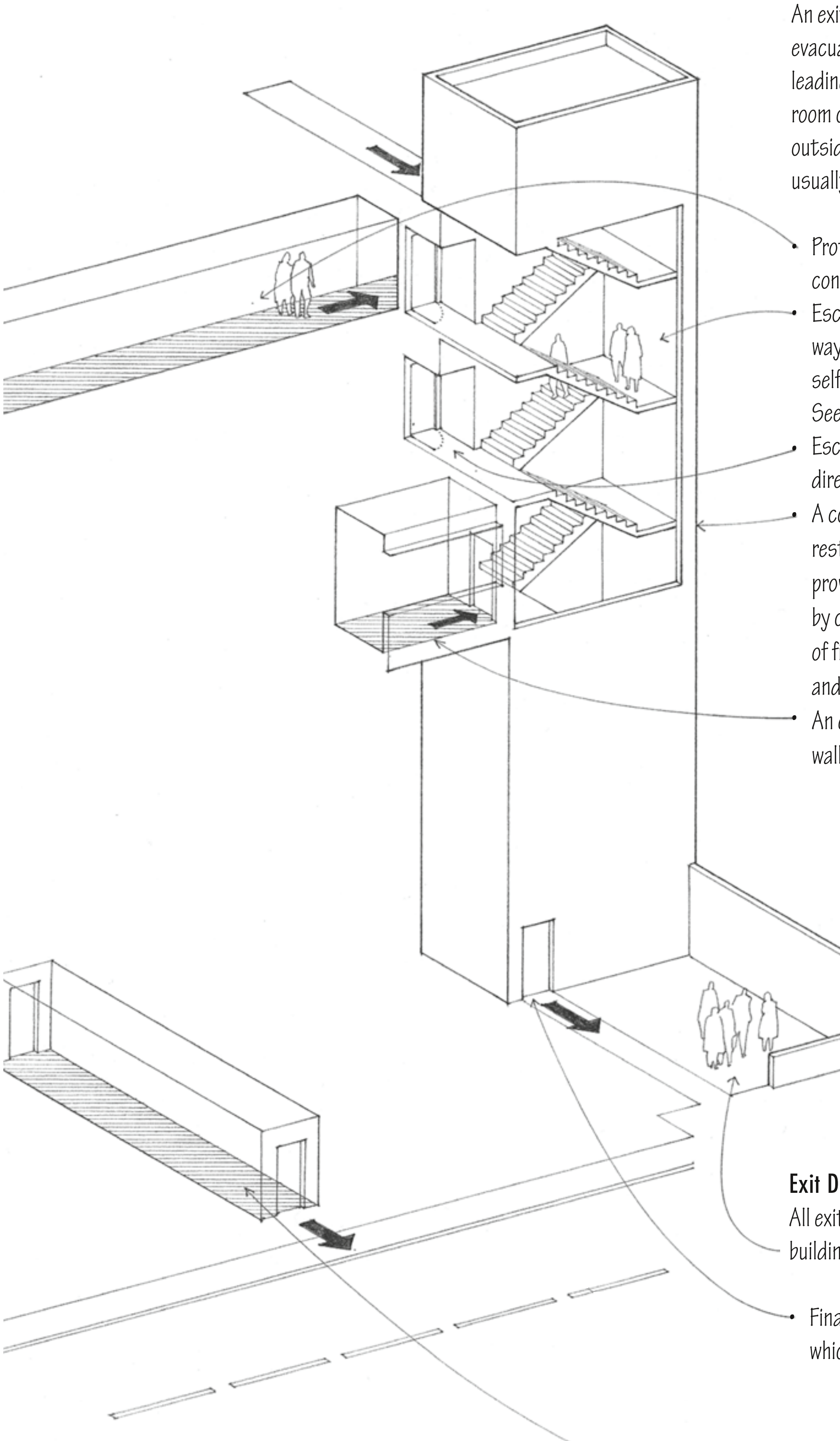
The path or passageway leading to an exit should be as direct as possible, be unobstructed by projections such as open doors and be well lit.



- Building regulations specify the maximum travel distance to an exit according to a building's use, occupancy and degree of fire hazard
- Building regulations also specify the minimum distance between exits when two or more are required. For most occupancies, a minimum of two exits is required to provide a margin of safety in case one exit is blocked
- Exit paths for safe egress from a building should be illuminated by emergency lighting in the event of a power failure
- Exits should be clearly identified by illuminated signs



- A final exit is an exit from a building leading to a place of safety from a protected escape route
- An inner room is a room where escape is only possible through another room. Inner rooms should generally be avoided and are only permissible in limited situations
- An area of refuge affords safety from fire or smoke coming from the area from which escape is made



Exits

An exit must provide an enclosed and protected means of evacuation for the occupants of a building in the event of fire, leading from a protected route to a final exit. From a ground-floor room or corridor, it may simply be a door opening directly to the outside. From a room or space above or below grade, a required exit usually consists of an exit stairway.

- Protected corridors must be enclosed by walls of fire-resistant construction in order to serve as required exits
- Escape stairs lead to an exit passageway, an exit court or public way, enclosed by fire-resistant construction with self-closing fire doors that swing in the direction of exit travel. See 9.04–9.05 for stairway dimensions and requirements
- Escape doors provide access to a means of egress, swinging in the direction of exit travel, and are usually equipped with a panic bar
- A compartment is an area within a building divided from the rest of the building through the provision of floors and walls providing a high level of fire resistance. The separation provided by compartmentalisation is designed to slow down the spread of fire, provide areas of relative safety, aid fire-fighting strategy and to help to contain the fire
- An exterior exit balcony is a landing or porch projecting from the wall of a building and serving as a required means of egress

Exit Discharge

All exits must discharge to a safe place of refuge outside the building, such as street or public area at ground level.

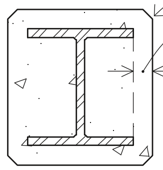
- Final exit is an exit door opening directly to a place of safety which could be a street or open area

- An exit passageway is a protected passageway leading from escape stairs to a final exit

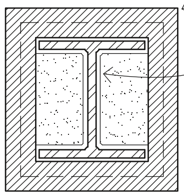
Fire-rated materials, assemblies and construction have a fire-resistance rating required by their uses. This fire-resistance rating is determined by subjecting a full-size specimen to temperatures according to a standard time-temperature curve and establishing the length of time in hours the material or assembly can be expected to withstand exposure to fire without collapsing, developing any openings that permit the passage of flame or hot gases, or exceeding a specified temperature on the side away from the fire. Fire-resistant construction therefore involves both reducing the flammability of a material and controlling the spread of fire.

Materials used to provide fire protection must be non-flammable and be able to withstand very high temperatures without disintegrating. They should also be low conductors of heat to insulate the protected materials from the heat generated by a fire. Such materials include concrete, often with lightweight aggregate, gypsum or vermiculite plaster, gypsum wallboard and a variety of mineral fibre products.

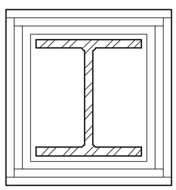
On this and the following page is a sampling of fire-resistance ratings for various construction assemblies, these are for guidance only and should be confirmed with manufacturers. For more detailed specifications, consult the relevant building regulations. See also 2.06 for a table of the fire-resistance rating requirements for major building components.



