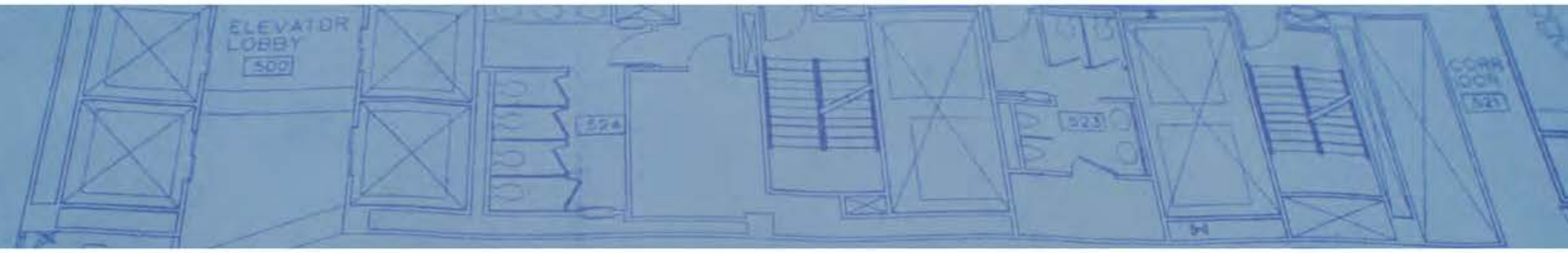
Fifth Edition



The Construction of Houses

Duncan Marshall, Derek Worthing,
Nigel Dann and Roger Heath

EG Books

ROUTLEDGE

THE
CONSTRUCTION
of HOUSES

The fifth edition of this successful textbook is aimed specifically at those students and practitioners who require a broad understanding of building construction as part of a wider sphere of professional activity. The book provides a comprehensive introduction to the principles and practice of modern construction and services.

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THE CONSTRUCTION *of* HOUSES

FIFTH EDITION

Duncan Marshall,
Derek Worthing,
Nigel Dann,
and Roger Heath

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Preface

This is the fifth edition of *The Construction of Houses,* which was first published in 1990. The book has continually evolved through each edition, but this latest edition has seen, perhaps, the most significant changes in content. For this new edition each chapter has been thoroughly reviewed and new content added where appropriate. Furthermore, the very important issue of sustainability, which has had such a significant effect on the construction of houses, is reflected in the reworked individual chapters of this new edition, and placed in context by a new chapter giving an overview of sustainability. New chapters on ventilation and decoration, plus an introductory chapter which sets construction in its wider context and establishes its background, have been added.

Despite these significant changes, the aim remains the same as it did for the first edition: to produce an interesting, up-to-date, and informative introduction to domestic building construction and services which will be of value to all those students and practitioners who work, or intend to work in what is now commonly known as the Built Environment.

The book is aimed not just at those who need to develop a broad understanding of domestic construction as part of their studies; it will also be invaluable to those already in professional practice seeking reference or guidance.

Although much of the content has been updated and new material added for this latest edition, it retains the three main objectives that have helped to shape all the previous editions of the book:

- *to provide a broad understanding of the principles of house construction*
- *to introduce the reader to current building practice*
- *to explain earlier forms of construction in order to reflect the fact that dwellings built after 1990 account for only about 12% of the housing stock.*

This book is not, therefore, a catalogue of modern construction details, but is intended to provide a balance of knowledge and understanding in order to give students and practitioners:

- *a good foundation for further study*
- *confidence and competence in their dealings with other building professionals or members of the public*
- *the ability to evaluate the mass of authoritative advice and trade literature currently available.*

Following on from the contextual material contained in Chapter 1 Introduction and Chapter 2 Sustainability, the chapters are divided up into the key elements of a house (foundations, floors, walls, etc.) with additional chapters on thermal insulation and condensation and on 'system' building/modern methods of construction. The chapters covering building services concentrate on providing a broad introduction to the various systems and installations available, rather than a detailed examination of their individual components.

Where possible, each chapter traces the evolution of modern construction, partly because, as we have said, much of the UK's existing housing stock is old, but also to show that today's building practice has largely developed through an understanding of yesterday's failures, or new requirements for how a house fulfils its function.

The first two editions of the book contained short sections on building defects. These have been omitted in the later editions, partly to make way for new material, and partly because our other book, *Understanding Housing Defects* (third edition published in 2009 and a fourth edition planned for publication in 2013) covers this area in much more detail.

It is important to understand that the construction methods and materials that are described in this book, while up to date and current, intentionally reflect 'the norm' in new-build house construction as it stands at the early part of the second decade of the twenty-first century. It, therefore, reflects what is being built by the 'average' developer for the majority of occupiers. So, for example, while the book includes changes in construction, materials and services which have been developed and used as part of a reaction to sustainability and energy efficiency issues (such as photovoltaic cells and solar panels), it does not include discussion of elements or features which are not in mainstream use at present, or which are unlikely to be in the near future (such as green roofs, straw bales and hemp-based materials). Also, the book does not include reference to services such as wind power and community heat and power schemes, because it has concentrated on the construction of the individual house – albeit that those described in the book are most likely to be built as part of a larger development. Because the book deliberately concentrates on the type of house that is likely to be built by the mainstream developers, it makes no reference to the 'one-off' types of design and construction that might be used by individual architects for specific clients (e.g. those making use of 'steel and glass' or glulam beams).

Finally, as the title implies, this is a book about house construction, and so, although there are one or two references to the differences in treatment between flats and houses, these are in the nature of asides rather than a discussion on the construction of those domestic dwellings that are not houses.

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Marley Eternit
Naylor Bros (Clayware) Ltd
Samantha Organ
Polypipe Terrain
Prestoplan
Redrow
RMC Flooring
Roger Bullivant Limited
Solar Trade Association
Steetley Brick & Tile Ltd
Styro Stone
Surebuild (steel framing)
Truss Form (Midlands) Ltd
Viridian Solar
Wavin Ltd
Yorkshire Fittings

DUNCAN MARSHALL

Duncan Marshall and Derek Worthing were the authors of the first four editions of *The Construction of Houses*. Sadly, Duncan died in 2009. Duncan is still rightfully included as one of the authors of this new edition, not only as a sign of respect, but also because he was such an important part of developing the character and content of the original book and all the previous editions and, while most of the new material in the book had to be written without him, the core and feel (and indeed much of the content) of the book remains that which he and Derek developed over the years. Duncan's memory lives on in this new edition, which we would like to dedicate to him.

Derek Worthing, Nigel Dann and Roger Heath

Introduction

1

This chapter provides guidance for those new to the subject on how to set about the study of building construction. It includes general notes on a number of over-arching principles, statutory requirements, standards and procedures that apply to the construction process, particularly to houses. These are also highlighted, but not necessarily discussed in detail, in the chapters that follow. Reference is also made in this chapter to sources where further information on building construction and design may be found.

The book focuses on low-rise domestic construction, i.e. houses of two or three storeys and bungalows. Where appropriate, reference is made to flats/apartments, although these are more often to be found in high-rise buildings, which are outside of the scope of this book.

House construction in England and Wales is the main focus of the book. While specific practices that differ from those in Scotland and Northern Ireland may exist, the principles of construction are similar throughout the United Kingdom.

It must be realised that the construction process is a continuum. The development and application of new design and building techniques, materials and components never ceases. The environment in which it takes place does not remain constant. The performance requirements of buildings are continually increasing. The way in which space is used as well as the appearance (internally and externally) of buildings are all subject to frequent change as they react to shifts in the housing market, driven by consumer demand, government legislation and the influence of building designers.

How to 'read' construction

Some students of building construction have no difficulty in assimilating and understanding what it is all about. The written descriptions and the details set out in the construction diagrams all make logical sense from the moment they open their first textbook. Others simply struggle; however often they read the text and review the diagrams and photographs, all they see is a fog of facts and details, none of which makes clear sense. Even if one part does become clear, making connections with the other areas of construction remains difficult.

How is it possible to overcome this challenge?

Many students do overcome this initial barrier, including at least one of the authors who spent the first year of his studies wondering if the construction of a building would ever make sense. There is probably no 'Eureka!' moment for most of us; it is simply a matter of working out a strategy that enables us to comprehend the construction process and its details.

One method of study that creates difficulties for many students of construction is attempting to learn the subject from just reading one or more textbooks. Construction is very much a hands-on subject and attempting to learn about it by simply cramming information from a book is not highly productive. The learning process needs a much more pro-active engagement with the subject. This book can provide basic knowledge, but the student also needs the stimulus of going out and looking at buildings in the light of that knowledge. This will aid assimilation. If possible, also look at active building operations. It is also very helpful to sketch or draw construction details, whether from real life or from a textbook.

The importance of learning how to sketch

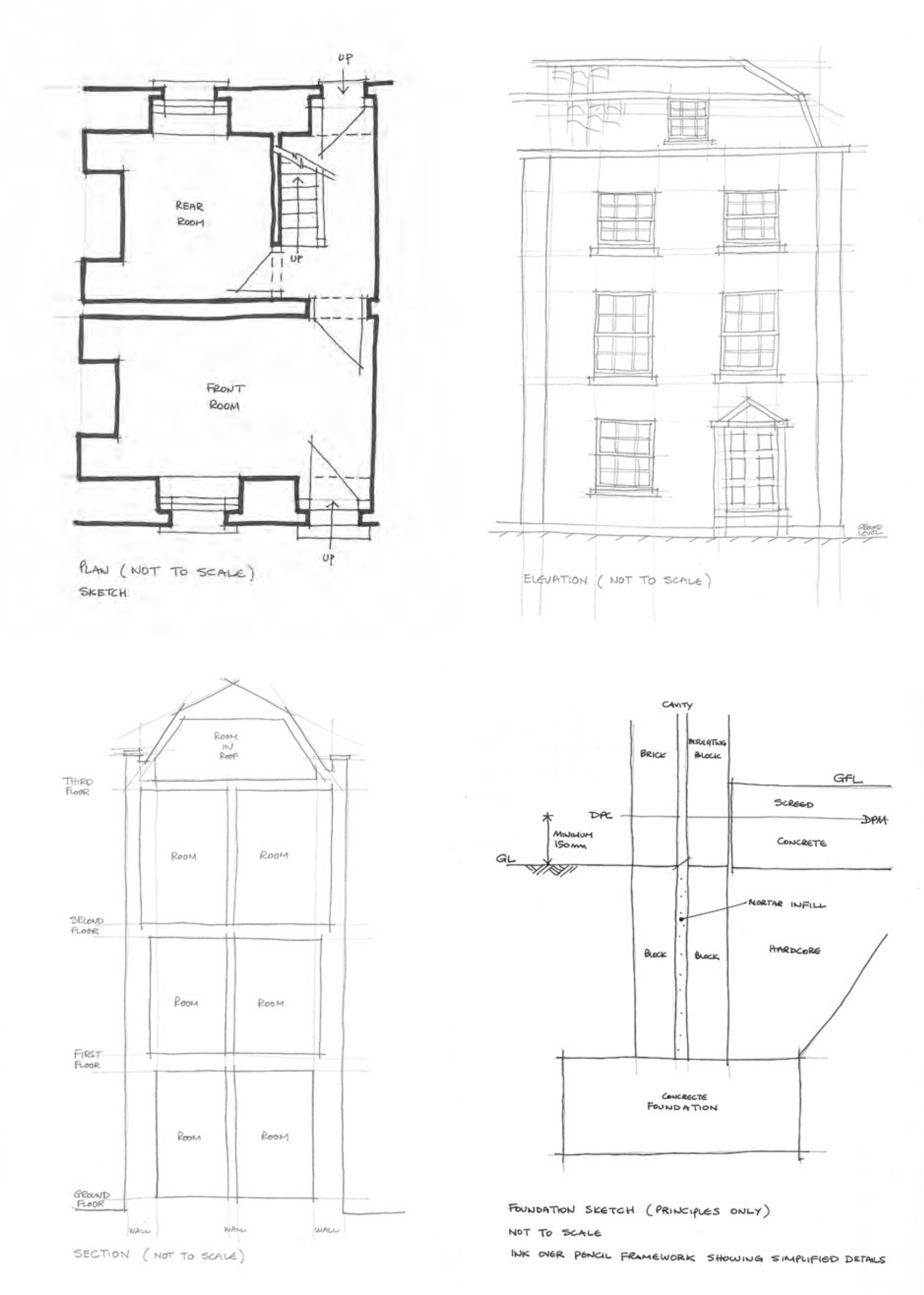
It is an important skill for any student of construction (and for the experienced practitioner as well) to be able to sketch or draw construction details, whether from real life or by copying from a textbook. Sketching, in this sense, means freehand drawing, while drawing is based on the use of straight edges and set-squares to aid greater accuracy (and confidence). You may have heard of technical drawing, which normally involves drawing to scale, but that level of accuracy is not needed at this stage, unless you plan to make design part of your future profession. As a beginner, you may also find it helpful to purchase a good book on architectural draughtsmanship.

In this book, as in other books on construction, there are many diagrams showing plans, sections and elevations of houses. These, in combination with the accompanying text, help to explain design and construction principles and application. An example of each is illustrated opposite.

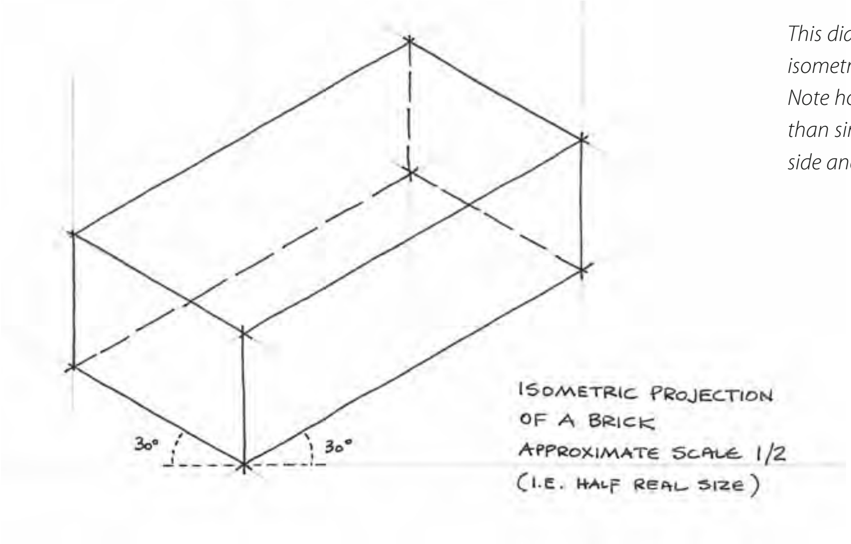
The first point to understand is that you need to learn to sketch (or draw) what you actually see. Choose a simple diagram from the book and then redraw it as a sketch. Always sketch or draw using a fairly soft pencil, such as HB. It can be helpful to sketch on graph paper, especially if you lack confidence in your draughtsmanship. At the first attempt lines may be wobbly, but that is unimportant. What matters is that the sketch gives you a better appreciation of the construction detail. The lines will become straighter and more clearly defined with practice. Use light pencil lines to start with to shape an outline or framework of what you see (at this stage a ruler may be helpful) and then firm the lines up (freehand) to make a copy of what you see – you can try inking them in as shown in the sketch of the floor plan opposite. Such an exercise will transform the selected detail, be it of a foundation or a roof, from some vague representation in your textbook to hard fact that means something to you. If it does not work first time, repeat the exercise as many times as necessary for the construction detail to become meaningful. The use of different coloured pencils or pens to highlight particular details can also aid your knowledge assimilation.

Repetition of the exercise for the same piece of detail or sketching of the different parts of a building should enable you to master a skill that you initially feared. It is surprising how students who believe that they have no artistic or technical ability can, with application, develop sufficient drawing skill to really aid their understanding of construction details and processes. Even a crude sketch, clearly executed, can be informative. Sketching also means clearer communication of construction principles and ideas generally in terms of examinations or in a future career.

As practice makes you more proficient, you could practise sketching what is known as an orthographic projection. This is a method where you draw or sketch a three-dimensional object, such as a brick or a house, in two dimensions, i.e. on a sheet of paper. Detailed guidance on how to go about this can be obtained from books on draughtsmanship, where you will find that there are a number of different types of orthographic projection, including isometric projection. You could start by sketching something simple, such as a brick, and graduate to more adventurous subjects. An example of a brick drawn in isometric projection is shown on page 4.



The first three sketches are of a Georgian house – plan, elevation and section. The fourth sketch (bottom right) is of a modern foundation and cavity wall. In all of them, you can see the initial pencil framework on which the hard detail is finally sketched.



This diagram is an example of an isometric projection of a brick. Note how much more informative it is than simple diagrams of each of the side and end elevations.

When undertaking detailed design of a building, it is usual practice to produce scale drawings showing the design information. Sketching, in contrast, is not usually to scale as it is difficult to draw freehand to an exact scale. The technical drawings, i.e. plans, elevations and sections, are normally drawn to one or more scales that reflect the level of detail required by the development team, so that land, buildings or objects shown are represented at a size that is in proportion to actual size – normally a smaller scale for land and a larger scale for construction details. For example, 1/50 (which means that the drawing is one-fiftieth of the full-size subject) would be used for a floor plan or elevation, while 1/200 would be used for a site plan showing a proposed building in outline plus the land on which it sits. Today, technical drawings for building projects are normally produced by computer-aided design (CAD) systems.

Some key terms

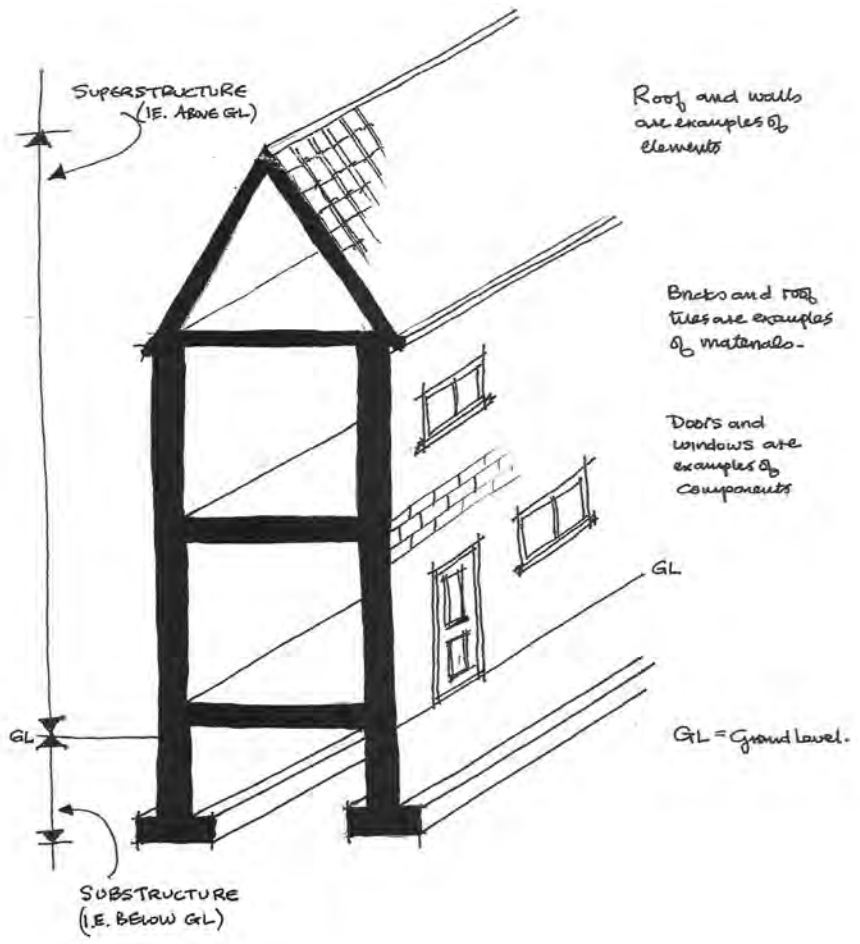
You also need to become familiar with some of the key terms that are used by construction designers and contractors. They include elements of construction, materials and components.

An **element of construction** (or element) is the term used to describe the basic units from which a building is formed, such as the walls, the floors and the roof. A simple building, such as a garage, will have six elements – four external walls, the ground floor and the roof. A building of complex design will have many more elements: external and internal walls, several floors and possibly a number of different roofs. The elements are carefully fitted together so that, in principle, walls provide support to each other as well as to floors and roofs.

Each element is formed from various **materials** and may contain **components**. For example, a wall may be solid or have two skins with a cavity between. A solid wall may be formed from one or more materials. Each skin of a cavity wall can be formed from different materials, for example, an outer skin of brick and an inner skin of concrete blocks. The wall may have one or more components built into it, such as a window or a door. Internal fittings, such as kitchen units or wash basins, etc., are also components.

Buildings consist of above- and below-ground construction. That part of the construction below ground is known as the **substructure**, all of the structure above ground level is called the **superstructure**.

The construction process is further divided between first fix and second fix. **First fix** comprises all construction from foundations to the provision of plaster on walls and includes all carcassing joinery (e.g. roof and floor timbers), plumbing pipework and electrical wiring. **Second**



fix denotes that part of the construction process that completes the building and includes finishing joinery (e.g. staircases, skirtings, door frames and doors), plumbing fittings and electrical components. These two terms are more likely to be used during the actual construction process rather than when a building is being designed.

Metric and imperial dimensions

One final point must be made. Until comparatively recently, UK building design and construction was based on the imperial system of measurement rather than the metric system. All construction design and manufacture is now based on the latter and you will find only metric dimensions used in this book.

However, when inspecting and dealing with construction in older buildings, it should be noted that component and material sizes do not readily translate between the two measurement systems and, therefore, it is helpful, but not essential, to have knowledge of both. Some metric sizes make sense (e.g. a 200mm x 100mm piece of timber), others are odd conversions from the old imperial sizes, one example being that of a standard brick. Under the imperial system, its nominal measurements including the mortar joints were 9″ (228.6mm) long x 4½″ (114.3mm) wide x 3″ (76.2mm) high. A metric brick is nominally sized at 225mm x 112.5mm x 75mm which, although slightly smaller, is a close conversion from the imperial size. Metrification also means that care must be taken when working on older buildings to take account of sizing differences, although some manufacturers of materials and components do still provide imperial products for the refurbishment market.

The statutory control of building and development

Historic background

The materials and techniques used in the construction of our houses have changed considerably during the past few hundred years. This evolution is due to a number of factors besides the obvious one of advances in technology. Economic, political and social pressures have all played their part in affecting the quality of our built environment. Perhaps the most influential factors were the social pressures brought about by the realisation of the connection between poor housing and ill health. This led to a number of Acts of Parliament from the Victorian period onwards that eventually established basic requirements for decent housing conditions. These requirements included adequate sanitation, water supply, natural light, ventilation, and freedom from damp. These criteria still influence the way that houses are designed and built today and many of them are covered by the Building Regulations, which were first introduced in 1965 and have been amended several times since. The primary purpose of the Building Regulations is to establish minimum standards to ensure the health and safety of the building's occupants. They do not, as some people assume, necessarily define quality or levels of workmanship.

Other legislation affecting the construction of houses includes Public Health Acts, Housing Acts, Planning Acts and the Water Regulations. Brief details of some of the key statutes and regulations are set out below and further references to them are made, where relevant, in the chapters that follow.

The Building Regulations

All new building work and most alterations to existing buildings must meet the requirements of the Building Regulations. These set mandatory standards of design and construction and cover all of England and Wales. There are separate Building Regulations for Scotland and for Northern Ireland. The regulations are concerned with the health and safety of building users, energy conservation and access to and use of buildings and are made under the statutory powers of the Building Act 1984. The Building Regulations for England and Wales have been updated at frequent intervals since their introduction in 1965 and the latest edition at the time of writing is the Building Regulations 2010. Further reviews are in the pipeline.

Guidance on how to comply with the Regulations is set out in a series of Approved Documents which detail 'broad functional requirements' for the performance of a building. They offer designers the opportunity of strictly following the technical guidance that they contain or, alternatively, undertaking more liberal interpretations, as long as the design meets the minimum performance standards set out.

A sense of the range of the performance requirements of the Building Regulations 2010 can be gained from the headings of the Approved Documents:

A: Structure
B: Fire safety
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
L2A: Conservation of fuel and power – new buildings other than dwellings
L2B: Conservation of fuel and power – existing buildings other than dwellings
M: Access to and use of buildings
N: Glazing – safety in relation to impact, opening and cleaning
P: Electrical safety – dwellings
7: Materials and workmanship.

As well as the Approved Documents, there are sections within the Building Regulations dealing with definitions, procedures to be followed and the types of building that are exempt from control. Each edition of the Building Regulations has raised and extended the performance standards required of buildings, much of the recent focus being on electrical safety and sustainability requirements, including the conservation of energy.

A key point to note is that, once controlled work has been completed, a building does not have to conform to later and higher building standards unless work is subsequently undertaken on it that requires further statutory permission. This means that many houses do not comply with current building standards.

Planning controls

It has been a statutory requirement since the Town and Country Planning Act 1947 that all 'new development' within the United Kingdom requires planning permission. Subsequent legislation has amended the 1947 statute, but the principle is that all new development (including totally new buildings, new extensions if above a certain size or to the front of a building and the change of use of a building) is subject to planning control. Heritage protection is also important and there are further planning controls over listed buildings (i.e. buildings placed on the Statutory List of Buildings of Special Architectural or Historic Interest) and over buildings situated in a conservation area.

An application must be made to the appropriate local authority, setting out details of the proposed development. In terms of a wholly new building, the application may be for outline permission or detailed permission. There is a system of appeal to the Secretary of State (for the environment) if a planning application is rejected by a local authority; appeals are handled by the Planning Inspectorate (a government body).

The statutory controls allow certain classes of development to houses, but not to flats and other buildings, to be 'permitted development', i.e. certain changes can be made to a house without the need to obtain planning permission. These are known as '**permitted development rights**' and include, subject to certain restrictions, such building works as the erection of small extensions and porches and also loft conversions.

The Defective Premises Act 1972

This statute applies to dwelling houses in terms of new construction, enlargement of an existing dwelling or conversion to a new dwelling. It states that the work is to be done in a workmanlike or professional manner with proper materials and the dwelling is to be 'fit for habitation' when complete. It imposes a legal liability on a contractor, designer or developer to a domestic client plus any subsequent purchaser or tenant for a six-year period from completion of the building work.

Sources of 'authoritative advice'

There are a number of sources of 'authoritative advice' which offer advice and guidance on good building practice. Perhaps the most prolific and significant source is the British Standards Institution (BSI), which regularly publishes detailed guidance on a variety of technical matters. This guidance includes British Standards (BS), which cover such areas as the quality, performance characteristics and dimensions of materials and Codes of Practice (BSCP) which deal with wider issues such as building design and construction methods. However, the European Union (EU) is attempting to harmonise building practice across Europe with the result that many British Standards have been, or are about to be, superseded by European Standards (EN). The EU has also introduced Eurocodes; these are recently standardised design codes for building and civil engineering in Member States and are intended to become mandatory.

Further 'authoritative advice' is published by the British Board of Agrément (BBA), which appraises new products and techniques, and also by the Building Research Establishment Group (BRE), which produces a number of invaluable reports and digests on all aspects of construction.

Trade bodies, such as the Brick Development Association (BDA), the Lead Development Association (LDA), the Timber Research and Development Association (TRADA) and also many material and component manufacturers produce excellent guides on specific products (for example, the design tables from TRADA are specifically referenced in the Approved Documents of the Building Regulations Part B). Finally, most volume house-builders are members of the National House-Building Council (NHBC), which sets out minimum standards of construction for new housing and produces regular bulletins and guidance relating to those standards and to building defects.

A brief history of housing in England and Wales

The historical recognition of the form of houses tends to be identified by reference to a period of English architectural style, for example Tudor or Victorian. The majority of the current housing stock dates from the middle of the nineteenth century and later, although there are earlier houses in existence, such as sixteenth century (Tudor), seventeenth century (Stuart, Carolingian, William and Mary), eighteenth century (Queen Ann, Georgian) and early nineteenth century (Regency). Nearly all of the extant houses of the sixteenth, seventeenth, eighteenth and early nineteenth centuries are houses that were built for the so-called middle class (e.g. merchants and professionals) and upper class. Only rare examples of cheaper housing from these periods still exist.

The mid- and late nineteenth century (Victorian) saw a huge boom in the construction of housing in response to the mass movement of people from the countryside into the cities as a result of the Industrial Revolution. Cheap terraced houses for the workers, more spacious semi-detached houses for the managers and detached villas for the owners were developed in vast numbers on the outskirts of older towns, often by speculative builders, sometimes by the well-off themselves. These houses had solid walls of brickwork and/or stone, sometimes finished with render, roofs of clay tiles or slates, brick or timber-framed internal partitions, gas lighting, rudimentary cooking, washing and lavatory facilities and coal fires for heating. Much of the cheapest housing was of poor quality, using, for example, sun-baked bricks, and has subsequently been demolished. However, large numbers of terraced, semi-detached and detached Victorian houses are still in existence, albeit modernised at various times during the intervening period.

Houses built in the first decade of the twentieth century (the Edwardian period) are considered by many experts to be the pinnacle of quality in terms of workmanship and materials. Facilities are similar to those of the preceding century but of better quality. This period also saw the rise of the Garden City Movement, based on the writing of Sir Ebenezer Howard, who was highly critical of the urban development of the period and promoted the idea of a planned city with generous public spaces and buildings, low-density houses with large gardens in broad tree-lined streets and separate zones for factories and other industrial development. This led to the creation of garden city towns, such as Letchworth, Hampstead Garden Suburb and Welwyn.

The period between the First World War and the Second World War (the inter-war period) saw much greater state intervention in housing. Previously, involvement on the part of the state had been restricted to the provision of legislation encouraging local authorities to take action, but now the government legislated and provided the funding for the development of council housing, i.e. local authority social housing. There was also considerable private speculative housing development, leading to the suburban expansion of many cities. Both the council and the private housing of the period, particularly the former, reflected some of the principles of the Garden City Movement, especially the low-density housing, large gardens and broad tree-lined streets. This period saw cavity-wall construction and concrete foundations become standard. Floors and roofs were still constructed using cut timbers, bathroom and kitchen fittings were installed as standard, but were still very basic, hot water was often provided by a gas heater and space heating was again based on open fireplaces. Many rural houses still had no piped water, mains electricity or mains drainage.

During both World Wars housing development was suspended and after the Second World War little housing construction took place, apart from repairing bomb-damaged houses, until the mid-1950s when the post-war period of house building really commenced. Both council housing and private speculative development boomed for the next 20 years, although the standards were still relatively low, e.g. few new houses had central heating and roof insulation was non-existent until 1965, and then only minimal. However, most rural properties now had mains electricity and water, and mains drainage became more common. Gradually, from the 1970s onwards, trussed roofs, often finished with concrete tiles, became standard and modern timber framed construction became relatively popular after a difficult introductory period; even where cavity construction continued to be used, timber or steel framed internal partitions were commonly installed. Central heating became the norm, and during the 1990s, cavity wall insulation and double glazing became standard in new housing developments. Dry wall finishes were also prevalent for new development. During the past 30 years or so, increasing use has been made of new materials and techniques. Examples include composite timber products for structural purposes and finishes and plasticised products, ranging from components such as windows to paint systems. There has also been recognition that many older and sometimes discarded, or unfashionable, products and materials are still relevant, e.g. clay roof tiles, roofing slates, lead work and lime mortar.

The construction process

There are two distinct elements to the construction process – design and construction – and the whole process from initial idea to delivery of a finished building is known as procurement. Building procurement is a very complex subject, with a number of alternative methods, and the following description is a simplified introduction to it.

A person or organisation (known as the client or employer) will wish to have building works carried out, e.g. a project for the construction of a new house. Frequently, the client will raise the finance for the project and look for a professional designer (e.g. architect, architectural technician, building surveyor) and a building contractor to undertake all construction; this is known as traditional procurement, where design and construction are undertaken by separate organisations. However, in an increasing number of projects, the client will expect to have the whole construction process undertaken by a single organisation, which carries out both the design and the construction processes, and this is known as design and build procurement. The two procurement methods referred to above are those most commonly used for house construction. Selection of a contractor is normally by means of a tender process – this is a procedure in which competing contractors submit prices and other information that enable the client to make a considered choice of a specific contractor.

Whichever procurement method is used, once appointed (normally by means of a formal contract), the chosen contractor will carry out the building works. Sometimes the contractor will undertake all of the necessary works itself, but more often they will be carried out by specialist subcontractors who work under the direction of the contactor (who is then usually referred to as the main contractor). Subcontractors include bricklayers, electricians, plasterers and plumbers. Specialist suppliers provide materials (such as sand, cement, timber, bricks and plaster) and components (such as bathroom and kitchen fittings, doors and windows).

The new-build housing market is divided between the private and public sectors. The private sector is dominated by housing developers. These are building contractors who undertake both the design and construction of housing, often with in-house staff, although they may also make use of subcontractors for either process. These housing developments may range in size from a few houses to many hundreds or thousands and in some cases complete new towns. In the private sector, there are a relatively small number of very large developers and a greater number of small and medium-sized developers. In the public sector, new housing is currently undertaken by housing associations, although before the 1970s new public sector housing was developed by local authorities. These public bodies make use of private sector developers and contractors to undertake the actual construction of the houses.

Although the majority of new housing is constructed by developers, there are many new houses built for individual owners by contractors. However, an alternative and increasingly popular means of new house construction is self-build. This involves an individual, or group of individuals, who wish to have a new house or houses built for their own occupation, finding suitable land, organising plans from a professional designer and then actually getting involved in the construction process itself, often by physically building the house themselves. Alternatively, they appoint specialist contactors to undertake all or some of the construction work under their own general direction or that of a professional project manager. Self-build currently provides approximately 20 per cent of all new homes in the UK.

Finally, it should be noted that the construction industry has always been one of the most dangerous industries to work in. It is safer now than formerly because there is wide-ranging and continually increasing legislation that applies to the health and safety of the workforce and those with whom it comes into contact.

Modern methods of construction (MMC)

Much prefabricated housing was constructed throughout the twentieth century, especially during periods of high housing demand. Approximately one million prefabricated homes were built, many of a temporary nature. Unfortunately, they were not always of a high standard due to a mixture of construction problems and poor workmanship, although it was evident that higher standards of prefabricated buildings were being achieved by the end of the century.

By the early twenty-first century, it had become apparent that high-quality prefabrication was needed in answer to the demand for faster construction and to overcome shortages of skilled labour. 'Modern methods of construction' (MMC) was derived as a term to highlight the creation and use of better prefabricated building products and processes throughout the UK construction industry that would result in greater efficiency and quality. The products and processes would also meet rising standards of sustainability and environmental performance. Overall, the aim of MMC is to provide economic and energy-efficient buildings.

The term refers to a range of relatively new industrialised construction processes and technologies that involve factory prefabrication, modular construction, off-site construction, manufacture and/or assembly and other forms of system building. MMC also includes the use of innovative building systems that are constructed on site, as well as the recycling of materials and the reduction or avoidance of waste. Some of these 'modern' methods have been used for some time, but they are all increasingly seen as providing the means of providing sustainable and affordable housing.

Examples of MMC processes (some of which are discussed in more detail in later chapters) include the following.

- **Modular construction (also called volumetric construction):** *Fully fitted-out three dimensional units (known as pods) are factory-produced and stacked on site, one above another, to form a building. They are mostly used for multi-storey buildings such as flats, although smaller bathroom and kitchen pods are increasingly used for housing.*
- **Panellised construction systems:** *Factory-formed flat panels (wall, floor and roof panels – the latter two known as cassettes) are assembled on site into a three-dimensional structure. There are many different types of panel including: open panels or closed panels – both associated with timber-framed and steel-framed housing construction – and structurally insulated panels (SIPs).*
- **Hybrid construction (also called semi-volumetric construction):** *Highly serviced areas, such as bathrooms and kitchens, are factory-constructed as pods and fitted into a dwelling that has otherwise been constructed with panels.*
- **Sub-assemblies and components:** *These are larger components that can be incorporated into conventionally built or MMC dwellings. Examples include: floor and roof cassettes, prefabricated dormers and prefabricated (i.e. pre-assembled) plumbing.*

Conclusion

This chapter and those that follow aim to give a clear insight into the principles of domestic building construction. Further knowledge can be gained from the many other sources of information on both the design and the construction of buildings that are available to the student or the practitioner, such as textbooks and websites as well as journals and magazines, including those published by professional bodies and trade organisations.

Sustainability

2

Sustainable development: an overview

The idea of sustainable development, that is to achieve sustainable outcomes from human activity, has been around for some considerable time. Sustainability can be seen as a rather complex notion that, in detail if not in concept, has become so all encompassing and can include so many factors that it is difficult to articulate, never mind measure. One of the consequences is that it is often easier to prove a negative (i.e. that something is not sustainable) than a positive (i.e. that something is sustainable).

The often quoted definition of sustainable development by the Brundtland Commission (1987), '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' is clearly aspirational but does raise the interesting distinction between 'needs' as opposed to 'wants'.

It is important to understand that, although the idea of sustainable development can be seen to have emerged from various environmental concerns, it is much wider in scope than just the interaction between development and the environment, because sustainability also encompasses social and economic issues and activities. Sustainable development can be seen as development that brings the best fit between social, economic and environmental concerns. It aims to maximise all of these three benefit categories as far as possible, but there is also an implication that there may be a trade-off between them. That is, there may be a case where realising social benefits is justifiable even where there may be some negative effects on the environment – and vice versa. A good example might be where the creation of employment opportunities or a need for a new housing development may result in some loss of environmental benefits. Alternatively, the necessity to protect the environment in a particular instance may come at a cost to social and economic benefits. So, although a sustainable approach would be to seek solutions that maximised all three benefits, it may be that some aspects of sustainability are considered, in particular cases, to be more important than others. There is, however, generally an implication that economic benefits should be long term rather than short term, and should not be sought at the cost of social and environmental benefits. It can be seen that a key aspect of sustainability is social sustainability – and that environmental benefits and certain economic benefits are also, or at least can be, social benefits.

Sustainable development, and hence the notion of sustainability, is therefore concerned with the synthesis and integration of social, economic and environmental benefits.

In the context of housing, sustainable development will require that a variety of issues, including such matters as affordable housing, mixing social and private housing, character and a sense of place, access to facilities, infrastructure and centres of employment, etc. are addressed alongside environmental issues.

In relation to housing development and environmental sustainability, issues such as where to build will raise a number of important policy issues, such as the provision of homes in rural areas, the use of brownfield sites (which essentially 'recycle' land), the capacity of existing infrastructure, access to public transport, etc. So a low-energy development which is situated so that people have no choice but to travel by car to shops, places of recreation, work, etc., cannot be considered to be environmentally friendly.

Within any housing development, design issues, such as safety, character, car-free areas, play areas, the provision of green and recreational space, and the encouragement and protection of wildlife habitat, etc., are examples of some of the environmental sustainability factors which should be addressed.

There has also been much emphasis on the risk of flooding in recent years. Ensuring that a housing development is safe from the risk of flooding is an important sustainability issue, which relates to whether or not the development is sited in a flood-risk area, and, if it is, how the design of the site and the individual properties can mitigate the risk of flood damage. There is a second aspect to the issue of flooding, and that is that new developments should be designed so that they do not increase the risk of flooding elsewhere. Sustainable drainage designs make an important contribution to reducing flooding (and pollution) risk.

All of the above issues need to be taken into account in planning, designing and constructing a new housing development in a sustainable manner. However, they are outside the intention and scope of this book. The book therefore only specifically addresses how the issue of sustainable development relates to the construction of individual new houses; it does not cover the planning and design of estates.

Environmental sustainability and the construction of houses

Background

Since the mid-nineteenth century there has been growing concern about the interaction between humans, buildings and the environment. However, the main focus of concern was usually the effect on human health rather than on the environment (as seen in the Public Health Act of 1875, for example). It was perhaps not until the 1960s that concerns about the effect of human activity on the environment started to be more widely discussed, but it was in the early 1970s that the specific issue of energy became more prominent, when the Western world found itself embroiled in a series of energy crises precipitated by the Arab oil embargo. The embargo highlighted the vulnerability of the many countries that were not self-sufficient in terms of energy supply and, to some extent, the present emphasis on reducing energy, while focused on tackling climate change, is also being driven by concerns about the security of energy supply, particularly given the reliance that is increasingly being placed on gas and oil from abroad. A greater environmental awareness, plus the wake-up call of the oil embargo, meant that there followed a relatively large amount of research into low-energy buildings and energy conservation generally. The results of some of this research can be seen in the development of 'alternative' energy sources, where power is derived, for example, from the wind, sun or the waves. Despite some advances in the development and implementation of these approaches, the vast majority of energy used today is still derived from fossil fuels. The obvious problem for the near future is that these fossil fuels are a finite resource. However, a more immediate concern is the environmental damage caused by the burning of fossil fuels, the two principal effects being:

- *the production of carbon dioxide (CO_2) (and other gases), which contributes to the 'greenhouse effect' and thus to global warming (climate change)*
- *the emission of oxides of nitrogen and sulphur, which contribute to the production of 'acid rain'.*

A significant proportion of CO_2 emissions are produced by houses through the amount and type of fuel used in their construction and repair, as well as in the day-to-day running of the house. This latter factor is affected by:

- *energy used to heat (and perhaps ventilate) the house*
- *electricity required to provide adequate lighting*
- *energy required to provide hot water*
- *energy required to run increasing numbers of domestic appliances.*

The built environment and climate change

It is clear that the biggest environmental challenge facing humanity is the problem of climate change caused by global warming. The principal cause of global warming is the production of greenhouse gases. Although carbon dioxide is the main culprit, other gases, such as methane, nitrous oxide and fluorocarbons, contribute to the problem (the focus on CO_2 is due to the comparatively large amount of this gas that is produced and also the length of time that it remains in the atmosphere).

The major factors generating the production of greenhouse gases are the burning of fossil fuels, the destruction of forests (including rainforests) and some agricultural practices.

Figures from the UK Government suggest that the construction industry produces approximately 47 per cent of the UK's total carbon dioxide emissions and about 63 per cent of this figure is produced by the domestic sector.

In the recent past, it was common to concentrate on attempts to build homes which used less energy for heating and lighting. This is still a very important focus, but the sustainability agenda has widened the scope of appropriate issues and engendered a more holistic approach. The appropriate environmental issues to be addressed, in addition to energy used during occupation of the house, include:

- *energy used, and carbon dioxide released, in the production of building materials and in their transport to site*
- *whether materials used are naturally renewable – and, if so, whether they are derived from sources which are managed in an ecologically beneficial manner*
- *the extent to which materials have to be treated with chemicals in order to make them perform effectively*
- *the amount of water used in the production of materials and in their use in the construction process*
- *the amount of (and nature of) materials which are wasted on site*
- *the extent to which the production and use of materials might produce environmental pollution*
- *the life expectancy of material and components.*

UK Government policy

A number of national and international agreements and policies have focused on the need to reduce global warming, and these have therefore had a significant effect on developing guidance, legislation and practice in relation to the construction of housing. Perhaps the best-known of the international agreements is the 1997 Kyoto Protocol, which led to legally binding targets for reducing greenhouse gases. In the UK these targets were enshrined in the 2008 Climate Change Act, which set down the Government's aim to reduce the UK's CO_2 emissions by at least 34 per cent below 1990 levels over the period 2008 to 2022, and by at least 80 per cent by 2050.

In 2006, the Government-commissioned Stern Review produced an influential and often quoted report entitled *The Economics of Climate Change*. The report considered the consequences of climate change from an economic, political and social perspective as well as an environmental one and suggested that:

> *climate change will affect the basic elements of life for people around the world – access to water, food production, health, and the environment. Hundreds of millions of people could suffer hunger, water shortages and coastal flooding as the world warms.*

It also suggested that:

> *the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. [...] If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.*

The Stern Report also said that stabilisation of climate change required that annual emissions of greenhouse gases would have to be brought down to more than 80 per cent below current levels and that this could be achieved through:

- *increased energy efficiency, effected by changes in demand, and through adoption of clean power, heat and transport technologies*
- *extensive carbon capture and storage (in order to allow the continued use of fossil fuels without damage to the atmosphere)*
- *cuts in non-energy emissions, such as those resulting from deforestation and from agricultural and industrial processes.*

One specific action implemented by the Government to reduce carbon dioxide emissions in new housing has been the Code for Sustainable Homes. The aim is that, by 2016, all new houses should be 'zero carbon'. The Code is discussed later in more detail. Examples of other policies, statutory obligations and incentives that have been enacted, and which affect the wider construction industry as well as the housing development sector, are given below.

The European Commission's (EC) Energy Performance of Buildings Directive (EPBD)

This Directive was introduced in 2003 and strengthened in 2010. One of its requirements is that all EU countries apply minimum standards of energy performance for new and existing buildings and ensure the certification of their energy performance. This Directive was the driver for the certification of the energy performance of new and existing buildings in the UK (and indirectly the Code for Sustainable Homes), a requirement that was transposed into legislation by the Housing Act of 2004 and the Energy Performance of Buildings (Certificates and Inspections) (England and Wales) Regulations 2007. Energy Performance Certificates (EPCs) are required for buildings when they are constructed, sold or let. An EPC gives information on a building's energy use in operation, together with information on how performance could be enhanced and CO_2 emissions reduced.

Planning Policy Statement 1: Planning and Climate Change (PPS1)

This was introduced in 2005 and relates to the delivery of sustainable development within the planning system. PPS1 requires regional planning bodies and local planning authorities to ensure that development plans contain policies that reduce energy use, reduce emissions and promote the use of renewable energy. Such policies might relate to, for example, encouraging developments that reduce the need for travel by car, or a requirement for the use of renewable energy in new housing developments (usually by reference to the Code for Sustainable Homes – see below).

Building Regulations

The Building Regulations directly and significantly affect all new or substantially altered buildings. They are seen as a key instrument for the delivery of zero-carbon homes by 2016. The intention is to achieve this goal through progressively stringent 'stepped-changes' to, in particular, Part L of the Regulations – Conservation of Fuel and Power.

Feed-in Tariff

The Feed-in Tariff (FIT) scheme was launched in April 2010 and was facilitated through the Energy Act 2008. The aim of the scheme is to encourage the installation of small scale (less than 5MW), electricity generating renewable and low-carbon technology.

Site Waste Management Plans (SWMP)

The Site Waste Management Plans Regulations came into force in 2008. The aim of the Regulations is to reduce construction waste by requiring a SWMP to be prepared and implemented on those construction projects that have an estimated cost greater than £300,000 (excluding VAT). Failure to produce or implement a plan is an offence for which there are relatively substantial fines. An SWMP is a requirement of the Code for Sustainable Homes.

Landfill tax

This was introduced in 1996 and is intended to encourage a reduction in the waste generated through construction (and other activities) by charging developers for the disposal of waste.

Aggregates levy

This was introduced in 2002 with the aim of reducing the demand for primary or 'virgin' aggregates by increasing their cost to a level which better reflects their true environmental cost (in terms of noise, dust, vibration, visual intrusion, loss of biodiversity and amenity, etc.). The intention is to encourage the use of less expensive recycled and secondary materials.

Land Remediation Tax Relief (LRTR)

This was introduced through the Financial Act 2001. It is a tax credit for the costs incurred in 'cleaning' contaminated sites and is intended to provide an incentive for the development of previously used land (brownfield) in preference to greenfield sites.

The Code for Sustainable Homes

The Code for Sustainable Homes was introduced in 2007 and applies to England, Wales and Northern Ireland. It superseded the Building Research Establishment's (BRE) EcoHomes assessment. The Code was a direct response to, amongst other drivers, the Stern Review and the Government's consultation *Building a Greener Future: Towards Zero Carbon Development* (2006). An overarching aim of the Code is to lead the way in delivering the Government's target of all new homes being zero-carbon rated by 2016 (although the Welsh Assembly have aspirations to achieve this target earlier). The Code rates dwellings on a scale of one to six – referred to as levels – where 1 would have a slightly better environmental performance than the Building Regulations and 6 is considered to be zero carbon.

It should be noted that at the time of writing there is still some discussion about how exactly the term 'zero carbon' will be defined in practice (the 2010 edition of the Code states that the definition will be defined in future by legislation).

Although the title might imply that the Code addresses all aspects of sustainability, the emphasis is in fact on environmental concerns and it is, in essence, an assessment method which provides a framework for judging relative environmental performance of new dwellings. It does, however, also consider such things as accessibility, adaptability, daylighting, etc. which could be considered to be issues of social as well as environmental sustainability, as could, of course, be the reduction in fuel poverty which would hopefully be a product of a sustainable house.

The Code is a voluntary national standard which is intended to provide a framework and targets for the sustainable design and construction of new homes. As such, it has more stringent requirements than the Building Regulations (which cover some of the same areas as the Code) but which are enforceable statutory obligations. Although compliance with the Code is not a statutory obligation there are instances where compliance will be necessary. For example, in order to qualify for government funding, housing providers are required to meet specified Code levels (social housing providers have been required to meet increasing levels of the Code since April 2008). Additionally, local authorities can insist that new housing meets specific levels of the Code as part of local planning requirements (see the reference to PPS1 above).

As we have noted, the Code is voluntary while the Building Regulations are a statutory obligation. The Code, to some extent, is a device for signalling in advance obligatory step changes which will, or are likely to, occur in the Building Regulations, in particular Part L: Conservation of Fuel and Power (albeit that the Code has a wider reach regarding sustainability than have the Building Regulations).

The Code is seen as a useful vehicle for providing information to homebuyers and tenants about possible running costs of their home as well as its environmental impact. The Housing and Regeneration Act 2008 requires all new housing to be rated under the Code (even if it is rated as 0) and, as the Code already provides the certification and the information required by the EPC regulations (see above), houses that have been assessed under the Code are not required to have an additional EPC.

Measuring the Code level

In determining the performance of a house under the Code, reference is made, amongst other things, to levels, categories, issues and performance criteria. It is inappropriate to examine all of the steps necessary to determine a Code level in detail in this book and so only an overview is provided.

Essentially, the Code is based on the measurement of the sustainability of a new home against nine 'categories' of sustainable design which, when taken together, arrive at a rating that is expressed as one of six Code levels (with level 6 being the highest). Each of the nine categories is divided up into a number of 'issues' and for each 'issue' there is a performance target. The achievement of these performance targets, taken together, will determine the Code level that the dwelling has achieved. One of the intentions of the Code is to allow flexibility in design and construction and, to this end, whilst there are mandatory performance requirements for some of the issues in six of the nine categories, there is flexibility in the remainder. There is, therefore, a mixture of mandatory and 'tradeable' issues depending on the category and this provides designers with a degree of flexibility in choosing an appropriate way of meeting the requirements of the Code.

The Code categories and issues are detailed below.

1. **Energy efficiency/carbon dioxide:** *This category covers energy efficiency and* CO_2*-reducing measures. The category is broken down into the following issues: dwelling emission rate, fabric energy efficiency, energy display devices, drying space, energy labelled white goods, external lighting, low- and zero-carbon technologies, cycle storage and home office. The mandatory issues in this category are Dwelling emission rate and Fabric energy efficiency.*

2. **Water:** *The issues that this category is concerned with are water-saving measures, both internally and externally. Of these two issues, it is indoor water use that is mandatory.*
3. **Materials:** *This category is concerned with the issues of environmental impact of materials and whether they are sourced responsibly. The environmental impact issue is mandatory in this category.*
4. **Surface water run-off:** *This category relates to two issues. First, the extent to which measures are taken, and systems installed, to reduce the risk of flooding and, second, the minimising of surface water run-off (which can add to the pollution of watercourses and rivers). It is the latter issue, the management of surface water run-off from developments, that is mandatory.*
5. **Waste:** *This category relates to two distinct issues: one is the provision of storage for non-recyclable and recyclable waste and compost in the built property, and the other is the efforts made to reduce, reuse and recycle materials during the construction stage. The mandatory issue here is storage of waste (but not composting).*
6. **Pollution:** *The category title here may be slightly misleading as the emphasis is on the extent to which the heating system and the insulation materials used might add to global warming. There are no mandatory issues in this category.*
7. **Health and well being:** *The issues in this category are related to the provision of a 'good' environment for the occupiers by considering the quality of daylight provision and sound insulation measures, private space and the design criteria set out in the Lifetime Homes standards, which focus on issues of adaptability and accessibility. Lifetime Homes is a mandatory issue in this category (see www.lifetimehomes.org.uk/ for further information).*
8. **Management:** *This category relates to the provision of a home user guide, the incorporation of security issues in the design, participation of the developer in the Considerate Constructors Scheme and the extent to which the impact of the construction site has been taken into account and managed. There are no mandatory issues in this category.*
9. **Ecology:** *The issue in this category relates to the extent to which the ecology of the development site and the surrounding area has been protected and enhanced during the construction and in the long term. There are no mandatory issues in this category.*

The actual code rating of level 0 to level 6 is arrived at by assessing the categories and issues against performance criteria for which credits are awarded – which then, through a weighting and point system, can be converted into a Code level. The performance criteria can be in the form of improvements upon, or compliance with, specific cited standards. For example, with category 1 (energy and carbon dioxide) the performance criterion is related to percentage improvements on the requirements of the Building Regulations.

As stated above, this chapter provides only an overview of the Code, not only because examining the detail of the Code is inappropriate in the context of the aims of this book, but also because the Code is a document and a concept that is evolving and changing (particularly in regard to performance criteria). For further information on the Code, and to keep up to date with developments, reference should be made to information published by the Department of Communities and Local Government and its Technical Guide to the Code.

Design and construction implications of the Code

The Code does not specify how a house is to be constructed and the possible solutions can include both traditional methods (i.e. brick and block systems) and MMC. There are, however, a number of characteristics of a new house built under the Code which are likely to be commonplace, particularly given the mandatory issues in the document. Such characteristics include:

- *high levels of thermal insulation*
- *emphasis on tight detailing (i.e. low levels of air permeability) in order to restrict the amount of heat lost through poorly fitting elements; that is, ventilation, and therefore the air changes in the house, should be planned and designed and not 'accidental'*
- *low-energy lighting*
- *reduced water use through the incorporation of devices and fittings which reduce the amount of water used by items such as showers and WCs (which use comparatively high levels of water), and also the use of techniques for rainwater harvesting*
- *the use of materials which have a comparatively reduced impact on the environment (e.g. their production generates comparatively low levels of* CO_2*).*

The use of high levels of insulation and ensuring low air permeability is sometimes referred to as incorporating 'passive measures'. This phrase is used in this context to indicate parts of the thermal design which do not require an energy input in order to work. However, where unintentional heat loss is countered by the application of airtight detailing, there will come a point where it will be necessary to provide controlled ventilation through mechanical means (by the use of mechanical ventilation heat-recovery systems, for example) in order to provide sufficient air quality. This will provide more control over a property's heat losses but will have to operate correctly and be maintained. Such systems also require an energy input.

Note: Reference is now frequently made to a Passivhaus or the Passivhaus Standard. The Passivhaus was developed in Germany in the early 1990s and its approach emphasises the need for high levels of thermal insulation and airtightness, combined with whole-house mechanical ventilation (see Chapter 20 for more information on mechanical ventilation).

The term 'passive solar energy' is used for designs which try to maximise the heat energy of the sun. They do so by orientating window openings towards the south. The intention is to make use of the heat from the sun in order to supplement the heating system. Passive solar energy can be particularly effective where the structure can absorb and store some of the heat, and where energy-efficient windows, such as those discussed in Chapter 15, are used. The (southerly) orientation of the house will also be important for ensuring the effectiveness of renewable energy devices that utilise solar energy (such as photovoltaic cells and solar water-heating systems – see Chapters 22 and 18).

Orientating houses to the south in order to utilise solar energy through the windows will also tend to maximise daylighting, which in turn will also reduce the energy required for artificial lighting. A possible downside to passive solar energy is that large windows may cause problems with overheating through solar gain. This is an issue that is dealt with in the Building Regulations, which require that a design is checked to ensure that the house will not suffer from excessive solar heat gain during the summer months. Any such problems can be alleviated through the use of shading devices and thermal mass.

The thoughtful orientation of the building can also allow for natural ventilation (i.e. through opening windows and background vents) to occur more effectively.

Renewable energy

In 2008, the UK Government signed up to a European Union scheme whereby participating countries would be set targets for renewable energy. The UK target was to be producing 15 per cent of its energy needs through renewable sources by 2020.

In relation to new housing, the inherent logic and approach of the Code for Sustainable Homes is that, in order to achieve the higher levels of the Code, a house will need to have increasing proportions of its energy provided by renewable sources.

Renewable energy is that which comes either from elemental sources that are readily available, such as the sun, wind or water (and the ground), or from materials that can be harvested and renewed. The latter category includes biomass (biofuels), such as plants and timber. These natural sources are not only renewable but are also generally considered to be 'carbon neutral', based on the assumption that either they produce no CO_2 emissions in use or, if they do – as is the case with biomass fuels when they are burned – such emissions are taken to be equal to or less than the amount of CO_2 the plant originally absorbed for food and growth. Crops and timber which are burned to provide energy (as biomass) are renewable, but may not be considered sustainable if they originate from sources that are not managed ecologically and/or have to travel long distances to reach their point of use. Also, systems such as heat pumps and solar thermal hot water systems cannot be considered to be 100 per cent renewable as they require some electricity to drive a pump – although the electricity could be supplied by renewable technology.

Non-renewable sources include energy derived from fossil fuels, such as coal, gas and oil. Not only are these fossil fuels non-renewable, their extraction and use brings with it numerous environmental problems, as noted earlier.

Nuclear power might, possibly, also be considered to be 'environmentally friendly' because it could be seen as coming from a renewable source, and it does not produce CO_2. However, the use of nuclear energy remains a controversial topic, not least because of the potential consequences of accidents and the issue of dealing with waste from nuclear reactors.

In reality, most energy sources give rise to concerns and debate – ranging from tidal power and wind power in relation to their effects on wildlife and visual amenity to the energy costs and pollution arising from the production and shipping of solar panels.

Passive solar energy is, as we have observed, a potential source of effective renewable energy which can be utilised to supplement space-heating requirements. However, it will be mainly the 'active' renewable energy approaches which will be emphasised by the Code. Examples of active renewable energy sources are given below, along with the chapters in which they are discussed and explained in this book.

- **Space heating:** *Air and ground sourced heat pumps (Chapter 19), biofuel boilers (Chapter 19)*
- **Hot water:** *Solar panels (Chapter 18)*
- **Electricity:** *Photovoltaic cells (Chapter 22).*

There are other sources of renewable energy that are not discussed in the book as they are outside both its scope and its intent. These sources include wind power, because, although wind turbines are available for use on individual houses, they are not particularly effective from either the point of view of environmental benefits or cost effectiveness. Wind turbines which serve a group of buildings or an area or estate are more likely to be effective but are not common at the present time.

Foundations

3

Introduction

This chapter explains the principles and practice of domestic foundations. The chapter is divided into two sections: Section One concentrates on the general factors which affect the choice of foundation and Section Two considers appropriate solutions for specific ground conditions.

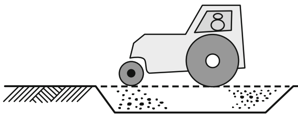
For most houses, the design and construction of foundations is a relatively straightforward exercise. The simplest and most common form of foundation comprises a strip of concrete under all of the loadbearing walls. The depth and width of the concrete strip is determined by the nature of the ground and the load of the building. However, there are a number of situations where strip foundations are not suitable. These situations (as explained in Section Two) usually require more complex foundations which are often designed by structural engineers and constructed by specialist contractors. The picture below shows strip foundation trenches ready for concrete.

Terminology

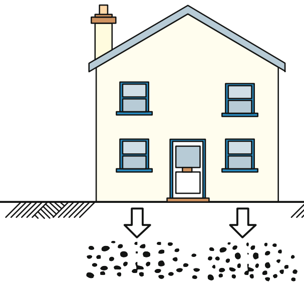
This chapter is not intended as a technical manual and we have consciously tried to avoid unnecessary emphasis on detail. However, there are some basic definitions that are commonly misunderstood and misused and it is important that you spend a little time familiarising yourself with these before continuing.

- **Bearing capacity:** *The load which the sub-soil can carry.*
- **Bearing pressure:** *The pressure on the sub-soil caused by the building load.*

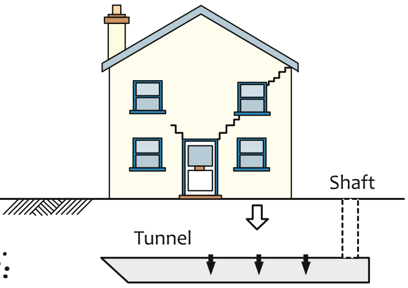
- **Compaction:** *The act of increasing the density and strength of a material by the application of impact forces, e.g. a heavy roller.*
- **Consolidation:** *The act of increasing the density and strength of the sub-soil by the expulsion of water and air under self-weight and constant external loading.*
- **Dead load:** *The load exerted on the sub-soil by the structure of a building plus its permanent fixtures and fittings.*
- **Heave:** *Expansion of the soil due to climatic and other factors (e.g. frost or removal of trees).*
- **Imposed load:** *The load exerted on the sub-soil by the contents of a building (e.g. people and furniture) and external loads (e.g. snow on a roof).*
- **Settlement:** *Downward movement of the ground, or any structure on it, due to soil consolidation as a result of the load applied by the structure of the building.*
- **Soil creep:** *The slow movement of rock and soil down a slope under the influence of gravity, often triggered by the presence of a high water content.*
- **Subsidence:** *Downward movement of the ground, or any building on it, due to changes within the sub-soil.*



Compaction by roller or vibrating plate.



The building slowly settles as the ground consolidates under load.



Subsidence caused by, for example, old mining works.

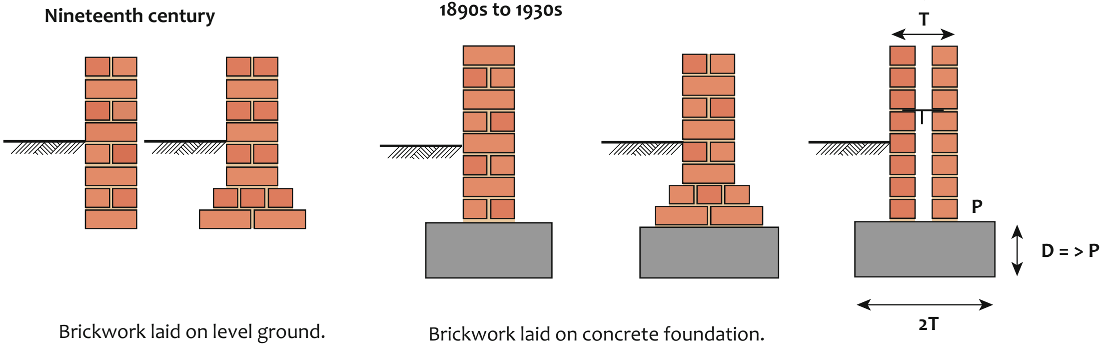
Function

The foundations of houses must carry the dead loads of the walls, the roof and the floors, etc., together with the imposed loads of occupants and furniture, as well as snow, and transmit them safely into the ground. They must be designed so that settlement is sufficiently controlled to keep any distortion (and possibly cracking) within acceptable limits.

Old foundations

Although the Public Health Act 1875 required concrete foundations for all new houses, it was several years before this practice became widespread, particularly in the provinces. Prior to this, there was a variety of foundation types, none of which would be acceptable today. Where houses were built on firm, dry ground, failure or settlement were not inevitable and, where minor movement occurred, the superstructure often accommodated it safely. This was because the brickwork or stonework was laid in soft lime mortar rather than cement mortar. There are many surviving properties with these types of foundation, five examples of which are shown below.

Foundations for two- and three-storey housing



Brickwork laid on level ground.

Brickwork laid on concrete foundation.

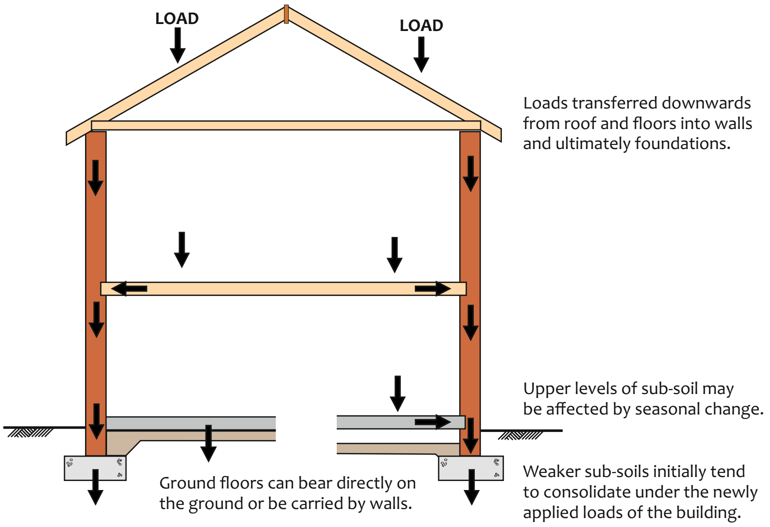
Cavity brickwork laid on concrete foundation. Width and depth dictated by Model Bye-laws.

Section One: general factors which affect the choice of foundation

Building load

For a typical modern three-bedroom detached house, the total of the dead and imposed loads is about 120 tonnes and most types of ground can easily carry this load using simple foundations. The exact dead and imposed loads can be calculated using simple tables produced by the British Standards Institution.

Simplified diagram illustrating loading



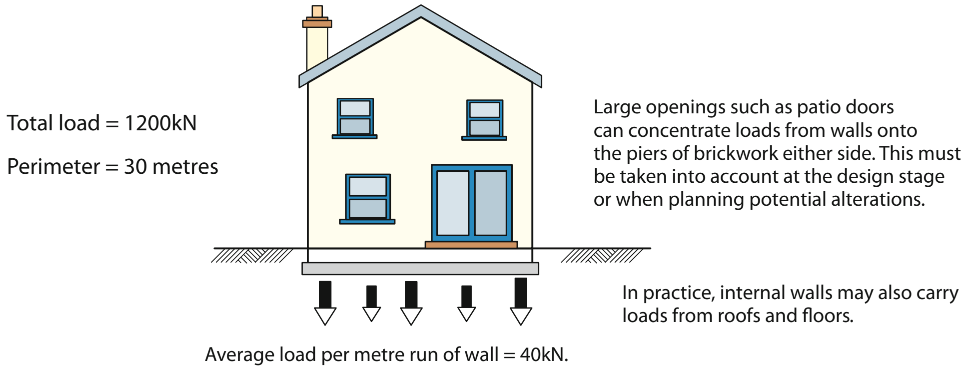
Loads transferred downwards from roof and floors into walls and ultimately foundations.

Upper levels of sub-soil may be affected by seasonal change.

Ground floors can bear directly on the ground or be carried by walls.

Weaker sub-soils initially tend to consolidate under the newly applied loads of the building.

When designing buildings, engineers are primarily concerned with forces rather than weights and the unit of force most commonly used is the kilonewton (kN); 1 tonne is roughly equal to 10kN. Therefore, a building load of 120 tonnes exerts a force on the sub-soil of 1,200kN. If the load of a building is carried by the external walls and the perimeter of the building is 30m, simple calculation shows that each metre in length (i.e. metre run) of foundation is carrying about 4 tonnes or 40kN. In practice, allowance must be made for the nature of the loading, which varies according to the direction of roof and floor spans. Furthermore, uneven loading can be caused by large openings, such as patio doors. Once the average loading per metre run of the building is established it must then be related to the safe bearing capacity of the ground in order to enable the design of an appropriate foundation.



Soils

Most soils consist of a mixture of solid particles, water and air. In addition, the soil near the surface of the ground will also contain organic material and this top soil must never be used as a base for a foundation. It varies greatly in volume due to changes in water content and is very unstable due to the amount of organic material it contains.

Before construction commences the top soil (about 150–300mm thick) should be removed from the site or stockpiled for future landscaping or off-site disposal.

Below the top soil lies the sub-soil (often just referred to as soil) and it is this which actually supports the building. Apart from organic soils and rock, there are two broad categories of soil type: cohesive and non-cohesive. Cohesive soils are those, such as clay and silt, with microscopic particle size and which can contain very high levels of water. The shape of the tiny particles makes them cling together, trapping water in between and it is this which gives clays their characteristic smooth, sticky feel. Non-cohesive soils, such as sands and gravels, contain negligible amounts of water and have large particle sizes which are held together mainly by their weight. Unlike clays, they do not stick together and the soils can be very loose in structure.

Clay subsoil.

One point to note is that there can be differences in sub-soil conditions across a building site and these can result in different foundation solutions for adjoining buildings, e.g. traditional strip foundations next to piled foundations. Both types of foundation are detailed below.

Soils under load

Increasing the pressure on a sub-soil by applying the load of a building squeezes some of the water out of the sub-soil, causing it to consolidate and allowing slight settlement of the structure above. In non-cohesive sub-soils such as sands, water movements are rapid and a building will normally complete its settlement during its construction. In addition, because sands only contain a very small amount of water, any settlement will be minimal. Cohesive sub-soils, such as clay, lose their water much more gradually and buildings may slowly settle for many years before equilibrium is reached. The softer clays contain large amounts of water and thus permit extensive settlement.

Sub-soil types

There is a wide range of sub-soil types in the UK, ranging from rocks, such as granite, limestone and sandstone, which can support very high loads, down to soft clay and silt, which often require specialist foundation techniques due to their low bearing capacity.

The table below summarises some of the common sub-soils and their suitability for house foundations.

GROUND	COMMENTS
Granite Limestone Sandstone Slate Hard chalk	Require pneumatic or hydraulic tools for excavation. Generally provide good support to foundations.
Compact sands Gravels	Can be excavated by machine without special tools. Provide good support to buildings.
Firm and stiff clays Sandy clays	Can be excavated by hand or machine. May require wider foundations than sands and gravels.
Loose sand Soft silt Soft clay	Easy to excavate, but normally need specially designed foundations.

Note: Peat is unsuitable for supporting foundations.

Site investigation

Before foundation design can begin, there are a number of preliminary stages. These separate stages are grouped under the general heading of site investigation.

Site investigation normally involves three basic stages:

- **Desk study:** *Takes into account existing information about the site. This information will come from a variety of sources and will include such diverse matters as the history of the site, its topography, geology, vegetation, etc.*

- **Walk-over survey:** *A direct inspection of the site giving the engineer/designer the opportunity to identify the nature of the ground and the nature of any hazardous features.*
- **Ground investigation:** *A physical exploration and inspection of the ground by means of boreholes or trial pits.*

Desk study

The desk study is the first stage in the site investigation. Essentially, it comprises the collection and analysis of existing information about the site. The information will come from a variety of sources and, once analysed, will form the basis for the second stage, the walk-over survey. The desk study has two main objectives:

- *to determine the nature, past use and condition of the site*
- *to determine whether this has any implications for the proposed building and its foundations.*

A sensible starting point is to consult large-scale maps of the proposed site and check the site boundaries, building lines, existing buildings and other man-made or natural features which will affect the future buildings. A comparison with older maps may give some clues to determine former use and, therefore, potential hazards. Geological maps, other written records and local knowledge will help to identify the likely nature of the sub-soil and determine the extent of difficult ground conditions. While most sub-soils, including firm and stiff clays, compact sands, gravels and rocks, will easily support the relatively low loads of two- and three-storey housing by using simple strip foundations, soft cohesive sub-soils, peaty sub-soils and filled ground pose problems. A site that has been mined also needs to be treated with caution as foundation solutions can be costly. Large-scale historical maps, often held at city and county libraries, may show the extent of former mining and the Coal Authority offers various information search systems. Searching these sources is very important as thousands of old shafts and tunnels still exist; unfortunately, many are not properly recorded.

Other items which might come to light during the desk study include the likelihood of:

- *filled or contaminated ground*
- *quarrying or mining*
- *rights of way*
- *ponds, watercourses, groundwater levels and the risk of flooding*
- *utility services (drains, electricity, gas, telephone, optical cables, etc.)*
- *previous vegetation (e.g. large felled trees)*
- *landslip*
- *naturally occurring aggressive chemicals (e.g. sulfates), harmful gases (e.g. radon) and landfill gases (e.g. methane and carbon dioxide).*

Walk-over survey

A walk-over survey is the second stage in the site investigation. It is a detailed site inspection which:

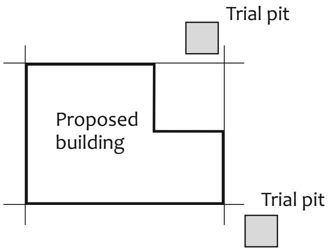
- *enables much of the material discovered in the desk study to be confirmed or highlights the need for further investigation*
- *identifies other potential hazards*
- *enables the surveyor to make photographic records*
- *gives the surveyor/engineer the opportunity to measure and make detailed drawings of all those items (trees, existing buildings, watercourses, etc.) which will have implications for the building design.*

Ground investigation

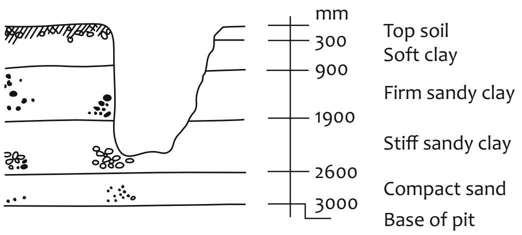
A direct ground investigation is the third stage in the site investigation. As far as low-rise housing is concerned, its main objective is to determine whether strip foundations will be suitable and, assuming they are, whether they can be designed in accordance with the simple 'rule of thumb' approach contained in the Building Regulations. The ground investigation will provide detailed information on:

- *the nature and thickness of made-up ground/top soil above the sub-soil*
- *the nature, thickness and stratum depth of sub-soil*
- *an assessment of allowable bearing pressure*
- *groundwater levels, chemicals in the ground, etc.*
- *existing structures or hazards in the ground.*

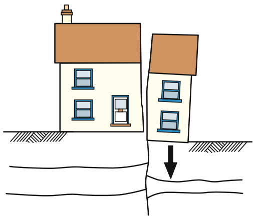
For low-rise housing on greenfield sites, machine-dug trial pits are probably the most common method of ground investigation. The pits do not normally need to be deeper than 4–5m unless specific problems are encountered. Trial pits should be excavated close to the proposed foundation, but not so close as to affect its actual construction. The number of pits is usually a matter for judgement and will depend on the size of the proposed development, the nature of the site and the consistency of the sub-soil across the site.



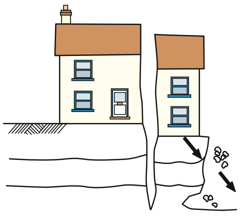
The depth of trial pits depends on the nature of the ground. They will usually be at least 3 metres deep.



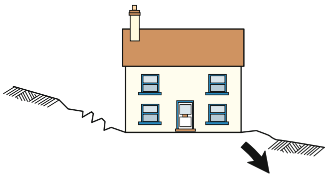
TYPICAL HAZARDS TO BE INVESTIGATED



Movement of the ground caused by earth tremors is rare in the UK, but not unknown.

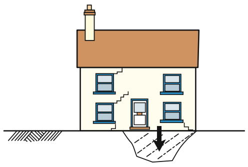


Building near escarpments, cliffs, or on the edges of rock formations may lead to problems in the future. Land slip is not uncommon.



In clay soils, on sloping ground, the risk of soil creep should be identified at the site investigation stage. If the ground appears terraced, special foundations will be required.

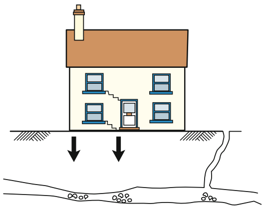
At the site investigation stage, careful note should be made of local knowledge and other clues which may suggest previous use of the site. Ponds, water courses, ditches etc. can be as hazardous as previous industrial use.



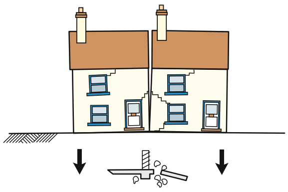
'Soft spots', outcrops of rock, or sudden geological variations in the sub-soil will prevent even settlement of the new building resulting in differential movement and cracking.

High water tables may require expensive foundation solutions. In addition, wet ground may exacerbate chemical attack from sulfates.

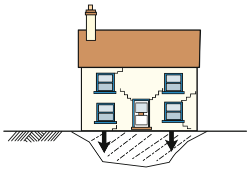
Natural gases such as methane and radon should also be identified at the site investigation stage.



In mining areas the collapse of tunnels can cause subsidence. This, almost inevitably, affects buildings above.

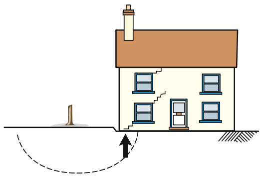


If old foundations, basements, tanks or other remnants of our industrial past are below the house, settlement will not be even and cracking may occur.



Filled ground rarely provides a good foundation. Settlement is likely to be uneven and cracking may occur. In addition, the filled ground may contain toxic waste. Some soils, such as peat and silt should also be avoided, or possibly removed.

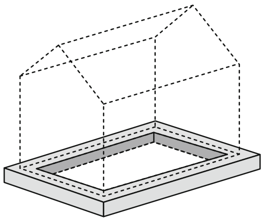
When building near trees, careful site investigation is required. Large trees will extract considerable amounts of moisture from the ground. In long, hot summers this may reduce the moisture content of clay soils. Shrinkage can lead to foundation settlement.



Removing large trees can cause the reverse problem. Clay soils will slowly take up moisture formerly used by the tree. Ground heave can force part, or all, of the house upwards.

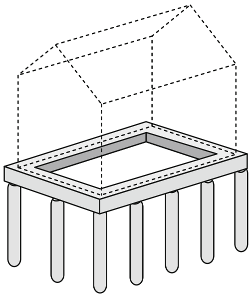
Foundation types

There are three basic types of foundation used in low-rise housing and these are shown in the diagram below. Of the three, the strip foundation is by far the most common.



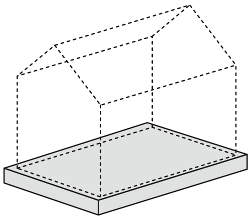
Strip foundation

Strip of concrete under all loadbearing walls. The strip width and depth depends on building load and nature of ground.



Pile foundation

Long, slender concrete members used to transfer loads through weak or unstable soil to ground of higher loadbearing capacity.



Raft foundation

Concrete raft which spreads loads over whole ground floor area.

Concrete

Concrete, as we know it today, is a relatively recent material and has only been commonly used in foundations for just over 100 years. In its simplest form, it is a mixture of Ordinary Portland Cement (so called because its original makers claimed it resembled Portland stone), stone and water, mixed together in varying proportions. By increasing the proportion of cement, concretes of increased strength can be formed.

The stone which forms the bulk of the mixture (often referred to as the aggregate) should be graded to ensure a reasonable balance of small and large particle sizes. This helps to ensure that the concrete is free from voids, as the smaller grains fill the spaces between the larger grains and, in addition, provide a strong workable mix with the minimum of cement. To ensure that the proportions and grading of the aggregate are correct, it is delivered separately to the site or concrete plant as fine aggregate (sand) and coarse aggregate (stone or chippings). It can then be mixed as required. Fine aggregate has particles which run through a 5mm sieve. Coarse aggregate has particles ranging from 5mm to 40mm depending on the purpose of the concrete.

Water is added to the mix to enable the chemical reaction to occur which binds the cement and aggregate together (this process is called hydration). The correct amount of water is the minimum to ensure completion of the chemical reaction and, in addition, adequate plasticity of the mix for placing and compacting, i.e. it should not be so wet that it flows around the trenches unaided. If too much water is added, the excess (not required for hydration) will evaporate leaving tiny voids in the concrete which seriously reduce its strength, i.e. it will not achieve its required design strength. If insufficient water is added, complete hydration will not take place and the concrete will be very difficult to place and compact. In good conditions, a well-proportioned concrete will set within a few hours and will reach full strength after several weeks. Because concrete reaches a relatively high strength quickly, bricklayers can usually start building on the foundations a few days after it has been poured.

There are various ways of specifying concrete. The Building Regulations require a minimum mix ratio of 50kg of cement to 200kg (0.1m^3) sand and 400kg (0.2m^3) stone for simple strip foundations. This, traditionally, was often known as a 1:3:6 mix. Stronger mixes were often referred to as 1:2:4 or 1:1½:3. Nowadays concrete is normally specified in accordance with BS 8500 (this is the UK complementary standard to the European Standard BS EN 206-1).

On most building sites, concrete is delivered ready for use, i.e. 'ready mixed' to the required specification. The strength and nature of the concrete mix for foundations will take into account a variety of factors including:

- *its purpose (i.e. the type of foundation)*
- *its durability (i.e. the intended working life)*
- *whether the concrete will be reinforced*
- *the risk of chemical attack*
- *the method of pouring (e.g. whether it will be pumped).*

Other considerations

After determining the building load and the nature of the ground there are some other important considerations which may affect the foundation design.

The water table

The level of water in the ground is often referred to as the water table and this tends to follow, in a gentler manner, the topographical features of the surface above. It is not constant but rises and falls with variations of rainfall, atmospheric pressure and temperature, and in coastal regions can be affected by tides. When the water table reaches the surface, springs, lakes, swamps and similar features can be formed.

In most cases, the water table will be below the depth required by traditional strip foundations and it will have little effect on their construction. However, occasionally a high water table will be found and this can lead to extra expense in pumping out the trenches while the concrete is being poured.

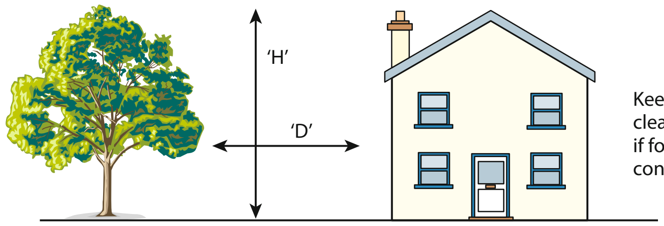
Sulfate attack

In some sub-soils, there can be a problem with sulfate attack. Calcium, magnesium and sodium sulfates occur naturally in some clays and other sub-soils. They can, in wet conditions, attack the concrete (as well as below-ground cement mortars and some types of bricks) and cause severe deterioration of the foundation. A high water table will exacerbate this problem. The sulfates dissolve in the groundwater and permeate the concrete. This leads to an aggressive chemical reaction between the sulfates in solution and one of the chemicals in the cement. The resulting compound expands rapidly as it forms and this can crack the foundation concrete. If sulfate attack is a possibility, it is wise to use sulfate-resisting cement.

Special problems of clay soils

The majority of clay sub-soils can cause foundation problems as they slowly change in volume due to increases or decreases in water content. This change is related to the seasons, with the ground expanding in the winter and contracting in the summer because of the difference in rainfall and moisture content. This seasonal change, which may normally be in the order of +/- 30mm at ground level, can affect the clay to a depth of about a metre (with the ground below this level having a fairly stable moisture content).

Where clay sub-soils contain trees, the problem is more severe. Trees and large shrubs draw a considerable amount of water from the ground during the growing season. For example, a mature poplar takes up as much as 1,000 litres of water per week. In long, hot summers with little or no rainfall, the tree will continue to draw moisture out of the ground and the clay will shrink. This is in addition to the seasonal drying mentioned above. When a building is sited near trees (in particular, groups of trees, where the effects may be more severe), serious cracking in the walls can occur as a result of this ground movement. To prevent this movement from affecting foundations, they must be deeper than the tree roots. An alternative is to site the building well clear of the trees.



Ground level above root zone may fall by as much as 75mm in a long dry summer.

Keep buildings well clear of growing trees if foundations are concrete strip.

For poplars, elms and willows:
if 'D' = 'H' foundation should be 1.5 metres deep.
if 'D' = 0.5 'H' depth should be 2.3 metres.

For other trees:
if 'D' = 'H' foundation should be 1.0 metres deep.
if 'D' = 0.5 'H' depth should be 1.5 metres.

➡

At depths below 1.5 metres, it may be more economic to consider piled foundations.

Where trees have been removed from clay sub-soils, the opposite problem occurs. As the ground slowly regains moisture, it will expand and this can continue for a period of up to 10 years. The pressure that dry clay develops when reabsorbing moisture is likely to be greater than that imposed by the building load and upward movement of the structure can occur. If houses are built on the site before this ground expansion is complete, cracking will occur in the walls and foundations; the swelling will be uneven because it will be concentrated around the removed tree(s).

Groundwater and frost heave

Water can move very easily through fine-grained sandy sub-soils and silts and this can give rise to two common problems. First, loss of ground can occur if underground springs or watercourses are allowed to run across a site. The flowing water can wash out the finer particles of soil, reducing its bearing capacity and stability. In this situation, the site must be avoided or stabilised with land drains before building commences. Second, if the water table is close to the ground surface, there is a danger of frost heave. This can affect some fine sandy sub-soils, silts and chalk. Water fills the voids between the particles and, in freezing weather, forms thin layers of ice. As the ice forms, it expands causing the ground above to heave. In the UK, the ground is rarely frozen at depths of more than 600–700mm and this should be sufficiently deep for most strip foundations in these types of soil.

Section Two: foundation solutions for specific ground conditions

Compact sands and gravels

These sub-soils can easily carry the weight of two- and three-storey houses using simple strip foundations. A table in the Building Regulations indicates acceptable minimum widths of the concrete strip depending on the load and the type of ground. For sands and gravels, two-storey houses normally require a concrete strip 400–500mm wide. However, in practice the width of the trench is dictated by the minimum space in which a bricklayer can work and this will usually require at least 600mm. A trench depth of 450mm (the minimum permitted under the Building Regulations) is usually adequate, although this has to be increased to about 700mm if there is a danger of frost heave. The trenches are usually excavated by machine using a bucket of the required foundation width.

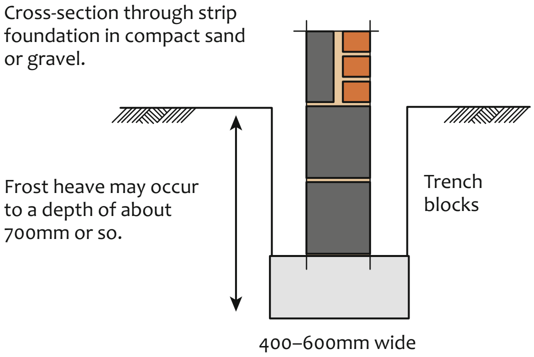
Nowadays, foundations are invariably dug by machine. Buckets are available in various sizes to suit required trench widths. When the trench has been excavated, it should be 'bottomed out' (i.e. loose material should be removed and the bottom of the trench levelled out). Deep trenches will require support to prevent potential collapse and injury to operatives.

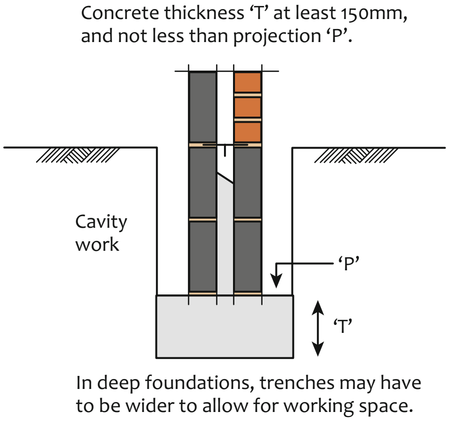
When the foundations have been excavated and the trenches approved by a relevant authority, the concrete can be poured. Concrete can be batched (i.e. mixed) on site, although it is more common to use ready-mixed concrete which will be brought onto the site when required. For chemically non-aggressive sub-soils, the Building Regulations set out specific alternative concrete mixes. Special design measures are needed where the sub-soil contains aggressive chemicals, such as may occur in the redevelopment of former industrial sites.

A traditional strip foundation is shown below.

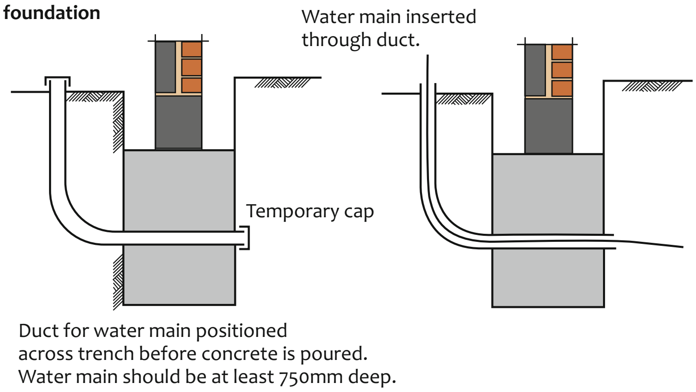
After a few days, the substructure construction can commence. The substructure walls can be formed in cavity blockwork or in solid blockwork. In modern construction, brickwork walls are rare because of their higher cost.

An alternative solution is to use trench fill and this method is often preferred by builders. It avoids the need for working space and trench support and offers savings in the costs of excavation and soil disposal. As mentioned previously, most sands and gravels can safely support low-rise housing with a concrete strip only 400–500mm wide and such sub-soils are therefore ideal for this form of construction. There are two potential problems: if the trench is not cut dead straight and in exactly the right position, the bricklayers will have difficulty in setting out the walls; it is also important to leave ducting through the concrete for service connections that are required below the finished concrete level.



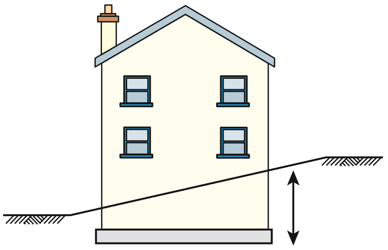


Trench fill foundation

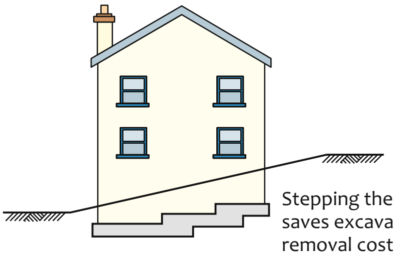


Trench fill is a very effective means of providing a good foundation. Construction is quick and working space for bricklaying is not required. If ducting is not placed in the correct positions, remedial action can be expensive. Foundations (traditional strip or trench fill) can both be stepped in sloping ground (right).

Foundations obviously have to be laid level and this can be expensive in sloping ground. In order to reduce the cost, it is possible to 'step' the foundation to keep the excavation to a minimum. The Building Regulations contain simple rules for stepped foundations to ensure that the load is evenly distributed over the ground and to prevent cracking at the step itself. These are shown in the diagram below.

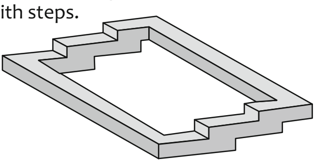


Excavation is deep – this has cost and safety implications.



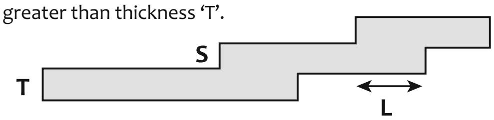
Stepping the foundation saves excavation and sub-soil removal costs.

Traditional strip foundation with steps.



The overlap 'L' must be a minimum of twice the step, or the thickness 'T', or 300mm, whichever is the greater.

Step 'S' no greater than thickness 'T'.



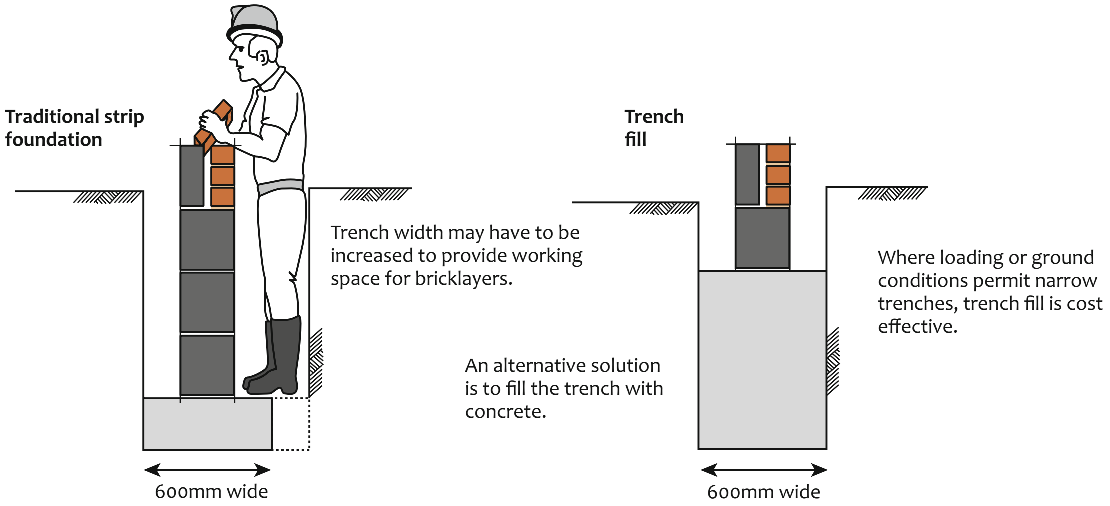
In a trench fill foundation, the overlap should not be less than twice the step, or 1 metre, whichever is the larger.

Firm and stiff clay soils

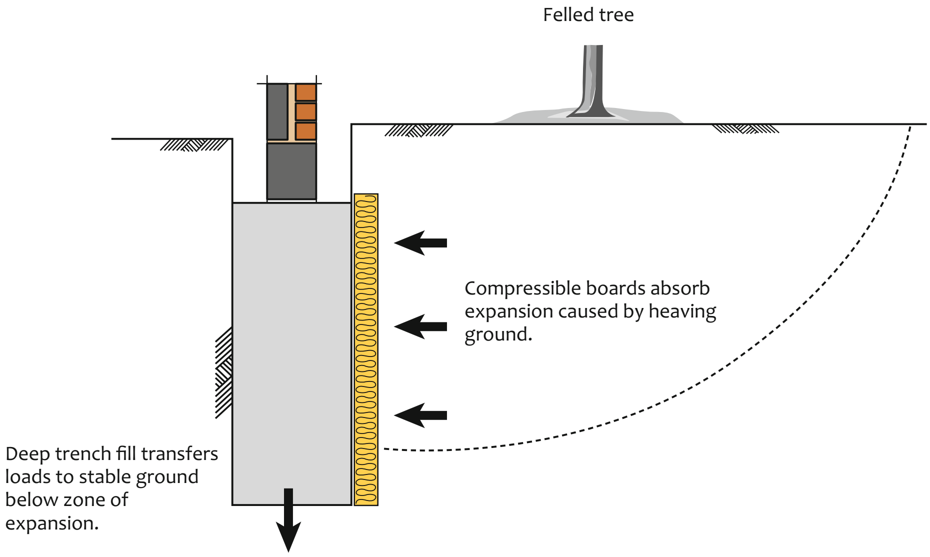
It was mentioned earlier in the chapter that most clays are affected by seasonal change and this can lead to expansion or contraction of the sub-soil. This change in volume will occur to a depth of about a metre. To prevent excessive movement of a building, it is important that the foundations are at least this depth. Some clays have a lower bearing capacity than sands or gravels and these may require slightly wider foundations in order to spread the load over a sufficiently large area of ground. A depth of 600mm is usually sufficient for normal two-storey buildings. If trees are growing on the site in close proximity to the building (or have recently been felled), this form of construction is generally not suitable. Appropriate solutions are described in the later section on piled foundations. As in the previous example, trench fill can be used to avoid the need for working space and to keep the trench width to a minimum.

This trench in a shrinkable clay sub-soil has been excavated to a depth of at least 1,200mm to avoid the effects of seasonal change.

The Building Regulations require a minimum depth of 750mm for strip foundations in clay sub-soils. In practice, most foundations in clay will be deeper than this to avoid the effects of seasonal change. However, both traditional strip and trench fill foundations become uneconomic if the required depth is more than 1,000mm. With any trench, there is a large volume of excavated material to dispose of, in wet weather the open trenches may need pumping out and trenches in soft sub-soils require temporary support to prevent the sides collapsing. These problems are increased with deeper trenches and a sensible alternative is to use piled foundations (these are discussed in a later section).

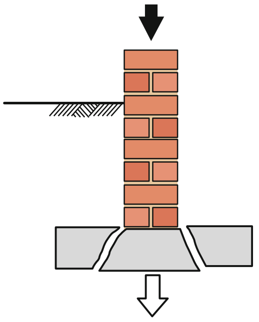


Besides the disadvantages already mentioned, there is the additional problem of swelling ground, caused by seasonal change or by the removal of trees, acting laterally against the foundation. To prevent this from damaging the building structure, it is necessary to use some form of low-density material on the side where the swelling is likely to occur.

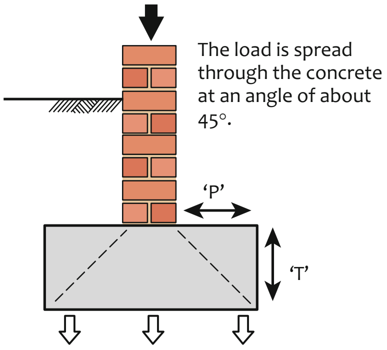


Soft clays and silts

The loadbearing capacity of soft clay and silt is quite low and strip foundations will have to be fairly wide if they are to safely support a building. The table in the Building Regulations referred to earlier only gives dimensions for soft clays and silts that are for very light loads, such as might

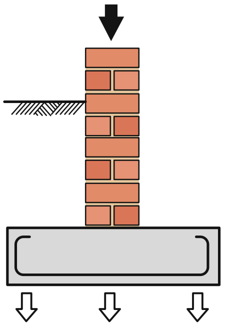


Wide, thin foundations can crack in the manner shown. This is known as shear failure.



The load is spread through the concrete at an angle of about 45°.

If 'T' equals 'P', the load is safely spread across the ground.



A more economic solution is to reinforce the foundation with steel bars.

be imposed by a bungalow or garage. This means that the exact width of the foundation will need to be calculated by an architect, engineer or surveyor to ensure that the soft ground, which can vary considerably in loadbearing capacity, is capable of supporting the building load. These foundations are expensive to construct due to the wide trenches that have to be excavated and the large volumes of excavated material which have to be removed from the site. There is also an additional problem that is caused by the structural properties of concrete. A wide, thin foundation will crack as the load is applied, but this can be resolved by either increasing the thickness of the concrete or providing steel reinforcement. However, if the foundation is reinforced, a stronger concrete mix is necessary to prevent the reinforcement from rusting.

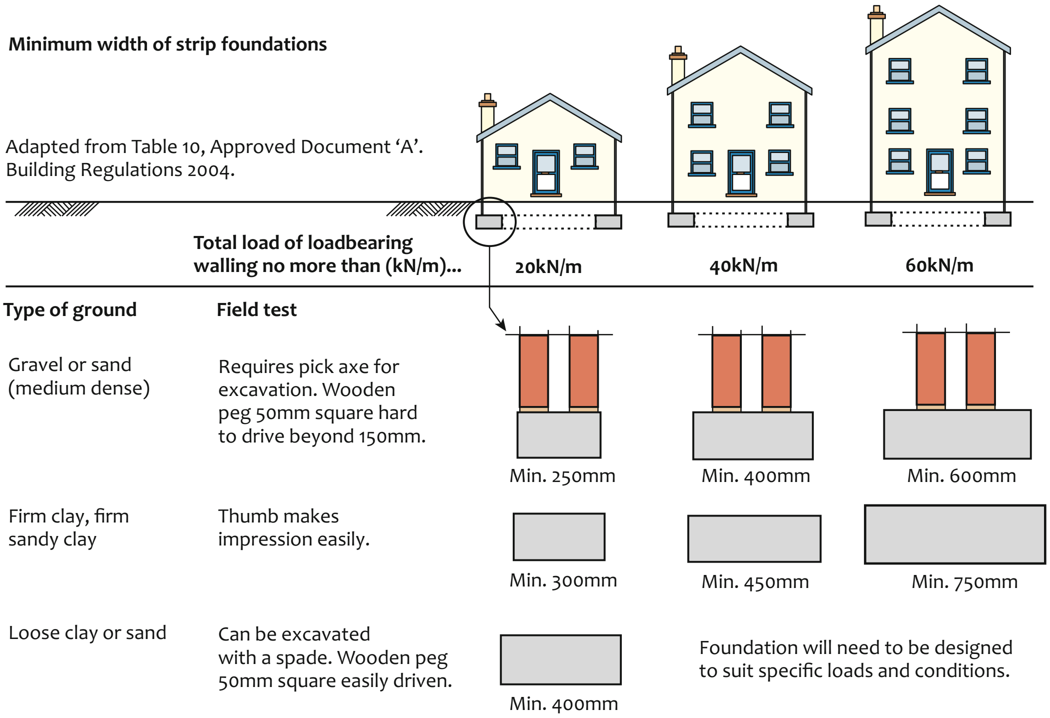
In many cases, it is probably more economic to use raft foundations or, if a firmer stratum exists at a lower depth, piled foundations.

Strip foundation summary

The drawing below is a simplified version of a table in the Building Regulations. It shows how building load and ground type affect foundation size. Note that where the load is high, or where the ground is weak, these 'deemed to satisfy' provisions no longer apply and the foundation will need to be designed to reflect its specific circumstances.

Minimum width of strip foundations

Adapted from Table 10, Approved Document 'A'. Building Regulations 2004.



	Total load of loadbearing walling no more than (kN/m)...	20kN/m	40kN/m	60kN/m
Type of ground	**Field test**			
Gravel or sand (medium dense)	Requires pick axe for excavation. Wooden peg 50mm square hard to drive beyond 150mm.	Min. 250mm	Min. 400mm	Min. 600mm
Firm clay, firm sandy clay	Thumb makes impression easily.	Min. 300mm	Min. 450mm	Min. 750mm
Loose clay or sand	Can be excavated with a spade. Wooden peg 50mm square easily driven.	Min. 400mm	Foundation will need to be designed to suit specific loads and conditions.	

Piled foundations

There are a number of situations in which a strip or trench fill foundation would be unsuitable and where it would be appropriate to make use of a piled foundation. They include situations where existing or new trees are close to proposed houses, where trees have been felled to clear a site and where the uppermost sub-soil is too soft to build on. In these circumstances, it may be possible to form deep strip foundations that reach below the affected area, but this is a slow, expensive and dangerous process, especially as depths over 3m may be necessary.

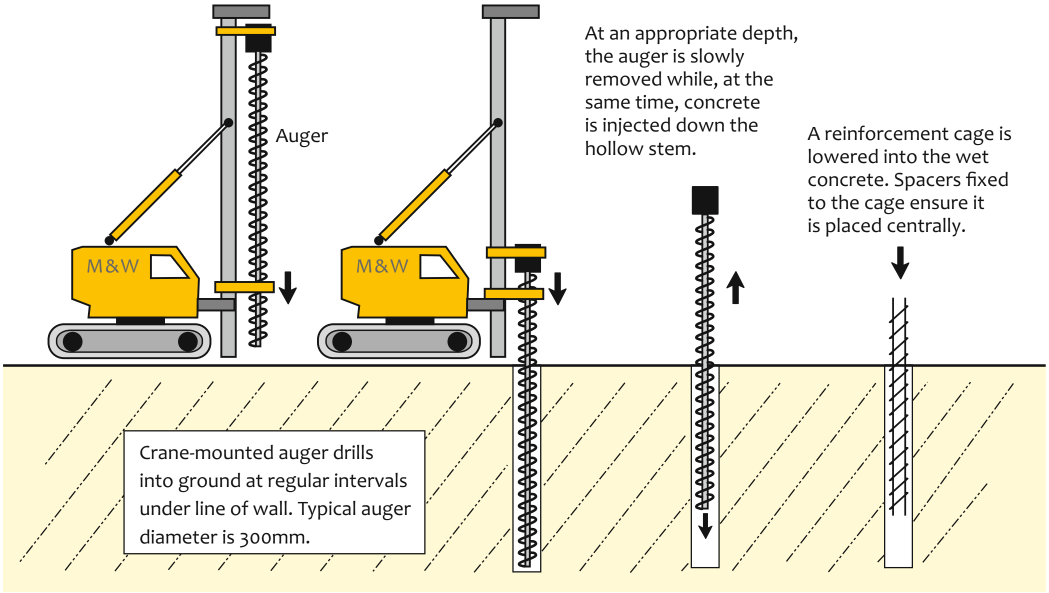
It is far better (and cheaper) to use piled foundations, which are installed by a specialist subcontractor. Piled foundations are a means of transferring the load of a structure to a sub-soil at a depth below the ground surface that can support the load properly. Piling can also take place in freezing or wet weather, which often stops traditional foundation methods. In addition, there is less excavated material to dispose of, which helps keep the site and the surrounding roads clean. However, builders are often reluctant to use piling, partly because they do not wish to be dependent on specialist subcontractors and partly because it is seen as an expensive process.

There are two main types of piling system suitable for domestic construction – replacement piles and displacement piles.

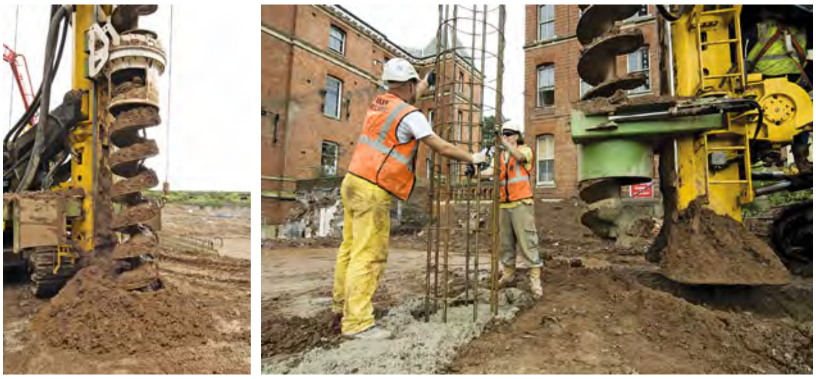
Replacement piles

These are often used for low-rise housing, especially where there are trees in close proximity. The process involves a bored pile that extracts the soil by boring or auguring and replaces it with reinforced concrete. Such piles can be used in non-cohesive and water-bearing sub-soils, but are also ideal for deep cohesive soils such as clays which may, on occasion, be unsuitable for strip foundations, for example if tree roots are present. The load is transmitted into the soil partly by the end bearing of the pile, but mainly through the friction between the pile sides and the soil. These piles also offer the benefit of being effectively vibration-free, but do produce arisings (i.e. excavated soil) that has to be removed.

One system of replacement piling is the continuous flight augur pile (CFA pile) and this is shown below.



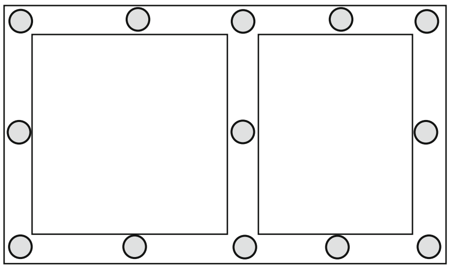
The process of piling using an auger drill followed by the insertion of the reinforced metal cage can be clearly seen in the photographs overleaf. Photographs courtesy of Roger Bullivant Limited.



When the piles are in position and the tops have been cut down to the correct length, a reinforced concrete beam is cast over them forming the base for the walls. The beam is designed to span from pile to pile. The ground beneath it only provides temporary support until the concrete has achieved its full strength. Should growing trees reduce the moisture content of the clay and should shrinkage occur, it will not affect the building.

The piles are cut down to the correct size, then a shallow trench is dug and blinded with a thin layer of concrete to form a working base. Steel reinforcement cages span from pile to pile. The thick plastic acts as formwork to prevent concrete contamination and wastage.

Plan showing pile layout and ground beam.

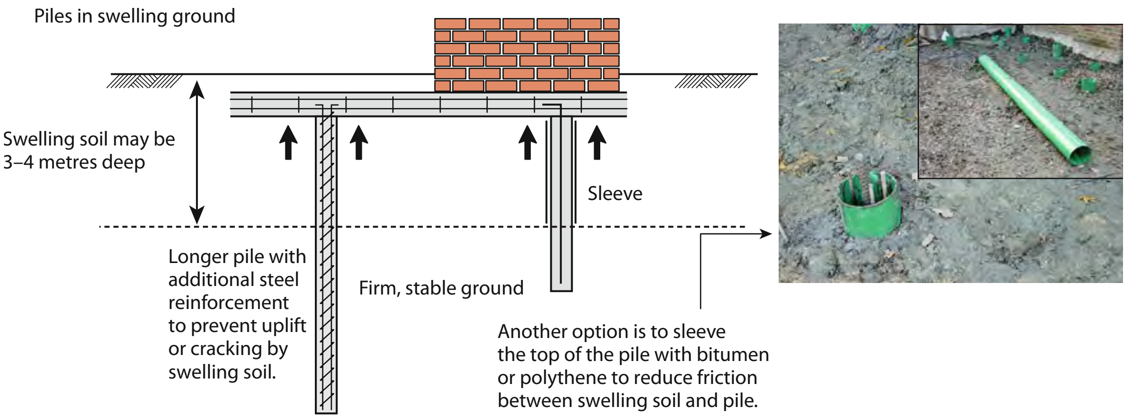


Typical pile centres are 2.4 to 3.0 metres.

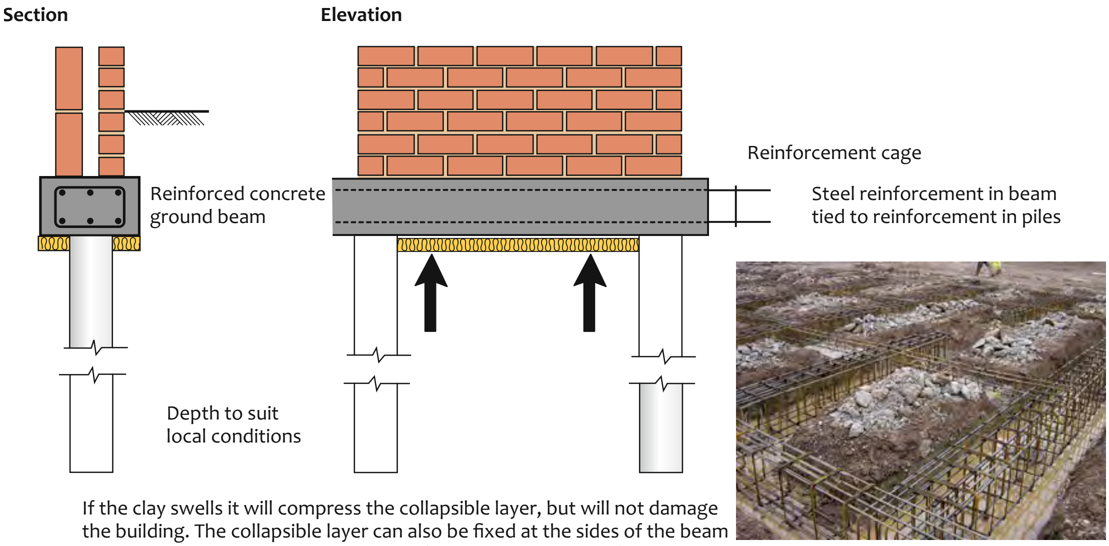
External and internal loadbearing walls require piles.

Ground beams are normally formed in in-situ concrete. If the ground is very poor, casting in-situ beams is not feasible and a sensible alternative is to use pre-cast beams. The photographs show a pre-cast beam system which will carry the floor structure and the house walls.

If trees have been felled, then the opposite problem is likely to occur. The ground slowly absorbs the excess moisture and steadily increases in volume. This is known as soil heave. It is important, therefore, that, when building on sites from which trees have been removed, the foundation design resists, or is not affected by, these upward forces. The piling system already described can be used in this situation, but the piles will need to be increased in length. A longer pile that is driven further into firmer, deeper sub-soil offers sufficient frictional resistance to resist the upward force of the swelling clay. In addition, extra steel reinforcement is required to prevent the pile from cracking as a result of the increased tensile stresses. An alternative approach is to use a piling system which incorporates a sleeve at the top of the pile to reduce friction between the clay and the concrete pile.



The force from the swelling may be much higher than that caused by the building load and, to prevent the swelling ground from cracking the reinforced beam, it is good practice to provide some form of collapsible layer underneath the beam. Low-density polystyrene insulation boards are an ideal material and suitable construction is shown in the diagram below.

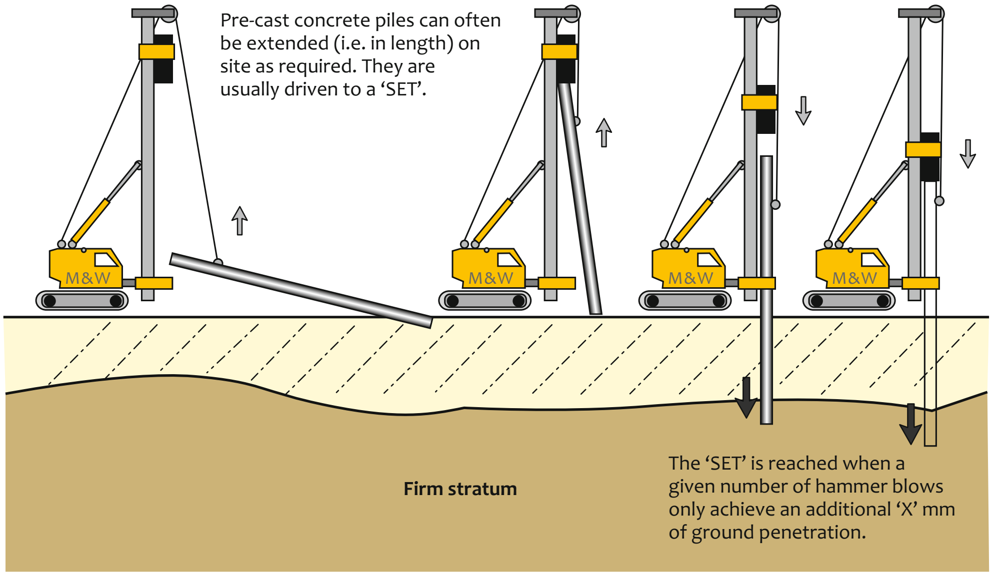


If the clay swells it will compress the collapsible layer, but will not damage the building. The collapsible layer can also be fixed at the sides of the beam if there is a danger of lateral expansion (see right-hand picture).

Displacement piles

In granular soils, such as compact sands and gravels, displacement piles, which are also known as end-bearing piles, can be used. Their use in housing is very rare, as these soils are generally ideal for strip foundations. However, for blocks of flats they may sometimes offer cost savings over strip foundations. They produce little or no arisings (i.e. excavated material), but do have the disadvantages of producing noise and vibration as they are driven. They can be formed in a number of ways and two of the most common are driven pre-formed (pre-cast) piles and driven cast in-situ piles.

Driven piles



Pre-cast concrete piles can often be extended (i.e. in length) on site as required. They are usually driven to a 'SET'.

The 'SET' is reached when a given number of hammer blows only achieve an additional 'X' mm of ground penetration.

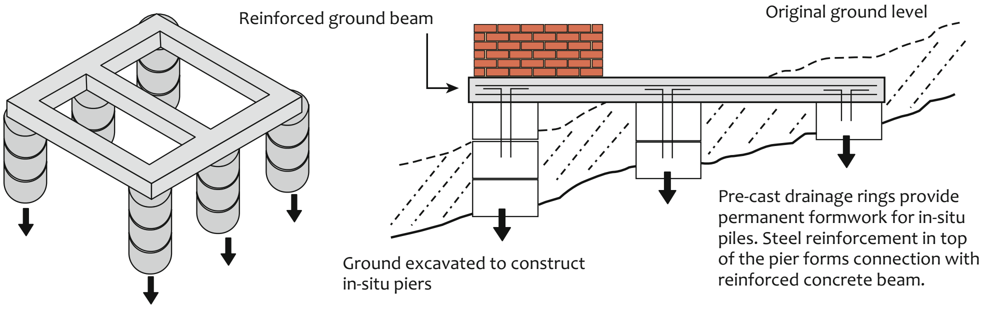
On this site (next to a former dock), driven piles were specified. The piles were pre-cast concrete and about 10m long. The piles could be joined together to extend them if necessary (see inset box). Where piles hit unforeseen obstructions and, as a result, are cracked, stronger steel piles can be driven alongside.

Another type of displacement pile is the continuous helical displacement pile (CHD pile) in which a special type of hollow-stemmed augur is screwed into the ground until it reaches a suitable bearing stratum. The soil penetrated is compacted as the drilling proceeds so there are no arisings. The hollow stem is filled with concrete and the auger is then unscrewed and withdrawn to leave the pile in place. The photographs opposite (top) give an idea of the process.

Photographs courtesy of Roger Bullivant.

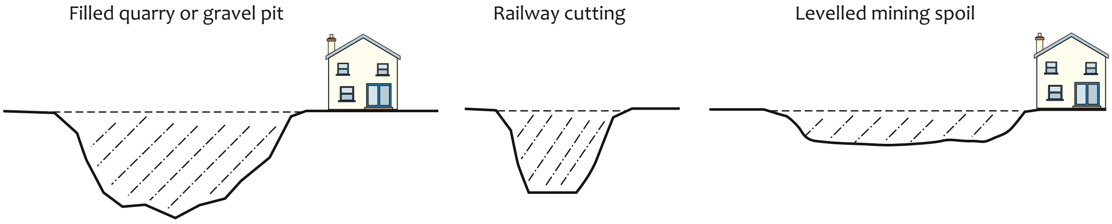
Pier foundations

Pier foundations are sometimes used as an alternative to piling. If the site contains old basements or other obstructions, or if the ground is too steep for piling rigs, pier foundations are sometimes specified. They usually comprise a series of thick concrete piers that are formed in situ and support a reinforced concrete ground beam. Large concrete rings, of the type usually used for drainage inspection chambers, can provide a permanent formwork for the wet concrete. A typical house might be supported by six or eight piers. When constructing pier foundations, it is usually necessary to excavate the whole area below the building to the required depth of the piers. Once the piers have been poured, the ground is replaced.



Filled ground

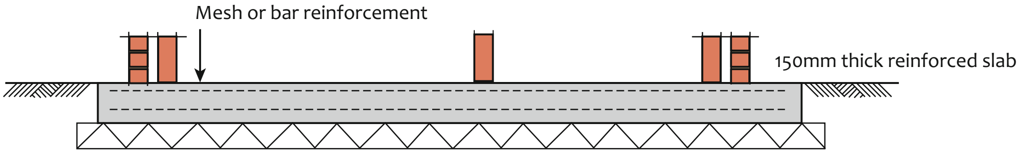
Scarcity of good building land will often necessitate building on areas of filled ground. A variety of materials can be found in filled sites, ranging from quarry and mining waste to household and industrial refuse. Sites filled with refuse can give rise to problems of internal combustion, methane gas and other toxic chemicals; therefore, building on these should be avoided whenever possible.

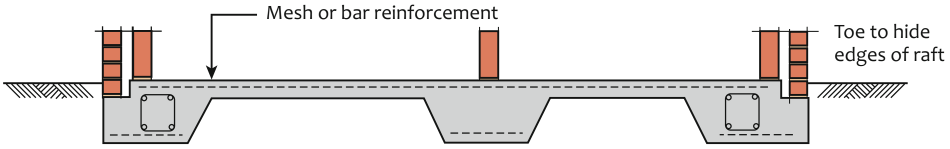


If the fill is fairly shallow, then the most sensible option is to use piled foundations. The augured pile system described above is often not suitable in fill as large stones and rubble are likely to be encountered. An alternative method is to use a driven pile, as shown in an earlier diagram. A further option is to use a driven pile made up of individual hollow pre-cast concrete sections, typically 300–400mm in diameter. Using a special crane, the pile is driven into the ground, adding extra sections as necessary. It has reached its correct depth when repeated hammer blows only produce minimal downward movement of the pile; this is known as a 'set' and is specified by an engineer.

As the fill naturally consolidates over the years, there may be a downward force on the piles due to the friction of the ground against the pile sides. This 'down-drag' is rarely even and the resulting differential movement can cause cracking of the building. In a previous section, we discussed how soil heave could be overcome by sleeving the top of the pile and, in this instance, a similar technique can be adopted. However, in practice it is difficult to sleeve the whole length of a pile and several manufacturers prefer to coat the pile sections with a bituminous compound during manufacture. The bituminous compound acts as a viscous fluid and reduces the effect of the down-drag (or up-lift) on the pile.

Deeper fill is best dealt with by the use of rafts. The raft spreads the load from the walls over the whole ground floor area. However, with raft construction some movement over time is to be expected and it is, therefore, essential to make sure that the services which enter or leave the property have flexible connectors immediately adjacent to the external wall. Rafts, when designed for poor-quality ground, or ground where subsidence is expected, can be very expensive and must be designed by structural engineers. However, they are a fast form of construction with minimal excavation and are, sometimes, also used on soft clays as an alternative to the reinforced wide-strip foundation. The diagrams below show a simple raft foundation formed from 150mm reinforced concrete slab and a more complicated raft foundation with down-stand or perimeter beams.

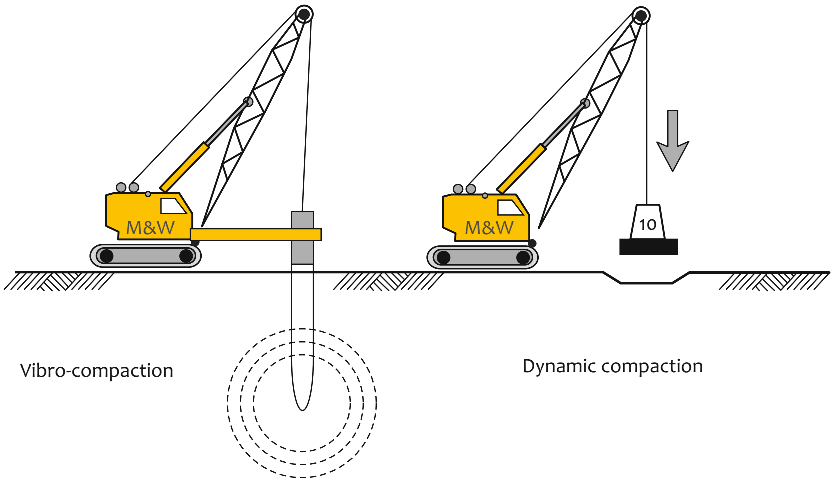




Vibratory ground improvement techniques

It is sometimes possible to undertake some form of ground treatment of filled ground and also of naturally weak soft or unstable sub-soils such as gravels, sand and silt. Once the ground has been treated, the new buildings are constructed with either reinforced concrete strip or raft foundations. On very large housing sites, this technique can be cheaper than the use of piling. There are a variety of methods which attempt to increase the stability and bearing capacity of the ground.

- **Vibro-compaction:** *This method involves the use of a crane-mounted poker which is driven into the ground. A spinning eccentric weight inside the poker causes it to vibrate and this helps to compact the surrounding ground. The poker is then slowly extracted from the ground at the same time as sand is pumped through the poker to fill the void. The operation is then repeated at 2 or 3m intervals to form a regular grid across the site.*
- **Vibro-replacement:** *This form of ground treatment can be used to treat granular soils or cohesive soils. A special poker or piling rig is used to drill down to the relevant depth. A small amount of aggregate or stabilised soil is introduced into the hole and this is compacted before the next layer of aggregate or soil is added. Successive layers are built up to form a 'stone column'. A grid of stone columns is formed in the ground. At the same time, densification of the surrounding soil is undertaken by the specialist contractor. Although the stone columns act as weak piles transferring building loads to a firmer stratum, the stone columns and the treated soil work together to share the load of the building.*
- **Dynamic compaction:** *This is a further alternative form of ground treatment with a very grand title but, in fact, it simply involves dropping a weight of several tonnes on to the ground from a crane. However, it is not suitable if there are existing buildings in the immediate vicinity.*



These two photographs show a site receiving vibro-compaction prior to development. Photographs courtesy of Roger Bullivant.

Peat

This soil, which commonly occurs in moorland areas, has a very low bearing capacity and is unsuitable for supporting any foundation for housing. If a site contains large areas of peat and it is not possible to avoid building on them, there are two solutions. If the peat is shallow, it can be excavated and replaced with a good-quality fill, compacted in layers and used to support a raft foundation. The alternative is to pile through the peat to a firmer stratum. However, both forms of construction can be very expensive.

Mining areas

Where subsidence is likely to occur as the result of mining, it is important to obtain guidance on past (and possibly future) workings from the Coal Authority. Designing suitable foundations is definitely the province of specialist engineers and often requires the use of very sophisticated rafts. Such work is beyond the scope of this book.

Summary

The table below summarises suitable foundation solutions for typical conditions. It should not, however, be regarded as a set of rules. There is no reason, for example, why raft foundations or piling should not be used on soils of good bearing capacity. Nevertheless, in practice it is often more economical to use simple strip foundations that do not require sophisticated design and that are not dependent on skilled labour or specialist subcontractors.

STRIP FOUNDATIONS	PILED FOUNDATIONS	RAFT FOUNDATIONS
1. On rock, gravel, dense sand or stiff clay, narrow strip foundations are usual. 2. On soft clay or soft sandy clay, wider strip foundations are usually required.	1. On shrinkable clays with new or felled trees. 2. Where a firmer layer of ground is at considerable depth, i.e. where strip foundations would be uneconomical. 3. Where the water table is close to the surface of the ground.	1. On grounds of low bearing capacity, such as soft clay or silt. 2. In mining areas, where subsidence is a risk. 3. On deep areas of fill, where piling would be uneconomical.

4

External masonry loadbearing walls

Introduction

This chapter explains the principles of wall construction and traces the introduction and evolution of the modern cavity wall.

Function

The external wall of a house wall has two basic functions:

- *to transfer the loads from suspended floors and the roof to the foundations*
- *environmental protection.*

In order to satisfactorily fulfil these functions there are a number of requirements for an external loadbearing wall. These are:

- *strength and stability*
- *weather protection*
- *good thermal insulation*
- *good acoustic control*
- *fire protection*
- *durability.*

Early materials

Up until the sixteenth century, timber was the dominant structural material for most vernacular buildings. After that time, building in brick and stone became more common for a number of reasons, including shortages of timber supplies and, perhaps more significantly, the disastrous experience of fires in towns and cities which led James I (and later, following the Great Fire of London in 1666, Charles II) to issue proclamations insisting on the use of stone or brick.

Traditional timber-frame buildings.

Stone

In early construction, the type of stone used for a particular building would largely depend on its geographical location. It was rare to transport stone across the country, other than for the most prestigious of buildings. The stones most commonly used were those that could more easily be quarried and cut. Sandstone and limestone were the two most common materials, although flint, slate and granite were also used. The cheapest type of stone wall was made from random rubble, where stones of assorted shapes and sizes were laid in a cement or lime mortar.

An example of random rubble.

There are a number of variations on random rubble, mostly defined by reducing 'randomness' (for example, random rubble laid to courses, squared rubble and squared rubble laid to courses). Some examples are shown in the photographs below.

Random rubble.

Random rubble laid to courses.

Squared rubble.

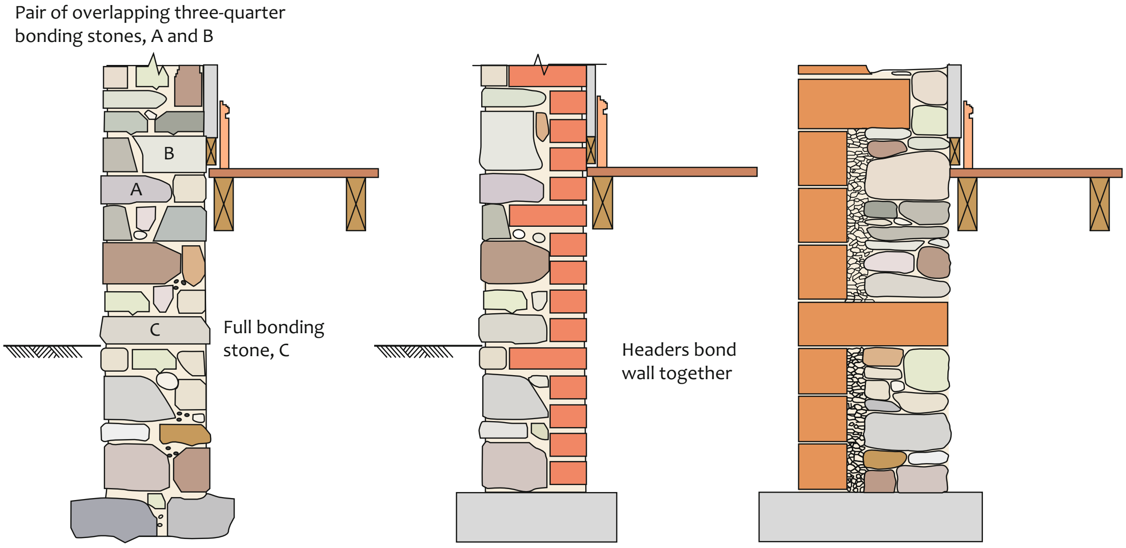
Squared rubble laid to courses.

The alternative to rubble walls is ashlar. Ashlar (which is a style not a material) is stone cut with great accuracy and laid on very thin mortar joints. Although rubble work was often valued for its 'rustic' appearance as well as its relative cost, ashlar generally tended to be associated with more prestigious buildings.

Ashlar stone (close up).

Rubble and ashlar were often used together, typically with rubble being 'framed' by ashlar at the corners of elevations, or by the use of ashlar around windows in a rubble wall. Also, it is not uncommon to see ashlar used for a bay in a predominantly rubble elevation – as shown in the image to the right.

Because of its expense, ashlar was normally only used as a facing material and required a structural backing in the form of brickwork or rubble. Essentially, these solid walls were built as two 'skins'. In order to bond the ashlar to the backing material, some of the facing stones ran 'through' the wall. Alternatively, ashlar was sometimes fixed back to the brickwork with iron ties. Rubble walls were also constructed in a similar fashion and, particularly in the latter part of the Victorian period, they would often have a stone outer skin and a brick inner skin. Again 'through stones' (or header bricks) would be used to tie the two skins together – as shown in the diagram below.



Simple rubble wall

Rubble wall with brick backing

Ashlar wall with rubble stone backing

Brickwork

The choice of brick or stone as the favoured building material in any given part of the country was for many years influenced by the simple factor of geography, and therefore the availability of materials. It was also affected by the development of trade skills and advances in technology which allowed for more efficient quarrying of stone or excavation of clay, as well as industrialised kilns for brick production which improved the ability to control both quantity and quality. The creation of canals and, later, the rail system had a dramatic effect, particularly on the ability to distribute bricks to areas with no clay deposits. Less pragmatic, but perhaps more significant, factors were the issues of style and status. For example, brick was popular in the Restoration period and the artistic skills practised by the bricklayers in both decorative and precision work during this era was, and still is, much admired. The Georgian period is often characterised by the stone buildings of cities such as Bath, but brick was a fashionable material for developments in, for instance, Liverpool, London and Bristol. Because of the links between style and status, the aspiring classes looked to these materials to demonstrate social position. In the Regency and early Victorian periods, people aspired to the appearance achieved by ashlar stone. There were, however, surges in the status of brick, including that which arose during the 'Battle of the Styles' – an example being the Queen Anne revival in the 1870s. At other times in the Victorian period brick was equal to stone in status, partly because of the increasing precision with which bricks could be made. This precision, allied to the wide range of colours, finishes and shapes that became available, appealed to the Victorians' sense of pride in technological achievement as well as to their liking for colour and decoration. Clearly though, this appeal was not universal; many late Victorian houses in cities such as Bristol have stone walls at the front with brick being relegated to the side and rear elevation, where it was often rendered. There are, however, geographical areas where brick was used to the front elevation with stone being relegated to the side and rear.

Brick side wall on a stone-fronted Victorian house.

An early eighteenth-century town house in Queen Anne style constructed in brickwork.

Georgian terraced housing in Liverpool constructed in brickwork.

The dominance of either brick or stone has waxed and waned over the centuries. For various reasons modern houses tend, in the main, to be defined by walls with an external leaf constructed in brick. However, some modern houses are finished with a render (see Chapter 12) or a cladding material and, in these cases, the external leaf may well be constructed in concrete blockwork. It is also the case that some houses will be built using a stone or artificial stone outer leaf (artificial stone is a mixture of stone dust, colouring agent and cement). Sometimes stone or artificial stone is utilised on a selection of houses on a modern development in order to provide aesthetic variety, but there are also cases where it is used because it reflects the vernacular. In some instances this may be a planning requirement. For the purposes of clarity and consistency, and given that the details will essentially be the same or similar, this chapter concentrates on masonry walls which typically have a brick outer leaf and a (concrete) block inner leaf.

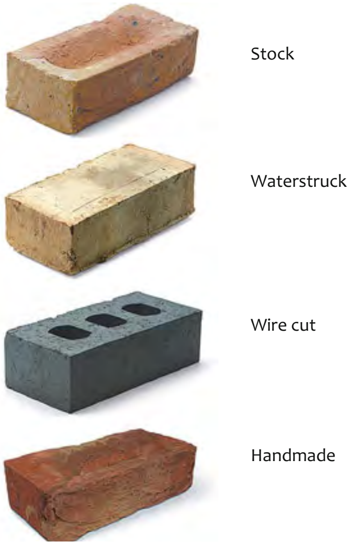

Stonework on a new development – in this case used to reflect the local building materials.


Rubble stonework on the front elevation of a new house – presumably to introduce variety into the estate.


Rubble stonework being used on a new development in a conservation area.

Brick production and classification

The majority of bricks are made from clay, which is usually prepared by grinding and mixing with water. This plastic compound is formed into the required brick shape and then dried and fired in a kiln. Different clays have different characteristics and, by using special manufacturing techniques and adding a variety of additives, bricks of various colours and strengths can be produced. Some bricks are still made by hand using practices that have barely changed for several hundred years. Large lumps of wet clay are dropped into wooden moulds, tipped out, and then left to dry before firing. However, nowadays



These examples of bricks produced by Ibstock Ltd show how different manufacturing processes can achieve different aesthetic appearances.

most bricks are either machine-pressed into steel moulds or extruded. In the extrusion process, a continuous ribbon of clay is cut by wires to form bricks of the correct size. By altering the extrusion process and cutting wires, a number of surface finishes can be obtained.

Bricks can broadly be described as:

- *common bricks – these are suitable for general building work where the face of the brick will be covered with plaster, render or another finish. It is unusual to find these bricks being used today in housing*
- *facing bricks – these come in a wide range of finishes, colours and strengths and are used where the face will be left exposed. The most common use today is for the external walls of houses*
- *engineering bricks – these are dense bricks with high compressive strength and low rates of water absorption. They are categorised as class A or B. Although class A bricks are sometimes used as facing bricks for houses (often because of their distinctive blue-grey colour) they are more likely to be found in civil engineering structures such as retaining walls and bridges. Class B engineering bricks (sometimes referred to colloquially as semi-engineering bricks) are used, among other things, in brick manholes.*

Bricks can also be classified by their resistance to frost attack. Some bricks are totally resistant to frost attack while others are quite vulnerable. Bricks suitable for severe exposure are classified F2, those suitable for moderate exposure are classified F1, and those suitable for what is referred to as 'passive' exposure are classified as F0. Class F2 bricks are therefore suitable for use in any part of an external wall, including situations where they may be saturated and have to undergo repeated cycles of freezing and thawing (with the caveat that the brickwork is detailed correctly). This includes parapets, copings and retaining walls. Class F1 bricks are normally suitable for the outer face of a building, as long as exposure is not severe and appropriate measures have been taken in the design of the wall to prevent saturation. This generally means they are suitable from above the DPC to below the eaves. Class F0 bricks are generally for internal use only.

Bricks can also be classified by their soluble salt content. Classes S2 and S1 have imposed limits on the percentage of salts they contain while Class S0 bricks have no such limits.

Calcium silicate bricks

These bricks are made from sand or crushed flint and lime mixed with coloured pigments. The materials are mechanically pressed into shape and then placed in hardening chambers into which steam is injected under pressure. During hardening, a chemical reaction occurs to produce hydrated calcium silicate. This is not dissimilar to the setting of cement. The bricks are very regular in shape and can easily be recognised by their pale colours. By varying the manufacturing technique, bricks of different strengths and densities can be produced. They are generally resistant to frost attack and virtually free from soluble sulfates. Calcium silicate bricks are prone to shrinkage and this needs to be taken into account in the way they are specified and detailed. They enjoyed a period of popularity in the 1960s and 1970s but are less fashionable now.

Calcium silicate bricks in a 1960s house.

Concrete bricks

The majority of concrete bricks are made by blending and compacting dense aggregate with a cementitious binder under high pressure. Coloured facing bricks are manufactured by blending different aggregates or by adding special pigments. By varying the proportions of cement, the bricks can be manufactured in a variety of strengths. The material for concrete bricks can be mixed with crushed stone aggregate to produce a material which mimics natural stone.

Blockwork

Blockwork has become very popular in the past 60 years or so because of its cost advantages over brickwork (see the later section on cavity walls). Most blocks are equivalent in size to six bricks (three bricks high and two long) and are available in a range of widths from 50mm to 300mm. Blocks less than 75mm wide are unsuitable for loadbearing walls. Blocks are made from cement and aggregate, and by varying the quantity of cement and the nature of the aggregate, blocks with different strengths and levels of insulation can be formed. Since blocks first became popular in the late 1920s several different aggregates have been used in their manufacture, such as crushed gravel, pulverised fuel ash, blast furnace clinker, gas coke breeze and pumice.

Changes in industrial processes have meant that some of these aggregates are no longer available.

Blocks can be broadly classified into two types: dense blocks (heavyweight blocks) and lightweight blocks.

Dense blocks

Dense blocks are made from cement, sand and crushed gravel and are suitable for work above and below ground level. Because of their high density, they are good conductors of heat and are therefore unsuitable for modern cavity walls unless additional insulation is provided. However, they provide good sound insulation and are therefore ideal for party walls and loadbearing partitions.

In the 1950s to 1970s dense blocks were used to form the internal leaf of cavity walls. Today, they tend to be used for foundation walls, internal loadbearing walls and party walls – all areas where thermal insulation is not a primary requirement. The photograph shows a 100mm loadbearing partition incorporating a steel lintel and softwood door lining.

Lightweight blocks

These incorporate a variety of lightweight aggregates and are generally used for the internal skins of cavity walls. Although slightly more expensive than ordinary dense blocks, they have much better levels of insulation and are light and easy to handle. The level of thermal insulation varies depending on the type of aggregate used. However, because of their low mass they do not provide very good sound insulation and are not always suitable for party walls.

In modern construction a particular type of lightweight block made from autoclaved aerated concrete (AAC), generally known as aerated blocks, have become very common. Aerated blocks are made from cement, lime, sand, pulverised fuel ash and aluminium powder. Once these materials are mixed with hot water the aluminium powder reacts with the lime to form millions of tiny pockets of hydrogen. These subsequently diffuse from the material to be replaced by air.

Aerated blocks are easy to handle and provide good thermal insulation. They are very easy to cut and shape and will directly take the fixings of screws as well as nails. Some aerated blocks are not suitable for party walls because of their low density, although in recent years a number of manufacturers have produced aerated blocks specifically designed for this purpose.

In modern cavity walls, with their emphasis on high levels of thermal insulation, aerated blocks are by far the most common method of forming the internal leaf.

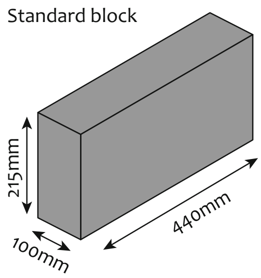
Aerated blocks being cut on site (note that the blocks shown are those used in 'thin joint systems' and are therefore larger than standard aerated blocks). Photograph courtesy of H+H UK Ltd.

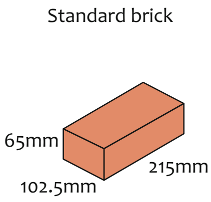
Weather protection

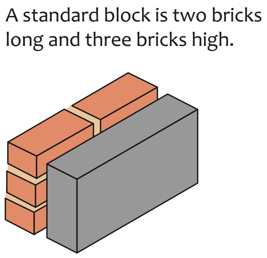
Many concrete blocks absorb water more readily than brick or stonework and, if used externally, may require additional weather protection. Suitable protection includes weather boarding, tile hanging and render. Aerated blocks, unlike their dense concrete counterparts, usually have a closed cell pore structure which limits moisture penetration.

Size of bricks and blocks

A standard metric brick is 215 x 102.5 x 65mm and a standard block 440 x 215 x 100mm. Allowing for the mortar joints (10mm), six bricks are equal in size to one block. These sizes may seem a bit arbitrary but they are, more or less, a direct conversion from imperial measurements.







Mortar

Mortar is the material which binds the bricks and blocks together. It helps to distribute the load through a wall and 'seals' the brick or block joints against water ingress. Mortars should have:

- *good workability*
- *sufficient resilience to accommodate long-term thermal movement of the masonry*
- *adequate bond strength*
- *good resistance to water penetration.*

Mortar is made from fine aggregate (usually sand) and a binding agent (nowadays usually cement). When mixed with water, a chemical reaction, called hydration, occurs and the mortar sets. Early mortars were usually based on lime and sand but they were very slow to set and readily absorbed rainwater. There are two basic categories of lime:

- **Non-hydraulic lime:** *This is produced by burning (pure) limestone in a kiln in order to convert it into 'quicklime' which is then slaked in water to produce lime putty. A mortar made from lime putty sets through a process known as carbonation, where the lime gradually hardens by absorbing carbon dioxide from the atmosphere.*
- **Hydraulic lime:** *This is produced from the burning of limestone that contains impurities – such as clay, for example. Hydraulic limes are used in powder form and set through contact with water (i.e. hydration). See also Chapter 12 External rendering.*

Modern mortars use cement as the main binding agent. Hydrated lime – a powdered form of non-hydraulic lime – was, in the past, often introduced into the mix to make it more 'workable'. This happens less frequently nowadays as mortars tend to rely on chemical admixtures to provide the qualities which the addition of lime formerly produced. The use of lime in a mortar mix improves the mortar's ability to cope with thermal and moisture movement, improves the adhesion between the mortar and the brick and the strength of the brickwork. It also improves the resistance of the mortar to rain penetration – partly because it is less likely to shrink and crack, but also because it produces a mortar which will allow moisture to evaporate.

Admixtures

Admixtures, such as liquid plasticisers, can be used in place of lime to improve the workability of a mortar. Plasticisers break down the internal friction in the cement, making it less dense and therefore easier to work. A mortar mix of 1 part cement to 5 parts sand, plus plasticiser, is roughly equivalent to a 1:1:6 cement/lime/sand mix. Although a plasticiser will improve workability it will not provide some of the other benefits, such as flexibility and breathability that adding lime does.

Another option is to use masonry cement. This is a pre-bagged mix of cement and chemicals, which have been added to improve the workability of mortar.

Mix proportions

By varying the proportions of the cement, the strength of the mortar can be increased or decreased as required. Strength, at least in this context, refers to hardness and permeability. As a general rule, a weak mortar mix (i.e. one with relatively less cement) will suffer less shrinkage when it sets and is more able to withstand the long-term rigours of thermal and moisture movement. In addition, if minor cracking does occur in the wall, it is more likely to occur at the joints, which can easily be raked out and repointed. However, the mortar must not be too weak or it will become too porous and may be crushed under high compression forces. A weaker mortar will also generally be less durable.

It is essential to ensure that there is adequate adhesion between the bricks and mortar. To achieve good adhesion a mortar must have good workability. Mortar of poor workability will not 'give' adequately, and will allow air to be trapped between the brick and the mortar, thus preventing a proper bond. The term 'fatty' is sometimes used to describe an ideal consistency for a mortar – a 'fatty' mortar will stay on the trowel but not stick to it. It will also spread easily and not set either too quickly or too slowly. Cement-rich mortars are difficult to work with and there is a temptation on site to add extra water. This will ultimately reduce the mortar's strength.

Mortar sand needs to be well-graded. This means that it should contain a mixture of particle sizes because a volume of sand where all the particles were of similar size would contain more air than would be the case with a well-graded sand, meaning that a greater proportion of binding agent (i.e. cement) would be required. A given volume of graded sand contains approximately 25 per cent of air space. The strength and physical properties of a mortar are determined by the type of binder that fills this air space. For example, a cement/sand mix of 1:3 will result in the air space within the sand being completely filled by the cement, producing a strong but brittle mortar. The relatively high cement content will probably result in shrinkage as the mortar sets. Many bricks and blocks cannot resist this shrinkage, resulting in loss of bond and cracks in the mortar. By replacing some of the binder with lime (say, 1:1:6, cement/lime/sand) the binder/aggregate ratio is maintained at 1:3 and the mortar has improved workability, better adhesion and longer durability. Some typical mortar mixes are shown below.

↑ Increasing strength & improving durability

Ability to accommodate movement ↓

Category	Cement:lime:sand	Masonry cement:sand	Cement:sand (with plasticiser)
i	1:0.25:3	1:3	1:3
ii	1:0.5:4	1:3 or 4	1:3 or 4
iii	1:1:5 or 6	1:5 or 6	1:5 or 6
iv	1:2:8 or 9	1:7 or 8	1:7 or 8

Increasing resistance to frost during construction →

← Better adhesion and resistance to rain penetration

Table adapted from Brick Development Association publication.

Pre-mixed mortars

These are delivered to site in sealed containers, ready for use. They usually contain a retarder so they remain usable for 36–48 hours or so. At the end of this period they develop their strength in the same way as normal mortars.

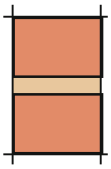
An alternative to pre-mixed mortars, which can often be seen on larger building sites are dry mixed silos. These contain a dry mortar mix with appropriate proportions, colourants and materials for the particular purpose (e.g. for the mortar for facing brickwork or for aerated blockwork) required on the specific site. The silos have an integral mixer and allow different sized batches of a consistent mortar to be mixed as and when required.

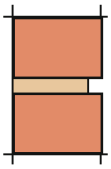
Dry mix mortar silos on site.

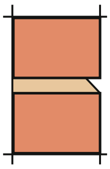
Jointing and pointing

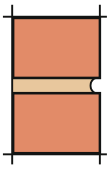
The face of the mortar joint between the brick or block may be finished in a number of ways. These are largely dependent on the exposure of the building, the type of brick and the preference of the designer. Examples of the most common joints are shown below.

Flushed joints are formed by skimming off excess mortar from the face of the mortar. For the other joint profiles the mortar is left to harden slightly and the joint profile is then formed using an appropriate tool. Tooled joints offer the best weather protection because the tooling smoothes and compresses the joint. Recessed joints are not suitable for buildings in exposed


Flush


Recessed


Struck


Bucket handle

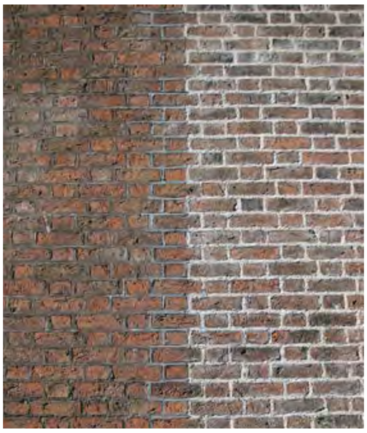
Brickwork in the process of being jointed.

situations because they do not readily shed water – the recess interrupts the flow down the face of the wall and it will tend to stay wetter for longer than if one of the other joints were used. For this reason, only bricks with good frost resistance should be used with recessed joints.

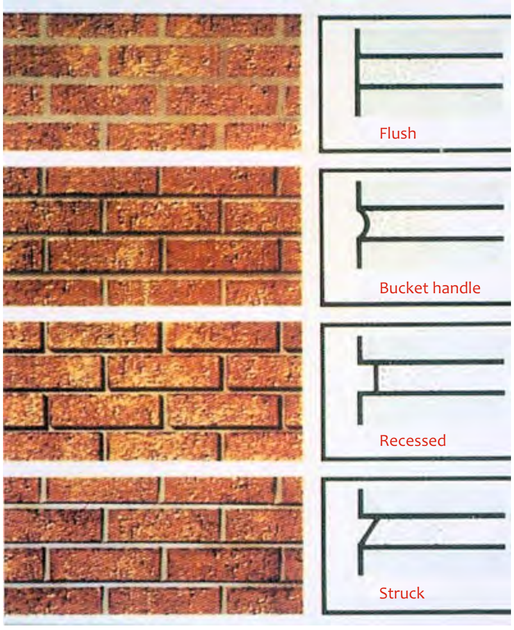
Most brickwork, these days, is jointed as work proceeds. Pointing is the term used to describe existing or new joints which have been raked out and filled with fresh, often coloured, mortar. Pointing is relatively rare in new construction because coloured mortar mixes are now relatively cheap. However, the Brick Development Association observes that for some joint profiles it is only practicable to form them as pointing – they give the weather struck and cut joint as an example. With pointing, the mortar mix must be slightly weaker than the jointing mortar. If it is stronger, the outer face of the bricks, immediately above and below the pointing, will carry excess load. This can result in the edges of the bricks spalling.

Mortar joints have a significant visual effect on a brick wall. The Brick Development Association points out that, with stretcher bond, about 17 per cent of a wall is mortar. The colour of the mortar can have a dramatic visual impact on the overall appearance of the wall – as demonstrated by the repointing of the brickwork shown in the photographs on the right.

The choice of joint profile can also have a significant effect, partly due to the way that they either accentuate or obscure the junction between the brick and the joint and partly in the way that different profiles cast shadows and reflect light. The image below, for example indicates how different profiles affect the appearance of a wall built with the same bricks.



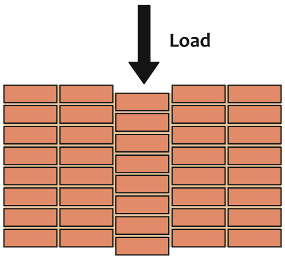
Close-up of repointing to elevation shown above.



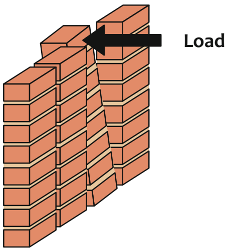
Courtesy of the Brick Development Association.

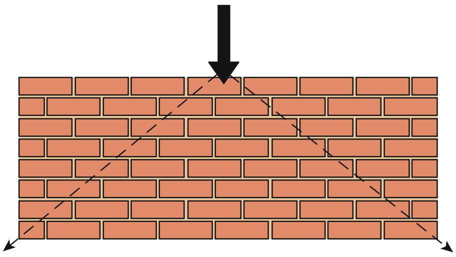
Laying the bricks to a 'bond'

The simplest of brick walls is a 102.5mm thick one (usually referred to as a half-brick wall). In order to satisfactorily fulfil its structural function, the bricks have to be bonded in a particular pattern. If the bricks are stacked as shown in the diagram below and the wall is loaded either vertically or horizontally, the panel of brickwork will gain no support from the bricks on either side. By rearranging the bricks in a different pattern, suitable support can be provided.



Unbonded wall





Bonding spreads loads across wall. This bond is called stretcher bond.

Stretcher bond.

The bond above is known as stretcher bond because you can see the long face or 'stretch' of the brick (the short face is known as the head).

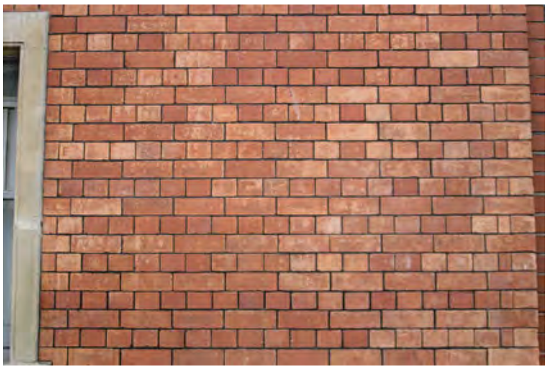
External walls before the 1920s

The relatively thin wall shown in the diagram above (i.e. a half-brick wall) is not suitable for domestic construction due to its low insulation and poor weatherproofing qualities. However, it will sometimes be found in poor-quality small extensions such as old sculleries, outside WCs and coal sheds. A wall must be at least 215mm or one brick thick to provide reasonable weather protection and this was the standard form of construction for the majority of brick-built houses before the 1920s. For one-brick walls, stretcher bond is not suitable as it would entail building two half-brick skins side by side, each acting independently of the other; this would seriously weaken the wall.

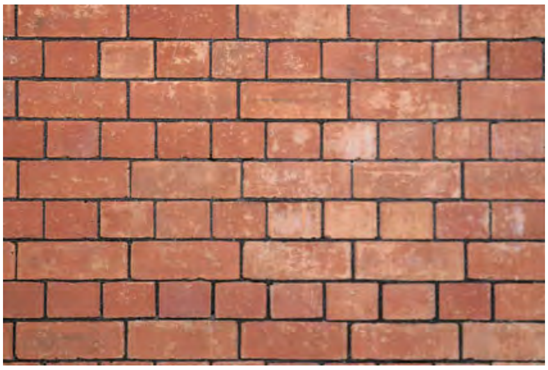
To overcome this problem different bonding techniques were (and are) used for one-brick walls. Two common bonds are English bond and Flemish bond.

English bond and Flemish bond both differ from stretcher bond in that some of the bricks are laid at right angles to the face of the wall in order to bind the two halves of the wall together. These bricks are known as headers and are illustrated in the diagram opposite.

As the photographs opposite show, English bond comprises a row of stretchers followed by a row of headers while Flemish bond comprises alternate headers and stretchers in each course.

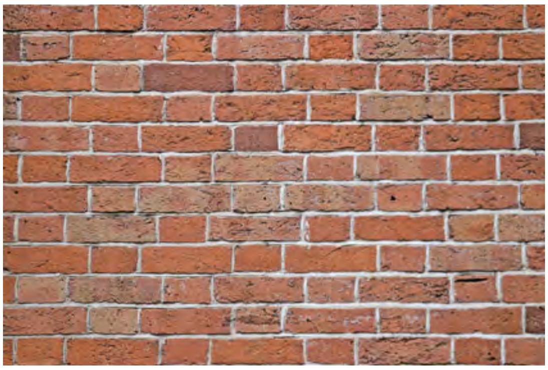


English bond .

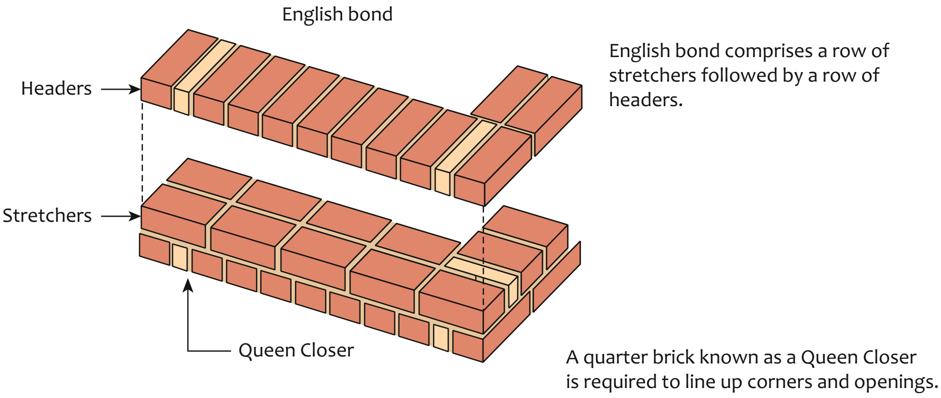


English bond .

Flemish bond .



Flemish bond .



From the diagram above it should also be clear that additional bricks, known as Queen Closers, are required to complete the bond. They are positioned at either end of a run of brickwork. They are also required to maintain the bond at corners. Consider the Closer in the middle course of bricks. If this is replaced with a header, the front and side walls would no longer be bonded together because there would be a straight vertical joint at that point (i.e. they avoid a joint that goes through more than one row).

Flemish bond with Queen Closers at a return in a brick wall.

Garden wall bonds

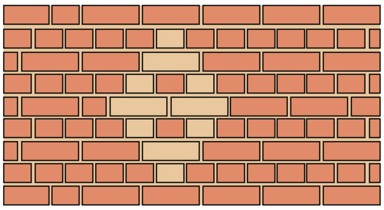
A number of different bonds were developed in the Victorian era, including 'garden wall' versions of English bond and Flemish bond. These were, as the name suggests, used for garden walls but were also often used to construct the main walls of the house, although they were usually, but not always, confined to rear and side walls and were often rendered.

Flemish garden wall bond to a gable wall on an early 1920s house.

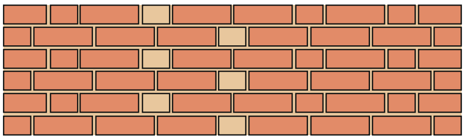
English garden wall bond to the side of a Victorian house with a rubble stone elevation.

As can be seen in the photographs on the previous page, both bonds have a greater number of stretchers than their 'true' bond equivalents, and it is this aspect that probably made them popular. It is easier to lay and level stretchers than headers and there is less waste because oversized bricks (which might have to be rejected as headers) can be accommodated by adjusting the thickness of the joint. In fact, true English bond is rarely found on houses in this country. Although it is a very strong bond and is found in Victorian engineering works, such as viaducts and bridges, it is not particularly common in housing. Flemish bond is much more common.

Other variations on English bond included, for example, English Cross bond, often used where patterned brickwork is required, while Monk bond was a variation of Flemish bond.



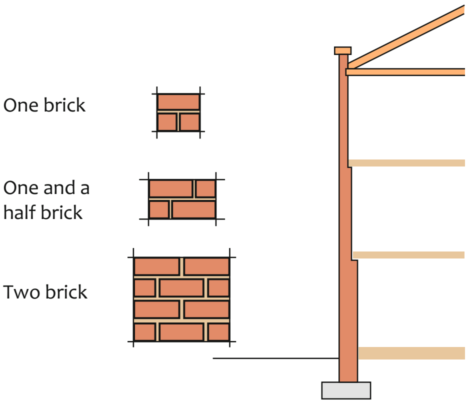
English Cross bond



Monk bond

Wall thicknesses

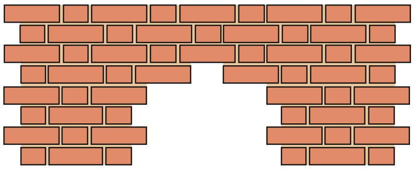
On Victorian and Edwardian properties over two or three storeys high, the walls are often more than one brick thick at lower levels. This was done to improve their stability. The walls reduced in thickness at each floor level as the imposed loads decrease.



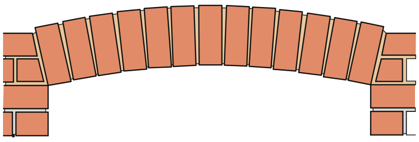
Openings in solid brick walls

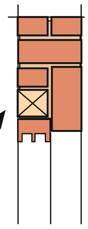
Where openings occur for doors or windows, support is required at the top, or head, of the opening. A window frame is not designed to carry any wall loading. The load which has to be carried is, in fact, quite modest due to the bonding of the brickwork. Stretcher bond is not used for solid walls but it does show the principle quite clearly. The loads can be supported in a number of ways and some common methods used for older houses with solid walls are shown overleaf.

The bonding of the bricks means that only a small area of brickwork is supported by the lintel.

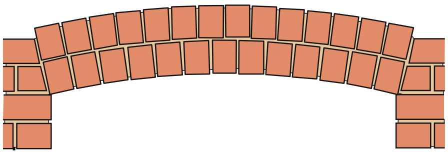


This is known as a segmental rough arch: segmental because the arch is a segment of a circle, rough because the taper is in the mortar.

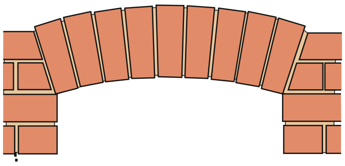




Timber lintels often found on the inner face (common until 1920s).



The taper is less obvious if the arch is laid in ‘rings’.



In an axed arch the bricks are cut to a taper on site using chisels and saws. Joints are 10mm or so.

In a gauged arch the bricks are shaped on site very precisely and laid with very thin joints, perhaps just 3mm or so. The bricks themselves are often quite soft so that they can be rubbbed or sanded to a taper. Arches can be any shape: semicircular, segmental or even flat. Flat arches have a very slight camber. Without it the arch would appear to be falling.

Gauged arch with rubbed bricks.

The flat gauged arch (shown in the photograph left) is more likely to be found in better quality housing. The soldier arch and segmental arch are common in the cheap speculative inner-city housing of the late Victorian period. In practice, most openings in Victorian and Edwardian solid walls have a timber lintel over the inner half of the wall, further reducing the load that needs to be supported by the arch. Arches add significantly to the character of older houses – and a selection are shown opposite.

Ringed segmental arch.

Segmental arch (i.e. it is a segment of a circle).

Semicircular arch.

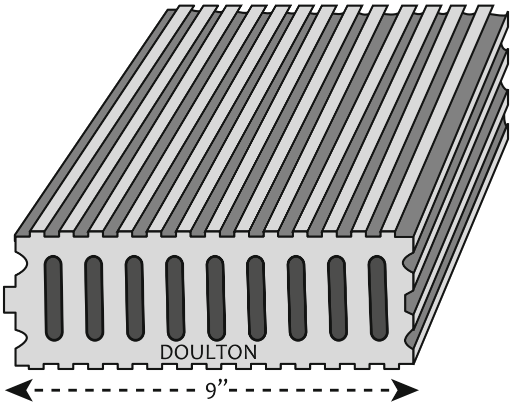
More elaborate/decorative versions of these basic arch designs are shown below.

Early damp proof courses

The wall below ground level is likely to be permanently damp and, to prevent moisture rising through capillary action, it is, nowadays, a requirement of the Building Regulations that walls should resist the passage of moisture. This requirement is most commonly complied with through the provision of a damp proof course (DPC). DPCs first came into use towards the end of the Victorian period when materials such as tar and sand, or hessian soaked in tar were commonly used. On more prestigious buildings, lead and copper were often employed. It was also common to find buildings with two or three courses of engineering bricks or layers of slate providing a barrier to rising damp. The DPC should be well clear of the ground (at least 150mm) and should ideally be a flexible material to allow for slight differential movement. Slate DPCs often failed due to cracking as the building settled slightly during its life.

Slate DPC on a house from the early twentieth century.

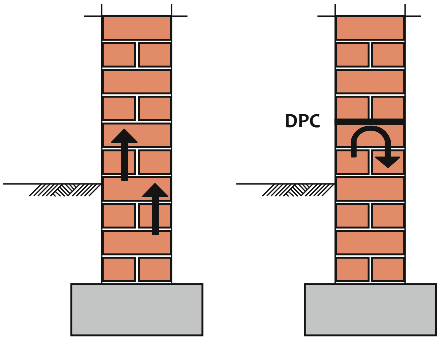
Example of a vitrified clay DPC.



Vitrified Clay was also used as a dpc in the Victorian period.

Bitumen felt DPC (in a stone wall).

In practice, many early DPCs are no longer effective; materials become brittle with age, buildings settle, and external levels often change due to such measures as the resurfacing of footpaths and the like. Fortunately, many buildings can cope adequately without a DPC as long as the brickwork is of the right quality and the ground is well drained.

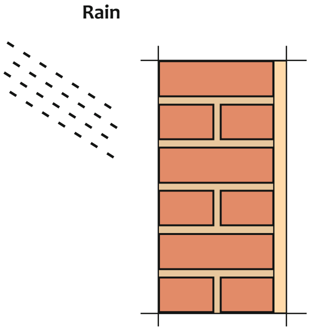


DPCs should be at least 150mm above ground level (to stop splashing wetting the brickwork above). In practice, this gap is unlikely to be found in older houses, particularly where paths and pavings have been resurfaced.

Environmental performance of solid walls

Damp penetration

A well-built and properly pointed one-brick (or stone) wall which is in good condition should exclude rain unless it is in the most exposed of situations. Although some rain will be absorbed by the wall during heavy rainfall, its thickness should prevent damp from reaching the inside face. When the rain stops, the water will evaporate and the wall will dry. However, over the years the general deterioration of poor quality brickwork and old lime mortar can result in damp penetrating to the inside face and effective solutions can be costly. If a solid brick wall were to be used in an area of severe exposure, the Building Regulations recommend that it should be 1½ bricks thick (325mm).

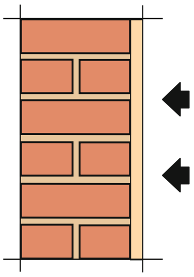


Heat loss

A one-brick (or stone) wall would not meet the thermal insulation requirements of the current Building Regulations. However, in an existing house they do act to some extent as thermal moderators because of the way that they can absorb and store heat, and then release it slowly to the interior of the house. So, for example, thicker walls can absorb excess heat from solar energy coming through the windows and slowly release it to the interior in the evening, thus preventing houses becoming too hot in the summer months. In the same way they will absorb heat produced by the heating system and then release that stored heat once the system is turned off. However, because they act as a ‘thermal store’ this does mean that they will take a relatively long time to heat up as well as to cool down. This factor, and how it might affect decisions about how to improve the thermal insulation of solid walls, is discussed further in Chapter 16.

Condensation

Condensation on inside face



If a building with a solid wall is constantly heated, condensation is unlikely to occur as the structure will be kept warm. However, in the majority of domestic buildings the heat is switched on and off as required by the occupants. If the inside face of the wall cools below a particular temperature then moisture in the air will condense on the cold surface. As observed above, solid walls will take a relatively long time to heat up and, particularly if they are not insulated, they can be prone to condensation (for further information on condensation refer to Chapter 16).

The cavity wall

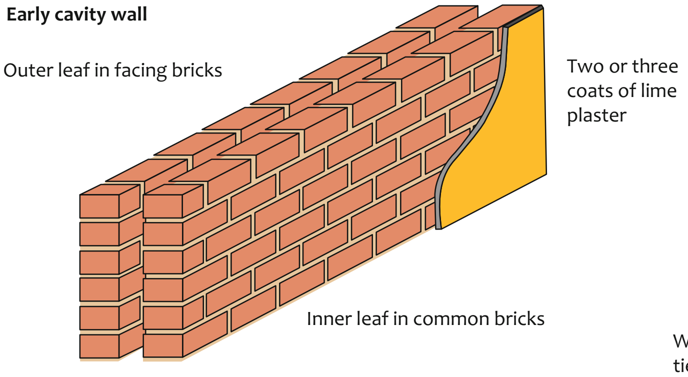
Although there are earlier examples, the cavity wall started to become more common in the 1920s and it helped to overcome the three problems of damp penetration, heat loss and condensation described above. An early cavity wall basically comprises two skins or leaves of brickwork separated by a gap of 50–70mm.

The cavity has two functions:

- *it prevents water from reaching the internal skin*
- *it improves the thermal efficiency of the wall as the air in the cavity is a good insulator.*

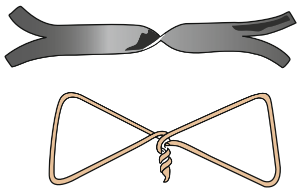
Two 100mm skins of brickwork each acting independently are not very strong or stable and it is a requirement of the Building Regulations that the two leaves of the wall are tied together at regular intervals in order to ensure that the finished wall is strong enough to carry the required loads. This is done by the use of wall ties.

Early cavity wall



Two leaves of brickwork with 50mm or 70mm cavity

Wall ties

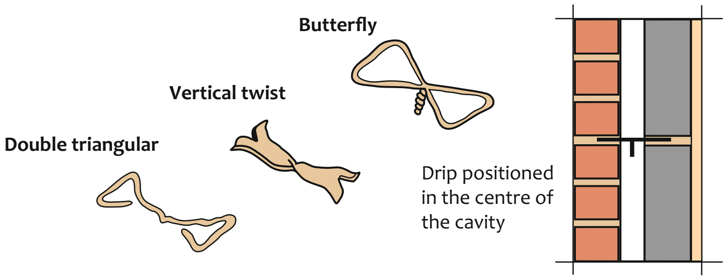


Wall ties from 1925 trade catalogue. The upper ties were available tarred or galvanised. The lower ties (wire) were galvanised.

Some of the very early ties were made from iron, which was brittle and rusted very quickly. Later ties were made from galvanised steel (steel coated with zinc) and, albeit in limited numbers, copper. Plastic ties have also been used. Current Building Regulations recommend that stainless steel ties are used, although other materials would be acceptable as long as they complied with the British EN Standard or had a suitable form of third-party accreditation – such as the British Board of Agrément.

It is important that the tie is correctly positioned to ensure that any water in contact with the tie does not reach the inside skin. Three suitable examples are shown in the diagram below. The Building Regulations set out recommendations for the frequency and position of the ties, but generally they should be spaced 900mm apart horizontally and 450mm vertically (at every sixth course of bricks and every second course of blocks). Extra ties should be positioned horizontally within 225mm of openings, such as window and door openings, as well as at verges, movement joints or ends of walls. In these positions the ties should be no more than 300mm apart vertically.

Ties are formed with a 'drip' to prevent water passing along the tie from the outer to the inner skin (see below). Special ties are required for wide cavities, and special ties and additional proprietary clips are required when cavity insulation boards or batts are used (see photographs on p. 71).

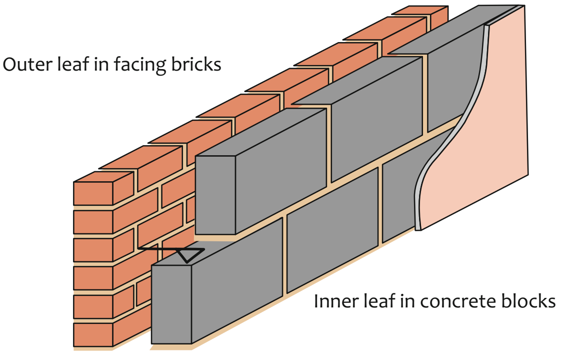


A selection of wall ties.

As mentioned above, early cavity walls had brickwork in both skins; facings on the outside and commons on the inside. However, it soon became popular to use concrete blocks for the inside skin because they were cheaper and quicker to lay, and they improved the wall's thermal insulation. Over the years there have been a variety of concrete blocks on the market, differing mainly in the type of aggregate used. Increasing emphasis on thermal efficiency means that only a few of these blocks are suitable nowadays unless additional insulation is provided. Typical construction for modern walls is shown in the next section.

The modern cavity wall

Thermal insulation and cavity walls



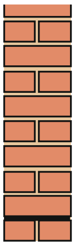
Cavity wall from the 1950s formed with dense concrete block inner skin and no insulation. Note, however, that an inner skin of brickwork may still have been used in this era.

A typical house from the 1950s.

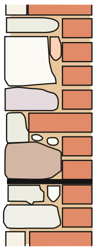
To a large extent the development of the cavity wall has, particularly in recent years, been driven by the need to improve the thermal performance of external walls. Since the 1970s, the Building Regulations have required external walls to have increasingly lower U-values, therefore increasing the need for higher levels of thermal insulation (see Chapter 16 for an explanation of U-values).

Approximate U-value W/m^{2}K

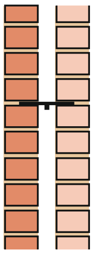
One-brick wall
U-value 2.10



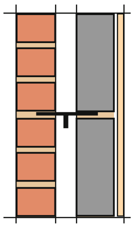
350mm stone/brick wall
U-value 1.70



Early cavity wall
U-value 1.80

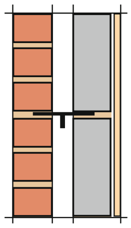


1972
U-value 1.70



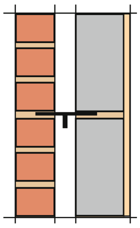
103mm facing brick
50mm clear cavity
100mm dense block
any plaster finish

1980
U-value 1.00



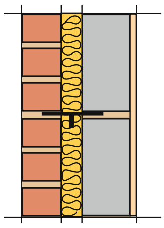
103mm facing brick
50mm clear cavity
100mm lightweight block
any plaster finish

1985
U-value 0.60



103mm facing brick
50mm clear cavity
125mm lightweight block
any plaster finish

1990s
U-value 0.45



103mm facing brick
50mm cavity insulation
125mm lightweight block
any plaster finish

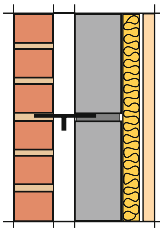
The diagrams above show the changes to the minimum 'back stop' average U-value required by the Building Regulations from the early 1970s until the 1990s. This was reduced to 0.35 in 2006 and to 0.30 in 2010.

Following amendments to the Building Regulations introduced in 2010, the minimum 'back stop' limiting U-value required for an external wall (or a wall to an unheated area such as a garage) is 0.30. But this is in the context of the approach known as the target emission rate (TER), which is the recognised holistic way of showing compliance with the requirements of the Regulations and it concerns itself with the carbon dioxide emission rates from new dwellings. The Building Regulations state that the achievement of the TER is likely to require a thermal performance higher than 0.3. In practice, this will also depend on factors such as the space and hot water heating system efficiency, the type of fuel used and the air permeability of the fabric. As part of the 2010 amendments there is also a requirement for the insulation of any party walls to other dwellings to achieve a minimum 'back stop' limiting U-value of 0.2.

The diagrams below illustrate some of the ways that a U-value of 0.3 might be achieved.

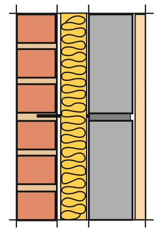
U-value 0.30W/m^{2}K (approx.)

Clear cavity



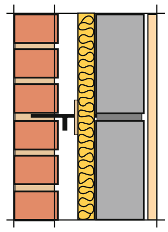
103mm facing brick
50mm clear cavity
115mm aerated block
40mm thermal board

Filled cavity



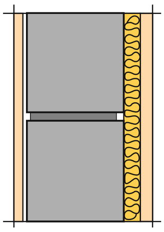
103mm facing brick
75mm cavity batts
115mm aerated block
any plaster finish

Partial cavity



103mm facing brick
30–50mm cavity board
50mm cavity retained
125mm aerated block
any plaster finish

Solid

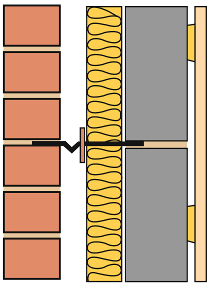


15mm render
215mm aerated block
30mm thermal board

It may seem pointless to fill a cavity with insulation (as in the second example from the left, bottom of previous page) when the cavity is acting as an insulator in the first place. However, it is important to remember that the insulating material itself does not provide any insulation; it is the tiny pockets of air trapped within the material that prevent or reduce heat transfer. Uninsulated cavities do permit some movement of air and therefore heat is lost through convection. Trapping the air within the insulation means that the air is not free to move and heat is retained. A comparison of the advantages and disadvantages of each approach is contained in Chapter 16 on insulation.

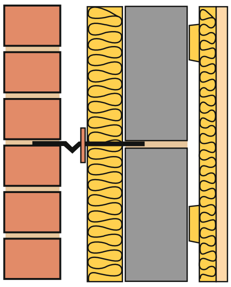
The challenge of meeting minimum U-value requirements has been addressed by improvements in the thermal performance of blockwork and insulation materials, as well as by increasing the thickness of both elements. It is expected that amendments to the Building Regulations in 2013 and 2015, and the associated moves towards a zero carbon policy, will require further reductions to minimum U-values. It should be noted, however, that in order to achieve certain levels of the Code for Sustainable Homes (see Chapter 2), minimum U-values for external walls will have to be lower than those required by the current Building Regulations (i.e. the 2010 amendment). Two examples of wall insulation related to the Code are shown below.

Level 3 – U-value 0.18



Brick 102mm
Residual cavity 50mm
Cavity board 75mm
Aerated block 100mm
Plaster dab cavity 15mm
Plasterboard 12.5mm

Level 4 – U-value 0.15

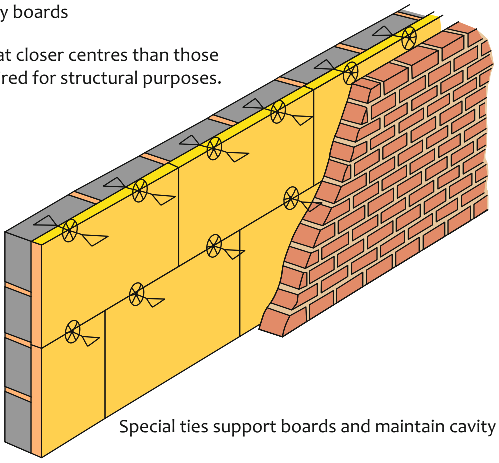


Brick 102mm
Residual cavity 50mm
Cavity board 75mm
Aerated block 100mm
Plaster dab cavity 15mm
Thermal board 40mm

Cavity insulation boards

Cavity insulation boards are generally rigid and are fixed against the internal leaf of blockwork with large plastic retaining washers which clip over the wall ties. The boards are normally supported between two rows of ties – to do this properly requires ties at greater frequency than those required for structural stability. The ties should be in line, not staggered.

The image (right) shows the insulation board and cavity tie before the retaining washer is put in place. The washer, which holds the insulation in place, is shown in the images on this page. This retains the partial cavity.



Structural stability

In domestic construction, the stability of an external wall is assisted by the 'bonding in' of internal partitions and flank walls. Additional stability is provided by the floor joists and roof timbers. These items are all considered in more detail in later chapters and details of typical examples are given.

Sound insulation

To reduce the problems of sound interference from adjoining properties, the Building Regulations recommend minimum performance standards for party walls. Airborne sound (from voices, radios, etc.) is reduced by mass and, in practice, this can be achieved by using dense blocks or bricks in either a 215mm solid wall or a 250mm cavity wall. Materials such as standard aerated (lightweight) concrete blocks are not always suitable because of their low density.

Fire protection

The Building Regulations demand that the external walls of a dwelling provide adequate fire resistance for the building to retain its structural stability and allow occupants to escape. They must also restrict the spread of fire to or from adjoining properties.

The Building Regulations recommend that dwellings with the top floor within 5,000mm of ground level should have 30 minutes' fire resistance and 60 minutes' fire resistance for houses with any floors above this level. Also, regardless of the height of dwellings, walls to adjoining properties (party or compartment walls) should have 60 minutes' fire resistance to both sides. These levels of fire protection are easily achieved by default when using materials such as clay bricks and concrete blocks.

In order to prevent the spread of fire to or from other buildings or dwellings, the Building Regulations also limit the amount of 'unprotected areas', such as doors and window openings or sections of walls that do not have the required amount of fire resistance. This limitation is related to the distance to a relevant boundary. Likewise guidance is given on the permitted areas of combustible cladding materials used on external walls, such as timber or uPVC cladding, again depending upon the type of material and the distance to relevant boundaries.

Modern damp proof courses

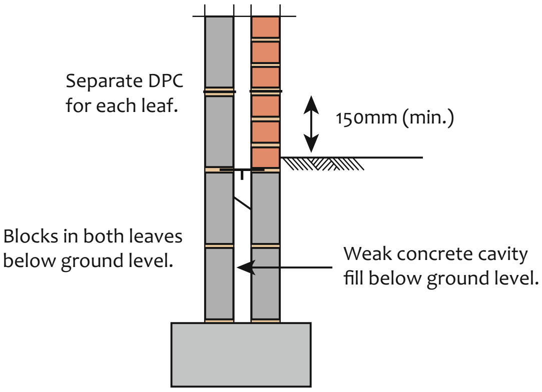
Modern damp proof courses (DPC) are made from flexible materials and, if correctly laid, should prevent any damp from rising into the superstructure. It is also important to ensure that there is a good joint between the DPC in the wall and the damp proof membrane (DPM), which is there to prevent damp rising through the floor. This is covered in more detail in Chapter 5.

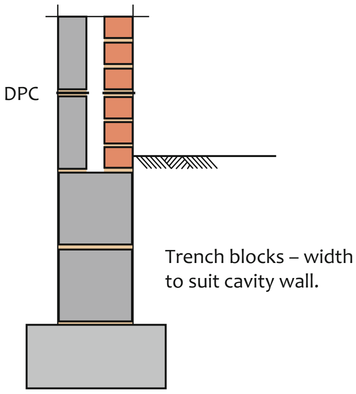
Modern materials for a DPC include bitumen felt, lead cored bitumen felt and dense polythene (by far the most common). It is essential to ensure that the DPC does not cross the cavity as this will provide a path to the inside skin for any water running down the cavity.

DPC being laid to cavity wall (shown here on brick outer skin but will also be applied to inner skin of blockwork). Photograph courtesy of H+H Ltd.

Most modern DPCs are made from polythene. The DPCs should not project into the cavity where a possible build-up of mortar might bridge the cavity and allow damp to penetrate.

Note: If it is necessary to provide a DPC across the cavity to give protection against ground gases such as radon, a cavity tray and associated weepholes should be provided above the DPC to direct any moisture or water that enters the cavity to the outside (see section on radon at end of Chapter 5 Ground floors).





There are three points worth mentioning about the diagrams above.

- *In the first example the outside skin is built in blockwork rather than brickwork below ground level. Aerated (lightweight) blocks can be used below ground level, but for reasons of economy dense blocks are more likely to be used. Manufacturers produce extra wide blocks and these are shown in the second example. They are quick to lay and provide good stability.*
- *The cavity below ground level is filled with a weak mix concrete to prevent the leaves being squeezed together when the trenches are backfilled. It is important that this cavity fill stays well below DPC level if future problems of damp penetration are to be avoided.*
- *The DPC is laid in two separate strips, one for the internal skin and one for the external skin.*

The two images above show aerated trench blocks being laid. Photograph courtesy of H+H UK Ltd.

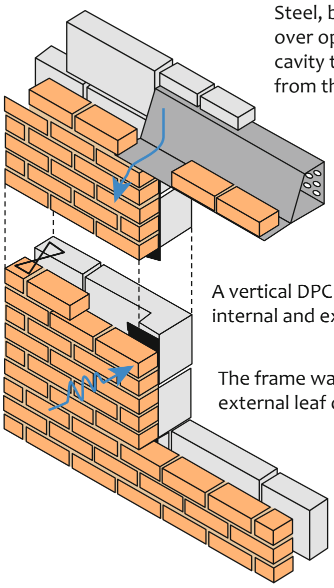
External wall up to the level at which it will receive a suspended concrete ground floor.

The cavity fill below ground level helps to ensure that the two leaves are not squeezed together by pressure from the ground when the trenches are backfilled.

Openings in cavity walls

There are a variety of ways in which openings can be made in external walls to accommodate windows and doors. However, any design must safely support the loads from above and prevent lateral damp penetration.

The diagram below shows a typical detail of a wall built in the 1960s or 1970s. During this period cavity insulation was rare. At the top or head of the opening a box-section steel lintel with an extending ledge or toe supports the external skin. In cavity wall construction it is the internal skin which requires most support from the lintel. The perforations in the back and bottom of the lintel are to ensure bonding of the plaster. At the sides or jambs of the opening, the blockwork is returned across the cavity in order to provide stability at the opening and a good fixing for the window frame. If the blockwork touches the brick, a path is created for damp and therefore the two materials are separated by a vertical DPC. At the bottom of the opening there is a window board on the internal skin and a window sill on the external skin. On the underside of the sill there is a groove or notch which is known as a drip. This prevents water running back under the sill and into the wall (see p. 80 and Chapter 15).



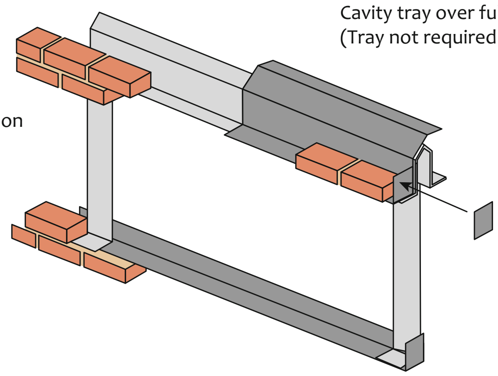
Steel, box-section lintel carries loads over opening. The sloping face forms a cavity tray to direct any water away from the internal leaf.

Perforations on the back of the lintel provide a key for the plaster.

A vertical DPC separates the internal and external leaf.

The frame was fixed to the external leaf of brickwork.

In modern construction there is more emphasis on preventing damp penetration (as well as thermal bridging) and recommendations in the British Standard include additional protection against damp.


Cavity tray over full length of lintel. (Tray not required by some lintels.)

DPC with 25mm projection into cavity and lapped behind tray and in front of sill DPC.

Stop ends if insulation fills cavity (to stop water running off ends of tray and wetting insulation).

DPC at sill required if sill is permeable or jointed, or if sill is in contact with insulation or inner leaf.

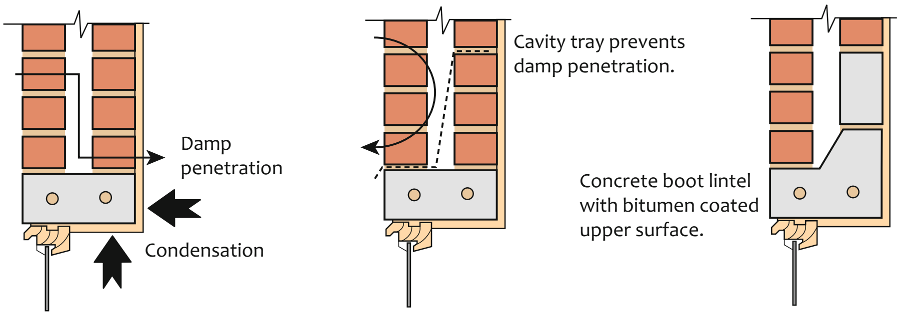
Sill DPC (with stop ends as required).