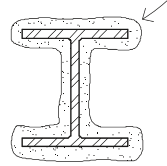
- Reinforced concrete
- Thickness of the concrete cover and size of the steel member determine the fire rating



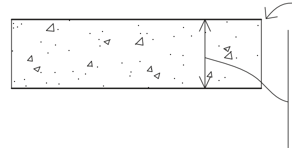
- Clay brick and mortar fill
- Building paper to break bond



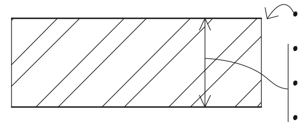
- Multiple layers of gypsum wallboard or fire-rated plasterboard



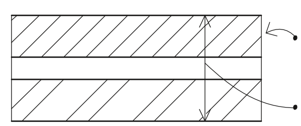
- Spray-on fireproofing is a mixture of gypsum plaster, mineral fibres with an inorganic binder, or magnesium oxychloride cement, applied by air pressure with a spray gun to provide a thermal barrier to the heat of a fire
- Coatings of intumescent paint can offer a degree of fire protection to structural steel elements



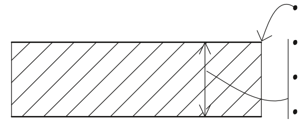
- Solid reinforced concrete
- 165 mm 4-hour rating
- 150 mm 3-hour rating
- 125 mm 2-hour rating
- 90 mm 1-hour rating



- Solid brick masonry
- 205 mm 4-hour rating
- 150 mm 2-hour rating
- 100 mm 1-hour rating



- Brick outer block; inner leaf cavity wall
- 300 mm 4-hour rating



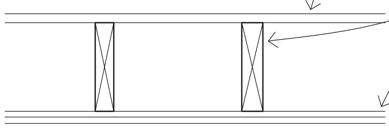
- Concrete masonry wall
- 205 mm 2 to 4-hour rating
- 150 mm 1½-hour rating
- 100 mm 1-hour rating

Structural Steel

- Because structural steel can be weakened by the high temperatures of a fire, it requires protection to qualify for certain types of construction

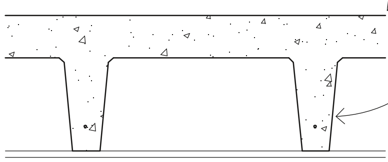
Concrete and Masonry Walls

- Ratings of all masonry walls may be increased with a coating of portland cement or gypsum plaster

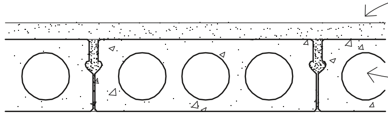


- Timber flooring
- Wood joists at 400 mm centres
- Two layers 12.5 mm fire-resistant plasterboard lapped with taped joints and skim coat plaster

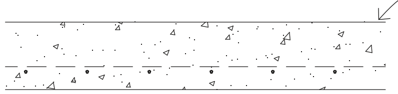
1-Hour Rating



- 75 mm slab
- Reinforced-concrete joists
- Two layers 12.5 mm fire-resistant plasterboard lapped with taped joints



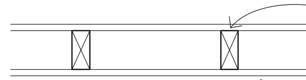
- 50 mm floor screed
- 200 mm precast-concrete slabs with all joints grouted



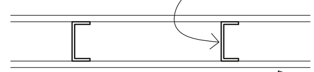
- 200 mm concrete slab

4-Hour Rating

Floors

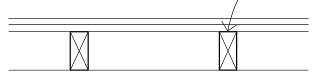


- 50 x 100 mm studs at 400 mm centres
- 15 mm fire-resistant plasterboard and skim coat

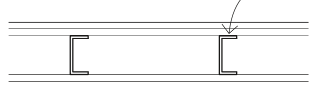


- 65 mm steel studs at 400 mm centres
- 15 mm fire-resistant plasterboard and skim coat

1-Hour Rating



- 50 x 100 mm studs at 400 mm centres
- Two layers 12.5 mm fire-resistant plasterboard lapped with taped joints

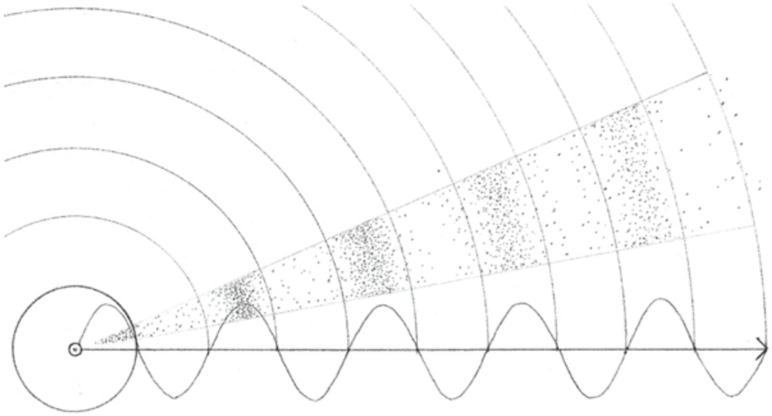


- Steel studs at 400 or 600 mm centres
- Two layers 12.5 mm fire-resistant plasterboard lapped with taped joints

2-Hour Rating

Walls and Partitions

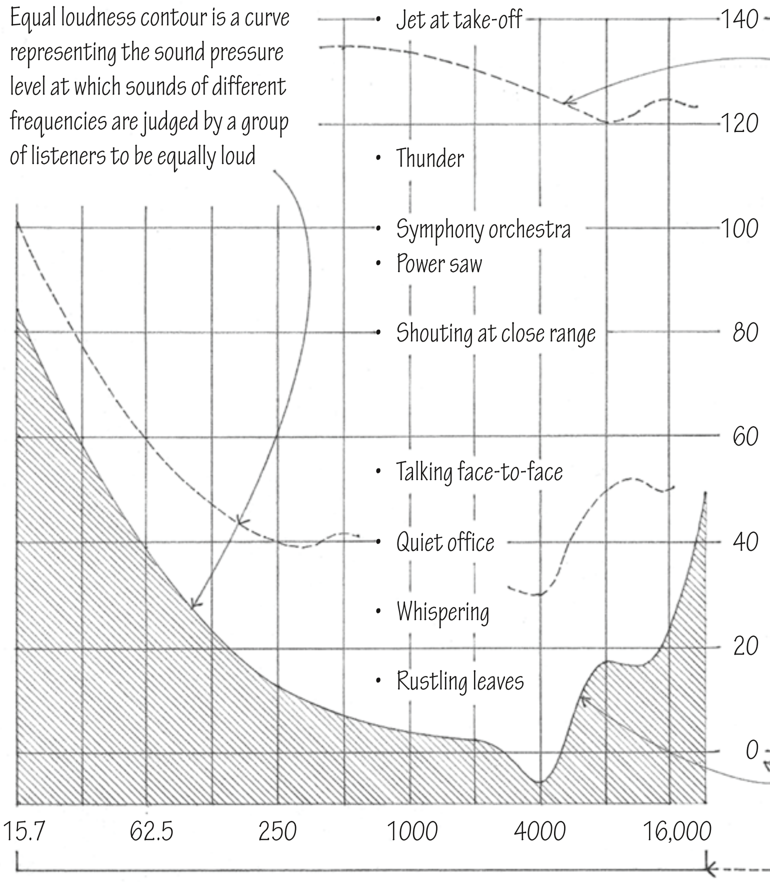
A.12 ACOUSTICS



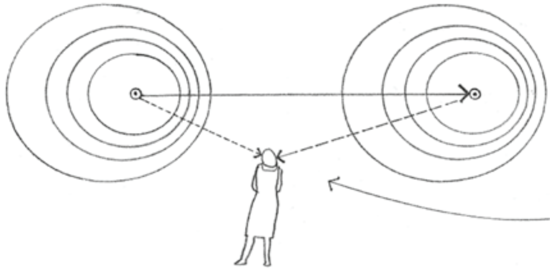
Acoustics is the branch of physics that deals with the production, control, transmission, reception and effects of sound. Sound may be defined as the sensation stimulated in the organs of hearing by mechanical radiant energy transmitted as longitudinal pressure waves through the air or other medium.