The head

In the 1940s and 1950s lintels were often made from concrete in a variety of patterns. Some contained cavity trays but many did not; as a result, problems of damp penetration were common.

Some concrete lintels were 'boot' shaped and painted on top with bitumen to provide a tray; others had a separate tray provided in lead or, in later houses, polythene. In the 1960s and 1970s steel lintels became common. 'Catnic' lintels were usually box shaped and incorporated a cavity tray. They were lighter than concrete and could be carried by one operative.

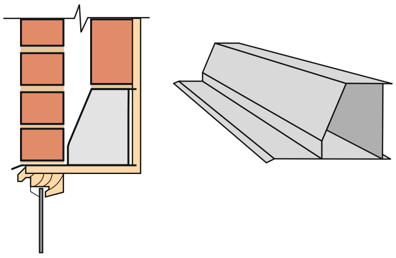
Concrete lintels from the 1930s–1950s



Cavity tray prevents damp penetration.

Concrete boot lintel with bitumen coated upper surface.

Steel lintel from the 1960s–1980s


'Catnic' hollow box-section lintel. These are quite light and do not require a separate cavity tray. They are still popular today – modern ones contain insulation.

These three imagess are of 1950s houses with concrete lintels.

Nowadays several patterns of lintel are available incorporating some form of insulation. The photographs below and on the next page show modern insulated lintels.

Insulated lintel from a house built in 2005.

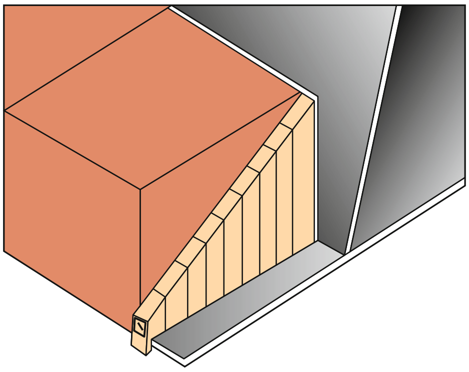
An insulated lintel over a window opening of a modern house. Note the plastic vertical insulated cavity closer in place (below the lintel); see the section on jambs below.

Note the thermal insulation to the lintel.

A cavity tray should be incorporated above the window or door opening in order to direct any water running down the cavity away through the external leaf. Weepholes, which allow the water to escape, should be located every 450mm or so. These are usually formed using plastic inserts (in the past they were often just open perp (perpendicular) joints).

Weepholes above a window.

Weepholes above a window.



Weepholes formed on a cavity tray.

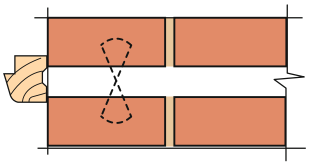
Sometimes (as here) the cavity tray is located a few courses above the opening.

Some lintels have an integral cavity tray while others need a separate tray – this is usually formed using DPC materials on site or installed as part of a proprietary pre-formed system. The cavity tray usually sits directly on top of the lintel, although sometimes it is located a few courses above it.

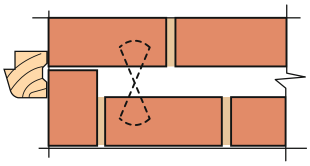
A cavity tray in the process of being formed over a lintel.

The jambs

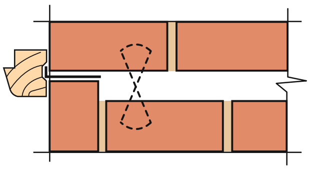
At the sides or jambs of the opening a good fixing for the window should be provided and the detailing should prevent damp from bridging the cavity. Until recently it was normal practice to close the cavity by returning the inner leaf to meet the outer leaf and to prevent damp from crossing into the blockwork a vertical DPC is required. In some early cavity walls (1920s) the DPC was omitted.



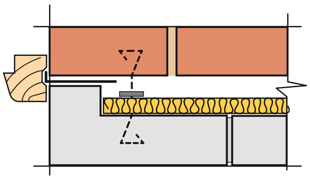
In some early cavity walls the cavity was not closed. This provided a poor fixing for the frame.



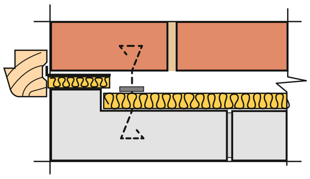
Some early cavity walls had closed cavities but no vertical DPC.



From the 1930s onwards most cavity walls had vertical DPCs. Internal leaves could be block or brick.



Better protection is provided in modern walls where the DPC should project into the cavity by about 25mm. In modern construction the internal leaf will normally be lightweight blockwork and the cavity will normally be insulated.



Nowadays an insulated vertical DPC is required or a proprietary plastic cavity closer.

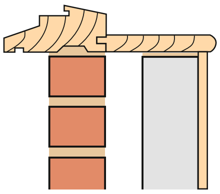
Proprietary cavity closers are quick and easy to install. The windows are secured to the closer and are usually fixed when the brickwork is complete (see Chapter 15 for further details). Note the insulation has not yet been added to the closer.

In recent years the use of extruded plastic has become a common alternative for closing the cavity. The plastic cavity closer will have an insulation infill. Special plastic ties are built into the internal and external leaves. Using this method precludes the need for cutting the blocks and does not require a separate vertical DPC. Renewing the windows in later years may be a more complex exercise.

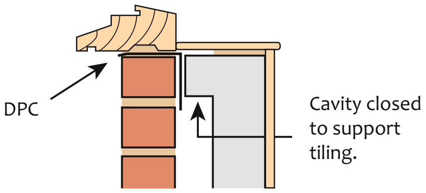
Another alternative to these plastic cavity closers are window sub-frames, which act as a cavity closer and also provide an airtight means of fixing windows in place (see Chapter 15 for further details).

The window sill

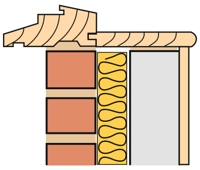
Until the 1980s, it was not common practice to close the cavity at the sill if standard windows were used because the window board covered the cavity. Where tiling, which needs continuous support, was used in place of the window board, the cavity could be closed as shown in the drawing. In modern construction, a horizontal DPC protects the underside of the timber sill and prevents any water from running under the sill and penetrating the cavity insulation.



In the 1960s and 1970s it was common practice to bed the sill on the external leaf and leave the cavity open. The window board hid the gap.



In kitchens and bathrooms it was normal to provide tiling on the inner sill. The cavity had to be closed to provide adequate support. Closing the cavity requires a DPC to separate the two leaves.



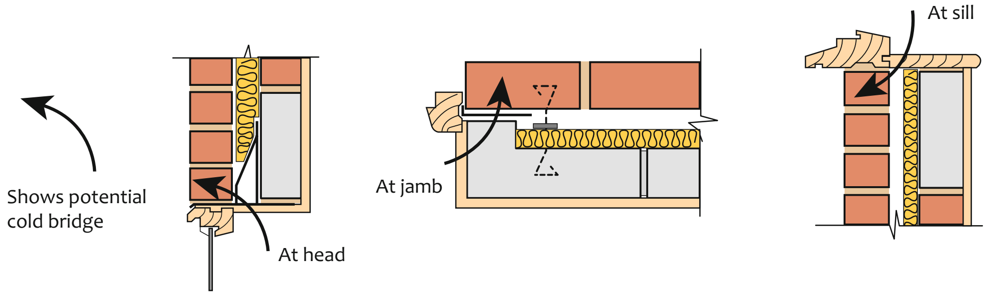
In modern construction cavities are usually insulated. A DPC under the sill may be required under timber windows or where sub-sills are jointed.

Some windows are designed for use with separate sub-sills – in this case tiling.

Note: The details above show timber window frames but the principles are the same as for plastic windows and these are discussed further in Chapter 15.

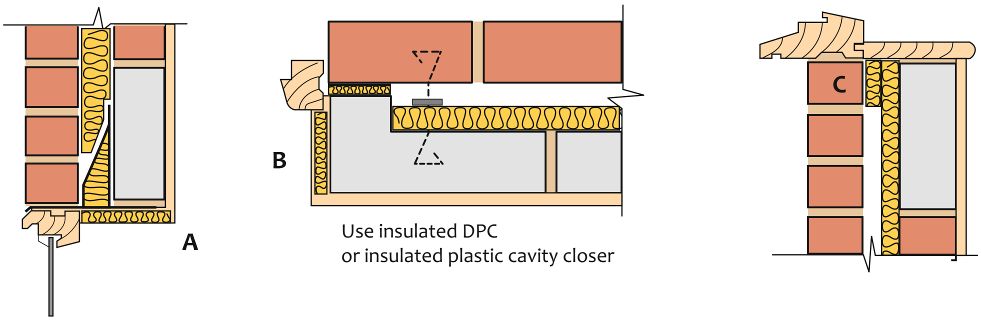
Cold bridging

In modern, highly insulated cavity walls the risk of cold bridging has become more likely. Part of the head, jamb or sill, just behind the frame, can be relatively cold. If warm moist air comes into contact with these cold areas, condensation can occur. The Building Regulations recommend that the insulation of a building should be continuous, and that reasonable provision should be made to prevent cold bridging (and the associated condensation and mould). The drawing opposite shows two typical scenarios. The arrows indicate the path of greatest heat loss.



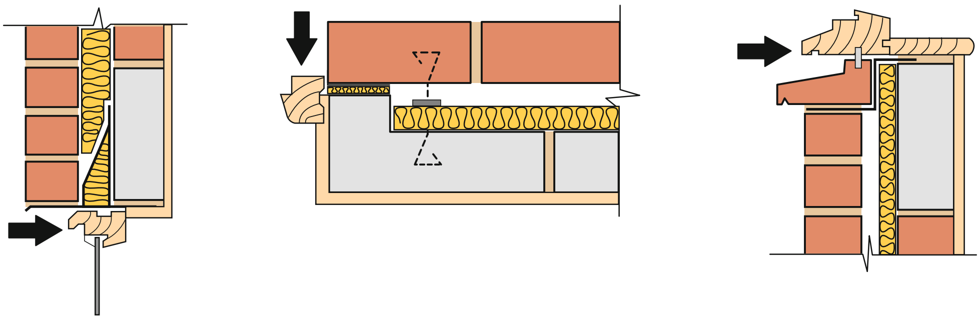
There are a number of options to reduce this risk. In the first example, insulation board, fixed behind the plaster, maintains a high inner surface temperature.

The cold bridge can be eliminated by insulating the soffit of the lintel (A), the jamb (B) and the cavity just below the window board (C).

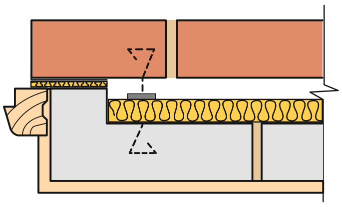


Use insulated DPC
or insulated plastic cavity closer

In the second example (below) the frame is fixed deeper into the reveal and covers the cold bridge. This second approach requires wider sills, or the use of sub-sills to ensure that the drip is clear of the brickwork. Sub-sills can be formed from stone, concrete, timber, slating and tiling. Other examples of sub-sills are shown in Chapter 15.

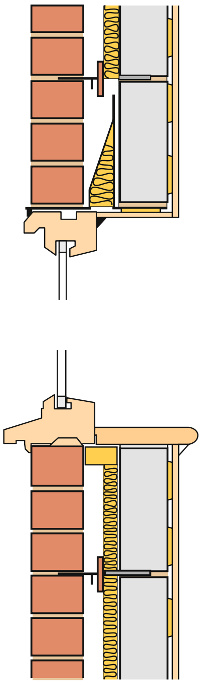


The detail can be improved further by protecting part of the frame with the outer leaf of brickwork – known as a 'check reveal'. The Building Regulations recommend this form of construction to be used wherever exposure to driving rain is severe.



In Scotland check reveals have been used for years. In this form of construction the brickwork overlaps the frame by about 25mm or so. It provides good weather protection and prevents cold bridging. In the Building Regulations 2010 (England and Wales) this form of construction is required wherever exposure to driving rain is severe. This includes a large part of the west of the country.

Section

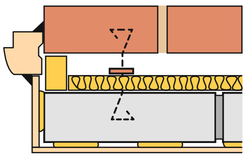


Good modern practice

This is an example of a modern window opening (this particular one has pre-formed cavity closers) which conforms to widely accepted good practice. The mastic seals help prevent air leakage. Some authorities suggest that the gap behind the frame should be filled with an expanding foam to further limit leakage. This example is not suitable for very severe exposure.

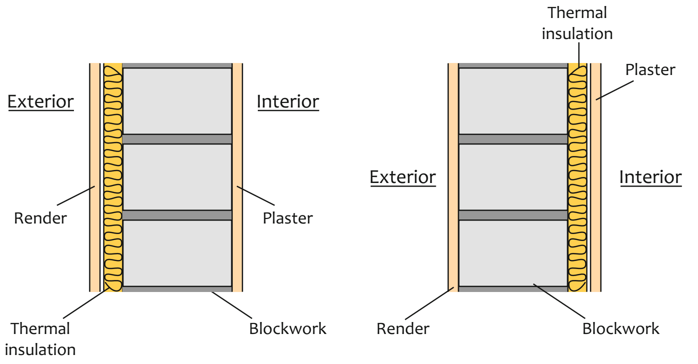
Note that there are several other ways of providing an acceptable detail.

Plan



Solid walls

This chapter has concentrated on cavity walls because, at least in England and Wales, this is the most popular approach to the construction of external walls. It is, however, perfectly possible to construct solid external walls that comply with design and statutory criteria – including thermal insulation standards, airtightness, fire resistance and resistance to moisture penetration.



Note: a vapour control layer will be needed between the plaster and the insulation on an internally insulated wall. (See chapter 16)

A solid wall might, for example, be constructed of a 215mm aircrete concrete block, with render on its external face and internal insulation of about 55mm thickness (depending on the thermal qualities of the insulation material). Alternatively, a 215mm block could be used with external insulation of about 75mm (again, depending on the thermal qualities of the insulation material) and protected with a render.

A solid wall has several potential advantages over a cavity wall, including

Solid block external wall under construction. Photograph courtesy of H+H UK Ltd.

avoiding those details and processes which are necessary to form a cavity, as described above. In addition, a solid wall with external insulation could act as an effective thermal store.

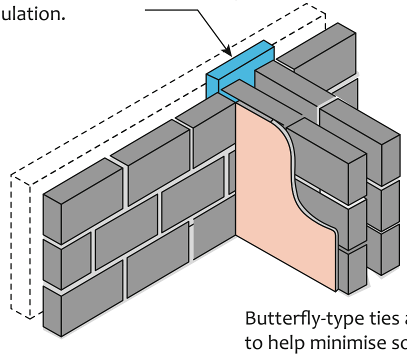
Party walls

Party walls must provide good fire protection, thermal insulation, airtightness and adequate resistance to the passage of airborne sound (there are no requirements for impact sound performance in the Building Regulations). Party walls must also achieve a minimum U-value of 0.20. In older houses, one-brick solid walls are common. In modern houses, the most common method of construction is blockwork. Standard dense blocks, laid flat, are suitable. Some aerated blocks are also acceptable.

Dense concrete blocks laid flat can also provide a good party wall. They can be bonded in to the internal leaf of the cavity wall or connected by ties. As in the above example, a flexible cavity stop is required in the external cavity.

Cavity construction can be used but a solid wall is generally cheaper to lay. Fully filled mortar joints are essential if the party wall is to fulfil its function. Joists should be supported on hangers and should not be built into the wall (although this would have been standard practice historically). Plasterboard can be used on party walls but it may require an undercoat of wet plaster (usually 6–8mm thick) to seal any gaps in the wall.

In modern construction, party walls are subject to testing to ensure they meet minimum requirements of sound insulation. An alternative to testing is a system known as Robust Details. This is a certification scheme which applies to party walls (and floors between separate dwellings). Robust Details show a number of forms of construction which exceed the standards required in the Building Regulations. If Robust Details are adopted, testing is not required. One of the forms of construction from Robust Details is shown below.



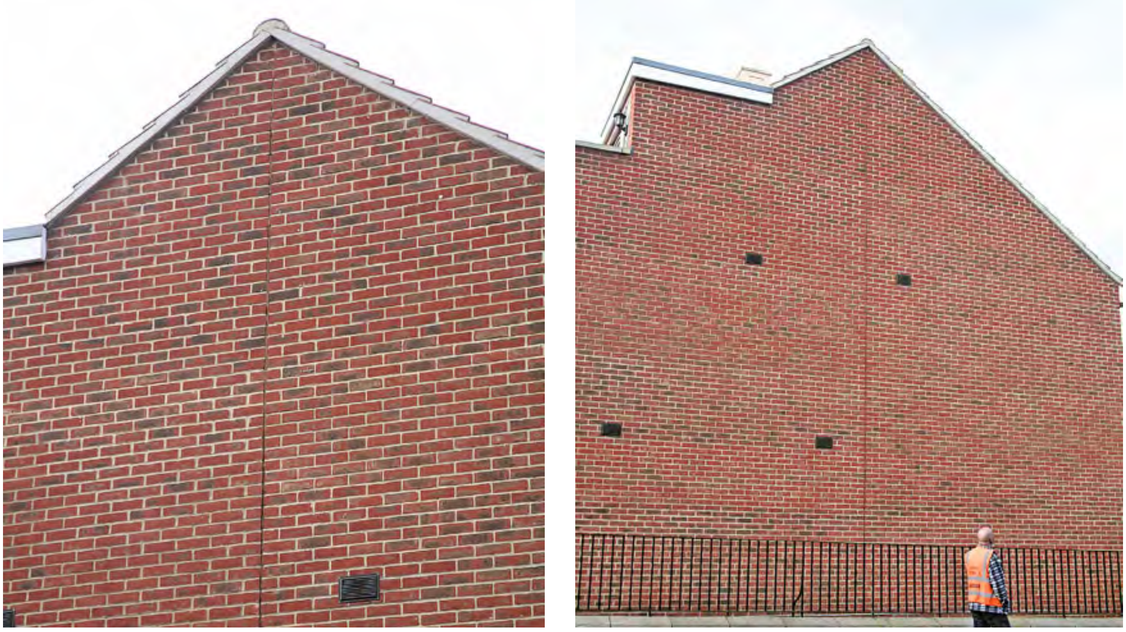
Thermal movement

Over the course of an average year, an external wall will suffer extremes of heat and cold. As the wall heats up it will expand, and as it cools it will shrink. Expansion and contraction also occur due to changes in moisture content. In addition, new clay brickwork will expand slightly for several months as it slowly absorbs moisture from the air until equilibrium is reached. Calcium silicate and concrete bricks will shrink slightly (like all cement or hydraulic-lime based materials). Allowance for this movement must be made at the design stage, otherwise cracking will occur. In long terraces of houses, particularly those built with a strong cement mortar, cracking caused by thermal and moisture movement is a common problem. Even in semi-detached houses the expansion may be enough to cause the ends of the houses to oversail the substructure (the DPC provides a slip layer).

To prevent expansion and contraction from causing damage, in the form of cracking, it is usual to divide long runs of brickwork or blockwork into shorter panels and provide movement joints. Terraces of houses, wide gable walls and long garden walls should contain these joints at regular intervals; typically every 12m for clay brick external leaves and 6m for freestanding garden walls.

Movement joint (vertical line between two red doors) on a terrace of modern houses.

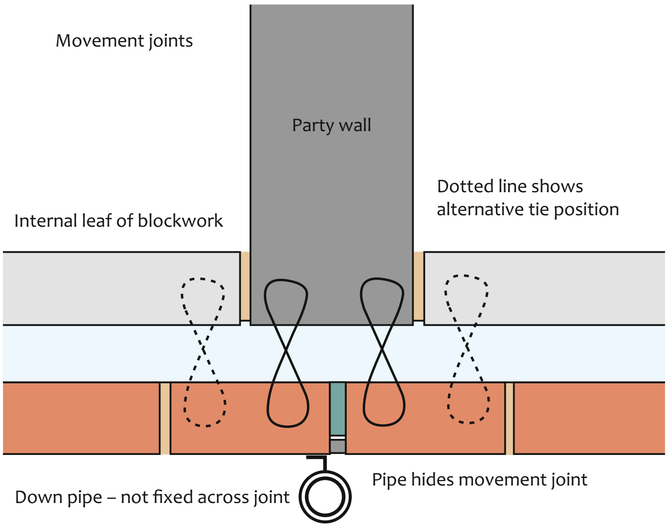
Detail of movement joint to gable wall shown below. Note the joint stops at DPC level.



(left and right above) The vertical line stretching from the ridge downwards in this gable wall is a movement joint.

The joints only occur in the outside skin of cavity walls. Joints are rarely necessary in the internal skin as long runs of walling are broken up by party and partition walls, and temperature tends to be fairly even.

In cavity walls, the joint is normally formed by providing a gap of adequate width (between 15 and 25mm) and filling it with a compressible filler, faced with a flexible waterproof sealant as shown in the (plan) diagram below.



Parapet walls

Parapet walls were common in the Georgian and some parts of the Victorian era. Although they are not particularly popular in modern houses they can sometimes be found – notably in buildings that are a pastiche of Georgian design and in conjunction with particular elements, such as balconies.

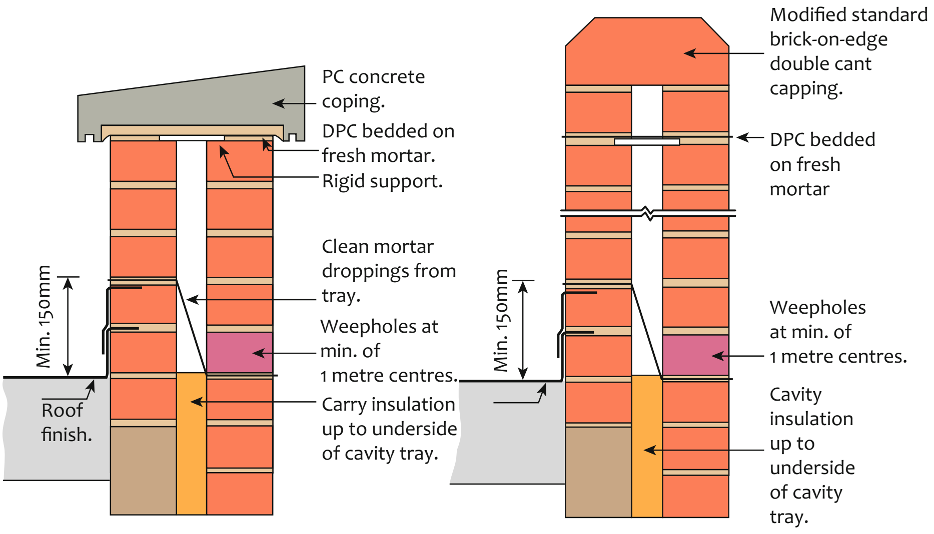

(above and right) Georgian houses with parapet walls.

Parapet wall in a Victorian building.

Parapet wall to the balcony of a new house.

Where parapets are used in modern housing their detailing needs careful attention, particularly because, by their very nature, they are exposed on both sides to the elements and so, for example, frost-resistant bricks with low salt content should be used in their construction.

At the top of the parapet wall it is good practice to provide a weathered coping. The coping can be once or twice weathered – in other words it can slope in one direction as shown in the image below (left) or in both directions. A once-weathered coping normally directs the water onto the roof to avoid water running down the external face. The coping stone should overhang the wall on either side and will incorporate small drips (a throat) to prevent water running back under the coping. A full-width DPC should be bedded in mortar to prevent water penetrating the coping through the coping joints. The DPC should be laid on a rigid support to prevent it sagging into the cavity and allowing water to pond, where it may freeze and expand in cold weather.



If the inner leaf of brickwork becomes saturated, or if water penetrates the wall through the joints, then there is a possibility that water will run down the inner face of the inner leaf and enter the building. To prevent this, a cavity tray should be used in the manner shown in the diagram above.

Thin joint system

This is a relatively recent approach to the construction of brick and block walls which uses proprietary, thin joint, pre-mixed, mortars in place of a traditional mortar mix. The thin joint mortar is applied by an applicator rather than a trowel. The applicators are designed to deposit a controlled quantity of mortar onto the block (or brick) in order to produce a joint of about 2–3mm. Thin joint mortars are quick setting, which allows for faster construction, particularly when used with the larger sized lightweight blockwork that is another feature of this system.

The use of thinner joints provides, theoretically at least, for a more airtight construction and the thinner joints will improve the U-value of the wall. Thin joint systems are one of the approaches that are categorised as being a 'modern method of construction' (MMC).

(left and above) Blockwork wall under construction using a thin joint system. Photographs courtesy of H+H UK Ltd.

The thin joint is formed using special tools (in this example a 'scoop') to apply the mortar. Photograph courtesy of H+H UK Ltd.

Where a thin joint system is being used for the blockwork inner skin of a cavity wall with a brick exterior, the horizontal joint of the blockwork will not coincide with the horizontal joint of the brickwork because of the larger sized blocks used in thin joint systems. This means that the cavity wall ties will be fixed in a different manner from the 'normal' method – in thin joint systems the wall ties are mechanically fixed either by being driven into the blockwork (e.g. with a helical type tie) or with expanding nylon anchors and then placed, as usual, in the horizontal mortar joint of the brickwork.

The two images above show wall ties being mechanically fixed into the thin-joint blockwork in line with the bed joint of the exterior skin of brick. Photographs courtesy of H+H UK Ltd.

Where both the outer and inner leaf are built using the thin joint system (and therefore the horizontal joints coincide), special thin joint ties can be used (see image right). However, some manufacturers suggest that mechanically fixing a helical tie through both leaves is a preferable option.

In order to boost the strength of thin joint mortars, reinforcement mesh, usually made of nylon or stainless steel, is used to reduce the risk of cracking caused by loading and thermal/moisture movement.

Manufacturers of thin joint systems will give guidance on where bed joint reinforcement is required but, as an example, one manufacturer recommends that it is used in every other course as a minimum.

In most thin joint systems the first blockwork course above the joint that includes the DPC will be laid in a traditional mortar with a joint of normal thickness (i.e. 10–12mm). This is usually referred to as the 'base course'. The main purpose of the base course is to enable any discrepancies in the substructure to be evened out in order to provide a horizontally level structure from which to begin the thin joint blockwork.

Photograph courtesy of H+H UK Ltd.

This image shows reinforcement mesh in the horizontal joint of the blockwork. Photograph courtesy of H+H UK Ltd.

Photograph courtesy of H+H UK Ltd.

The two images above show the first course of a thin joint block being laid on a mortar of traditional thickness in order to ensure a level base for subsequent courses. Photographs courtesy of H+H UK Ltd.

Ground floors 5

Introduction

The function of a ground floor is to provide a level, smooth and dry surface which will safely support the loads of both the people and furniture which rest upon it. It is also required to provide a degree of thermal insulation.

To do this successfully the ground floor must have the following properties:

- *strength and stability*
- *resistance to damp penetration*
- *durability.*

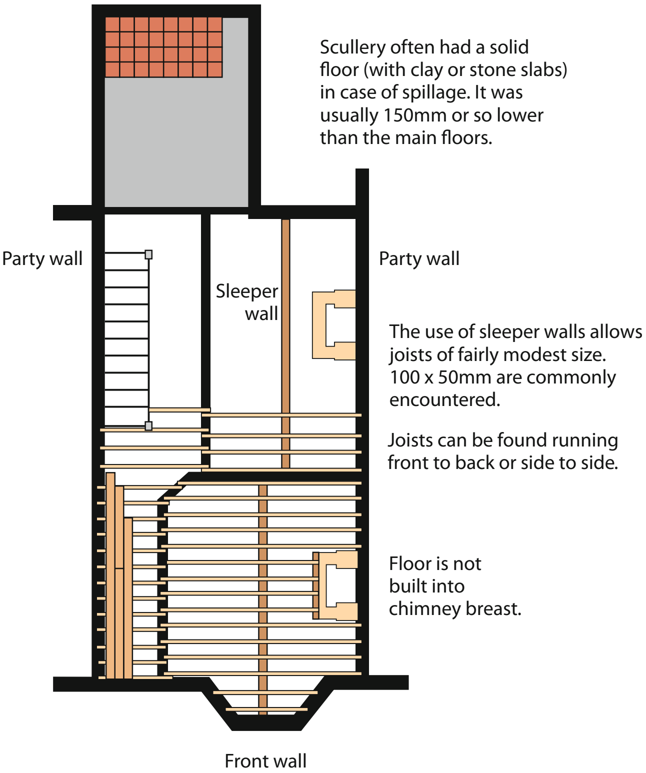
This chapter explains the evolution of ground floor technology and details the associated materials.

Timber floors

Early timber floors

The majority of houses built from the latter part of the nineteenth century until the mid-twentieth century had ground floors constructed from timber. Exceptions to this would be basement rooms, where damp could damage the timber, and rooms which were likely to be wet due to their function, e.g. kitchens and sculleries. For more information on timber see Chapter 13.

Timber ground floors – often referred to as suspended timber floors – consist of a series of joists supported by loadbearing walls and covered with floorboards. The size of a joist depends largely on its span; as its length or span increases, so must its depth in order to safely support the load imposed upon it. Deep joists are expensive and to reduce joist size intermediate supports known as sleeper walls are introduced. These are shallow masonry walls built directly onto the ground or on small foundations. In practice, ground floor joists are significantly less deep than those used in upper floors, where such intermediate support is not possible because of the habitable rooms beneath.



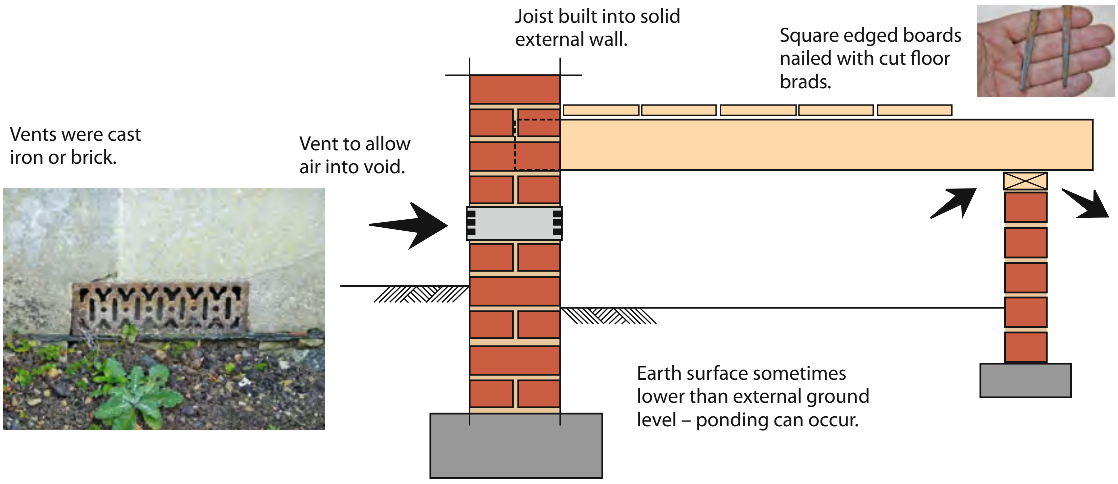
Scullery often had a solid floor (with clay or stone slabs) in case of spillage. It was usually 150mm or so lower than the main floors.

The use of sleeper walls allows joists of fairly modest size. 100 x 50mm are commonly encountered.

Joists can be found running front to back or side to side.

Floor is not built into chimney breast.

The plan (previous page) shows the ground floor layout of a typical late-Victorian terraced house. The joists run from side to side (front to back is another option) and are supported on the party walls, internal loadbearing partitions and intermediate sleeper walls. The joists are usually at 350–400mm centres – this offers the most economic arrangement.



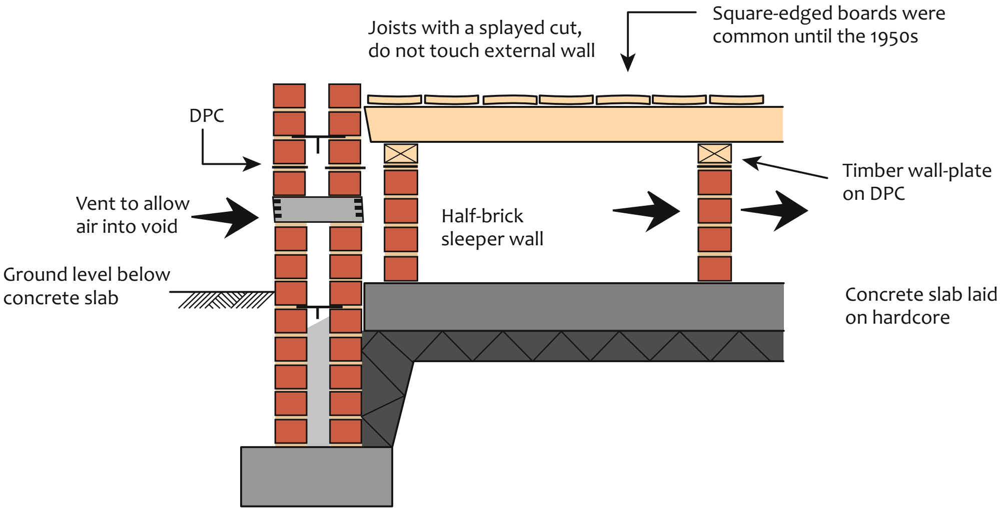
In practice, such floors can often give rise to maintenance problems due to poor design and varying standards of workmanship. The following should be read with reference to the drawing above, which shows part of the floor in detail.

- *It was formerly common to build the joists into the external wall to provide end support. This practice carries the danger that moisture from rising or penetrating damp can penetrate the end of the joists, causing rot. Some properties have slightly thicker walls below floor level and this gives improved protection against penetrating damp.*
- *Until the turn of the twentieth century damp proof courses were rare. Consequently, rising damp can attack not only the joist ends, but also the middle of the joists where they sit on the intermediate sleeper walls.*
- *The level of the earth or rubble infill under the floor was often below external ground level and in wet conditions, or areas with high water tables, the underfloor space was often permanently damp.*
- *It is important to provide ventilation to these floors in order to try to keep the underfloor space dry. In the past this was usually achieved by a series of cast iron or terracotta vents positioned just below floor level. Over the years the vents can become blocked, either through changes in external ground level or just general accumulation of debris. The reduced ventilation can lead to excessive levels of damp, which ultimately can cause outbreaks of rot.*

- *The sleeper walls could also impede ventilation through the floor, although in better quality construction these walls are fitted with vents or built as honeycombed walls.*
- *Due to the limitations of woodworking machinery, square-edged boards were common until the mid-twentieth century. Over time the boards would shrink slightly as their moisture content stabilised, resulting in small gaps appearing between the boards and draughts in the downstairs rooms.*

In a honeycombed sleeper wall there are a series of gaps to allow cross-ventilation.

During the early part of the twentieth century the construction of raised timber floors improved. The drawing below shows a typical example of good-quality construction typical of the 1930s to 1950s. The defects mentioned previously are less likely to occur.



In particular note that:

- *the entire floor is separated from the substructure by the DPCs*
- *the bare earth is covered with a concrete slab (often referred to as 'oversite') which is at, or above, external ground level to prevent the build-up of water*
- *the floor joists are usually supported by honeycombed sleeper walls, enabling cross-ventilation; additionally, the joists do not touch the external wall*
- *vents are provided, clear of ground level, and sleeved to prevent cold air entering the cavity.*

The floor was built in about 1960. The sleeper wall is roughly honeycombed and, although there is no wall-plate beneath the joists, there is a course of dense engineering bricks acting as a DPC.

Modern timber floors

In modern construction timber floors are very rare, but where they are constructed they must conform to some specific aspects of the Building Regulations, for example:

- *The ground surface should be above the level of the surrounding ground or, on sloping sites, laid to a fall with sub-soil drainage and covered with either at least 100mm of concrete laid on an inert base of hardcore or a minimum of 50mm of concrete or fine aggregate laid on a blinded sealed 300µm DPM.*
- *There should be a minimum gap of at least 75mm above the top of the sub-soil blinding to the bottom of any wall-plates and 150mm to the underside of any joists.*
- *Ventilation should be provided throughout the underfloor void and through any sleeper walls with a minimum cross-vent hole size of 100mm, to a minimum level of 1,500mm2 per m2 or 500mm2 per m2 of floor area, whichever is the greater. In practice this means that 225 x 75mm proprietary plastic air bricks, installed at 3–4m centres in opposing faces of the floor void will meet the requirements for effective ventilation.*
- *The floor must be provided with adequate levels of insulation, typically fixed or suspended between the joists to prevent heat loss and sealed to prevent air leakage.*
- *In certain areas of the country some sites may need bases provided with sealed DPMs, linked to sealed DPCs to provide protection and stop natural gases that are harmful to health, such as radon, methane or brownfield site gases, or other vapours entering the building.*

Due to the airtightness, acoustic and sometimes structural requirements of the Building Regulations, joist ends in the walls are now usually supported by joist hangers rather than being built into sleeper or external walls. Details of joist hangers can be found in Chapter 6.

Floor finish

The majority of houses built before the 1930s had square-edged floorboards. They could be of various sizes but are generally 150–175mm wide and 18–25mm (finished thickness). The boards were fixed with special nails called brads, which helped to prevent them from working loose with age, and the boards were usually laid with staggered joints as shown in the diagram below. Obviously these joints must occur over joists. From the 1930s onwards wider use of more sophisticated woodworking machinery facilitated the production of tongued and grooved boards, which have distinct advantages over their square-edged counterparts:

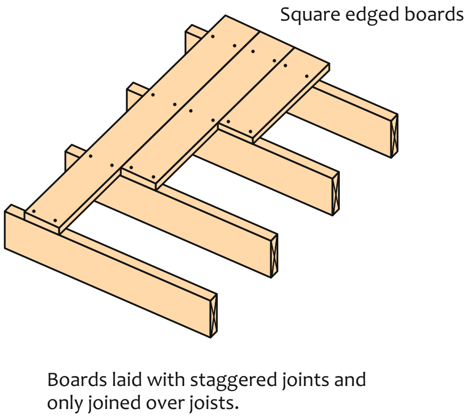
- *point loads from heavy furniture are spread across other boards, thereby allowing reduced board size*
- *there is less chance of the boards warping and the close-fitting joints form a reasonably smooth surface on which to lay a variety of finishes (one disadvantage is that the boards are difficult to lift for access to the services)*
- *they provide better smoke and fire resistance.*

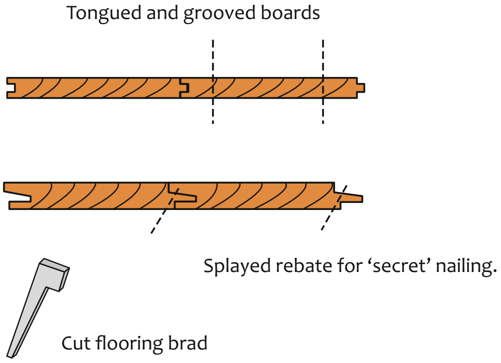
Both types of board are made from fast-growing coniferous trees (known as softwoods), although solid hardwoods, such as oak, may be found in more prestigious developments.

In modern construction, both tongued and grooved floorboards and square-edged boards have largely been superseded by chipboard, which consists of small wood chips bonded with synthetic resin and then compressed to form large sheets. The boards are typically 2,400 x 600 x 18mm thick and are available with tongued and grooved edges all round. A sheet of chipboard is four to five times the width of a typical solid timber floorboard. They have good wear resistance and should be maintenance free as long as they do not remain wet for long periods. Their popularity lies in their cost advantage over solid timber. To ensure that the requirements of the

Building Regulations are met, floor boarding that will not be damaged by spilt water or moisture in rooms such as kitchens, utility rooms, bathrooms and WCs should be used. This could be either a proprietary moisture-resistant type or a minimum of 20mm thick natural timber floor boarding. Even these materials cannot withstand long-term water saturation.

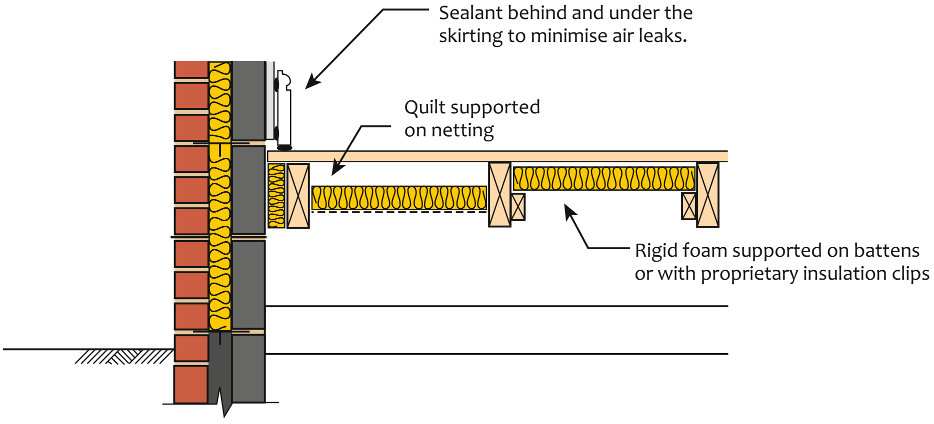
Laminated flooring has become popular in recent years. Products range from thick veneers of expensive timbers ('engineered timber'), laminated onto moisture-resistant man-made board, to plastic-based timber-lookalike materials. All laminate floors are tongued and grooved on all edges and they are generally designed to provide a floating floor (see below) on top of a solid concrete floor, although some are designed to be fixed directly to timber joists and some to be applied to a chipboard floor.





Thermal insulation

Although a suspended timber floor may feel warm to the touch, it does permit considerable heat loss due to the flow of air underneath the joists. Since the mid-1990s, it has been a requirement that all new ground floors contain insulation and, by containing a reasonable amount of insulation and sub-floor ventilation, the floor will also achieve the Building Regulations requirement that it be free from condensation and mould growth. Some simple insulating methods are shown in the diagram below. A more detailed examination of insulation, and the associated risks, is contained in Chapter 16.

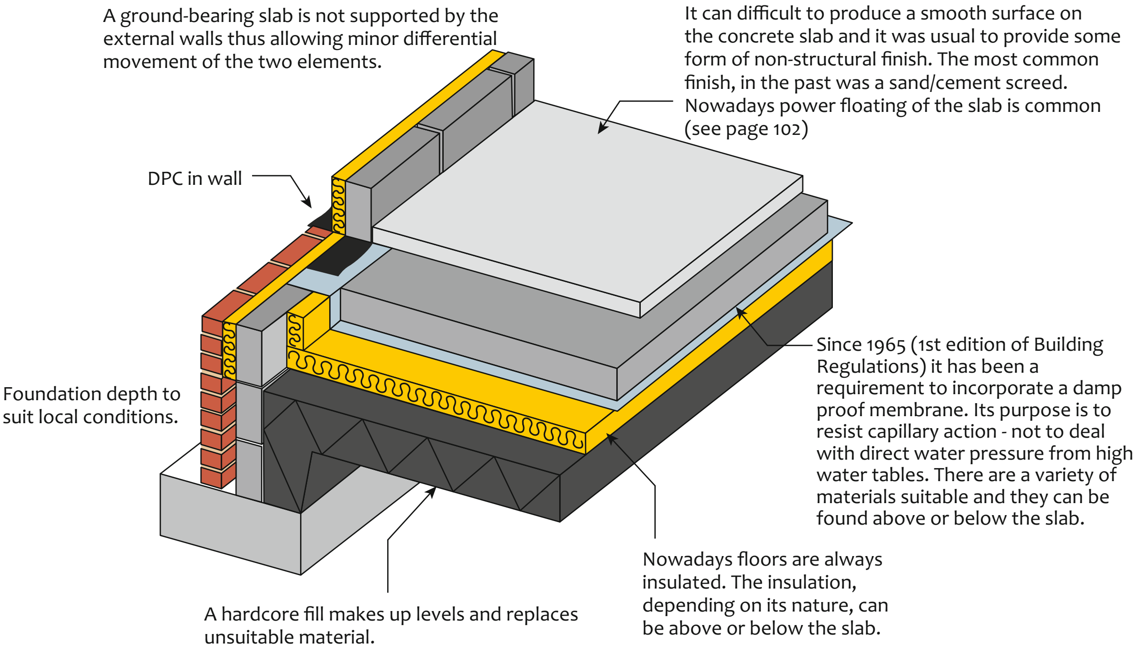


Concrete ground bearing floors

After the Second World War, new forms of construction were developed. This was mainly due to a shortage of materials, particularly timber, which had to be imported, as well as a shortage of skilled labour. Although some pre-war examples do exist, concrete ground bearing floors were predominantly developed as a response to these shortages.

Essentially, they are comprised of a bed of concrete which is supported by the ground directly beneath it. They abut, but are not tied into, the external walls in order to accommodate slight differential settlement between the wall and floor. Because of the relatively low superimposed loads of furniture and occupants, they are suitable for many types of ground and, between the 1960s and the 1990s they were the most common type of ground floor. In contemporary construction this type of floor is becoming increasingly rare. Nevertheless, there are millions of houses built using this type of ground floor. Nowadays pre-cast suspended concrete floors are the predominant ground floor construction method. These are covered in a later section.

The following drawing explains the function of each element. Early floors were not insulated and did not always include a damp proof membrane.



Construction sequence

It is first necessary to remove all topsoil and vegetable matter from the site. Topsoil is easily compressed and, if laid on such a surface, the floor slab would undoubtedly settle.

Once the foundations are in position and the loadbearing walls are built to DPC level, this type of floor construction can commence. To prevent loose earth from contaminating the wet concrete and to both provide a suitable base for the slab and to spread its load evenly, a layer of hardcore at least 150mm thick is spread over the ground. Hardcore is usually obtained from a quarry and consists of graded stone, i.e. it contains a wide range of particle sizes so that it can be firmly compacted. Compaction is usually assisted by a small vibrating plate or roller.

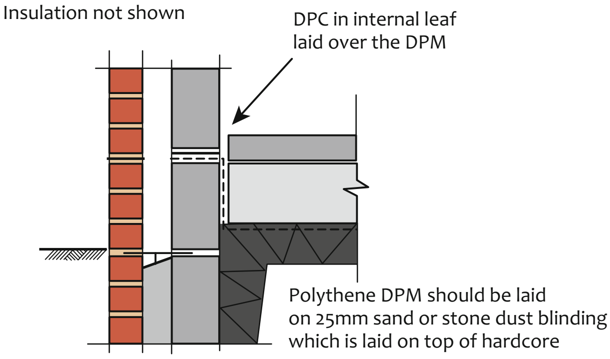
If the hardcore is deep, because some of the original subsoil is unsuitable and requires excavation, or because the site is on a slope, it is important to compact the hardcore in layers (about 200mm thick). Failure to do this will almost certainly lead to problems in the future as the hardcore consolidates. In situations where the hardcore is likely to be over 500–600mm deep, a suspended concrete floor would usually be specified. There are other reasons why these have become more commonly specified and these are explained later in the chapter.

There are alternatives to quarry-based hardcores, these have included broken bricks, builder's rubble and colliery shale. The use of such materials has, on occasion, caused a number of defects due to chemical reaction and expansion between materials. More recently, a number of recycled materials, such as crushed concrete, have proven to be suitable substitutes for traditional hardcores.

The hardcore is compacted by a vibrating plate or roller. The top of the hardcore is kept below the substructure blockwork so that the slab can be cast inside the walls.

Damp proof membrane (DPM)

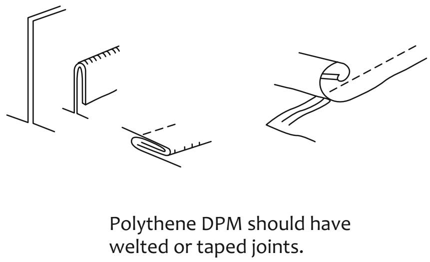
Although concrete is a dense material, it is not completely impervious to water and it is therefore important to provide a barrier against rising damp. This barrier can be either above or below the concrete slab and can be formed from a variety of materials.



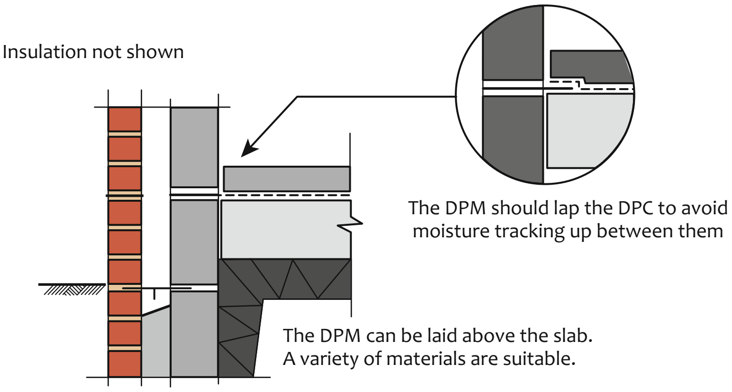
Insulation not shown

DPC in internal leaf laid over the DPM

Polythene DPM should be laid on 25mm sand or stone dust blinding which is laid on top of hardcore



Polythene DPM should have welted or taped joints.



Insulation not shown

The DPM should lap the DPC to avoid moisture tracking up between them

The DPM can be laid above the slab. A variety of materials are suitable.

DPMs can be applied as hot applied asphalt or as a three-coat coating painted on top of the concrete slab. However, the cheapest and most common method of protection is to use a barrier or DPM made from polythene (at least 0.3mm thick). The polythene is laid over the hardcore before the slab is cast and, if correctly laid, should ensure that the floor slab remains dry throughout its life. There is a danger that sharp stones in the hardcore can tear the polythene and it should therefore be protected by a layer of blinding. Sand or stone dust are suitable materials for blinding and a thin (25mm) layer is spread over the hardcore before a polythene DPM is positioned. As the diagram on the previous page shows, the DPM must lap the DPC running along the walls to ensure that the whole superstructure is isolated from the substructure. In order to achieve the Building Regulations requirements to protect the building or the occupants against gases such as radon in certain locations, any joints within DPC or DPM or between them should be sealed with gas-proof tape. In addition to this, the cavity should also be sealed across DPCs and cavity trays to ensure that the substructure is gas-proof and that moisture from the walls in the cavity cannot pass back into the building.

Once the DPM is in position the concrete slab, which is normally 100–125mm thick, can be poured. The concrete is usually brought into the site ready mixed and, although this is not a requirement, this procedure should ensure that the concrete is of the correct quality and strength as set out in the Building Regulations guidance.

If the ground below the slab contains any localised soil weaknesses, the concrete can be reinforced with a layer of steel mesh.

When the slab has been cast it is tamped with a straight edge to level it and remove surplus air and water. Mechanical powered tamps are also available.

Protection

Once poured, the concrete will set in a few hours and achieve its full strength after a few weeks. In adverse weather conditions it is important to protect the concrete to ensure it reaches its designed strength. In hot weather it can be temporarily protected with a sheet of polythene to prevent excessive evaporation of the water, which would reduce the strength of the concrete and cause subsequent cracking of the slab. In cold weather it can be protected with hessian or sand to prevent it from freezing. If the temperature is very low, concreting should be delayed until the weather improves.

Floor screeds

In the past it was common to lay a concrete screed onto the concrete slab towards the completion of the building, prior to hanging the doors and fixing the skirtings. The function of the floor screed was to provide a smooth finish suitable for carpets, tiling or other finishes. Screeds are a mixture of cement and coarse sand (typically one part cement to three or four parts sharp sand) mixed with the minimum amount of water. Excess water can weaken the screed and delay the subsequent moisture-sensitive operations, such as laying of floor tiles. Screed applied directly onto the concrete slab is laid to a thickness of 38–50mm. It is possible to lay the DPM (as a polythene sheet or as a wet-applied bituminous paint or a hot-applied asphalt) onto the slab itself. In this case, because the screed does not bond directly to the slab, it must be thicker to avoid cracking and should be a minimum of 65mm. A screed applied to an non-compressible insulation layer (i.e. polystyrene or other foamed board), which itself has been applied on top of the concrete slab, must be thicker still, i.e. up to 75mm and often reinforced too.

Laying a floor screed is a skilled operation. The cement/sharp sand mix should be laid fairly dry if subsequent shrinkage is to be avoided. It is levelled with a straight edge and then trowelled. It should be smooth enough to take carpets or vinyl tiles.

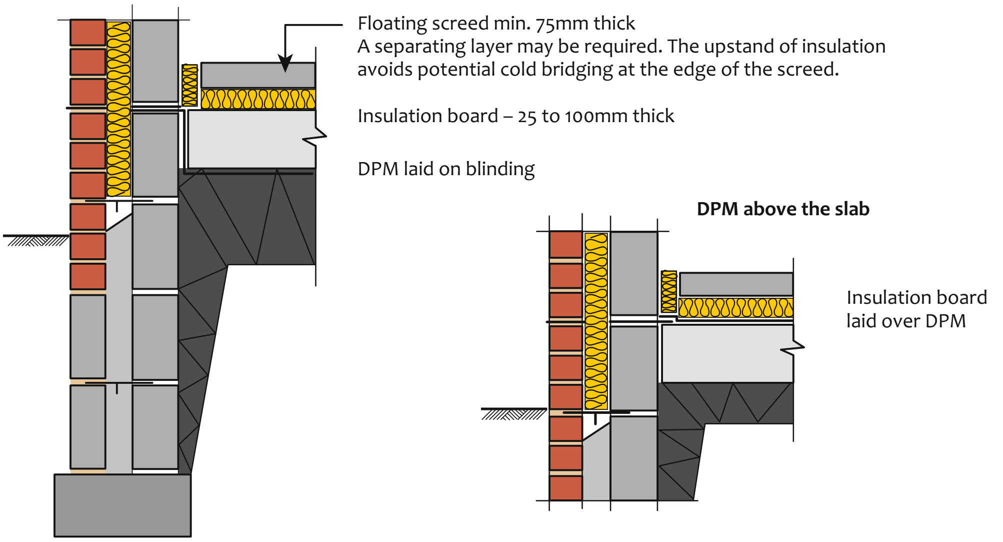
Thermoplastic tiles were commonly applied to finished screeds between the 1950s and 1970s. More recently, fitted carpets, vinyl sheet and traditional linoleum were applied to screeded floors.

Thermal insulation

Until the 1980s, ground floor insulation was comparatively rare but now it is a requirement of the Building Regulations. Chapter 16 examines the legislation and energy efficiency requirements in more detail; this next section concentrates on the technical options.

For ground bearing concrete floors typical insulation materials are rigid foamed sheets of varying thickness. The decision on whether to place the insulation boards above or below the slab is generally a matter of design preference. Theoretically, an intermittently heated room is best served by insulation above the slab as, once the heating is switched on, the floor finish will warm up fairly quickly thus preventing any condensation.

Insulation above the slab – screed finish



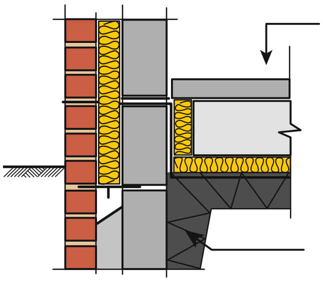
DPM above the slab

DPM below the slab

In the two examples on the previous page, the internal leaf is constructed with aerated blocks. If dense concrete blocks are used, the insulation should also protect the edge of the slab to prevent cold bridging. This phenomenon is explained in more detail in Chapter 16 on insulation.

The examples below show insulation boards below the slab. Where boards are of closed cell structure they can be laid under the DPM and the blinding referred to earlier is not necessary. The saving on the blinding more than offsets the extra cost of the insulation.

Insulation below the slab – screed finish



Bonded screed 38–40mm thick (approx.)

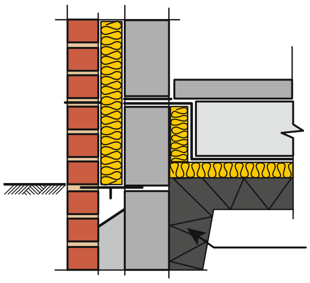
If insulation is not moisture resistant it must be laid on a DPM.

Blinding required under DPM.

Hardcore

DPM below the insulation

DPM above the insulation



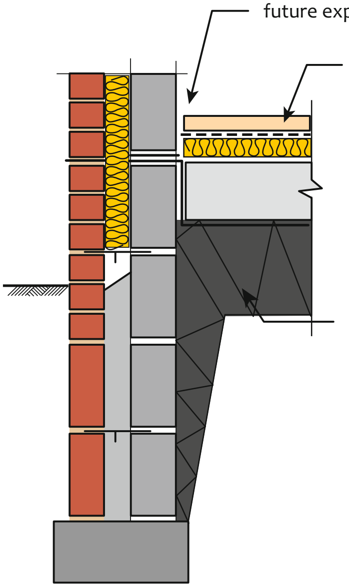
If insulation is moisture resistant it can be laid below the DPM.

In this case blinding may not be required.

Hardcore

Floating floors

All the previous examples showed a sand/cement screed. This can take several weeks to dry – longer if the membrane is below the slab – causing substantial delays for subsequent moisture-sensitive operations. A floating floor provides a dry alternative method of construction. These are commonly formed using chipboard (or other particle board). The tongued and grooved sheets, with the joints glued together, are laid on insulation boards and provide a surface which can be tiled or carpeted. However, as moisture from a drying floor slab can damage chipboard, it needs the protection of an additional vapour control layer if the DPM is laid below the slab.



10mm gap to allow for future expansion.

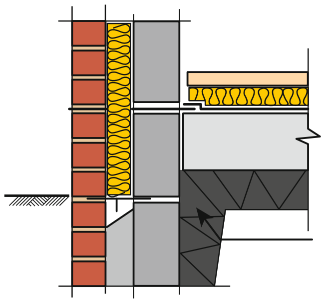
18mm flooring grade chipboard laid on vapour control layer.

Vapour control layer prevents moisture in the slab affecting the chipboard.

DPM below the slab

Hardcore

Vapour control layer not required if DPM is over slab.



Hardcore

DPMs vary in quality. A liquid DPM probably offers the best protection for the chipboard but it must be compatible with the insulation.

In kitchens or bathrooms, moisture-resistant chipboard should be used. This is not impervious to water but is less likely to be affected by occasional spillages.

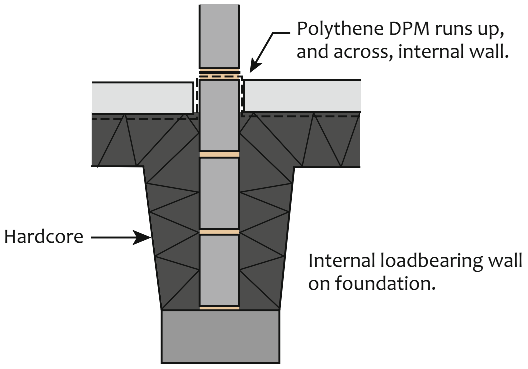
A number of solid timber and laminate floor products can also be used to form a floating floor. These have proven to be very popular but, given the additional moisture-sensitivity of timber products, care must be taken to ensure that an effective vapour control layer has been incorporated.

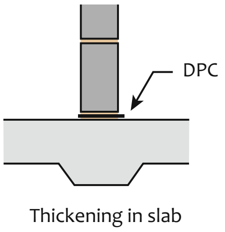
Internal walls, DPC and DPM details

The walls inside a house are of two basic types: loadbearing walls, which divide space, support part of the upper floors and, perhaps, part of the roof and non-loadbearing walls, which merely divide space and, as such, impose modest loads on the floor slab. Where internal walls are supporting part of the structure it is likely that these walls will require their own foundation. In this situation it is important that the DPM is correctly laid to prevent damp penetration. Where the internal loadbearing wall is only carrying small loads the Building Control Body may permit thickenings in the slab. Both scenarios are illustrated in the diagrams below.

In both cases DPCs are required under the walls because polythene DPMs are not always completely vapour proof.

In the right-hand example, the DPC also stops moisture rising up the wall as the slab dries out. Leaving out the DPC can cause minor expansion of the blocks and may affect any finishes.





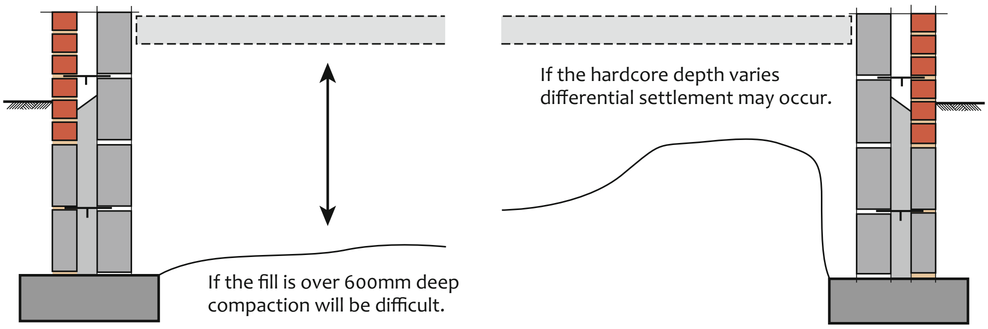
Suspended concrete ground floors

Given the relative complexity of ground bearing concrete floors, the time needed for such construction to dry out, the risk adversity of developers and the increasing use of sites with variable and weak soil conditions, their use in new construction has become increasingly rare.

Suspended concrete ground floors now predominate in new house construction in the UK. In the past they were used in specific conditions where the use of a ground bearing concrete floor was not technically suitable. In the following specific technical situations it is preferable to use a suspended concrete floor:

- *the nature of the sub-soil may result in unstable ground, e.g. shrinkable clay. As mentioned in Chapter 3, ground such as this will require deep strip foundations or piles. If ground bearing slabs are used, problems of ground heave or settlement are likely*
- *a large volume of top soil or soft unsuitable ground has to be excavated and backfilled with hardcore. This is not only expensive but risky as future consolidation could cause settlement*

- *a sloping site may result in excessive and uneven depth of hardcore (right)*
- *the water table is high (DPMs are designed to resist capillary action, not direct water pressure)*
- *aggressive chemicals are present in the ground which may attack the hardcore or concrete slab*
- *the risk of ground gases entering into the building must be avoided by the provision of a ventilated floor void.*



Developers are also selecting the suspended solution as standard because of the improved short- and long-term certainty, as the floors are not reliant on stable ground conditions to the same extent as ground bearing floors. In a similar way to the older suspended timber floors, it is the foundations and loadbearing walls and not the ground under the floor area that provide the support for the ground floor. Should any settlement or heave of the ground beneath the floor occur, suspended concrete ground floors should not be affected.

Pre-cast concrete T-beams are suspended in the loadbearing walls. The spacing relates to the width of concrete blocks, i.e. 440mm. The depth is reliant on span and the beams are individually manufactured according to the specific span required. The T-beams are now nearly universal in new construction and, as in this case, are increasingly used in extensions too.

The suspended concrete floors are prefabricated in a factory and brought onto the site for assembly. Several manufacturers produce floors of this type and they are both easy and quick to assemble. The floors are usually made from a series of inverted T-beams, 150–200mm thick. The actual depth is dependent on the span and the beams are designed and manufactured to span specific distances without the need for intermediate sleeper walls.

Generally, the beams are spaced so that the infill between them is made up of a standard concrete block, i.e. 440mm infill. The use of aerated, rather than dense concrete blocks is common. This helps to reduce the amount and overall thickness of thermal insulation which is required by the Building Regulations to be provided as part of the floor. When the walls are built to the appropriate level and the DPC is positioned, the beams can be manhandled or craned into place, the concrete blocks are then positioned in between the beams.

When the beams and blocks are in position a damp cement and sand grout is brushed over the surface, filling the gaps between them. The grout helps to distribute loads across the floor, and prevents any future movement or 'rocking' of the blocks, it also keeps out insects and vermin and contributes to airtightness. The floor is then ready to receive the floor finish, which is normally laid towards the completion of the building.

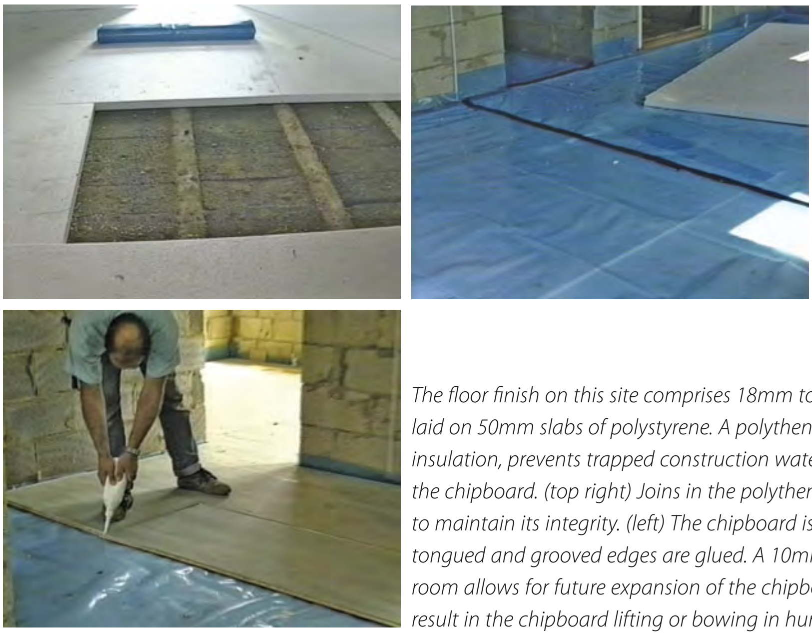
If the air space under the floor is well vented and the ground is effectively drained there is no need for a DPM or concrete oversite, unless required for gas or vapour protection by the Building Regulations. The ground below the floor should, of course, be free of all organic material. Modern pre-cast floors are ventilated in much the same way as the timber floor described earlier.

The floor is strong enough to support non-loadbearing partitions, although any walls carrying loads from the upper floors or roof will usually require a foundation in the normal way.

The pre-stressed floor beams sit inside the ground beams (see Chapter 3). Concrete blocks, in this case aerated blocks, are then placed between the floor beams. When all the blocks are in position, any small gaps are filled with grout.

Floor finish

Different manufacturers recommend a number of finishes. The most popular is a floating chipboard floor, but a screed is also possible; both are laid on insulation boards. Chipboard floors should be laid on a polythene membrane to protect them from any moisture trapped in the concrete beams. Garage floors should be finished with a reinforced screed. Both these finishes have been explained earlier in the chapter.



The floor finish on this site comprises 18mm tongued and grooved chipboard laid on 50mm slabs of polystyrene. A polythene vapour control layer, laid over the insulation, prevents trapped construction water in the floor structure affecting the chipboard. (top right) Joins in the polythene vapour control layer are taped to maintain its integrity. (left) The chipboard is laid with staggered joints and the tongued and grooved edges are glued. A 10mm gap around the perimeter of the room allows for future expansion of the chipboard. Failure to leave the gap may result in the chipboard lifting or bowing in humid conditions.

Composite suspended concrete floors

These floors are similar to the one shown on the previous page in that they both are based on pre-cast beams. Composite floors are partly pre-cast and partly cast in situ. They use the prefabricated inverted T-beams. However, the infill blocks are no longer standard concrete blocks but are specially profiled dense polystyrene blocks. These are easier to handle, quick to lay, they extend around the underside of the pre-cast concrete beams and provide a high level of thermal insulation.

Pre-cast concrete T-beams are now also being used with high-density profiled polystyrene blocks. The fact that these insulating blocks wrap around the underside of the T-beam reduces the incidence of cold bridging. The other advantages are that the structural concrete topping that is laid on top provides an insulated thermal mass within the building, which enables a more efficient, smoother heating cycle. Additionally, the thickness of the floor is reduced when compared to other similarly insulated options.

In order to provide a suitable structural surface, a poured concrete structural topping, about 75mm thick, is applied across the entire surface of the floor. This can be finished with a screed, with chipboard on insulation, or it can be power-floated, a relatively recent mechanical process which compacts and smoothes the poured concrete. It provides a similar finish to a screed, but without the need for a subsequent operation. Power floating must be carried out before the concrete hardens fully and, once complete, will require protection from the construction stages that follow. The poured concrete for these composite floors is commonly reinforced with a light steel mesh or glass fibre.

(top left) The polystyrene blocks all in place. Note that the periscope ventilation is also in place – these floors require ventilation – not for dampness, but in order to avoid a potential build-up of gas (i.e. piped natural gas for heating).
(top right) The process of power floating has ended the requirement for a screed finish on top of the structural concrete.
(left) The power floated slab does, however, require protection from subsequent site processes and is covered in sand.

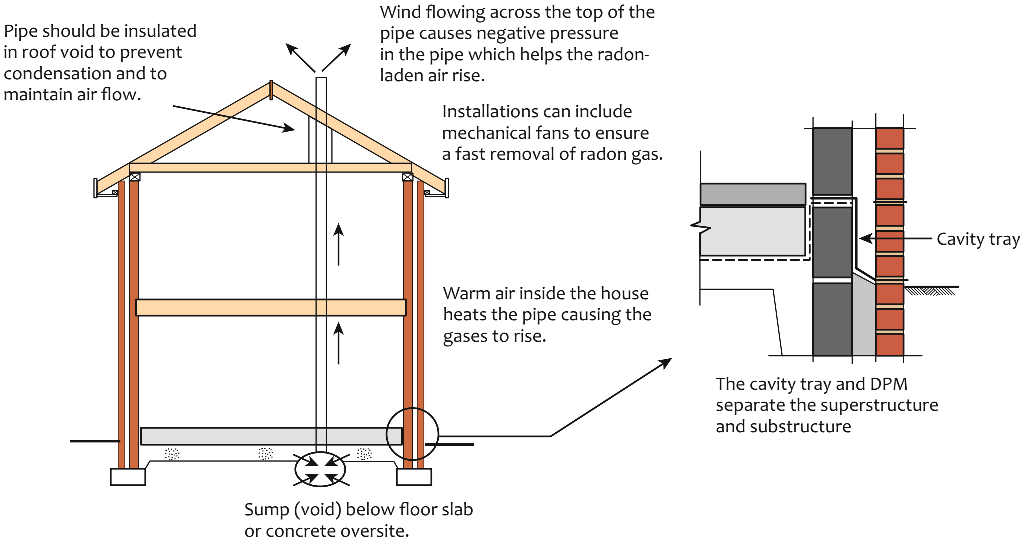
Radon gas

Radon is a naturally occurring gas. It is radioactive and has been identified as a cause of lung cancer. Until recently, Cornwall was believed to be the geographical area most affected, as granite rock strata are a significant source of radon. However, radon gas has also been detected in some limestones and therefore a number of so-called 'hotspots', where specific protection measures are needed, have been identified across the UK.

Radon seeps into a building mainly through gaps, junctions or joints in the substructure or floor structure. In certain areas of the country, which can be identified in the Building Research Establishment (BRE) publication BR211 or from the site investigation, it is therefore necessary to adopt precautionary measures when constructing ground floors, particularly where an underfloor void is created. The publication recommends that, depending on the radon levels where the building is located, one of two different levels of protection is provided to a building: either 'basic' or 'full' protection.

The most effective method of dealing with radon gas is to ensure that the ground beneath the ground floor is sealed with a gas-tight membrane that is linked and sealed to the DPC so it provides a continuous barrier throughout the building to the outside walls to prevent gas entering the building. Additionally, in areas of high radon gas concentration, ground floors should be suspended, typically on the wall inner leaves to prevent settlement and damage to membranes, and a ventilated sump should be formed under the radon barrier to collect the gas under the floor and duct it to the external air. This can be either by an active process, i.e. by means of an electric fan, or as a passive process reliant on natural air convection.

Typical 'basic protection' is shown in the diagram below, with the DPM and DPC being joined and the inner wall of the building protected from moisture in the cavity by a cavity tray. The diagram also shows the typical location and operation of the sump. In addition, the suspension of the floor slab would be required for 'full protection' and the number and positioning of sumps would depend on the area of the floor. In both cases any construction joints in or around the floor, and to services such as pipes or ducts passing through the floor, would need to be sealed with gas-proof proprietary tapes, flexible sealants and 'top hat seals' to prevent the entry of radon.



Further information on radon levels can be obtained from the National Radiological Protection Board or British Geological Survey (BGS). Advice on suitable construction details can be obtained from the Building Research Establishment.

Upper floors

6

Introduction

This chapter explains the principles and practice of the construction of upper floors and also includes an overview of their historical development.

The primary function of an upper floor is to allow the normal range of household activities to take place safely, comfortably and effectively. In order to do this, the floor must be able to support the loads imposed upon it by, among other things, people and furniture.

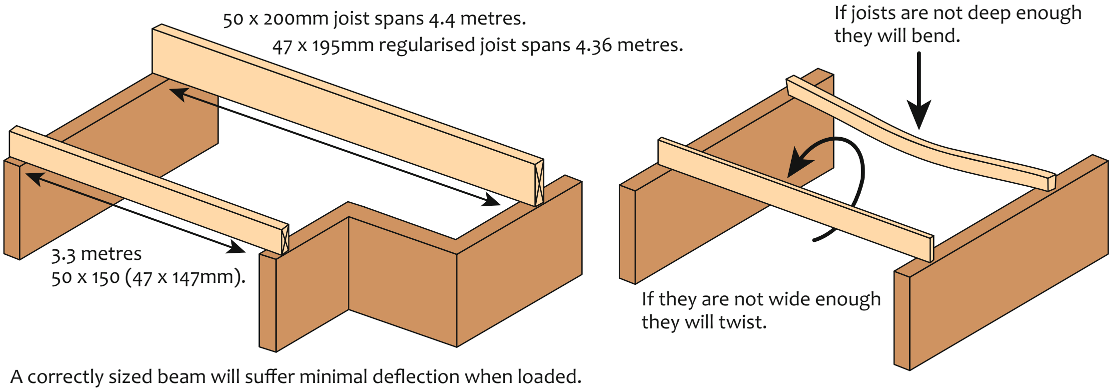
In order to fulfil its functions in a safe and satisfactory manner there are a number of technical requirements that a floor must meet:

- *it must be structurally stable and must not suffer excessive deflection when a load is imposed on it*
- *it should provide restraint for the external walls*
- *it should provide suitable fire protection to delay the spread of fire and smoke (note: the level of fire protection required will depend on the number of storeys and the nature of the building – for example there is a distinction between flats and houses)*
- *it should provide good sound insulation (again, there are different requirements for houses compared to flats).*

Section One: elements of upper floor construction

Timber floors are usually constructed from a series of joists or beams covered with timber floorboards or, more commonly nowadays, sheets of chipboard. Plywood sheets are suitable but are rarely used in practice. The size of the joists depends on the expected loading, the spacing between joists and the required span. Until 2004, joist sizes were included in the Building Regulations but they now refer the reader to tables (the *Eurocode span tables for solid timber members in floors, ceilings and roofs for dwellings*) produced by the Timber Research and Development Association (TRADA). However, the use of timbers sized by calculation, for example by a structural engineer, would also be considered acceptable under the Regulations. The Building Regulations were introduced in 1965 and, prior to this, the size of joists was either calculated by rule-of-thumb methods or by reference to local by-laws.

As the distance that the joist is required to span increases, so must its depth if it is safely to support the loads imposed on it. So, for example, under average loading a joist 50mm wide by 150mm deep will span just over 3m (about the size of a small modern room), whereas a joist 50mm wide by 200mm deep will span a distance of nearly 4.5m. In calculating the correct timber sizes for a particular span, the strength of the timber must be taken into account. Because it is a natural material there will be inherent variability in strength and so timber is assigned a strength grade or class which denotes particular mechanical properties.



A correctly sized beam will suffer minimal deflection when loaded.

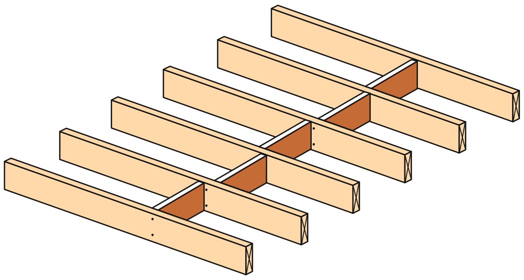
Joists 47mm x 195mm (ex 50 x 200mm) and of strength class C24, will span 4.36 metres if the joists are at 400mm centres and the loading is between 0.25 and 0.50 kN/m^2.

The width of a joist only marginally affects its permitted span, but it does affect its resistance to twisting and warping. Joists less than 38mm wide warp readily, and also provide insufficient area on which to nail and join floorboards.

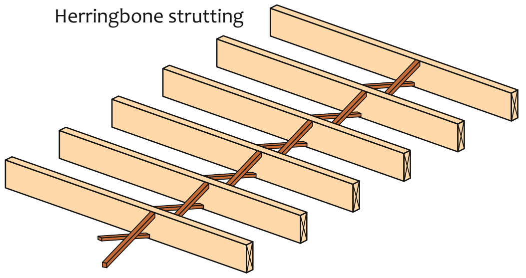
Traditionally, timber was used for both upper and ground floor structures because there was no simple, cheap alternative. Nowadays, however, concrete and steel are both suitable for floor construction. However, concrete and steel floors are most likely to be found in blocks of flats where requirements for fire protection and sound insulation are much higher than normal domestic construction. In houses, timber is still the most suitable material because:

- *it is readily available*
- *it is relatively cheap*
- *it is easy to cut and shape*
- *fixings are easy, i.e. nails and screws*
- *timber is relatively easy to repair (or alter).*

In order to stop the floor joists from twisting or warping (and possibly damaging the ceiling finish), it is usual to find a line of strutting fixed at right angles to the joists. Strutting also helps to 'tighten up' a floor, thus reducing 'bounce'. The struts can form a herringbone pattern or can be solid off-cuts of timber; usually staggered so that they can be easily nailed to the joists.



Staggered strutting using 'off cuts' from joists. The struts are staggered so that they can be nailed.

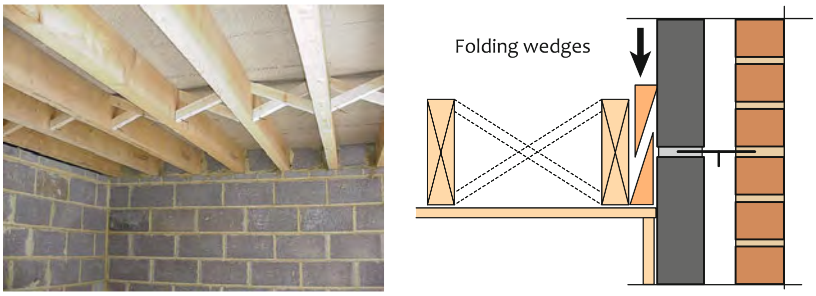


Strutting 'tightens up' floor thus reducing 'bounce'. It also reduces twisting of the joists which could damage the ceiling finish.

Herringbone strutting is probably the more traditional method, although straight strutting is often found in houses dating back to the Georgian period. Where herringbone strutting is used in more modern houses, it is sometimes made of stainless steel instead of timber.

Strutting to a traditional cut joist upper floor.

It is normal to find one set of struts for an average-sized room, or two sets if the joint length exceeds 4.5m. However, if the joist width is less than 50mm, extra struts may be required to prevent the timbers from twisting.



The photograph (left) shows strutting to a modern floor. The principle has not changed although stainless steel struts are sometimes used in place of their timber counterparts. If the strutting is to be effective, the floor structure needs to be braced against the adjacent wall(s). Traditionally, this was achieved by inserting folding wedges between the wall and the end joist.

Note: The use of the traditional solid ('cut') timber joists has, in recent years, been largely superseded, particularly in volume housebuilding, by the use of timber I-beams or metal web joists (see later). Floors using these engineered joists are specially designed for each individual job and the need for strutting can usually – though not always – be designed out. There may, however, be a need to stiffen or brace the joists at certain points or for longer spans. Such details will be provided by the manufacturer – but, as an example, see the reference to 'strongbacks' later in this chapter.

Spacing of joists

Traditionally, joists were normally fixed at 400mm (16”) centres. This is probably the most economic arrangement of the timbers. Joists spaced more widely apart require deeper sections because they are carrying extra load and the floorboards also need to be deeper in section due to their increased span. Joists that are closer together use excessive amounts of timber, even allowing for their smaller cross-sectional area. However, building control was fairly lax until the development of Model Bye-laws in the first part of the twentieth century and it is not unusual to find joists at centres of 500mm or even 600mm.

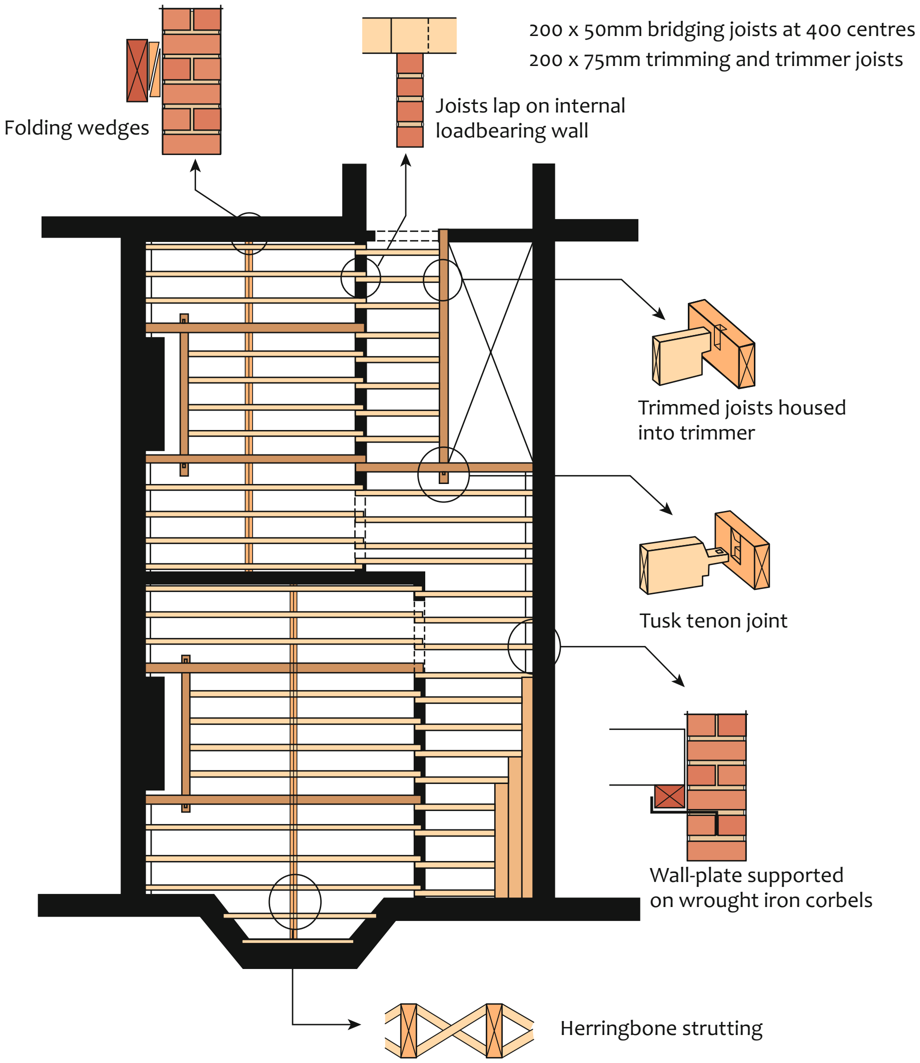
This photograph shows a traditional cut first floor in a house constructed in 2012. The struts have not yet been inserted. If the joists are 50mm wide and they are fixed at 400mm centres they will be 350mm apart. This is still the norm in modern construction. Modern floor coverings and ceiling boards are often made in multiples of 400mm to minimise waste.

Early floors

The next few pages illustrate typical construction details of floors built before the 1930s.

The photograph (opposite) shows a typical upper floor from about 1880 and the drawing below it shows a typical joist layout (terraced house) from the same period. The joists run side to side and are supported and joined over an internal loadbearing wall. The use of a loadbearing wall reduces the span of the joists and precludes the need for long deep-section joists which were (and still are) expensive and difficult to obtain. Joists were often built into the wall but brick corbels or cantilevered brackets were sometimes used (see drawimg on p. 110).

Many early floors are still functioning as originally intended. If problems of rot or insect attack can be avoided, a floor should last almost indefinitely. Some early floors are undersized by modern standards. This problem can be exacerbated by excessive notching, etc. to provide service runs.



Where issues of restraint and fire protection were not important, the joists would normally be found spanning the shortest distance across a room. This provided some savings in cost because the joist depth could be reduced.

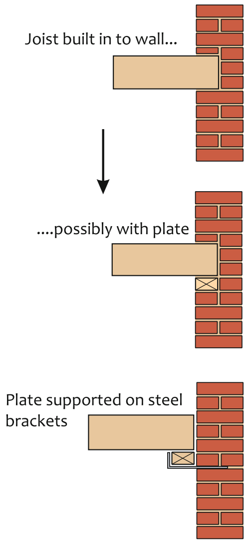
In some houses the joist direction was determined by factors other than those given above. Terraced houses with large bay windows, for example, sometimes have joists running parallel to the bay. This reflected contemporary construction practice; it was not uncommon to construct the bay, possibly in stone rather than brick, after completion of the brickwork and floors. The joist direction can be determined quite easily; they always run at right angles to the floorboards.

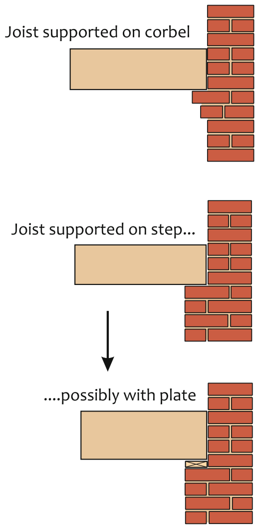
Fixing the joists to the external wall

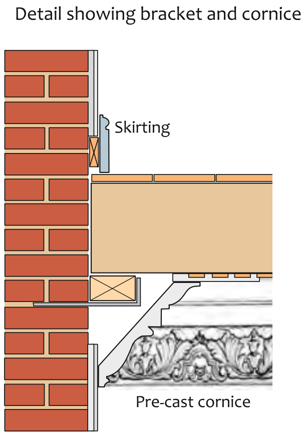
When joists are built into solid external walls, there is a danger of damp penetration which can ultimately cause rotting of the timbers and collapse of the floor. If the wall is over one brick thick this problem is less likely to occur. However, the majority of houses built before the introduction of cavity walls have walls which are one brick thick (i.e. 225mm) and, in these cases, the joist ends are only protected by 100mm or so of masonry. This will often be insufficient to prevent penetrating damp reaching the ends of the timber joists and subsequent problems of rot can be expensive to resolve.

In some properties a timber wall-plate was inserted under the joists in order to provide a level surface on which to fix the joists. These levelling wall-plates were sometimes used where the brickwork was of poor quality or where stone rubble or irregularly sized bricks precluded level courses. In this situation an outbreak of rot in the wall-plate may ultimately lead to instability of the wall. This form of construction is not uncommon in Georgian and Victorian properties.

In other properties, attempts were made to provide the joists with the full protection of the wall. The example below shows a timber wall-plate supported by wrought iron or steel brackets. These are fairly rare as they require expensive ceiling cornices in the rooms below to hide the plate and brackets.



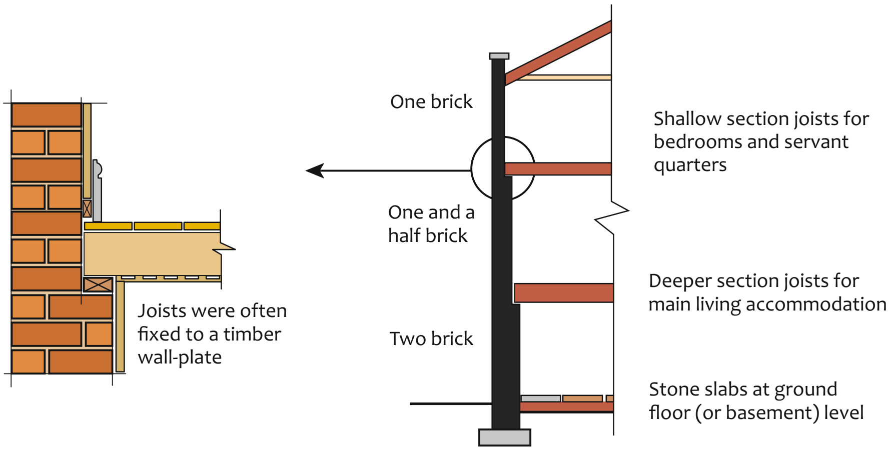




Upper floor joists built into an external wall.

The photographs above are of the party wall remaining after the demolition of a Victorian house. The 'sockets' where the first and second floor joists were built into the party wall are clearly visible. The close-up view shows the empty sockets, but also note the stretcher and header bricks of the front external wall, which are clearly visible to the left-hand side of the image.

As indicated in Chapter 4, some larger Victorian and Georgian properties have walls that vary in thickness (becoming more slender on the higher floors). In such properties it was common to support the floors as shown in the diagram below. The joists and wall-plate are, for the lower floors at least, well protected by the thick external wall.



Support from internal walls

Most older houses contain internal loadbearing walls which support the joists and, in some cases, part of the roof structure. It is unlikely, except in the smallest of older houses, to find joists which span from external wall to external wall without intermediate support. The use of an intermediate supporting wall meant that shorter joist lengths could be used, and that the joists did not have to be too deep. The floor plan on page 109 shows how joists can be supported on internal loadbearing walls.

In recent years, I-beam and metal web joists have become more common. These can span greater distances than timber joists, often precluding the need for internal loadbearing walls. More information on these is provided later in the chapter.

Finishes

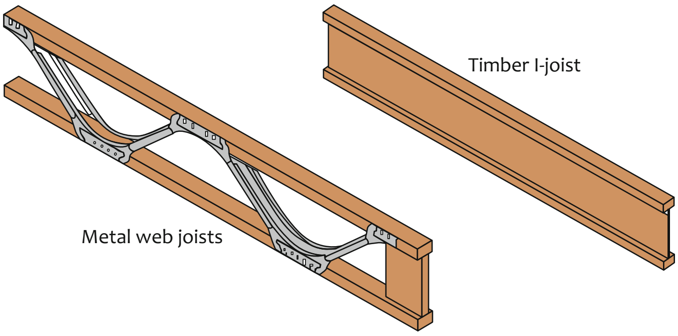
As mentioned in Chapter 5, older floors are likely to be covered in square-edged or tongued and grooved floorboards, with the latter being more common in buildings of the 1930s to 1950s, though it is difficult to be precise about this because regional differences exist.

Until the 1930s, the majority of ceilings were formed in timber lath, finished with three coats of plaster. The timber laths, basically long, thin strips of cheap softwood, were nailed to the underside (soffit) of the joists, forming a mechanical key for the plaster. The first coat of plaster squeezes through the lath and forms a good key for the subsequent coats, which provide a smooth finish ready for painting or papering.

This was the most common method of forming ceilings until the 1950s. The timber laths form a mechanical key for the plaster. The first coat, the 'pricking up' coat, squeezes through the lath and forms the key. Two subsequent coats were required to provide a smooth, even finish.

Section Two: modern floors

In modern construction the principles of the design of upper floors have not changed. However, there are a number of differing details, mostly requirements of current Building Regulations. In addition, in recent years the use of engineered structural joists has increased as a substitute for what we might now call traditional solid timber joists ('cut' timber joists). The two main types of engineered joists are metal web joists and timber I-joists.



A modern house (2012) using solid ('cut') timber joists to form the first floor.

Both of these can span larger distances than (routinely available) timber 'cut' joists. One advantage of this is that the need for loadbearing partitions in the rooms below is reduced. Metal web joists provide another advantage because they do not require notching or drilling for pipes and cables.

The I-joist usually consists of timber flanges (chords) at the top and bottom and a 'web' which is usually made of oriented strand board (OSB) but may be hardboard or plywood. The metal web joist uses a similar approach but with metal as the webbing material connecting the upper and lower timber flange. The webs are formed out of profiled thin-gauge steel. They are usually V-shaped and connected to the flanges by integral nail plates. In addition to facilitating longer spans, they are comparatively light and easy to handle on site.

Metal web joists.

Metal web joists.

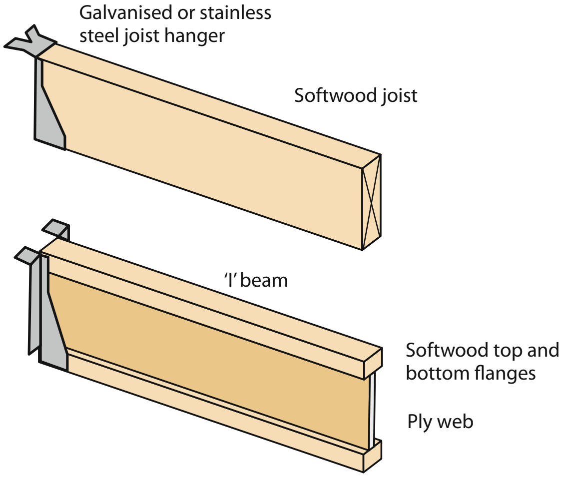
Metal web joists being fixed on joist hangers.

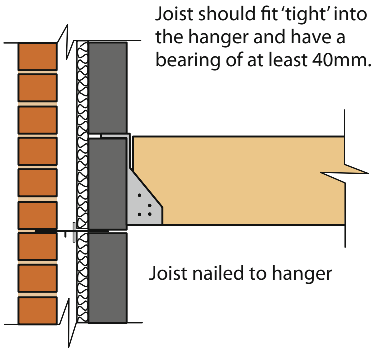
I-joist built into wall.

Both types of engineered joists are purpose-made for each project so manufacturers' publications must be consulted for details of construction – and therefore only general points are made here and, for simplicity, the majority of the diagrams used in this chapter show traditional joists, supplemented by photographs of metal web joists and I-beams.

Joist hangers

Modern walls are usually formed in cavity construction and it is common practice to use galvanised steel hangers to support the joists, although they can be built into the wall. Joist hangers are made in a variety of patterns and sizes – a typical one is shown in the diagram below.





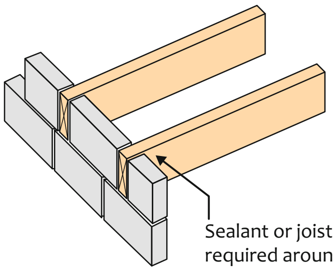
'Cut' timber joists should normally be notched to ensure even ceiling line.

When the bricklayers have reached the first floor level, the carpenters position the hangers and joists, and then the bricklayers can complete the next lift of brick or blockwork. The ends of the hangers are embedded in the wall and the joist sits in the hanger and is fixed using nails. The use of hangers means that the joist has the protection of both the internal and external skin of the wall. The bottom of the joist needs to be notched where it fits into the hanger; failure to do this will result in an uneven ceiling line.

The Building Regulations imply that hangers must be used for joist support but it is still acceptable to build the joists into the internal leaf of the external cavity wall (though not into party walls) as long as either a sealant is used around the joist end or a proprietary joist cover (sealing box) is provided to prevent air leakage and therefore heat loss. The fact that this precaution is not necessary with a joist hanger is an additional advantage to using them.

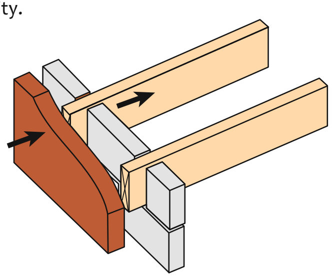
The danger of building joists into the wall is the risk that moisture vapour in a damp cavity may, over a long period, raise the moisture content of the ends of the joists. As the moisture content of the timber settles into equilibrium with the damp air in the cavity, conditions may be created which encourage attack by wood-rotting fungi.

Joists can be built into inner leaf of blockwork. They should be bedded in, and surrounded by, mortar to ensure a good bond with the wall.



Sealant or joist cover/box required around joist to prevent air leakage.

On no account should the joists be allowed to touch the outer leaf. This can bridge the cavity.



Floor joists should not project across the cavity and touch the external leaf of brickwork or stone work. Even slight projections into the cavity can cause problems as mortar droppings can become attached to the timber and cause bridging of the cavity.

I-joist built into wall and using sealant to prevent air leakage (I-joist above and metal web joist right).

Photograph courtesy of Truss Form (Midlands) Ltd.

Joist hangers supporting solid timber joist.

Web joist on hanger.

Metal web joists using hangers on block wall and on joists where attached to each other. Photograph courtesy of Truss Form (Midlands) Ltd.

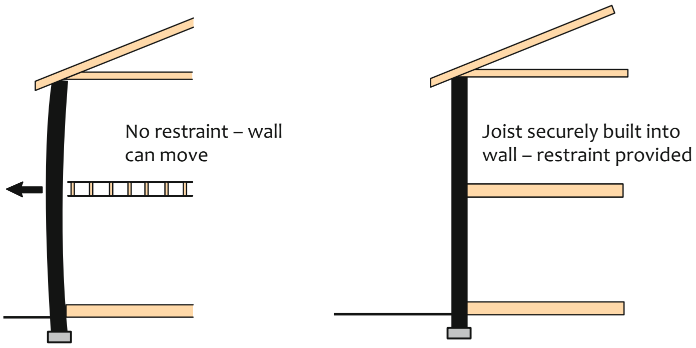
Web joists supported by hangers. Photograph courtesy of Truss Form (Midlands) Ltd.

Support from internal walls

Long traditional solid joists (over 5.4m or so) are expensive and difficult to obtain. It is usually cheaper to provide internal loadbearing walls to reduce the required span. Such walls are typically constructed in 100mm blockwork. The joists can be fixed to wall-plates bedded on the internal wall, built in, or can be supported on hangers. As observed above, modern I-beams and metal web joists will often span right across a house without the need for internal loadbearing walls. This not only provides savings in capital cost, it also means that the ground floor space is more adaptable.

Restraint of external walls

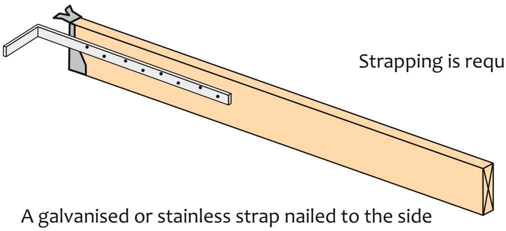
It was mentioned in Chapter 4 that the walls of houses require restraint from upper floors. The reason for this is shown in the drawing below. The flank wall, if it were free-standing, could collapse in high winds, or as a result of traffic vibration. In practice, the wall might remain standing because it gains support from the return walls at each corner and from any loadbearing partitions which are built into it. The upper floor joists also have a role in providing restraint, although in many older properties there is no effective restraint where the joists run parallel to the wall. The Building Regulations require restraint at the junction of all upper floors and external walls and it can be provided in a number of ways.



Joists can be built into the wall as long as any gaps around the joists are sealed to prevent air leakage.

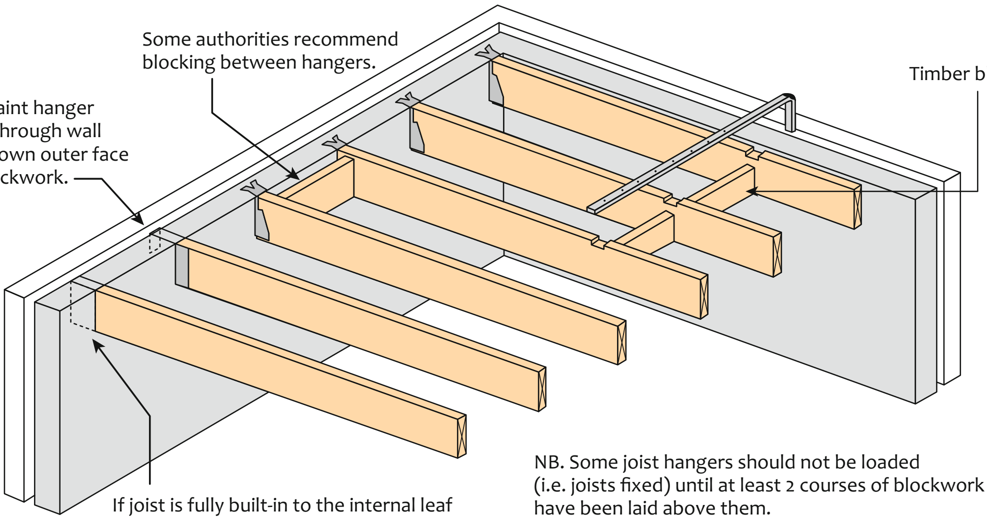
If the joist ends are built firmly into the internal skin of the cavity wall, they will provide adequate restraint. However, if hangers are used, some form of lateral restraint is necessary to prevent the wall from moving outwards. One method is to fix galvanised or stainless steel straps to the side of the joists. The strap runs through the internal leaf and hooks behind it. These straps are required every 2 metres – approximately every fifth or sixth joist (see diagram opposite). A simpler option is to use restraint hangers. The photograph opposite shows that the special hangers run over the internal leaf and down the cavity, thus preventing outward movement of the wall. These special hangers are only required every 2 metres; the remaining joists can be supported by the ordinary hangers described previously.

Restraint hangers.



Where the joists run parallel to the wall, restraint can be provided by galvanised or stainless steel straps which hook over the inner skin and then extend over at least two joists. The hook on the strap prevents the wall from moving away from the floor. To prevent the wall from moving inwards it is important to provide timber blocks in between the two joists under the strap and between the end joist and the blockwork (see photograph overleaf).

Tying in the external wall to the upper floor where joists run parallel. A galvanised strap extends over three joists with timber blocking below. The joists are notched slightly to ensure that the top of the straps are flush with the top of the joists.



If joists are supported on standard joist hangers, restraint, in the form of straps or restraint hangers, will be required at 2 metre centres.

Where joists run parallel to the internal leafs straps can be used to provide restraint. The straps should be at least 30mm x 5mm cross-section and should extend over three joists. Timber blocking, in between the joists, provides rigidity.

Some authorities recommend blocking between hangers.

Timber blocking

Restraint hanger runs through wall and down outer face of blockwork.

NB. Some joist hangers should not be loaded (i.e. joists fixed) until at least 2 courses of blockwork have been laid above them.

If joist is fully built-in to the internal leaf no additional restraint is necessary but joint must be sealed against air leakage.

Party walls

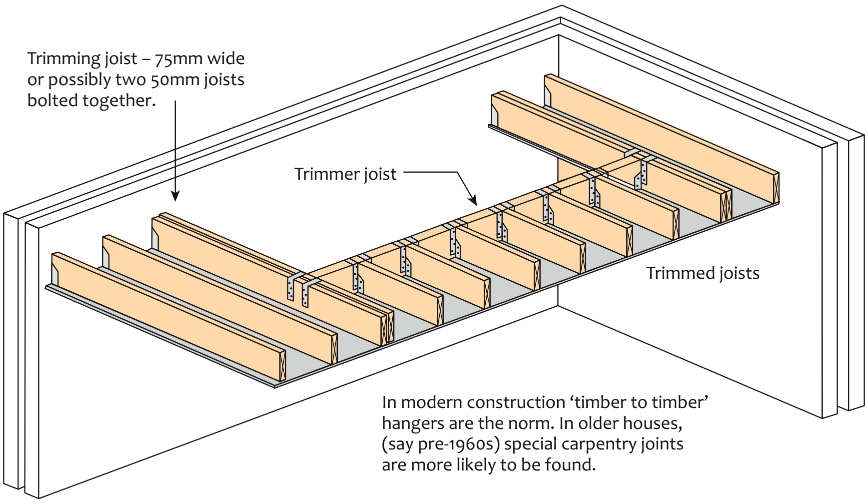
If the joists are parallel on either side of the party wall, and where there is contact along the length of the wall and floors at least every 2 metres, no restraint is necessary. Examples of such 'contact' include an internal wall at right angles to the party wall or strutting to the floor. Where joists run at right angles to the party wall they should be supported by joist hangers with restraint hangers provided at 2m intervals. Joists should not be built into party walls to ensure fire protection, sound insulation, thermal insulation and also to help prevent air leakage.

This photograph shows typical construction at a party (separating) wall using joist hangers. Good sound insulation and fire protection are difficult to achieve if the joists are built into party walls. There is also the problem of air leakage.

Openings in timber floors

Nearly all upper floors have openings in them to accommodate stairwells and, possibly, chimney stacks. Forming the opening is known as 'trimming' and is a relatively simple exercise.

The diagram below shows a modern floor that has been trimmed to form a stairwell. The joists in the diagram are supported at the wall by steel hangers, but they could be built into the inner leaf of the blockwork. On either side of the stairwell the joists are doubled up and bolted together, providing extra strength to these two joists which are carrying extra load. An alternative is to use a wider single joist. These double joists, known as the trimming joists, support a trimmer joist which, in turn, supports the trimmed joists. The joists are joined together using 'timber to timber' hangers, shown in the left-hand photograph below.



A staircase opening showing trimming, trimmed and trimmer joists (refer to the diagram above).

Staircase opening in a traditional cut floor.

Stair opening formed in a metal web joist floor.

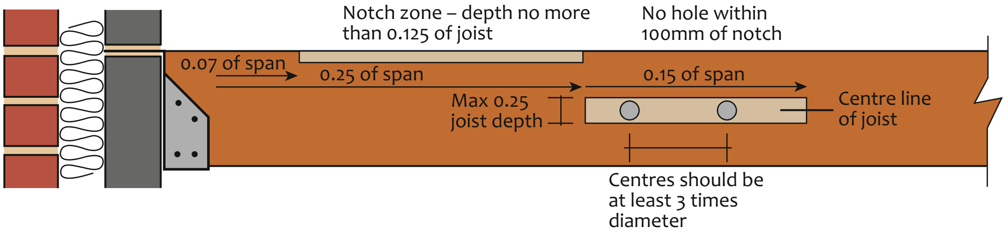
Stair opening formed with an I-joist floor. Note the blocking pieces behind the joist hanger to allow proper fixing of the hanger.

(left and below)
Staircase opening being formed with web joists.
Photographs courtesy of Truss Form (Midlands) Ltd.

Holes and notches in joists

Holes and notches that are cut into the joist for services, such as pipe runs to central heating, etc, may affect its structural integrity.

The safe positioning of notches and holes is shown in the TRADA guidance document referred to earlier. This recommends that notches should not be cut deeper than 0.125 of the joist depth and should be positioned in a zone away from the joist bearing end at least 0.07 to 0.25 of the span. Holes, which should not be greater than 0.25 of the joist depth in diameter should be positioned on the joist centre line, at least three times the hole diameter apart and positioned away from the joist bearing end in a zone of 0.25 to 0.7 of the span.



Services in a solid joist. As a general rule (but not invariably) cables are run through holes drilled in the centre line while pipes are laid in notches cut on the upper surface.

Copper service pipes running through notches in a solid timber upper floor.

In the case of I-joists, the manufacturers will usually specify where holes for service runs can be drilled and how big they can be as part of the specific calculations for the particular job.

Services running through I-joists.

With metal web joists (see photograph below), these problems do not arise because service pipes, cables, etc. can be run through the gaps which are integral to their composition.

View through open web of metal web joists.
Photograph courtesy of Truss Form (Midlands) Ltd.

Services are easily run through the open web in metal web joists.

Finishes

As mentioned in Chapter 5, most modern floors are covered with tongued and grooved chipboard. Alternatives include plywood and oriented strand board (OSB). Tongued and grooved floorboards are still available and could be used where the floor is to be left exposed and varnished as a decorative feature. Although not commonly used nowadays, floorboards have the advantage that they are easier and less disruptive to lift when access to the floor void is required.

To ensure that the requirements of the Building Regulations are met, floor boarding that will not be damaged by spilt water or moisture in rooms such as kitchens, utility rooms, bathrooms and WCs should be used in these areas regardless of the floor location or level. This could be either a proprietary moisture-resistant type or a minimum of 20mm thick natural timber floorboard.

Modern ceilings are nearly always formed in plasterboard. This is covered in more detail in Chapter 10, but the construction basically consists of large sheets of plasterboard, nailed or screwed to the underside (the soffit) of the floor and finished with plaster.

Chipboard flooring being fixed (glued) in place.

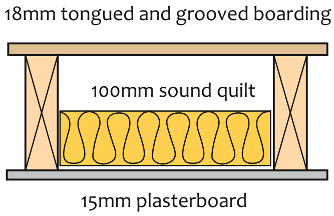
This photograph shows chipboard flooring wrapped in plastic. The chipboard should be a moisture-resistant grade. The plastic covering is temporary and is intended to protect against rain penetration and material spills, etc. during construction.

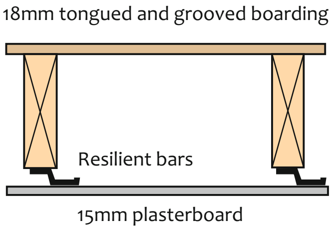
Fire protection

The purpose of fire protection is not to render a floor non-combustible, but to ensure that it will resist collapse for a sufficient period of time to allow evacuation of the building. The Building Regulations require that dwelling houses with floors within 5m of ground level have 30 minutes' fire resistance and 60 minutes' fire resistance to all the floors in dwelling houses with a floor above 5m. Typically, 30 minutes can be achieved with one 12.5mm layer of proprietary plasterboard skimmed or self-finished and 60 minutes with two layers of 12.5mm proprietary plasterboard with the joints staggered and filled.

Sound insulation

Until 2003, there were no specific requirements for sound insulation of the intermediate floors of houses. The Building Regulations were revised and required a minimum performance standard of acoustic insulation for floors to bedrooms, bathrooms and other rooms containing a WC. The requirements are not difficult to achieve; if a suitable thickness of proprietary ceiling boards and acoustic insulation quilt is included in the construction, this will also normally achieve the fire resistance requirements, as previously mentioned, by default. More sophisticated construction is required for flats, where there are also issues of impact sound and fire protection to be considered.





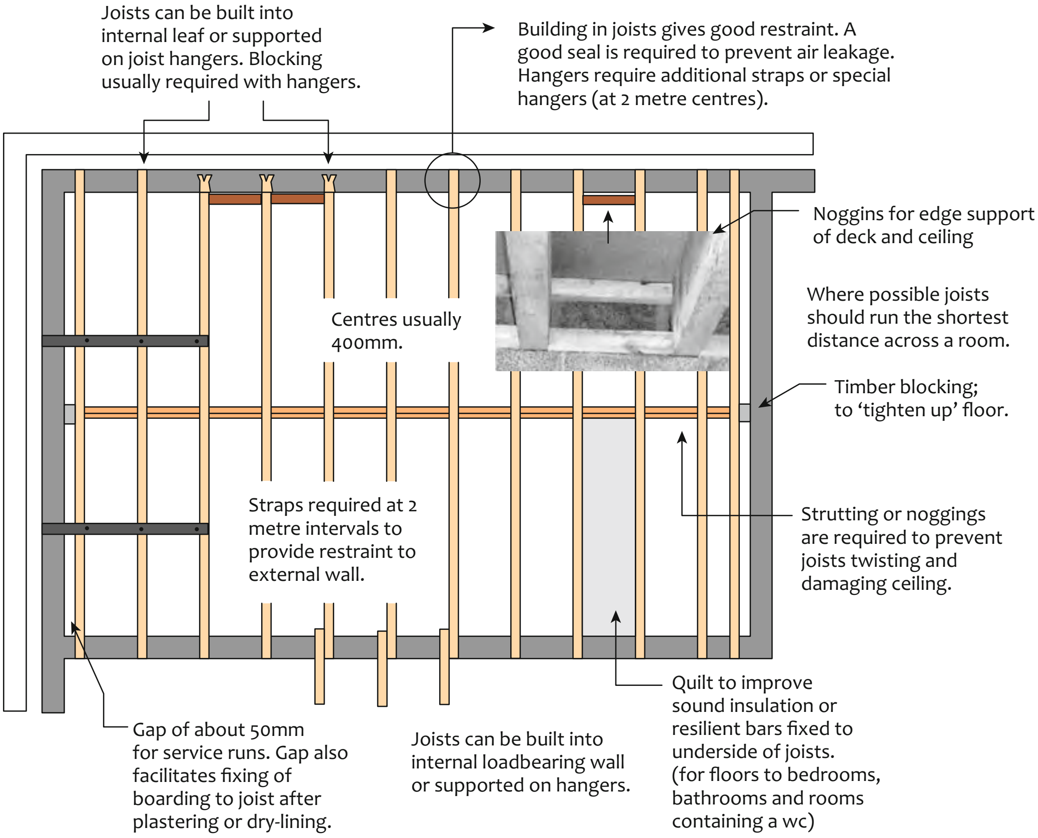
This photograph shows a floor comprising metal web joists, covered with tongued and grooved chipboard with resilient ceiling bars fixed to the underside of the joists. These reduce the chances of ceilings cracking and improve sound insulation. If 15mm plasterboard is fixed to these bars, the 100mm sound insulation quilt can usually be omitted.

Thermal insulation of upper floors

To achieve the conservation of fuel and power requirements (as well as the resistance to condensation and mould growth requirements) the Building Regulations recommend that upper floors over unheated areas in a dwelling, such as integral garages, external passageways or feature overhangs, are insulated to the same standard as ground floors. This can be done in a very similar manner to the approach adopted for ground floors, with the omission of the ventilation but with the addition of a fire (and moisture-resistant if external) board or cladding material to the underside of the floor if, say, a timber floor was used that would not have these inherent qualities.

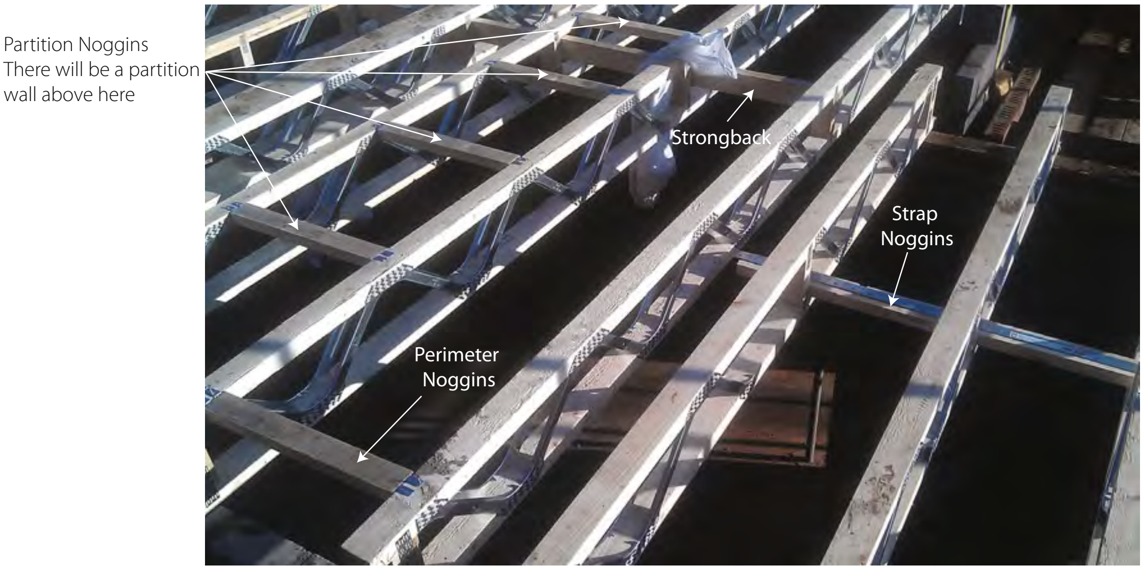
Summary

Part of a typical modern floor is shown in the diagram below. It shows the layout of the joists, the position of straps and the provision of strutting.



The photograph below is of a metal web joist floor and shows the following:

- *a timber brace (called a strongback) running at right angles through the joists, which is needed where the clear span is over 4,000mm in order to 'stiffen' the floor*
- *a stainless steel strap, which is restraining the wall (because the joists run parallel to it); it is fixed to a timber noggin which, in turn, is fixed to the first three metal web joists*
- *timber noggins to support (non-loadbearing) partitions*
- *perimeter noggins to support the edge of the floor decking at that point.*



Photograph courtesy of Truss Form (Midlands) Ltd.

The image above shows the strongback running at right angles through the metal web joists. It is usually fixed to a vertical timber block that has been inserted in each joist and therefore all the joists are connected and stiffened. Image courtesy of Truss Form (Midlands) Ltd.

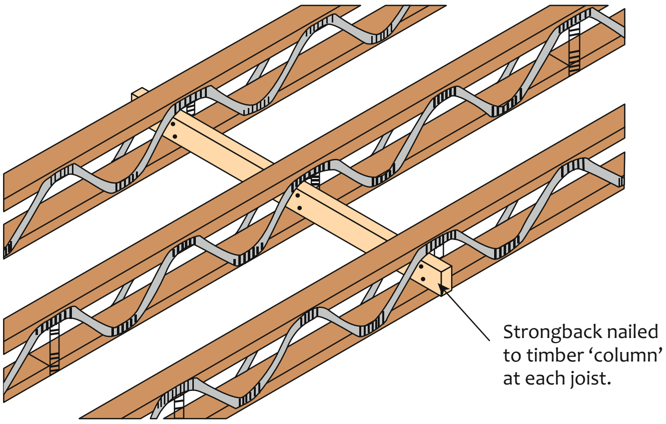


Image courtesy of Truss Form (Midlands) Ltd.

Section Three: concrete floors

In recent years, one or two developers have started to build new houses with upper floors made from concrete – usually in the form of beam and block or plank floors.

Inverted T-beam and block floor

This is a common form of pre-cast floor and is very similar to the one detailed in Chapter 5 on ground floors. The beams are up to 200mm deep, permitting spans of up to 8m. During manufacture, each beam is reinforced with steel wires which run along its length and prevent it from cracking under load. The majority of concrete beams have pre-stressed reinforcement – this involves stretching the wires to a specific tension before placing the concrete in the moulds. When the concrete has cured, the tension in the wires is released and this produces a very strong but lightweight beam.

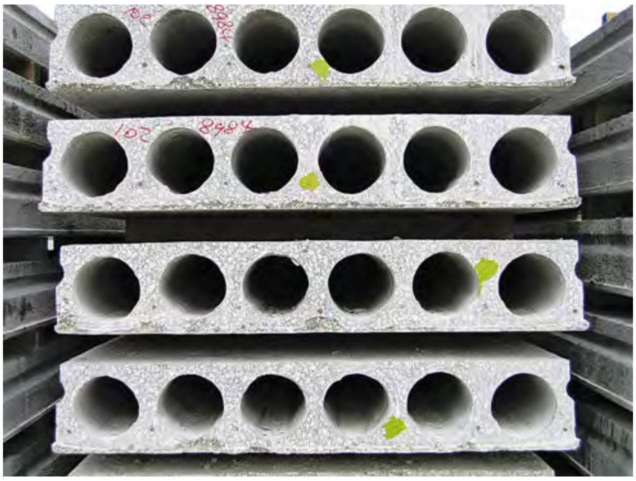
When the external walls have been built to the correct level (this may require cut blocks) the beams are lifted into position by crane. They are supported at either end by the internal skin of the cavity wall, and it is important for structural reasons that they have a full 100mm bearing. Once the beams are in position, the blocks (or hollow concrete pots) are slotted into place and then a fine mix of concrete is brushed over the surface to fill any gaps and 'tighten up' the floor to prevent any cracks appearing in the ceiling finish. The fine concrete also helps to improve sound insulation and fire protection. The construction is very quick and does not require highly skilled labour. In addition, the construction provides much better fire protection than timber joists and obviously there is no danger of rot or insect attack.

In a beam and block floor the beams should usually have at least 100mm bearing on the internal leaf of cavities and special narrow 'slips' are available to fill the space below the infill blocks.

The beams are positioned to suit the size of the blocks. Beams can be 'doubled up' to carry heavier than normal loads (see photograph below).The beams are usually strong enough to support internal non-loadbearing walls. They will not usually support the loads of loadbearing walls.

As with timber floors, restraint straps will be necessary where the beams run parallel to the external walls.

Plank floor



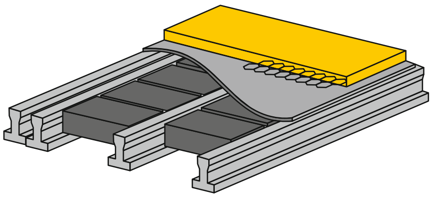
Photograph courtesy of Floorspan UK Ltd.

An alternative to the inverted T-beam is the pre-cast plank floor. These are reinforced lightweight concrete planks which sit side by side, supported as before by the internal leaf of blockwork. The planks are built into the blockwork at the sides as well as the ends and therefore restraint straps are not necessary in this instance.

Photograph courtesy of Floorspan UK Ltd.

Floor finish

A concrete floor can be finished with a sand and cement screed. The addition of a floating floor can provide good resistance to impact sound (from footsteps, etc.). This usually involves separating the floor finish from the structure by a thin layer of resilient material, i.e. a material that will return to its original size after being compressed. One way of doing this is to lay a sand/cement screed on a mineral fibre quilt with a paper backing (to prevent the screed entering the fibres). Some sheet foam materials are also suitable. To prevent the screed from cracking it should be at least 65mm thick and reinforced with a fine galvanised mesh.



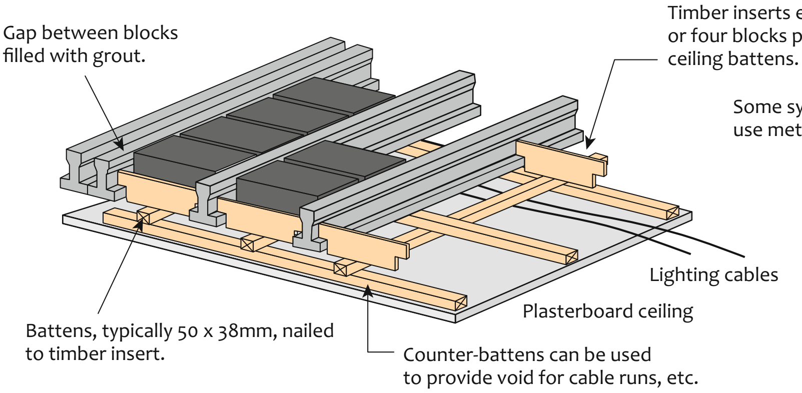
50mm sand cement screed laid on top of beam and block floor. For improved resistance to impact sound a 65mm screed reinforced with galvanised 'chicken wire' laid on a resilient quilt or foam can be specified.

Chipboard floating floors may be an acceptable alternative (see text). The chipboard should be laid on a vapour check in case the beams are damp. The vapour check is laid over sheets of polystyrene (or similar) insulation board. A levelling screed may be required prior to laying the insulation boards to 'take up' the effect of the beam camber.

An alternative solution is to lay chipboard (or similar) on sheets of semi-rigid insulation. A thin levelling screed may be necessary below the insulation to even out the camber on the beams.

Ceiling finish

Plank floors, and some block and beam floors, are designed so that the soffit is flush. The ceiling finish, in these cases, can be in-situ plaster. However, these ceilings are susceptible to minor cracking along the lines of the beams or planks, particularly where the grouting has not been very thorough. A more common approach involves fixing battens to timber inserts or wires positioned between the blocks. Plasterboard can then be nailed to the battens. Counter-battens can be used to provide a service void for lighting cables.



Note: Beam and block or plank floors are usually pre-stressed – drilling or shot firing to provide ceiling fixings may affect their structural integrity.

Roof structure

7

Introduction

This chapter explains the principles and practice of the construction of traditional and modern roof structures. Roofing is one of the most complicated elements of house construction and the chapter is best studied in sections. Section One covers traditional roofs, Section Two covers trussed rafter roofs and Section Three condensation and insulation.

Function

The primary function of a roof is to protect the building below from the weather. In order to satisfactorily fulfil this function over a period of many years, it must be strong, stable and durable. The Building Regulations also require that roofs must provide resistance to the passage of moisture from external elements, not cause surface condensation and mould, provide reasonable levels of thermal insulation and prevent the spread of fire from adjacent or adjoining properties. All these aspects are covered in more detail in this, and the following, chapter.

Roof pitch

The majority of houses in this country are constructed with pitched roofs. The angle of the pitch may be dictated by aesthetic or structural factors; it may also be influenced by the nature of the roof covering. Modern tiles permit very shallow pitches but some of the older traditional coverings, such as hand-made clay tiles, require quite steep slopes to ensure that rain does not penetrate the roof covering. Shallow pitches are generally cheaper to construct, with savings in both timber and tiling. Flat roofs are covered with very different materials as described in Chapter 8.

This timber building (above left) is a traditional timber-frame building. The building is new but it is based on typical construction from the fourteenth or fifteenth centuries. The sloping timbers – the rafters – are supported by a wall-plate at the bottom and a ridge board at the top. Intermediate support is supplied by a horizontal purlin. Modern roofs can be built in a similar way although most are built from prefabricated components erected on site. This pitched roof (above right) is nearly 200 years old and most of the timbers are still in good condition. The construction, in fact, is not dissimilar to the 'medieval' roof on the left.

Section One: traditional roofs

Introduction

This section explains traditional construction techniques found in most houses built before the 1950s. Millions of such roofs remain in existence. They are often referred to as 'cut' roofs. This seems to be because most of the timbers used would have had specific cuts or joints, of varying complexity, made to produce a durable structure. Although there were minor regional variations in technique these were mainly differences in detail and overall there was a level of standardisation in timber sizes. Steel nails were the most common fixing.

Shortages of timber in the post-war period encouraged the development of new roofing techniques: these have come to dominate current construction and are covered in Section Two.

There are some key technical terms which will crop up several times in this chapter. These are illustrated in the photographs below.

Gable: Triangular section of wall apparent at end-of-terraces, semi-detached and detached houses.

Verge: Edge of a pitched roof where it abuts or overhangs a gable.

Eaves: The lowest point on a pitched roof where rainwater is removed.

Ridge Board: Timber at the apex of the roof providing fixing point for pairs of inclined timbers (rafters).

A dormer window

Collar: A horizontal timber linking and restraining pairs of rafters. They are located closer to the ridge rather than the eaves.

A Rafter: Inclined timber (in pairs) fixed at their apex to the ridge and jointed & fixed at the bottom to the wall plate.

A Purlin: A large section horizontal timber supporting the pairs of rafters normally at mid span.

A Wall-Plate: A horizontal timber located on top of the wall head, to which the feet of the rafter are jointed & fixed.

A gable ladder forming a verge

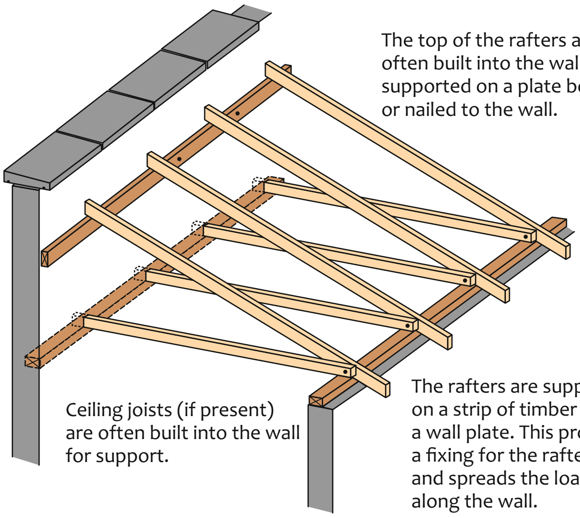
Mono-pitched roofs

The simplest of pitched roofs is the 'lean-to' or mono-pitched roof. The diagram below shows a typical example from the turn of the twentieth century, commonly found forming the rear extensions (e.g. rear additions) to Victorian terraced housing. The sloping timbers, known as rafters, were often supported at the top by building them into the solid wall (not recommended practice nowadays) and at the bottom by securing them to a wall-plate. The wall-plate was a strip of timber bedded in mortar on top of the wall. This distributed the loads from the roof evenly and provided a good fixing for the rafters. Mortar cannot actually bond the timber to the wall and the roof stayed in position due to its weight. The wall-plate was usually the imperial equivalent of 100 x 75mm or 100 x 50mm, although in practice a variety of smaller sizes were used.

If a level ceiling is required, joists could have one end fixed to the wall-plate and rafter. The other end was often built into the wall individually or even supported on a wall-plate bedded within the wall. This practice cannot be regarded as sound construction. Damp penetration in old solid walls is common and persistent dampness may lead to problems of rot.

Victorial mono-pitched roofs

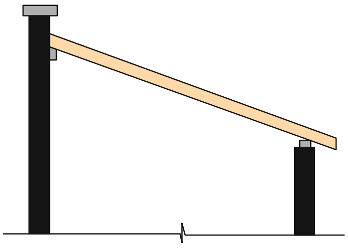
In Georgian and Victorian construction it is quite common to find timbers built into the external wall. Damp penetration through the external wall can lead to rot in the plates. This can affect the stability of the wall itself.



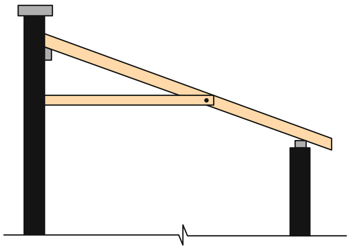
The rafters were skew (diagonally) nailed to the plate and could be a range of sizes; typical width was 50mm with a depth of 75mm, 100mm or 125mm. The depth of the rafter depended on its span and loading. The width is primarily to prevent twisting and to provide a sufficiently wide surface on which to nail the battens supporting the tiles. It was, and is, good practice to notch the bottom of the rafter where it sits on the wall-plate as this gives a good bearing and aids alignment of the rafters. This 'birdsmouth' joint should be no more than one-third of the depth of the rafter itself. Timbers of any given depth may vary slightly in size, and to prevent an uneven roof-line the birdsmouth joint can be increased or decreased as required. The rafters were usually fixed at 400mm centres, this being the most economical arrangement of the timbers. Other spacings, 450–600mm were sometimes encountered and were acceptable under by-laws. However, spacing at increased centres required rafters of increased depth. In modern construction the sizing and spacing of the timbers is controlled by the Building Regulations, which require the sizes, spacing and spans of the timbers to be adequate for the loadings and the Approved Document A 'Structure' refers to a secondary TRADA document (*Eurocode span tables for solid timber members in floors, ceilings and roofs for dwellings*), which contains tables of timber sizes and spans that would satisfy the requirements of the Regulations if used according to the guidance. However, if alternative timber sizes or spans are proposed rather than the TRADA guidance, structural calculations and details should be prepared by a suitably qualified person to satisfy the Building Control body that the proposed design is adequate for the anticipated loadings. Prior to 1965, building standards were controlled by local by-laws, various Building Acts and generally recognised good practice.

Additionally, the Approved Document recommends that in certain areas of England softwood roof timbers are treated to resist attack by house longhorn beetle.

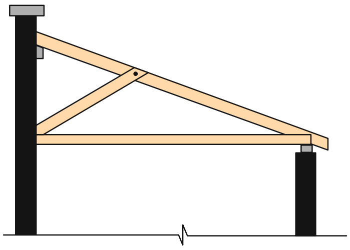
The 'lean-to' roof appears in many forms. The middle example is probably the most common but there are others. Using traditional techniques 'lean-to' roofs could achieve only very modest spans due to the structural limitations of their design. By inclining pairs of rafters against a central ridge (double pitch) increased spans could be attained, and this was the most common form of traditional roof construction.



No ceiling joists (ties) – ceiling finish applied to rafter soffit.



The tie is above wall-plate level giving partially increased ceiling height.



A strut helps prevent sagging or deformation in the rafter.

Double-pitched roofs

The majority of roofs in this country have inclined pairs of rafters forming a symmetrical double pitch, with the triangular ends of the roof protected by the walls (known as gable walls). This roof type, often referred to as a gable roof, can easily be adapted for semi-detached and terraced houses by providing intermediate block or brick walls.

Simple double-pitched roofs (couple and closed couple roofs)

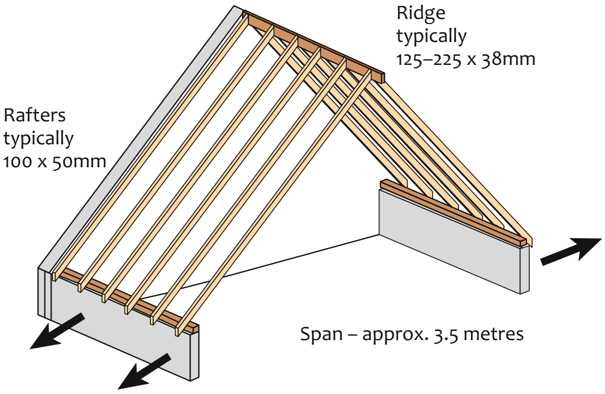
At the top of traditional double-pitched roofs, a timber ridge board will span from gable to gable. This provides a fixing for the top of the pairs of rafters and prevents their lateral movement.

In a couple roof, because of the lack of horizontal restraint at the feet of the rafters, the loads tend to push the supporting walls outwards. Therefore, unless these walls are very thick or buttressed, this type of roof is limited to a span between wall-plates of 3.5m or so.

The closed couple roof, the right-hand example on the next page, introduces a ceiling joist which is nailed to the feet of the rafters and, ideally, to the wall-plate too. This restrains the horizontal thrust, achieving effective triangulation.

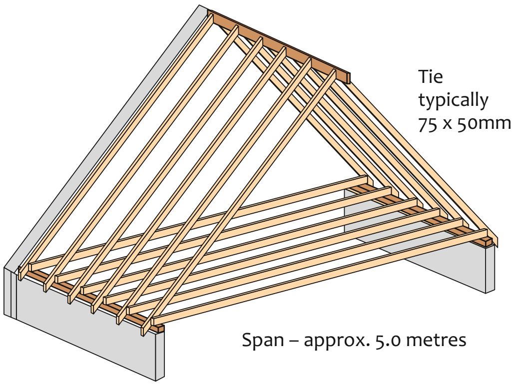
Triangulation is an important principle in pitched roof construction. A triangular structure, with appropriately sized members and effective fixings at each node, is highly resistant to distortion and deflection. Effective triangulation enables closed couple roofs to have an increased span – up to 5m. This type of roof is utilised on houses such as cottages that are only one room deep and poor-quality terraced housing built during the Industrial Revolution.

Couple roof



The weight of tiles and snow etc., tend to push the rafters outwards. This can cause ‘spreading’ at the rafter feet. In extreme cases it can push the external walls outwards.

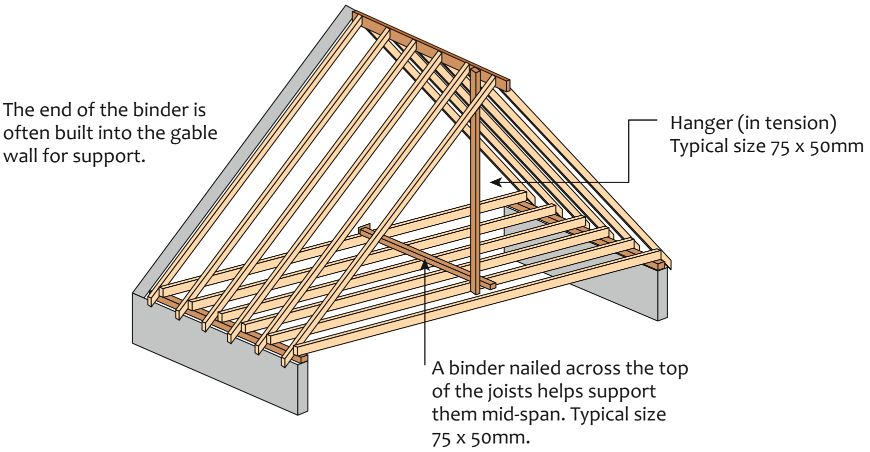
Closed couple roof



Spreading can be prevented by providing a tie. In this example the ties also act as ceiling joists. In order to function properly the connections between all the timbers must be sound, i.e. to ensure effective triangulation.

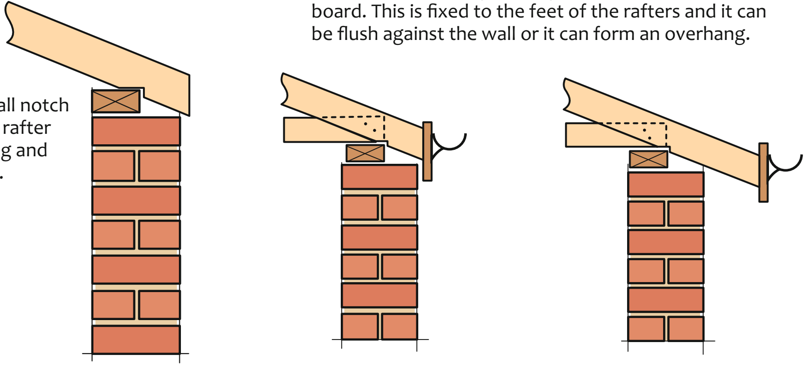
Support for ceiling joists

The ceiling joists, which span from wall-plate to wall-plate, were often of smaller section than rafters. To prevent them sagging in the middle, if no intermediate support was available in the form of internal loadbearing walls, some alternative form of support was required. The most common solution, in all types of traditional roofs, was to secure the ceiling joists to a horizontal member, called a binder. The binder itself was often supported by using a hanger, attached to the ridge or sometimes to the side of a rafter. An alternative was to use joists of increased depth, but this was usually a more expensive solution.



Eaves

The diagram overleaf shows examples of typical eaves details that might be found on relatively simple Victorian houses. At the bottom of the rafters a fascia board protects the rafter feet from the elements and provides a fixing for the guttering.



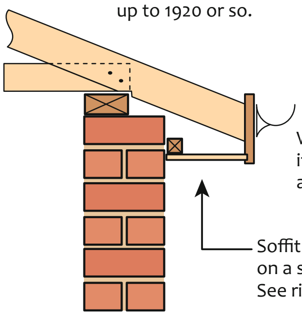
In most houses the guttering is supported by a fascia board. This is fixed to the feet of the rafters and it can be flush against the wall or it can form an overhang.

Birdsmouth joint, a small notch in the underside of the rafter provides a good bearing and helps align the timbers.

Flush fascia

Overhanging fascia

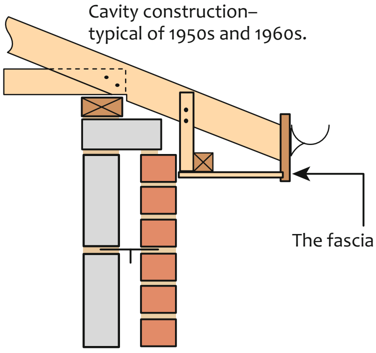
Overhanging eaves usually incorporate soffit boards. Fascias and soffits can be made from a variety of materials and were traditionally softwood boarding but nowadays, plywood, plastic or a number of other synthetic materials are available. Often, these are supported by a simple timber framework nailed to the rafters or secured as shown in the drawing below. The soffit board prevents insects and birds from gaining access to the roof space. Overhanging eaves provide far better weather protection to the wall below. They are more expensive but have been common since the 1930s. Fascias and soffits, together with issues of roof ventilation, are considered in more detail in Section Three.



Solid wall construction – up to 1920 or so.

Where there is a large overhang it is common practice to provide a soffit board.

Soffit can be supported on a batten or on a simple framework fixed to the rafters. See right hand example.

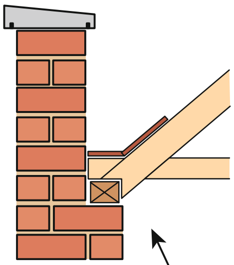


Cavity construction– typical of 1950s and 1960s.

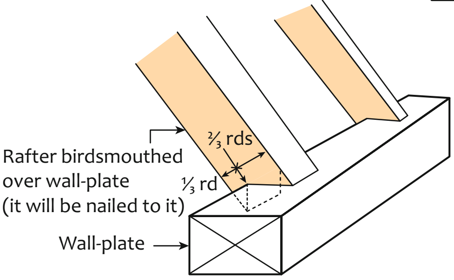
The fascia board.

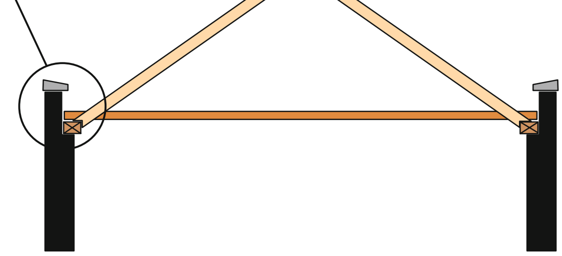
Parapet walls

In some houses the external walls continue above the eaves to form parapets. In these dwellings a different type of eaves detail is required. The rafters were often cut as shown in the photograph opposite. Drainage would be provided with a zinc- or lead-lined gutter where the rafters meet the parapet.



Roofs with parapet walls cannot, by their very nature, have rafters projecting beyond the wall-plate. It is normal practice to cut the rafters as shown in the illustration. The gutter (i.e. behind the parapet wall) is usually lined with lead.

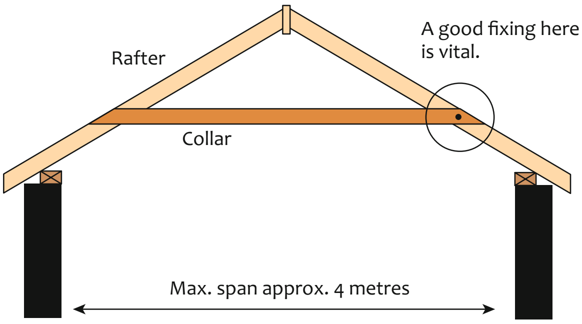




Collar roofs

In some houses collar roofs can be found. The principle is not dissimilar to the closed couple roof but the horizontal tie is higher up the rafters. Houses with collar roofs often have rooms formed partly in the roof space, which results in a lower overall height and subsequent savings in walling materials. However, if the collar is too high it will not be effective and the rafters below the collar can still exert an excessive lateral thrust on the supporting walls. If the collar is kept fairly close to the rafter feet (not more than one-third of the roof height) and a good joint is formed between the rafters and collars by bolting or the use of fixing plates or carpentry joints, the roof should remain stable.

Collar roofs were quite common in the Victorian period. The collar allows part of the accommodation to be provided within the roof, thus saving a few square metres of brickwork. They tend to be found in rural areas. Remember that the higher the tie, the less effective it is at restraining the rafter feet.



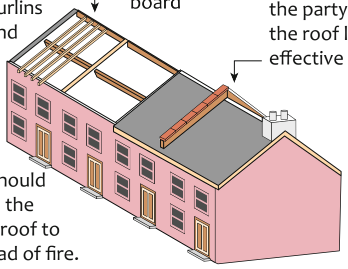
Purlin roofs

The majority of houses with traditional roofs are too deep for simple closed couple or collar roofs. Houses that are two rooms deep normally require roofs which can span at least 7m. The load from the roof coverings, snow and wind will cause the rafters to deflect, placing extra strain on the nails securing the rafter feet. In theory, it is possible to increase the span of a roof and prevent deflection by using ever-increasing rafter sizes. However, the use of very deep sections is both uneconomic and also creates handling problems on site due to their weight. In traditional construction this problem was solved by the introduction of purlins. Purlins are large timber beams which support the rafters' span, thus preventing deflection. Purlins span from gable to gable (sometimes with intermediate support) and, besides supporting the rafters, they provide lateral stability to the gable walls and, in terraced housing, to the party walls.

This is a modern purlin roof. This roof is slightly unusual in that there are two purlins on each slope (one on each slope is more common). The purlins support the rafters which, in turn, support the roof battens and tiles. The purlins are built into the gable wall and the party wall for support.

The purlin roof is a very common type of construction, particularly in its simplest form, where it is used extensively in terraced housing.

In the photograph above the party wall terminates within the roof void, rather than extending above the roof line as a parapet. This is not uncommon. The party wall's effectiveness as a fire break would have to be confirmed in these houses.



Rafters supported mid span by timber purlins built into gable and party walls.

Timber ridge board

In some parts of the country the party walls extend above the roof line to provide a more effective fire break.

The party walls should always extend to the underside of the roof to prevent the spread of fire.

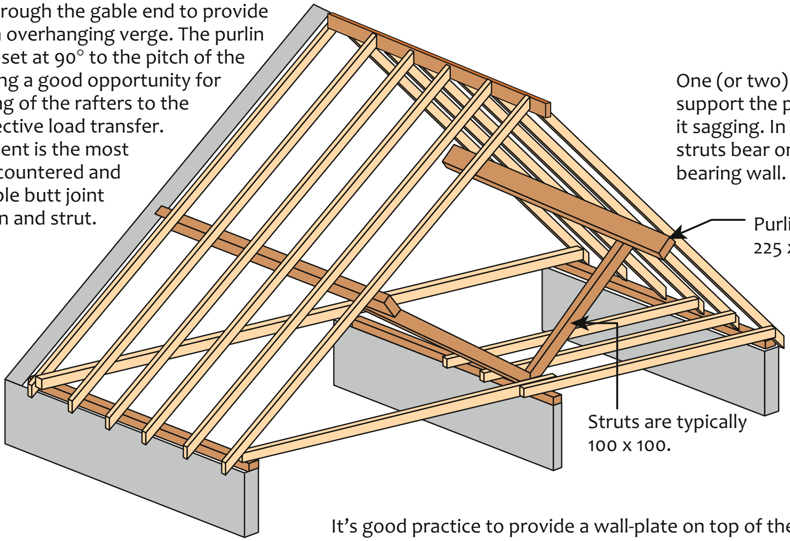
As in an earlier example, some form of support will be required for the ceiling joists. This can be in the form of hangers, although it is more likely to be in the form of an internal loadbearing wall, which divides the front and rear bedrooms. As with timber floors, the ceiling joists are often in two pieces because long lengths of timber were not (and are not) readily available. This type of purlin roof is suitable for spans up to 8m or so.

Complex purlin roofs

Terraced housing is usually fairly narrow (4–6m or so) and purlins can generally span from gable wall to party or gable wall. However, as the width of a property increases, so must the depth of the purlin if it is to be strong enough to carry the load without undue deflection. Very deep purlins, say over 250mm, are expensive, difficult to obtain and difficult to handle on site. In practice, it is more economic to use smaller purlins and provide intermediate support in the form of struts, built off internal loadbearing walls. In a large terraced house, semi-detached houses or an average sized detached property, it is common to find one or two pairs of struts, depending on the availability of supporting walls.

In the first example, shown below, the internal loadbearing wall runs parallel to the ridge and, by using timber struts inclined at an angle, the purlin can be provided with adequate support. The internal wall also provides support for the ceiling joists (partially shown in the drawing), thus reducing the need for hangers and binders which can restrict the roof space. This is a very commonly encountered arrangement.

Note that the struts are most effective when they are approximately at right angles to the pitch of the rafters.



The purlin is usually built into the gable end. In some examples it runs right through the gable end to provide support for an overhanging verge. The purlin is shown here set at 90° to the pitch of the rafter, providing a good opportunity for effective nailing of the rafters to the purlin and effective load transfer. This arrangement is the most commonly encountered and enables a simple butt joint between purlin and strut.

One (or two) pairs of struts support the purlin to stop it sagging. In this example the struts bear on an internal load bearing wall.

Purlin is typically 225 x 100.

Struts are typically 100 x 100.

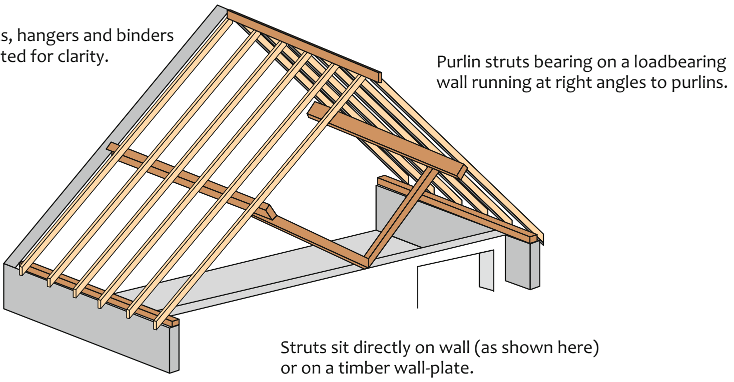
It's good practice to provide a wall-plate on top of the internal loadbearing wall. This provides a surface on which to nail and join the ceiling joists.

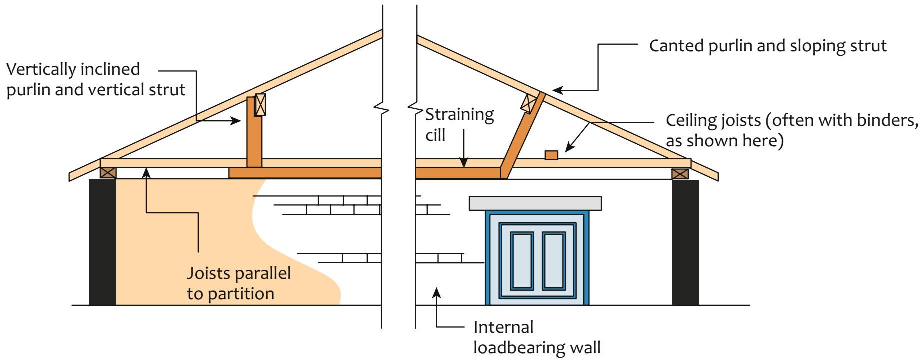
Horizontal ties or collars can sometimes be found in large, strutted roofs. It is normal to find them fixed just below or above the top of the struts. The collar provides extra bracing and prevents deformation of the roof structure in high winds. The photographs overleaf show a typical purlin roof from the 1950s.

This roof dates from the 1950s and is a good example of a strutted purlin roof. The purlins are supported by two sets of angled struts bearing on a loadbearing wall (see below).

The purlins are built into the party walls (this is a terraced house). The purlin should not run completely through the party wall. This reduces the possibility of fire spread. A collar, just above the struts, keeps the roof rigid in high winds. The rendered brickwork (to prevent smoke leakage) on the party wall shows how the flues are 'gathered' below the chimney stack.

Wide roofs with low pitches can be difficult to strut effectively. Where internal loadbearing partitions run at right angles to the purlins, the angle of the struts can be adjusted by using a straining cill, as shown in the diagram below. The straining cill enables the struts to be maintained at an effective angle to counteract the roof loads. If a loadbearing partition runs at right angles to the ridge, the purlin can be supported by vertical struts. To reduce the point loads on the loadbearing partition, it was common to bed a timber wall-plate on top of it. This also provided a fixing point for the struts.





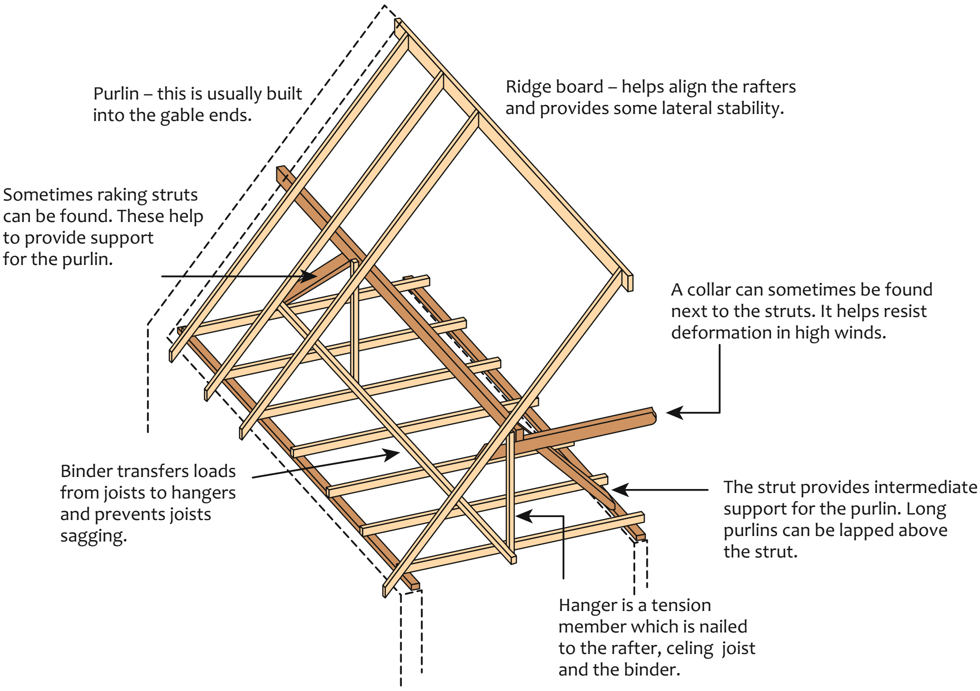
The left-hand example shows a vertically inclined purlin with a vertical strut bearing on internal loadbearing wall. The right-hand example shows a canted purlin with a sloping strut. In a shallow pitched roof, and on very wide span roofs, the struts may not meet (as they do in the example in the previous drawing) and, in these situations, you will sometimes find a straining cill to help secure the strut base and counteract the loading. In both roofs, there may be hangers and binders to prevent the ceiling joists from sagging.

The lower diagram on the previous page shows an example of canted purlins (i.e. the purlin is turned to 90° to the pitch of the rafter). However, vertically inclined purlins, such as those shown in the photographs above, are possible. Vertically inclined or canted purlins are the result of the personal preference of the designer or builder; the former being easier to build into the brickwork and the latter providing a flat surface against which the rafters can be fixed. If the purlin is vertically inclined, it is good practice to use a birdsmouth joint where the rafters pass over the purlin. However, in many cases the rafters simply rest on the corner of the purlin and are secured by nailing.

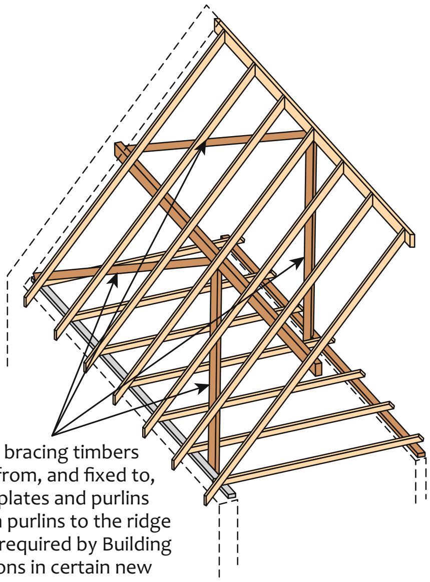
Summary

The diagram overleaf shows a typical traditional roof containing many of the elements described in this section. The function of each member is explained below.

- *The ridge board provides a good fixing for the top of the rafters and prevents lateral movement.*
- *The purlins prevent the rafters from sagging and help to prevent lateral movement of the gable ends.*
- *The struts prevent the purlin from sagging.*
- *The horizontal joists restrain the ends of the rafters and provide a fixing for the ceiling. An effective joint where the two separate ceiling joists meet over the internal loadbearing partition is essential for triangulation.*
- *The hangers and binders prevent the ceiling joists from sagging. These can be provided under the ridge or under each purlin. It is possible to provide a hanger for every joist, and in this case the binder is not required. However, this requires more timber and is therefore less economical.*

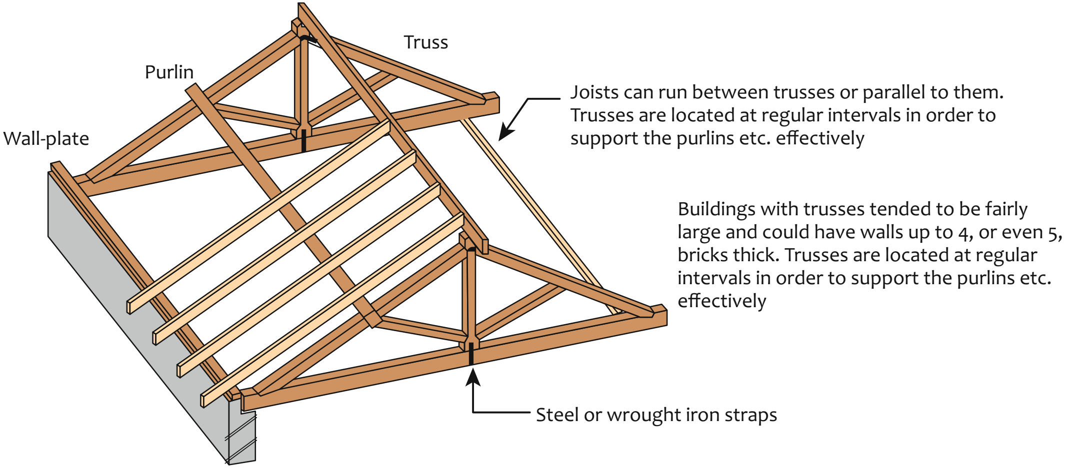


Note: Approved Document A recommends that roofs to detached houses with a pitch of over 40° are provided with diagonal bracing, which stabilises both the roof and the gable walls – an example of this bracing is shown below.



Trusses

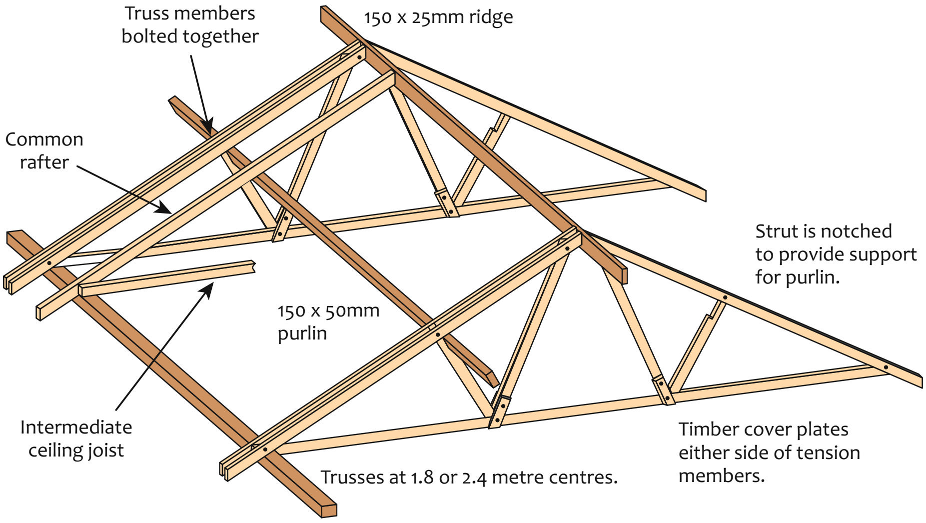
Some older roof structures have timber trusses to support the purlins. These are substantial triangulated structures formed using large section timbers. They are jointed, bolted and/or strapped together. They are capable of spanning from external wall to external wall and were quite common in the past in large buildings, where big rooms resulted in few loadbearing walls. The function of the truss is to support the purlins in the absence of such loadbearing walls. On very wide buildings, such as old warehouses, churches and chapels, trusses may support three or four purlins on each slope. They are very rare in modern construction, although a lightweight version was popular in the 1950s, designed by the Timber Research and Development Association (TRADA), as a response to the post-war shortage of materials. Trusses can be found in a variety of designs. This particular example (opposite) is a king post truss. The king post is the vertical element in the centre of the truss.



The left-hand image shows a king post truss. They provide support for the purlins without the need for internal loadbearing walls. This enables the floor space below to remain open plan. The photograph on the right shows a queen post truss. In some forms of construction these are so big that accommodation, i.e. attic space, can be formed within them.

TRADA trusses

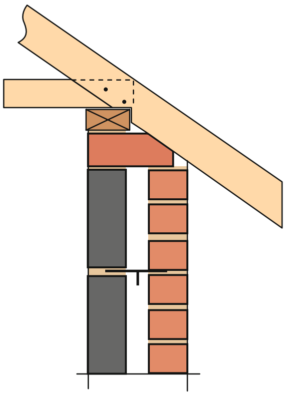
In the post-war period, TRADA produced a number of designs for lightweight trusses in response to timber shortages. As with the earlier, more substantial trusses their purpose was to provide a means of supporting the purlins, precluding the need for internal loadbearing walls. TRADA trusses were normally positioned at 1.8–2.4m centres with common rafters and ceiling joists in between. Hangers and binders were often incorporated to provide support to the intermediate ceiling joists. The trusses were made up using a series of small section timbers bolted together to keep them rigid. The acceptable span depended on the size and arrangement of the timbers. The example shown overleaf is capable of spanning approximately 8m.

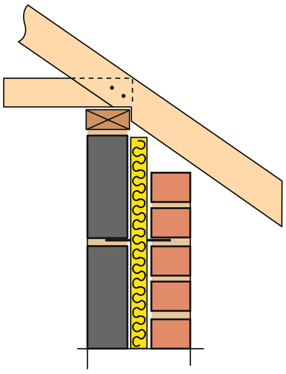


Modern cut roofs

Although it is rare to find traditional roofing techniques used in modern estate developments, individual new properties are sometimes built with traditional cut roofs, particularly where there is extensive use of the roof for accommodation. The principles outlined earlier have changed little, although the Building Regulations guidance document published by TRADA is more onerous with regard to the sizing, spacing and spans of timbers. It is not uncommon to observe sound, undistorted timbers in an older traditionally cut roof whose dimensions are significantly smaller than those prescribed by such tables. The structural quality and durability of timber used in the past, particularly pre-1914, is generally superior to that available today.

Most modern houses are built with cavity walls and a typical eaves detail is shown below. The cavity is normally closed before positioning the wall-plate. This acts as a cavity barrier in case of fire and prevents moist air from the cavity entering the roof space where it can condense and lead to conditions which encourage rot to occur. Closing the cavity is not necessary if the cavity is filled with insulation. However, recent guidance from the National House-Builders Council (NHBC) suggests that there have been some incidences of horizontal cracking just below the wall-plate caused by differential movement of the internal and external leaves. They attribute this to the use of lightweight blocks in the internal leaf. The NHBC, therefore, recommends that cavities should be closed with a flexible mineral wool positioned inside the top of the cavity.

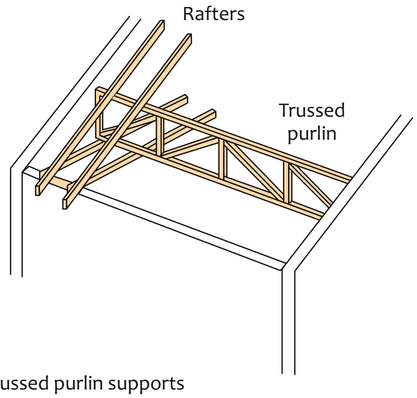

In houses with no, or partial, cavity fill it is standard practice to close the cavity at the eaves to minimise air movement in the cavity, to prevent moist air entering the roof space and, perhaps most important, for fire protection.


If cavity batts are used there is no need to close the cavity. It is the internal leaf, not the external leaf, which supports the roof loads.


A birdsmouth joint. The rafters are thus notched over and nailed to the wall-plate. This is a collar roof so the tie is fixed further up the rafters. The cavity fire barrier has yet to be installed.

Current Building Regulations guidance documents allow the use of traditional solid timber purlins, although their acceptable spans are limited. Trussed timber purlins (factory fabricated and engineered specifically for their intended purpose) or steel sections are a modern alternative. Steel sections can be built into party walls, although trussed purlins are usually bolted to the inside face of the walls or supported on steel 'shoes'. The party wall is important in terms of fire protection and if timbers are built into this structure this will reduce the wall's effective fire resistance.

A trussed purlin spans from gable to gable.
It can be bolted or supported on steel brackets.



The trussed purlin supports
the rafters and the ceiling joists.

Purlins can also be made from steel sections.
They are usually supported by 'building in' or
by steel brackets bolted to the gables.

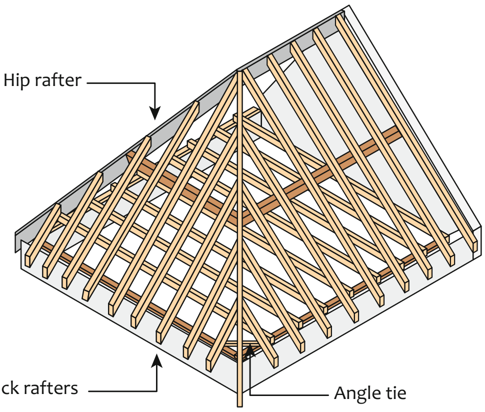
A timber wall-plate is usually bolted to the top of
the steel purlin to provide a good fixing for the rafter.

The Building Regulations Approved Document A 'Structure' recommends the use of straps in roof construction. These ensure that the gable walls cannot buckle or move as a result of wind pressure, by linking the walls to the roof bracing and structure, so tying the roof structure to the external walls. The requirements relating to strapping of wall-plates are primarily for shallow pitched or lighter non-traditional roofs rather than their heavy traditional counterparts. Consequently, details of strapping are contained in the section on modern trussed rafters in Section Two.

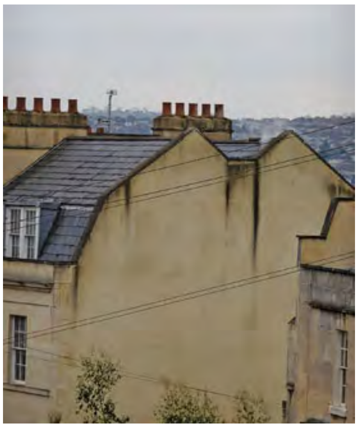
Other roof shapes

Simple gable roofs are probably the most common shape in both early and modern construction, but a variety of other designs are possible. Some of these are illustrated in the diagrams overleaf.

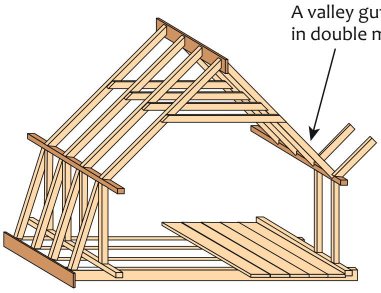
Hipped roofs are an alternative to gable roofs. Larger examples include purlins on all slopes, sometimes supported by struts and trusses.



A single mansard (1955)



A double mansard (c. 1780)



Mansard roofs have two pitches on each slope. A purlin normally supports the rafters where the two pitches meet. These roofs include living accommodation in the roof void. Valley gutter if a double mansard roof.

Hipped and mansard roofs

These have been popular at various times during the past 200 years or so. In principle they do not differ greatly from gable roofs but there are a number of additional structural concerns:

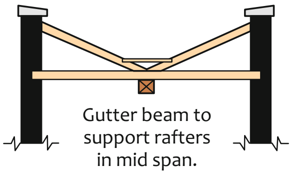
- *Often, hipped roofs are also purlin roofs. As there is no gable at the hipped end, the purlins supporting the two main slopes and the hipped end are all cut and fixed onto the back of the two hip rafters. Although the purlins are often provided with support struts, there is significant thrust along the hip rafter and this requires special structural arrangements. Dragon or angle ties link the two wall-plates and provide restraint against the thrust from the hip rafter.*
- *Inevitably, some of the rafter ends (usually those on the hipped end) will not be effectively tied in as the ceiling joists will run parallel to parts of the wall-plate. This needs consideration and careful detailing in design and construction to ensure stability.*

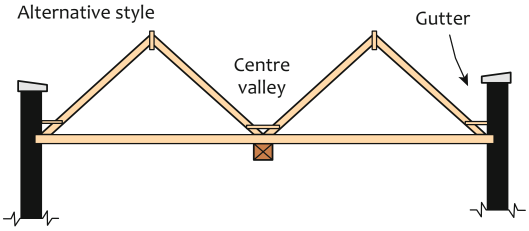
Typical construction is shown above.

Double lean-to or butterfly roofs

Most butterfly roofs date from the eighteenth and nineteenth centuries. They are prone to failure because the roof drains towards the centre of the building rather than away from it. This is not dissimilar to the effect of the valley created in a double mansard. Leaks in the valley gutters are potentially very serious. In some cases these roofs were built because they were cheap, in others they were built to keep the ridge as low as possible (for aesthetic reasons). This type of roof is rarely found in modern construction.

These roofs are prone to leakage through defects in the valley and gutters. Valley gutters are usually formed in lead sheet. The detailing can be quite complex and due allowance must be made for the high thermal movement of the lead.





Section Two: modern roofs

Trussed rafters

Most modern roofs are constructed from trussed rafters. Trussed rafters have been popular for 40 years or so and have almost totally replaced the traditional roofs shown earlier. The most common pattern is the Fink or ‘W’ truss, designed for symmetrical double-pitched roofs, although there are a variety of shapes suitable for most roof designs. The trussed rafters are prefabricated and delivered to site ready for lifting onto the supporting walls, although occasionally you will find the entire roof structure assembled on the ground and lifted into place by crane.

The timbers, which are typically around 80 x 40mm (the British Standards prescribe a minimum thickness of 35mm for spans up to 11m) in section are butt jointed and held together by special metal nail plates, which are pressed into position by machine. The truss suffers minimal deflection under load due to the triangulation of the timbers and the metal nail plates fixing the members firmly together.

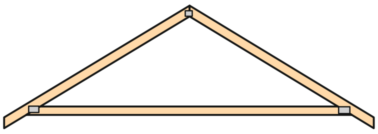
Trussed rafters offer several advantages in comparison to traditional roofing methods:

- *no internal support is required from loadbearing partitions*
- *spans of up to 12m can easily be achieved*
- *they offer very fast construction*
- *highly skilled labour is not required*
- *they are relatively cheap*
- *they can be designed to very shallow pitches.*

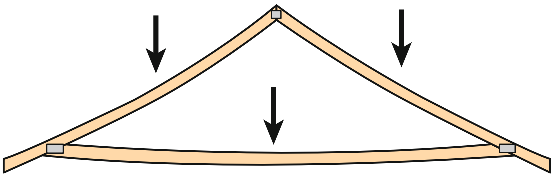
Perhaps their major disadvantage is that Fink trusses severely limit the use of the roof space for storage and loft conversion is impossible without their complete replacement or the need to carry out major structural works, such as the provision of new purlins, floor beams and joists to satisfy the structural requirements of the Building Regulations.

Design and fabrication

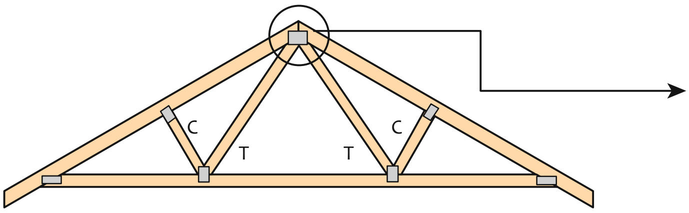
Separate purlins, hangers and ridge boards are not required with trussed rafters, although some timbers have to be added on site to convert the individual trusses into a single structural roof unit (see overleaf).



For very small spans, about 3 metres, the trusses can be like the example above. The timbers are joined with metal plates pressed into the timber.

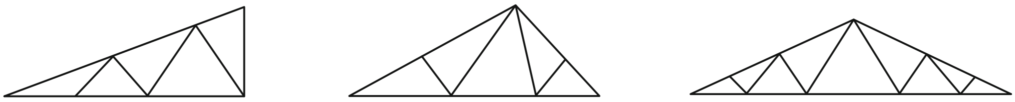


If larger spans are required this simple truss design will not be effective. Deeper section timbers could be used but this is very expensive.



Adding the internal compression and tension members makes the truss rigid and minimises deflection. Spans of up to about 11 metres can be achieved using this design. This 'Fink' pattern trussed rafter is the most commonly encountered pattern.

During manufacture toothed metal plates are pressed into the timbers. All the timbers are butt joined.



There are literally hundreds of different designs, each one engineered for its specific task.

When ordering trussed rafters, the following information will have to be provided to the suppliers before manufacture commences:

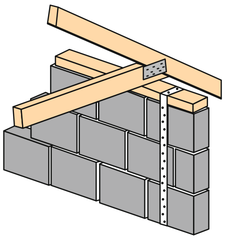
- *span, shape and pitch of the roof*
- *type, and therefore load, of coverings*
- *location of supporting walls*
- *overhang at eaves*
- *height and location of buildings, so that wind loads can be assessed*
- *whether the specification calls for treated timber (although, in practice, timbers are almost always pre-treated against rot and insect infestation)*
- *if water tanks or cylinders are to be provided, the location and size/loads.*

Fixing

Trussed rafters can be fixed in position as soon as the external wall is at eaves height. Completing the gable wall or party wall is often done after the trussed rafters have been erected, because they provide a template for the bricklayers or masons. As with traditional roofs, a timber wall-plate is bedded in mortar on the wall and the trussed rafters are fixed by nailing or by the use of special clips. Although they can be skew-nailed through the wall plates, this can cause damage if not done with care and most manufacturers recommend the use of truss clips. Trussed rafters are usually designed to be fixed at 600mm centres.

It is good practice to strap the wall-plate down to the external walls. This can be done using galvanised or stainless-steel straps which are screwed to the top of the wall-plate and to the internal skin of blockwork. The Building Regulations Approved Document A guidance does not stipulate that this form of strapping is necessary for all roof structures, but it is cheap to install and does prevent the roof lifting in high winds. Straps are normally positioned every 2m and they should extend downwards for at least 1m.

Trussed rafters are fixed to a timber wall-plate bedded on the inner leaf of the cavity wall. The truss is often fixed before the gable wall is complete – it acts as a template for the bricklayers.

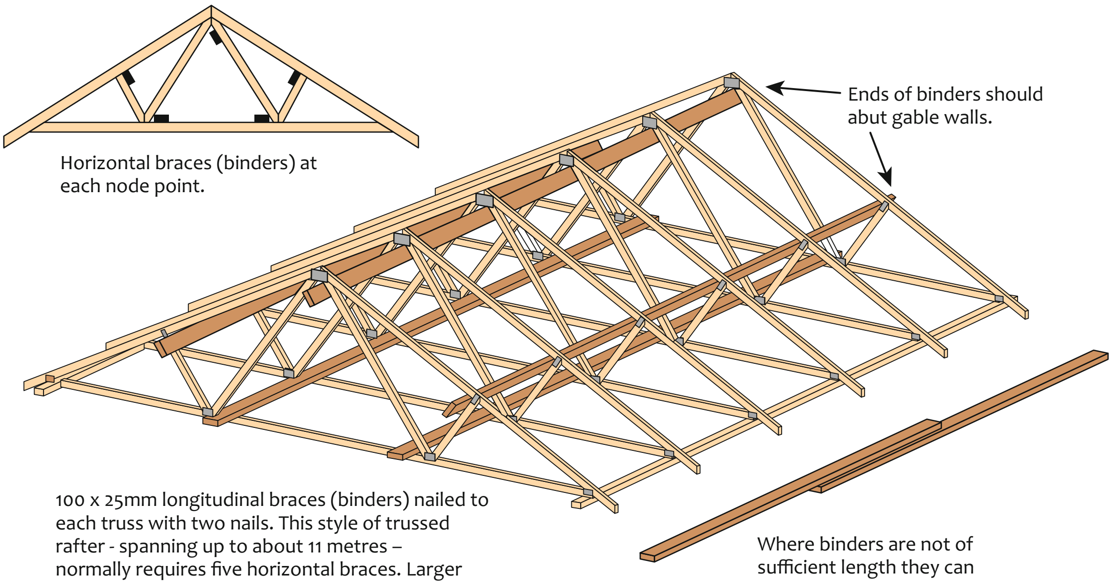


Galvanised straps at 2 metre centres secure the plate in position.

Trussed rafters are sometimes fixed by nailing through the plate but this can cause damage. A better method is to use special truss clips. See Image below.

Once in position, the trussed rafters must be linked together with additional timbers to form a single structural roof unit.

The rafters must also be fixed in the correct position and at the correct spacing. This is achieved by the use of braces (sometimes referred to as binders), which are nailed at right angles to the trusses, as shown in the diagram below.



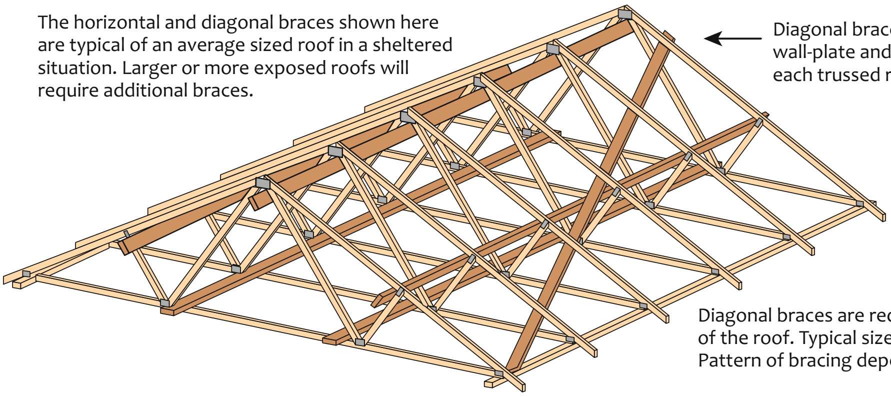
Horizontal braces (binders) at each node point.

Ends of binders should abut gable walls.

100 x 25mm longitudinal braces (binders) nailed to each truss with two nails. This style of trussed rafter - spanning up to about 11 metres – normally requires five horizontal braces. Larger trusses will need additional braces.

Where binders are not of sufficient length they can be joined by lapping them over two trusses.

Although these braces tie the trussed rafters together, they do not prevent racking – where the structural units move out of plumb en masse. To prevent this, a diagonal brace is nailed to the underside of the top member, as shown in the illustration overleaf. This diagonal brace prevents racking and keeps the whole structure rigid. Omitting it is a common cause of trussed rafter roof failure. It is possible to omit the diagonal and rafter level longitudinal bracing if an appropriate rigid sarking board is fixed to the top external face of the rafters. Typically, this might be a 9mm thick external grade plywood.



The horizontal and diagonal braces shown here are typical of an average sized roof in a sheltered situation. Larger or more exposed roofs will require additional braces.

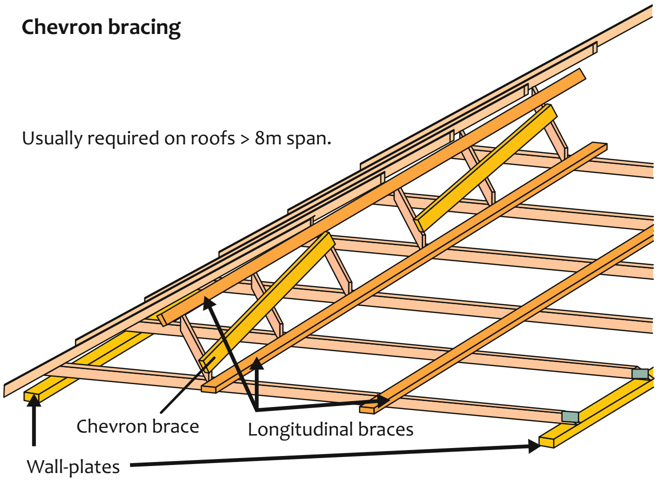
Diagonal braces are nailed to the wall-plate and to the underside of each trussed rafter.

Diagonal braces are required on both slopes of the roof. Typical size – 100 x 25mm. Pattern of bracing depends on roof size.

Horizontal brace (100 x 25mm) being fixed in position with a nail gun.

The diagonal brace keeps the roof structure rigid. The pattern of bracing depends on the roof size.

For trussed roofs with a span of over 8m, some designers and manufacturers of trusses have a requirement for what is referred to as chevron bracing – this is fixed to the upper side of the internal compression member.



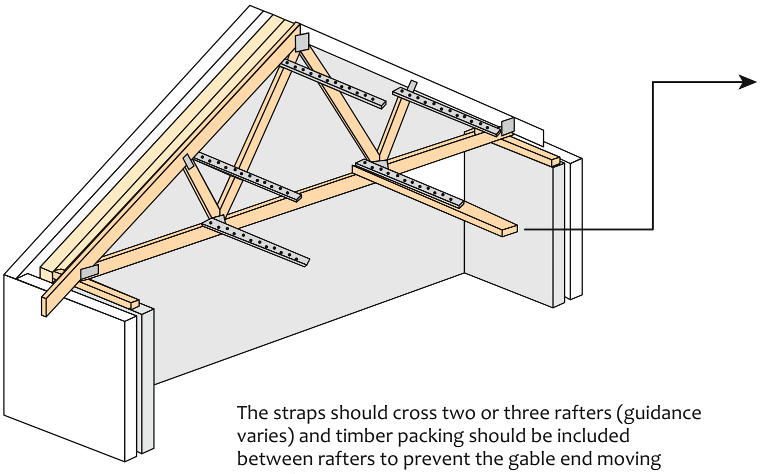
Chevron bracing

Usually required on roofs > 8m span.

Strapping

The Buildings Regulations Approved Document A recommends the use of straps in new roofs, so that the gable walls are tied back to the roof structure at intervals of not more than 2m. The strapping is to prevent movement of the gable walls under wind load. This strapping is required at rafter level and, in steep roofs, at ceiling-joist level to prevent the middle of the wall from buckling or bulging. The principle is exactly the same as for suspended floors which are described in Chapter 5 under Timber floors).

Gable ends strapped to roof structure at 2 metre centres. If the roof is steep additional straps may be required at ceiling level.

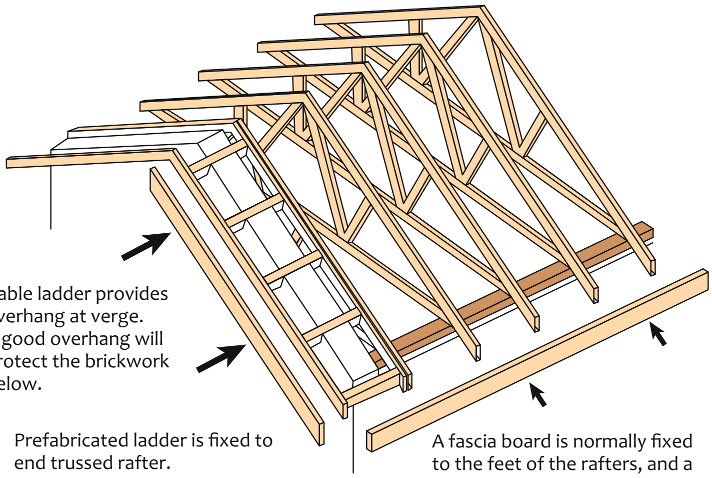


The straps should cross two or three rafters (guidance varies) and timber packing should be included between rafters to prevent the gable end moving inwards.

The straps are usually fixed along the horizontal braces.

Other details

As described earlier, the feet of the rafters can be finished with flush or overhanging eaves. The principles are the same as for traditional roofs and further details are contained later in this chapter. On some houses an overhang is also provided at the verge (where the roof overhangs the gable wall). This can be provided in the form of a prefabricated gable ladder. The ladder is nailed to the end trussed rafter and cantilevers over the gable end masonry. Similar techniques can be used for traditional roofs. When the ladder is in position the roof is finished by returning the fascia and soffit board along the projecting verge. This feature protects the brickwork below, but has cost implications.



Gable ladder provides overhang at verge. A good overhang will protect the brickwork below.

Prefabricated ladder is fixed to end trussed rafter.

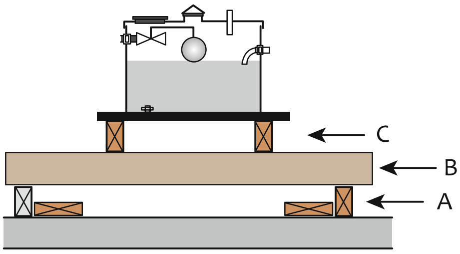
A fascia board is normally fixed to the feet of the rafters, and a barge board to the outer face of the gable ladder.

A gable ladder provides an overhang at the verge. Although this will require periodic maintenance it does help to keep the wall below dry. Walls that remain saturated for long periods can develop a number of problems, including damp penetration, chemical attack and even wall tie failure.

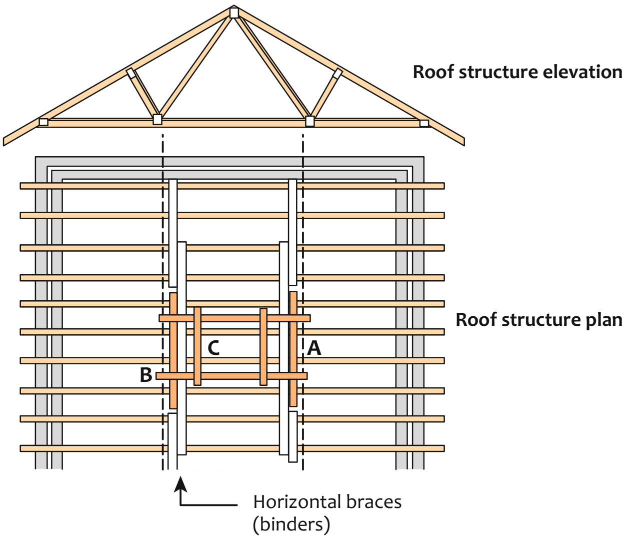
Support for water tanks

Depending on the nature of the water supply and heating system, it may be necessary to provide water tanks in the roof space. These can be very heavy, and to avoid over-stressing the trussed rafters there are a number of recommendations for their support. The specific details will depend on the size of the tanks and the spacing of the trussed rafters. Typical arrangements are shown opposite.

The exact details will depend on the size of the tanks. Small tanks can be supported on three trusses - larger tanks on four.



Typical bearer size
A & C – 50 x 75mm bearers
B – 50 x 125mm bearers



Other roof shapes

Although trussed rafters are best suited to simple double-pitched roofs they can be adapted for a wide range of roof shapes. Detailed information can be obtained from the various manufacturers who produce excellent trade information illustrating the versatility of their products. Some trussed rafters are designed to allow accommodation in the roof. These are usually referred to as attic trusses. Unlike Fink trusses they often require support from internal loadbearing walls.

An attic truss.