- Sound waves are longitudinal pressure waves in air or an elastic medium producing an audible sensation
- Sound travels through air at approximately 300 m per second at sea level, through water at approximately 1400 m per second, through wood at approximately 3600 m per second, and through steel at approximately 5500 m per second

- Equal loudness contour is a curve representing the sound pressure level at which sounds of different frequencies are judged by a group of listeners to be equally loud



- The threshold of pain is the level of sound intensity high enough to produce the sensation of pain in the human ear, usually around 130 dB
- Decibel (dB) is a unit for expressing the relative pressure or intensity of sounds on a uniform scale from 0 for the least perceptible sound to about 130 for the average threshold of pain. Decibel measurement is based on a logarithmic scale since increments of sound pressure or intensity are perceived as equal when the ratios between successive changes in intensity remain constant. The decibel levels of two sound sources, therefore, cannot be added mathematically: eg, 60 dB + 60 dB = 63 dB, not 120 dB
- The threshold of hearing is the minimum sound pressure capable of stimulating an auditory sensation, usually 20 micropascals or zero dB
- The audio frequency is a range of frequencies from 15 Hz to 20,000 Hz audible to the normal human ear. Hertz (Hz) is the SI unit of frequency, equal to one cycle per second

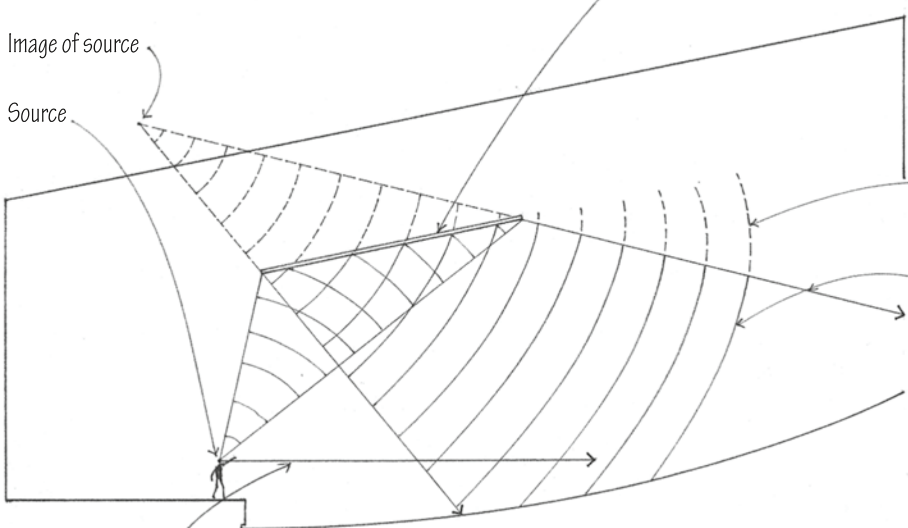


- Doppler effect is an apparent shift in frequency occurring when an acoustic source and listener are in motion relative to each other, the frequency increasing when the source and listener approach each other and decreasing when they move apart

Acoustic design is the planning, shaping, finishing and furnishing of an enclosed space to establish the acoustic environment necessary for distinct hearing of speech or musical sounds.

- Reflecting surfaces are non-absorptive surfaces from which incident sound is reflected, used to redirect sound in a space. To be effective, a reflecting surface should have a least dimension equal to or greater than the wavelength of the lowest frequency of the sound being reflected

- Image of source
- Source

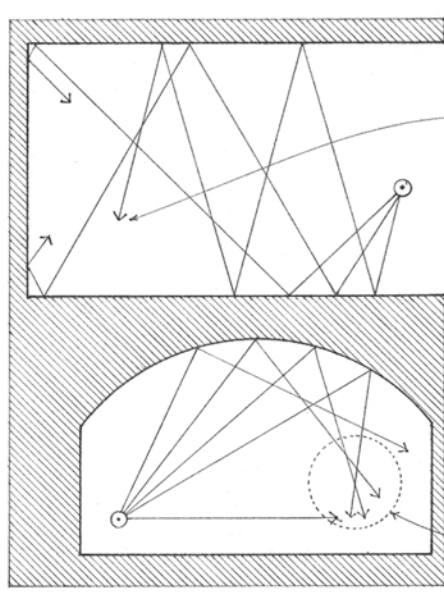


- Diffracted sound is airborne sound waves bent by diffraction around an obstacle in their path
- Reflected sound is the return of unabsorbed airborne sound after striking a surface, at an angle equal to the angle of incidence

- Airborne sound travels directly from a source to the listener. In a room, the human ear always hears direct sound before it hears reflected sound. As direct sound loses intensity, the importance of reflected sound increases

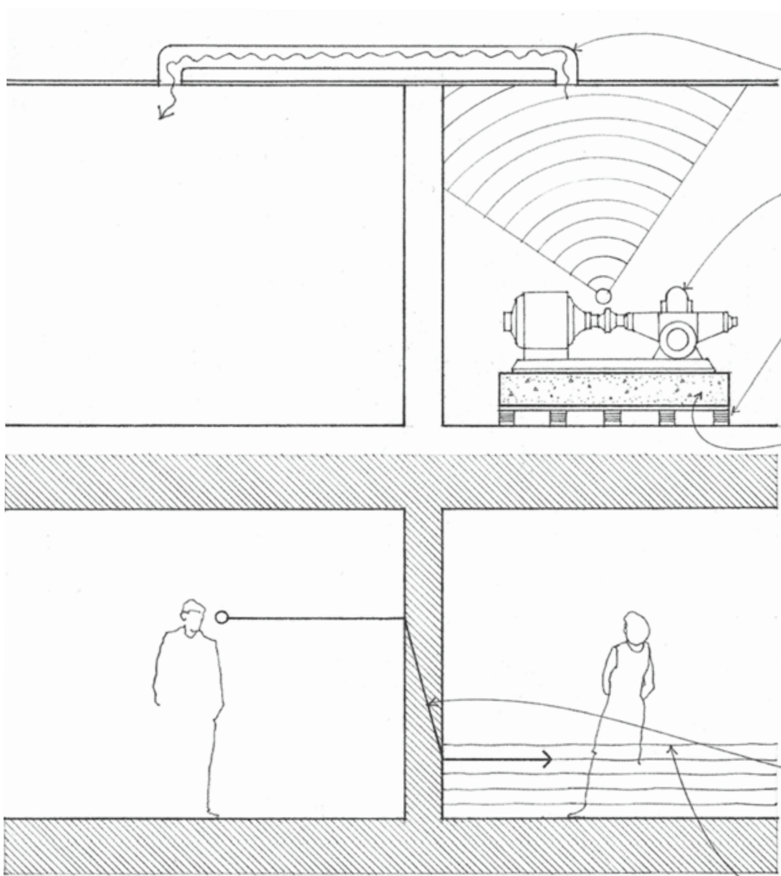
- Attenuation is a decrease in energy or pressure per unit area of a sound wave, occurring as the distance from the source increases as a result of absorption, scattering or spreading in three dimensions