Recent developments

Recently, whole roof structure systems have become available. These are mainly intended for use where the roof void is used extensively for habitable space. These 'roof cassettes' are similar to typical timber-frame wall panels but are designed to be inclined and supported by prefabricated timber floor and gable or party wall structures. Unlike timber frames, the panels are 'closed' – i.e. prefabricated with insulation, a vapour control layer, roof window openings, felt and battens ready for tiling and counter-battened ready to form an internal service void. They are delivered to site ready for site erection by crane.

Roof cassettes are a form of 'stress skin panel', where the principal structure consists of a series of prefabricated engineered timber I-beams spaced at 600mm centres. These are braced and fixed together by gluing and fixing a sheathing board (9mm oriented strand board is common) to either side of the I-beams. This creates a very strong and rigid composite panel. The depth of the I-beams is determined by the span and loading required, but it also relates to the required depth and type of insulation. Very low U-values (<0.15Wm²/K) can be achieved and the built-in service void is intended to ensure that the integrated vapour control layer remains uncompromised during service installations.

A new pitched roof structure. Rather than using solid sections of timber the designers have used metal web timber technology. These are very similar in nature to the metal web joists increasingly being used in upper floors. Their use in the roof structure precludes the need for purlins or for complex attic trusses. In addition, the roof can be insulated cost effectively at rafter level.

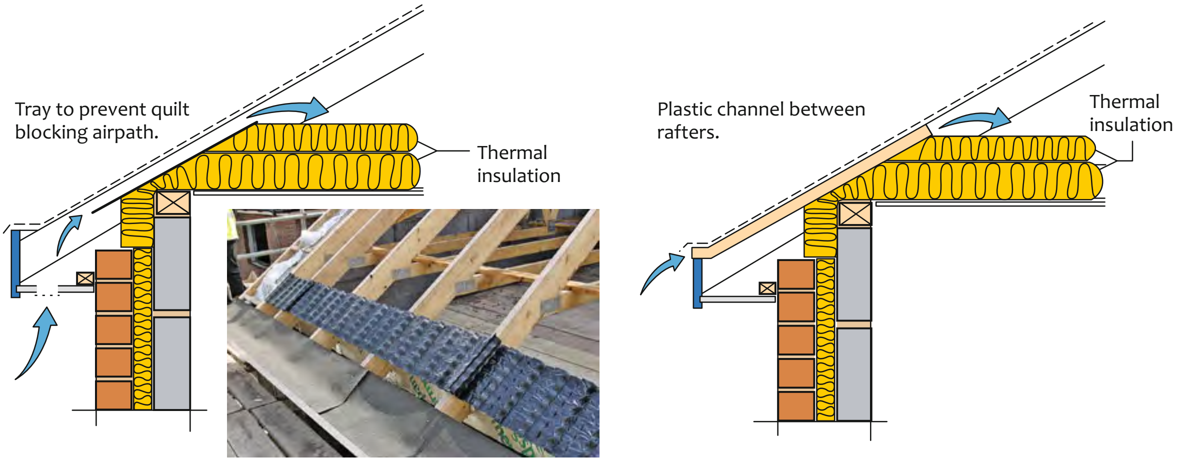
Section Three: condensation

Thermal insulation is normally provided just above ceiling level in order to retain the heat in the rooms below. The roof space is therefore relatively cold and if warm, moist air collects in the roof space it is very likely to condense on the cold timbers and roofing felt. If this potential problem is not addressed, the regular wetting of timbers can lead to rot. In addition, ferrous nails and the nail plates can corrode. The Building Regulations Part C 'Site preparation and resistance to contaminants and moisture' requires that the roof is designed, constructed and insulated in such a manner as to prevent the build-up of condensation and the growth of mould. Condensation can be prevented by the use of roof ventilation to remove the warm moist air and also by providing a vapour check immediately below the insulation. With ever-increasing levels of insulation, condensation has become a major cause of roof failure and is particularly common in older buildings where insulation is installed without the provision of suitable ventilation or a vapour control layer. Chapter 16 explains the phenomenon of condensation in more detail.

For normal double-pitched roofs (traditional and modern), there should be ventilation openings at eaves level to produce cross-ventilation. The most common means of providing this ventilation is by the use of specially manufactured soffit boards, plastic ventilating strips or by leaving a gap between the soffit and the wall. Some tile manufacturers also produce plastic vents which fit under the bottom course of tiles. The Building Regulations Approved Document C refers to a British Standard for the design of ventilation to roof spaces to prevent condensation. This recommends that roofs with a pitch of 15° or less have an eaves ventilation gap equivalent to 25mm. For other pitched roofs with the following:

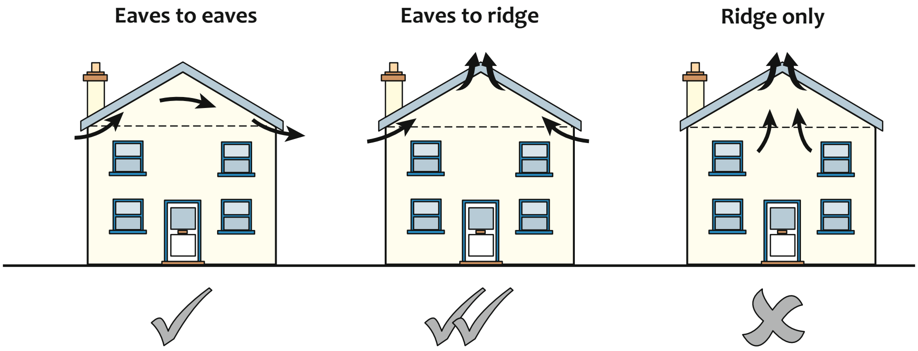
- *a pitch greater than 15°*
- *a span greater than 10m, or*
- *if the roof is of lean-to or mono-pitched construction*

it recommends a minimum eaves ventilation gap of 25mm, a clear ventilated space of 50mm between any insulation and the roof felt, and a high-level ventilation gap to be provided at the ridge or abutment level, equivalent to a 5mm gap.



Ventilation can be provided through the soffit board or by plastic channels which fit between the rafters.
If the former are used it is wise to include a metal section tray to prevent the insulation from blocking the flow of air.

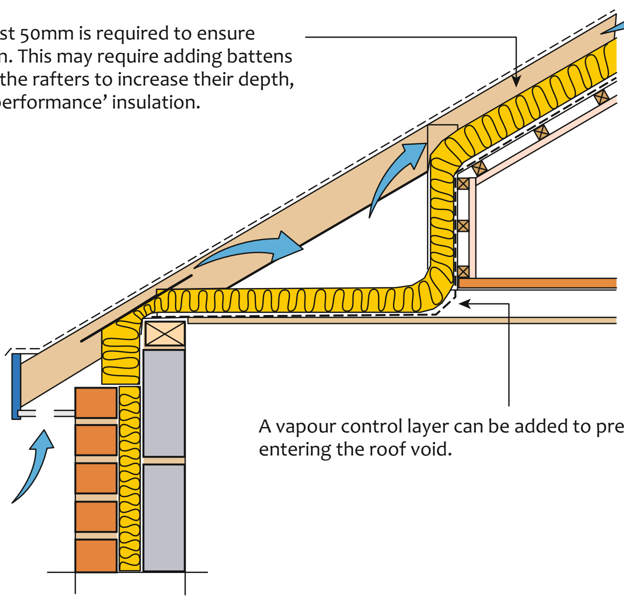
Eaves-to-eaves ventilation is one approach commonly adopted, although it is not always completely effective. Ventilation only occurs when the wind is blowing and there is a risk of stagnant warm moist air being retained in the upper part of the pitch where, evidence suggests, most of the condensation occurs. A better form of ventilation is to use eaves-to-ridge ventilation, as shown below. This has the advantage of ventilating the whole of the roof void and also functions when there is no wind, due to the natural convection currents which occur in the roof space.



On no account should ridge ventilation alone be used. As the wind blows over the roof it creates a vacuum in the roof space which will suck air from the rooms below, increasing the transfer of moisture vapour from the building into the roof space.

Ventilation can be provided through the soffit board or through plastic trays which sit above the fascia and between the rafters. In the former, it is wise to include special section trays to prevent the roof insulation from obstructing the flow of air. The examples below show the implications for ventilation.

If there are rooms in the roof space, the provision of ventilation is more complicated, as part of the insulation will follow the line of the rafters. To ensure a flow of air in this situation there should be a gap of at least 50mm between the top of the insulation and the roofing felt and high-level or ridge ventilation equal to a 5mm gap. Failure to provide this may result in condensation on the roofing felt, wet insulation, stained ceilings and potential problems of rot. This is a common cause of failure, particularly in existing roofs which are subsequently converted into rooms.



A clear gap of at least 50mm is required to ensure adequate ventilation. This may require adding battens to the underside of the rafters to increase their depth, or the use of 'high performance' insulation.

If the plasterboard is supported by battens a void is created which can contain the services. This precludes the need to puncture the vapour control layer.

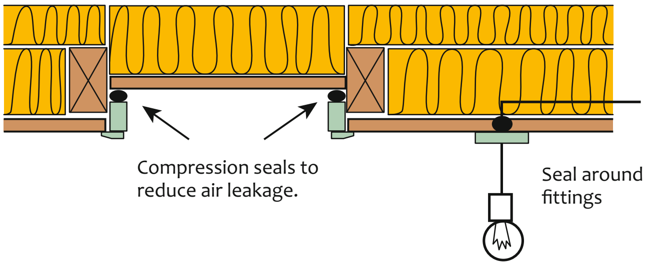
A vapour control layer can be added to prevent moist air entering the roof void.

Vapour control

The use of a vapour control layer at ceiling level will help to reduce the amount of water vapour that finds its way into the roof space. These can be in the form of polythene laid under the insulation or foil-backed plasterboard. However, due to the joints in the vapour control layer and holes cut for loft hatches and ceiling lights, they should not be regarded as completely reliable and should be used in addition to ventilation, not in place of it.

In addition to providing a vapour control layer, attention to detailing is important in order to reduce the amount of water vapour entering the roof from the rooms below. The diagram below indicates typical vulnerable points, which could be made less so by the use of seals.

Cables should be laid above the insulation to prevent them overheating. Alternatively, increase cable size.

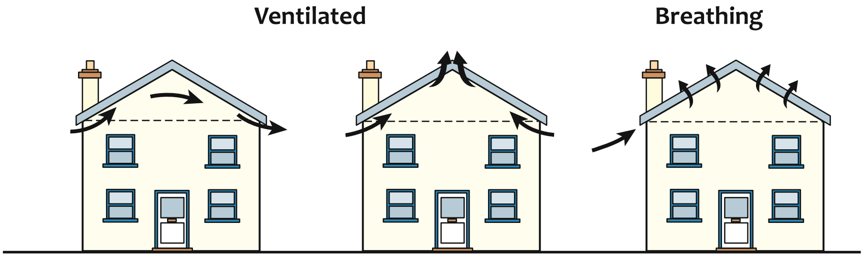


Compression seals to reduce air leakage.

Seal around light fittings

Breathing roofs

The majority of new houses in the UK are built with ventilated roof spaces. However, in recent years another method of controlling condensation has been introduced. This is known as a 'breathing roof'. Its title is slightly misleading because the roof does not actively breathe, instead it allows vapour to escape from it via a vapour permeable underlay. Although some insulation manufacturers recommend breathing roofs, some tile manufacturers prefer ventilated roofs.



The features of a cold breathing roof are:

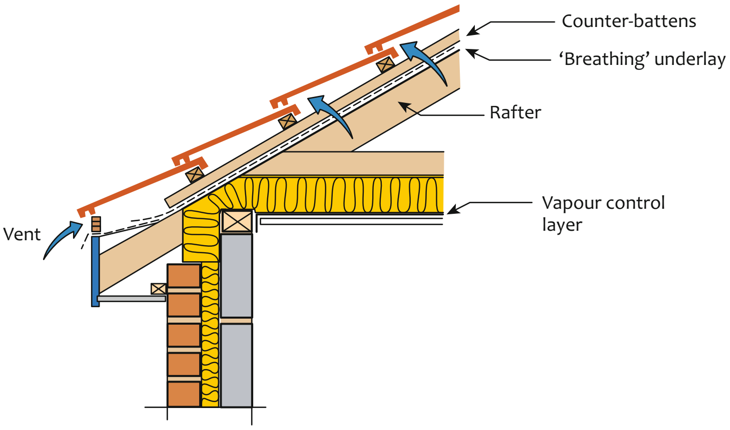
- *a vapour control layer at ceiling level to limit the amount of water vapour entering the loft*
- *a breather membrane as the roof underlay, to allow dissipation of water vapour from the loft space and, just as importantly, to act as a windproof layer*
- *10–25mm deep counter-battens to provide an air space above the breather membrane for improved ventilation (i.e. to aid dissipation of moisture vapour)*
- *ceiling level insulation that is pushed up tight against the breather membrane to prevent air leakage into the loft at eaves level.*

A breathing roof provides a loft space which is clean and relatively dry. Additionally, the avoidance of draughts improves the energy efficiency of mineral wool insulation.

However, when considering breathing roofs the following should be taken into account:

- *they should only be used in dwellings with a simple rectangular plan: complex plans hinder the degree of ventilation*
- *achieving a convection-tight ceiling is quite difficult in practice*
- *close-fitting tiles will require tile ventilators*
- *the underlay should have taped joints*
- *a breathing roof should never be used without first carrying out a condensation risk analysis*
- *capital costs are higher than for ventilated roofs.*

The drawing below shows typical construction for a cold breathing roof – in other words the insulation is at ceiling-joist level.

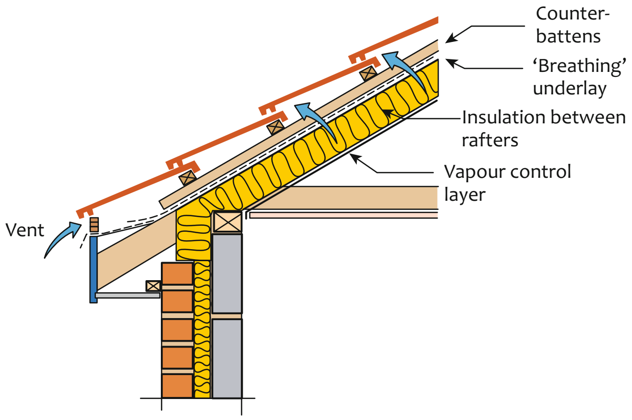


In a cold 'breathing' roof a vapour control layer helps prevent warm moist air from within the building entering the roof void. A 'breathing' underlay allows any vapour in the roof void to escape and the counter-battens provide a ventilation space.

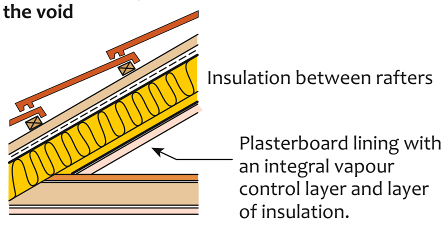
A roof in the process of battening and counter-battening.

The construction is slightly different for rooms in the roof. In a 'true' warm, breathing roof, the insulation would be on top of the rafters. However, in practice, the required thickness of insulation would make the construction impractical. You are more likely to find the insulation in between the rafters or, if they are not very deep, in between and below the rafters. A vapour control layer is required on the warm side of the insulation. If the roof space is to be used for accommodation rather than storage, it would be normal practice to use the construction shown on the right.

Standard warm breathing roof



Warm breathing roof with accommodation within the void



This is a modern breathing roof – with rooms in the roof for accommodation. It is similar to the construction shown in the figures above.

Roof coverings 8

Introduction

Today many types of tiles, slates and other materials are available to cover pitched roofs. For specific technical information, reference should be made to the manufacturers' detailed trade literature which shows how their products should be used.

Section One of this chapter describes the range of materials that have been used for covering pitched roofs over the past 300 years or so. Section Two considers the principles of laying slates and tiles. Section Three reviews construction details and Section Four details coverings for flat and shallow pitched roofs.

Flat roofs are rarely used in modern houses – especially in the case of volume housebuilding – and, therefore, we have omitted a detailed discussion of this type of roof and its coverings. However, Section Three briefly discusses the materials which might be found on flat roofs and relatively shallow pitched roofs. Essentially, these are what are referred to as sheet materials.

Section One: materials

Thatch

Although clay roof tiles were used by the Romans between AD 43 and AD 410, for the next 1,000 years or so thatch was the most common roofing material. However, as towns grew in the late medieval period its use declined because of the ever-present risk of fire. As early as 1212 (after fire had destroyed the timber-built London Bridge), King John decreed that all shops on the Thames should have their thatched roofs 'plastered over'. During the following centuries thatching disappeared in towns although it was still common in rural areas. Better quality houses were thatched in reeds, straw or rye; the houses of the peasants were usually covered in much more basic materials, which included heather and earth.

Thatched roofs should have at least a 50° pitch to aid water run-off and need a substantial overhang at the eaves to throw the water clear of the walls.

Thatched roofs are still a common feature of some rural counties, such as Devon and Suffolk. However, thatch is not a particularly durable material and requires frequent renewal (e.g. wheat straw every 15–40 years, water reed every 50–80 years). It is subject to fungal attack, can harbour vermin and there is always the risk of fire. It is also very expensive to install.

Natural slates

Slate has been used for hundreds of years as a roof covering, although its early use was mostly confined to those areas where it occurred naturally, such as Wales, Cornwall, Cumbria, parts of Yorkshire and Scotland. However, in the early nineteenth century, with improvements in transport, it became the most popular roof covering in Great Britain, and it was not until the end of the century that the development of improved manufacturing techniques for clay tiles steadily eroded slate's popularity.

Slate is a rock that was laid down in a series of thin beds. Large blocks of slate, which is a dense and very fine-grained material, are mined or quarried and then split by hand or machine to form sheets of the correct thickness. The blocks are easy to split due to the laminations which run along the lines of the original naturally-occurring beds.

Slate is virtually impermeable and is highly resistant to chemical attack. The best quality slate can last for hundreds of years. In many cases longevity of a slate roof is determined not by the material itself, but by the nails and battens which hold the slates in position. Slate is available in a range of sizes and thicknesses and is instantly recognisable by its dark grey/blue or grey/green colour. Nowadays, slate is quarried in Cornwall and Cumbria as well as North Wales and cheaper slates are also imported from Brazil, China, Spain and other countries.

The performance of slate depends on its thickness as well as the quarry from which it was produced. Its durability also depends on the slate's resistance to acid attack. Carbonates present in the slate react with the acid present in rain to form calcium sulfate, the crystals of which force the thin laminations of the slate apart. Damage often starts underneath the slate, where moisture has been drawn by capillary action and, therefore, the signs of decay are easy to miss during a building inspection.

A slate roof being laid – note how the slate is being centre nailed. Slate is normally fixed by nailing. The nail holes can be pre-drilled at the quarry or formed on site using a special hammer called a zax.

The laminated structure of slate can clearly be seen in the photograph above.

Synthetic slates

Synthetic slates were introduced to Britain in the early part of the twentieth century. They were originally made from a mixture of asbestos and cement and these slates became popular in the 1930s. They can still be seen on some domestic buildings. However, in recent years the use of asbestos fibres has stopped for health and safety reasons and in modern versions of these slates the asbestos has been replaced by synthetic fibres. The slates are less durable than their natural counterparts, but they are significantly cheaper and lighter.

The bungalow in the left-hand photograph was constructed in the 1930s and the roof was covered with diamond pattern asbestos slates. The right-hand photograph shows a roof of modern synthetic slates fixed with nails and rivets. The slates are performing properly, the gutter is not. Note the slate-and-a-half slates above the verge.

Stone slates

In a number of rural counties in Great Britain, the traditional roof covering was formed from slabs of sandstone or limestone. These slabs are usually referred to as stone slates and they occur in a wide range of colours depending on the locality – Cotswold stone, for example, is a very pale yellow which, over the years, weathers to a pale brown. In traditional construction, stone slates were often laid in diminishing courses, i.e. with large slates at the eaves and progressively smaller slates towards the ridge (natural slate can be laid in the same way). This, together with the use of random slate widths, gave the roofs an unmistakable character.

Unlike natural slate, the stone slates are not impermeable to water and, as a result, when wet they become heavier. To guarantee total weather protection, it was common to use thick slates laid to a steep pitch in order to encourage efficient rainwater run-off.

Stone slates can be found in many rural areas. For example, limestone slates, such as those above left, are found in the Cotswolds, while the sandstone slates on the right can be seen in parts of South Wales. Note the considerable thickness of each slate and the diminishing size as the coursing increases in height.

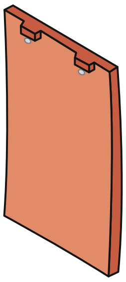
The roof structure had to be very strong to support this thick, heavy covering, and this is one reason why it is rare to find natural stone slates used in modern construction. However, a number of manufacturers currently produce imitation stone slates which are usually made from pigmented concrete and which are light enough for use on modern trussed rafters.

Plain tiles

This clay plain tiled roof is of some age. Generally, the tiles are still performing adequately but a number have slipped.

Handmade plain clay tiles have been used in Britain since the Middle Ages, but they lost popularity as the use of slating spread during the early nineteenth century. However, new industrial techniques, developed at the end of the century, enabled the production of machine-made tiles. As a result, their use became widespread for the large estates built in-between the World Wars, not only as a roof covering, but also as a vertical cladding to walls. Plain tiles vary in colour from red to deep purple and are immediately recognisable due to their small size. Unlike slates, tiles have small projections called 'nibs' which enable them to hang from the tiling battens.

Several firms still manufacture clay plain tiles, but they are an expensive form of roof covering in terms of both labour and materials. Nevertheless, they can still be found in more expensive properties, where they provide a durable finish capable of lasting at least 100 years. For the past 50 years or so, plain tiles have also been made out of concrete.



A clay, plain tile with two nibs. The slight curve, or camber, prevents capillary action (see beginning of Section Two). Hand made tiles were sometimes cambered across, as well as along, the tile. For the past 50 years or so, these tiles have also been made in concrete. These are old clay tiles and several are damaged.

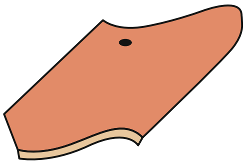
The manufacturers of plain and other tiles (both concrete and clay) produce a number of ornamental tiles and other decorative features, such as this finial forming the top of a hip.

At the end of the nineteenth century, there was a huge increase in the production of clay tiles. Some early tiles contained impurities which led to defects. Modern manufacturing quality control should avoid these problems.

Pantiles

Clay pantiles were originally imported from Holland and were not produced in this country until the eighteenth century. They are single-lap tiles (see later section), usually bright orange or red, with a pronounced curve similar to a horizontal 'S'. The early handmade examples were sometimes irregular in shape and could not prevent rain or snow from being blown into the roof space through the small gaps between adjoining tiles. Prior to the widespread use of underlay, it was common practice to fill these gaps from inside the roof with a mixture of mortar and horse hair, a process known as torching.

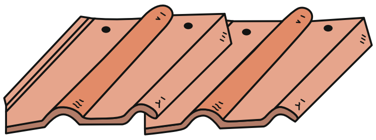
The use of clay pantiles offered substantial savings over both plain clay tiles and slates in terms of labour and materials. However, in modern construction they have largely been superseded by concrete tiles of similar design, but manufactured as double rather than single pantiles.



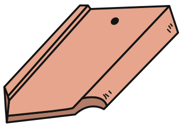
The diagram shows a typical single clay pantile. However, modern through coloured interlocking concrete double pantiles (as shown in the photograph) have become very popular because of their appearance, ease of installation and quality of performance.

'Roman' tiles

Towards the end of the nineteenth century, improved manufacturing techniques enabled the production of imitation Roman clay tiles – reflecting rather than copying tiles used in ancient Rome. These were much cheaper than slates or plain tiles, and more effective than pantiles. They were initially produced in Bridgwater and quickly became popular throughout large areas of Great Britain. There are two common patterns, single Roman and double Roman, the latter being the more popular. From the latter part of the nineteenth century until the Second World War, they were used extensively. However, like the clay pantile, they have now been superseded by concrete tiles of similar design.



Clay double Roman tiles



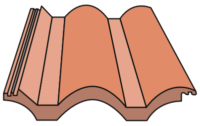
Clay single Roman tile

On the left are clay single Roman tiles, whilst those on the right are clay double Roman tiles.

Interlocking tiles

Traditional pantiles and Roman tiles prevented rain from penetrating the roof due to their side lap. Improved protection is provided by making these side edges interlock. Vast numbers of clay interlocking tiles were imported during the 1920s and 1930s and several patterns were also made in the UK.

Since the 1950s, the vast majority of roofs have been covered using interlocking concrete tiles and these probably account for over 80 per cent of modern roofing tile production. Over the past 30 years or so, there have been great strides in the development of concrete tiles and they are now available in a vast range of colours and shapes. Modern interlocking concrete tiles are usually through-coloured. These have replaced the granular-faced tiles which were common in the 1950s and 1960s as they are less likely to fade and are less prone to moss formation.



Modern interlocking tiles are available in a variety of profiles. Some are flat – they look like slate, but are still interlocking tiles.

In the 1980s, some manufacturers introduced artificial interlocking tiles that mimic slates. These are made out of a mixture of resins and crushed natural slate. They closely resemble their natural slate counterparts in appearance and are called slates but are, in fact, interlocking tiles and, as such, are laid with a single lap (described later). Artificial slates are also made from concrete that is cast in special moulds to give them the appearance of natural slate. These are stronger than fibre cement slates (and much heavier) and are usually head nailed.

Fascia and soffit boards

The fascia board protects the feet of the rafters, supports the bottom course of tiles and provides a fixing for the guttering. It is normally made from softwood or plywood, although uPVC is becoming increasingly common. It can be supplied with a shallow groove on the inside face which supports the outer edge of the soffit board.

Soffit boards, which are fixed between the back of the fascia and the face of the adjoining wall, can be made from softwood, plywood, inert building board or uPVC. They can be supported by a timber framework fixed to the bottom of the rafters (shown in Chapter 7), or by a timber batten fixed to the brickwork. To achieve the necessary flow of air through the roof space, the soffit (or the fascia) should be provided with ventilation holes.

Fuller details on fascias and soffits are contained in Chapter 7.

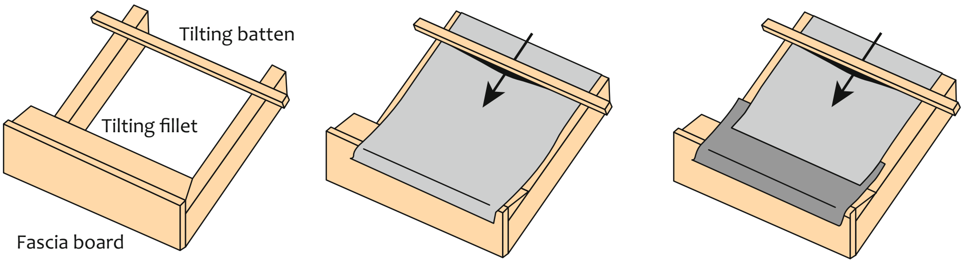
The grey fascia board and the white soffit board can be clearly seen in the photograph. Note how far the tile overhangs the fascia to discharge into the gutter.

Roofing underlays and battens

If laid at the recommended lap and pitch, the roof covering should cope with the heaviest downpours. However, most slates and tiles have small gaps between the individual units and, in certain wind conditions, fine rain and powdery snow can be blown into the roof space. Traditionally, this was prevented by either timber boarding of the roof (rare except for the most expensive houses) or by torching. Torching is a mixture of mortar and hair which is trowelled into the gaps between the tiles or slates from inside the roof. In the 1930s, it was generally replaced with roofing underlay (also known as underfelt or sarking felt).

Torching retained moisture, thus encouraging rot attack in the battens. In addition, it was easily dislodged in the event of even slight structural movement of the roof timbers.

The primary function of roofing underlay (when it was first introduced) was to reduce the flow of air through the roof, thus preventing the ingress of wind-blown snow or rain. In addition, the reduced flow of air improved the roof's insulation (this latter function is less relevant today due to the use of insulation materials at ceiling or roof level). If any rain or snow does penetrate the slates or tiles, it must be free to escape and it is therefore important that the felt is correctly laid to enable the water to run down the roof slope and into the gutter.



The fascia board projects above the rafters slightly to keep the bottom row of tiles at the right level. To prevent the underlay ponding behind the fascia, it should be supported by a tilting fillet. The felt should sag slightly between rafters to allow water to run down to the gutter.

Some roofing underlays are vulnerable where they project beyond the roof. A better detail is shown above. Here a dense polythene strip or eaves carries forms a more durable detail.

Two examples of reinforced bitumen felt. On the left, a felted and battened roof is ready for slating. On the right, a felted and battened roof is ready for interlocking tiles to be laid. The felt has been lifted back to reveal the tilting fillet at the eaves.

The photographs show a microporous underlay secured with counter-battens laid over each rafter. The counter-battens support the battens and permit airflow beneath the slates or tiles as well as drainage of any moisture beneath the roof cover.

There are three common materials used nowadays for underlays. For the past 80 years, reinforced bitumen felt has been used. This comprises a layer of jute, hessian or other fibres embedded in bitumen. It is long-lasting, but tears quite easily. Modern alternatives include polythene underlays and also vapour permeable underlays (VPU). The latter, of which there are air permeable variants, are also known as microporous underlays and are becoming increasingly popular. They are made from a variety of synthetic materials which contain microscopic holes. Moisture on top of the underlay cannot penetrate the holes due to the surface tension of the materials used, but water vapour within the roof can escape through them, thus helping to reduce the risk of condensation. For more information, see Section Three of Chapter 7.

Microporous underlays (breather membranes) are very popular. In the left-hand photograph a breather membrane has been secured with counter-battens, while the right-hand photograph shows a further stage of the roofing process – stone slates have been fixed to battens over the counter-battens with breather membrane beneath.

Rolls of roofing underlay are usually 1–1.5m wide and can vary in length from 10m to 50m. Laying the underlay is a straightforward operation, although care is needed as most underlays can easily be punctured. The underlay is laid horizontally across the roof, starting from the eaves, and should be lapped about 150mm both vertically and horizontally. It should sag slightly between the rafters to ensure that any water finding its way through the tiles can drain down the felt to the gutter. If this cannot be achieved, counter-battens should be installed under the battens to ensure that water that gets behind the slates or tiles can flow down to the eaves.

Underlays should not be exposed externally as they become brittle with age due to exposure to ultraviolet light and they can be damaged by birds. It is good practice to specify a layer of UV durable eaves carrier where the underlay runs over the eaves and into a gutter (see drawing on previous page).

The underlay is held in position by the tile battens. These are long strips of softwood which span from rafter to rafter and to which the tiles or slates are fixed. The battens should be treated against rot and insect attack and many suppliers will guarantee them against such problems for 60 years when treated and fixed in accordance with their recommendations. Battens are required to be either 25 x 38mm or 25 x 50mm, depending on the tile design, although smaller battens were allowed until quite recently. When used with traditional roofs, where the rafters are likely to be at 400mm centres, they are usually 25 x 38mm. They should be slightly thicker, say 25 x 50mm, if used with trussed rafters as these are more likely to be at 600mm centres. The battens should be fixed with galvanised or sheradised nails and end joints must be positioned over rafters. In addition, end joints over rafters should be staggered, so that not more than 1 in 4 battens is joined on any one timber. The spacing of the battens will obviously depend on the size and characteristics of the tiles or slates being used.

Summary

The table overleaf shows a brief summary of the most common forms of tiling and slating.

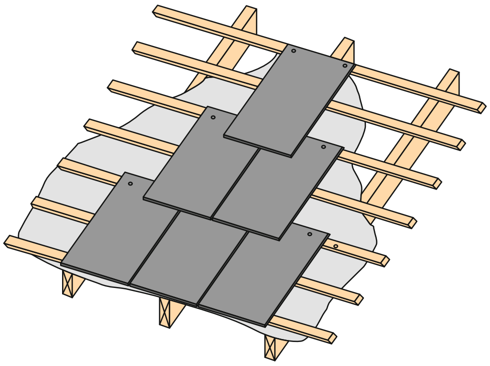
NAME, SIZE AND WEIGHT	MIN. PITCH (°)	FIXING	DURABILITY	GENERAL COMMENTS
Plain tiles 265 x 165mm 70–90kg/m²	35–40	Usually nailed at perimeter and every fifth tile – on steep pitches every course. Minimum lap 65mm.	Clay tiles vary depending on composition, at least 50+ years. Concrete tiles probably 75+ years.	Originally made from clay. Concrete plain tiles available from 1940s. Later concrete tiles are through-coloured rather than granular-faced. Several decorative tiles available.
Double Roman tiles, pantiles (clay) Typically 400 x 300mm 35–50kg/m²	35	Some double Romans have nail holes, others do not. Pantiles now becoming more common; they can be single nailed or clipped.	Many late-Victorian roofs still have the original clay tiles. Early concrete tiles 50–75 years, more recent tiles 75+ years.	A number of companies still produce interlocking (strictly speaking overlapping) single tiles. Most are now double tiles. Some tiles are also available with a glazed finish.
Interlocking tiles (concrete) Various profiles 410 x 300mm 40–45kg/m²	As low as 15	Perimeter only is usually fixed. On steep pitches, every tile should be twice nailed. Some tiles can be clipped.	Granular-faced concrete tiles have been used for 50+ years. Through-coloured tiles should last 75+ years.	Many different patterns available. Huge range of colours. Some tiles can have a weathered finish to make them look more 'natural'.
Natural slates 600 x 300mm and smaller sizes 50–100kg/m² depending on thickness and size	30	Every slate fixed with two nails (non-ferrous). Modern slates are centre nailed. Lap varies with slate size and pitch – minimum 50–65mm. Slate hooks can be used.	Good quality slate can last 200+ years. Life depends mostly on thickness.	Traditionally laid in diminishing courses using slates of random width. Nowadays laid to even courses. Most modern slates are imported, but there are still a few working quarries in the UK.
Stone slates Size varies 60–120kg/m²	40	Traditionally fixed with wooden pegs or brass screws.	Depends on nature of sandstone or limestone. Several examples of 200+ years.	Virtually impossible to find new stone slates although there is a thriving second-hand market. Concrete imitation slates, cast in stone slate moulds, provide reasonably accurate copies.
Synthetic slates (various cements) 600 x 300mm or 500 x 25mm (and others) 20–25kg/m²	30	Two nail holes per slate. Usually centre nailed.	Early asbestos cement slates, from about the 1930s, still in place although brittle. Probably about 40 years for modern synthetic slates.	Originally made from asbestos cement, but now made from fibre cement and finished with a coloured acrylic resin.

Section Two: the principles of laying slates and tiles

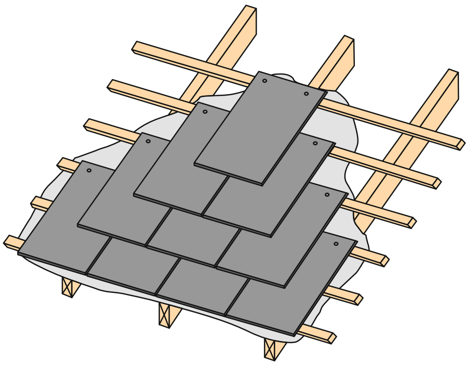
Fixing slates

Slate is sometimes referred to as a double lap covering and, although this is quite a simple principle, it can cause some confusion. If the slates are laid single lap, they would appear as in the left-hand diagram below. It should be clear that, as the water runs off the top slate into the gap between the two slates below, water will be free to drop into the roof space (or onto the felt below).

To prevent water entering the roof though the slates, there must always be two layers of slate at any given point on the roof and three layers at the laps. As the water runs off the top slate, some of it may pass through the gap in the slates below, but there is another slate below this so that the water can run safely off the roof.

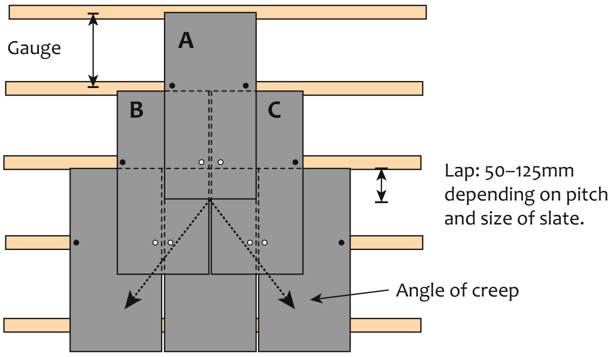


Water running off the top slate can run into the gap between the two slates below.



The problem is resolved by laying the slates with a double lap. The top slate, therefore, laps two in the course below and one in the course below this.

In practice, the situation is made slightly more complicated by capillary action. While it is generally true that water tends to run downhill by the most direct path, capillary action, which can occur in between the slates, causes the water to 'creep' sideways. Slates fit very closely on top of one another, leaving very fine gaps which cause any water to creep in a fanwise direction due to surface tension between the slate and the water (i.e. capillary action).

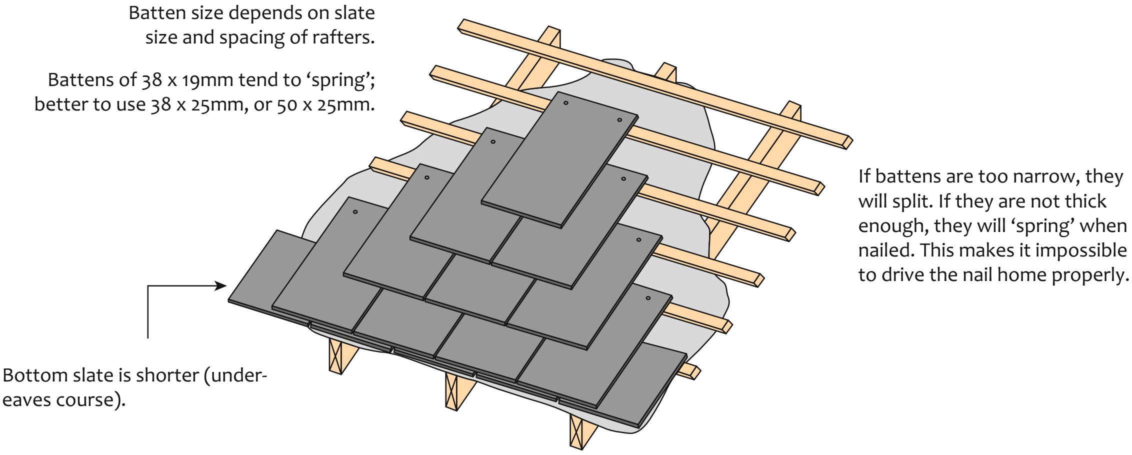


The slates are laid as shown in the photograph above and the movement of moisture is shown by the dotted lines in the diagram above. Any water running off slate A and into the gap between slates B and C will spread under these two slates; the angle of creep depends on the pitch of the roof. If the angle of creep is very wide, as might occur on a very shallow pitched roof, the water can penetrate the roof space via the nail holes. If the angle of creep is wider still, it can penetrate the roof space via the joints in the slate. Similar problems can occur if the slates are very narrow, or if the head-lap is insufficient. It is for this reason that shallow pitched roofs require fairly large slates, say 600 x 300mm, with a head-lap of 90mm. A very steeply pitched roof, say 45°, has a reduced angle of creep and can safely be constructed with 300 x 150mm slates with a head-lap of 65mm. These are very general rules and, in practice, it is always wise to follow the manufacturer's recommendations.

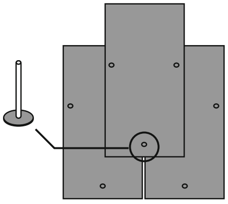
The diagram above also shows centre-nailed slates, which is the normal method of fixing. The holes can be drilled at the quarry, but are often formed on site using a special hammer known as a zax (see photograph right). Although galvanised steel nails can be used to fix the slates, their use is not recommended. As the nail is driven through the hole, some of the galvanising (which is quite soft) can be scraped off, leaving the nail free to rust. It is better practice to use non-ferrous nails, such as aluminium or copper, for fixing slates. The holes should always be made from the underside as this creates a countersunk hole on the topside. The slate can then be turned over and secured, with the nail head lying in the countersunk hole on the top surface.

Note: The zax has a pointed end for forming the hole and a hammer end for fixing the nail.

Head-nailed slating, which is an alternative method of fixing, is shown in the diagram below. Although this method ensures that the nails are protected by two layers of slate, there is a danger that in high winds the bottom ends of the slates can lift. This is particularly likely on roofs of a low pitch or where large slates are used.



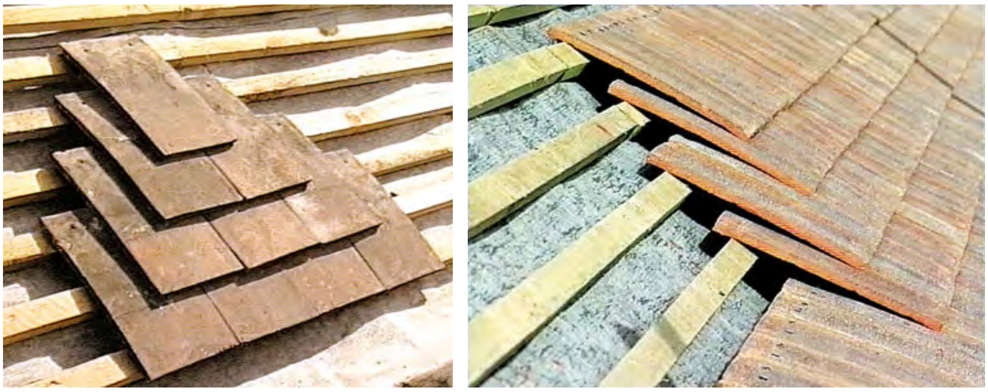
Synthetic slates are generally lighter than natural slates. The most common size is 600 x 300mm, with a thickness of about 4mm. Earlier versions of such slates were fixed in the same way as centre-nailed natural slate, although for all modern synthetic slates an additional fixing is required at the tail or bottom of the slate to prevent lifting in high winds. This is achieved by the use of a small copper disc rivet as shown in the photograph and diagram on the next page. Modern interlocking synthetic slates are top fixed in a similar fashion to a tile; they also have nibs (like a tile) for hanging on the batten.



Synthetic slates are always laid double lap because they do not have a side interlock. They can be secured with galvanised nails, but copper nails are better. The holes are preformed and are positioned for centre nailing. These slates are not strong enough for head nailing. The head of the disc rivet (which holds down the tail) is secured in position by sliding it under the joint in the slates below.

Fixing plain tiles

Plain tiles, like slates, are double-lap coverings. The major difference is that plain tiles are slightly cambered, and thus there is less chance of capillary action. This means that plain tiles can be quite small and their size has remained fairly constant for centuries. Standard plain tiles are 265mm long and 165mm wide. In addition, plain tiles, unlike slates, have nibs which enable them to hang from the battens and it is, therefore, unnecessary to nail every tile in position. Nevertheless, most manufacturers recommend nailing every fourth or fifth course of tiles plus all those around the roof perimeter to avoid displacement in high winds. In very exposed situations or on steep pitches, it may be necessary to nail all of the tiles. As with slate, the use of galvanised steel or other ferrous nails should be avoided. To prevent wind from blowing rain up into the roof space, and to ensure that rainwater runs cleanly off the roof, the pitch should be at least 35–40°.

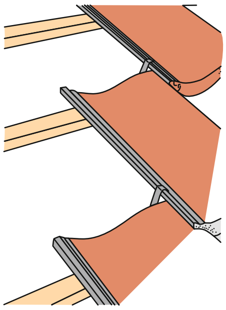


Examples of plain tiling that show the double lap and the head-lap, i.e. the amount by which each tile laps the next but one below, which should be at least 65mm.

Fixing interlocking tiles

All interlocking tiles, whether of clay or concrete, are single lap. This means that there is only one layer of tiles on the roof, apart from the overlaps. The water should not penetrate the side joints due to the side interlock on the tiles. Some modern interlocking tiles can be used on very low pitches, in some cases as low as 15°. As a general rule, the perimeter tiles should be fixed by nailing, or by the use of special clips, and on steep roofs, say over 45°, it may be necessary to clip and nail all the tiles. In practice, some modern tiles have to be fixed by clips as they do not have nail holes (see diagram and photograph overleaf).

Interlocking tiles are laid with a single lap. Such roofs are lighter than those formed with slates or plain tiles and can be laid to shallower pitches. One advantage of single-lap tiles is the savings in battening costs (see previous photograph).



The lap on interlocking tiles is usually about 75mm.

Some modern tiles can be fixed with hidden clips. These are usually made from stainless steel.

Section Three: details

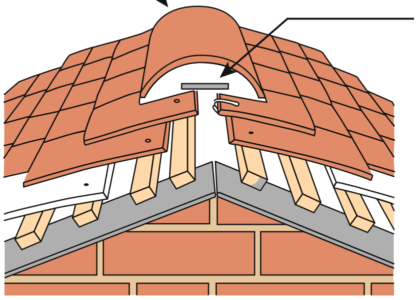
Introduction

The following details show how roofs can be finished at ridges, eaves, verges and hips. The Section also discusses flashings, valley gutters, soil vent pipes and the prevention of fire spread at roof level. There are, in practice, several ways in which these details can be handled and this chapter can show only typical solutions. Plain tiled roofs and slate roofs are discussed initially as their finishing details are often very similar. Roofs formed with other types of tile are reviewed more specifically later, but they can also be finished in a similar manner to plain tiled roofs.

Plain tiles and slates

Ridges

At the top, or ridge, of a roof, the most common method of forming a watertight joint is to use ridge tiles. These are available in a range of designs, but the most common is probably the half-round ridge tile. The ridge tiles are traditionally bedded in mortar, but modern practice is to mechanically fix them as well so that they cannot be dislodged by high winds. Special ridge tiles are available with a loop of galvanised wire cast into the tile, which can be nailed to a short piece of batten fixed at the apex of the roof. With double-lap coverings, such as plain tiles, the ridge tiles must be wide enough to lap two courses of tiling on either side of the apex in order to maintain weather protection.



End ridge tile wired and nailed to short length of batten

Fibre cement board or plain tile undercloak to form support for overhang.

Where ridge tiles join, broken slips of plain tile can be used to support mortar bedding

Top course of tiles can be:
a) 225mm long nailed to batten, or,
b) 190mm long clipped to tile below

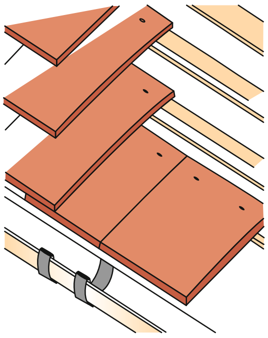
If standard plain tiles are used for top course, a wider ridge tile is required to maintain double lap

Slate roofs can be finished with clay ridge tiles, although a lead roll often formed the traditional finish. The lead ridge is formed by running it over a wooden roll and securing it by the use of small strips of lead known as tingles. The tingles can be nailed to the ridge or hip rafter (as shown in the photograph and diagram in the 'Hip' sub-section that follows) sand then folded over the lead sheet to hold it in place.

Top left photograph shows a plain tiled roof with clay ridge tiles. The slate covered porch on the top right is finished with clay ridge tiles. Each slate roof on the bottom left has been finished with a lead ridge, which has been dressed over a roll, while the bottom right photograph shows a detail of a lead roll – note: it should have a capped end.

Eaves

A smaller plain tile or slate is required to maintain the double lap at the eaves. If a standard tile is used, it would project beyond the edge of the roof. The first two courses of tiles should be nailed to the battens and should overhang the gutter by about 50mm. Slate eaves are formed in a similar way.

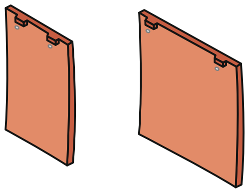


A shorter tile forms the undereaves course and maintains the double lap. The bottom two courses should be nailed.

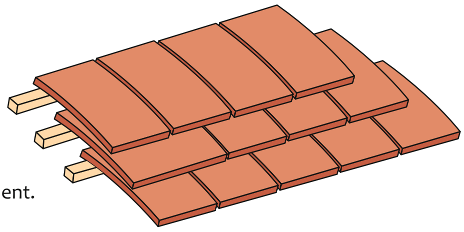
A standard plain tile is 265 x 165mm. The undereaves tile is 215 x 165mm.

Verge

At the verge, it is normal to fill the gaps underneath the tiles with mortar. To permit a slight overhang in order to protect the wall beneath, a row of plain tiles, or a thin piece of external grade composition board, can be positioned on top of the wall, held in place by the battens above. This is known as an under-cloak and not only gives the required projection (usually about 50–75mm), but also lifts the ends of the battens slightly. This lift means that the end tiles drain back onto the roof and reduces the likelihood of rainwater running over the verge and down the gable walls. The end tiles in alternate courses have to be wider than standard plain tiles to give a straight edge at the verge – these wider tiles are called 'tile-and-a-half'. This is shown in the diagram below.



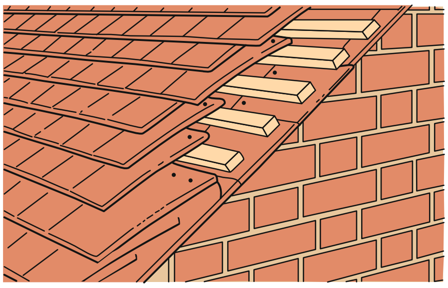
Standard plain tile and a 'tile-and-a-half' tile.



Minimum pitch approx. 35°
Minimum lap usually 65mm.

Tile-and-a-half tile to maintain
straight line at verge or abutment.

Batten size depends on rafter centres. At 400mm centres, battens are typically 38 x 25mm; at 600mm centres, 50 x 32mm. (Some manufacturers may specify slightly different sizes.)



Undercloak formed from plain tiles

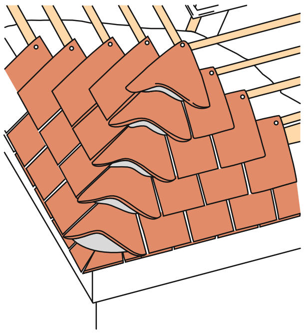
Slate verges can be formed in the same way, although the under-cloak will probably be formed with slates.

Dry verge tiles

These are discussed under Interlocking tiles below.

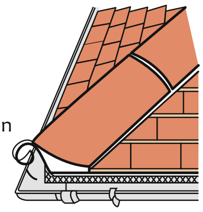
Hips

If the roof has hips, special bonnet hip tiles can be nailed to the hip board and the external gaps filled with mortar. This is considered to be quite an expensive operation. A commonly used and cheaper alternative is to use ordinary ridge tiles bedded in mortar. To prevent the ridge tiles from sliding off the roof, a galvanised hip iron should be fixed to the base of the hip board. Slate hips are normally finished with a lead roll.

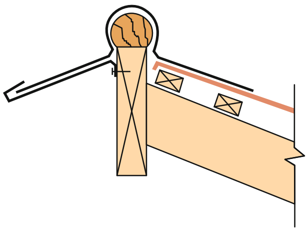


Bonnet hip tiles.

It is good practice to bed a couple of tile slips under the bottom bonnet hip tile to prevent the mortar from sagging. Ridge tiling can also be used on hips. It is a cheaper detail, but much quicker. A hip iron prevents the bottom ridge tile slipping off the roof.



Bonnet hip tiles with a slip tile, but no mortar or hip iron in place beneath the bottom hip tile. On the right, mortar and a hip iron are in place.



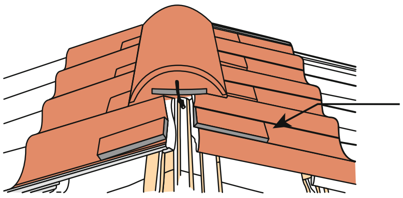
In slated and plain tiled roofs, lead is often used for hips and ridges.

Interlocking tiles

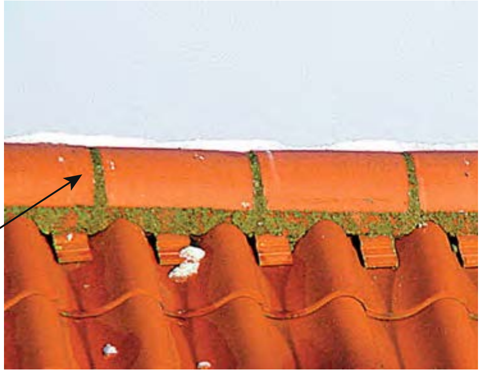
As previously observed, this is by far the most common type of tile used in modern construction and there are a variety of patterns available, although most patterns have similar ridge, verge and eaves details. They are manufactured in clay and concrete and manufacturers can provide further guidance on selection and installation.

Ridges

As with plain tiles, half-round ridge tiles are the most common profile and these are normally bedded in cement mortar (usually 1 part of cement to 3 parts sand), with the end ridge tiles wired in position to prevent displacement in high winds. Recent good practice requires all ridge and hip tiles to be mechanically fixed. Pantiles and some other tiles with a pronounced profile, have fairly bold rolls and it is good practice to place small slips of tile, known as 'dentils', before bedding the ridges to prevent the wet mortar from sagging, as shown in the photograph below.



Where ridge tiles join, a broken piece of tile supports the mortar bedding.

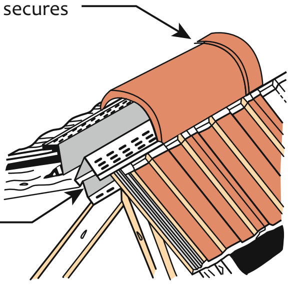


Dentil slips form a neat finish and prevent mortar sagging or cracking.

Special ridge tiles are available for terminating extractor fans, soil vent pipes and flues. There are a number of rules regarding their positioning, related mainly to their function. A gas flue, for example, must not be situated near windows or other vents which might allow exhaust gases back into the building.

Dry ridge systems

The majority of houses have ridge tiles which are bedded in mortar, as shown in an earlier diagram. However, in recent years, the use of mechanically fixed dry ridges has become increasingly popular. There are a variety of systems available, for both plain and interlocking tiles, most of which incorporate uPVC vents to permit 'eaves to ridge' ventilation.



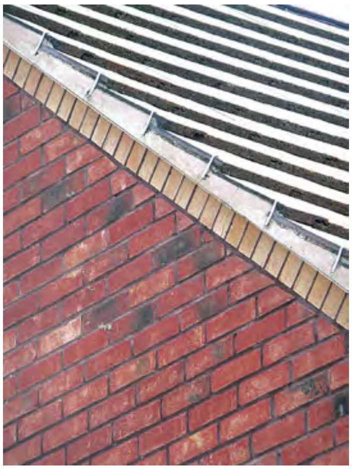
Plastic cover strip secures ridge.

Plastic strip with ventilation grille secured to roof structure.

A dry ridge system (over double Roman clay tiles).

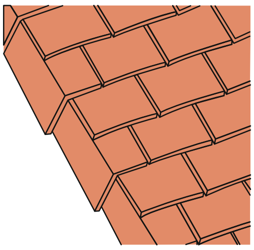
Verges

As with plain tiles, the verge can be pointed. This is the traditional method of construction. An undercloak, usually formed from composition board, provides a small overhang. The under-cloak is secured in position by the tiling battens (photograph below left). The need for verge clips (to resist wind uplift) will depend on pitch and exposure (photograph below right).



Dry verge tiles

The mortar bedding of the verge is often one of the first parts of a roof to deteriorate. To avoid this problem, some manufacturers produce special verge tiles which can be used with tiles and synthetic slates, as illustrated in the diagram below. These are known as dry verge tiles. They are nailed in position and are a faster form of construction than the traditional method. They should also be more durable.



Dry verge tiles save the need for pointing and may, in the long term, prove to be a durable finish. However, many developers fix a barge board beneath the tiles. This will need regular maintenance and seems counter productive.

Dry verge tiles preclude the need for pointing, but they are sometimes fixed with a barge board underneath and this will still require periodic maintenance (see bottom left-hand photograph on previous page). Some tile manufacturers also produce PVC filler pieces which clip on to the ends of standard tiles (see bottom right-hand photograph on previous page), thereby avoiding the need for pointing.

Flashings

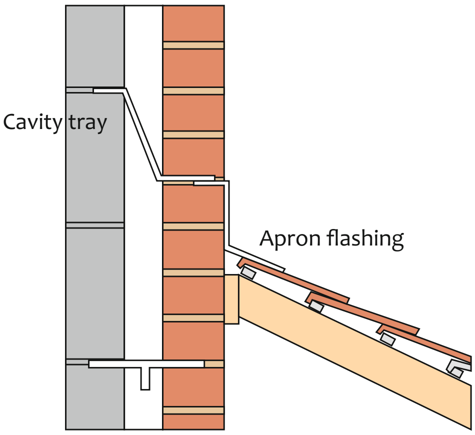
Lead flashings

Where the roof covering (single lap and double lap) abuts vertical brickwork, blockwork or stonework, some form of flashing is required to prevent ingress of water. Lead, zinc, copper and even mortar have been used for flashings, but in modern construction lead sheet is the most common material. Lead sheet is very durable and versatile, easy to cut and can be worked with simple hand tools. However, lead work is a skilled trade and is also very expensive. It is available in a range of thicknesses (Code 3 being normal for soakers, Code 4 for flashings and aprons) and is usually cut to the correct width by the suppliers.

The left-hand photograph above shows an abutment between a roof and a flank wall with the lead flashings 'dressed' down over the profile of the tiles. The flashing is then turned up the brickwork and tucked into a bed joint to secure it in position. The right-hand photograph shows a lead apron flashing between a roof and the wall behind. Note how the lead is dressed fully over the profile of each tile.

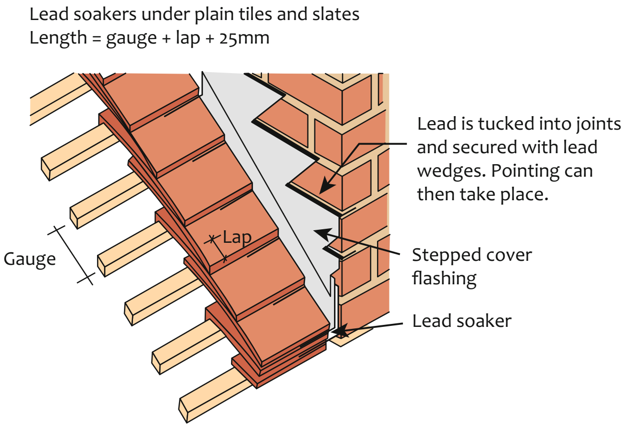
An alternative method of forming a waterproof joint at an abutment is shown above. On the left, short pieces of lead (known as soakers) are dressed over individual tiles and up the face of the stone parapet wall. One of them has a problem. Separate cover flashings (called stepped flashings) weatherproof the junctions with the abutting wall. On the right, soakers are dressed over synthetic slates and then up the wall under a cover flashing. Here, a cavity tray is also required because the vertical abutment is the outer leaf of a cavity wall.

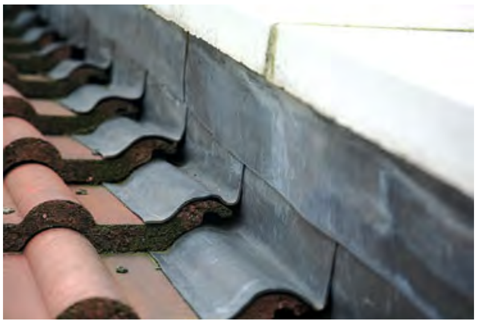
In cavity construction, a cavity tray must be included above any flashing secured to the wall in order to prevent water running down the inside face of the external leaf. These are usually formed in lead or part lead and part plastic.



Several companies produce alternatives to traditional lead cavity trays. However, they all work on the same principle; they prevent water running down the inside face of the cavity wall, leading to damp patches on internal surfaces.

In double-lap tiling and slating, the traditional method of forming a good joint at a vertical abutment is to use soakers with a cover flashing (see overleaf). This method prevents the leadwork lifting in high winds. The soakers are individual pieces of lead equal in length to the gauge (centre to centre of the battens) plus the lap. An additional 25mm should be added to the total to allow for turning the lead over the top of the tile or slate to prevent the lead soaker from slipping. The soaker must be sufficiently wide to allow at least 100mm under the tile, plus a 75mm turn-up against the wall. When the soakers are in position, the joint against the wall can be weatherproofed with a stepped cover flashing. The cover flashing is stepped to match the bed joints in the brickwork.





Each tile has a soaker fitted and all are covered by a cover flashing (in this case, it has not been stepped)

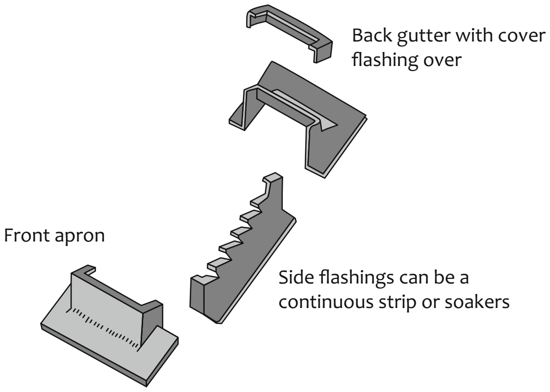
Mortar flashings

A clay double Roman tiled roof on an older building with a mortar flashing to an abutment with a parapet wall.

Mortar flashings were common before the 1940s as they are relatively cheap and easy to form. However, they are generally less effective than metal flashings due to their inability to accommodate even minor thermal and structural movement. They are also susceptible to frost attack. Cement mortar flashings are more likely to crack than those made of lime mortar. The risk of cracking can be reduced by bedding the mortar on polythene to form a slip layer over the tiles, but this can only be done on tiles with a substantial profile. On slates or plain tiles, it would provide a path for water penetration. They are still used occasionally, but are not recommended as good practice.

Chimney flashings

Flashings around chimneys can be quite complex. The nature of the flashing will depend on the location of the chimney. A stack positioned as shown in the photograph on the next page will require three flashings, fixed in the following order: front apron, side flashing and back gutter. The apron and side flashing are similar to those described on previous pages. A horizontal DPC may also be included – this is most likely to be found where the chimney is immediately above rooms (as in the photo).



The chimney flashing in the photograph above is formed in lead and comprises an apron flashing, side flashings and a back gutter. This particular side flashing is made from individual soakers with stepped flashings above. A horizontal DPC has been formed well above the flashings in order to prevent water running down the brickwork and staining the chimney breast in the room below. The horizontal DPC could have been stepped to reduce the exposed brickwork.

The photograph on the left shows a modern chimney stack with DPCs (top and bottom) in position. The flashing to the chimney on the right is complete except for some mortar pointing.

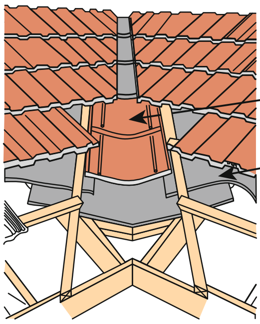
Valleys and valley gutters

Often, a valley has to be formed in a roof. Normally, they occur where roof slopes meet, often at an internal angle of 90°. They were frequently used by the Victorians to form butterfly roofs. There are a variety of ways in which this junction can be weatherproofed, but in modern construction it is usual to line the valley with lead or glass fibre or to use special trough valley tiles.

A butterfly roof above a Victorian terraced house showing how each slope drains into a valley gutter. The original lead valley gutter has failed and has been temporarily lined with felt. You can just make out the steps to the original gutter. Note: the clay double Roman tiles have been 'stretched' (i.e. have an extended gauge) to save cost – this is not good practice.

In plain tiled roofs, the valleys are often formed using special shaped valley tiles. Plain tile roofs can also have valleys which are laced or swept. Both laced and swept valleys have tiles or slates formed in such a way as to eliminate the need for a valley gutter. Manufacturers of clay tiles can provide specific details.

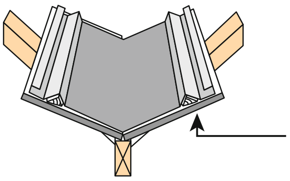
Valley tiles can be seen in this photograph of a concrete slate roof.



Valley tiles. Finished gap should be at least 100mm.

Underlay

Ply or softwood boarding supports felt and valley tiles. The gap between valley tile and roofing tile is pointed with mortar.



Note the position of the batten – see photograph below right.

Lead should be at least Code 4 (a measure of its thickness) and should be laid in lengths no longer than 1.5 metres and with a 150mm lap. The lead should be supported on 19mm boarding.

The left-hand valley is lead and the individual bays and steps can be seen. The right-hand one is made from glass fibre and is laid over the felt. When the tiles have been cut to the correct profile, they are bedded and pointed in mortar. This is not a skilled job (unlike leadwork) and it is relatively cheap. However, its durability is, as yet, undetermined.

Parapet gutters

Parapet gutters are comparatively rare in new construction and generally occur where houses have parapet walls. Parapet gutters are most likely to be found on Georgian or Victorian houses. Some are also found on modern 'mock' houses.

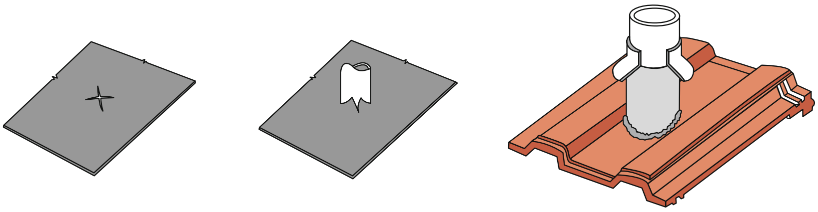
Lead is the traditional material for parapet and valley gutters, although other materials, such as zinc, felt or plastic are sometimes used. Code 6 is usually the minimum thickness of lead specified for such gutters, although Code 4 or Code 5 is often used for the smaller valley gutters found on modern roofs. Lead must be laid on a synthetic slip layer, as it is subject to thermal movement because it expands and contracts considerably in reaction to external temperatures.

The lead is laid in fairly short bays (or lengths) to prevent its thermal movement from causing buckling, bulging or splitting. Each bay has a shallow fall and, because bay lengths are relatively short, the lead needs to be stepped, as well, to form a watertight joint where two bays meet. On longer parapet gutters, the bays will increase in width as they step up and more than one sheet will be needed to accommodate the overall width of the parapet gutter. A timber roll must be introduced to form the side junction between the separate lead sheets of these larger bays and the lead formed over the roll with an unfixed end in order to allow for thermal movement.

In the top photograph, the steps in the lead parapet gutter can be identified at the points where the gutter narrows. The parapet wall is still to be completed. The lead details in the bottom photograph are of a gutter in a flat roof, but they demonstrate how bays are formed in leadwork with steps and rolls.

Soil vent pipes

In modern construction, soil vent pipes (SVPs) often penetrate the roof coverings. To make the joint watertight, a lead slate is often used. Roof manufacturers, such as Marley and Redland, also manufacture ventilation tiles that are suitable for capping soil ventilation pipes and extractor fan ducts as well as ventilating a roof. The ventilation tiles match the various roof tiles offered by the manufacturers and, in some cases, are extremely unobtrusive.



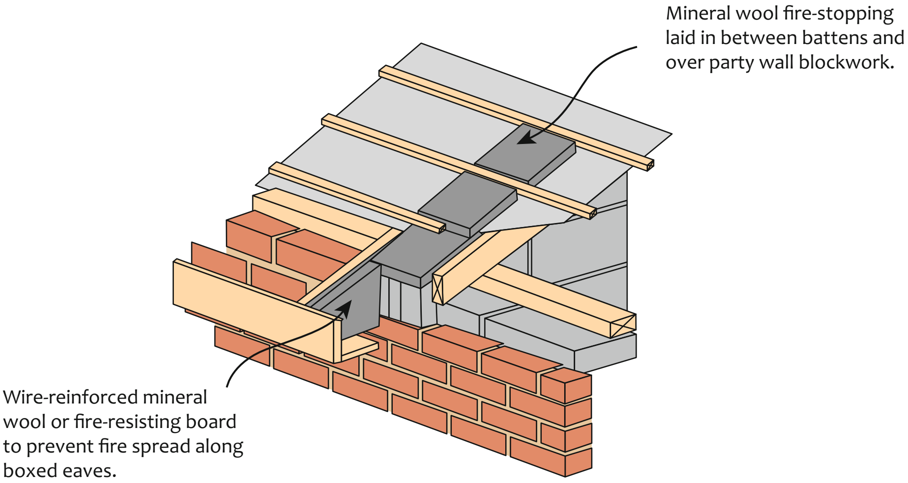
Where pipework runs through the roof, a lead slate is usually used to form a watertight joint.
The felt underlay should first be cut as shown, so the top flap folds up parallel to the ridge.
A lead slate with a welded upstand and plastic cover piece completes the detail.

This ventilation tile has been used to cap a soil vent pipe.
It could also be used to connect an extractor fan.

Fire spread

Note how the party walls are extended upwards by means of parapet walls to prevent fire spread between the roofs of this terrace of Victorian houses.

Where a property is semi-detached or terraced, special precautions are necessary to prevent the spread of fire to adjacent dwellings. This is most likely to occur behind boxed eaves or at the junction of the party wall and the roof coverings. In some parts of the country, it was common practice to fix the fascia board flush to the wall and this normally avoids the problem. It was also, until the twentieth century, common practice in some parts of the country to continue the party wall above the roof, as shown in the photograph above. This formed an effective barrier to the spread of fire, but was an expensive form of construction and often led to problems of damp penetration through failure in the copings or flashings.



In modern construction, an effective solution is shown in the diagram above. To prevent fire spreading from one dwelling to the next along the boxed eaves, the gap behind the fascia board can be filled with a variety of materials, such as mineral wool or 19mm plywood treated with a flame retardant. The material must be fixed securely, so that it remains in place even if the soffit board is destroyed by the fire.

To prevent fire spreading over the top of the party wall, the brickwork, blockwork or stonework should be kept approximately 25mm below the top of the rafters, and the gap beneath the roof underlay filled with a mineral wool or glass-fibre quilt. When the underlay and battens are in position, additional pieces of quilt are laid in between the battens. The quilt must be resilient enough to fill the irregular spaces under the tiles, but not so resilient as to lift or dislodge them.

Section Four: coverings for flat and shallow pitched roofs

As mentioned at the beginning of the chapter, flat roofs are rare in modern houses and so only a brief overview of this type of construction and its coverings is given here.

Despite the name, a flat roof is normally laid to a shallow pitch because of the need to shed rainwater. It is usually considered that a flat roof is one with a pitch of 10° or less. In practical terms, this pitch is translated into a fall or slope of between 1:60 and 1:80, depending on the nature of the weatherproofing material used. Because there is a danger that the desired fall may not be realised, in practice flat roofs are often designed with a steeper fall of about 1:40 to take account of possible design and/or construction errors. A consequence of such errors might be ‘ponding’ caused by water collecting in depressions created by deflections in the roof.

Although flat roofs are generally cheaper to build than pitched roofs, they often have a shorter overall life span. This is, in part, because it is generally easier to ‘design out’ or avoid potential defects in a pitched roof. It is also related to the more onerous conditions to which flat roofs are subjected, particularly with regard to wind flow patterns, which can exert strong suction forces at the edges and across the surface of the roof, as well as the, perhaps more obvious, issue of the efficient shedding of rainwater.

Although it could be suggested that a pitched roof is the most sensible design in a country of high rainfall, in reality the poor reputation of flats roofs is derived from mistakes or misunderstandings related to issues of design, specification or construction, often in combination. Earlier versions of ‘modern’ flat roofs often suffered from expansion and contraction of the structure, or the warping of square-edged boards used for the roof decking. These movements often led to damage in the waterproof covering. Later versions, when insulation became commonplace, were more likely to also suffer from condensation (see below).

In the recent past, where a flat roof has been used as an alternative to the pitched roof, its popularity has been mainly due to cheaper initial cost. In some large buildings, particularly with complicated plan forms, a flat roof may also be the logical solution. Architectural style has also had some influence. The most overt example of architectural style are the designs inspired by the Modern Movement whose influence, while strongest in the 1920s and 1930s, lingered on until the 1960s.

Modern Movement houses.

Post-war houses (1960s) constructed with flat roofs.

Main functional elements of flat roofs

Flat roofs will generally consist of the following elements:

- *a waterproof membrane: this is intended to prevent water penetrating the roof structure and the interior of the building*
- *a roof deck: this provides a base for the waterproof membrane and, in some designs, the insulation. The deck is usually supported by the primary structure*
- *thermal insulation: this reduces heat loss through the roof*
- *loadbearing or primary structure: this transmits the weight of the roof and any loads acting on the roof onto the loadbearing walls. It will often be constructed in timber, although examples of concrete slab or steel structures exist.*

Structure: timber flat roofs

The structure of a flat roof is similar to an upper floor (apart from the slope), although the type of loads applied will be different. Timber joists form the loadbearing structure and, as with floor joists, their structural stability is provided by their cross-sectional area related to expected loading, the spacing between joists and the required span. In respect of the loading on the roof, the joists can be made smaller if access is limited to those operations necessary for maintenance and repair, although account will have to be taken of the loads imposed by the roof structure itself, as well as other factors such as snow. Spacing of the joists is similar to floor joists and must relate to the thickness of the deck which is supported. As with floors, strutting may be necessary in order to prevent twisting of the joists.

Decking

There are a number of materials which can be used for decking, but for the domestic situation the usual choice is between the following:

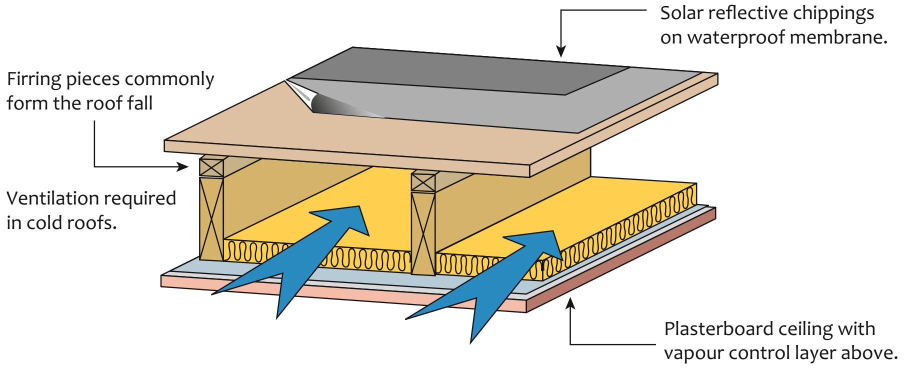
- *Softwood timber boards: These will be similar to the floorboards referred to in Chapter 5. They should be tongued and grooved for reasons similar to those mentioned in that chapter, particularly to minimise any warping and shrinkage which may damage the waterproof covering and impede rainwater disposal. Timber boards can be considered as the traditional decking for timber flat roofs; however, while they are still specified, their use has been superseded to a certain extent by other materials such as plywood and chipboard.*
- *Plywood: This comes in the form of boards suitable for roofing purposes; one of the requirements for the grade is the performance of the adhesive used to bond the segments of the ply together.*
- *Chipboard: This comes in board form and in grades which are intended for use in roofs. It should be noted, however, that a number of bodies have expressed concern about the use of this material, because it has been found to absorb moisture in some circumstances. If this occurs it can lose its structural integrity. Care should therefore be taken in using chipboard, particularly in situations which may suffer from high humidity.*

The form of flat roofs

Flat roofs can be categorised as either cold roofs or warm roofs. The terms refer to the position of the thermal insulation

Cold roofs

Until perhaps the 1970s, this was a common approach to the design of flat roofs. The diagram below shows the insulation placed immediately above the ceiling and between the joists. A vapour control layer (below the insulation) and adequate ventilation of the void (above the insulation) is necessary in order to prevent moisture vapour condensing on the colder timbers.



In practice, achieving adequate (cross) ventilation is difficult with many flat roofs and so this form of roof is rarely used nowadays.

Note: firring pieces are timbers cut at an angle to produce the fall. Reflective chippings are used in order to reflect ultraviolet light from the sun because this would otherwise cause degradation of the waterproof covering.

Warm roofs

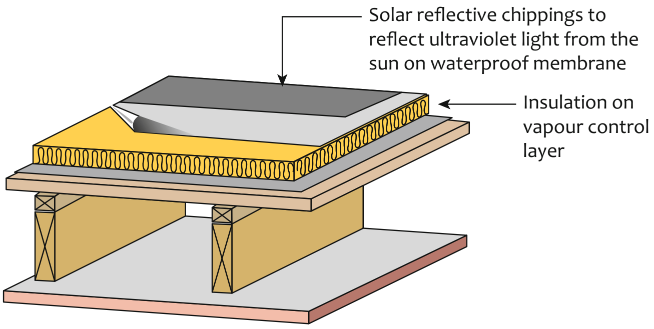
Warm roofs can themselves be divided into two types:

- *sandwich.*
- *inverted (upside down).*

In both of these approaches the insulation is located above the deck. This means that the temperature of the structure and the deck are kept close to the temperature inside the building (hence warm), protected from extremes of heat and cold, and therefore the potential for damage caused through movement is reduced. As there is less likelihood of condensation occurring in the warm roof space, a ventilated void is not required; indeed ventilation in these roofs could increase the likelihood of condensation occurring due to a drop in air temperature. A vapour control layer should be incorporated to minimise moisture movement.

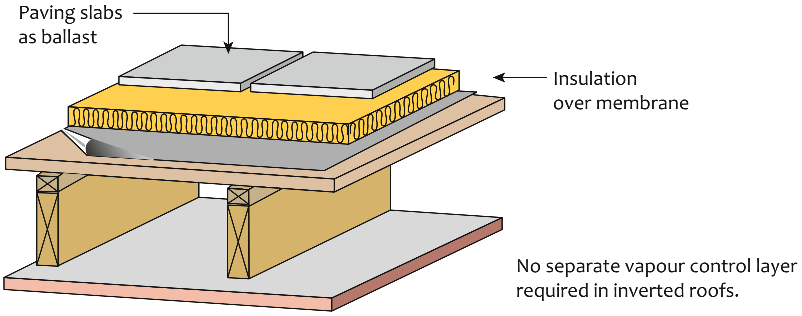
Sandwich roofs

In this type of roof the insulation is placed above the deck, but below the waterproof covering, i.e. it is 'sandwiched' between the deck and the waterproofing.



Inverted roof

In this case, the insulation is placed above both the deck and the waterproof membrane, i.e. the waterproof layer is inverted in comparison to its 'normal' position. It is mainly used in commercial buildings, but mentioned here for completeness.



Types of roof covering

During the Victorian and Georgian periods, flat roofs were fairly common, particularly on large complex roofs. These flat roofs were usually covered with sheets of lead, laid to falls and overlapping in a similar way to single-lap pitched roof coverings. Most domestic flat roofs built during the twentieth century were quite different because they were covered with a waterproof membrane.

A lead flat roof to a Georgian house.

The Victorians also used asphalt, and this became a successful substitute for metal, as it is a very good waterproofing material which also resists damage from foot traffic. In the period before the Second World War, bituminous felt materials were developed and these became the most popular choice for waterproof coverings for domestic roofs. Their use was widespread during the housing boom which followed the Second World War. The practice of using built-up felt with timber roof structures and asphalt with concrete slab roofs seems to have developed over the years, although there is no overriding technical reason why this should be so. In more recent years, single-layer membrane roof coverings have been developed. They are made from synthetic polymers or rubber. However, they are mainly used in non-domestic buildings, such as factories, light industrial units and warehouses, as they tend to be uneconomic unless used on large roofs.

Lead is still an option today, although it is relatively rarely used on new domestic roofs due to, among other reasons, its high capital cost. The Victorians used other metals, such as copper and zinc, although, like lead, these materials tend to be rare in new housing today.

In part, the poor reputation of flat roofs has been related to the inadequate performance of the waterproof covering. This was often related to inherent weaknesses in materials used in the past, combined with problems caused by thermal or moisture movement.

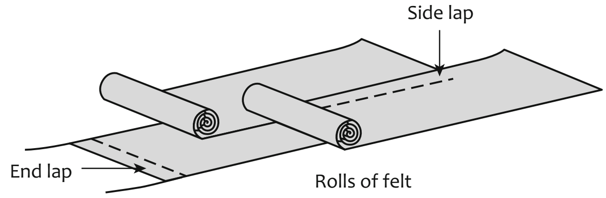
Built-up felt

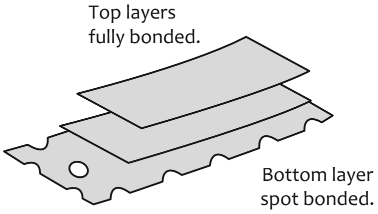
This is probably still the most common material for domestic flat roofs. The word ‘felt’ is somewhat inappropriate for the modern materials that are used, but is still in common use. It is a sheet material which comes in rolls and is laid on the roof, usually in two or three layers, depending on the material used and its situation.

The felt usually consists of a reinforcement base impregnated with bitumen and then covered on both sides with a further layer of bitumen. The function of the base is to help provide resistance against weathering and ageing, as well as providing strength. The bitumen provides the waterproofing. The materials for the base can vary. Originally, it was an organic base formed by saturating animal or vegetable fibre with bitumen distilled from crude oil; later, asbestos and glass fibre bases became available. Of these, probably the most reliable was glass fibre, but all of these materials suffered from questionable durability. Because of their poor durability, other materials have been developed over the past 40 years or so and these are still often referred to as ‘high-performance felts’. These, in the main, are felts which have a base of polyester or similar material. They are stronger and resist age-hardening better than traditional felts. The bitumen has been improved as well and has resulted in a material which is more flexible in cold weather and firmer in hot weather. Felts are sometimes referred to by the type of additive they contain, i.e. APP (atacticpolypropylene) or SBS (styrene-butadienestyrene). These high-performance felts are more durable than the older types and one would expect to see them specified in most circumstances.

Built-up felt covered flat roofs (above and below).

Felt is traditionally laid by 'pour and roll' techniques, where hot liquid bitumen is poured in front of the felt as it is rolled out and applied to the roof. The felt is usually laid with staggered joints and with side laps and end laps.





Another method which can be adopted in laying some of the high-performance felts is known as 'torch on'. This involves specially coated felts where extra bitumen is melted by the application of heat from a blowtorch as the felt is unrolled. These have the advantage of easier application and remove the need to have a boiler close at hand to melt the bitumen. However, they are, to a certain extent, more reliant on good workmanship to achieve a proper bond. APP felts are usually suitable for 'torching' or hot-air welding. SBS felts are generally intended for application by the pour and roll technique, although some can be 'torched on'. Self-adhesive SBS felts are also available.

Sheet metal coverings for flat and pitched roofs

A lead covering to the flat portion of a Georgian mansard roof.

Lead flat roof on a seventeenth century building.

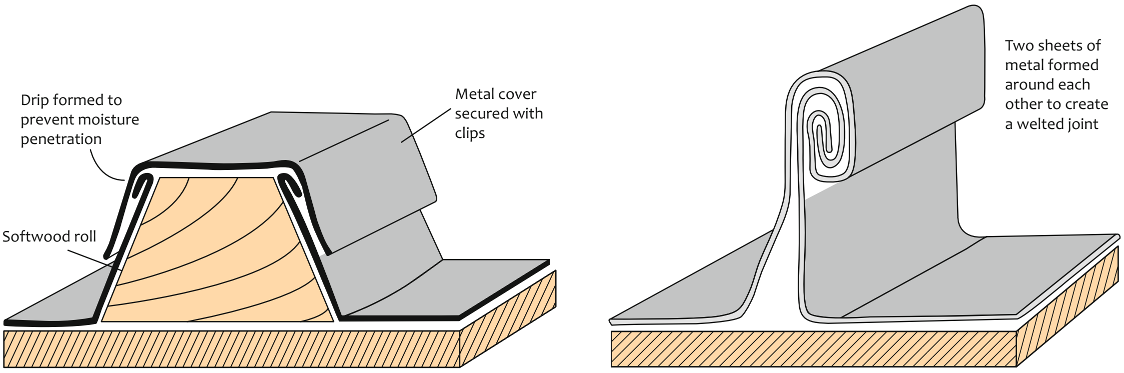
A number of sheet metals are commonly used in the UK for covering flat and low-rise domestic pitched roofs. Lead, previously discussed in terms of flashings, soakers and gutters, is occasionally used for new pitched roofs, but, as we have observed, because of its weight and cost it is mostly used for conservation work on the pitched roofs of older buildings. Two other metals, copper and zinc, are sometimes used for the pitched roofs of new houses because they are relatively light and not as expensive as lead.

This sea-front shelter in Weymouth has recently been re-roofed in leadwork. Note the individual lead sheets dressed over the rolls and the hip detail.

All three metals are subject to differing levels of thermal expansion and this has meant that, traditionally, their installation involved relatively small bays divided by rolls and steps. However, both copper and zinc have benefitted from the introduction of standing seam technology.

These two photographs show different types of standing seams secured with secret fixings. On the left is an older copper roof clearly showing the individual sheets, while on the right is a recently installed profiled steel roof.

The creation of a standing seam involves sheets of the metal being connected by means of turning each edge through 90° and then forming a welted joint, as shown in the diagram below. This permits a much more flexible approach, especially when the smaller metal sheets are joined together above a solid backing to create a larger composite panel. Large individual composite panels can then be connected to each other by further standing seams. This approach means that panels of up to 8.5m long can be formed with the standing seams running down the slope. Factory prefabrication of the large panels, combined with the use of machines on site that form mechanised standing seams to connect the panels, results in very strong metal roofs. As they age, copper and zinc develop a patina or skin, green for copper and grey for zinc, which is self-healing, with the result that zinc roofing has a life of 40 years or more and copper much longer, often over 100 years.



On the left, the joint between two sheets of metal is formed over a softwood batten or roll, a traditional method. On the right is a modern standing seam that is based on each sheet of copper or zinc being folded or welted around the next sheet.

9

Partitions

Introduction

This chapter describes the development of internal loadbearing and non-loadbearing walls (often referred to as partitions), and explains some of the various proprietary partition systems available for use in housing.

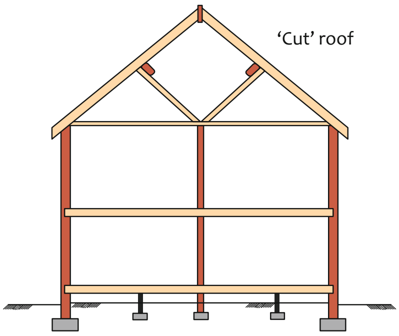
Non-loadbearing partitions can be constructed from a variety of materials, such as brick, block, steel, timber and plasterboard, and their primary function is to divide space. Loadbearing partitions have the additional function of supporting upper floors and, in some cases, part of the roof. Suitable materials include bricks, blocks and timber.

Structural considerations

Chapter 7 on roof structures explains the advantages of modern trussed rafters, one of which is the ability to span large distances without any intermediate support. This effectively means that modern houses do not require any form of internal loadbearing walls on the upper floor when this type of roof construction is used. Similarly, in many modern houses internal loadbearing walls are no longer required to support upper floors because of the use of I-beams instead of timber joists (refer to Chapter 6 on upper floors).

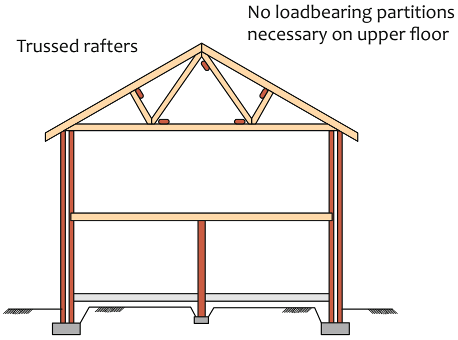
Consider the two diagrams below. The example on the left shows a cross-section through a typical house built in the early part of the twentieth century. An internal loadbearing wall was often required to support the first floor and part of the roof structure. The diagram shows the partition in the centre of the house, but they were often also off-centre as rooms were of different sizes. In the second example, which is typical of most construction since the 1960s, the loadbearing wall is only supporting the first-floor joists. Sometimes such a loadbearing wall would be built on a thickening in the slab rather than a traditional foundation.

Up to mid twentieth century



Loadbearing partition supports first floor joists and part of the roof structure.

Mid twentieth century onwards



Loadbearing partition to support first floor joists. Partition is supported by thickening in slab or on foundation.

General requirements

When designing partitions, the following factors should be considered:

- *strength and stability*
- *durability*
- *fire protection*
- *sound insulation*
- *cost.*

Until recently, the internal walls (excluding party walls) of houses did not have to meet any specific levels of sound insulation. The Building Regulations now specify minimum acoustic standards for all walls that surround any bedroom, bathroom or room containing a toilet.

Note that the above list excludes thermal insulation. This is because if the temperatures on either side of the partition are similar, there will be minimal flow of heat, i.e. no real heat loss.

Early partition systems

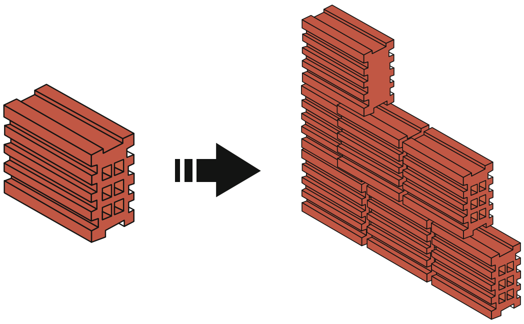
The following diagrams illustrate common methods of building partitions in houses prior to the 1930s. It is impossible to be precise about this date as there are regional differences and, in fact, there are examples of brick partitions built as late as the 1960s.

Brick partitions

The first example (below left) shows part of a property with one-brick thick external walls and an internal loadbearing wall, half-brick thick, in stretcher bond. The internal loadbearing wall supports the upper floor, the ceiling joists and the struts from the purlin roof. The wall is built on a shallow strip foundation (below right).

Clay block partitions

Hollow clay blocks were also popular for non-loadbearing partitions 50 or so years ago and, although still available, they have been superseded by the modern systems mentioned below. The blocks were originally available in a range of sizes and had grooved sides to give a good key for the plaster. They are light in weight and provide excellent fire resistance. However, the blocks are difficult to cut as they shatter easily and attaching fixings for shelving, etc. can prove difficult.

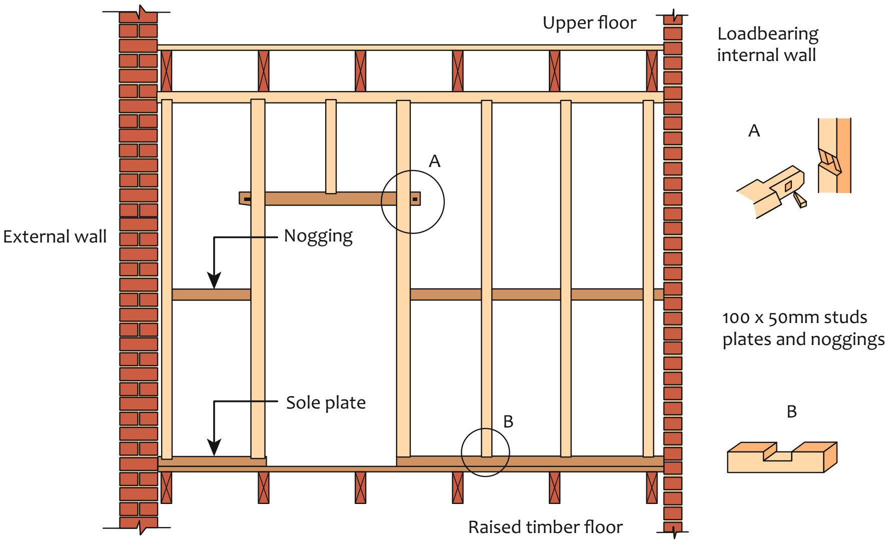


Hollow clay blocks laid in stretcher bond.
Grooves provide good bond for plaster finish.

Early timber stud partitions

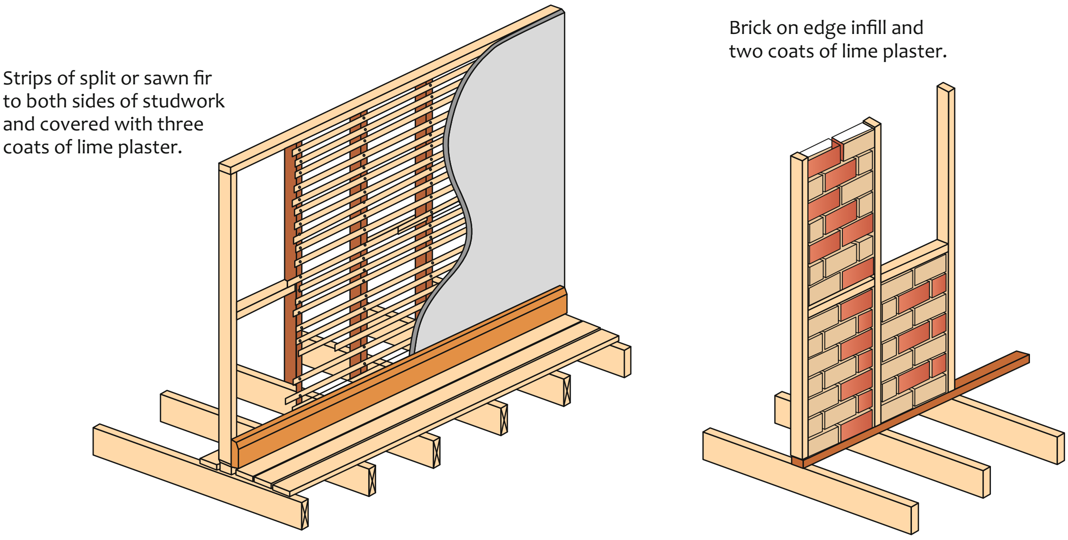
Timber stud partitions were an alternative to brickwork and could act as both loadbearing and non-loadbearing walls. If they were supporting a load of any significance, they were likely to be built on brick sleeper walls which terminated at ground floor level. The diagram below shows a typical non-loadbearing stud partition supported by a timber ground floor. If acting as a loadbearing partition, extra diagonal bracing timbers would be added – see photograph overleaf.