- Reverberation is the persistence of a sound within an enclosed space, caused by multiple reflection of the sound after its source has stopped. Reverberation time is the time in seconds required for a sound made in an enclosed space to diminish by 60 dB
- Resonance is the intensification and prolongation of sound produced by sympathetic vibration, the vibration induced in one body by the vibrations of exactly the same period in a neighbouring body



- Echoes are the repetitions of a sound produced by the reflection of sound waves from an obstructing surface, loud enough and received late enough to be perceived as distinct from the source; echoes may occur when parallel surfaces are more than 18 m apart
- Flutter is a rapid succession of echoes caused by the reflection of sound waves back and forth between two parallel surfaces, with sufficient time between each reflection to cause the listener to be aware of separate, discrete signals

- Focusing is the convergence of sound waves reflected from a concave surface



Noise is any sound that is unwanted, annoying or discordant, or that interferes with one's hearing of something. Whenever possible, undesirable noises should be controlled at their source.

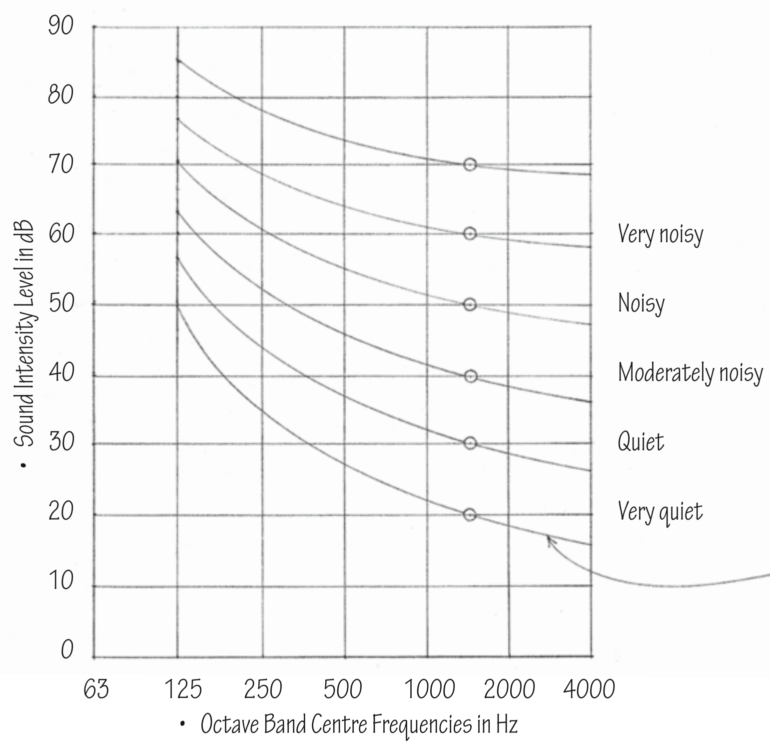
- Block flanking paths that transmit sound through plenum spaces and along such interconnecting structures as ductwork or piping
- Select mechanical equipment with low sone ratings. Sone is a subjective unit of loudness equal to that of a 1000 Hz reference sound having an intensity of 40 dB
- Use resilient mountings and flexible bellows to isolate equipment vibrations from the building structure and supply systems to reduce the transmission of vibration and noise to the supporting structure
- Inertia block is a heavy concrete base for vibrating mechanical equipment, used in conjunction with vibration isolators to increase the mass of the equipment and decrease the potential for vibratory movement

Noise Reduction

The required reduction in noise level from one space to another depends on the level of the sound source and the level of the sound's intrusion that may be acceptable to the listener. The perceived or apparent sound level in a space is dependent on:

- The transmission loss through the wall, floor and ceiling construction
- The absorptive qualities of the receiving space
- The level of masking or background sound, which increases the threshold of audibility for other sounds in its presence
- Background noise or ambient sound is the sound normally present in an environment, usually a composite of sounds from both exterior and interior sources, none of which is distinctly identifiable by the listener

- White noise is an unvarying, unobtrusive sound having the same intensity for all frequencies of a given band, used to mask or obliterate unwanted sound

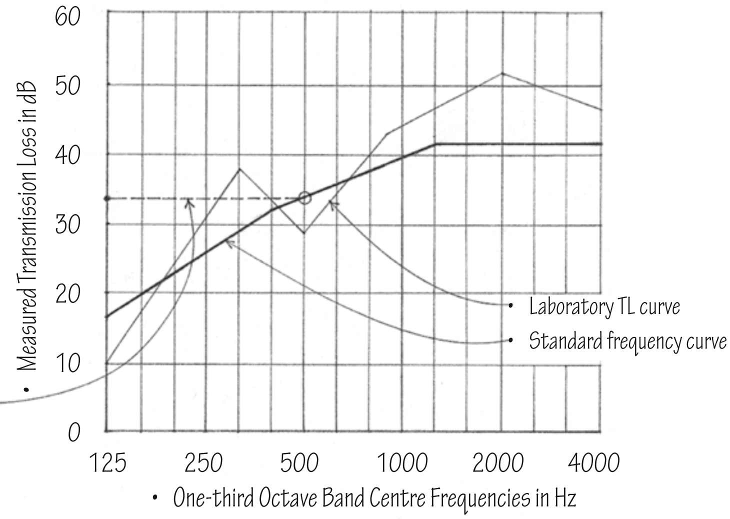


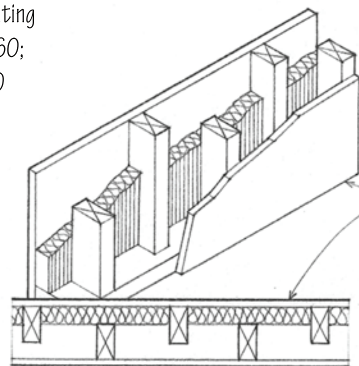
- Noise rating (NR) curve is one of a series of curves representing the sound pressure level across the frequency spectrum for background noise that should not be exceeded in various environments. Higher noise levels are permitted at the lower frequencies since the human ear is less sensitive to sounds in this frequency region

Transmission Loss

- Transmission loss (TL) is a measure of the performance of a building material or construction assembly in preventing the transmission of airborne sound, equal to the reduction in sound intensity as it passes through the material or assembly when tested at all 1/3 octave band centre frequencies from 125 to 4000 Hz: expressed in decibels
- Average TL is a single-number rating of the performance of a building material or construction assembly in preventing the transmission of airborne sound, equal to the average of its TL values at nine test frequencies

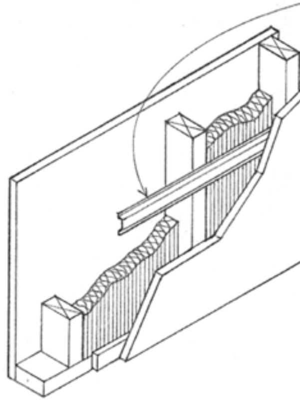
- Sound transmission class (STC) is a single-number rating of the performance of a building material or construction assembly in preventing the transmission of airborne sound, derived by comparing the laboratory TL test curve for the material or assembly to a standard frequency curve. The higher the STC rating, the greater the sound-isolating value of the material or construction. An open doorway has an STC rating of 10; normal construction has STC ratings from 30 to 60; special construction is required for STC ratings above 60

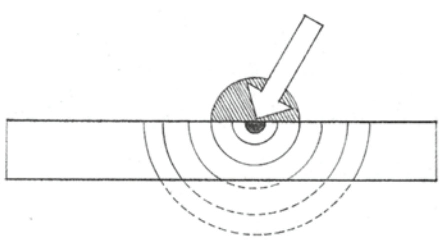




Three factors enhance the TL rating of a construction assembly: separation into layers, mass and absorptive capacity.

- Staggered-stud partitions for reducing sound transmission between rooms are framed with two separate rows of studs arranged in zigzag fashion and supporting opposite faces of the partition, sometimes with a fibreglass blanket between
- Resilient mounting is a system of flexible supports or attachments, such as resilient channels and clips, that permits room surfaces to vibrate normally without transmitting the vibratory motions and associated noise to the supporting structure
- Air spaces increase transmission loss
- Seal pipe penetrations and other openings and cracks in walls and floors to maintain the continuity of sound isolation





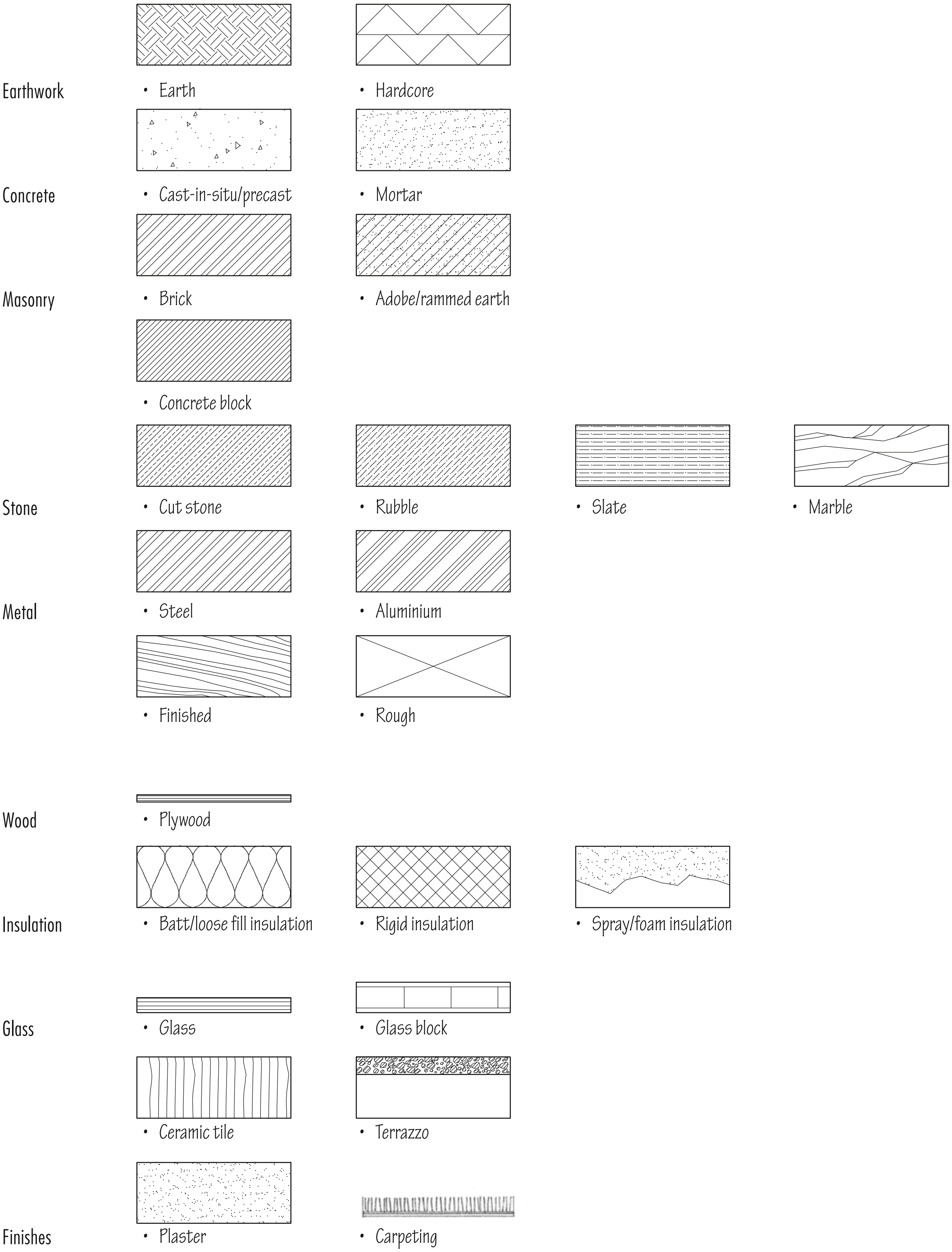
Impact Noise

Impact noise results in structure-borne sound generated by physical impact, as by footsteps or the moving of furniture.

- Impact noise is measured in terms of sound-level transmission. Generally floors with greater mass or that include sound-absorbing layers will have greater levels of sound insulation

- Acoustic mass resists the transmission of sound by the inertia and elasticity of the transmitting medium. In general, the heavier and more dense a body, the greater its resistance to sound transmission
- Absorption coefficient is a measure of the efficiency of a material in absorbing sound at a specified frequency, equal to the fractional part of the incident sound energy at that frequency absorbed by the material

GRAPHIC MATERIAL SYMBOLS



Eurocode 0: Basis of Structural Design

Eurocode 1: Actions on Structures
Part 1-1: *General actions – Densities, self-weight and imposed loads*
Part 1-2: *General actions – Actions on structures exposed to fire*
Part 1-3: *General actions – Snow loads*
Part 1-4: *General actions – Wind actions*
Part 1-5: *General actions – Thermal actions*
Part 1-6: *General actions – Actions during execution*
Part 1-7: *General actions – Accidental actions*
Part 2: Traffic loads on bridges
Part 3: Actions induced by cranes and machinery
Part 4: Silos and tanks

Eurocode 2: Design of Concrete Structures
Part 1-1: *General – Common rules for building and civil engineering structures*
Part 1-2: *General – Structural fire design*
Part 2: Bridges
Part 3: Liquid retaining and containment structures

Eurocode 3: Design of Steel Structures
Part 1-1: *General rules and rules for buildings*
Part 1-2: *General – Structural fire design*
Part 1-3: *General – Cold formed thin gauge members and sheeting*
Part 1-4: *General – Structures in stainless steel*
Part 1-5: *General – Strength and stability of planar plated structures without transverse loading*
Part 1-6: *General – Strength and stability of shell structures*
Part 1-7: *General – Design values for plated structures subjected to out of plane loading*
Part 1-8: *General – Design of joints*
Part 1-9: *General – Fatigue strength*
Part 1-10: *General – Material toughness and through thickness assessment*
Part 1-11: *General – Design of structures with tension components*
Part 1-12: *General – Supplementary rules for high strength steels*
Part 2-1: Bridges
Part 3-1: Towers, masts and chimneys – Chimneys
Part 4-1: Silos, tanks and pipelines – Silos
Part 4-2: Silos, tanks and pipelines – Tanks
Part 4-3: Silos, tanks and pipelines – Pipelines
Part 5: Piling
Part 6: Crane supporting structures