Stud partition – typical construction from early twentieth century.



The timber stud partition on the upper floor has diagonal bracing (on the left-hand side) so it was meant to be loadbearing. The lower partition was non-loadbearing. However, because there is no supporting partition on the lowest floor, both upper floors are sagging as the design did not properly take account of the load from the partitions themselves plus the roof.

Before the invention of plasterboard, the studding was usually covered with timber lath or infilled with bricks on edge. The latter is heavier and therefore less suitable for upper floors where a supporting wall underneath may not exist. It does, however, offer improved sound insulation.



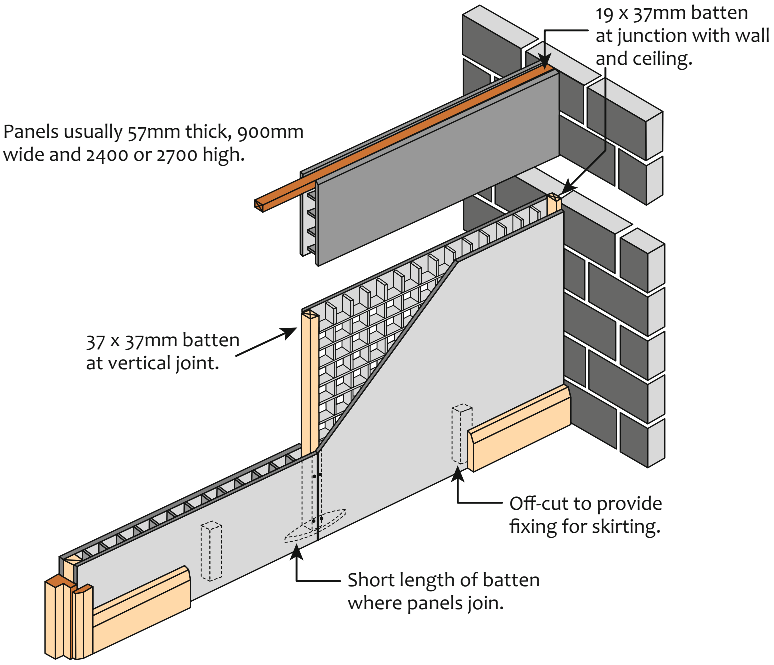
In practice, it can be difficult to establish whether a partition is loadbearing and careful examination is always necessary before alteration works take place. Before removing what is assumed to be a non-loadbearing partition, it is always worth lifting a couple of floorboards in the room above, or checking in the roof space, to determine whether joists or roof struts are supported by the wall. Mistakes can be very expensive to rectify.

Later partition systems

The following types of partition are no longer installed, but a brief description of each of them is included as many domestic buildings still have them in situ.

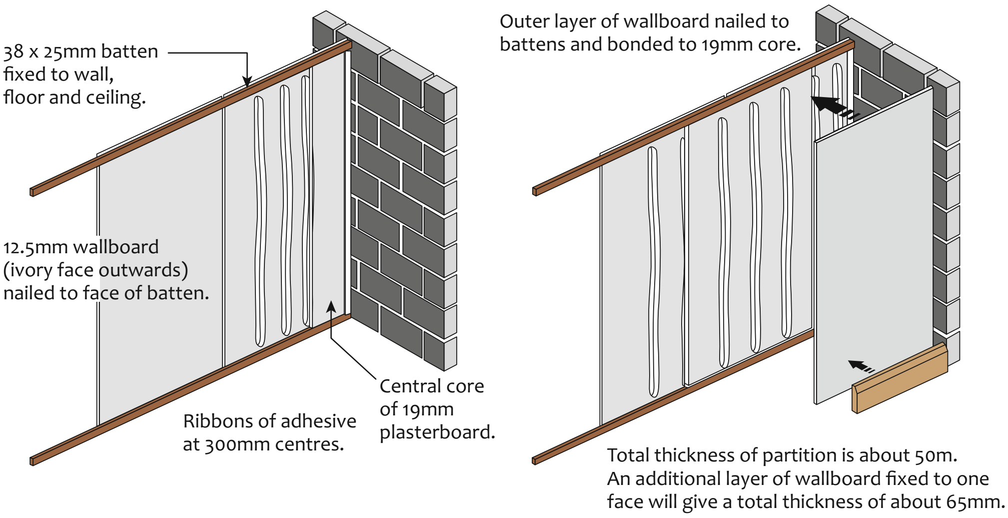
Panelwall (originally called Paramount) partitions

These were very popular in the last quarter of the twentieth century and comprised two layers of plasterboard factory-bonded to a cardboard core (see diagram below). The panels were either ivory-faced for direct decoration or grey-faced to receive a plaster skim. The panels came in a variety of sizes to suit different floor-to-ceiling heights – up to 2,400mm high with a thickness of about 50mm and larger panels (2,700mm and 3,600mm high) being slightly thicker to ensure stiffness and stability. The panels could be erected and decorated very quickly.



Laminated partitions

This type of partition consisted of three layers of plasterboard. It was quickly assembled and provided acceptable sound insulation and fire protection for housing. The outer faces of the partition could be plastered, but it was usual to use ivory-faced wallboards for direct decoration, with tapered vertical edges of the boards for jointing with a special compound, as described in Chapter 10 on plastering. As with the Panelwall system, the partitions were not loadbearing. The thickness of the partition was usually 50mm, but where extra sound insulation or fire protection was required thicker partitions could be made by using extra and/or thicker boards.



Stramit partitions

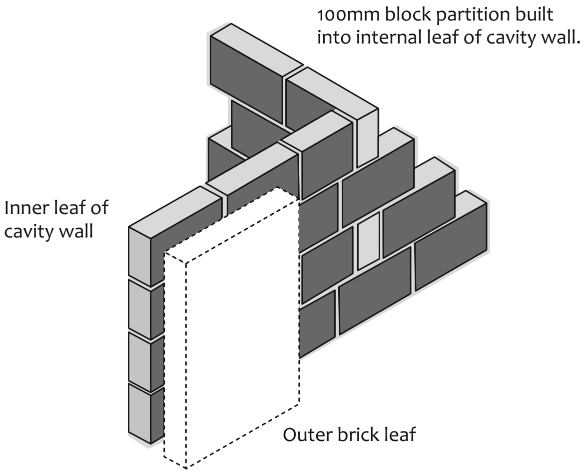
These are rarely found in modern construction, but were popular in the 1950s and 1960s. The system is similar in principle to the Paramount partition mentioned earlier. However, the central core was made from densely compressed straw rather than open cardboard webs. The joints in the partition were covered with a jute scrim and then a skim of plaster was applied. They had good airborne sound insulation and no open core for fire to penetrate.

Modern block partitions

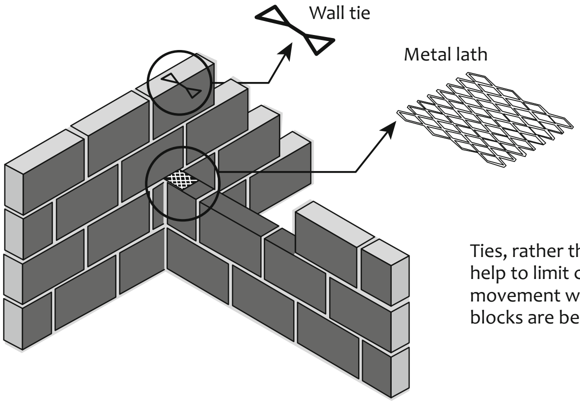
Loadbearing partitions

Concrete blockwork has largely superseded brickwork for reasons of economy and is, nowadays, probably the most common form of loadbearing partition. Dense concrete blocks offer the best sound insulation and are slightly cheaper than lightweight blocks. They are usually 100mm wide and will require a foundation or thickening of the slab, depending on the load they are carrying.

In order to maintain lateral stability of the partition, it is important to ensure that the blockwork is well bonded into any external or internal adjoining wall. The best method is shown in the diagram on the next page. Alternate courses of blockwork in the partition are bonded into the internal skin of the cavity wall.



An alternative method of providing lateral stability is to use wall ties or galvanised mesh. As the external wall is built, the bricklayers position the wall ties in line with the partitions, as shown in the diagram below. This method is inferior to bonding as it provides a much weaker joint. It is, however, suitable for non-loadbearing partitions.



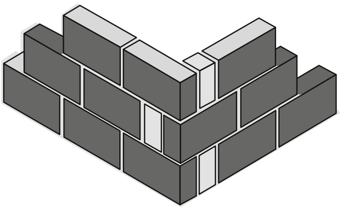
Walls can also be joined by wall ties or metal lath. Neither method is normally as effective as building-in.

Ties, rather than building-in, may help to limit cracking caused by differential movement where, for example, lightweight blocks are being joined to dense blocks.

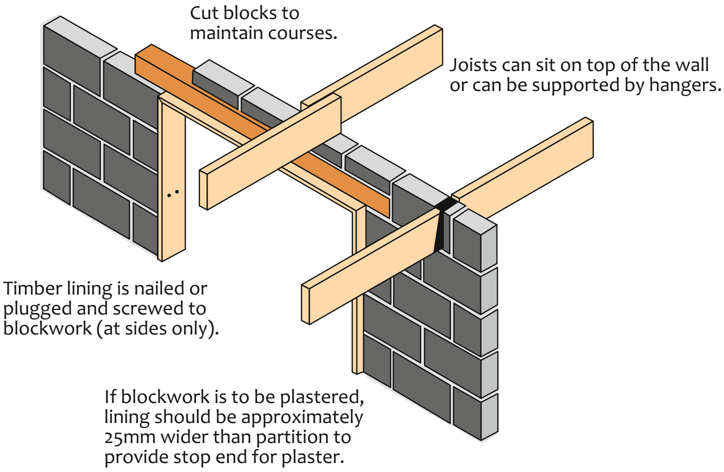
A further means of tying walls together is to use a proprietary wall starter kit. This comprises vertical fixing plates of stainless steel or galvanised metal that are bolted to the receiving wall. The vertical plate has horizontal ties at right angles that secure the masonry at the end of the partition.

Concrete blocks are laid in a cement/sand mortar (often with a plasticiser added to aid curing) or cement/sand/lime mortar. A strong mortar, i.e. one with a high proportion of cement, should be avoided as it limits the ability of the partition to accommodate thermal and moisture movement, which may result in cracking. In addition, the concrete blockwork should be allowed to dry thoroughly before plastering takes place, as water absorbed by the blocks (from standing in the rain) causes slight expansion and plaster applied before the blocks have dried out will crack as the blocks slowly shrink. Where the partitions return at right angles, cut blocks are used to maintain the bond and where doors are to be incorporated, steel or concrete lintels are built in over the opening.

At first-floor level, the joists, which are supported by the partition, can either sit on top of the wall or be supported by joist hangers. In many cases, a loadbearing wall will continue up to the roof level to support part of the roof structure (if traditional roofing is used). In nineteenth-century and earlier buildings, a timber levelling plate (i.e. a wall-plate) was often built into the wall to support the upper floor joists. This is no longer done as problems of rot or insect attack may result in failure of the plate and subsequent failure of the wall above.



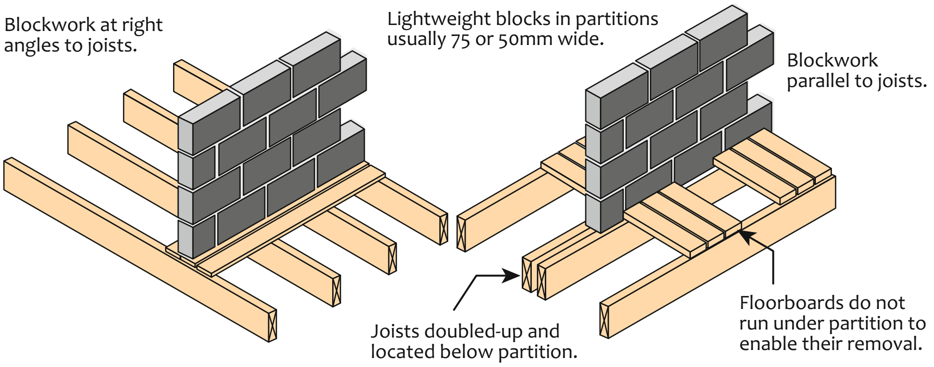
Cut blocks to maintain bond.



An opening in a modern internal loadbearing wall. The wall is made from dense blocks (unlike the internal leaf of the cavity wall on the right which is lightweight block). Upper floor joists are built into the top of the wall and are supported over the opening by a steel lintel. Note: the right-hand side of the lintel should be supported by a full block not a cut one.

Non-loadbearing blockwork

Most of the details above also apply to non-loadbearing partitions, although they may be of thinner construction than their loadbearing counterparts. Blocks of 50mm and 75mm are available and must be well tied into the external walls and other partitions to ensure lateral stability. As the walls are carrying no load, they can be built directly off a concrete or timber floor, although in the latter case it is important to ensure that there is a joist (preferably two) under the partition if it is parallel to the run of the joists.



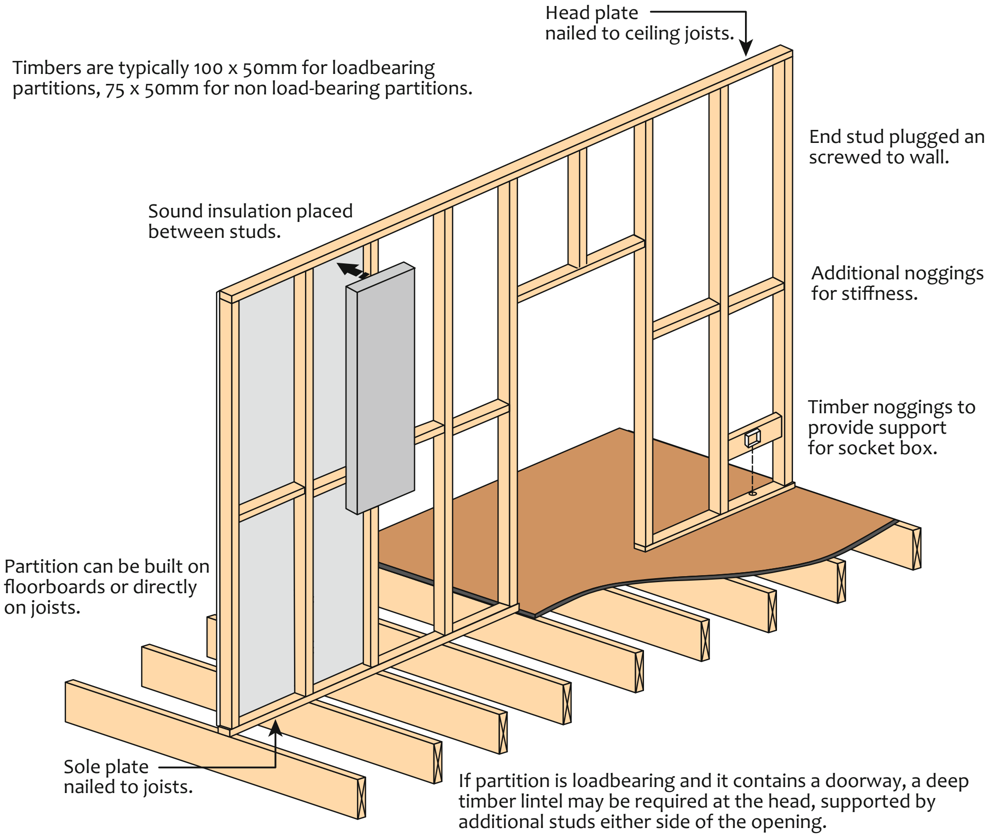
In the above example, the floorboards are supported on either side of the partition. (Note: the flooring is now more likely to be chipboard, as shown in the next diagram.) It is possible to lay the floorboards right across the joists, in which case the partition will sit on the boarding. However, the disadvantage of this will soon become apparent when the boarding needs to be lifted for new or extra wiring.

If thin blocks are used and heavy doors are to be fitted, it is wise to consider the use of storey-height linings. The constant slamming of doors is one of the most common causes of cracking in partitions. The storey height lining gains additional support from the floor joists above and the panel over the door can either be in-filled with blockwork or glazed to form a borrowed light.

Both loadbearing and non-loadbearing partitions can be finished with wet plaster or dry lined, as described in the next chapter.

Modern timber stud partitions

Timber studding was mentioned earlier in the chapter and in modern construction it is still quite common. A modern timber stud partition comprises a softwood framework covered with plasterboard on both sides. The thicker the plasterboard, the better the sound insulation and fire protection. If timbers of approximately 100 x 50mm are used, the studding can be loadbearing and this can be seen in timber-frame housing. If the partition is not carrying any load, the studding is more likely to be 75 x 50mm. Stud partitions are very adaptable and are often favoured by designers and builders when converting and altering buildings. In new estate construction, they have become less popular as steel framed partitions are considered quicker and cheaper. A typical timber stud partition is shown overleaf.



An occasionally used alternative to plasterboard is to nail sheets of galvanised mesh to the studding and plaster the mesh. A proprietary gypsum plaster should be used that contains a rust inhibitor to prevent staining of the plaster at cut ends in the mesh.

Stud partitions can be covered with various types of plasterboard. The plasterboard can be self-finished or plastered. In recent years, it has become common practice to sandwich a sound-deadening quilt between the studs (this a mandatory requirement for partitions around bedrooms, bathrooms and any room containing a toilet).

Sound-deadening quilt has been inserted between the timber studs of this partition to a kitchen. Noggings fitted between the studs support power points and provide a good fixing for kitchen base units and cupboards.

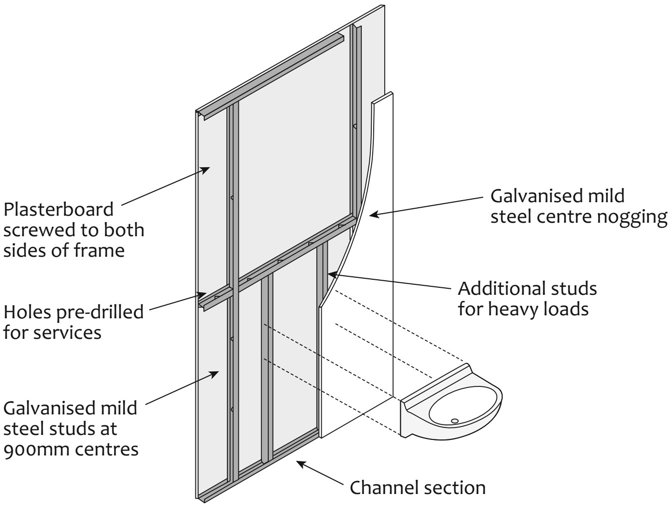
Door linings are nailed to the studs. The lining projects about 15mm from the studs to allow for the plasterboard finish. A timber door stop is fixed around the inner face of the lining during the second fix stage (after plastering/dry-lining). An architrave, nailed around the outer edge of the lining, hides the edge of the plasterboard.

Modern steel framed partitions

Steel framed partitions have become increasingly popular over the past 20 years for new-build developments and are the current basis (instead of timber) of many manufacturers' proprietary partition systems.

The partitions are formed with galvanised lightweight steel sections which are 'I', 'C' or 'U' shaped and are installed in a similar manner to the framework of a timber framed partition. Vertical studs are erected at intervals to suit the plasterboard along with sole and head plates. Timber levelling plates may be needed beneath the sole plate if the floor is uneven and extra studs or timber backing plates can be inserted to support any heavy fittings to be attached to the partition, e.g. cupboards, wash-hand basins. Door openings may need extra support at the head.

The plasterboard is fixed to the framework with self-tapping screws and timber door linings are extended out to provide protection to the edge of the plasterboard. Sound insulation can be fitted between the studs where required and some manufacturers produce specially shaped metal studs that give increased acoustic performance.



The diagram shows details of a typical steel framed system.

Steel partitions are becoming very common. They are light, easy to handle and quick to erect. In principle, they are the same as timber stud partitions. When the framing is complete, plasterboard (12.5mm or 15mm) is screwed to the steel channels. A sound-deadening quilt can be used to improve sound insulation. A layer of plywood sandwiched between the plasterboard and the frame will provide better fixings for shelving, etc. The boards can be taped and self-finished (the normal method) or plastered.

Plastering and dry-lining 10

Introduction

This chapter explores the development of internal finishes. In the past these were dominated by wet-applied plasters. Although these are still used, it is dry, prefabricated materials and techniques, known as 'dry-lining', which have become more commonly used in new construction.

This chapter looks at the historical development of plastering techniques and materials and explains the use of plasterboard and dry-lining.

Internal finishes are applied to the inner faces of external walls, partitions and to the underside of upper floors to form ceilings. This is to:

- *cover the irregularities in masonry walls*
- *provide a suitable smooth surface for decoration*
- *improve the thermal insulation of a building*
- *increase fire resistance*
- *mitigate the effects of condensation*
- *help prevent damp penetration.*

Besides fulfilling the above functions, the internal finishes should be durable, relatively cheap and should resist everyday impact damage.

Plastering

Lime plaster

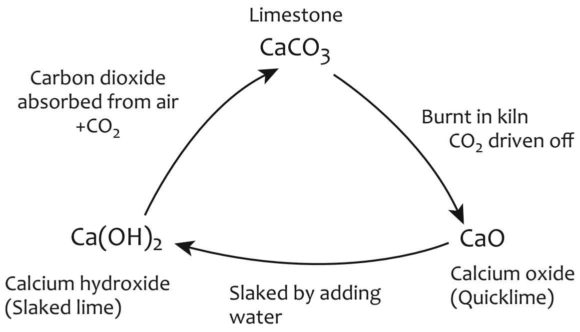
Lime plasters were common in the UK until the early 1950s. They can still be found in use today, although generally this use is confined to conservation work.

Lime is the binding agent in these plasters. It is created by processing limestone or chalk. Binders made from pure limestones and chalks, with a calcium carbonate content of 95 per cent or more, are known as air limes because they harden solely through absorbing atmospheric carbon dioxide – this process is known as carbonation. Air limes were commonly used for internal wet-applied plasters, where the necessary prolonged exposure to carbon dioxide could be controlled. Other limes were derived from limestones which have natural clay-based impurities. These produce a faster and stronger initial hardening. This occurs only once they are mixed with water; in fact they harden under water too. These 'hydraulic' limes were used as a binding agent in external and exposed situations where the slow, and somewhat delicate, carbonation process would have been compromised (see Chapter 12).

The creation of an air lime starts with the quarried and crushed limestone/chalk being heated to high temperatures in kilns; a process which drives off carbon dioxide. The material formed in this process is calcium oxide, known as quicklime. Quicklime is then slaked in water (a very vigorous and sometimes dangerous reaction generating very high temperatures) to form calcium hydroxide. The slaking action rapidly breaks up the quicklime into a fine, milky slurry. The excess water is then removed, leaving lime slurry with the consistency of thin cream. After a minimum of four weeks of storage the lime thickens up and is ready for use. It can, however, be stored indefinitely in the right conditions. Indeed, the longer the maturing period, the greater the stability of the binding agent. For air limes, the calcium hydroxide in this thickened and mature form is known as lime putty.

Hydrated lime (calcium hydroxide) is nowadays also bought as a dry powder in bags. This is an air lime in a dry form, produced when exactly the right amount of water is added to the quicklime, i.e. enough to convert the calcium oxide to calcium hydroxide, but not enough to leave a water residue, creating a lime putty. Hydrated lime is easier to obtain than lime putty and it can be more convenient. If used as a replacement for lime putty it is recommended that the dry powder is mixed with water to form a putty at least 12 hours before being mixed as a plaster.

The 'triangle' of lime

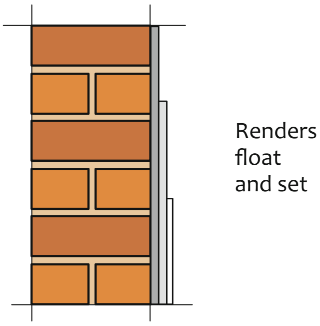


The lime putty, already a moist, semi-liquid form, is mixed with sand or other fine aggregate to form the plaster. This can then be used to plaster brick, block, lath and stone walls. Once applied to the wall, the plaster hardens by carbonation. This process can take several months, especially if thick coats are laid onto the wall, because the surface hardens first, making passage of air to the centre of the plaster more difficult. In the early stages, moisture vapour is also necessary for carbonation to be effective.

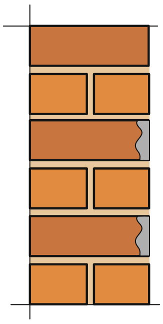
Lime plasters were normally applied in three coats, known as render, float and set. The render coat roughly levelled out the wall. The floating coat evened out the suction caused by the differing thickness of the render coat and provided a level surface for the setting coat, which gave a smooth true finish.

Lime plaster shrinks as it dries (as the water evaporates the lime tends to consolidate) and to help prevent cracking of the first two coats they were reinforced with animal hair. By keeping each coat fairly thin, a good bond could be maintained with the background and this also helped to reduce the effect of shrinkage.

Typical mixes would be three parts sand to one part lime for the render and floating coats, and equal parts of lime and very fine sand for the finishing or setting coat. The total thickness would depend on the nature of the wall. On good brickwork a total thickness of about 19mm is typical (8mm, 8mm and 3mm). Attempting to apply thicker undercoats was rarely successful; it was difficult to squeeze out any trapped air pockets and the thick coats were more likely to sag. The photograph overleaf shows three-coat work: render and floating coats with ash and sand aggregate, and a thin setting coat with fine sand aggregate.



Render and floating coats are undercoats. The setting coat is the top, or finish, coat.



On uneven walls ‘dubbing out’ (filling of irregularities) may be required before applying the render coat.

Old walls like this one often need extensive dubbing out.

Ceilings could be formed by applying the plaster to a series of timber laths nailed to the soffit of the joists. Early laths were split (riven), although by the early 1900s they were more likely to be sawn.

Lath ceiling showing softwood laths and lime plaster. The spacing of the laths is crucial. A ‘finger’s gap’ was typical. This gap enabled the wet plaster to extrude between the laths and form a mechanical key. If the laths are too close, little key will be provided. If they are too far apart, the weight of the plaster may overcome the mechanical key and the plaster will break away from the laths.

Lime plaster is rare in modern house construction: it was superseded by gypsum plaster.

Gypsum as a binder

Gypsum offers three major advantages:

- *it sets in a few hours*
- *it expands very slightly on setting, thus preventing any shrinkage cracking*
- *it can be successfully applied in thicker coats.*

The mineral gypsum was formed by the depositing of salts in inland lakes during the course of many geological periods. Pure gypsum is white in colour but small proportions of various impurities cause the colour to vary to shades of grey, brown and, most commonly, pink.

In simple terms, gypsum consists of calcium sulfate chemically combined with approximately 20 per cent of water. In the manufacture of plaster the gypsum rock is crushed and ground to a fine powder. It is then heated to drive off most of the naturally combined water and the resultant product is known as hemi-hydrated gypsum plaster, commonly referred to as Plaster of Paris. In building it was used to form the fine mouldings often found on the ceilings of quality houses, but as a material it sets (hardens) too quickly for convenient use on walls. However, by adding various chemicals the setting time can be delayed.


Plaster of Paris console bracket used for decorative effect.

When gypsum plaster is mixed with water it returns to its original state – calcium sulfate; the plaster sets by combining with water to form gypsum crystals which interlock and bind together with the fine aggregate. When gypsum plasters first appeared they were often added to lime/sand plasters to impart early strength and help reduce drying shrinkage. During the housing boom of the post-war years, lime plaster became less and less popular and sanded gypsum plasters became the norm. On site, the gypsum was mixed with fine aggregates for undercoats and used 'neat' for the finish coat. However, the popularity of such self-mixed gypsum plasters was relatively short lived and they were superseded by lightweight pre-mixed gypsum plaster, which nowadays enjoys a virtual monopoly in wet plastering.

Gypsum plasters

Gypsum plasters are factory produced, pre-mixed plasters with lightweight expanded minerals as the aggregate and gypsum as the binding agent. They require only the addition of water on site to make them ready for application. In addition to the qualities of sanded gypsum plaster (see above), they provide the following additional advantages, they:

- *are easy to mix and no aggregate has to be added on site*
- *improve thermal insulation*
- *help to mitigate the effects of condensation*
- *are light and therefore easy to apply*
- *have good fire resistance.*

These plasters have proved very popular over the past 40 years, though in the past ten years or so their use has diminished significantly as the house construction industry has sought prefabricated and dry-finishing solutions such as dry-lining (see later section).

Gypsum plasters are generally applied in two coats and manufacturers produce a range of undercoats and top coats designed to suit different circumstances.

Undercoats have the addition of coarser aggregates than finishing coats and are designed for specific backgrounds and for practically every requirement. For example:

- *Browning: works well on solid backgrounds, such as block or brick with moderate suction and adequate mechanical key (dense concrete blocks or bricks with well raked-out joints).*
- *Bonding: works well for low-suction backgrounds, such as smooth dense concrete or plasterboard.*
- *Toughcoat: an undercoat with good impact resistance for most backgrounds including metal lath.*
- *Hardwall: can be applied by hand or machine. It is suitable for most backgrounds, except plasterboard.*

Finishing coats contain finer ground aggregates and gypsum than the undercoats to give a smooth, even finish. Three types of finish are typically manufactured:

- *a fine finish which is suitable for plasterboard*
- *a final coat plaster suitable for gypsum undercoats*
- *a final coat plaster suitable for a range of backgrounds (i.e. lime or cement or gypsum-based undercoats).*

In the more recent past, a number of single-coat plasters have been introduced; largely, these are designed to be machine projected, rather than hand applied.

Application

On normal surfaces, such as brick- or blockwork, two-coat work (float and set) is common, with an undercoat 11mm thick and a finish coat 2mm thick. The undercoat should be lightly scratched to form a key, and the finish coat should be applied when the base coat is firm but not dry. On metal lathing two undercoats are usually necessary, the first filling the gaps between the lath and the second to provide even suction for the finish or setting coat.

On board finishes (see the next section on plasterboard and dry-lining) two-coat work can be used but, unless the boards are being plastered to improve thermal insulation or fire protection, there is no need for the floating coat. A setting or finish coat is quite adequate as long as the boards have been fixed correctly.

When mixing gypsum plaster it is important to use clean water and clean tools to avoid contamination, which may accelerate or retard the setting time. To ensure good adhesion and to exclude any pockets of air the plaster should be applied with very firm pressure. Trying to put thick coats on in one layer is therefore rarely successful.

Gypsum plasters are mainly applied by hand. Machine projection is possible, and favoured, for large runs of work.

Once the undercoat has been applied and it is still wet, it is ruled flat using a long straight edge known as a 'Derby'. Any depressions are filled with additional undercoat to create a flush surface. Once the undercoat has started to set it will be scratched to provide a suitable key for the application of the top coat.

The top or setting coat, a hard smooth gypsum plaster with very fine aggregate, is applied to the undercoat to a thickness of about 2–4mm.

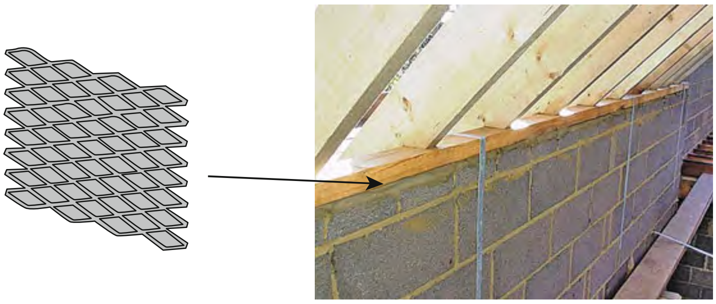
Difficult backgrounds

Stable backgrounds with a good key and moderate suction are suitable for most types of gypsum plaster. Materials with high suction, such as aerated blocks, can present a problem. Special plasters with water-retaining agents are often recommended because aerated blocks absorb water readily. Water in the mix may be absorbed to such an extent that the chemical reaction which binds the plaster together cannot occur. Some plasterers try to get round this problem by wetting the blocks prior to plastering, not always with successful results. It is difficult to wet the blocks consistently and very wet blocks will expand slightly and shrink on drying. This can lead to cracking. Success can be achieved by spraying the wall sparingly with a fine 'mist' of water.

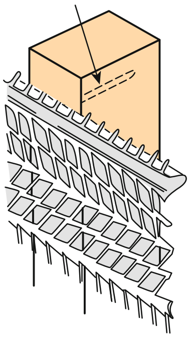
Some very smooth surfaces, such as dense in-situ concrete, offer a poor key and low suction. In this situation it is common practice to specify a PVA adhesive to be applied to the background before the application of the undercoat or single coat plaster.

Some materials, such as timber or very porous old stonework, are unsuitable for plastering directly. In such cases a galvanised or stainless steel lath can be fixed to the background and this acts as a mechanical key for the plaster. A good example of this would be where the masonry wall meets the timber wall-plate which supports the roof structure.

Metal lath is available in rolls and sheets. A thin strip is usually fixed to the wall-plate covering the mortar bedding below. This is not required if the wall is dry-lined.



Rib lath can be fixed to battens with nails or staples.



Rib lath can also be fixed to walls or steel channels.

Large areas of metal lath should be plastered with a plaster designed for such application. When plastering metal lath an initial coat, known as the 'pricking-up' coat is required. This should be forced through the lath and lightly scratched to form a key for the floating coat. There are a variety of metal laths on the market.

External angles

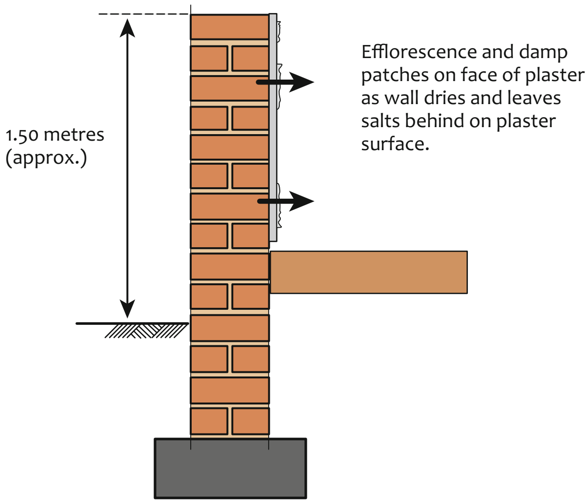
In early lime plastering it was common to find external angles (e.g. on a chimney breast) formed in a harder plaster or protected with long timber strips. Nowadays, galvanised or stainless steel angle beads are the norm, and these are fixed with nails or plaster dabs prior to plastering, as shown in the left-hand photograph below. Galvanised beads can be damaged by the razor-sharp edge of the trowel. As the galvanised surface is scraped away, the bead is free to rust and, in the humid conditions which can occur in the drying-out process, decay can be rapid. Angle beads are available for plasterboard (see the right-hand photograph below).

Damp walls

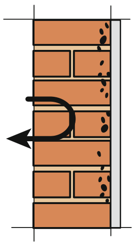
In existing houses with damp walls, or where walls are to be re-plastered following the installation of a DPC, gypsum plasters are not suitable. They readily absorb water and will eventually break away from the background. Furthermore, gypsum plaster cannot stop the passage of salts caused by migration as water evaporates from the wall. Some of these salts occur naturally in building materials, others are drawn from the wet ground. These salts, depending on their chemical make-up, can either appear as efflorescence on the surface of the wall (a white fluffy powder) or as well-defined damp patches. Efflorescent salts are nearly always present in building materials and their presence merely indicates that moisture is evaporating from the structure. Much more serious is the presence of chlorides or nitrates; chemicals which will have been drawn into the wall through failure of the DPC. These materials are hygroscopic. Hygroscopic salts continually absorb moisture from the air, resulting in damp patches on the walls. This can be confused with failure of a replacement DPC.

Following DPC replacement it is usual to use render and floating coats of sand and cement containing a waterproofer or salt retarder to keep the salts away from the face of the plaster. The thickness depends on the nature of the wall, but will be in the region of 8–10mm per coat. The sand should be clean, 'sharp' and well graded. The finish or setting coat is usually a gypsum plaster applied in a very thin layer, about 2mm thick. This gives a smooth finish ready for decoration.

In wet conditions a chemical reaction can occur between cement and calcium sulfate. It is therefore important to ensure that the floating coat is reasonably dry before applying the finish. A dry floating coat will help to ensure that the effect of any shrinkage in the finish coat is minimised. Sand/cement plasters are very brittle and are not always suitable for application to walls which may have been laid in lime or weak cement mortars. The dense plasters cannot readily accommodate minor movement of the wall and cracking will occur. Lime or plasticisers can be added and the strength of the mix should take into account the key and the suction of the background.

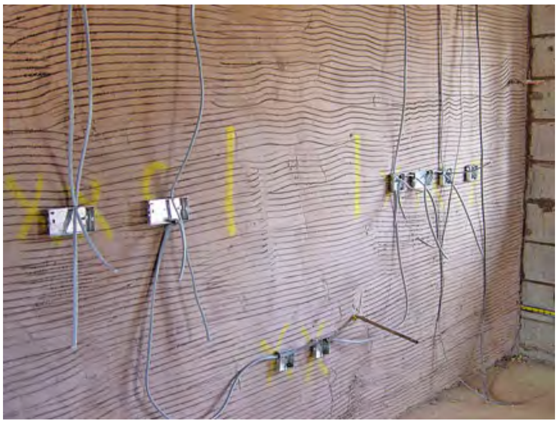


Efflorescence and damp patches on face of plaster as wall dries and leaves salts behind on plaster surface.



Cement/sand or 'Dri-Coat' plasters keep salts away from plaster surface.

Alternatively, other specialist plasters, such as Limelite can be specified. Limelite is the trade name for pre-mixed plaster with cement and lime, rather than gypsum, as the binding agent. It shares the same advantages as gypsum lightweight plaster, i.e. for use after the installation of a DPC in an existing building. Unlike some of the gypsum plasters, Limelite is not suitable for use on plasterboard.



Where there is no risk of dampness there seems little point in using site-mixed, cement-based plasters. They are slightly more expensive, offer less thermal insulation, are prone to drying shrinkage and are more likely to be contaminated as mixing with sand is required on site. However, they are sometimes required by some Building Regulations Approved Document design solutions or accredited construction details schemes for party walls, as they help to improve sound insulation by blocking any small air paths or gaps in the wall. See the two images above: both are party walls and have been plastered using a sand/cement plaster to reduce incidence of noise transfer. The walls will subsequently be dry lined.

Condensation

Earlier in the chapter it was mentioned that one of the advantages of lightweight gypsum plaster is its ability to help prevent condensation. If the surface of a wall plastered with dense plaster is cold, then condensation may occur on its surface. Gypsum is a more porous material than lime or cement, with a much lower density and will absorb some of the moisture, releasing it when the temperature increases and the wall warms up. Because gypsum plasters use lightweight aggregates they will also improve the insulation of the wall and help to increase its internal surface temperature. However, with gypsum if the humidity is too high the plaster will become saturated and large patches of damp will appear, which are an excellent breeding ground for mould growth. To counter this occasional effect some authorities suggest that a small amount of lime mixed in with the gypsum will help to reduce mould growth.

Plasterboard and dry-lining

Plasterboard

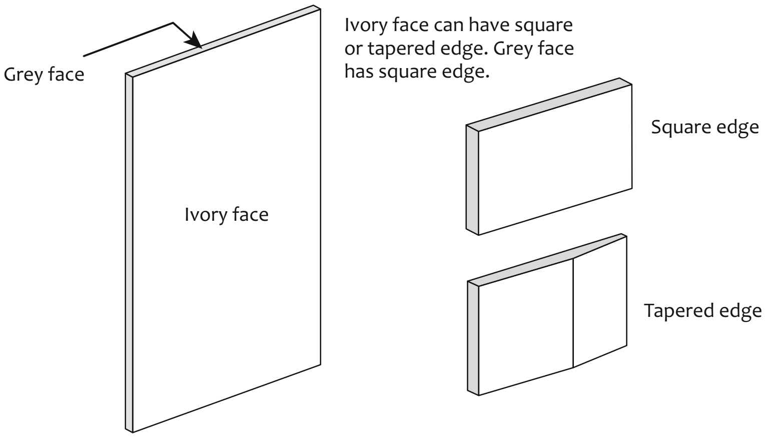
For the past decade or so in most new housing developments, as well as in extensions to existing houses, wet-applied plasters have increasingly been replaced by prefabricated dry finishes. These consist primarily of plasterboard (a factory-made board consisting of a core of gypsum plaster with thick paper linings on either side) bonded and/or mechanically fixed to the background, with the joints between boards filled, ready for decoration.

Plasterboard has been available since the 1920s. Its early use was mainly confined to ceilings where it proved a cost-effective and quick alternative to traditional lath and plaster. Nowadays it is available in a huge range of grades and sizes and is used for a variety of purposes including ceiling linings, wall linings and proprietary partition systems. It can also be used to improve thermal insulation, sound insulation, fire protection and to provide vapour control layers. Early plasterboards were always intended to receive one or two coats of plaster but in modern construction most plasterboard is self-finished; in other words the plasterboard surface can be painted or papered. Manufacturers produce their own specific products, many with their own trade names. The section below explains, in general terms, the most common types.

Because plasterboard uses a gypsum plaster with lightweight aggregate it will have a relatively low thermal capacity and will warm up quickly where heating is intermittent (e.g. a typical modern domestic central heating system timed to switch on in the early morning). This will help to reduce the risk of surface condensation. Standard plasterboard is sensitive to moisture and is therefore not suitable for areas of high humidity or areas which are permanently damp.

Wallboard

Wallboard, despite its name, is used for a variety of applications including dry-lining walls, lining ceilings and on stud partitions. Typical thicknesses include 9.5mm, 12.5mm 15mm and 19mm. It is available in a range of sizes, e.g. 1,800 x 900, 2,400 x 900, 2,400 x 1,200, 3,000 x 1,200mm, and can have tapered or square edges (on the long sides). The tapered edges are designed for direct decoration or skimming and the square edges for plastering or textured finishing, such as Artex.



Plaster or paint should only be applied to the ivory surface.

Vapour control wallboard

This is the same as wallboard, although the inner face is covered with a thin vapour control membrane. It is used in situations where there is a risk of condensation, such as bathrooms.

Thermal boards

This is a wallboard with insulation bonded to the inner face. The insulation can be of various types, including polystyrene and phenolic foam. Thermal boards often contain an integral vapour control layer to minimise the risk of condensation.

Lath

Lath is the oldest form of plasterboard and is designed to receive a plaster finish. The boards are fairly small and easy to handle in constrained spaces. Some lath boards are available with vapour control layers. Typical sizes are 1,200 x 600mm or 1,200 x 400mm.

Moisture-resistant boards

These are usually 2,100 x 1,200mm with a thickness of 9.5, 12.5 and 15mm. They can be used for external soffits or as a base for wall tiling around showers, etc.

Other boards

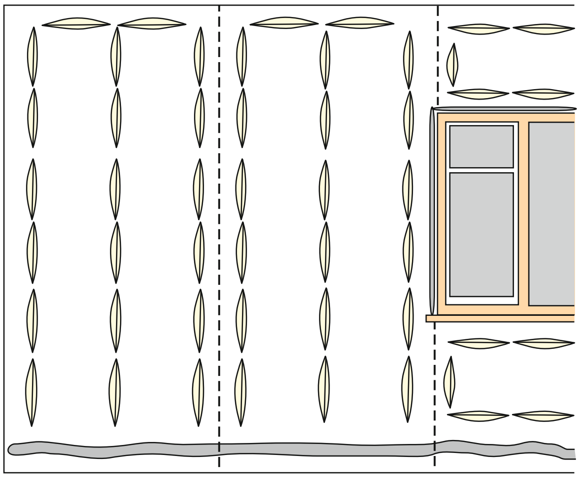
There are several other boards but most of them are beyond the nature and scope of this book. They include boards with specially designed plaster cores to improve sound insulation and fire protection. Many of the specialist boards are designed for industrial and commercial use rather than for domestic housing.

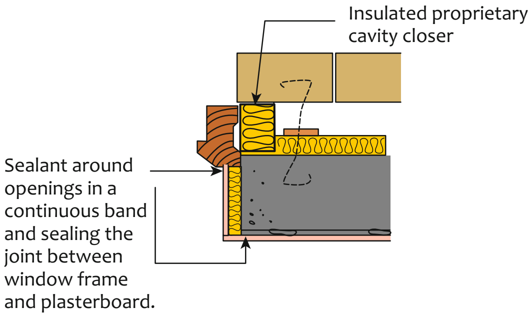
Dry-lining

When plasterboard is used as a wall finish in place of wet plaster it is referred to as dry-lining. In modern construction there are two main approaches: bonding the boards to adhesive dabs or securing the boards to metal channels, which themselves have been bonded to the background. Some builders prefer to fix the boards to timber battens attached to the wall. The systems described below are based on one manufacturer's recommendations and, to keep this section simple, only basic installations will be described.

'Dot and dab'

The use of adhesive dab is the simpler and more popular of the two systems. It comprises a series of adhesive dabs applied by trowel to the wall. These are typically 50mm to 75mm wide and 250mm long. Three columns of dabs are normally required per board (9.5mm board 1,200mm wide usually requires four) with horizontal dabs between the columns at ceiling level, and a continuous band of adhesive at skirting level. When the dabs are in position, the board (cut 15mm short of wall to ceiling height) can be pressed and tapped into position, tight against the ceiling. It is temporarily supported at floor level by off-cuts of board. An insulated closer or an accredited closing detail, possibly using an insulated reveal board, should be used to prevent cold bridging, air leakage, condensation and mould growth around openings. Reflecting concerns about heat energy losses due to casual draughts and air leakage, the Building Regulations are demanding and testing for higher levels of effective airtightness. There have been some reported problems with the airtightness of dot and dab applied dry-lining, so the effective and complete application of the requisite adhesive in continous bands, particularly around openings and service penetrations (such as socket boxes), is essential.





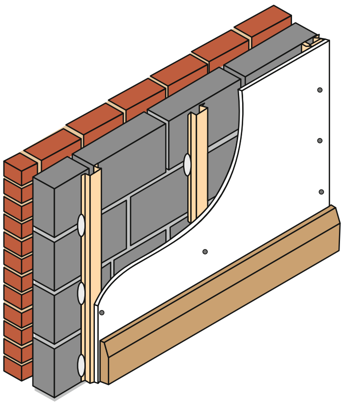
Typical pattern of adhesive dabs and adhesive band behind skirting.
Sequence of the images below dry-lining being applied to a wall.

Thermal board

The procedure for the use of thermal laminate board (a plasterboard with an inner layer of insulation) is similar, although two screw fixings are required – 15mm in from the board edge and at mid height. These are required to ensure that the plasterboard maintains its integrity in a fire (i.e. protects the flammable insulation layer).

Metal channels

In this alternative system, the boards are fixed to a series of metal channels, which are themselves bonded on adhesive dabs to the background. The vertical channels are fixed at 600mm centres with top and bottom channels running horizontally. The boards themselves are fixed to the channels with special screws, typically at 300mm centres.

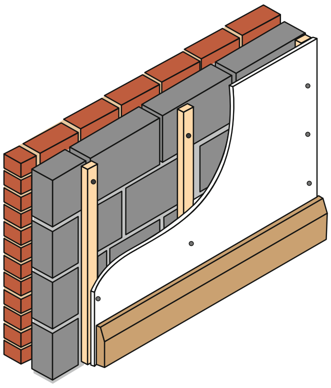


Metal channels bedded in dabs of bonding compound.

Note: The boards must be well fitted to ensure that there is no flow of air behind the boards. Failure to do this will reduce their thermal performance. Additional sealant can be provided around the edges of junctions, i.e. around window reveals, external angles, etc.

Other methods

In the past, many builders, when dealing with the repair and improvement of older buildings, have fixed plasterboard to a series of battens attached to the wall. However, there is always the risk of dampness in the cavity (i.e. behind the plasterboard) affecting the battens. To avoid this, builders sometimes fix the battens to the wall but separated from it by a vertical DPC. Solid external walls (which are likely to be cold once the dry-lining is fixed) should always be dry-lined with boards which contain an integral vapour check if interstitial condensation is to be avoided. Fixing plasterboard to timber battens is not recommended where walls are likely to be damp or where condensation may occur.



Timber battens nailed or screwed to wall.

Jointing for direct decoration

When the boards have been fixed they are ready for jointing and finishing. In current practice the boards are normally self-finished. However, if required, they can be covered with plaster (though not all plasters are suitable for plasterboard). Plaster gives a significantly better finish but is more expensive and requires application by skilled plasterers. For direct decoration, jointing is necessary to provide a good surface for decoration and to minimise the risk of cracking along board joints and at internal angles, such as the corners of rooms and the junction of walls and ceilings.

Sequence of work

Jointing can be carried out manually or using a hand-held machine. Assuming that the ceiling has already been taped, the normal sequences is:

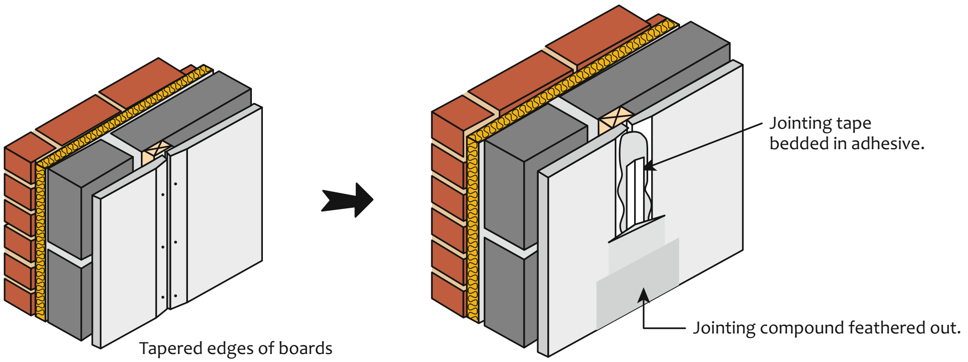
- *internal angles, then*
- *tapered edge joints, and finally*
- *external angles.*

The basic procedure is as follows:

- *apply jointing compound along the tapered joint*
- *bed joint tape into compound*
- *apply jointing compound along the top of the tape and feather out*
- *and repeat this process once or twice.*

Internal and external angles can be finished in the same way (external angles usually require a special pre-formed reinforcing tape).

The taping and jointing exercise can be done by hand or by machine. Where square-edged boards have been used, obtaining a smooth, flush surface is very difficult; these boards are best used when a skimmed plaster finish is to be applied.

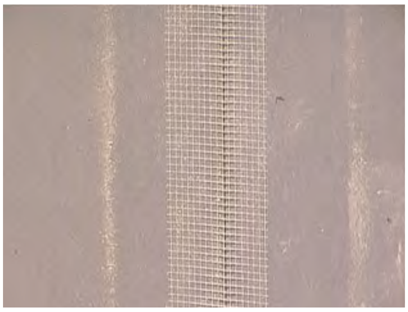


Tapered edges of boards ready for jointing.

Jointing tape bedded in adhesive.

Jointing compound feathered out.

Plasterboard jointing can be done by hand or hand-held machine. There are a number of jointing techniques although they do not differ much in principle. In the left hand example the operative is using a hand-held machine to apply a paper tape to the junction of the ceiling and the wall.
The lower examples show (left to right) hand joining, a reinforcing tape being applied to a external corner at window reveal and a self adhesive skim tape applied to plasterboard joints.



Sealing

When the boards have been taped and finished it is good practice to give them a coat of primer/sealer. These products vary from manufacturer to manufacturer. Their purpose is to even out the difference in texture and absorption between the board surface and the jointing compound. Without it, the joints may 'grin' through the paint. Some primer/sealers also aid the subsequent removal of lining paper (see Chapter 11 on decoration) and can improve vapour control properties of the board. The latter might be required where interstitial condensation behind the board is a potential problem.

The jointing here is complete. Tape has been applied to the junction of the ceiling and walls, the joints between the boards. The tape has been covered with jointing compound, which has been feathered out. The boards are now smooth enough to receive a coat of sealer.

Skimming

This is an alternative to self-finishing and usually takes the form of a 2mm skim coat of suitable finishing plaster. Board preparation for square-edged or tapered boards usually involves joint reinforcement, as described above. Another option is to use a self-adhesive mesh tape applied directly to the board. To minimise the risk of cracking it is important to ensure that plaster is pushed through the mesh to fill any gaps between the boards. External angles can be formed using thin coat angle beads.

In some cases the boards can be finished with two coats of plaster, a floating coat (6–8mm) and a setting coat (2mm). This is usually only necessary where improved fire protection is required. Special undercoat (floating coat) plasters are normally required for plasterboard.

On this site the designer required the dry-lining to be finished with a plaster skim. The joints between the plasterboard are filled with the skim plaster and this is supported by a self-adhesive tape which was applied to the joints prior to the application of the plaster. You can see the joints as the plaster skim had not yet dried out. Skimming dry-lining can provide a superior quality finish to simple jointing.

Ceilings

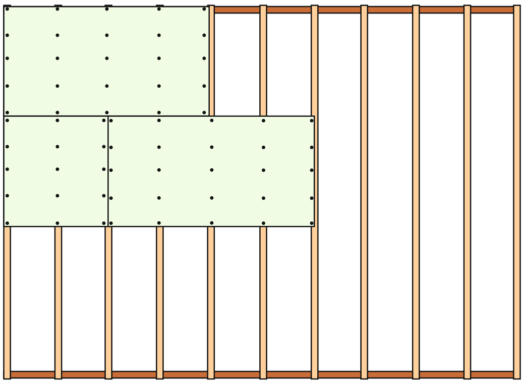
Wallboards can be used for ceilings, although in some circumstances smaller plasterboards are more manageable. Plasterboards should be fixed with the long edges running at right angles to the joists. Detailed guidance on the need for perimeter and centre noggings can be found in the product literature provided by the plasterboard manufacturers. The guidance here represents generally accepted good practice. Wallboard of 12.5mm requires only perimeter noggings if the joists are at centres of 400 or 450mm and will normally achieve the Building Regulation requirements for 30 minutes' fire resistance to intermediate floors of dwellings that have floors which are not higher than 5m above ground level. At 600mm centres, both perimeter and centre noggings are required. Where 15mm wallboard is used, no noggings at all are required for 400, 450 and 600mm centres. The boards should be fixed with special plasterboard screws, usually at 200mm centres (screws should be long enough to provide 25mm penetration into the joists). Nails can also be used – and were commonly used in the past. The recommended centres for nails are approximately 150mm. The use of screws minimises the risk of 'surface popping' and impact damage to plasterboard associated with nailing.

Ceilings formed with wallboard can be finished by taping and jointing, priming (to provide even suction for the paint) and painting. Tapered-edge boards will normally provide the smoothest finish, if the boards are square edged the tape will be slightly proud of the board surface and it is not so easy to get a smooth, blemish-free paint finish.

Alternatively, ceilings formed with wallboard can also be plastered (most plasterboards only have one face designed for plaster and this must be taken into account when fixing the boards). A 2mm plaster skim can be used or, to achieve an even better quality finish, a 5mm undercoat of bonding plaster followed by a 2mm skim coat – though this is rare in practice. Plasterboard lath is only designed for plastering (it cannot be self-finished) and does not usually require taping.

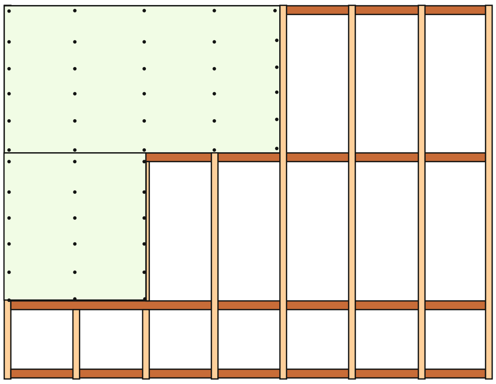
LOOKING UP

1,800 x 900mm plasterboard, 12.5mm thick.
Joists at 450mm centres



Boards laid with staggered joints. Perimeter noggings required but centre noggings not required. Perimeter noggings not required for 15mm plasterboard.

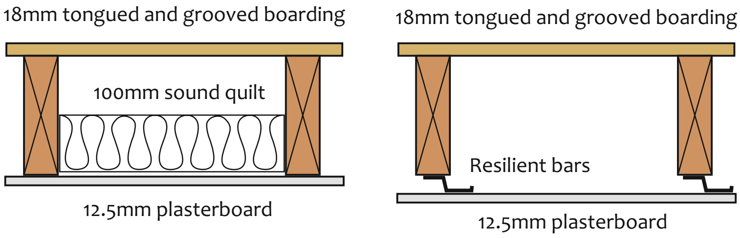
2,400 x 1,200mm plasterboard, 12.5mm thick.
Joists at 600mm centres



Boards laid with staggered joints. Perimeter noggings required but centre noggings also required. Neither required for 15mm plasterboard.

Sound insulation

Until 2003, there were no specific requirements for sound insulation of the intermediate floors of houses. The Building Regulations were revised and required a minimum performance standard of acoustic insulation for floors to bedrooms, bathrooms and other rooms containing a toilet. The requirements are not difficult to achieve; if a suitable thickness of plasterboard and acoustic insulation quilt is specified in the construction this will also normally, as previously mentioned, usually achieve the fire resistance requirements by default.



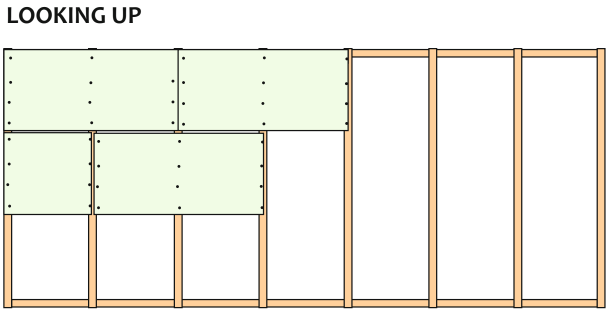
In both cases 15mm plasterboard will provide slightly better sound insulation, with only a marginal increase in cost.

Fire resistance

The Building Regulations require that dwellings have minimum periods of fire resistance for intermediate floors and that any associated supporting elements, such as walls, columns, piers or beams, meet the same standard. The Regulations require that dwelling houses with floors within 5m of ground level have 30 minutes' fire resistance and 60 minutes' fire resistance to all the floors in dwelling houses with a floor above 5m. Typically, 30 minutes can be achieved with one 12.5mm layer of proprietary plasterboard, skimmed or self-finished, and 60 minutes with two layers of 12.5mm proprietary plasterboard, with the joints staggered and filled. However, ceilings to roofs of normal dwelling houses do not require any fire resistance, but some roof truss manufacturers or designers may require a certain thickness of plasterboard to help provide restraint or bracing to the undersides of the trusses.

Plasterboard lath

Plasterboard lath is a relatively common type of ceiling plasterboard in refurbishment work. Plasterboard laths are quite small (1,200 x 400mm) and do not normally require noggings or jointing. Because each board is small and because there are so many joints, stresses and strains from drying, etc. are spread across the ceiling, thus reducing the risk of cracking. The boards are also easy to handle and can be fixed by one person. They are only suitable for ceilings which are to be plastered.



Section through lath joint, showing skim plaster extruding through joints between laths.

Fixings

When securing shelving or cupboards to plasterboard it is important to use the correct type of fixing. Inadequate fixings can lead to damage of the board and, in extreme circumstances, can pull the board away from the wall.

Decoration 11

This chapter is concerned with the decoration of both the internal and the external surfaces in houses. Decoration has a number of purposes:

- *to provide an aesthetic finish, i.e. providing style, colour and visual interest*
- *to increase the durability of the decorated surface, e.g. through moisture and ultraviolet (UV) light protection*
- *to maintain functionality, e.g. through avoidance of saturation (particularly externally).*

This chapter briefly explains the historic development of wallpapers and paints, but concentrates on current developments and techniques.

Wallpapers

Until the eighteenth century, those who could afford to decorate the internal surfaces of their dwellings may well have had timber panelling fixed to the internal surfaces of walls and partitions. The purpose was to provide a suitably robust and aesthetic finish which provided a degree of hygiene and was as easy, or easier, to maintain and clean as unfinished masonry or plastered surfaces. Tapestries and other fabric wall hangings were also used but, like timber panelling, were affordable only by the wealthy. As Britain became gripped by speculative development in the eighteenth century, plastered finishes became more economic and far more common. Paint was an option for plastered finishes but effective painting for lime plaster relied on a limewash or the use of oil-based paints, which required the plaster to dry out for a minimum of 20 months prior to decoration.

A Victorian decorator's catalogue showing a range of hand- and machine-printed wallpapers.

The first wallpapers to be used were imported from France and China. They were expensive handmade, hand-printed papers and therefore the preserve of the wealthy. By the early part of the nineteenth century, a small indigenous wallpaper industry received a significant boost as a combination of new machine-printing techniques, and the removal of a wallpaper tax, meant that home-produced wallpapers became increasingly popular.

Over the next century and a half, fashion ebbed and flowed and various design and stylistic trends have come and gone; however, pasting paper to walls and ceilings is still a popular and effective means of decoration today.

Wallpapers can hide poor quality plastered finishes and they can provide a rapidly applied decorative scheme, reducing lengthy painting and drying-out processes. The vast majority of wallpapers come in 10m long rolls and in a standard width of 520mm. Lengths are cut in accordance with the specific requirements of the wall/ceiling for application and are pasted vertically onto the prepared internal wall finish. Some wallpapers are pre-pasted, requiring controlled soaking in water, but the majority of wallpapers require the application of a paste across one entire surface of the paper prior to being 'hung', or pasted and smoothed, onto the wall. Some highly absorbent wall surfaces may also require 'sizing', which is the application of a dilute paste to the wall, in addition to the paste applied to the paper itself. This is in order to avoid suction, where the wall absorbs the moisture from the paste, making wallpaper manipulation (for lining up patterns, ensuring a good joint between sheets, etc.) and adhesion, difficult.

There are three principal types of wallpaper:

- **Patterned and coloured designs:** *generally these have a repeating pattern which must be lined up between sheets during application in order to produce the overall desired effect. Protecting the printed surface of such papers during pasting and application and achieving an effective finish requires skill and care. Some examples can be very elaborate and the more exclusive handmade papers are highly expensive. Some patterned and coloured papers have a vinyl layer which forms the surface for the pattern to be printed on. This enables papers to be more readily washable in areas such as kitchens where staining is possible. Some vinyl papers can also better resist higher levels of humidity and some enable easy removal from walls as the vinyl layer peels away from the paper backing, which itself remains on the wall, effectively forming a lining for subsequent decoration.*
- **Embossed and textured sheets and wallpapers:** *these became popular in the late nineteenth and early twentieth century under trade names such as Lincrusta and Anaglypta. Lincrusta were coloured, hard, durable sheets of paper and linseed putty, intended to provide cost-effective imitations of expensive moulded fibrous plaster. Anaglypta were heavy-duty papers with bold and repetitive patterns embossed into them ready for subsequent painting. While products sold under both trade names are still widely available, the more common type of embossed papers currently used are simpler, stiff papers and provide a textured pattern to the wall. They are all designed to be painted after hanging.*

A modern reproduction Anaglypta paper beneath a dado rail. This wallpaper is embossed and designed to be decorated. In this particular case, as it is located in a hallway, a water-based eggshell paint has been selected for its hardwearing and durable qualities.

- **Lining papers:** *Originally these were intended to be applied to walls to hide minor defects and provide uniform suction prior to hanging more expensive patterned papers. Lining papers come in 530mm width rolls, so that, if used vertically, the lining paper's joints do not coincide with the joints of the patterned paper. It is not uncommon, however, for lining papers to be laid horizontally rather than vertically: for this reason they often come in double-length rolls (20m). With the advent of cost-effective emulsion paint, lining papers have also been used to improve the wall surface prior to painting. Lining papers are graded (800–2,000) in terms of their thickness and stiffness. For example, an 800 grade lining paper is thin and lightweight and might be used on a good wall finish with very minor imperfections. A 2,000 grade paper is more akin to a thick cartridge paper and would be selected for an uneven wall with lots of imperfections. However, because of the relative thickness, a 2,000 grade paper is much harder to manipulate and hang effectively. 'Woodchip' is a form of lining paper with small wood chips captured in its surface. This was commonly used to cover walls where there was significant surface damage to the wall finish and is designed to be painted. It was very commonly used in refurbishment schemes in the last few decades of the twentieth century.*

Although hanging paper is often intended to reduce the impact of poor quality or uneven finishes, this does not mean that surface preparation prior to paper hanging can be ignored. Typically, a significantly greater amount of time should be budgeted for preparation of wall surfaces than for the paper hanging itself. In new houses, patterned paper is relatively rare; equally, it is very rare to find lining paper used prior to initial painting.

Paints

Paints have been used throughout history to provide colour, style and protection to virtually every surface in houses. They need to be liquid, with varying degrees of viscosity, in order to enable effective application. Once applied, they need to dry rapidly to form opaque and durable finishes to both internal and external surfaces of houses.

Paints consist of three elements:

- **Pigments** – *which impart colour and opacity (i.e. the prevention of light penetrating through to the substrate). This is useful in protecting from UV radiation and masking previous colours. In the past, naturally occurring and metal-based pigments were common; nowadays synthetic pigments offer both economy and reduced health risks.*
- **Binders** – *resins which are the film and body-forming component of paint, binding the pigments together to give the paint 'body'. In the past, milk, bones, lead and various oils were commonly used. More recently, synthetic resins such as vinyl, polyurethane and alkyds predominate.*
- **Dilutents** – *in which the pigments and binders are suspended. In the past, natural and man-made solvents, such as turpentine, white spirit, alcohol, etc., were common. Nowadays water is increasingly common as a paint dilutent as there has been increasing regulation concerning the environmental and human health impacts of volatile organic compounds (VOCs), such as white spirit and the other solvents mentioned above. Once applied, the dilutents evaporate leaving the pigments and binders as a surface coating.*

Paints are designed and selected to provide differing levels of surface quality and protection according to a number of factors:

- **the degree to which they are exposed to external weather conditions:** *this impacts on the number of coats required and the nature of the paints themselves*
- **the nature of the surface to which they are applied:** *generally, oil-based paints were used on timber joinery internally and externally, water-based paints on masonry and plaster; however, this distinction has become less and less relevant because of the increasing use of water-based paints, related to concerns about VOCs*

- **the likely degree of mechanical damage/wear and tear:** *doors, windows and skirtings potentially suffer greater mechanical wear and tear than ceilings and walls, for example. This impacts on the selection of the finish of the paint itself: essentially, gloss finishes provide better weather and mechanical protection. Matt paints provide less protection and are less washable but, as they contain less binder (the expensive part in modern paints), they are generally cheaper to produce. Matt paints also mask surface irregularities better than glossier finishes.*

The development of modern paints

Until the twentieth century, paints would have been manufactured by the painters and decorators themselves – it was very common for all trades to be merchants for their materials as well as contractors. Great skill and knowledge of the various materials used was required. Early pigments were generally either naturally occurring minerals (ochre, etc.) or animal-based products (blood, crushed insects, etc.); some were relatively cheap and others, brighter, non-earth colours, were very expensive. For oil paints, the most common binder was lead carbonate (which was highly toxic but did provide a durable and dense body to the paint), which was commonly mixed with linseed oil. Turpentine – a distillation of pine resin – was a common dilutent for oil-based paints. Water-based paints for masonry were limewashes, consisting of lime putty, pigment and water and, for internal walls and ceilings, distempers made from crushed chalk, animal bone glue, pigments and oils suspended in water. Limewashes and distempers were moisture permeable and highly alkali. They would therefore not impede the transmission of moisture nor the slow hardening of lime-based plasters and renders.

During the twentieth century, industrial production of paint completely replaced craft production. Development of the petrochemical industries enabled new materials to become available. White spirit replaced turpentine as a dilutent for oil-based paints and alkyd, vinyl and polyurethane binders replaced lead and linseed oil.

"Themagloss" Enamel Paint

For the highest class of Decorative Work. Dries with a Brilliant Gloss.

A Selection of Shades.

Cream	Light Stone	Dark Stone
Light Oak	Dark Oak	Antique Oak
Golden Brown	Light Grey	Blue
Pale Green	Middle Green	Myrtle Green
Holly Green	Light Bronze Green	Dark Bronze Green
Chocolate	Marone	Bright Red

Also in Black, White and Dark Grey.

Suitable for Interior or Exterior use. Easy to apply.

"Themagloss" gives a most efficient, durable high gloss finish entirely free from brushmarks, at the same time possessing remarkable opacity. Is suitable for use on almost any surface, including ironwork, stonework, etc. Can be applied on any firm, hard surface, but for the very best work we recommend our Flat Undercoating, which can be supplied at the same price.

A 1930s trade catalogue identifying a far brighter, industrially produced and widely available range of oil-based paints.

The first emulsion paints appeared in the 1950s and these rapidly replaced distempers, as they were harder wearing and more reliable. They consist of latex or, latterly, vinyl binders suspended in water, which form a relatively non-permeable skin. This change was matched by the switch away from lime-based plasters (with their associated slow hardening and permeability) to fast-setting, water-soluble gypsum plasters. Although most internal plaster paints were water-based emulsions, some walls, particularly those which were likely to suffer significant wear and tear (corridors and areas in institutional buildings with lots of human traffic), were sometimes painted in oil-based 'eggshell paints' – so called because the finish was hard, impermeable and semi-gloss like an eggshell. Eggshell paints could also be used on internal joinery, such as skirtings and doors. They had a durability and washability that was superior to a water-based emulsion. They were also useful in bathrooms and kitchens where their superior impermeability coped more effectively with the elevated levels of condensation common in such rooms.

Until recently the most common paints used on joinery were alkyd based. These required three coats to provide sufficient protection for bare timber: a primer coat to stop subsequent coats being absorbed and help to fill the timber grain; an undercoat to further fill the timber grain and provide opacity and a uniform flat surface, followed by the top coats – two were commonly specified. These were hard-wearing colour-fast gloss paints. The build-up of coats necessary with alkyd paints provided cost-effective protection, opacity and, for externally applied paints, good UV light repellence. UV light is one of the key mechanisms in degradation of external building materials. However, these multi-coat paints could be complicated to apply, required regular maintenance (a three- to five-year repainting cycle was common) and were relatively brittle. In the past ten years, EU Regulations concerned with air quality and the health of construction workers have required the development of low-VOC paints: essentially this means that the majority of paints, whether for plaster, external masonry or timber are increasingly water-based.

External masonry paints

Although limewashes are increasingly being used in conservation, the majority of paints used on external masonry surfaces nowadays will be water-based emulsions. In the past, oil-based paints have been used on external masonry surfaces and this has led to various problems. For example, there can be a reaction between the lime/cement-based render and the paint, leading to flaking and cracking. The oil-based paints are less porous than their water-based alternatives and any moisture getting under the paint can become trapped behind the relatively impermeable paint – pushing the paint off the surface. Nowadays, special high-performance emulsion paints are commonly used. These differ from emulsion paints for internal wall surfaces as they contain fungicides and other additives to accommodate a greater degree of movement of the substrate and provide greater durability. Dusty or friable surfaces must be primed with a stabilising solution prior to the application of two coats of the paint. They tend to be matt (although gloss and semi-gloss options are available), come in a huge range of colours and are applied by brush, roller or spraying. Once applied, redecoration at regular intervals will be required.

Internal wall and ceiling paints

Modern-day water-based vinyl emulsions are the most common finish to all internal plastered/dry-lined finishes. In refurbishment, where existing wall finishes may have deteriorated over time, or for a superior finish in new construction, such paints can be applied onto lining paper. Usually, however, emulsion paints are applied directly to dry-lined or plastered internal finishes. It is recommended that the first coat is applied as a 'mist coat'. This is a diluted first coat and acts as a primer. Generally, two to three subsequent coats are sufficient to provide coverage and, while emulsion can be sprayed or brushed on, the most common method of application is by roller. Emulsions come as a matt or semi-matt – often referred to as 'silk' – finish. A matt finish obscures minor wall defects and undulations most effectively. A silk finish is slightly harder wearing and is marginally more washable – it is often specified in bathrooms, kitchens and in areas of high usage. An alternative in these circumstances is to use a water-based eggshell paint. These paints have superior moisture and water resistance and are applied in the same way as a standard emulsion.

Vinyl-based emulsion paints are popular, cost effective and easy to use. Rollers and brushes are the most common means of application.

Painting external joinery

Timber is a hygroscopic material: it acts like a sponge, swelling and shrinking as moisture is absorbed or evaporates according to atmospheric conditions. While alkyd paints attempted to provide a waterproof barrier for joinery, there were several paths for moisture into the timber: ineffective putties and glazing beads, end-grain timber and microscopic cracks in the paint film being the most common. Changes in timber moisture content were problematic for alkyd paints because, as the wood moves, the rather brittle paint cracks, allowing more moisture into the timber. As these paints are effective water barriers, part of this moisture becomes trapped behind the paint film, leading to a loss of paint adhesion, more cracks and flaking and a downward cycle as more moisture is absorbed by the timber. Manufacturers have responded to this problem and developed water-based microporous paints: these are designed to shed water while increasing the vapour permeability of the paint film, allowing a significantly greater proportion of any moisture behind the paint surface to evaporate through the paint. The increased stability of the timber reduces the incidence of cracking and flaking of the paint film – creating a virtuous circle. Tests have shown favourable results, suggesting that an extended five- to seven-year maintenance cycle can be achieved, but the advantages of these microporous gloss paints depend on strict adherence to manufacturers' instructions. For example, the reduced number of coats, frequently a single combined primer/undercoat and a single gloss topcoat, encourages porosity, but means that the quality of the painting must be exceptional to ensure performance. There have been some concerns regarding external gloss paints which are claimed to be effective after a single coat. A single coat may not provide sufficient thickness to give effective UV protection and guarantee water-shedding properties. However, such single-coat paints may be effective internally. Increasingly, external gloss paints are now water-based as new acrylic binders have been developed. Nowadays much of the joinery used in new housebuilding is pre-finished with various paint systems prior to its arrival on site. This is a more efficient method of protecting such joinery, it also adds significantly to the longer term durability of joinery.

Wood stains

These remain less common in existing buildings but are relatively common in new houses. They are of two types: 'low solid' and 'high solid' stains. Low solid stains consist of a very thin paint with a very small proportion of binder. In these stains the pigment is drawn into the surface of the timber and there is little surface build, leaving the grain pattern of the timber intact. These generally have very high porosity but as there is little surface build (due to how thin the paint layer is) they have reduced water-shedding qualities. Alternatively, high solid wood stains are significantly more popular and are, in effect, a form of translucent paint. They contain less pigment, but as they have a surface build they offer better resistance to weather than do low solid stains. An advantage of such products is that, generally, a single product applied in two coats can offer several years of service – five to ten years is frequently claimed. Many wood stains are solvent based but an increasing number are water based.

Internal joinery is commonly finished using the same products as external joinery. Clearly, there are fewer concerns with UV stability and water-shedding issues than for external joinery.

Preparation

The quality of all finished decoration is dependent on the quality of both preparation and application. The key issues are:

- *masonry and plaster surfaces need to be dry, dust-free and stable prior to decoration*
- *minor imperfections should be filled using appropriate fillers: these are plaster based for masonry surfaces and, though some of these can be used for joinery, high performance fillers are more effective and durable for external joinery*
- *any exposed knots in timber to be painted must be treated with a suitable knotting product*
- *a number of joint- and gap-sealing mastics and caulking products are available and, if they are to be used externally, they need to be specified to be external quality*
- *manufacturers' instructions should be followed carefully, for example:*
    - *paints should be stirred thoroughly (where required to be)*
    - *overly thick coats should be avoided*
    - *the appropriate primers and undercoats must be used where recommended*
    - *checks must be made to confirm that a new paint system is compatible with any existing paintwork (there is little point in applying a microporous paint on top of existing non-porous paintwork)*
- *for external timber joinery, avoid leaving bare timber exposed for long periods and avoid painting during damp periods (October to April), or when it is likely to rain before the paint will dry, to avoid trapping excessive moisture under the paint surface*
- *if considering stripping existing painted joinery, check that the paint is not lead based (essentially any pre-1965 existing paint).*

External rendering 12

Introduction

This chapter explains the development and use of modern external renders:

- *examining their development historically*
- *considering the materials commonly used*
- *explaining the principles for successful design, specification and application*
- *identifying key detailing*
- *describing recent developments in techniques and technology.*

Historical development

Wet plasters have been applied to the external surfaces of houses for millennia. Historically, it was very common for rubble stone walls to be rendered to improve their waterproofing qualities, as well as to change their appearance.

Two hundred years or so ago it became very fashionable to finish buildings with 'stucco'. This was a render of lime (binding agent) and sand or other local aggregates. Stucco was not primarily applied as a weatherproofer (in fact, it needed regular painting with limewash to keep rain out), but it was often used to emulate more expensive properties constructed from dimensioned stone. It is not uncommon to find that stucco covered relatively poor quality masonry materials.

The binding agents used in stuccos were lime based. Similarly, internal plasters also used lime as a binding agent. Internally, 'fat' or 'air' limes were used. These are made from limestones which are virtually pure calcium carbonate. These limes harden by a slow process known as carbonation, which requires a prolonged exposure to the air (see Chapter 10) and the presence of moisture. This process could be suitably controlled inside a building; however, it was far more problematic externally. A quicker and harder set can be achieved by using a 'hydraulic' lime. Hydraulic limes are so called because they can set under water and do not need to be exposed to the air to harden. A hydraulic lime comes from limestones which contain clay impurities. These impurities combine with the lime to form complex crystalline structures of calcium silicates when mixed with water. Once they are mixed with water an irreversible setting process starts. This cement-like set means they develop early hardness (a necessity for external use) and provides increased strength and weatherproofing qualities to the finished render.

Another way to impart a hydraulic set is to add 'pozzolanic' aggregates to an air lime. These aggregates are all based on clays. The word 'pozzolan' derives from the village of Puozzolano in Italy where a volcanic deposit of clay-based material was quarried and exported throughout the Roman empire. Although many pozzolans were naturally occurring, crushed brick dust and some ash wastes were found to have similar properties. In the absence of a hydraulic lime, pozzolanic aggregates were used to create durable stuccos.

In the 1820s, Portland cement was patented. Cement is made by blending precise proportions of limestone and clay, firing them to a clinker and grinding them to a powder. The result is very similar to a strong hydraulic lime. Throughout the Victorian period and up to the introduction of cavity walls during the 1920s and 1940s, it became common to render buildings using cement- and lime-based renders. This was partly for weather protection, partly to hide poor quality brickwork and also for aesthetic reasons.

During the Regency period (early 1800s) it became fashionable to render buildings. The render usually hides rough and ready brickwork or rubble. Brighton and Cheltenham are two good examples of Regency towns. Fine lines were sometimes incised into the render to give the appearance of more expensive stonework. This technique is still common today.

Defective rendering is one of the more common building defects today and the principal causes are incorrect proportioning of materials, incorrect application and inadequate preparation of the background.

Interwar houses, from the 1920s and 1930s, often made use of roughcast render.

Modern renders

In both new construction and refurbishment, houses can be rendered for one or more of the following reasons:

- *to prevent damp penetration*
- *to provide a decorative finish*
- *to hide poor quality bricks, blocks or stonework*
- *to improve thermal insulation.*

Modern renders are a mix of binders (cement/lime) and aggregates (sand), applied in one, two or three coats. The number of coats is dependent on the choice of render system, the nature of the background and the exposure of the building. The top coat can have a smooth finish, a textured finish or can contain a coarse aggregate to give a variety of decorative effects. Chemicals can be added to the mix to provide increased plasticity, flexibility or improved waterproofing qualities.

Rendering is a highly skilled trade, requiring not only a high level of technique but also a thorough knowledge of materials, together with an understanding of how these materials will perform in what is often a very exposed situation. Concerns regarding consistency, efficiency and long-term durability of self-mixed renders have led to the development of pre-mixed polymer renders and synthetic thin coatings. Although they still require a high level of skill in application, their use has reduced the risk of inappropriate or ill-informed material and proportion selection inherent in self-mixed renders. Pre-mixed renders are detailed towards the end of this chapter.

The materials and principles of rendering are considered in the following section.

Materials

Binders: cement and lime

Cement

The type of cement used will depend on the location of the work, the conditions of exposure, the nature of the background and the colour of the finish required. For most conditions, ordinary Portland cement (OPC) or masonry cement (which contains a plasticiser) can be used. Where there is a risk of attack from soluble sulfates, which may be present in some bricks or in the ground behind rendered retaining walls, the use of sulfate-resisting cement is advisable. Some white or light-coloured finishes will require white cement.

Lime

The addition of lime to a sand cement mortar has several advantages. It improves the workability of the mix which makes it easier to apply to the wall. It helps to reduce the amount of drying shrinkage and also improves the suction of the render (explained later), thus assisting the application of subsequent coats. Lime will also improve the vapour permeability of a render. Nowadays hydrated lime is supplied as a powder in bags and is usually non-hydraulic. Further information on lime can be found in Chapter 10 on plastering and dry-lining.

Aggregates

Fine aggregates: sand

A 'sharp' sand should be used for renders (i.e. a sand with angular particles); this is different from that used for masonry mortars, where a 'soft' sand, with more rounded particles, is usually specified. The sand should be clean and well graded (i.e. with a range of fine and coarse particle sizes). The grading is important as it affects the water/cement ratio: a badly graded sand requires a lot of water to achieve a workable mix. Shrinkage will occur as the excess water evaporates, causing stresses within the render which can result in cracking.

Coarse aggregates

Roughcast and dry-dash finishes (described later) require the use of coarse aggregate, which can either be mixed in with, or applied to, the finish coat. The aggregates vary in colour, shape and size throughout the country and are often referred to by traditional names. Examples include Canterbury spar, Dorset spar and Welsh spar.

Additives

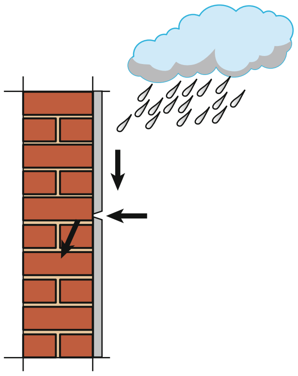
These are often incorporated into render mixes to improve the working properties of the material or to modify its properties in the hardened state. Plasticisers may be used to improve the workability of a render, without the need to add lime or to increase the water content. Water-retaining additives may be used to prevent a rendering from drying out too quickly when applied to an absorbent (high suction) background and waterproofers may be used to make a rendering less absorbent to rainwater.

Principles

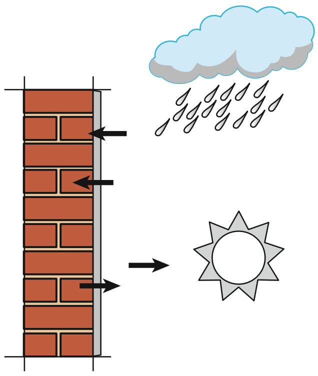
A render mix containing too much water will shrink as it dries. As the render shrinks, cracking can occur. Similar problems can be caused by excess cement.

The ill-informed assume that a good render mix must, by implication, contain a high proportion of cement if it is to be dense enough to prevent rain penetration. There is an element of truth in this but, in practice, the application of dense renders, particularly to porous or unsound backgrounds can increase the likelihood of damp penetration if shrinkage cracking occurs. This is illustrated in the diagram opposite. It is better practice to use a weaker mix, which will suffer less drying shrinkage, such a mix will also be more durable, as it can more readily cope with the extremes of thermal and moisture movement that it will encounter during its life. Although a weak render will absorb some rain, the relatively porous nature of the render allows evaporation to occur when the weather changes.

The strength of the render should also relate to the background material. Dense concrete blocks, with raked out joints, provide an excellent base for renders. Their strong mechanical key (a product of the pitted and undulating surface), will normally prevent dense renders from shrinking. However, a weak background, such as aerated concrete blocks, despite a good mechanical key is less dense, less strong and will be less likely to cope with the stresses created as the render shrinks and cracking is likely to occur. In extreme cases, the render will part company with the wall. The important principle, therefore, is that the render should be marginally weaker than the material to which it is applied. Thus, topcoats should be slightly weaker than undercoats.



Strong renders are prone to cracking caused by drying shrinkage. Water enters the cracks and cannot escape because the dense render prevents evaporation.



Weaker renders are less likely to crack. Although the wall may absorb some water it will evaporate when weather conditions change.

The strength of a render also relates to its thickness, and it is therefore another important principle that topcoats should be thinner than undercoats.

Renders with a textured or aggregate finish provide better weather protection than smooth renders. This is because the rough surface helps to spread the rainwater evenly across the wall. On smooth renders rain can form concentrated long streaks or large patches of water. This can lead to saturation and potential problems of damp penetration. Some finishes are more sensitive to variations in workmanship. This is particularly the case in smooth renders, which need expert application to ensure an attractive appearance. If the topcoat is over-trowelled, some of the cement rises to the surface and causes tiny hairline cracks which can adversley affect appearance, as well as encouraging water ingress. Textured renders, or those with an aggregate finish, are easier to apply, and usually weather well, although the coarser finishes may quickly attract dirt in urban situations.

Mix proportions

The materials in a render mix should be proportioned so as to produce a reasonably dense, void-free structure, with good workability. When mixed with water, the binder (cement/lime), forms a paste which coats all the particles of aggregate. Before the cement paste sets, it effectively lubricates the mix, aiding workability. There must be sufficient cement paste to perform both functions. However, because the cement paste shrinks as it dries, in order to avoid the risk of cracking or surface crazing, an excess of paste should be avoided.

The optimum proportion of binder to aggregate is one part binder to three parts aggregate, measured by volume. This is commonly referred to as a ratio of 1:3. This ratio is selected because a typical volume of sand contains about 25 per cent air. Replacing the air with the binder creates a void-free structure. If too little binder is in the mix, the render will be weak and difficult to apply; too much and it will be too strong and suffer excess shrinkage. Strength and durability are provided by the cement, but a 1:3 cement/sand mix is unsuitable for all but the strongest backgrounds and, in order to decrease the render strength, the proportion of cement in the render mix is reduced. To keep the binder/aggregate proportions at approximately 1:3, some of the cement is replaced by lime. Thus, a mix could be 1:1:6 or 1:2:9, both of which combinations have the binder and aggregate in the proportion 1:3.

Although the lime does not contribute to the development of strength at early stages, it improves the workability of the mix, making it more cohesive and easier to apply. Moreover, a mix containing lime remains workable for longer and helps to prevent rapid drying out of the rendering. Lime also improves the suction of a render and is often specified in undercoats to ensure good adhesion of the finish coat. Plasticisers can be used in place of lime; they act as air entraining agents, decreasing the internal friction of the render and improving its workability. However, plasticisers are not as good at dealing with suction.

Until recently, most renders were self-mixed, i.e. the designer or craftsperson selected the materials and their proportions. Nowadays pre-mixed, pre-formulated renders are coming to dominate new housebuilding.

Backgrounds

The background to which the render is applied will, to a large extent, determine the nature and strength of the render. To ensure a good bond, three factors must be considered: the suction of the background (i.e. its ability to absorb moisture), the strength of the render and the mechanical key of the background. If the suction is too low the render will not bond properly to the background and if too high the background will suck the moisture out of the render, preventing proper hydration.

Dense smooth materials

Smooth concrete and dense smooth bricks with flush joints do not provide a suitable background for render, unless some form of mechanical key is provided. One of the best methods is to use a stipple coat, comprising one part cement and two parts sand with a proprietary bonding agent, such as PVA. This is mixed with water and then brushed generously over the surface. Stippling with a coarse brush gives a rough textured surface which, once thoroughly dry, will provide a mechanical key and improved suction for the render.

Moderately strong, porous materials

The majority of bricks and non-aerated blocks usually have sufficient suction and provide an adequate mechanical key for most renders. Mortar joints should be raked out and the wall slightly dampened before applying the render – this helps to reduce suction. Alternatively, some builders prefer to use a stipple (spatterdash) coat based on sand and cement, and possibly containing proprietary bonding agents.

Weak, porous materials

These backgrounds, such as old porous brickwork and rubble stonework, may have very high suction. This can be overcome by dampening the wall or by the provision of a stipple coat (see image below). If excessive suction is likely, a water retention admixture can prevent rapid drying of the render and enable it to be worked satisfactorily.

Metal lathing

Some surfaces require separate support for the render, usually in the form of metal lathing. Examples include old crumbling brickwork (see photo below), porous stonework and some lightweight blocks. Metal lath can also be used where render has to be applied to composite surfaces, such as a concrete frame with block infill. If lath is not used there is a danger of cracking, caused by differential movement of the two background materials. The metal lathing, which can be galvanised or stainless steel, can be fixed directly to the surface using masonry nails or stainless steel screws. Three render coats are necessary, the first of which protects the render from corrosion and forms a key for subsequent coats.

Metal lathing is available in various grades. At its simplest it comprises a stainless steel or galvanised mesh screwed and plugged to the wall. Three-coat renders are usually required.

Application

Many modern renders are applied in a series of coats, which should become thinner and weaker towards the final coat. The majority of new walling will be covered adequately by two coats of render, though some pre-mixed renders (see later) are designed to be applied as a single coat. For self-mixed renders in exposed areas or where lath is used, three coats may be required. Some very undulating or pitted surfaces may require an additional dubbing-out coat to fill voids prior to the first coat.

Undercoats

The undercoat performs a variety of functions besides keeping out the rain; it should level uneven surfaces, it should equalise the suction for the top coat and it should prevent the joints from grinning through. Single-coat renders, like plaster, can often be identified by the grinning of the joints; this is particularly noticeable after rain. However, recent developments in rendering materials have enabled single-coat techniques to be effectively used.

This existing wall with soft bricks required a relatively weak render because the nature of the wall would not be able to resist the shrinkage of a strong render. In the left-hand picture the undercoat has been applied and, before it hardens and sets, the coat has been scratched. This controls the inevitable shrinkage that will occur. It also provides a good mechanical key for the top coat. Note the 'bellcast' drip forming the bottom edge of the render. In the right-hand picture the thinner and weaker top coat is in the process of being applied. It will be finished as a smooth render.

The thickness of the first coat should not exceed 15mm and should be a mix appropriate to the background. When the undercoat has begun to stiffen it should be combed, as shown in the photograph on the previous page. This is partly to provide a key for the final coat and partly to provide stress relief points, which prevent undue shrinkage occurring as the render hardens and sets. Cracking in a base coat can affect subsequent coats if they are applied too soon: a base coat should therefore be left for several days before applying additional render coats.

Final coats

The nature of the final coat will depend on the undercoat and on the desired finish. The next few paragraphs describe the most common forms of finish. For specific details of mixes and pre-mixed renders, you should refer to manufacturers' trade information; one of the best guides is produced by the Mortar Industry Association.

Smooth and scraped finishes

The topcoat is applied to a thickness of about 6mm and finished flat. It should not be over-trowelled as this can bring a thin film of water/cement paste to the surface, which forms tiny hairline cracks as it dries. Before the top coat has set it can be 'rubbed up' with a wooden or plastic float to roughen the surface slightly, providing an even finish.

If a scraped finish is required, it will be created by scraping or rubbing it with a 'Devil float' (see photograph on p. 248) or a wooden float covered with expanded metal. The scraping should be firm enough to remove the surface skin of mortar and expose the aggregate. It is not uncommon to paint smooth and scraped renders, but the type of paint should be chosen with caution. Conventional oil-based paints are unsuitable, as they are not compatible with the alkaline nature of the cement and also form an impervious layer, which prevents evaporation of moisture from the wall. External grade paints are better alternatives, although painting is not a 'once only' treatment and will require periodic renewal. This issue partially accounts for the increasing use of pre-mixed renders (described later), which are 'through-coloured'.