Eurocode 4: Design of Composite Steel and Concrete Structures
Part 1-1: *General – Common rules and rules for buildings*
Part 1-2: *General – Structural fire design*
Part 2: Bridges

Eurocode 5: Design of Timber Structures
Part 1-1: *General – Common rules and rules for buildings*
Part 1-2: *General – Structural fire design*
Part 2: Bridges

Eurocode 6: Design of Masonry Structures
Part 1-1: *General – Rules for reinforced and unreinforced masonry, including lateral loading*
Part 1-2: *General – Structural fire design*
Part 2: Selection and execution of masonry
Part 3: Simplified calculation methods for masonry structures

Eurocode 7: Geotechnical Design
Part 1: *General rules*
Part 2: *Ground investigation and testing*

Eurocode 8: Design of Structures for Earthquake Resistance
Part 1: *General rules, seismic actions and rules for buildings*
Part 2: Bridges
Part 3: Strengthening and repair of buildings
Part 4: Silos, tanks and pipelines
Part 5: Foundations, retaining structures and geotechnical aspects
Part 6: Towers, masts and chimneys

Eurocode 9: Design of Aluminium Structures
Part 1-1: *General common rules*
Part 1-2: *General – Structural fire design*
Part 1-3: Additional rules for structures susceptible to fatigue
Part 1-4: Supplementary rules for trapezoidal structures
Part 1-5: Supplementary rules for shell structures

A.18 EUROPEAN COMMITTEE FOR STANDARDIZATION

The European Committee for Standardization (CEN) produces harmonised European Standards (EN) covering a wide range of fields including the construction industry, health and safety, and products. The CEN standards produced are in turn given the statute of 'national standard'. At the same time any existing national standard in conflict with the EN standard is then withdrawn or superseded.

Structural Eurocodes are harmonised codes for structural buildings and civil engineering; see A.17. Each Eurocode also has an EN number as it is a European Standard.

Some of the key European Standards produced by the European Committee for Standardization are set out below. This list is not exhaustive, a detailed search can be carried out at www.cen.eu/esearch.

- EN 1767:2002 Products and systems for the protection and repair of concrete structures – Test methods – Infrared analysis

- EN 14600:2005 Doorsets and openable windows with fire resisting and/or smoke control of characteristics – Requirements and classification

- EN 14305:2009 Thermal insulation products for building equipment and industrial installations – Factory made cellular glass (CG) products – Specification

- EN12207:1999 Windows and Doors – Air permeability – Classification

- EN 15035:2006 Heating boilers – Special requirements for oil-fired room sealed units up to 70kW

- EN 846-5:2012 Methods of test for ancillary components of masonry – Part 5: Determination of tensile and compressive load capacity and load displacement characteristics of wall ties (couple test)

- EN 15383:2012 Plastics piping systems for drainage and sewerage – Glass-reinforced thermosetting plastics (GRP) based on polyester resin (UP) – Manholes and inspection chambers

- EN 15161:2006 Water conditioning equipment inside buildings – Installation, operation, maintenance and repair

- EN 13142:2004 Ventilation for buildings – Components/products for residential ventilation – Required and optional performance characteristics

In addition to these standards, a number of important European directives have been produced that impact upon the construction industry.

Energy Performance of Buildings Directive

The Energy Performance of Buildings Directive (CEN 2002/91/EC) was brought into place to encourage energy-efficient design, construction and refurbishment across Europe. The requirements of the Energy Performance of Buildings Directive (EPBD) have been implemented across member states. They require member states to:

- Establish an appropriate calculation methodology for the calculation of energy performance of buildings, thus allowing a like-for-like comparison
- Establish the requirement for the provision of Energy Performance Certificates when a building is constructed, sold or let
- Establish regulations that require minimum energy requirements for new building or during the refurbishment of large existing buildings (largely implemented through building regulations and planning control)
- Establish a requirement for the inspection of heating and air-conditioning systems

Some large public buildings are required to have a Display Energy Certificate (DEC) which reflects the in-use energy performance of the building. An Energy Performance Certificate (EPC) is based on a standard calculation of energy performance based on the construction of the building, as such it cannot take account of occupant behaviour.

Construction Products Directive

The European Construction Products Directive (CPD) aims to ensure the free movement of construction materials across Europe while ensuring that minimum health and safety requirements are met and ensuring a certain level of quality. A product marked with a 'CE' stamp has been certified under the CPD.

The British Standards Institute (BSI) produces a wide range of standards for the construction industry in the UK although many have been adopted in other parts of Europe and indeed globally. The standards set out minimum requirements and testing requirements and are largely referred to within the UK Building Regulations.

The list adjacent is not exhaustive, but gives an indication of the subjects covered. More detailed information can be found on the BSI website: www.bsigroup.com.

- BS 8300:2009 Design of building and their approaches to meet the needs of disabled people. Code of practice
- BS EN ISO 14688-1:2002 Geotechnical investigation and testing. Identification and classification of soil identification and description
- BS 8437:2005 Code of practice for selection, use and maintenance of personal fall protection systems and equipment for use in the workplace
- BS EN 361:2002 Personal protective equipment against falls from a height. Full body harnesses
- BS EN 15643-1:2010 Sustainability of construction works. Sustainability assessment of buildings. General framework
- BS EN 15643-2:2011 Sustainability of construction works. Assessment of buildings. Framework for the assessment of environmental performance
- BS 8536:2010 Facility management briefing. Code of practice
- BS EN 806-4:2010 Specifications for installations inside buildings conveying water for human consumption. Installation
- BS 8499:2009 Specification for domestic gas meter boxes and meter bracket
- BS 8103-1:2011 Structural design of low-rise buildings. Code of practice for stability, site investigation, foundations, precast concrete floors and ground floor slabs for housing
- BS 5837:2012 Trees in relation to design, demolition and construction. Recommendations
- BS 1192:2007 Collaborative production of architectural, engineering and construction information. Code of practice
- BS 8541-2:2011 Library objects for architecture, engineering and construction. Recommended 2D symbols of building elements for use in building information modelling
- BS 6262-2:2005 Glazing for buildings. Code of practice for energy, light and sound
- BS 644:2009 Timber windows. Fully finished factory-assembled windows of various types. Specification

GERMAN INSTITUTE FOR STANDARDIZATION

The German Institute for Standardization produces a wide range of standards for use in Germany, although many have been adopted in other parts of Europe and indeed globally.

The list adjacent is not exhaustive, but gives an indication of the subjects covered. More detailed information can be found on the German Institute for Standardization website: www.din.de.

- DIN 18202 Tolerances in building construction – buildings
- DIN EN 356 Glass in buildings – Security glazing – Testing and classification of resistance against manual attack
- DIN EN 12831 Heating systems in buildings – Method for calculation of the design heat load
- DIN 4150-2 Structural vibration – Human exposure to vibration in buildings
- DIN EN 18555-6 Testing of mortars containing mineral binders; determination of bond strength of hardened mortar
- DIN EN ISO 13920 General tolerances for welded constructions – Tolerances for lengths, angles, shape and position
- DIN 1056 Solid construction, free-standing chimneys – Brick liners – Calculation and design
- DIN 1989-4 Rainwater harvesting systems – Part 4: Components for control and supplemental supply
- DIN 4020 Geotechnical investigations for civil engineering purposes – Supplementary rules to DIN EN 1997-2
- DIN 4074-2 Building timber for wood building components; Quality conditions for building logs (softwood)
- DIN 4102-1 Fire behaviour of building materials and elements – Part 1: Classification of building materials, requirements and tests
- DIN 4108-2 Thermal protection and energy economy in buildings – Part 2: Minimum requirements
- DIN 4126 Cast-in-situ concrete diaphragm walls; design and construction
- DIN 4172 Module coordination in building construction
- DIN 4242 Glass block walls; construction and dimensioning
- DIN 4262-1 Pipes and fittings for subsoil drainage of trafficked areas and underground engineering – Part 1: Pipes, fittings and their joints made from PVC-U, PP and PE

BREEAM®
New Construction UK 2011 Version

Management (22 Possible Credits)
MAN 01 Sustainable Procurement
MAN 02 Responsible Construction Practices
MAN 03 Construction Site Impacts
MAN 04 Stakeholder Participation
MAN 05 Life Cycle Cost and Service Life Planning

Health and Wellbeing (Up To 21 Credits)
HEA 01 Visual Comfort
HEA 02 Indoor Air Quality
HEA 03 Thermal Comfort
HEA 04 Water Quality
HEA 05 Acoustic Performance
HEA 06 Safety and Security

Energy (Up To 31 Credits)
ENE 01 Reduction of CO_2 Emissions
ENE 02 Energy Monitoring
ENE 03 External Lighting
ENE 04 Low and Zero Carbon Technologies
ENE 05 Energy Efficient Cold Storage
ENE 06 Energy Efficient Transportation Systems
ENE 07 Energy Efficient Laboratory Systems
ENE 08 Energy Efficient Equipment
ENE 09 Drying Space

Transport (Up To 12 Credits)
TRA 01 Public Transport Accessibility
TRA 02 Proximity to Amenities
TRA 03 Cyclists Facilities
TRA 04 Maximum Car Parking Capacity
TRA 05 Travel Plan

Water (9 Possible Credits)
WAT 01 Water Consumption
WAT 02 Water Monitoring
WAT 03 Leak Detection
WAT 04 Water Efficient Equipment

Materials (Up To 13 Credits)
MAT 01 Life Cycle Impacts
MAT 02 Hard Landscaping and Boundary Protection
MAT 03 Responsible Sourcing of Materials
MAT 04 Insulation
MAT 05 Designing for Robustness

Waste (7 Possible Credits)
WST 01 Construction Waste Management
WST 02 Recycled Aggregates
WST 03 Operational Waste
WST 04 Speculative Floor and Ceiling Finishes

Land Use and Ecology (Up To 14 Credits)
LE 01 Site Selection
LE 02 Ecological Value of Site and Protection of Ecological Features
LE 03 Mitigating Ecological Impact
LE 04 Enhancing Site Ecology
LE 05 Long Term Impact on Biodiversity

Pollution (Up To 13 Credits)
POL 01 Impact of Refrigerants
POL 02 NOx Emissions
POL 03 Surface Water Run-Off
POL 04 Reduction of Night-Time Light Pollution
POL 05 Noise Attenuation

Innovation (10 Possible Credits)
MAN 01 Sustainable Procurement
MAN 02 Responsible Construction Practices
HEA 01 Visual Comfort
ENE 01 Reduction of CO_2 Emissions
ENE 04 Low and Zero Carbon Technologies
ENE 05 Energy-Efficient Cold Storage
WAT 01 Water Consumption
MAT 01 Life-Cycle Impacts
MAT 03 Responsible Sourcing of Materials
WST 01 Construction Site Waste Management
WST 02 Recycled Aggregates

To receive BREEAM certification, a building project must meet certain prerequisites and performance benchmarks or credits within each category. Projects are awarded pass, good, very good, excellent or outstanding certification depending on the number of credits they achieve.

- Pass: 30–44 points
- Good: 45–54 points
- Very Good: 55–69 points
- Excellent: 70–84 points
- Outstanding: 85 points or more

LEED®2009
For New Construction & Major Renovations Version 2.2

Sustainable Sites (26 Possible Points)
SS Prereq 1 Construction Activity Pollution Prevention Required
SS Credit 1 Site Selection 1
SS Credit 2 Development Density & Community Connectivity 5
SS Credit 3 Brownfield Redevelopment 1
SS Credit 4.1 Alternative Transportation, Public Transportation Access 6
SS Credit 4.2 Alternative Transportation, Bicycle Storage & Changing Rooms 1
SS Credit 4.3 Alternative Transportation, Low Emitting & Fuel Efficient Vehicles 3
SS Credit 4.4 Alternative Transportation, Parking Capacity 2
SS Credit 5.1 Site Development, Protect or Restore Habitat 1
SS Credit 5.2 Site Development, Maximize Open Space 1
SS Credit 6.1 Stormwater Design, Quantity Control 1
SS Credit 6.2 Stormwater Design, Quality Control 1
SS Credit 7.1 Heat Island Effect, Non-Roof 1
SS Credit 7.2 Heat Island Effect, Roof 1
SS Credit 8 Light Pollution Reduction 1

Water Efficiency (10 Possible Points)
WE Prerequisite 1 Water Use Reduction Required
WE Credit 1.2 Water Efficient Landscaping 2–4
WE Credit 2 Innovative Wastewater Technologies 1
WE Credit 3 Water Use Reduction 2–4

Energy & Atmosphere (35 Possible Points)
EA Prereq 1 Fundamental Commissioning of the Building Energy Systems Required
EA Prereq 2 Minimum Energy Performance Required
EA Prereq 3 Fundamental Refrigerant Management Required
EA Credit 1 Optimize Energy Performance 1–19
EA Credit 2 On-Site Renewable Energy 1–7
EA Credit 3 Enhanced Commissioning 2
EA Credit 4 Enhanced Refrigerant Management 2
EA Credit 5 Measurement & Verification 3
EA Credit 6 Green Power 2

Materials & Resources (14 Possible Points)
MR Prereq 1 Storage & Collection of Recyclables Required
MR Credit 1.1 Building Reuse, Maintain Existing Walls, Floors & Roof 1–3
MR Credit 1.2 Building Reuse, Maintain Existing Interior Nonstructural Elements 1
MR Credit 2 Construction Waste Management 1–2
MR Credit 3 Materials Reuse 1–2
MR Credit 4 Recycled Content 1–2
MR Credit 5 Regional Materials 1–2
MR Credit 6 Rapidly Renewable Materials 1
MR Credit 7 Certified Wood 1

Indoor Environmental Quality (15 Possible Points)
EQ Prereq 1 Minimum IAQ Performance Required
EQ Prereq 2 Environmental Tobacco Smoke (ETS) Control Required
EQ Credit 1 Outdoor Air Delivery Monitoring 1
EQ Credit 2 Increased Ventilation 1
EQ Credit 3.1 Construction IAQ Management Plan, During Construction 1
EQ Credit 3.2 Construction IAQ Management Plan, Before Occupancy 1
EQ Credit 4.1 Low-Emitting Materials, Adhesives & Sealants 1
EQ Credit 4.2 Low-Emitting Materials, Paints & Coatings 1
EQ Credit 4.3 Low-Emitting Materials, Flooring Systems 1
EQ Credit 4.4 Low-Emitting Materials, Composite Wood & Agrifiber Products 1
EQ Credit 5 Indoor Chemical & Pollutant Source Control 1
EQ Credit 6.1 Controllability of Systems, Lighting 1
EQ Credit 6.2 Controllability of Systems, Thermal Comfort 1
EQ Credit 7.1 Thermal Comfort, Design 1
EQ Credit 7.2 Thermal Comfort, Verification 1
EQ Credit 8.1 Daylight & Views, Daylight 1
EQ Credit 8.2 Daylight & Views, Views 1

Innovation & Design Process (6 Possible Points)
ID Credit 1 Innovation in Design 1–5
ID Credit 2 LEED Accredited Professional 1

Regional Priority (4 Possible Points)
RP Credit 1 Regional Priority 1–4

LEED 2009 For New Construction & Major Renovations
100 base points; 6 possible Innovation in Design and 4 Regional Priority points.