Roughcast

This is a mix of cement, lime, sand and small stones, which is thrown onto the undercoat to give a rough textured finish. The topcoat is quite strong, which makes this form of finish unsuitable for weaker backgrounds. It requires great skill to obtain a uniform finish but does provide a very hardwearing surface. However, like most coarse finishes, roughcast will gradually accumulate dirt in an urban environment.

On a strong background with a good key, roughcast provides a very durable finish. It can be painted, but painting is a 'life sentence' in terms of future maintenance. Modern proprietary pre-mixed render systems are through-coloured and can be applied as roughcast – removing the decoration and redecoration requirement.

Dry dash or pebble dash

In roughcast, the coarse aggregate is mixed in with the final (top) coat before it is applied to the wall, but in dry dash the aggregate is thrown onto the topcoat after it has been applied and while it is still wet. Typical stones include small pebbles and various coloured chippings. Once the aggregate has been applied, it should be lightly 'tamped' (pressed) into the topcoat with a wooden trowel to ensure a good bond. It is usual to incorporate a waterproofer in the undercoat to reduce suction, i.e. to reduce the speed at which the top coat sets.

A number of coloured aggregates are suitable for pebble dash. It is cheaper than roughcast or smooth faced renders and requires less skill to obtain an acceptable finish.

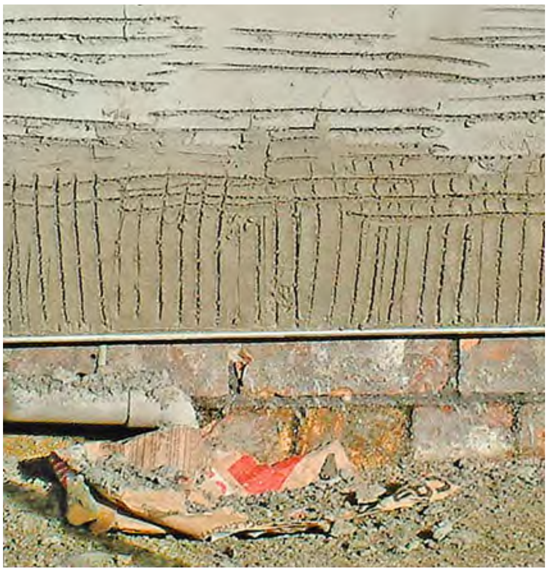
Tyrolean

This finish is usually applied by a hand-operated machine. Most builders use a pre-mixed material which contains fine aggregate, cement and coloured pigments. After the topcoat has been finished level, the Tyrolean is mixed with water then 'flicked' onto the wall. By varying the amount of water and the number of passes with the machine, different textures can be produced. The finished texture is not dissimilar to roughcast but has a more even appearance.

If the Tyrolean mix is too wet it will run down the wall. If it is too dry it will not develop a good bond with the render.

Design details

At the bottom of a wall the render should not bridge the DPC. This ensures that rising damp cannot bypass the DPC and saturate the brickwork above, which, in solid wall construction, would soon result in problems of damp penetration. Although bridging of the DPC will not necessarily lead to damp penetration in cavity walls, it can lead to unsightly staining of the render and may, in exposed cold areas, permit frost attack, which can force the render from the wall. In many properties built during the 1920s and 1930s it was common practice to render the wall down to ground level. On such properties, it is common to find thin hairline cracks at the level of the DPC caused by the differential movement of the brickwork above and below the DPC. As rain runs down the rendered wall it enters the crack, exacerbating the problems described above.



This image shows a 'bellcast' drip. This supports and protects the bottom of the render. Additionally, the DPC is not bridged by the render and thus remains effective.

To form a neat render stop, temporary battens can be fixed to the wall just above the DPC or, better still, a proprietary render stop – commonly known as a 'bellcast' bead or drip – can be used. Render stops can also be used at vertical edges.

A plastic 'bellcast' bead fixed just above DPC level, together with plastic edge beads at the quoin. These are plugged and screwed to the wall prior to the application of the render. Plastic is increasingly being used for reasons of both cost and durability. The drawing shows an edge stop-bead, which are also frequently plastic rather than galvanised steel.

If a wall is to be rendered, it is important that windows with integral sills are correctly positioned so that the drip is clear of the render. If thick, textured renders are used this can be difficult to achieve and, in such cases, it is important to use some form of sub-sill.

If there are movement joints in the brickwork, as described in Chapter 4, the joints must be continued through the rendering if cracking is to be avoided. A joint can be formed by cutting a groove in the render after it has been applied, but is better achieved by using a special movement bead, which is fixed either side of the joints and which contains a flexible plastic strip covering the gap (see photograph on p. 248).

External angles can be formed using plastic, galvanised or stainless steel angle beads (see Chapter 10). They should be fixed mechanically or on mortar dabs. With galvanised beads there is always the risk of rusting due to the fact that the galvanised layer is quite soft and is easily scraped off by the plasterer's float. For this reason, plastic and stainless steel beads are preferable.

Whatever their material, there is a temptation on site to bed angle beads in fast-setting gypsum plaster. This should always be avoided as there may be a future risk of sulfate attack if the render remains wet for long periods. In prolonged wet conditions the gypsum (calcium sulfate) reacts with a by-product in the cement to form a crystal which expands rapidly. It manifests itself as cracking along either side of the bead.

Recent developments

Because of concerns regarding the consistency of mix, loss of traditional skills, long-term durability and the need to redecorate painted renders, a number of pre-mixed renders have become increasingly popular in the past decade or so. These were originally developed in mainland Europe, where cavity construction is rare and render is commonly applied to single skin concrete-block houses – with or without externally applied insulation.

There are two broad categories of products:

- *monocouche renders: 'single coat' in French, intended primarily for masonry backgrounds*
- *acrylic or synthetic thin-coat renders, intended primarily for externally fixed insulation boards or timber-based boards (but can be used on masonry too).*

Monocouche renders are supplied to site as a pre-formulated dry mix, requiring the addition of water prior to application. These are all cement/lime based, but they also have a range of other additives. Although these are dependent on specific backgrounds, conditions and requirements, they will all have polymers added to improve their workability and bonding capacity when wet and their long-term flexibility once set. Additionally, various weatherproofing additives, such as silicone, will be included. The term weatherproofing, rather than waterproofing, is deliberate as these renders are designed to allow moisture vapour to pass from inside to outside while stopping the passage of raindrops in the other direction – so called breathability. The bagged dry mix will also contain selected aggregates and tinting agents to ensure a consistent colour throughout the mix – avoiding the requirement to decorate the finished render. Some manufacturers supply these in hundreds of shades.

Although they can be manually applied, they are generally projected, i.e. sprayed, onto the façade, ruled flat and finished by hand. If used as a single-coat render, the typical finish is achieved by scrapping back by 2–3mm of thickness to expose the aggregate and produce a consistent surface. If used as a single coat, the render must achieve a minimum finished thickness of 15mm. This is necessary to guarantee weatherproofing as well as avoiding grinning. If a more textured finish is required, such as roughcast or dry dash, then single coats are still possible. However, it is not uncommon in these circumstances to require two coats.

(top left) A pre-formulated monocouche render being applied to a concrete block wall.
(top right) The render has been ruled flat and is now relatively smooth. This is allowed to harden for several hours to form the initial set.
(middle left) 'Devil' float, designed to roughen the semi-set surface of the render, giving it a consistent finish. The finish will also be better at shedding water.
(middle right) 'Devil' float being used to produce the finished surface on the monocouche render.
(bottom left) The open-textured and consistent finish to the render. The plastic stop-beads are located over a thermal expansion joint in the masonry substructure to avoid unsightly cracking in the render finish.

Acrylic or synthetic renders have principally been developed for application onto surfaces other than masonry – though they can be used on them. These renders are nearly always applied in a minimum of two coats. Typically in housing these renders are used on externally applied, mechanically fixed rigid insulation boards. They could also be applied to the sheathing board on timber-frame panels and structurally insulated panels (SIPs).

The key, suction and movement implications of such materials require special binding agents: these are typically a combination of cements and synthetic polymers that impart a high degree of flexibility while maintaining weatherproofing. The base coat is typically 5–10mm thick and is almost always supported by embedding a synthetic mesh (nylon or glass fibre) throughout the area of the coat. Additional mesh is often required at movement-vulnerable points, such as above window and door openings. This reduces the risk of cracking and improves the bond at these critical points.

The base coat materials are supplied to site as a dry pre-formulated mix requiring the addition of water and are usually projected onto the surface to be rendered. Typically, the base coat will be self-coloured and this should match the top coat, which is effectively a thick, highly flexible, breathable, specially formulated acrylic paint. Silicone and other polymers are included in the formulation and it is supplied in tubs (rather than as a dry mix) ready for application. This mix is generally too thick for brush or roller application and is commonly trowelled onto the surface 3–4mm thick. Typical finished thicknesses for these systems range from 8–12mm.

The detailing of all these contemporary render systems is the same as cement-based renders: stop corner and bellcast beads are required to protect the vulnerable edges. Most manufacturers insist on plastic rather than metal beads and, given that many of these systems are self-coloured, there is a range of colour-matched components.

Insulating renders

External renders can be used to improve the insulation of a wall. There are a number of ways in which this can be done and there are several proprietary products on the market. One method uses lightweight aggregates in the render. These aggregates include materials of volcanic origin and polystyrene beads. Although these renders help to improve the U-value of the wall, they are not very hard and can be damaged by minor impacts.

Far more common are insulation systems which comprise an insulation board, mechanically fixed to the wall and covered with a render supported by a synthetic mesh (as shown below).

(left) An existing house undergoing thermal improvement. Externally applied rigid insulation panels have been mechanically fixed to the existing external wall.
(right) An acrylic pre-mixed render has been applied to the external surface of the insulation. A glass fibre mesh will be added to the wet render. Once set, a top coat will be added to complete the application.

These systems, like the contemporary rendering systems described above, are comparatively new and their long-term durability is not yet proven. A number of manufacturers have attained independent certification guaranteeing a 30-year life for both the rendering and the associated insulation systems. This is, however, dependent on the use of specialist accredited subcontractors.

System housing: timber-frame 13

Introduction

Modern timber-frame construction in the UK has been developed from North American and Scandinavian methods and bears little resemblance to the traditional, heavy oak-framed buildings of the late Middle Ages. Indeed, most modern timber-frame houses, when built, are visually indistinguishable from their brick and block counterparts. Modern timber-frame construction is based on off-site prefabrication and typically has the roof, the internal and external walls, the first floor and, often, the ground floor built in a factory and then transported to site for assembly.

These timber-frame buildings date from the late fifteenth century. They are made from a hardwood frame with a wattle and daub infill. The lower floor is covered with timber panelling. The curved timbers are not just decorative; they provide bracing to keep the structure rigid. In towns, timber was slowly replaced by brick during the course of the seventeenth century, although the traditional methods remained for longer in rural areas.

This timber-frame building dates from about 1920. It was sold as a 'kit' ready for erection and would have cost about £100. The timber stud walls are 100mm thick, covered externally with asbestos sheet and internally with some form of plaster or fibre board.

Although it is not difficult to find examples of 'modern' timber framing from the first part of the twentieth century, it did not become a popular form of construction until the 1960s. By the beginning of the 1980s, some 20 per cent of new houses were timber framed, but adverse publicity about quality and construction methods reduced this percentage considerably during the middle of the decade. Since the 1990s, improved design and more rigorous quality control have helped to reinstate the image, and the popularity, of timber-frame housing. The trend by successive governments to encourage the construction industry to adopt prefabrication techniques, such as modern methods of construction (MMC) – see Chapter 1 – as a means of improving quality and avoiding the problems of skills shortages has also given a boost to timber-frame construction. For the past few years, the share of timber-frame construction in the UK housing market has been about 25 per cent.

Timber-frame construction offers several potential advantages for developers over traditional brick and block forms of building. These include:

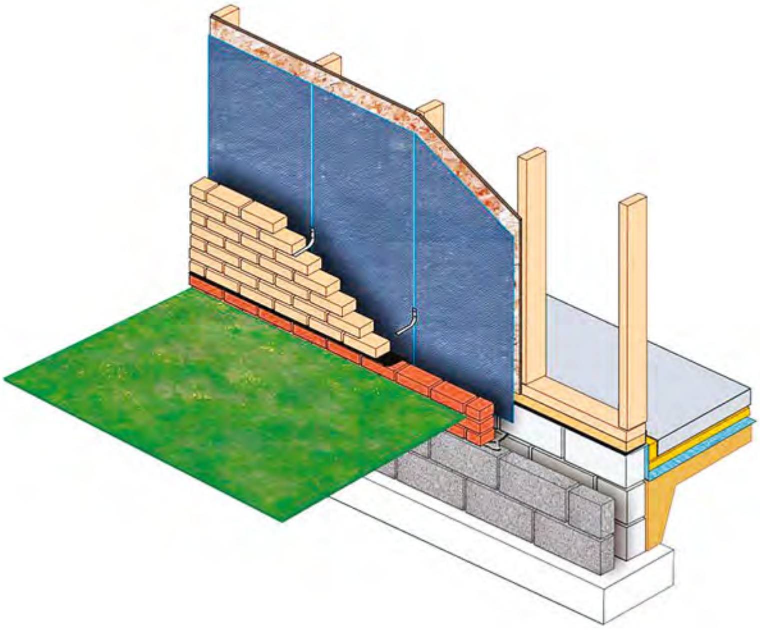
- *faster construction (producing a quick return on borrowed capital and less financial risk) – on-site construction is reduced because of the prefabrication that takes place in the factory. There is also a time advantage because a relatively weathertight building can be formed in a few days and this allows internal work to start quickly. In addition, there is no time lost waiting for the mortar to dry out (as would be the case with masonry) and freezing conditions will not affect site erection (unless an external masonry skin is added)*
- *less dependence on traditional 'wet' skills, such as bricklaying and plastering*
- *less costly due to the greater use of unskilled site labour*
- *reduced dead-load resulting in lighter and cheaper foundations.*

In addition, timber-frame construction can be relatively easily adapted to encompass high levels of thermal insulation.

Timber-frame construction offers the potential for greater quality control, in so far as this is potentially easier to achieve in factory conditions rather than on site. However, even where stringent factory quality control checks are in place, there may be installation deficiencies in relation to important details, such as vapour control layers, fire stops and cavity barriers, etc. and, therefore, good site management and control is essential. Prefabrication off-site also requires accurate setting-out on site – if components do not fit properly, quality may be compromised.

Timber-frame construction

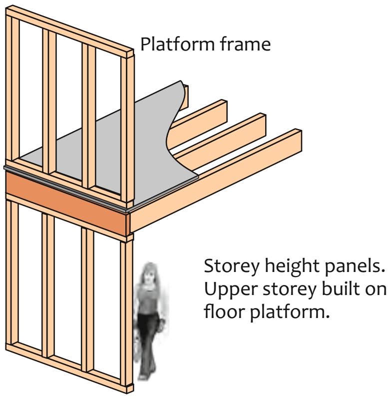
The principles of construction

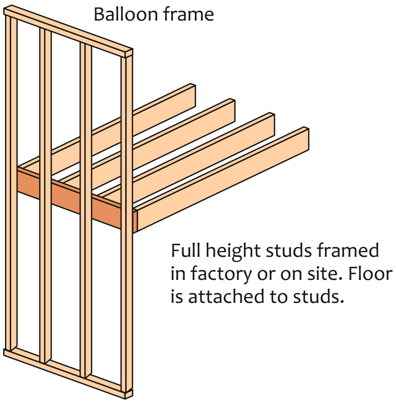


The diagram above shows typical modern timber-frame construction. The internal loadbearing leaf of the external cavity wall is formed in softwood timber and comprises a series of vertical timber studs nailed to top and bottom timber-plates. The outside of the studding is usually covered with plywood, oriented strand board (OSB) or other suitable sheet material. These sheets, known as sheathing, are used to stiffen the frame and help prevent deformation caused by wind loading. The internal face of the timber frame is covered with a lining of plasterboard and insulation is inserted between the studs. In order to provide weather protection to the house, the timber frame can be clad in timber boarding, vertical tile hanging or it can be protected by an outer leaf of brickwork (as above) which, in the UK, is by far the most common approach.

Most manufacturers use computer-aided design (CAD) to help them design panels and produce cutting lists and drawings. The panels are usually assembled on jigs (which provide guidance for fixing), occasionally by hand, although most manufacturers automate the whole process.

Although the frames can be made up on site, this is unusual and they are usually prefabricated into storey-height panels in lengths of up to 3.60m – this being based on the heaviest panel that two people can handle. Larger panels can be made for crane erection. The timber-frame system described in this chapter is known as the platform frame, and is the most common method presently used in the UK. The balloon frame is an alternative system. Specific construction details for either system may vary from manufacturer to manufacturer, but the principles remain the same and are shown below.





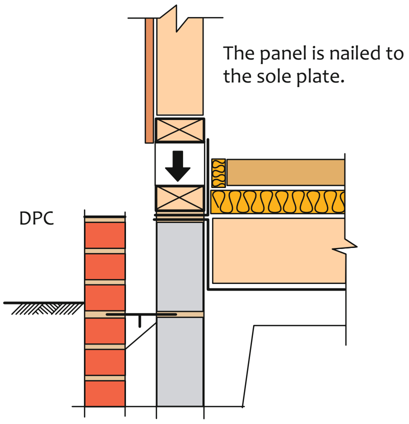

In this platform-framed house, the ground floor panels have been erected and are waiting for the first floor to be installed.

Foundations and substructure

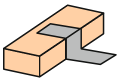
It would seem logical to use suspended timber-floor construction for the ground floor but, in practice, most developers use a solid concrete floor or, increasingly, a suspended beam and block system. The nature of the substructure depends on the ground conditions and the building load. Traditional strip foundations, often of trench fill, are the norm for timber-frame houses.

When the substructure is complete, a preservative-treated sole plate is normally fixed on top of the DPC and this forms the base for the wall panels. The sole plate provides a level, square and accurate surface on which to fix the wall panels, and ensures that the DPC is not displaced during erection of the shell. Three fixing methods have been used in recent years. Two involve the plate being fixed in position by either expanding bolts or shot-fired pins, which pass through the DPC and penetrate the blockwork or concrete below. The second of these two methods is preferable for two reasons. First, the nail driven through the DPC creates a tight collar which prevents damp penetration and, second, the use of nails does not require the wall panels to be trimmed where they fit over the heads of the bolts. Although both methods described require puncturing the DPC, there is no evidence to show that this has caused significant problems. Both of these methods require special high-strength blocks in the top course to avoid the risk of cracking or shattering. A third method of fixing the sole plate using galvanised metal strips has now become the most commonly used. This method is shown in the drawing and photograph below. Galvanised metal strips secure the sole plate to the substructure without having to puncture the DPC. A number of different patterns are available.

The nature and position of the DPM will depend on the type of floor structure and finish. In the drawing below, a ground bearing slab sits on a polythene DPM.



In this example, the DPM is below the slab and the floor finish is a sand/cement screed.



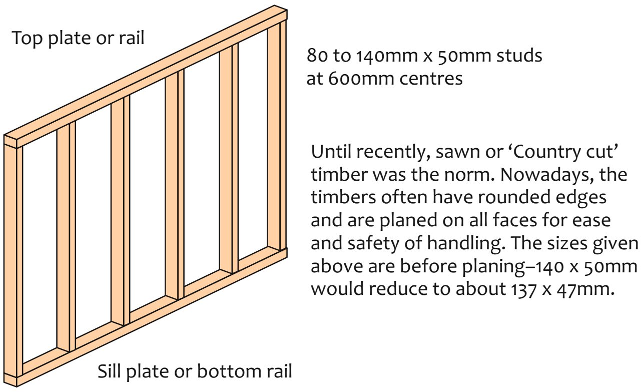
This photograph shows the clips which can be used to secure the sole plate. In this example the floor is pre-cast beams and blocks.

In the example shown in the photograph, the panels are fixed to a sole plate sitting on a pre-cast concrete slab. The floor comprises a series of inverted T-beams with a lightweight block infill. The sole plate consists of two strips of timber to accommodate the thickness of the floor finish.

Panel design and installation

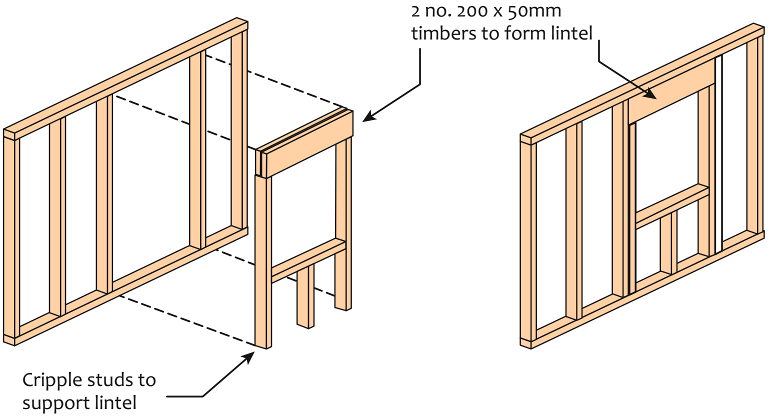
The studs and plates are made from stress-graded softwood. Timber widths have increased as higher insulation standards are demanded by Building Regulations for new housing and are currently up to 140mm deep to accommodate insulation material. The studs and rails are butt jointed and nailed together. The studs are normally spaced 600mm apart – although 400mm centres are sometimes used.

The panels delivered to site are either 'open panels' or 'closed panels'. In the open panel system, which is more popular in the UK, external boarding is factory-fitted to the panels and the insulation, plasterboard, etc. is installed on site. With the closed panel system, each panel is fully finished in the factory, including service pipes and cables. This system is more popular in Scandinavia.



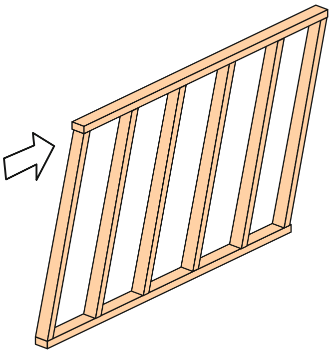
Until recently, sawn or 'Country cut' timber was the norm. Nowadays, the timbers often have rounded edges and are planed on all faces for ease and safety of handling. The sizes given above are before planing–140 x 50mm would reduce to about 137 x 47mm.

Where openings need to be incorporated for doors and windows, extra studs are introduced on either side of the opening to support the timber lintels, which are of a deeper section to safely carry the loads above.

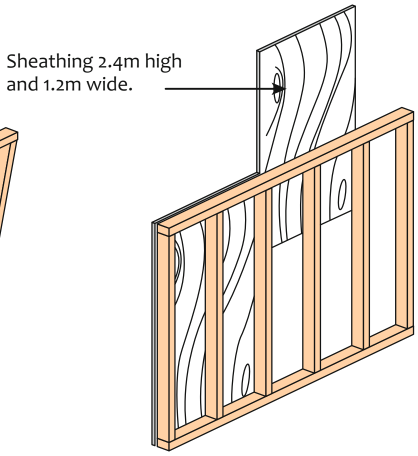


In some timber-framing systems, the panels can be delivered to site with windows already in position. A more common option is to fix the windows on site when all the panels are in position.

To prevent the panels from deforming under wind load (sometimes called 'racking'), the outside face is covered ('sheathed') in a sheet material, such as bitumen-impregnated fibreboard, OSB or plywood. The sheathing also helps to reduce wind penetration through the external walls. The boarding is available in widths of 1200mm to suit the spacing of the studs. The sheathing varies in thickness depending on its type, but it could be 8mm ply or 18mm OSB, both nailed at approximately 150mm centres to the plates and at 300mm centres to the studs. Where vertical joints occur in the sheathing, a small gap of 2–3mm may be required (depending on the material) to allow for moisture and thermal expansion. To protect the sheathing during the construction process, a waterproof membrane, applied either at the factory or on site, is stapled to its face. In the longer term, this waterproof, but vapour permeable, layer (often referred to a breather paper) protects the timber from any water, such as wind-driven rain, which finds its way across the cavity, while also allowing any moisture vapour in the panels to escape.

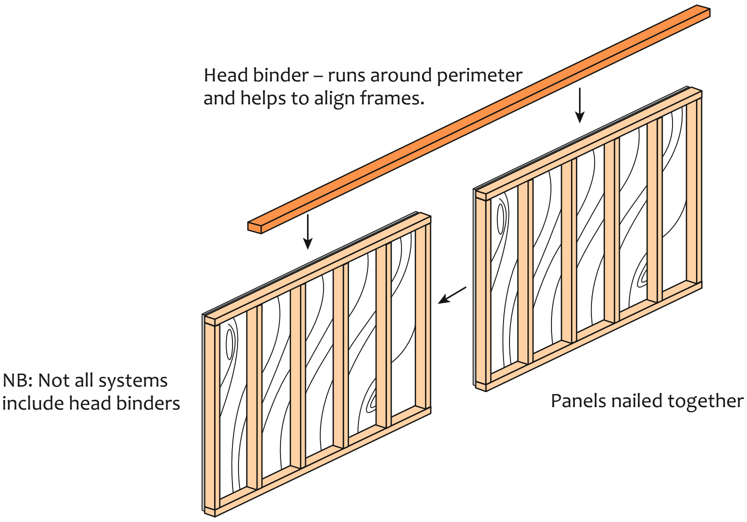


Racking can occur due to wind loading.



It is prevented by covering the outer face of the panel with a sheet material.

Once the ground floor panels are in place, they are capped with a head binder. This aligns the individual panels and secures them to each other. It also provides a base on which the first floor panels and flooring will sit and helps to spread their load.



This photograph shows the top of the panel and the head binder above (below the joist).

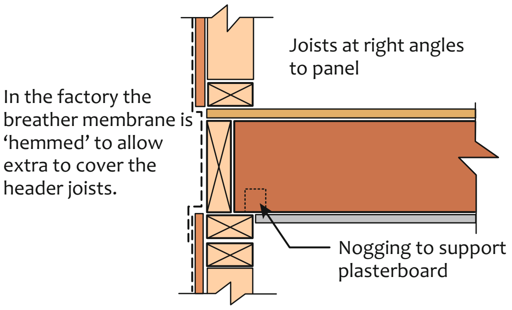
When all the ground floor panels are in place, the next stage is to build the 'platform' ready for the top storey panels. The panels are factory-fitted with a waterproof, but vapour-permeable, membrane.

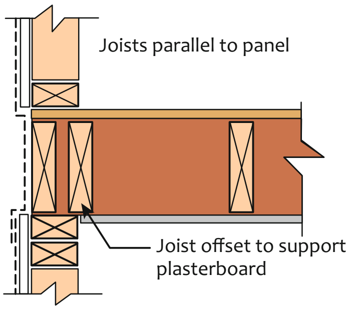
Panel junctions

Where panels join side by side, they are secured to each other by nailing. To ensure correct alignment, an additional piece of timber, known as a head binder, is normally nailed to the top plate (see last diagram). Where panels adjoin at right angles, the panels can be specially designed, or additional studs can be introduced at the corner.

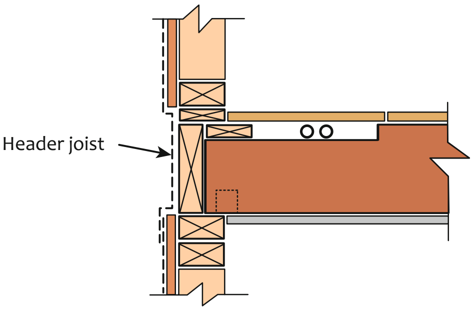
Intermediate floors and roof

The construction of the first floor is very similar to that used in more traditional houses. Traditionally, the floor has been constructed on site, but an alternative approach is to make use of a factory-assembled floor cassette, which is craned into position. The joists are usually at 400 or 600mm centres and are secured in position by nailing to the head binder. A header joist is nailed round the perimeter of the floor to provide a firm base for the upper floor panels; this also prevents fire from entering the floor cavities. Once the joists are in position, moisture-resistant chipboard or plywood deck is laid across the joists, forming a platform for the next lift of wall panels. Although this seems to be common practice, it does make future renewal of the flooring very difficult. A more practical option is shown in the bottom diagram.





Floors below bedrooms will normally include a sound insulation quilt or resilient bars and 15mm plasterboard. See Chapter 6: Upper Floors for more information.



This construction is slightly more expensive but it does facilitate future lifting of the boarding and, at the same time, forms a useful service void.

Floor joists in position awaiting the floor covering. Because the floor covering will be exposed for a few days, it should be moisture resistant. It is normal to install moisture-resistant chipboard with a heavy-duty protective film bonded to the top (this is removed prior to occupation).

When the upper floor panels are in position, another head binder is nailed along the top and then the trussed roof rafters can be fixed in position. Some forms of construction omit the top head binder, but if this is the case the trussed rafters must coincide with the studs in the wall to prevent excessive load on the top rails or the panel sheathing.

Once the panels are in position, the roof construction can commence.

Internal partitions

The timber stud partition is the most common form of internal space separation used in timber-frame houses, and it is common to find it used for both loadbearing and non-loadbearing walls. On the ground floor, some partitions may be loadbearing in order to support the first floor joists. However, the modern use of timber I-beams – as discussed in Chapter 6 – avoids the need for loadbearing ground floor partitions. On the upper floor level, it is unlikely that any of the partitions will be carrying a load, due to the almost universal use of trussed rafters, which can easily span from wall-plate to wall-plate without internal support.

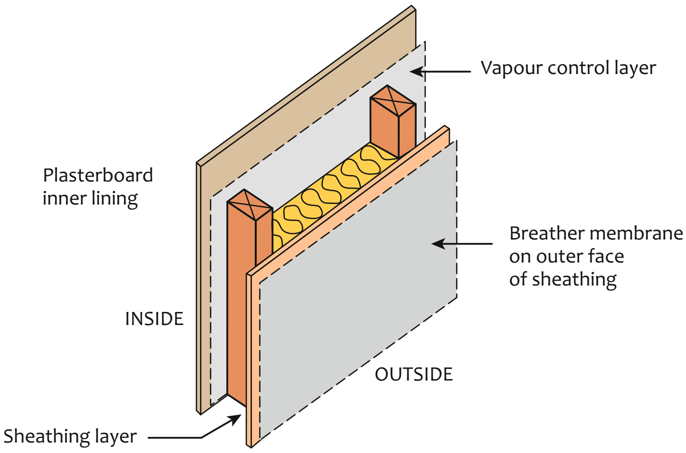
Non-loadbearing partitions are likely to be fabricated from slightly smaller studs than their loadbearing counterparts. Unlike the external walls, the partition panels do not require sheathing (unless extra racking resistance is required) and are usually covered in plasterboard on both sides. Where partitions adjoin bedrooms, bathrooms and any room containing a toilet, it is good practice to provide an extra layer of plasterboard and an acoustic insulation quilt is also required to improve sound insulation.

Current regulations require the partitions of bedrooms and rooms containing a toilet to be insulated against airborne sound. Sound-deadening quilt is incorporated in the internal studding where required.

Finishing the external panels

The external panels need to be insulated and normally mineral wool or glass fibre is fitted in between the studs. The thickness depends on the depth of the panel; up to 140mm is possible.

The inside face of the panels is usually lined with 12.7mm plasterboard, with the joints taped and filled.



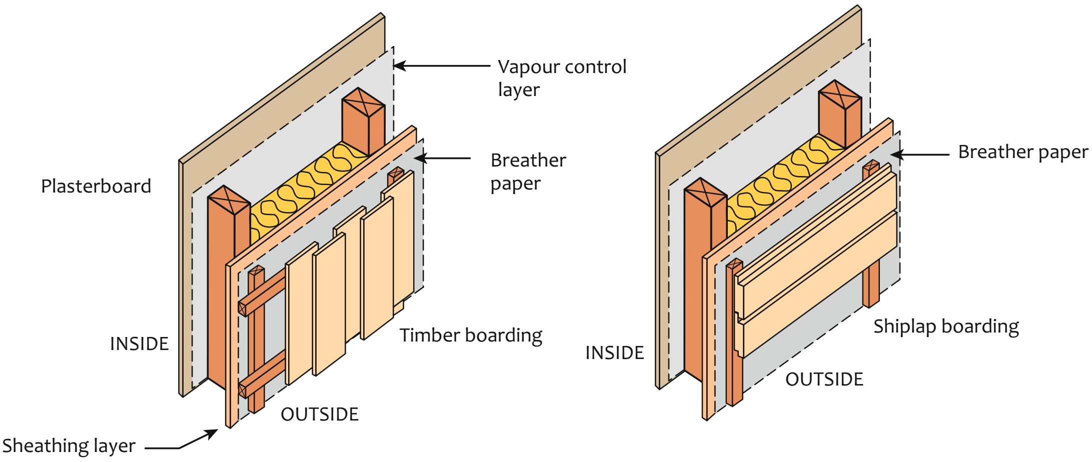
The usual practice is to install sheathing on the external face of the timber panels with a breather membrane on its outer surface. It is also essential to incorporate some form of vapour control layer in between the insulation and the plasterboard. This is to minimise the risk of condensation occurring within the wall panel. If moisture, in the form of vapour, passes through the plasterboard and through the insulation, it may condense on the colder inside face of the sheathing. It is not always practical to mechanically remove all the moisture generated by such activities as bathing, washing and cooking, so it is vital that the vapour control layer is effective. The most common material used for this purpose is polythene sheet, which should be fixed with generous laps and with the minimum number of perforations for sockets, switches and pipes. Such intentional perforations that do occur should be adequately sealed. In practice, the use of a plasterboard sealer, applied before painting or papering, improves the vapour resistance of the wall finish. The moisture content of the timber should be less than 20 per cent before the vapour control layer is fixed. It should be fixed at 250mm centres to the top and bottom of the panel, at side laps and around openings.

A 500 gauge polythene sheet is the most common material for the vapour control layer. It should be carefully cut around switches, etc. Some manufacturers produce plasterboard with an integral vapour control layer. These are quite acceptable, although the plasterboard must always be jointed over studs or noggings.

External cladding

Although other external claddings are possible (for example, lightweight ones such as tiles or weatherboarding), brick is by far the most common in the UK. This probably reflects the perceived demands of occupiers and an assumption that they would be reluctant to move away from 'traditional' forms of construction, rather than any issues of durability or practicality.

Lightweight claddings are normally fixed to timber battens, positioned vertically or horizontally (depending on the cladding material) on top of the breather paper and nailed through the sheathing into the studs. The battens provide for a vented cavity by which water or water vapour can be drained away or can evaporate.

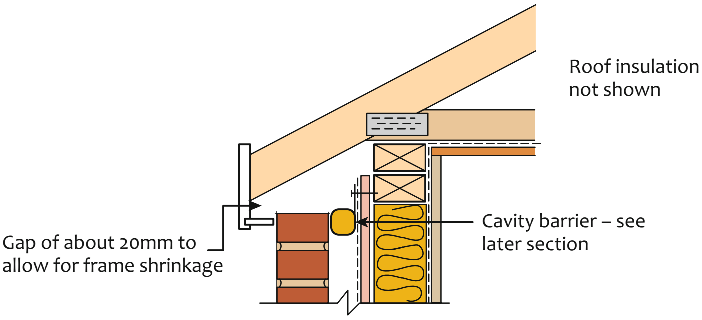


If the vertical battens were omitted drainage would be impeded.

Although brickwork is the most common form of cladding, it is possibly not the most suitable material for three main reasons:

- *its weight means that it cannot be supported by the timber frame and therefore it requires a foundation*
- *a free-standing wall would soon buckle and bulge in high winds, so it must be restrained by the timber frame*
- *the method of restraint must allow for differential movement between the brickwork and timber.*

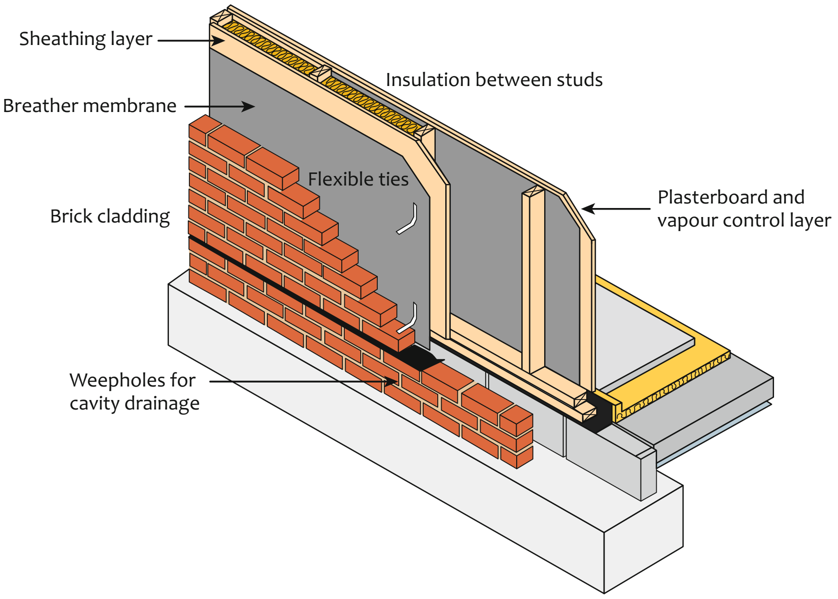
The timber structure will suffer slight shrinkage during its early life and the ties between the brickwork and the panels must accommodate this movement. Most shrinkage occurs across the grain; vertical shrinkage will therefore occur in the horizontal timbers, in other words the plates, rails and joists. The flexible ties should be laid to a slight gradient (i.e. sloping outwards) to ensure that shrinkage in the frame does not result in the ties sloping inwards. Shrinkage will be most evident at the top of the building and, as it could be as much as 20mm in a two-storey house, the brickwork should be kept clear of the roof structure by at least this distance.



When brickwork is used as the cladding, and therefore a cavity is formed, there is a danger of fire spreading along the cavity to an adjacent property where the houses are semi-detached or terraced. The Building Regulations require cavity barriers in order to delay the spread of any fire and this is explained in more detail in a later section.

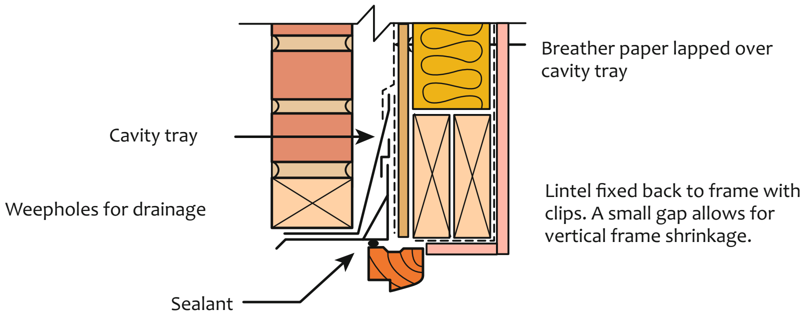
Wall ties should be fixed at 600mm horizontally and 450mm vertically. Extra ties will be required around openings. They should be spaced at 300mm centres vertically and within 300mm of the jambs. Ties must be fixed to the studs and not just to the sheathing. It is normal practice in the factory to mark the stud positions with a thin tape.

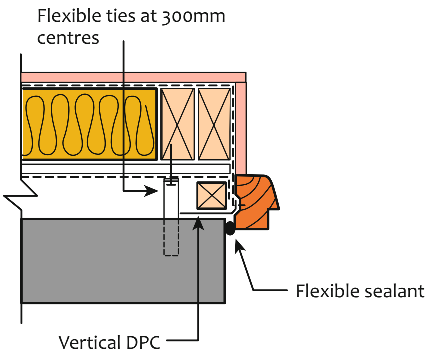
The drawing below shows an isometric view through a typical wall. It shows all the various layers mentioned in the previous sections.

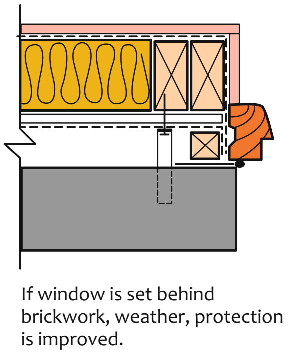


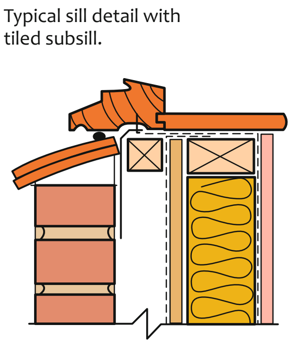
Openings

In a traditional brick and block house, the windows are normally fixed to the external leaf. Timber windows, for example, are usually built-in as work proceeds using galvanised cramps in the jambs. In a timber-frame building, the windows are normally fixed to the timber panels before the external cladding commences. One common method is to fix battens around the opening and then screw the windows to the battens. Differential movement between the inner timber frame and the outer skin often occurs and can adversely affect the window. This can be avoided by fixing the window to the timber frame. Typical modern details for a standard timber window are shown in the drawings below.









Party (separating) walls

If the house is part of a terrace or is semi-detached, the party (separating) walls must provide fire protection and adequate resistance to airborne sound. This requires more complex detailing than the external wall panels.

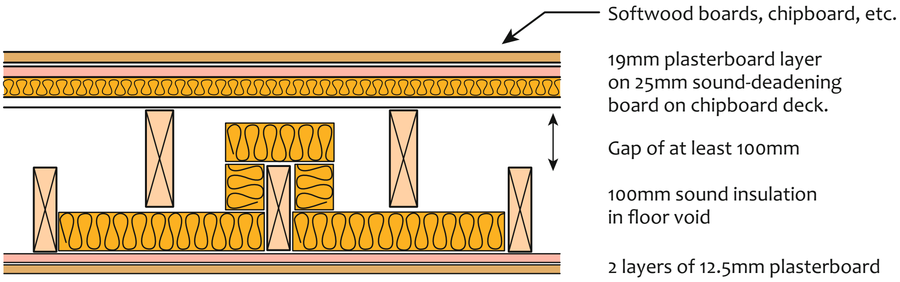
The required standards can be achieved by using two independent timber-framed panels, separated by a gap of about 50mm. Adequate fire protection is provided by two layers of plasterboard fixed to the outer face of the frames (31mm minimum thickness per side). Acoustic performance is obtained by the separation of the panels, combined with the mass of plasterboard and the inclusion of an anti-reverberation quilt within the cavity or between the studs in one of the panels. The quilt (mineral wool or glass fibre) works by deadening the sound waves, thus reducing reverberation of the plasterboard linings. In addition, the perimeter of the party wall must be filled with a suitable fire 'stopping' to prevent fire from entering the gap between the party wall frames. This is explained in more detail in a later section.

The detailing of the party (separating) walls will vary from one design to another, but must recognise the need for adequate sound and fire resistance. These panels are partly sheathed to improve racking resistance across the frame.

Looking down from above, it should be clear that the floor structure does not cross the party wall. Header joists on either side of the cavity provide support for the upper storey panels and will delay fire or smoke in the cavity of the party wall entering the floor void.

Separating floors

In recent years, timber framing has also become popular for flats. The separating floors must provide good fire protection and sound insulation. The example below meets current requirements. This construction is quite complex – certainly more complex than the requirements prior to 2004. This primarily reflects the need to provide good sound insulation.

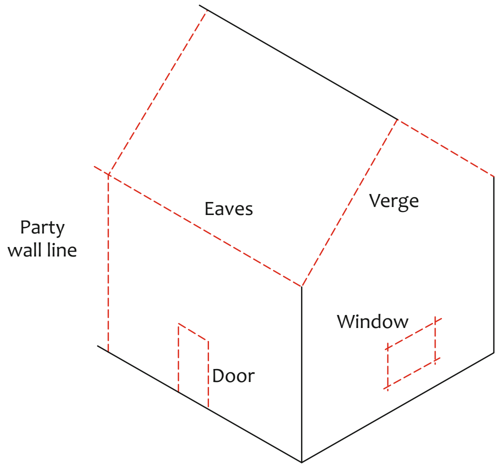


Ceiling supported by independent joists

Cavity barriers

To restrict the possible spread of fire or smoke in concealed places within the construction, the Building Regulations require cavities in timber structures to be closed with cavity barriers. Until the early 1990s, these had to be placed at the junctions of all elements (walls, floors, roofs), around openings and vertically at 8m centres. However, in the early 1990s, these rules were relaxed in England and Wales and now cavity barriers are required around all external openings, on the party wall line and at the top of all external walls, i.e. at eaves and verges.

A cavity barrier is a device which may be constructed of any material and is capable of providing fire resistance of at least half an hour. Such materials include timber battens at least 38mm square, mineral wool slab or a 'sausage' of mineral wool encased in a polythene tube. Until the 1990s, timber battens were the most common form of cavity barrier. However, they required protection in the form of a horizontal or vertical DPC and could not tolerate slight imperfections in setting-out or construction. If the cavity was not exactly the right size, the battens would either be ineffective at preventing fire spread or would tend to push the brickwork out of line. Nowadays, mineral wool slab or polythene-sleeved mineral wool, both installed under compression, are commonly used.



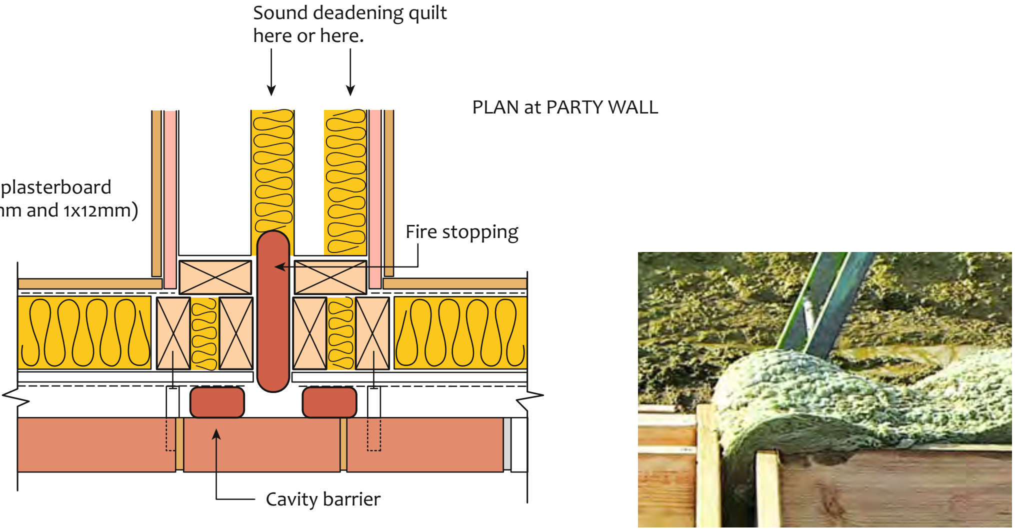
Cavity barriers in timber-framed houses

The current requirements for England and Wales are shown above as dotted lines.

Cavity barriers in a timber-frame house. Most developers, nowadays, use resilient materials encased in polythene. These are more 'forgiving' than timber battens and will accommodate minor differences in cavity width while still maintaining the integrity of the barrier.

Fire stops

In terraced or semi-detached houses, apart from cavity barriers, fire stops are necessary at the edge of the party wall to seal imperfections of fit at fire-resisting elements and to prevent fire from spreading along the cavity and entering the void between the party wall panels. Fire stops must be made from non-combustible material, such as wire-reinforced mineral wool quilt, and are required at the junction of the separating wall and the external wall and at the junction of the separating wall and roof.



Wire-reinforced mineral quilt provides a fire stop where the party walls join the external walls. The quilt runs from the ground floor to the eaves and then up to the ridge.

Structurally insulated panels (SIPs)

SIPs were invented in the USA in the 1930s and were introduced into the UK in the 1970s. They have been used for roof panels for some time, but only recently have they started to be used for wall and floor panels, in part because they are able to meet more stringent Building Regulations in terms of their environmental performance, e.g. thermal efficiency, negligible air movement/leakage and use of sustainable timber. They are considered to be a modern method of construction (MMC) – see Chapter 1 for details – and are an effective alternative to timber-frame construction.

A structurally insulated panel comprises a rigid insulation core, normally expanded polystyrene (EPS), set between two structural skins, the most common materials for these being oriented strand board (OSB) or laminated plywood. The insulation is injected between the skins in a hydraulic press, which creates a lightweight, but very strong panel in which the components are bonded together by the process. The edges of the panels are formed so that they can be simply and quickly fitted to each other, either directly or over a connecting plate. Some manufacturers finish the panels with a softwood bottom-plate, side-plates and head-plate.

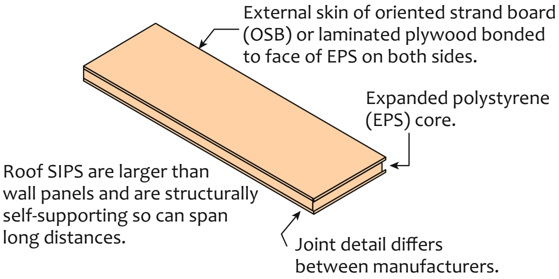
The wall panels are normally between 100mm and 150mm thick, up to 1,200 wide and 3,000mm high. Roof panels can be much larger, up to 6,500mm in size, and avoid the use of trusses as they are structurally self-supporting. This means that the roof space can become a useable area. Smaller panels can be installed by hand; larger panels need a crane.

The panels are custom-designed for each house or house-type and are manufactured under factory-controlled conditions. SIPs are structurally very efficient and form the external structural skin of the house as well as all internal partitions. They achieve high levels of insulation (external wall U-values as low as $0.10W/m^2K$ can be achieved) and, with the addition of one or two sheets of 12.5mm thick plasterboard, can achieve fire resistance of 30 or 60 minutes. The innermost plasterboard on the external skin should have an integrated vapour control layer to prevent condensation.

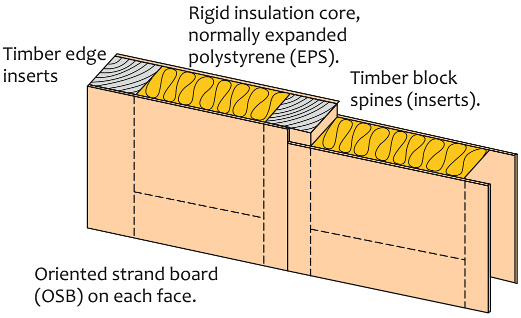
In a typical SIPs system, a sole-plate is installed above ground floor DPC level to provide a level base and secured with angle brackets to the floor. The bottom plate of each SIP sits on this. Door and window openings are factory-formed within the panels, finished with softwood plates and each door or window frame is installed on site. The first-floor joists or I-beams are supported on joist hangers that are secured to the panels. A wall-plate is fixed to the top of the upper floor panels before either a SIPs roof is installed or modern roof trusses are used.

Externally, a SIPs house can be clad in a similar fashion to a timber-frame building, for example brick skin and cavity or tile hanging or horizontal boarding, both fixed to the external face of the SIPs. Roofs can be finished with slates, tiles or a lightweight metal system.

Like timber-frame construction, SIPs impose a relatively light load on the substructure and, because they can be quickly erected, they provide a weather-resistant shell within a short period of time. Manufacturers claim that SIPs are comparable in cost to timber frame, are more easily erected, are five to ten times stronger and should give at least a 60-year lifespan if properly designed, constructed and maintained.



SIPS – typical roof panel (not to scale).



SIPS – typical panel and connectors (not to scale).

14

System housing: concrete and steel

Introduction

During the twentieth century, manufacturers developed a number of non-traditional building processes for the construction of housing. These forms of houses were known as system buildings. Modern timber-frame housing is such a system and has already been covered in some detail in Chapter 13. It is well-established and has been in use for over 50 years in the UK. This chapter discusses other system buildings used for housing: pre-cast concrete, in-situ concrete and steel-framed housing.

The period between the two World Wars saw industrialised processes introduced into the UK construction industry. Their popularity was due to the perception that they offered the following benefits:

- *greater efficiency of labour and materials due to factory processes*
- *increased speed of erection because of simple site assembly of factory-prefabricated components*
- *economies of scale due to specialisation in terms of component standardisation and mass manufacture*
- *better quality thanks to the greater use of factory-produced components rather than in-situ construction*
- *cheaper housing due to the economies created by the above factors.*

The majority of new houses were still built traditionally, i.e. all materials and components assembled on site, but a small number of system buildings were erected (about 50,000 or 1 per cent of the total during the inter-war period). These involved larger-sized factory-produced components (e.g. frames and claddings) being assembled on site.

The use of system building really accelerated as a result of the need to provide huge amounts of housing after the Second World War. In the first ten years after 1945, some 500,000 units of system-built housing were constructed. In the following 20 years or so, a further total of almost 1 million units were erected (this figure includes approximately 150,000 high-rise units). However, system building declined for a period from the late 1970s because the original units were often poorly designed and constructed, leading to many failures of structure and components. They also frequently suffered from condensation as well as poor thermal and noise insulation. Many have subsequently been demolished.

More recently, system building has been reintroduced, this time as a response to a report published in July 1998 by Sir John Egan (Head of the Government's Construction Task Force) who investigated the housebuilding sector and concluded that builders needed to focus on a number of factors to improve efficiency, quality and customer satisfaction. These included (among other suggested measures):

- *reducing construction costs*
- *increasing quality and programme predictability*

- *using sustainable construction with more emphasis on prefabrication and off-site manufacturing*
- *innovating to streamline the construction process.*

The subsequent response in the private sector has been fairly slow – it is clear that most house buyers prefer to buy traditional brick and block houses. However, providers of social housing are responding more favourably. This is partly due to Government pressure on the social housing sector, but also thanks to modern methods of construction (MMC), which encourages the use of greater off-site prefabrication and on-site assembly of components in the UK construction industry and is a key driver for system building (for a more detailed discussion of MMC, see Chapter 1). It is likely that system housing will, in the future as it did in the post-war period, make a significant contribution to solving the nation's housing shortage.

Pre-cast concrete housing

Introduction

Many thousands of pre-cast reinforced concrete (PRC) houses were constructed in the post-war period. They were produced within the public sector and provided much of the local authority housing stock. In the 1980s, many were purchased by their tenants under the 'Right to Buy' legislation of the Conservative government.

A large number of individual types of house were developed and constructed, some involving tens of thousands of units and others a mere handful. Many have now been demolished as little attention was paid to thermal or acoustic comfort and the often inferior design and construction processes led to serious condensation problems in many of the houses.

There were also serious problems with the PRC components in a great number of the houses. These were caused by adverse chemical processes within the concrete, often due to poor manufacture, and frequently led to its disintegration. Unfortunately, such problems were only discovered after many houses had been sold to tenants. Government-funded repair grants were introduced for certain low-rise houses designed before 1960, but only for private owners.

A pair of Airey system-built houses – the left-hand house has been reconstructed with a brick cavity wall, while the right-hand house is as originally built with pre-cast horizontal concrete panels and columns. Some 26,000 units were built.

There are still a considerable number of these pre-cast concrete system-built houses in existence. Some still have their original appearance as the frame and external cladding have performed well, although considerable internal refurbishment will have been undertaken to deal with any condensation problems and to raise the standards of thermal and acoustic performance. Others, more seriously affected structurally, have either been demolished or reconstructed, often with external cavity walls replacing the original frame construction.

Typical systems

The pre-cast concrete system houses were generally formed with a frame of PRC columns and an external cladding of pre-cast concrete slabs or panels, which were reinforced in some systems. A number of systems used PRC ring beams, which usually ran at both first floor and eaves level. These beams were connected to the columns in order to provide increased stability. In other systems, steel beams or steel bracing members were installed between the frame members for the same purpose.

A variety of internal linings were used, including plasterboard, clinker blockwork, wood-wool slabs and lightweight concrete panels. Ground floors were usually of cast in-situ concrete. Upper floors could be of PRC beams, timber or steel lattice beams and/or timber joists. Pitched timber roofs were the norm and could be formed in completely prefabricated roofing sections, traditional cut rafters or modern trusses covered with clay or concrete tiles or sheeting of asbestos or metal.

These two photographs show a Unity system-built house. Some 15,000 of these were erected, mostly in the 1950s. They comprised pre-cast horizontal concrete panels supported on pre-cast columns with steel bracing to prevent racking.

In-situ concrete housing

Introduction

The basic principle of using in-situ concrete (i.e. poured into reusable shutters) is not new. It was first used in the UK in the late Victorian period. It was also used in Holland immediately after the First World War when the country faced a shortage of traditional materials and skilled labour. It has been used for a number of housebuilding systems since. No-fines concrete was one of the more popular systems in the 1950s to 1970s and permanently insulated formwork (PIF) houses are being constructed now using in-situ concrete.

No-fines housing

By the 1920s, in-situ concrete was being used in the UK by several firms including Wimpey and Laings. Most of the systems used no-fines concrete – a mix which contains no sand. Omitting the sand makes the concrete lighter to handle and cheaper. It also gives benefits in terms of thermal insulation and has limited capillary action – effectively helping to make the concrete more weatherproof.

Only small numbers of no-fines houses were built in the 1920s and 1930s. By the end of the Second World War, two companies (Wimpey and Holland, Hannen & Cubitt) had built new prototypes, but it was Wimpey who used the system to construct large numbers of units. By 1951, this company was producing 10,000 no-fines houses annually and, by the mid-1960s, three-quarters of a million people were living in no-fines homes. Laings also built no-fines houses after the Second World War, mostly low-rise dwellings with external walls in cavity work.

Typical no-fines high-rise homes can be seen in the left-hand photograph. In the 1960s, a number of other companies developed their own in-situ systems. The photograph on the right shows a low-rise system which was based on aerated lightweight concrete. Apparently, the concrete finish was so good that the internal walls could be papered without the need for a plaster finish. The shells were usually clad in facing brick.

Permanently insulated formwork (PIF)

In this method, the insulation material forms an integral part of the final structure. There are a number of system manufacturers and one typical system is Styro Stone (a registered trademark) which is briefly described below.

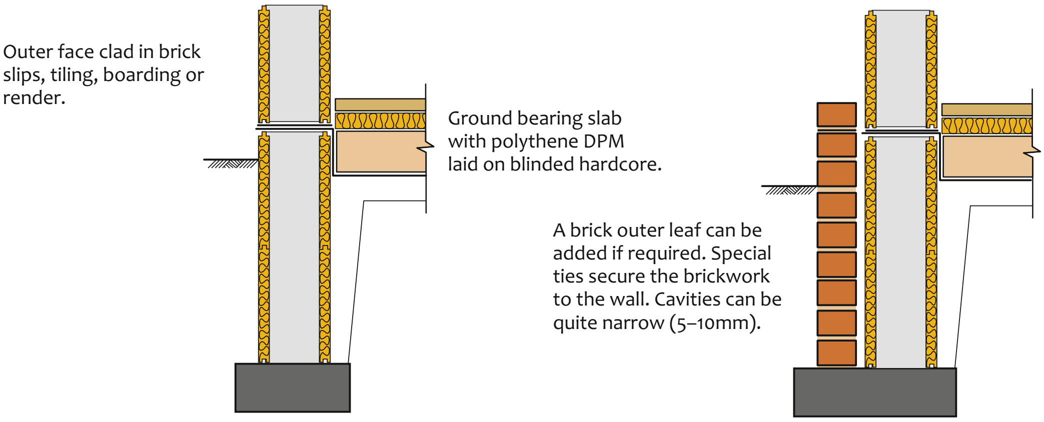
The Styro Stone system consists of open-ended, hollow expanded polystyrene (EPS) blocks which fit tightly together to form a permanent shuttering system. Dense concrete is poured into the hollow space to form a continuous wall. When cured, this wall supports the structural loads from floors and roofs and the permanent shuttering provides good thermal insulation.

In a conventional shuttering system, the shutters must be stripped after the concrete has set and then any finishing layers would be applied to the concrete wall surfaces. In PIF systems, the shutter is left in place, permanently fixed to the contained concrete.

The formwork is available in a variety of shapes and sizes. Thicker external EPS provides better insulation. The opposite faces of the formwork are joined by plastic ties which perform two purposes. Initially, they restrain the shutter faces, preventing distortion during the concrete filling process; then they assist in permanently securing the insulation to the body of the concrete. Photographs courtesy of Styro Stone.

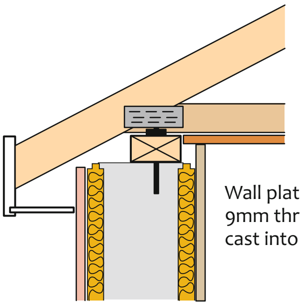
In the Styro Stone system, the design grid or module is derived from the basic unit, which is 1,000mm long by 250mm high and 250mm wide. The thickness of the sidewalls is 55mm, allowing for a 140mm width of retained concrete. The ends of the shutter are open, so that when shutter units are joined, the concrete is continuous. Except for lintels, steel reinforcement in walls will normally only be required for earth-retaining walls and basements. With a concrete thickness of 140mm plus an insulation total thickness of 110mm, the system can achieve U-values of between 0.29 and 0.099 W/m^{2}K by using different types of EPS with appropriate internal and external finishes

The substructure will depend on ground conditions. Strip foundations, rafts and piling are all suitable. Floors can be ground bearing or suspended (concrete or timber). The example below shows a simple strip foundation with a ground bearing slab. In the case of the substructure, the Styro Stones are filled with concrete before casting the floor. A DPC must separate the substructure and superstructure.



At first floor level, the construction can be in the form of timber joists or concrete beams. Timber joists are the most common method for forming an upper floor in the UK. The joist ends are built into the walls, bearing 50–75mm into the concrete.

Roof construction can be in the form of a traditional 'cut' roof or trussed rafters. In either case, a timber wall-plate is fixed with bolts cast into the concrete.



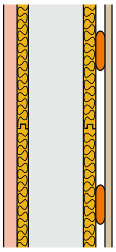
Roof insulation not shown.

Wall plate fixed with 9mm threaded bar cast into concrete.

Photographs courtesy of Styro Stone.

Typical party wall construction includes building two independent Styro Stone walls back to back along the length of the party wall and additional specialist acoustic linings.

The external finish can be of various types. Timber weatherboarding, tile hanging and render are all popular. Rendering normally comprises two-coat work. A fine mesh should be fixed with special adhesive to the outer face of the formwork before applying the base coat. An external cladding of brickwork can be built, but is not necessary for weather protection – an alternative is to use brick slips. These are shaped like bricks, and have the same dimensions on elevation, but are thin and non-loadbearing. Internally, the finish can be wet plaster or, preferably, plasterboard fixed to dabs. Lightweight fittings can be supported by the plasterboard lining. Heavier shelving, etc. should be fixed to timber supports cast into the concrete core.



The outer face of the formwork provides a good key for rendering.

The recommended internal finish is plasterboard on dabs.

Other external finishes include tile or brick slips, weather boarding or tiling (counter-battened). Photographs courtesy of Styro Stone.

Services can be accommodated in horizontal ducts run through the shuttering before the concrete is poured. Pipes and conduits up to 50mm diameter can be installed in the inner polystyrene panel. Plasticised PVC cables should be run in a rigid PVC or metal conduit to avoid contact with the polystyrene (which otherwise might cause long-term degradation).

This large detached house is nearing completion of the external walls and roof. The construction is very quick, particularly where the design does not include an external brick cladding. Once the substructure and ground floor are complete, it is possible to reach wall-plate level within a few days. Photograph courtesy of Styro Stone.

Steel housing

Introduction

Steel housing is not new. A small number of steel-framed houses were constructed between the World Wars. During the closing stages of the Second World War, thousands of single-storey temporary 'pre-fabs' were ordered, many of them from factories more accustomed to producing war planes. A typical pre-fab was built from lightweight steel sections with aluminium, asbestos or profiled-metal sheet (i.e. steel) covering, and fibreboard or plasterboard internal lining. Roofs were usually corrugated asbestos (pitched) or bitumen felt (flat).

'Permanent' steel houses were also designed and built. BISF (British Iron and Steel Federation) houses were built in large numbers; some 30,000 properties were completed, most of them semi-detached. Nowadays, they may look rather dated, but they have, for the most part, proved very durable (see photograph below).

A pair of BISF houses, the one on the left has been reclad and had a modern porch added, the appearance of the one on the right is more or less as-built.

Light steel frame (LSF) systems

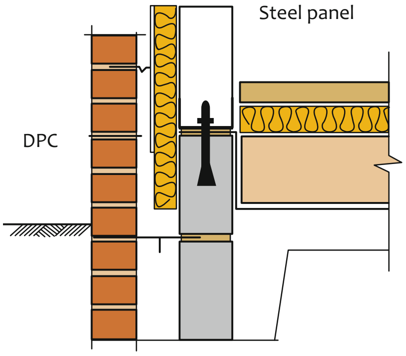
LSF systems were developed for the UK market in the 1980s. A number of manufacturers currently produce LSF systems. The design principles do not differ significantly from those of timber-frame housing; the basis of the structure is a platform frame which is assembled on site from factory-made panels. However, in this case the panels are not made from timber, but from galvanised steel sections – both hot-rolled and cold-formed (light steel) sections are used. The factory-produced panels are assembled with the steel components being joined together by welding or riveting; the panels are fitted together on site using self-tapping screws or bolts.

Resistance to horizontal loading (racking) is provided by means of the action of the floors and roof, in conjunction with diagonal steel braces fixed in specific areas of the steel frame. The vertical dead and imposed loads are supported by loadbearing external walls and internal loadbearing partitions – all made with steel frame members.

The left-hand photograph shows a braced and framed panel ready for its internal skin to be installed. On the right, the photograph shows part of a terrace of houses. The wall on the right is an internal loadbearing wall. The wall on the left is a separating (party) wall – hence the double panel construction. The diagonal braces help to stiffen the frame and prevent racking. The narrow steel strips fixed to the panels provide fixings for kitchen units, etc.

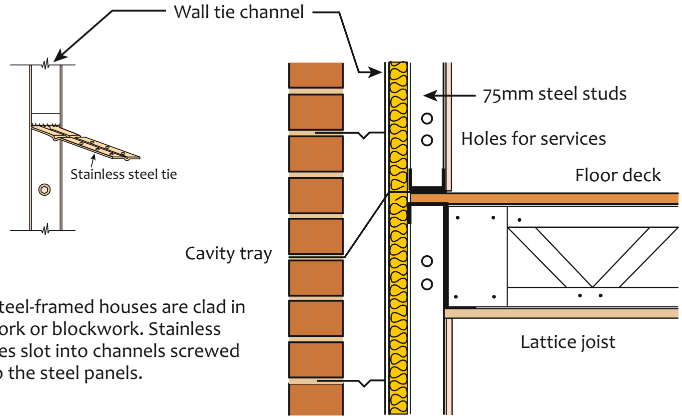
The steel frame forms the inner leaf of a cavity wall. Insulation, usually in board form, is fixed to the frame's outer face; a plasterboard lining to its inner face. The insulation is often a rigid, foil-faced foam board with a thickness of about 50mm. Better insulation values can be provided by using thicker boards or by placing additional insulation between the steel studs or behind the plasterboard. Because the steel frame stays warm (due to the insulation position), a vapour control layer is not normally required. This is quite different from most timber-frame systems where an effective vapour control layer is vital.

For the ground floor, an in-situ concrete slab or a proprietary suspended floor system may be used. In all cases, the conventions of lapping the DPM with the DPC must be followed to protect the floor and sole-plate from damp. The steel frame is usually fixed to the substructure with expanding bolts. In some cases (particularly when fixed to traditional blockwork rather than a raft foundation), holding-down straps may also be required.



Channel of bottom panel is bolted to the substructure slab or blockwork.

The external leaf is generally of brick or rendered blockwork tied to the inner leaf with stainless steel ties. Ties are typically positioned at every third or sixth brick course. The ties usually clip to vertical steel channels bolted to the steel panels. As in timber-frame housing, the external leaf does not carry any load from the floors or roof.



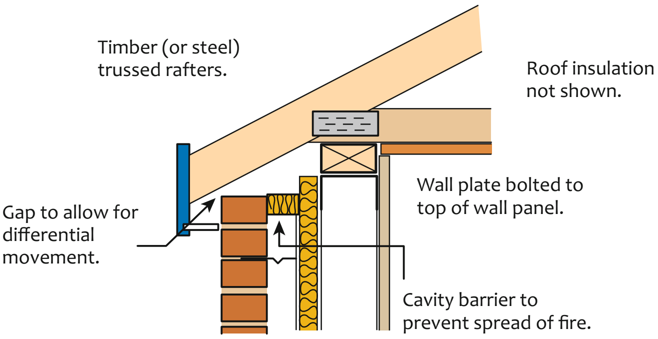
Most steel-framed houses are clad in brickwork or blockwork. Stainless steel ties slot into channels screwed back to the steel panels.

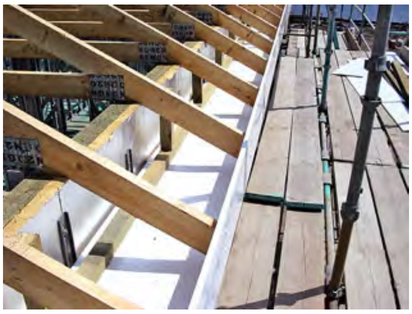
The first floor usually comprises a series of galvanised steel lattice joists covered with 18mm or 22mm chipboard, OSB or plywood. The floors are often pre-assembled as 'cassettes' in the factory.

This photograph shows a floor 'cassette'. Three or four of these are typically required for each dwelling. Notice the pre-formed holes for services.

The floor is normally underlined with 15mm plasterboard screwed with self-tapping screws to the lattice joists. Alternatively, the plasterboard can be screwed to resilient bars (see Chapter 6 on upper floors and Chapter 10 on plastering and dry-lining for more details). More sophisticated floor construction is required if the floor is a separating floor, i.e. if it is separating dwellings.

Roofs are formed using factory-made timber trussed rafters or lightweight steel trusses. If the former are used, it is normal practice to bolt a timber wall-plate to the top of the steel panels. Typical construction is shown below.





Party walls in semi-detached houses are usually constructed using two independent steel-framed panels (running right up to the line of the ridge). Mineral wool batts (i.e. precut panels of thermal insulation) are located between the two panels of the wall (and sometimes in between the studding) to provide the required acoustic properties. The panels are lined on their outer face with two layers of plasterboard to provide adequate fire protection and to improve resistance to airborne sound. The party walls may be designed to provide racking resistance – in this case they are likely to include diagonal bracing.

This photograph shows party wall construction (unfinished). You can clearly see the two independent panels. Fire stopping will be required to fill the cavity at the outer edge of the two panels and cavity barriers will be required in the external wall cavity. Typical details are very similar to timber framing.

The roof coverings are no different from those of a more traditional building. If required, the party wall panels can be continued through the roof to form parapets, although this is essentially an architectural feature.

Part of the separating wall (party wall) can be seen here.

Internal walls and wall linings

Loadbearing internal walls are formed from steel-framed panels, similar to those used in the external walls, with a lining of 12.5mm or 15mm plasterboard on both sides. Non-loadbearing walls can be formed in lightweight steel sections or using proprietary plasterboard partitions. Plasterboard linings are attached with self-tapping screws into steel members or nails into timber roof trusses. Joints in plasterboard wall linings are usually taped and filled in accordance with the plasterboard manufacturers' specification for direct decoration. Joints in ceilings are treated similarly.

Services

Service provision is facilitated by the formation of pre-punched holes in the studs and plates. However, the design and installation of electrical services must take into account the possible risk of long-term damage to the steel frame or the services. For example, to avoid the flow of electric current to earth at holding-down bolts, with a consequent risk of corrosion, local earth connections to the steel frame must be avoided. The frame must be connected to earth at one point and all earth connections in the circuit wired back to this point. In addition, it may be necessary to fit rubber or plastic grommets wherever cables pass through holes in the frame.

Windows, doors and stairs

15

Introduction

This chapter explains the development and current use of windows, doors and stairs. Collectively these components are called joinery. Joinery is intended to make the building habitable, rather than being an integral part of the structure of the building. Joinery components are generally made away from site and installed as the process of construction proceeds. Traditionally joinery was made from solid timber – both hard and softwood. Nowadays, timber is still common but there is an increasing range of materials being used for such components.

Windows

A brief history

Early windows were usually fixed lights or side-hung casements. The example below dates from around 1650. This is a leaded window (small panes of glass were much cheaper) with a fixed light directly glazed into the stonework and a hinged casement made from wrought iron.

In the late seventeenth century, sash windows were introduced to Britain. Early windows were usually formed in small panes (supported by glazing bars) because of the limitations of glass technology. The timber sections were quite thick and the window was set flush with the face of the brick or stonework.

The windows were controlled with lead (later iron) weights which counterbalanced the weight of the sashes (see overleaf).

Early 18th century sash windows dominating the façade: the thick glazing bars are necessary because of the limitations of glass technology. The box frames are exposed and virtually flush with the external brickwork.

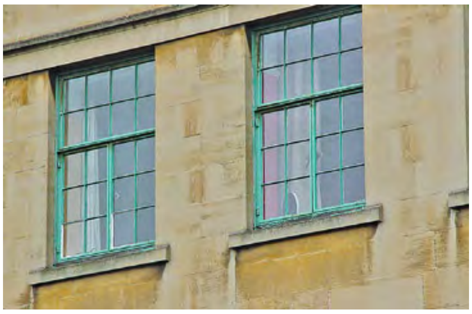
During the Georgian period, the glazing bars became thinner and thinner and, at the same time, the windows were set in rebates which hid the box frames. In houses with thick walls the inner reveals often contained shutters.

Towards the end of the Victorian period improvements in glass technology precluded the need for glazing bars altogether. Sash windows continued to be used in their traditional form until the 1950s.

Windows are visually important architectural elements. For example, windows were integral to the architectural philosophy of the Georgian era, where their proportions were closely defined in relation to the dictates of symmetry. During the Georgian era, window tax was introduced. This was levied on the number of windows in a house and goes some way towards explaining why some windows from this era were blocked up. In the middle of the nineteenth century this tax was dropped. This legislative change was accompanied by increasing concern with daylight and ventilation, which the Victorians associated with good health. Consequently, there was a move towards stipulating minimum window sizes.

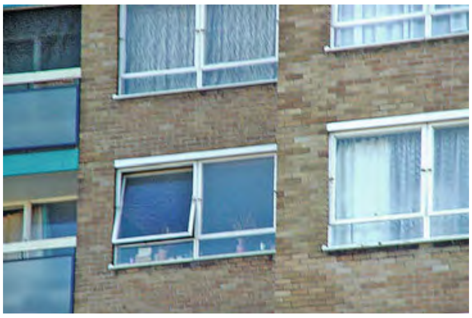
In the 1920s, top-hung and side-hung casements became popular. The example at the top of the next page dates from about 1920 and shows a single rebated window.

During the 1930s, metal windows (galvanised or plain steel) became available and proved popular until the 1970s. As houses became better insulated and less well-ventilated, their shortcomings became more obvious – the cold inner face of the frames resulted in condensation.



Ungalvanised steel windows from the 1930s.

In the post-war period, the development of high-rise housing required new approaches to window styles. Traditional sash windows could not possibly withstand the turbulence and exposure at high levels and casement windows would be impossible to clean. A common form of window was the horizontal pivot window. These could be made from galvanised metal, timber or aluminium and could be cleaned from the inside. Aluminium windows (illustrated below) became very popular during the 1970s but, in recent years, have been almost completely eclipsed by plastic.



In the 1970s, a policy of rehabilitating older properties replaced slum clearance and high-rise construction. In many cases budgets were not adequate and houses, originally refurbished for a life of 30 years or so, required substantial extra investment after less than 10 years. One example of cost cutting was the louvre window. These were cheap to make, requiring only a simple softwood frame, but were draughty, provided inadequate ventilation in the summer, were a security risk and could not easily be used as a means of escape.

Nowadays, windows are usually made from imported softwoods (left photograph) and hardwoods, or from plastic (right photograph).

There are many styles to choose from. The public has become accustomed to renewing windows, almost as fashion accessories, and often well in advance of their anticipated life expectancy. Because of this, replacing windows has become a very big, but in some cases completely unnecessary, business.

The design of windows and the choice of material used may be controlled by planning authorities in conservation areas. Plastic replacement windows are a focus for concern in such areas because they affect character and appearance. Even outside conservation areas the replacement of wooden sash windows will have a significant visual affect on, say, a street of Victorian terraced houses (see below).

Technology

Windows allow daylight into a house. They are also usually the main controllable source of natural ventilation. The Building Regulations place limits on the area of glazing in order to both restrict heat loss in colder months and prevent excessive solar gain in warmer periods. There is, surprisingly, no mention in the current Building Regulations regarding the need for natural light in houses. However, it is referred to in the Code for Sustainable Homes (see Chapter 2 Sustainability) in the context of the effective use of natural light in order to reduce the need for electric lighting. The Building Regulations do seek to ensure minimum standards of ventilation. In habitable rooms, such as bedrooms and living rooms, this is usually achieved by opening part of the window. In addition, trickle or slot vents should be provided to ensure 'background' ventilation. In bathrooms, kitchens, utility rooms and toilets, mechanical or other supplementary methods of ventilation should also be provided. The provision of natural and mechanical ventilation in houses is discussed in more detail in Chapter 20 Ventilation.

Windows should be:

- *reasonably strong and secure*
- *reasonably waterproof and airtight*
- *able to provide resistance to the passage of heat*
- *durable and maintenance-free*
- *able to provide reasonable sound insulation.*

It should be noted that the security aspects of windows should not be allowed to compromise the ability to use them as a means of escape in case of fire. Whether or not a particular window performs these requirements will depend on its design and construction, as well as the material from which it is constructed.

Materials

In modern houses, window frames are generally made from wood, aluminium or plastic. In the past, steel was used, particularly just before the Second World War. However, these windows suffered from rust and even the extra protection given by galvanising processes, introduced just after the Second World War, did little to reverse a decline in their popularity.

Wood

This can be considered the traditional material for windows; durability depends on the quality of the wood and the method of forming joints. Many softwood windows have suffered from wet rot due to deficiencies in these aspects. Advances in paint technology, and in particular the increasing tendency for paint finishes to be factory-applied prior to supplying and fitting, have improved durability. In theory, microporous paints allow the wood to 'breathe' and therefore let moisture out rather than trapping it in the wood. Windows can also be made of hardwood, which is generally more durable than softwood, but also more expensive.

Although wood requires periodic maintenance it has the advantage of being a good thermal insulator, particularly when compared to metals. This means that condensation is unlikely to occur on the inside of the frame due to its relatively high temperature. The majority of wooden windows are 'off-the-shelf' items available in a wide range of sizes and designs. Additionally timber windows, unlike most other materials, are repairable.

Aluminium

Aluminium windows have been used since the 1930s, although they did not become popular until the 1960s. Aluminium is a relatively light material and its durability can be increased by the use of a variety of treatments, such as anodising, which is a protective oxide coating. Aluminium windows are not very strong and for this reason they are sometimes fitted to a timber sub-frame.

Plastic

Plastic windows were introduced just after the Second World War, although they did not become popular until the 1970s. Early plastic windows were bulky and had to be reinforced by a metal or timber structure. Newer ones are much lighter and the smaller sizes do not require reinforcement. Plastic windows are relatively good thermal insulators. They also have the advantage of being self-finished and therefore require little maintenance. However, the repair costs of plastic windows following, say, a forced entry failure or failure of the window furniture, can be significant. Additionally, overall predicted life expectancy figures are being challenged. There are also more general environmental concerns about the use of plastic and resultant pollution at all stages of the window's life. The majority of plastic and aluminium windows are 'made to measure'.

Composite

Some manufacturers are now making windows which utilise two different materials. Such windows will always include a timber element (for its aesthetic as well as self-insulating qualities). Generally, the internally exposed parts of the window (i.e. the opening sash and frame) are in timber. This is combined with either plastic or aluminium sections for the externally exposed parts, where the innate durability and the self-finish qualities of such materials are ideal. The most commonly available window of this type is the 'Velux' window which is designed for installation in pitched roofs. These have a softwood pivoted casement and frame which are clad externally with profiled aluminium sections.

With increasing demands (from Building Regulations and voluntary codes such as Passivhaus) for lower and lower U-values, a number of manufacturers are producing made-to-measure composite high-spec windows. Some of these have external aluminium profiles and a laminate of timber and high performance rigid foamed insulation for the internally visible sections.

A composite roof window – known by its trade name 'Velux' – being installed in a new pitched roof.

Window designs

The terms 'casement' and 'sash' have specific technical meanings in joinery and both refer to the glazed opening part of a window, which in itself fits into a frame. In common terminology, however, a 'casement window' generally refers to a window with hinged casements (top and side hung). A 'sash' window generally refers to a vertically sliding double-hung window. The basic modern window designs are covered in the following sections. Most of the illustrations relate to timber windows, as these are the most commonly encountered. However, most of the issues raised are relevant to all windows, whatever material is used.

The choice of window type is affected by a combination of visual and functional considerations. The choice of size and type of glazed area and opening lights should take into account the exposure of the window.

Casement windows


Many modern windows are screwed to plastic extrusions which also close the cavity.

Casements are the most common window type in modern housing because they are generally the simplest and cheapest. Casements are available in a wide range of patterns. In the recent past, timber casement windows, which were to be painted or stained once built into the wall, were either built into the opening as work proceeded using fixing cramps, or alternatively a temporary timber dummy frame/former – replicating the exact external dimensions of the window frame – was placed and the wall was built around this. This was then removed and the windows inserted and fixed using metal strapping as shown in the image below.

Nowadays, concerns about the relative airtightness, thermal performance and durability of windows have led to changes in how windows are installed in new construction. The system currently widely used involves a purpose-made sub-frame. This is placed prior to wall construction where the window opening is required. It forms the cavity between the inner and outer leaf as the masonry proceeds. The sub-frame has a special plastic profile which acts as an insulated cavity closer. It also provides the opportunity for precise, relatively airtight location and fixing for the window itself. The window is not finally fixed into the sub-frame until all the wall construction is complete. Not only does this provide significantly improved airtightness, but it also means that virtually all the windows installed on site, whatever material they are made from, are completely glazed, and for timber windows, completely decorated. This significantly reduces the incidence of glazing failure (which was previously relatively common) and improves the long-term durability of timber windows.

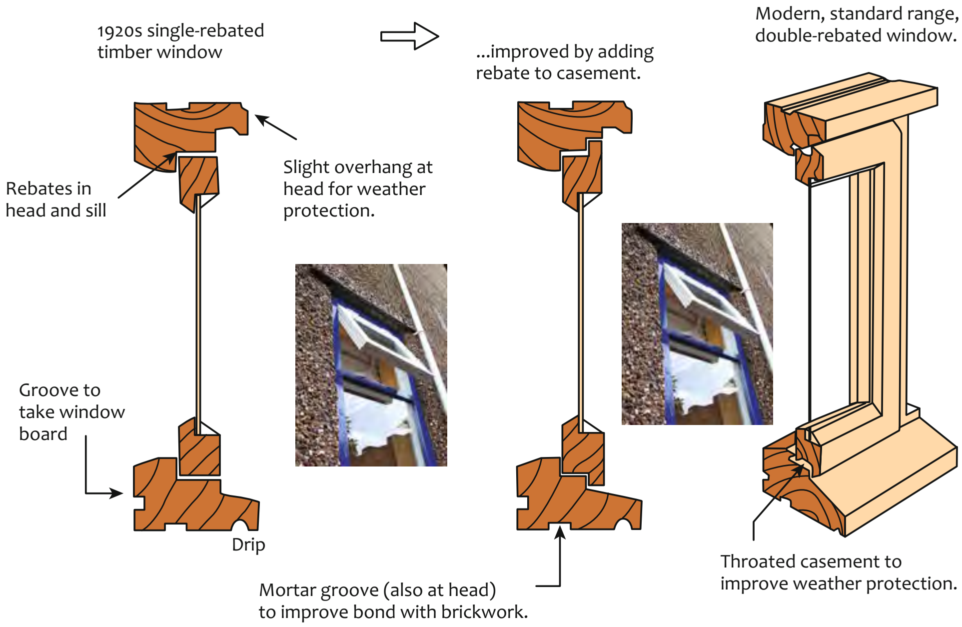
A range of sub-frames awaiting placement on site. Each one is designed to suit a specific window size, enabling it to be effectively fixed within the sub-frame once the masonry construction is completed.

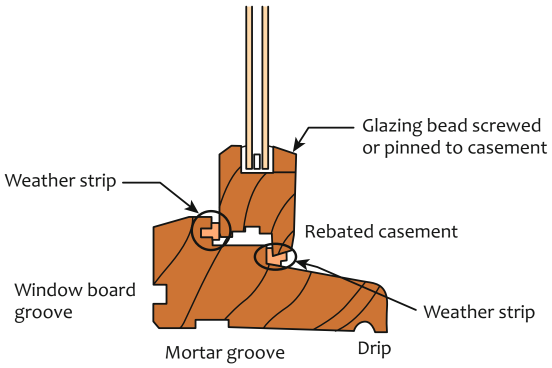
Window sub-frames in the process of being built in.

The design of timber casement windows has changed over the past 80 or so years. Windows from the 1920s were often single rebated. In the 1930s, an additional rebate was added to improve weather protection. These were sometimes referred to as 'stormproof casements'. Nowadays, double rebates are standard. In addition, weatherstrip seals are also now standard on all new windows. These seals are either neoprene compressible strips or plastic brushes, which are compressed as the casements shut. Compressing the seal can eliminate or significantly reduce any unintended air infiltration or draughts.

Traditionally, single glazing (a single pane of glass) was fixed by securing it in position using sprigs and putty. Sprigs are small nails without heads that mechanically secured the glass onto a thin bed of linseed oil putty, which was applied to the glazing rebate. Additional putty was added once the glazing sprigs were fixed. The putty would be finished to a neat smooth continuous strip, concealing the sprigs and providing water and weather protection. Other than in conservation work, new windows are no longer single glazed.

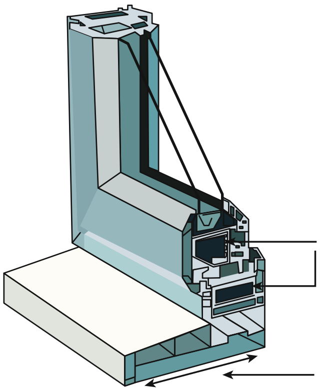
Multiple glazing has become standard – this is often 'double glazing' (two panes of glass separated by a layer of trapped air/gas) or even 'triple glazing' (three panes, etc.), explained in more detail later in the chapter. Multiple glazing is significantly thicker than the typical 4mm glass used in single glazing; it is also significantly heavier. Sprigs and putty are not an effective way to fix such glazing units and beads are the preferred method. Beads for timber windows, are small section moulded timbers which are specially cut and fixed by nailing. This secures the glazed unit in the casement's glazing rebate. A common defect in windows with multiple glazed units was poor on-site glazing and nowadays most windows are glazed prior to their arrival on-site – hence another advantage of fixing windows into the built-in sub-frame.





A section through a modern standard timber casement window. An additional weatherstrip seal is also sometimes added to a groove on the rebate of the opening casement where it closes against the timber sill.

Casement windows are the most common window design for plastic windows. The sections of plastic are not solid but are made up of various hollow thin sections. Some of these can be reinforced with metal sections. The illustration below shows a typical section through a plastic casement window. The opening sash opens outwards, as do all windows in the UK. The double glazing is secured with beads, as is the case with timber windows. However, with plastic windows, unlike with timber ones, it is common to find that window beads are on the inside rather than the external side of the window.

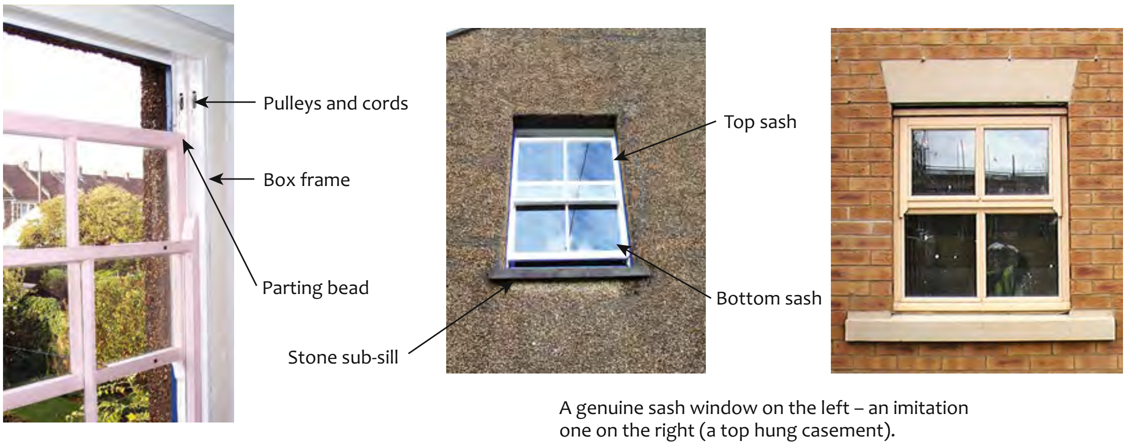


Unlike timber windows, the sill section can be extended to accommodate any required width. Often this precludes the need for a sub-sill with plastic windows.

Because of the weight of the multiple glazed units, all casements are hinged using sophisticated friction hinges. This plastic window has them. They are designed to be strong enough to support the load of the open casement while resisting wind gusts. In addition, they often allow the casement to be opened through 180° to enable the outside glass to be cleaned from the inside of the building. Finding exact replacement hinges, however, has proved to be quite difficult and in some cases impossible, requiring complete replacement of the entire window.

Sash windows

This is the type of window most commonly found in Georgian and Victorian houses. Traditionally, the two sashes open and close via a series of sash cords, pulley wheels and weights. In modern sash windows spring balances carry out this operation. Vertical sliding sashes are traditional although some modern windows, particularly aluminium, are available with horizontal sashes.



A genuine sash window on the left – an imitation one on the right (a top hung casement).

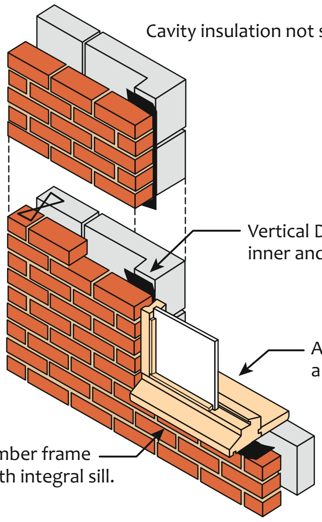
These sash windows are made from plastic. They are double glazed and open by vertically sliding in the same way that a traditional timber sash does. However, instead of pulleys, cords and weights the sashes have a spring balance which regulates their opening.

Pivot

These became popular in the 1960s, particularly in high-rise flats. The pivot can be horizontal or vertical and, depending on the particular design, they can provide a good solution to the continual problem of access for cleaning. There are also a number of proprietary window hinging systems which allow a combination of hinged side-hung casements which can also pivot – sometimes known as 'tilt and turn' windows. These are popular in both plastic and timber versions.

Window sills

A sill is necessary at the bottom of the windows to ensure that water is removed from the base of the window. A groove, or drip (see diagram), ensures that the water does not run back under the window sill and penetrate the brickwork. Ideally, the drip should be positioned 30–40mm away from the external face of the wall. The weight of the water accumulating in the drip overcomes its surface tension and the water falls away from the sill (and the wall).



Cavity insulation not shown.

Vertical DPC separates inner and outer leaves.

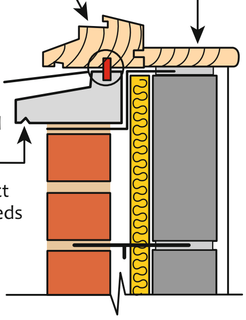
A window board fits into a groove in the back of the sill.

A DPC is required under the sill if it is made in sections (i.e. with joints). A DPC may also be required to separate the internal and external leaves.

In Scotland and areas of severe exposure in England and Wales the window should not be fixed to the external leaf – 'check reveals' are preferable.

Sub-sills

If a window is set back in the window reveal, a sub-sill may be necessary, as a sill integral to the window frame may not protrude far enough in relation to the wall face. This is particularly true in timber windows where there are limits to the width of timber used for sills because as the width increases so does the possibility of distortion. This is less of an issue with plastic windows where the lower sill sections can be manufactured to suit any width. Some windows are manufactured without any sill and therefore will always require some form of sub-sill.



If sub sill is in contact with inner leaf it needs a DPC.

Sub-sill can be timber, stone, tiling or special bricks.

The example on the right shows two courses of plain tiling.

Many plastic window systems have sill sections with a range of widths to suit the position of the window within the thickness of the wall. This opportunity to vary the sill width often precludes the need for a sub-sill.

Glass

Glass was used by the Ancient Egyptians and incorporated into windows by the Romans some time in the first century AD. After the fall of Rome, the use of glass windows was, to all intents and purposes, 'lost' for many centuries in Western Europe. With the exception of churches, glass was probably rarely used for windows until the Elizabethan period.