To receive LEED certification, a building project must meet certain prerequisites and performance benchmarks or credits within each category. Projects are awarded Certified, Silver, Gold or Platinum certification depending on the number of credits they achieve.

- Certified: 40–49 points
- Silver: 50–59 points
- Gold: 60–79 points
- Platinum: 80 points and above

Professional & Trade Associations

American Society of Heating, Refrigeration, and Air-Conditioning Engineers
1791 Tullie Circle NE
Atlanta GA 30329
USA
www.ashrae.org

Architects Registration Board
8 Weymouth Street
London W1W 5BU
UK
www.arb.org.uk

Association of Plumbing & Heating Contractors
12 The Pavilions, Cranmore Drive
Solihull B90 4SB
UK
www.aphc.co.uk

British Constructional Steelwork Association (BCSA)
4 Whitehall Court
Westminster
London SW1A 2ES
UK
www.steelconstruction.org

British Institute of Facilities Management
Number One Building, The Causeway
Bishop's Stortford
Hertfordshire, CM23 2ER
UK
www.bifm.org.uk

The British Standards Institution
389 Chiswick High Road
London W4 4AL
UK
www.bsi.group.com

British Woodworking Federation
The Building Centre
26 Store Street
London WC1E 7BT
UK
www.bwf.org.uk

The Building Research Establishment
Bucknalls Lane, Garston
Watford WD25 9XX
UK
www.bre.co.uk

The Building Services Research and Information Association
Old Bracknell Lane West
Bracknell
Berkshire RG12 7AH
UK
www.bsria.co.uk

The Canadian Standards Association (CSA)
178 Rexdale Blvd
Toronto, Ontario M9W 1R3
Canada
www.csa.ca

The Carbon Trust
4th Floor, Dorset House
27–45 Stamford Street
London SE1 9NT
UK
www.carbontrust.com

Chartered Institute of Architectural Technologists
397 City Road
London EC1V 1NH
UK
www.ciat.org.uk

Chartered Institute of Building
Englemere, Kings Ride, Ascot
Berkshire SL5 7TB
UK
www.ciob.org.uk

Chartered Institute of Housing
Octavia House
Westwood Way
Coventry CV4 8JP
UK
www.cih.co.uk

Chartered Institution of Building Services Engineers
222 Balham High Street
London SW12 9BS
UK
www.cibse.org

Considerate Constructors Scheme
PO Box 75
Ware
Hertfordshire SG10 0YX
UK
www.ccscheme.org.uk

Convention on International Trade in Endangered Species (CITES)
International Environment House
11 Chemin des Anémones
CH-1219 Châtelaine, Geneva
Switzerland
www.cites.org

The Electrical Contractors Association
ESCA House
34 Palace Court
London W2 4HY
UK
www.eca.co.uk

The Energy Savings Trust
21 Dartmouth Street
London SW1H 9BP
UK
www.energysavingstrust.org.uk

European Agency for Safety and Health at Work
Gran Via 33
E-48009, Bilbao
Spain
www.osha.europa.eu

Federation of Master Builders
Gordon Fisher House
14/15 Great James Street
London WC1N 3DP
UK
www.fmb.org.uk

The Forest Stewardship Council (FSC)
FSC International Center GmbH
Charles de Gaulle Straße 5, 53113 Bonn
Germany
www.ic.fsc.org

German Institute for Standardization
Am DIN-Platz
Burggrafenstrasse 6
10787, Berlin
Germany
www.din.de

Institution of Civil Engineers
One Great George Street
Westminster
London SW1P 3AA
UK
www.ice.org.uk

Institution of Engineering and Technology
Michael Faraday House
Six Hills Way
Stevenage
Herts SG1 2AY
UK
www.theiet.org

Institution of Occupational Safety and Health
The Grange
Highfield Drive, Wigston
Leicester LE18 1NN
UK
www.iosh.co.uk

Institution of Structural Engineers
11 Upper Belgrave Street
London SW1X 8BH
UK
www.istructe.org

International Organization for Standardization
1, ch. de la Voie-Creuse, Case postale 56
CH-1211 Geneva 20
Switzerland
www.iso.org

The Landscape Institute
Charles Darwin House
12 Roger Street
WC1N 2JU
UK
www.landscapeinstitute.org

National House-Building Council (UK)
NHBC House
Davy Avenue
Knowlhill
Milton Keynes MK5 8FP
UK
www.nhbc.co.uk

The Passive House Institute
Rheinstrasse 44/46
D-64283 Darmstadt
Germany
www.passiv.de

The Programme for the Endorsement of Forest Certification (PEFC)
10 Route de l'Aéroport
Case Postale 636
1215 Geneva
Switzerland
www.pefc.org

The Royal Institute of British Architects
66 Portland Place
London W1B 1AD
UK
www.architecture.com

The Royal Institution of Chartered Surveyors
Parliament Square
London SW1P 3AD
UK
www.rics.org.uk

The Royal Town Planning Institute
41 Botolph Lane
London EC3R 8DL
UK
www.rtpi.org.uk

Sustainable Energy Authority of Ireland
Wilton Park House
Wilton Place
Dublin 2
Republic of Ireland
www.seai.ie

Sustainable Forestry Initiative (SFI)
900 17th Street, NW
Suite 700,Washington, DC 20006
USA
www.sfiprogram.org

Timber Research and Development Association
Stocking Lane
Hughenden Valley
High Wycombe
HP14 4ND
UK
www.trada.co.uk

The UK Green Building Council
The Building Centre
26 Store Street
London WC1E 7BT
UK
www.ukgbc.org

World Green Building Council
5 Shoreham Drive
Downsview
Toronto, Ontario M3N 1S4
Canada
www.worldgbc.org

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Web Resources:

BREEAM	www.breeam.org
British Board of Agrément	www.bbacerts.co.uk
Central Point of Expertise for Timber Procurement	www.cpet.org.uk
Centre for European Standardization	www.cen.eu
The Construction Information Service	www.ihs.com
Convention on International Trade in Endangered Species	www.cites.org
European Environment Agency	www.eea.europa.eu
Global codes and standards	www.nssn.org
GreenSpec	www.greenspec.co.uk
Gulf Organisation for Research and Development	www.gord.qa
Health and Safety Executive (UK)	www.hse.gov.uk
International Council for Research and Innovation in Building and Construction	www.cibworld.nl
LEED	www.usgbc.org/leed
Passive House Institute	www.passiv.de
RAL Colour System	www.ralcolor.com
Usable Buildings Trust	www.usablebuildings.co.uk

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