Glass can be manufactured in a number of ways. Traditionally, window glass was produced by the crown process whereby a globe was produced by blowing. One side of the globe was flattened. The glass was attached to a solid iron rod, reheated and rotated, so forming a flat circular sheet. The part of the glass which was connected to the rod emerged as a bullion or 'bulls eye'. Clarity of vision through these panes was relatively poor and their potential size was limited. A development of this approach was cylinder blown sheet glass where glass was blown into a cylinder shape which was split open and then flattened. Machines were developed for this process, allowing an increase in output and the production of large panes.

Drawn sheet glass was first produced just before the First World War. Glass sheet was drawn directly from molten glass supplied from furnaces. This process was capable of producing large quantities of reasonable quality flat glass. For many years most glass was drawn sheet.

Plate glass was developed in the 1920s and was produced by directing the glass flow through rollers and then grinding and polishing the rough surfaced product. Plate glass was more expensive than sheet glass but was flatter and had fewer surface distortions.

Today, most glass is produced by the float method. This involves floating glass from the furnace on top of a basin of molten metal. The result is a smooth flat surface with few distortions.

Glass can be clear or, by adding texture or pattern, it can be made translucent for use in, for instance, bathroom windows.

Glass can also be:

- *wired – where a mesh is embedded so that when damaged the glass tends to remain in position. This glass can be used in fire doors*
- *toughened – where ordinary glass is subjected to a heating and cooling process which produces a material with a relatively high level of resistance to impact. If broken it will fall into small pieces (and it cannot therefore be cut to size)*
- *laminated – as the name suggests, two or more panes of glass are bonded together with a layer of another material, usually plastic, between them. Laminated glass may be used as safety glass, generally for specific purposes, e.g. anti-bandit or bullet resistant.*

Plastics

A number of plastic materials, such as acetates and polycarbonates, are available. They tend to be used for glazing in outbuildings, such as garages or sheds, because they are usually less translucent than glass. Some of the cheaper plastics discolour and become brittle with age.

Increasing the thermal performance of windows

The energy performance of windows can be improved by attention to the glazing and, to a lesser extent, the frame. Increasing the number of panes in a window can increase thermal performance and reduce sound transmission. Unfortunately, the optimum space between the panes is different for each of these requirements. For improved thermal insulation the space between the panes should be about 15–20mm and for improved sound insulation the space should be about 100mm.

Multiple glazing

Glass, in the thickness used in windows, typically 4mm, is a good conductor of heat. Multiple glazing improves the energy performance of a window by trapping air in the space between the multiple panes of glass. Multiple layers of glass interrupt the conduction path and the rate of heat flow is reduced.

In order to maintain the insulating qualities of multiple glazing units it is essential that the air trapped between the panes is dry and that the unit has a completely airtight seal – hence the term 'sealed unit'. In the past, some seals have been poorly formed. This has enabled moist air to leak into the sealed units: effectively negating almost all of their insulating qualities. Typically, the units mist up as moisture condenses between the two panes. Attention to the detailing of the seal and spacer bar, which permanently separates the panes, has reduced the incidence of failure. Additionally, for windows where the window beads are located externally, ensuring that the lowest horizontal bead, over which most of the rain drains, is effective at shedding water has proven to be essential. If this is not the case, the bottom edge of the sealed unit can potentially sit in water for significant periods of time. The effective detailing of this lowest horizontal rebate and bead involves allowing the bead to be ventilated (i.e. it should have gaps on its underside enabling trapped water to drain out). It is also important to ensure that the sealed unit itself does not rest directly on the rebate but sits on top of spacers, avoiding saturation of the vulnerable seal. Spacers are also used in the side rebates to allow for the thermal expansion of the glass itself. Given the past high level of failure of sealed units glazed on-site, it is common for windows to be glazed in the factory and to arrive on site complete. The use of sub-frames (explained earlier in this chapter) supports this approach.

The gap between the glass panes must be large enough to prevent conduction occurring across a narrow air gap, but not wide enough for convection currents to be set up. If convection currents are set up then the increased heat loss can offset the decreased losses in conduction. In theory, the wider the gap, the better the insulation. However, if the gap is more than about 25mm, transfer of heat by convection can become significant and the units can also be very difficult to seal effectively. Many early sealed units were available with a 6mm gap. A 6mm space in double glazing will give a U-value that is about 10 per cent higher than a 12mm gap and 25 per cent higher than a gap of 16mm. A 16mm gap is generally agreed to be optimum and is currently standard. This width of gap makes the total unit thickness 24mm, including the two 4mm glass panes. Some manufacturers are producing units with a 20mm gap (making a 28mm unit). The decrease in U-values between a 16mm and a 20mm gap is negligible.

Other methods are now being exploited which improve the thermal performance of sealed units without the need to enlarge the gap beyond 16mm. These are:

- *using glass with a low emissivity coating*
- *providing an inert gas between the panes instead of dry air.*

Low emissivity ('low e') glass

Low emissivity refers to a coating treatment to glass which can reflect heat back into the room. They are sometimes referred to as 'selective coatings' as they allow short-wave radiation to pass through but restrict the passage of long-wave radiation. In the case of windows, this means that solar energy can pass from the outside through the glazing and contribute to heating the room but heat energy from the interior will be reflected back into the room.

The coating is usually applied to the outer surface of the inner pane of glass in a double glazing unit. Applying it to this position protects the coating while ensuring that the heat is reflected into the room.

Gas

Coatings will reduce radiative heat transfer but performance of the window can also be increased by introducing a gas which is heavier than air into the gap between the panes of glass. These inert gases reduce the amount of convection occurring within the gap, so reducing the transmission of heat from the inner to the outer pane. The most commonly used gas is argon.

A double glazed window with a 'low e' coating and argon will have a slightly better U-value than triple glazing and the window unit will be lighter and less bulky.

The actual U-value of glazing will vary with exposure but approximate relative values can be seen from the table below.

GLAZING CONFIGURATION	U-VALUES (W/m^{2}K)		
Standard 4mm glass (single glazing)	4.7		
DOUBLE GLAZING GAP	12mm	16mm	20mm
Standard 4mm glass/air/standard 4mm glass	2.9	2.7	2.8
Standard 4mm glass/argon/standard 4mm glass	2.7	2.6	2.6
Standard 4mm glass/air /'low e' glass	1.9	1.7	1.8
Standard 4mm glass/argon/'low e' glass	1.6	1.5	1.5
Overall width of sealed unit	20mm	24mm	28mm

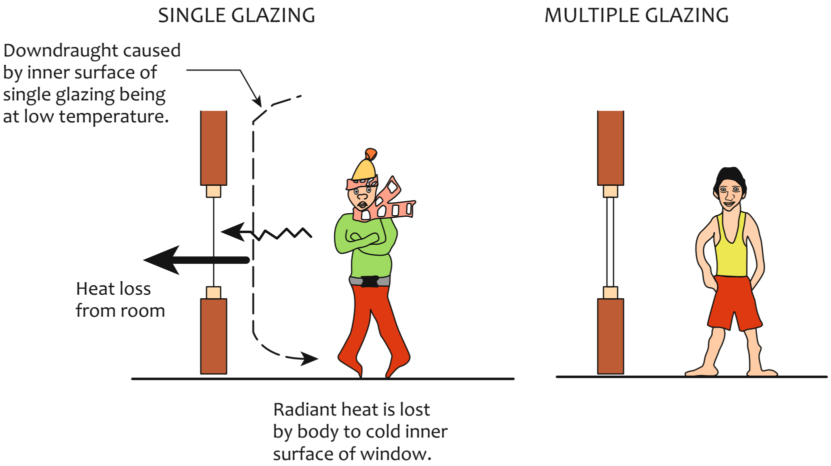
Multiple glazing can produce both a direct and an indirect thermal benefit. The direct benefit is the reduction in the amount of heat loss through the window. The indirect benefit is an increase in thermal comfort. The increase in thermal comfort occurs because the inner surface of the glass is at a higher temperature than it would be in single glazing. This higher temperature has two effects:

- *there is a reduction in downdraughts*
- *less radiation heat is lost from the person to the surface of the glazing.*

Draughts are caused near windows because the inside face of single glazing is relatively cold and as warm air hits this surface it is cooled and drops. This movement causes a draught. Draughts have an effect on a person's 'comfort perception' and therefore on energy demand. In other words, a draught can cause a perceived lowering of temperature which is greater than the actual reduction in air temperature.

Newly made and installed sealed units in timber joinery.

An additional benefit of multiple glazing may be derived from the savings in the installation costs of radiators. Radiators are placed under windows to mitigate the effects of cold downdraughts. This restraint on positioning is often costly because of awkward and extended pipe runs and the need to source specially sized radiators to fit below different heights of window sill. If downdraughts are reduced because of the higher internal temperature of the window, the radiator can be placed elsewhere. Additionally, heat losses for the room are likely to be reduced by placing the radiator on, say, an internal wall. In reality, factors such as window configuration, ventilation provision in the window, etc. will affect the situation. (It will also be affected by the curtains; not only their insulative value, but whether they influence the mixing of cold and warm air by, for example, the way they fall above, behind, or in front of the radiator.)



Multiple glazing improves thermal comfort as the inner surface temperature is higher. There is less of a downdraught and less radiant heat loss from the body.

Multiple glazing also reduces heat loss from the room so reducing energy costs and adding to improvements in thermal comfort.
There is also a saving in the capital costs of the heating installation.

The higher surface temperature should also lead to a reduction in the incidence of condensation on the glazing. In the past, the space bars which separate the panes within the sealed unit were made of aluminium. These were good conductors of heat and were effectively a cold bridge. Nowadays, plastic hollow-box section spacers, with a desiccant built into them (to absorb any residual moisture in the sealed unit) reduce the likelihood of cold bridging and condensation within the sealed unit.

Introducing more panes of glass, as with triple or quadruple glazing, produces a larger insulating buffer between outside and inside and divides the space up to reduce convective heat losses. The disadvantage of triple glazing is the weight and bulkiness of the window unit. A number of manufacturers are now routinely marketing triple glazed windows in the UK.

Secondary glazing

An alternative to double glazing is to introduce secondary glazing. This is a relatively cheap option but is less thermally efficient than (well-designed) double glazing because the air gap will usually be greater than the optimum of 15–20mm. However, the wider gap that is usual with secondary glazing will be more efficient than double glazing as an insulator against sound. The secondary glazing unit should be draught stripped but the outer window should not. This is necessary to allow for the ventilation of moist air – otherwise condensation may occur.

Secondary glazing should not be allowed to compromise the window's possible function as a means of escape in case of fire.

Energy performance of window frames

It is important to consider the window frame, particularly as it can account for up to 30 per cent of the area of the window opening. The type of material used, its design, the number of openings and its weather-sealing ability will influence the thermal performance of a window frame.

Infiltration losses through a poorly designed window are an important consideration, as are conduction losses through the frame. In the case of conduction losses, timber is a relatively good performer, as are the newer plastic windows (the frames of timber windows have a U-value of about 2.5, as do some plastic ones). Older plastic windows were constructed around metal sections, which produce a cold bridge, but now they can be produced using more rigid plastic materials, which eliminate the bridge. Also, the newer, more rigid, plastic frames can reduce the window frame area to about 7 per cent, which again reduces conductive heat loss and allows for greater solar heat gain. Aluminium windows are good conductors of heat, although their thermal performance has been improved over recent years by the incorporation of thermal breaks. It is important when using aluminium windows to ensure that a thermal break is incorporated because if the spacer is aluminium, rather than an insulating material, thermal transmittance through the frame will increase significantly.

Building Regulations

To ensure that the overall conservation of fuel and power performance requirements of the Building Regulations are met for new dwellings, windows and external doors with more than 50 per cent of their area glazed should achieve or exceed the minimum U-value recommendation of the Building Regulations. In addition, the replacement of external doors and windows is now controlled by the Building Regulations and replacements are required to achieve a minimum performance in terms of thermal efficiency. This means that, by default, replacement doors or windows should be double glazed, unless this changes the character of the building unacceptably, such as may be the case for a listed building.

In addition, to enable escape from a dwelling the Building Regulations recommend that for dwellings with floors within 4.5m of ground level all the upper floor habitable rooms and all inner rooms, even on the ground floor, should be provided with windows or external doors that can be used as a means of escape. For a window or external door to be suitable, it should be positioned within 1,100mm of the floor, have an opening area of at least 0.33m², with minimum opening casement dimensions of 450mm high and wide. Locks are permitted but, if not provided, a child-proof catch is recommended.

To limit injuries due to broken glass or glazing units, the Building Regulations recommend that any glazing to doors within 1,500mm of floor or ground level and 300mm either side of doors and within 800mm of the floor or ground level in windows or glazed lights should break in a safe manner. This can be achieved by the use of a safety glass, laminated or toughened glass, a preparatory safety film applied to the glass or the use of guarding.

To prevent people falling from a dwelling where there is a height difference of 600mm or more from ground level, the Building Regulations recommend that windows such as those to upper floors with a sill height of less than 800mm or for rooflights with a sill height of less than 600mm are provided with some form of containment, such as a guardrail or balustrade. Large areas of glazing within this zone should also be provided with containment or guarding if the glazing and framing system is not strong enough itself to resist the required forces.

Cavity barriers

The Building Regulations require that the spread of fire is restricted in concealed spaces. To achieve this the Building Regulations recommend that cavity barriers are provided around openings in walls, such as those formed by windows and doors. This requirement can normally be achieved by default if using timber or steel framing for the windows or doors and the cavity is closed by the framing. If using other materials for framing, such as uPVC or aluminium, which are not fire resistant, the use of either a proprietary 30-minute fire resistant cavity barrier around the openings or an accredited construction detail would be required.

Doors

Introduction

Doors should have some or all of the following characteristics, depending on their function and position in a building:

- *strength and stability*
- *weathertightness (in the case of external doors)*
- *security*
- *privacy*
- *thermal insulation*
- *sound insulation*
- *fire and smoke resistance.*

Materials

The main material for doors in houses is still wood, although aluminium, steel and plastic doors are becoming increasingly popular.

Designs

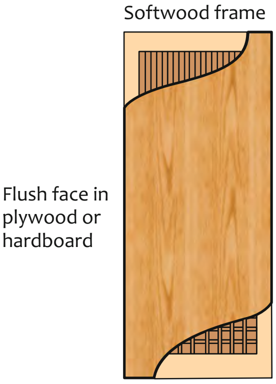
Panelled

Two typical traditional panelled doors. The left-hand door is internal and its total thickness is 35mm. On the right a part-glazed and panelled external door with raised and fielded panels and bolection mouldings. This more substantial and more complex door has a thickness of 45mm.

In this type of door the basic structure is exposed and is infilled with panels of timber or glass. They are, perhaps, the most enduring design for both internal and external doors. There are many variations in style, usually arising from the number of panels. These doors are generally quite expensive, particularly if made from hardwood. Cheaper doors of similar pattern can be made from compressed fibre but these are only suitable for internal use.

Flush

This is a style in which the basic structure is concealed beneath a flat face. They are available in various qualities and finishes.

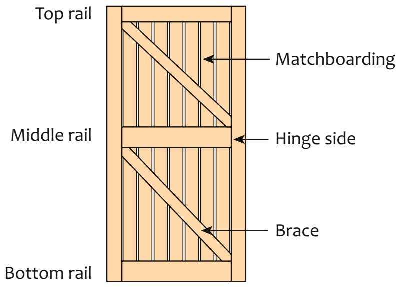


Core of door can be:

1. Celluar core made from lightweight materials such as fibreboard, expanded cellular paper or paper coils. These are light and relatively flimsy - suitable for internal doors only.
2. Semi-solid made from small timbers occupying 30–60 per cent of door area.
3. Solid core made from laminated strips of timber, high density chipboard or compressed fibre.

Framed, ledged and braced

These doors comprise vertical tongued-and-grooved boards fixed to a simple frame, which is braced to prevent sagging. They are usually found externally and are most commonly used for outbuildings such as sheds and garages.

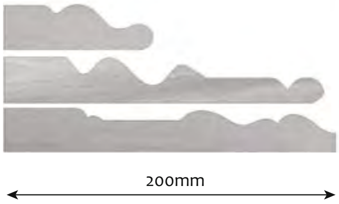


A framed, ledged and braced door.

Door linings

Internal doors are supported on hinges fixed to timber door linings. The lining is fixed to the partition by nailing or screwing and its width is determined by the thickness of the wall and wall finish combined. A cover strip, known as an architrave, is fixed over the joint between the wall and the lining. The door stop (see the diagram below) is provided by a separate piece of timber (a 'planted' stop) fixed to the lining.

Three examples of architraves



A lining fixed into new studwork partition. The edge of the studs and the gap between these and the lining will be finished in a wide softwood architrave.

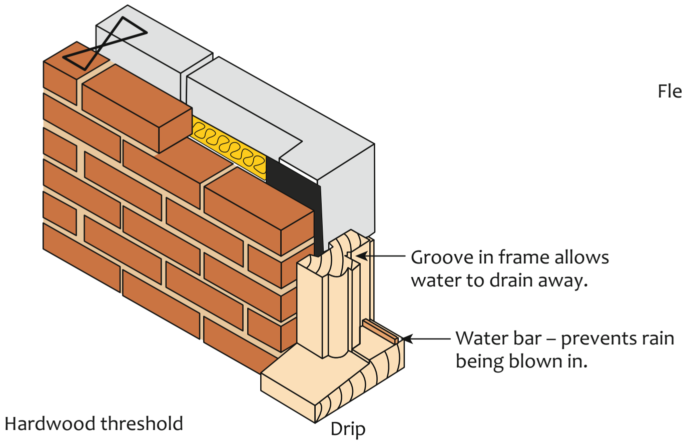
Picture 1 shows a door lining fixed to a stud partition. Picture 2 shows the partition plasterboarded ready for a skim of plaster.

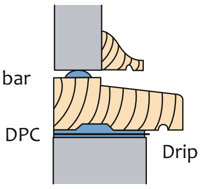
Door frames

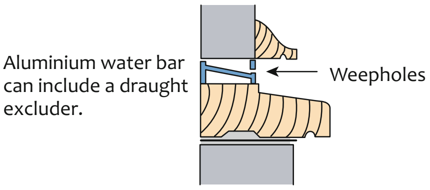
These generally support external doors and were usually built into the brickwork as work proceeded using stainless or galvanised steel cramps, similar to those used for windows. Nowadays purpose made, insulated cavity closers are built into the masonry, and the doors and frames are located into these once all the masonry is complete – as in the case on windows. Unlike linings, door frames do not have planted stops – here the stop is formed by rebating the frame itself. This provides better security and better weather protection. Nowadays, weather stripping is integrated into the rebating, improving the weatherproofing aspects of the frame. In extreme exposures the frame may be taken back further into the reveal and may be fixed into a rebate in the wall structure.

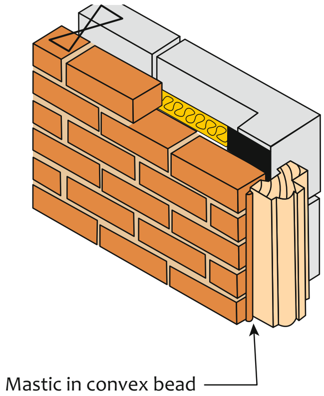
To prevent rain getting under an external door, the bottom of the frame is provided with a specially designed threshold. These are usually made from hardwood and are an integral part of the frame.

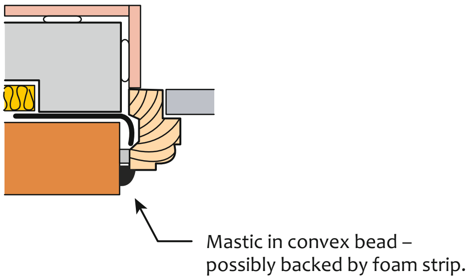
Sealants can be used to prevent water penetrating any gap between a door frame and the surrounding brickwork. These are not generally necessary in cavity construction unless exposure is severe. If a sealant is used it should be of adequate size to remain intact as the joint between the brickwork and frame moves. The sealant should be capable of adhering to the brickwork and the frame and should be a well-rounded convex bead at least 10mm wide. If the gap is more than 5mm wide, the sealant should be used in conjunction with a dense foam strip which controls its depth and ensures that the sealant is forced against the sides of the joint.





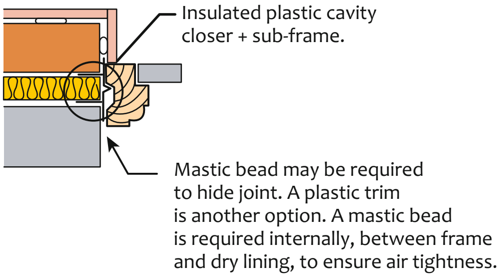






Cavities are now often closed using extruded plastic sections. In these cases door detailing is slightly different.

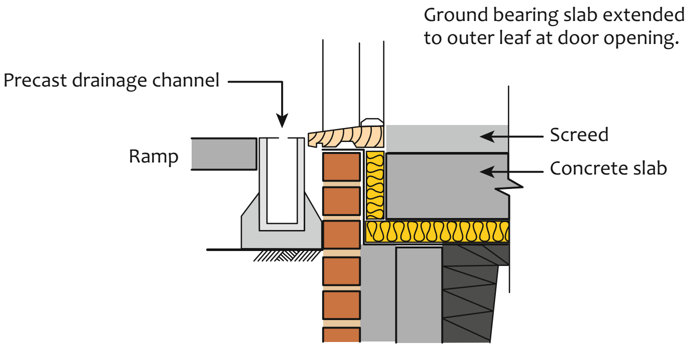
Modern extruded sections save the need to close the cavity with cut blocks.



Wheelchair access

To ensure that dwellings are accessible for any disabled occupiers or visitors, or to enable occupiers to stay in their home longer, the Building Regulations require that reasonable provision is made for accessible access into the dwelling either with a wheelchair or by foot via the principal access door, which could be a front, rear or side door depending upon the dwelling and site layout. The Building Regulations recommend that the approach and threshold is level or ramped within certain limits, the entry of moisture is prevented and that the door has a clear opening width of 775mm.

One method of providing this is shown below.



Fire doors

Fire doors are used to slow down or limit the spread of fire and the products of combustion in order to allow escape from a building which is on fire.

Fire doors must be able to:

- *resist collapse*
- *resist penetration of fire, smoke or hot gases*
- *resist the transmission of excessive temperatures.*

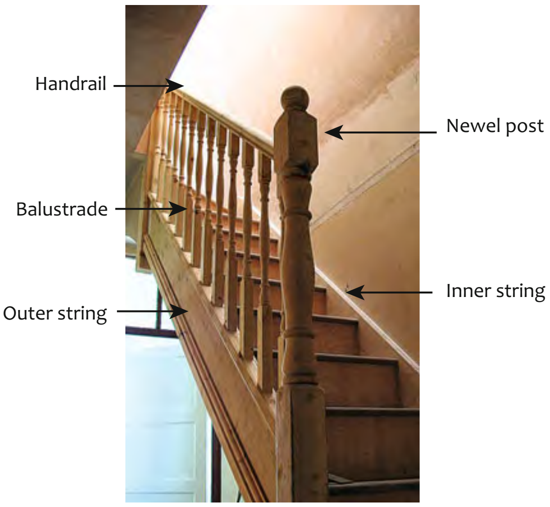
They are used in flats and also in particular circumstances in individual houses. For example, if a garage adjoins a house the connecting door should be a fire door. It should also be self-closing to ensure that it is not accidentally left open. For dwellings with three or more storeys, the Building Regulations recommend that the walls to the hall, stairs and landings are protected with 30-minute fire-resisting construction and the doors opening from rooms into these areas are fire doors of at least 20 minutes' rating, with the exception of a door to a garage which should be 30-minute rated with smoke seals, as detailed above.

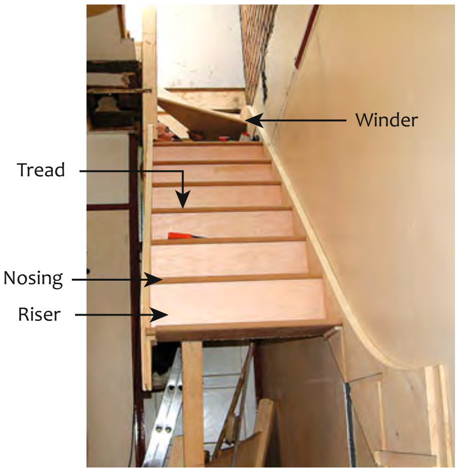
Fire doors are designated according to the time period that they should be able to resist fire while maintaining their integrity. Intumescent strips are elements that are usually fitted in grooves around the door or the door frame. They expand in reaction to the heat of a fire to fill the gap between door and frame. Combined smoke and intumescent seals are available. Perhaps the most important point to remember about fire doors is that they are tested and sold in relation to the precise constructional details of the door, plus the frame, the ironmongery and the surrounding wall. If any of these are altered, the fire integrity of the door may be impaired. Fire doors are usually flush-faced with specially designed cores.

Stairs

Introduction

Accidents on stairs in houses are a relatively common occurrence. Although the staircase itself is not responsible for all of these accidents, good design and construction are important safety aspects.



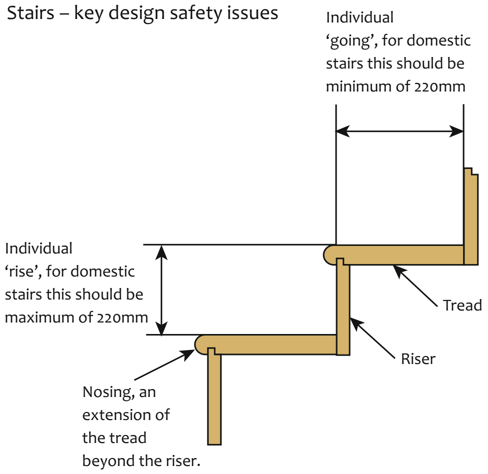


The inner string is plugged and screwed to load-bearing wall.

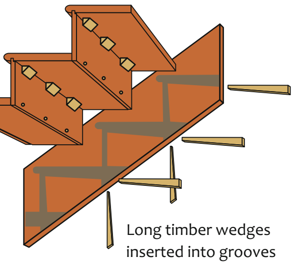
Modern timber staircases are usually prefabricated and brought to site for final assembly. A detailed technical knowledge of their construction is therefore unnecessary and this chapter concentrates on providing a brief introduction to the staircase components, together with a summary of the relevant Building Regulations.

Modern staircases are usually made from a combination of softwood, plywood and, increasingly, medium density fibreboard (MDF). They are available in a range of designs. The simplest is the straight flight. The staircase essentially comprises a series of stair treads supported by two strings, designed to span from floor to floor, usually without intermediate support.

In common with many other building elements, stairs have their own terminology and the steps themselves usually comprise a horizontal tread and a vertical riser. The going and rise are not components but dimensions and the size of these is controlled by the Building Regulations. The treads and risers are fixed by gluing and wedging them into the strings as shown opposite.

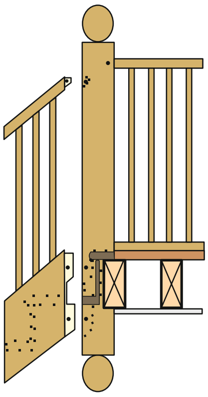

Stairs – key design safety issues

Stairs

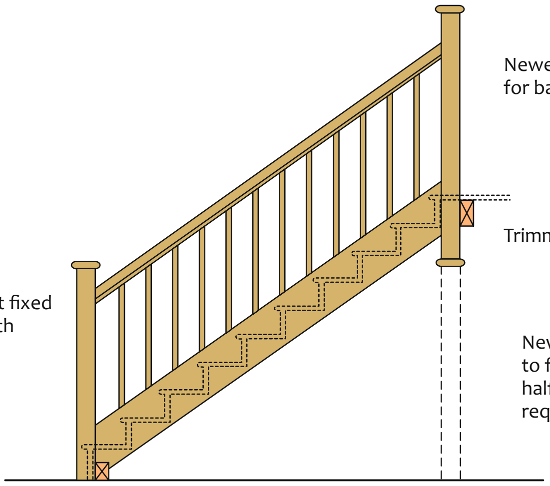


Treads and risers are jointed together at the front edge but not glued. In order to avoid movement at this vulnerable point, a series of timber blocks are glued to the underside of the joint between tread and riser. Not including these, or their failure over time, is responsible for much of the creaking in stairs. The bottom of the risers are screwed or nailed to the backs of the treads.

Long timber wedges inserted into grooves in the strings behind the treads and risers hold the staircase together. Over time the wedges can shrink causing movement of the treads with consequent creaking. In some circumstances the wedges can become so loose that the stairs come apart.

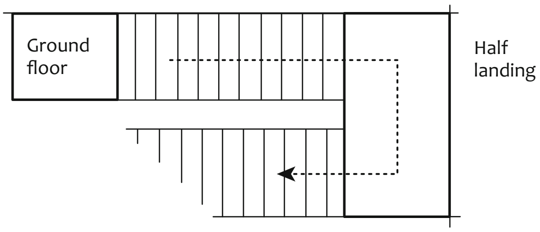


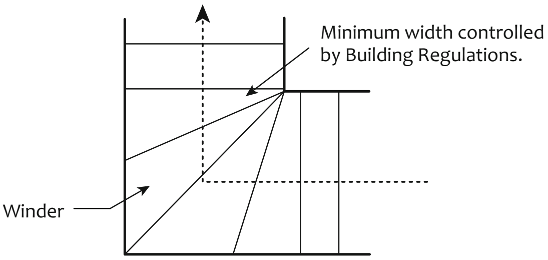
A newel post is frequently used to terminate one of the strings at both high and low level. The string is usually jointed into the newel using a pegged mortice and tenon joint, with the newel itself notched over and fixed back to a trimmer joist. The newels provide a good point to fix handrails and associated guarding for the stairs and the stair well. The handrails, like the strings are usually morticed into the newel.

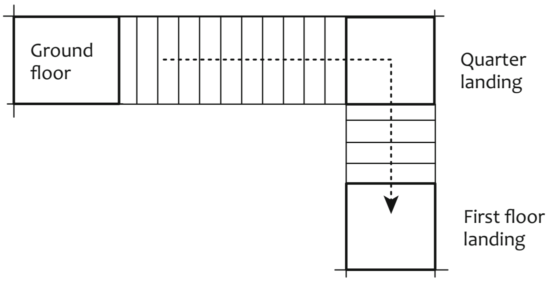


More complex design

The staircase may rise from one floor to the next by more than one flight. To do so requires the incorporation of landings as shown in the diagrams below. Quarter or half landings can be supported by adjacent walls or by newel posts extending to the ground floor. Instead of landings, winders may be used to turn corners. This approach was popular in earlier periods of housing, in particular in the Georgian period. They are generally not as safe as landings because of the narrowness of the tread.







Some stairs consist entirely of winders. The strings (left photograph) are cut, shaped and grooved. The photograph on the right shows the assembled stairs. The balustrades will be fitted next.

Dimensions of stairs

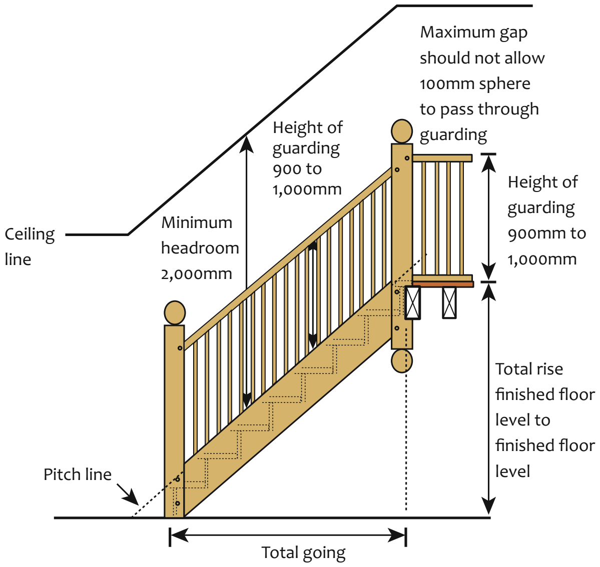
The Building Regulations recommendations for the design of stairs attempt to minimise the hazards of tripping or falling. They also seek to ensure that the stairs are easy to negotiate. This is done by controlling the dimensions of various parts of the stairs as shown in the diagram below. In other types of building, such as flats, shops and places of assembly (e.g. cinemas) the rules are more stringent involving both accessibility and fire safety requirements.

The pitch of a private staircase (i.e. a stair that serves one dwelling) is limited to 42° and there are also limits on the size of the rise and going treads (see drawing on p. 304).

To prevent people falling off the staircase or landings where the difference in levels exceeds 600mm, it should be provided with some form of guardrail, balustrade or wall.

If the staircase is less than 1m wide a handrail is needed only on one side. In practice, this is usually on top of the balustrade, except where a staircase runs between two walls and a separate handrail is required. Where the staircase is wider than 1m a handrail is required on both sides of the stair. The rules for handrails and balustrades only apply to staircases over 600mm high, i.e. more than three steps.

The Building Regulations do not give a minimum width for stairs provided inside dwellings. However, they require that landings equal to the stair width in length are provided at the top or bottom of the stairs or at changes of direction where tapered treads are not used. They also recommend that doors that swing across the landing are only permitted at the bottom of the stair and provide a clear space of at least 400mm between the base of the stair and door swing to prevent a person being struck by the door.



Thermal insulation and condensation

16

Introduction

The focus of this chapter is on how thermal insulation is used to reduce heat loss from a house as this is an important factor in the design and construction of energy-efficient dwellings. The chapter starts with a section on the basics of heat transfer followed by a section on U-values and the role of the Building Regulations. Section Three examines the properties and effectiveness of the thermal insulation materials available and Section Four deals with condensation, because well-designed and installed thermal insulation can help to prevent it while poorly thought out or inexpertly installed insulation will increase the likelihood of condensation occurring.

Section One: heat transfer

In order to design and construct an energy-efficient house, it is important that there is an understanding of the basic science of how heat is transferred and used and some aspects of this are explained below.

Heat is transferred because a material will attempt to achieve thermal equilibrium with its surroundings. Heat flow will occur within a material (solid, liquid or gas) or between materials until the temperature of each is equal. Heat transfer can occur through three mechanisms, which can operate alone or in combination, these are conduction, convection and radiation.

Conduction

Conduction is the process whereby heat energy is transferred through the physical contact between molecules within a material or between materials that are touching each other. The direction of flow will be from the warm area to the cool area.

Thermal conductivity is the rate of heat flow – a factor that is determined by the ability of the molecules to conduct heat. The human body is sensitive to this heat flow rather than to temperature. If a person stands with bare feet on a concrete floor in contrast to a wooden one, the body senses the different rates of heat flow. That is, heat will be transferred from the body to the concrete more quickly than to the wooden floor because concrete is a better conductor. The concrete floor will be less thermally comfortable than the wooden one.

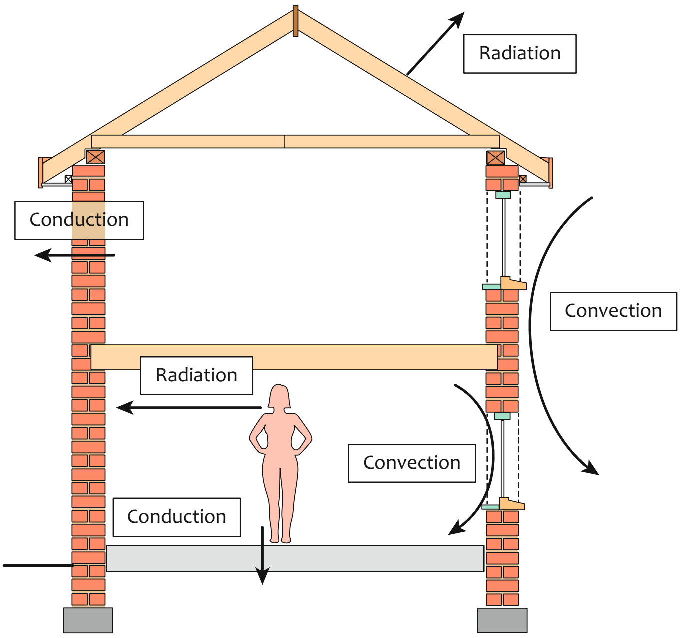
Convection

Convection refers to heat being transferred by the movement of a fluid. In buildings, the fluid in question is usually air or water. When it comes into contact with a warmer or colder surface, the air or water will either absorb heat (from a warmer surface) or lose heat (to a colder surface). If it becomes colder, the fluid will sink because of its increased density and vice versa.

Radiation

Heat can also be transferred through the air, or rather through space, from one 'body' to another by radiation. Heat is radiated to and absorbed from the surfaces that surround a body without heating the air. When radiant energy hits a body, some of the energy is reflected and some is absorbed. The respective amounts will vary between different materials and, for instance, colour will play a significant role in determining the amount reflected.

Buildings will lose heat by all three means. Heat will be conducted from the interior to the exterior through walls, floors and the roof. Convection can transfer heat from a warm interior cavity skin to the cooler outer skin and the wind will convect heat away from exterior surfaces of the building. The exterior surfaces of the building will radiate heat to its surroundings.



Human beings will also lose and gain heat by these mechanisms. They will lose heat by conduction when they stand on a cold floor, by convection because of draughts and by radiation to cold surfaces, such as windows or uninsulated walls. The mechanisms for heat loss for both buildings and people are relevant to decisions about how much insulation to place and where to place it, the heating system and its components and the effectiveness of elements such as windows (including decisions about such matters as double and triple glazing).

In a structure, the relative amount of heat which is lost through the main elements will vary from element to element. As an example, if we were to consider a small detached house with one-brick solid walls, a timber ground floor, an uninsulated roof and single glazing, then approximately 25 per cent of the heat goes through the roof, 30 per cent through the walls, 15 per cent through the windows, 15 per cent through the floor and 15 per cent through ventilation and draughts.

Thermal mass

This term refers to the amount of heat that a material can store. A so-called 'heavyweight' building will have a high thermal mass. High thermal mass can be useful in smoothing out fluctuations in temperature. Rooms with a high mass will heat up slowly and cool down slowly. Thermal mass can be useful for storing solar energy coming in through southerly orientated windows. Brick and concrete block walls would, for example, have a higher thermal mass than a timber-frame wall.

Section Two: the Building Regulations and U-values

Although the Building Regulations are primarily intended to protect public health and safety, they are also given the additional role of imposing minimum standards for buildings in relation to the conservation of fuel and power (as well as minimum standards for airtightness and reducing water wastage).

In considering the design of a low-energy house, generally the best approach is to insulate a property as much as technically and economically possible before deciding on a heating system (including those based on renewable energy). It is easily possible to have a 'super-insulated' house where there is no need for heating systems and the house is kept warm by human activity and the heat given off by household appliances. The logic behind considering and maximising thermal insulation is fourfold:

1. *a unit of energy saved is preferable to a unit of energy generated since some energy is needed to generate energy even from a renewable source*
2. *studies have shown that maximising insulation is the most effective means of achieving energy bill savings*
3. *there is currently a relatively long payback period for renewable technologies – although this is reducing year by year*
4. *heating systems, including those based on renewable energy, will be most effective in a well-insulated property.*

The requirements for minimum standards of thermal insulation in the Building Regulations first came into being in the 1960s, were strengthened following the oil crisis of the early 1970s and have been revised several times since. At the time of writing, the most recent changes were those introduced in 2010 and further changes are planned for 2013 and 2016, as the Building Regulations continue to play their role in meeting the target of achieving 'zero-carbon' houses (see Chapter 2).

U-values

The rate of heat loss from a building is measured by what are known as U-values, which are based on the transmission of heat flow through an element; that is, a U-value is a measure of thermal transmittance through a building element. It represents the amount of heat which will flow through 1m² of an element – wall, floor, roof, etc. – for every degree in temperature difference between the inside and outside. So, if a wall has a U-value of 2.5 and the temperature difference is 10°, the heat flow per m² is 25 watts.

Thermal insulation will reduce the amount of heat lost through an element and therefore will improve (i.e. lower) the U-value. For example, if a wall has a U-value of 1.6W/m²K (typical of a 1930s cavity wall) the heat loss through the wall (say, 100m²) on a cold winter's day (with a 20°

difference between the inside and outside temperature) could be 100 x 1.6 x 20 = 3,200 watts. If the wall is well-insulated, say U-value of 0.30, the heat loss will be 600 watts.

Indicative U-values of various building elements are shown below. These figures are simply for broad comparative purposes as the U-value will vary depending on the exact nature of the construction, the exposure of elements, etc.).

WINDOWS	
Single glazed steel/aluminium	5.8
Single glazed wood/plastic	4.7
Double glazed aluminium	4.2
Double glazed wood/plastic	3.0
Double glazed, 'low e' glass and argon filled (wood)	1.5–1.2
Triple glazed (wood)	2.1
Triple glazed, 'low e' glass and argon filled (wood)	0.5–0.7
WALLS	
Half-brick wall	3.2
One-brick solid (225mm)	2.1
Stone 300mm	1.9
Brick (and brick) cavity wall	1.6
Brick and 100mm lightweight block	1.0
Brick and 100mm aerated block	0.7
Brick and 125mm aerated block, 50mm cavity insulation	0.4
Brick and 125mm aerated block, 75mm cavity insulation	0.3
ROOFS	
Pitched, no insulation	3.3
Pitched, 25–50mm insulation	2.6
Pitched, 75mm insulation	1.0
Pitched, 100mm insulation	0.5
Pitched, 200mm insulation	0.3
Flat, uninsulated	2.0
Flat, 50mm insulation	0.7

Note: U-values for floors are not shown because the heat loss through a ground floor varies with its size and shape. This is because most heat is lost around the edges of the floor. So, for example, a house with a high perimeter to floor area ratio will suffer from a relatively higher heat loss. Heat loss will also vary in relation to ground conditions.

The Building Regulations and energy use

The Building Regulations are a statutory requirement which impose minimum standards for buildings that are newly constructed or substantially altered. The Regulations are supported by Approved Documents which contain guidance on how to comply with the requirements of the Regulations. However, the requirements may be satisfied in other ways or non-standard ways by calculations or test details from a manufacturer or an approved method of certification, such as an Agreement Certificate.

The relationship between the Building Regulations and the Code for Sustainable Homes has already been briefly outlined in Chapter 2.

Part L of the Building Regulations deals with the conservation of fuel and power and it is backed up by the following four Approved Documents:

- *L1A Conservation of fuel and power in new dwellings*
- *L1B Conservation of fuel and power in existing dwellings*
- *L2A Conservation of fuel and power in new buildings other than dwellings*
- *L2B Conservation of fuel and power in existing buildings other than dwellings.*

Before 1995, the main thrust of the Building Regulations was related to achieving stated U-values for each element of the building (i.e. looking at the roof, the walls and the floors in isolation). The changes to the Regulations which were introduced in 1995, and again in 2002, were comparatively sophisticated and sought to encourage awareness of the need to take a more holistic view when considering energy performance. The 2002 Regulations tried to encourage this holistic view of energy performance by allowing compliance to be demonstrated by either a 'target and average' U-value or by use of a 'standard assessment procedure' (SAP) rating, which took into account the overall energy performance of the whole house. Despite this, the most common method used for compliance was to follow the elemental route – referred to above and which was still allowed – where the different elements of the building, such as roofs, floors, walls and external glazing could not exceed a specified U-value. Further revisions in 2006 were brought in by the Government in order to help meet its own energy reduction targets, as well as comply with the requirement to implement the European Union's Energy Performance of Buildings Directive. There was also, in effect, a requirement in the Regulations to use an approved SAP calculation method to show design compliance, and prove 'as built' compliance, with the Regulations, for new dwellings – an approach which was reinforced by the 2010 amendments.

Standard Assessment Procedure (SAP), Target Emission Rate (TER) and Dwelling Emission Rate (DER)

The Standard Assessment Procedure (SAP) is a relatively sophisticated approach to considering the energy performance of a building. It allows design flexibility and takes account of maximum and minimum U-values for building elements, building orientation (and therefore solar gain), fuel type, efficiency of mechanical ventilation systems, the type and efficiency of the space heating, hot water and lighting systems used, as well as calculating the airtightness and thermal bridging standards of the design. In addition, it takes into consideration heat gains produced by the 'typical' activities that take place in a house – generated by both people and appliances.

The 2010 Building Regulations also use the concept of Dwelling Emission Rates (DER) and the Target Emission Rate (TER). The Target Emission Rate (TER) is the recognised holistic way of showing compliance with the requirements of the Regulations and it concerns itself with the carbon dioxide (CO_2) emission rates from the new dwelling. The dwelling design and constructed CO_2 emission rating should not be greater than the target emission rate for the design. This is calculated by the SAP calculation method, which uses an approved software and calculation system. The SAP calculation process methodology checks that the predicted rate of CO_2 emission – the DER – for the design is not greater that the dwelling's target emission rate – the TER. The SAP will also provide a rating for the dwelling of 1 to 100 and G to A. The higher the number, or the nearer to A, the better.

Note: The energy/CO_2 category of the Code for Sustainable Homes (see Chapter 2) is currently based on the same approach (i.e. the SAP and the improvement of the DER over the TER).

U-values and Part L

Although the SAP approach is a requirement for showing compliance with Part L, the Building Regulations also set out recommended minimum standards that the structure and elements of the building should achieve in terms of U-values (and air permeability). These minimum U-values are:

ELEMENT	MINIMUM (BACKSTOP) U-VALUE
Roof	0.2
Walls	0.3
Floors	0.25
Windows and doors	2.0

The 2010 amendments also included a requirement for the insulation of any party walls to achieve a minimum 'backstop' limiting U-value of 0.2. A minimum standard of air permeability for a dwelling is also set out in the Regulations.

However, the Building Regulations state that, in practice, achievement of the TER is likely to require a better thermal performance than, for example, the 0.3 shown for walls, and therefore the actual U-value required for a particular element will depend on factors such as the space and hot water heating system efficiency, the type of fuel used and the air permeability of the fabric. It should also be noted that, as we have observed earlier, in order to achieve certain levels of the Code for Sustainable Homes, minimum U-values will have to be lower than those required by the (current) Building Regulations (i.e. the 2010 amendment).

The Building Regulations also give recommendations for what the fixed building services (i.e. heating, hot water and mechanical ventilation systems) should achieve in terms of efficiency, controls and performance. A secondary document, the *Domestic Building Services Compliance Guide*, which can be accessed online, provides guidance on the efficiencies, controls and performances required.

The Regulations also require that air permeability tests are carried out on houses 'as built'. In the case of a housing estate or development, a sampling approach is used. An additional requirement is that all the heating, cooling, ventilation and hot water systems and associated controls, etc. that can be adjusted are commissioned and tested to verify that they operate in a correct and fuel-efficient manner (i.e. as they have been designed and as shown by the DER).

Information to occupiers

The idea of providing a document to homeowners about how to maintain and repair their house has been around for a long time. The 2010 Building Regulations require such documents, typically for those aspects that affect energy use, ventilation and fire safety. The requirement is for the developer to provide the occupiers with sufficient, clearly understandable information and instructions about the dwelling, the fixed services and any associated maintenance requirements to enable them to be able to control the services in a correct and energy-efficient manner. This document for the services should, as a minimum, provide instructions on items such as timing and temperature controls and maintenance requirements.

Section Three: thermal insulation

Although energy use in a building is a complex issue, the relatively simple technology of increasing the thermal insulation value of the walls, floors and roof is a straightforward cost-effective measure. A well-insulated house will reduce energy costs and improve the thermal comfort of the occupier by keeping the house warm in cold weather and, depending on the position of the thermal insulation within the structure, cool in hot weather.

Thermal insulation will lower energy use by reducing the amount of heat lost through an element of the house. The effectiveness of the insulation in restricting heat loss will be related to the thickness and the conductivity of the material used.

Conductivity depends on:

- *the temperature of the insulation material: in normal conditions this does not have a significant influence*
- *the moisture content of the material: the higher the moisture content, the lower will be the material's resistance to heat flow. For some insulation materials, the moisture content will affect thermal insulation properties*
- *the structure of the material: insulation materials are generally constructed so that they trap still air in small pockets within the material. Air is a poor conductor of heat and the pockets are so small that the air cannot move so that heat transfer by convection is minimised.*

Although resistance to the passage of heat (thermal resistance) will increase with the thickness of the insulation, after a certain point, cost effectiveness (at least in simple payback terms), decreases as the thickness increases. For example, doubling the thickness of existing roof insulation will not save double the amount of energy. In practice, the thickness of insulation will also be determined by construction factors, an obvious example being the width of the cavity in masonry walls. However, the continued emphasis on the need to reduce the amount of energy used by houses may mean that increased levels of thermal insulation will have to be accommodated by changes to what is regarded as normal construction practice in elements such as walls – a factor which itself will increase construction costs. Despite these caveats it is generally true that, in order to produce a low-energy house, maximising the amount of thermal insulation is the sensible first step before making decisions about appropriate heating technologies – including the use of renewable energy sources.

Decisions about the thermal insulation's positioning and thickness should be made in conjunction with the design of the heating system to ensure that they complement each other – not least because thermal insulation levels may affect both the choice of heating system and the required capacity of the heat source (e.g. the boiler).

Thermal insulation materials

These are produced from three main sources:

- *vegetation (i.e. organic fibres)*
- *minerals (often volcanic in origin)*
- *coal or oil (in the form of cellular plastics).*

There are a number of insulation materials that have been used for some time (what we might refer to as 'conventional') and these include polystyrene, polyurethane foam, fibreglass and mineral wool. These materials are relatively inexpensive but they carry an environmental cost because of the energy required to produce them. They also contain chemical adhesives and other additives, such as fire or surface spread of flame retardants, which may be required depending on the particular location in which they are used, the location of the building or the type of wall construction.

Products sometimes referred to as 'green' insulation materials, because they are based on natural materials, have grown in popularity and range in recent years. Natural materials include insulation produced by, for example, sheep's wool, plant fibres such as flax and hemp, wood fibre and cellulose (mainly in the form of recycled paper).

Insulation materials come in different forms – the main ones being:

- *batts and rigid boards*
- *quilts*
- *loose fibres or granules*
- *foam*
- *as an integral part of a construction material (e.g. blockwork or plasterboard).*

Effectiveness of insulation materials

Some insulation materials will have a higher insulation value than others. However, there may be reasons why the better insulating material is not specified in particular circumstances, for example:

- *cost*
- *the material may not be available in the form required*
- *the material may be inappropriate for the specific position on the building that is being insulated – it will sometimes have to resist loads (on floors and flat roofs, for example) or be stable under conditions of heat from the sun (external insulation, flat roofs) or resistant to water absorption (inverted flat roofs) – or may not be suitable for walls over a particular exposure rating*
- *some insulation materials can settle with age or become displaced. Some materials are both flexible and resilient. They fit well into awkward spaces and therefore reduce the potential for thermal bridging and heat loss at gaps between the insulation and the structure, and between different sections of insulation material*
- *the fire-resisting properties and combustion characteristics of the insulation material should be taken into account. This includes the possibility of toxic gases being released in a fire*
- *there may be adverse reactions between insulation materials and other materials. For example, polystyrene insulation should not be allowed to come into contact with PVC (in the form of perhaps DPCs, cavity trays or electric cables) as it may cause them to become brittle*
- *the risk factors involved in installation: for example, foamed insulants rely on two components – a resin and a hardener – being mixed together correctly, and the placing of insulation on the exterior of a building is dependent on the performance of the render protecting the insulation, which is sometimes poorly specified and applied*
- *acknowledgement of wider environmental concerns – as with conventional versus natural materials referred to above. Some materials may offer higher insulation values but have a more adverse impact on the environment due to their associated extraction, manufacture, transport and disposal processes.*

Section Four: condensation

When considering energy matters, an understanding of condensation is vital. The elimination of condensation and its associated mould growth is often quoted as one of the benefits of improving energy performance, and the prevention of it is one of the objectives of the Building Regulations, due to the deleterious effect that mould can have on the respiratory and general health of the dwelling occupiers. While this is true, it is also the case that ill thought out energy improvements can create or exacerbate a condensation problem. Reducing the risk of condensation occurring requires a holistic view of the performance of the dwelling and its elements – in particular the interaction between thermal insulation, heating and ventilation. In addition, occupants need to understand that it is the activities of the house, such as cooking, bathing, cleaning and drying clothes, which produce the moisture that leads to condensation.

Condensation is caused when moisture-laden air comes into contact with a cold surface and the moisture that the air is carrying as vapour is deposited as water on that surface. Air can hold varying amounts of moisture, depending on its temperature. The higher the air temperature the more moisture it can hold. Moisture in the air occurs due to natural conditions but is added to in a building by people breathing, by activities such as washing and cooking and as a by-product of burning substances such as paraffin or bottled gas in heaters. The amount of water generated in an 'average' family house can be as high as 14 litres a day. The problem is aggravated if high amounts of moisture are generated over a short period of time by cooking, drying clothes, etc., especially if this takes place in one particular room. Kitchens and bathrooms are, therefore, the rooms most likely to suffer from condensation.

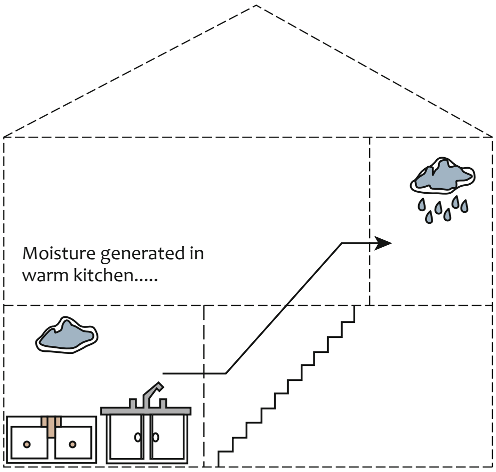
Relative humidity

Relative humidity is the term used to indicate the amount of water vapour that is being held by a volume of air, as a percentage of the amount that it is capable of holding. Therefore, if the air in a house is at a certain temperature and it is holding all of the moisture that it can, its relative humidity is 100 per cent (known as the saturation point). If the temperature is raised and there is no increase in water vapour, then the relative humidity will drop, because the warmer air can hold more moisture. However, if the temperature drops, the air will have reached saturation point, because it cannot hold all the water vapour and this excess vapour will be deposited as condensation. The temperature at which condensation occurs is known as the dew point.

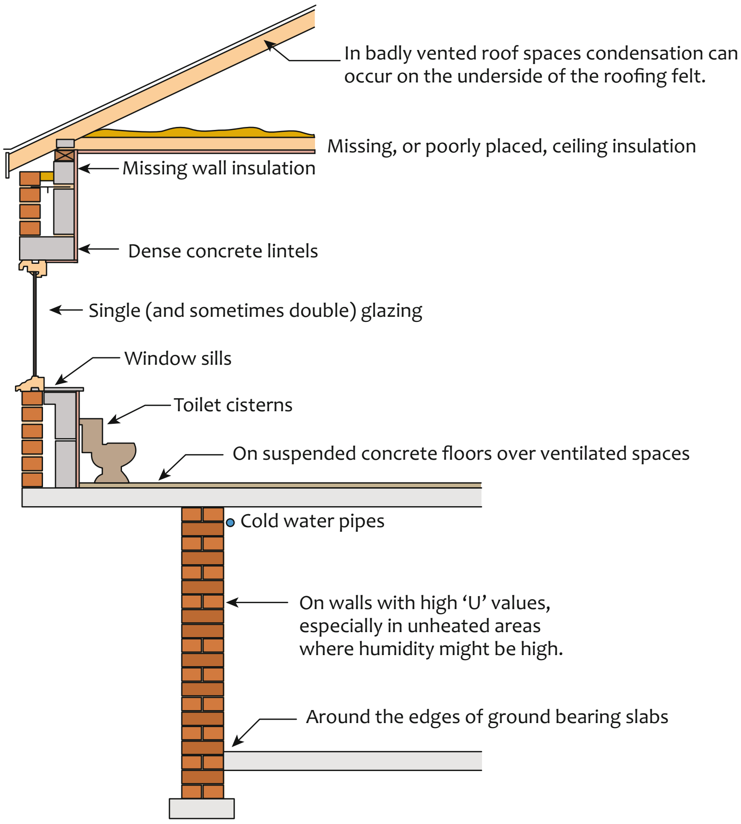
Where condensation occurs

As we have observed, the moisture in the air may condense in the room in which it is generated but it can also, of course, travel around the house due to air movement.

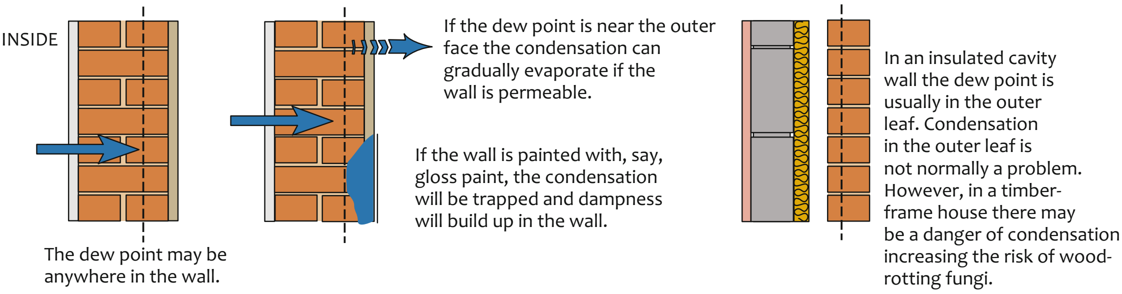
In a house, the air is cooled when it comes into contact with a cold surface. So windows, solid walls (particularly on exposed parts of the house), cold water pipes and cold bridges are the most common places for condensation to occur (see diagram overleaf).



.... condenses in cold bedroom



Condensation is less likely to occur on insulated elements, such as double glazing or insulated walls, because the internal surface temperature will be relatively high, i.e. above the dew point. Sometimes, condensation will occur inside porous structures, such as walls where the temperature of the inside face may be above the dew point but there may be a lower temperature in the wall itself. When this occurs it is known as interstitial condensation. This may cause particular problems in timber-frame housing (see Chapter 13).



Condensation is perceived as a problem of relatively modern houses. To a certain extent its causes are due to changes in the way we have built houses in the recent past, as well as the way they are heated and ventilated. For instance, some Victorian houses had relatively thick walls and were heated by coal fires. The fires tended to stay alight all day, keeping the air temperature and the temperature of the structure relatively constant. The chimney for the fire, whether it was burning or not, also aided ventilation. In comparison, many houses constructed in the 1960s, particularly for local authorities, were built without chimneys and were designed in such a way that they had poor thermal capacity (the ability to retain heat) and poor thermal insulation. This was often coupled with the provision of heating systems which were expensive to run and which were, therefore, used intermittently. These circumstances combined to make condensation almost inevitable. Examples of this situation include many prefabricated concrete structures with electric space-heating systems.

In more recent times, the increased emphasis on making houses airtight, to reduce heat losses through 'accidental' ventilation, has increased the likelihood of condensation occurring, particularly where the design has not introduced strategies and details for controlled ventilation (see Chapter 20).

Avoiding condensation

Reducing the risk of condensation occurring requires an understanding of the interaction of various factors, taking into account the outside climate, the environment within the house, the structure of the house and the activities of the occupiers. They include:

- *preventing excess moisture being created*
- *removing excess moisture*
- *keeping the air and fabric temperature relatively high.*

Preventing excess moisture being generated

At its simplest, this is a matter of educating occupiers to cover up cooking pots, not use tumble dryers without ventilation and make proper use of ventilation devices. It is also an issue, as with energy use, of poverty or lack of facilities, where, for example, people are unwilling or unable to use forms of heating which they find expensive to run. Excess moisture can also be compounded by poor housing design – for example inadequate facilities for drying clothes, etc.

Removing excess moisture

Proper ventilation will help to combat condensation by removing moisture-laden air before the vapour can condense on a cold surface. The amount of ventilation that is achieved is important. Minimum amounts are necessary, of course, for breathing, removal of odours, etc. and will, in many existing buildings, be provided as a matter of course due to gaps and general ill-fitting parts of the structure. In newer, more airtight buildings a ventilation 'strategy' must be worked out. It would be possible, in theory, to remove all moisture by increasing ventilation. However, if the rate of air change is dramatically increased then there will be a tendency for the air and fabric to become colder, which may actually increase the likelihood of condensation occurring.

Ventilation can be achieved by simply opening a window. Of course, if this causes too much heat loss it will be counterproductive in energy terms and it may also, as mentioned previously, increase the likelihood of condensation occurring. Therefore, the design of the window becomes important in relation to condensation. For example, if the window has a small portion which can be opened, such as a top opening light, this provides an alternative to opening the whole window casement. Also, incremental control of ventilation is more easily achieved with a sash window than it is with a casement window. Chapter 20 discusses ventilation and some of the approaches used in more detail.

Air temperature and fabric temperature

High air and fabric temperatures reduce the risk of condensation by keeping the temperature of the structure above the dew point. In practice, this is best achieved through a combination of thermal insulation and heating. Insulation helps to prevent condensation because:

- *it reduces heat losses and keeps both the air temperature and the temperature of internal wall surfaces high*
- *less money will need to be spent on fuel to achieve comfortable conditions and therefore heating systems are more likely to be used.*

The usefulness of insulation will be related to the heating system. If a building is well-insulated then even with a low level of background heat, the fabric may stay at a high enough temperature to prevent condensation. If, however, there is no heating or it is intermittent, condensation may occur.

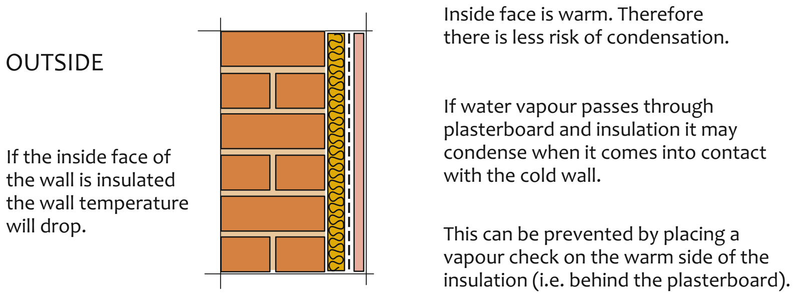
The role of space heating can be complex. By raising the fabric temperature the risk of condensation is reduced. However, warmer air can absorb and transport water vapour to cooler parts of the building, increasing the risk of condensation elsewhere. In practice, tackling condensation can be quite complicated and thermal insulation, ventilation and heating need to be considered together.

Vapour control layers

In general, when insulation is applied to a surface, the area beyond the insulation will drop in temperature. This will usually require the presence of a vapour 'barrier' on the 'warm side' of the insulation, in order to reduce the passage of water vapour and potential problems of (interstitial) condensation.

In reality, it is very difficult to achieve a complete barrier to vapour movement and, therefore, the term vapour check or vapour control layer is used. These, as their names imply, do not present an impenetrable barrier but rather slow down the rate of transfer of vapour. Because of this it is usually also necessary to prevent condensation occurring by providing adequate ventilation and allowing an escape route for the vapour. In practice, vapour control layers are often inappropriately installed or become damaged on site. In some cases, lack of understanding on the part of site operatives exacerbates the situation. However, the problem does not always begin at the site and, in many instances, it is the way in which vapour control layers are designed and detailed which presents a problem.

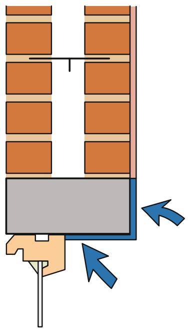
The diagram below illustrates why a vapour control layer is necessary when internal insulation is used (see later in the chapter).



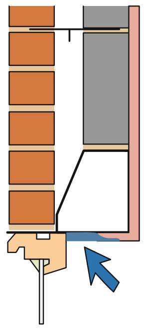
Cold bridges

Cold bridges (or thermal bridges) occur where there are gaps in, or bridges across, the insulation. Cold bridges allow the transfer of heat at a higher rate than occurs through the surrounding structure. They can contribute significantly to overall heat losses in a well-insulated dwelling. They allow the heat to drain from a relatively large area and they often cause problems of condensation because of the low surface temperature of the cold bridge compared to the surrounding structure.

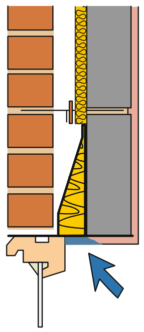
Cold bridges can be particularly troublesome in well-insulated buildings where the difference in inner surface temperature between insulated and bridged areas can be considerable. Cold bridges occur in localised spots where the nature of the construction allows heat to escape through the structure. Their internal surface temperature can be quite low, thus encouraging patches of local condensation. These damp patches are often confused with penetrating damp, especially where they occur around window or door openings. A few typical situations where cold bridges might be formed are shown below.



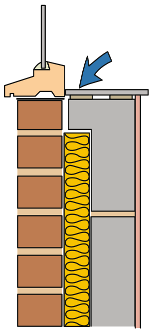
Concrete lintels which cross the cavity will have cold lower and inner surfaces (early twentieth century).



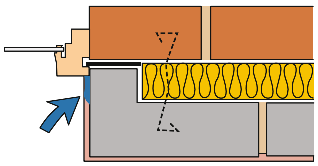
Uninsulated box-section lintel (1960s to 1990s).

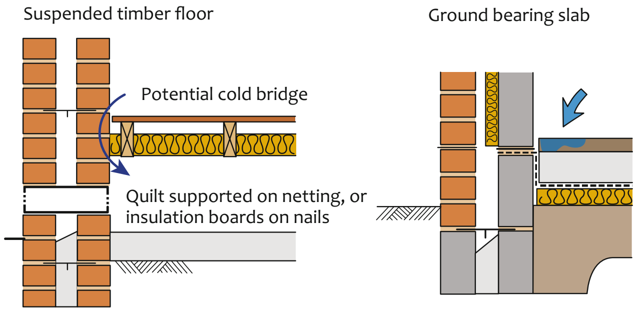


Lower steel member of insulated lintel creates cold bridge.

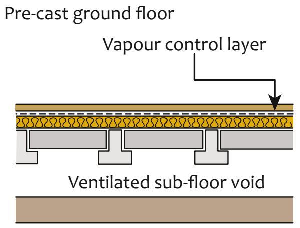


Cold bridges can be created at jambs and sills. Two examples are shown here. The left hand example shows a cavity wall with the dense block inner leaf returned to the brickwork to support a tiled sill. The right hand example shows a similar problem at the jamb. In modern construction insulated cavity closers avoid this problem.





The risk of cold bridging depends, to some extent, on the nature and position of any wall insulation and the insulating properties of the internal leaf.



Condensation on ground-bearing slabs usually occurs around the edges, if at all. In suspended pre-cast floors it is more likely, particularly if the sub-floor void is vented. A vapour control layer helps to prevent it.

The Building Regulations specifically require the limiting of thermal bridging around windows, doors and other openings. In addition, thermal bridges caused by construction elements have to be taken into account in the calculation of the U-value for the element and in the SAP calculations. An example might be the size and spacing of stud work in an insulated timber frame wall.

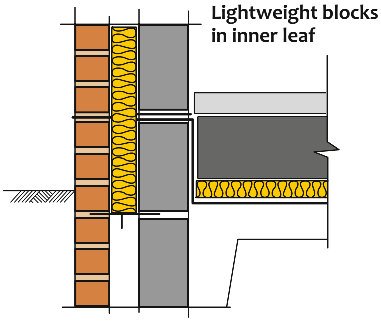
Insulation to walls and floors

Insulation is required in the walls, floors and roofs of domestic dwellings. Previous chapters have included details of how the levels of insulation can be achieved and the following section explores the relative advantages and disadvantages of various options for floors and walls (roof insulation details are covered in Chapter 7 Roof structure).

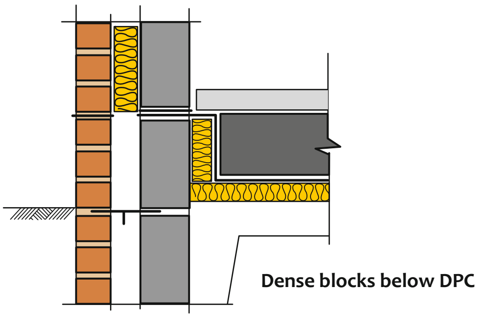
Ground floors

In the past it had been argued that there was relatively little heat lost through the floor. This view is now generally agreed to be incorrect, although the amount of heat loss can vary considerably from building to building and will be related to factors such as the type of soil below the building, the amount of groundwater and the nature of the floor construction.

With a solid floor, the thermal insulation can be placed either above or below the ground floor slab. The position will affect the choice of insulation material and its form (because of the need to resist loading or to be protected by the damp proof course, for example). The position of the insulation within the slab usually has little effect on heat loss through the floor; however, the temperature profile of the floor surface may affect feelings of thermal comfort and the insulation position will affect the thermal storage capacity of the floor. That is, if the insulation is placed below the slab, energy will be used in heating up the concrete and it will feel cool to the touch for a period – however, once it has warmed up, it will be slow to cool down when the heating is switched off. If the insulation is placed between the slab and the screed, the floor will warm up quickly but it will also cool quickly (see the later reference to similar points regarding internal and external wall insulation).



If the internal leaf is lightweight block cold bridging is less likely to occur.



If dense blocks are used below the DPC and/or if the insulation does not protect the side of the slab, edge insulation should be included.

The edge of an insulated floor slab needs to be well-detailed to avoid thermal bridging. The correct detail will take into account the relative position of the insulation in the floor and the wall, and the insulation properties of the wall material.

The use of insulated chipboard as a covering for solid floors has been mentioned in Chapter 5 Ground floors.

Pre-cast beams span between loadbearing walls.

Polystyrene blocks waiting to be laid between pre-cast beams.

In modern construction, ground bearing floors are becoming quite rare. Pre-cast floors now account for approximately 65 per cent of all new ground floors. The system shown here uses polystyrene blocks which fit in between the beams (and extend below it to prevent cold bridging). An in-situ concrete topping completes the floor. This can be screeded or power floated.

(left and above) Polystyrene blocks placed between pre-cast concrete beams.

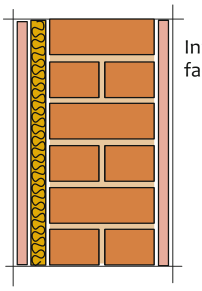
In situ concrete topping placed over beams and polystyrene blocks.

Wall insulation

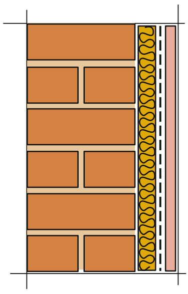
For the insulation of walls the insulation can be placed:

- *in the cavity*
- *externally*
- *internally.*

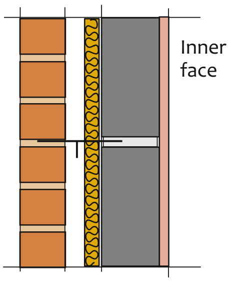
External insulation



Internal insulation

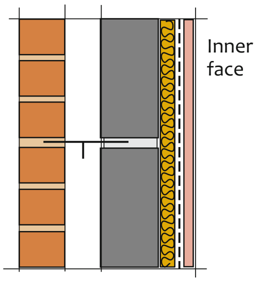


Cavity insulation



Partial or cavity fill

Internal insulation

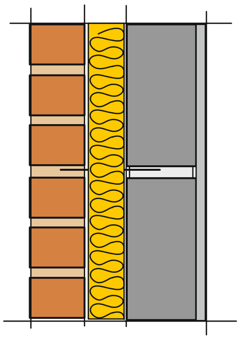


Insulated dry-lining

In practical terms, as with the position of floor insulation referred to above, whichever position is chosen it will not directly influence heat loss to a significant extent, but it may affect the overall energy performance of the house. For instance, the wall could be a lightweight one with insulation towards the inside. With this approach the interior would warm up quickly because the structure will not be absorbing any heat. It will also cool quickly because there is no residual heat stored in the structure. With a heavyweight wall with insulation on the outside, the interior will warm slowly because heat will be absorbed into the structure, but it will also cool more slowly because heat stored in the wall flows into the room as the interior cools. A heavyweight, externally insulated building therefore tends to react slowly but produces a more even thermal profile.

Cavity insulation

This is usually the cheapest, most straightforward option. It is the approach adopted in most new housing development in the UK. If it is decided that cavity insulation is appropriate, then a supplementary decision on whether or not to fill the whole width of the cavity must be taken. The photograph (below right) shows an example of partial fill. More details can be found in Chapter 4 External masonry loadbearing walls.



Filled cavity

Filling the cavity

The main problem here revolves around the possibility of water penetration across the cavity. The original purpose of the cavity was to prevent the passage of moisture into the building. Some fears have been expressed in the past that filling the cavity with insulation might affect the wall's integrity as far as water ingress to the interior is concerned. In practice, however, the concern was related mainly to the performance of an insulation material known as urea formaldehyde foam (UF foam). This material is discussed briefly below. The other problem with water penetration is that if the insulation itself becomes wet, its thermal transmittance properties are adversely affected. This is aggravated by the fact that filling the cavity reduces air movement within the cavity and therefore prevents the efficient removal of penetrating water and condensate. However, insulation materials, such as polystyrene beads or mineral wool, do not seem to present a problem. Both of these materials are water repellent and tend to allow water to percolate to the bottom of the cavity.

Susceptibility to rain penetration will depend on the exposure of the dwelling to wind and rain and the condition of the fabric. In reality, rain penetration across cavities which have been filled appears to be a rare event where these factors are accurately assessed.

The exposure rating of the walls that are to be insulated should be established in order to help ascertain whether wind-driven rain may result in rain penetration across the proposed cavity fill. In most urban situations this is unlikely to be a problem on two-storey dwellings, unless they are particularly exposed – for instance, on high ground with little or no protection from surrounding buildings, trees or foliage or if they have a porous masonry/brickwork external skin, or a method of pointing that does not shed moisture efficiently.

The effects of existing 'rain paths' within the structure (e.g. wall ties with mortar droppings) or unsuitable wall tie designs, may be exacerbated by the cavity insulation. Additionally, cavities which are narrower than 50mm (perhaps within an existing house) may be more at risk when filled with insulation. The greater the exposure of the external leaf, the more attention should be paid to its specification and detailing.

The other decision in regard to filled cavities is whether the operation takes place during or after construction. If during construction, then insulation batts can be used; if after, then it can be treated as an existing building and either foam or fibres can be pumped or blown into the cavity. There is an argument that it is better to place cavity insulation when the building is complete, or nearly so, in order to avoid the possibility of mechanical damage, or exposure to rainwater during the construction process. This must be weighed against the obvious problems associated with not being able to verify visually the correctness of the installation.

In a completed building, the insulation will be blown or pumped into the cavity. This is carried out by drilling holes in the outer leaf of the cavity wall. The number of holes which are necessary will be related to the type of material and its free-running properties. Blown-in or loose-fill materials include rock wool fibres, glass fibres, polystyrene beads and glass-fibre pellets.

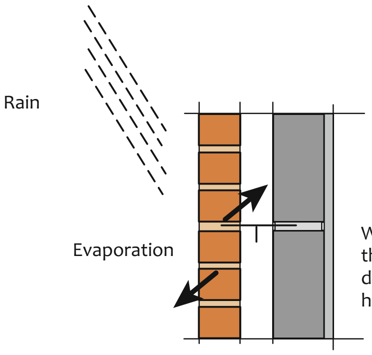
The pumped-in materials are foams, with the most common being polyurethane. Polyurethane foam has a high tensile strength and adheres well to masonry (there have been instances where it has been used to stabilise cavity walls after the wall ties have corroded).

Urea formaldehyde (UF) foam is an alternative, though it is probably the most controversial of the insulation materials for two reasons:

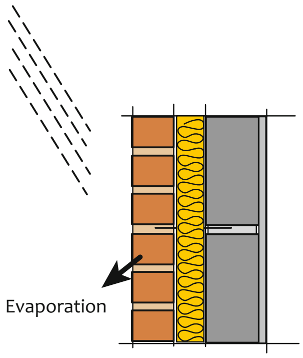
- *the possibility of it shrinking and cracking as it dries out and sets in the cavity, thereby allowing rain to pass from the outer to the inner leaf*
- *a gas called formaldehyde can be released as the material sets.*

UF foam is banned in some countries because of this latter problem. In the UK, the material can be used, but its use should be related to the exposure of the building (to try to avoid rain penetration) and it is subject to control by the Building Regulations (which state that it should only be used with walls that have an inner leaf of brickwork or blockwork and where the wall has been checked for suitability for filling in accordance with the British Standard before work is carried out).

It should be borne in mind that when thermal insulation is placed in a cavity the outer leaf will be exposed to a wider temperature profile than it would if no insulation were present. In other words it will experience colder temperatures because it is not being heated by the warm air that otherwise would have been lost through the wall. If the cavity is filled, the outer leaf will probably also experience warmer temperatures because heat from the sun will no longer be dissipated into the cavity. Also, with a filled cavity, the brick outer skin could become more saturated, and remain so for a longer period of time than it otherwise would have done, because there will be no evaporation into the cavity. A defect which may arise from this situation is frost attack. This occurs through a combination of saturation and low temperatures. Because of this risk it is important that the brick specification takes into account the exposure of the wall and the positioning of the insulation.



When cavity is not insulated the external leaf dries quickly due to free evaporation and heat gain from inner leaf.



When cavity is insulated external leaf stays wet for longer periods. In cold weather there is increased risk of frost attack.

Partial fill

Although partial fill avoids some of the problems mentioned above, concern has been expressed about the thermal integrity of the insulation material in this situation. This is because convection currents may be set up and their movement across the face of the insulation can lower its insulating value. However, the reduction in insulating value is probably minimal and is outweighed by the advantage of retaining a cavity. The existence of a void (i.e. the cavity) has itself given rise to further concerns. If the cavity is not correctly fire stopped for openings, or closed at the top, edges, verges and eaves of a wall or, around openings, such as doors and windows, either with masonry or proprietary cavity closers or barriers, then fire, hot gases or smoke could enter the cavity and spread to other parts of the building.

Where flues, ducts and pipes, etc. run through a cavity wall they should be isolated from the insulation and particular care taken with the choice of insulation material. Items such as flues, ducts and airbricks will require sleeves, and cavity trays should be installed over them.

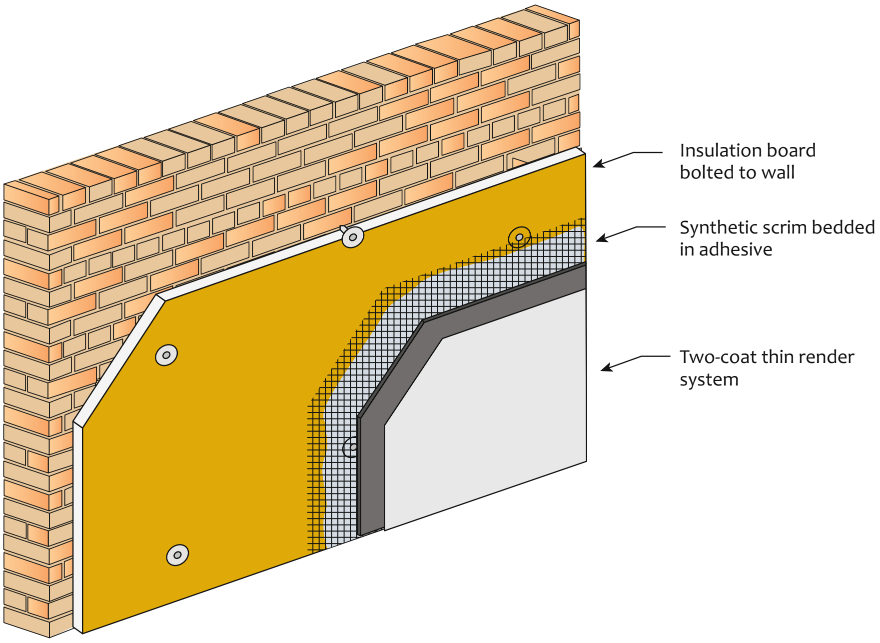
External insulation

External insulation is not used very widely in the UK, partly because of the visual effect of the protective render. In addition, its capital costs will usually be higher than both cavity and internal insulation. However, external insulation can provide a number of benefits, with increased weather protection being one example. External insulation may also be the most effective solution as an integral part of the overall energy approach, for example with a heavyweight structure which is intended to act as a thermal store because of occupancy patterns or the desire to utilise solar energy. The use of external insulation or cladding systems has a number of implications in relation to the Building Regulations and fire safety. For example, the Regulations recommend that walls within 1m or less of a relevant boundary have fire resistance on the external side of the wall in addition to the normal internal side of the wall.

External insulation involves fixing an insulating material to the wall, either with adhesives or by mechanical means. The insulation is then covered with a protective cladding.

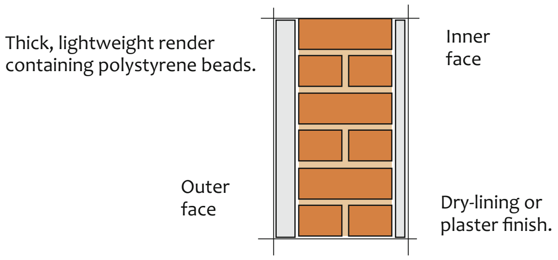
In modern houses, external insulation is usually based on a render-protected system, or possibly a ventilated rainscreen cladding system.

Render-protected system: In these systems, the insulant is fixed directly to the wall mechanically or with adhesives before a reinforced render and decorative finish is applied. In low-rise (two-storey) domestic situations this is, by far, the most common system.

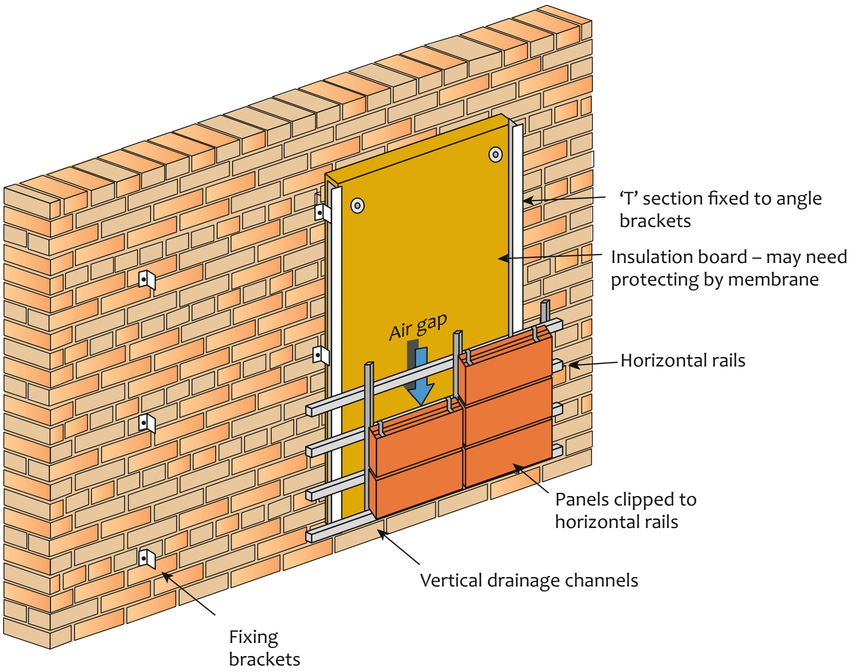


There are a variety of render specifications and many different finished textures. The render will typically be a relatively thick sand/cement mix applied over a wire mesh or a thinner polymer cement render applied over a fibre mesh. Thick, strong cement renders should be avoided where possible as these can be subject to cracking. Cracking is a potential problem with renders in any situation, but here it is exacerbated by the fact that the render is subjected to a wide temperature range because of the position of the insulation just below it. This means that, at one extreme, heat from the sun is not dissipated into the wall of the house, while, in cold weather, there is less heat loss from the house – which might otherwise raise the temperature of the render. The type of finish will not only depend on the type of insulation specified or the finish required but also on the building's exposure to wind and wind-driven rain as well as the risk of impact or vandalism.

An alternative, though less effective, approach involves the use of a lightweight insulation rendering, where expanded polystyrene beads are used as aggregates with resin additives.



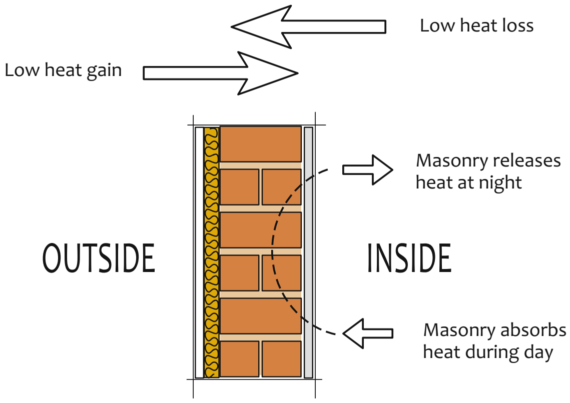
Ventilated rainscreen cladding system: With this approach, steel or aluminium rails are mechanically fixed to the substrate where they support slab insulation and a pre-formed cladding. A ventilated cavity behind the external cladding allows any moisture to evaporate back to the external environment. The insulation is placed between the solid masonry wall and the cavity. These systems are expensive (although easier than render to maintain in the long term) and tend to be used on blocks of flats and commercial buildings. In addition, the Building Regulations may, depending upon the wall construction and insulation type, require horizontal or vertical cavity barriers to be provided to prevent the spread of fire in the cavity, typically around openings or on lines of compartmentation, such as between different dwellings or flats.



It is, of course, possible to use alternative claddings, such as horizontal timber boarding or tiles/slates. Often these are used on existing properties which are being upgraded and the finish is chosen in order to fit in with the character of the house or the area. It is usual in such cases to use timber rather than metal 'rails'.

There are a number of non-thermal factors that might affect the decision to use external insulation. These are mostly associated with the fact that external insulation has a general beneficial effect as a thermal moderator, keeping heat inside the building and in the wall structure, while protecting the wall itself from the adverse effects of external heat and cold. The benefits of external thermal insulation are that:

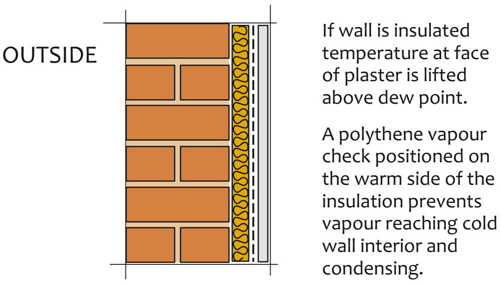
- *the whole of the structure becomes a thermal store. In effect this approach has a 'tea cosy' effect on the building and the structure is subjected to less thermal and expansion stress than it otherwise would be*
- *because the wall is kept warm there is less likelihood of frost damage occurring in the masonry*
- *because the insulation is on the outside, cold bridging problems will often be reduced, as will the risk of interstitial condensation.*



However, it should be borne in mind that the rendering material which protects external insulation is subject to relatively large changes in temperature. It receives no heat from the building because the insulation prevents this and it cannot dissipate heat gains from the sun to the mass of the wall for the same reason. This may lead to thermal stress and movement in the protective render material.

Internal insulation

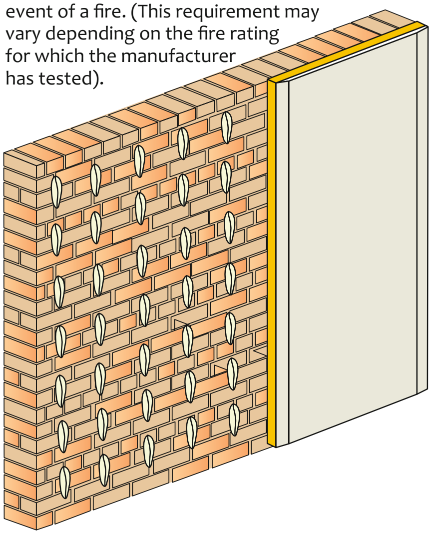
The dry-lining of walls is a well-established technique (see Chapter 10). With internal insulation the approach is similar, except that insulation is fixed to the wall first, or comes as an integral part of the plasterboard. Internal insulation may be useful in an intermittently heated building, as rooms will warm up quickly when the heating is switched on. Also, wall surfaces will feel warm, which is important in terms of thermal comfort. However, the room will also cool quickly when the heating is turned off because no heat is stored in the structure. A further consequence of this lack of thermal storage is that the room might overheat due to solar gain through the windows.



There is a potential fire hazard with internal insulation if a void is created between the insulation and the wall, and this cavity or space is not closed or provided with cavity barriers as recommended in the Building Regulations. The danger is that fire and hot gases can spread within the structure of the wall to elsewhere within the dwelling. If a combustible insulant is used it may become involved in the fire if the lining collapses, or if the fire finds some other pathway behind the plasterboard. There will also be a more rapid rise in temperature if a fire occurs, because of the presence of the thermal insulation.

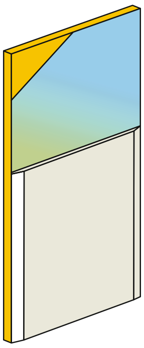
Unlike cavity insulation, internal insulation is vulnerable to impact damage.

Internal insulation can be fixed between timber battens or metal channels, which are themselves attached to the inside of the wall. Insulation, perhaps in the form of mineral or glass wool, is inserted between the battens and then covered with plasterboard. There is a potential problem with both of these materials; rot may occur if condensation forms where timber is used and if metal is used then there is a likelihood that a cold bridge will be formed. These approaches were often applied to existing buildings in the past. In a new house the usual approach is to use a laminate of plasterboard and insulation.

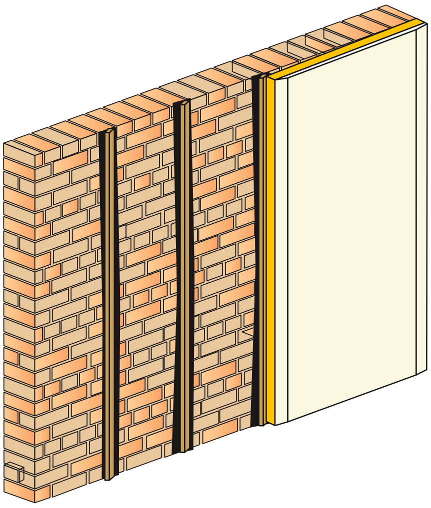


Thermal boards pressed onto plaster as a form of fixing. These are sometimes seen as 'dabs' but it is better that they are in the form of continuous 'ribbons', particularly at the top and bottom of the board and at openings, as this helps with airtightness, fire/smoke spread and acoustics. Additional mechanical fixings are also usually used to prevent the board coming adrift in the event of a fire. (This requirement may vary depending on the fire rating for which the manufacturer has tested).

Plaster dabs on to existing plaster or bare wall – (see chapter 10 for example of ribbon fixing).



Thermal board includes a vapour control layer.



Boards can also be fixed to vertical timber (protected with DPC) or galvanised steel battens.

Boards can be taped and self finished or plastered.

In all cases of internal insulation, a vapour control layer is essential on the warm side of the insulation. The majority of the laminate materials incorporate a vapour control layer sandwiched between the insulation and the board face.

Cold water supply 17

Introduction

Cold water is supplied to a house for drinking, washing, cooking and for the flushing of sanitary appliances. This chapter briefly explains how cold water is supplied, stored and distributed.

Water supply

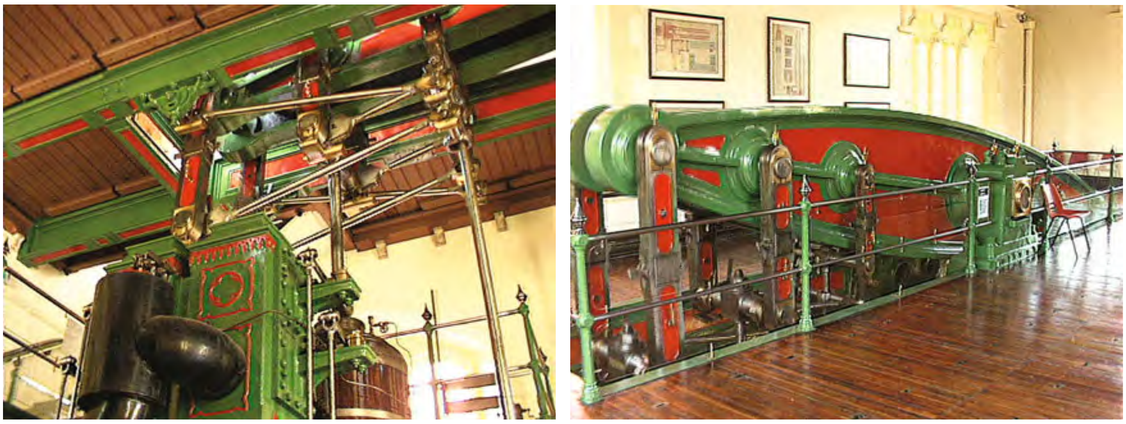
History

Water supply to houses did not become the norm until the latter part of the nineteenth century. Before this, water was collected in rooftop collection tanks, rainwater butts, from nearby streams or wells or from public conduits, although some households would have had access to a private water supply from a spring or well. Individual households collected their own water or purchased it from a delivery cart. The intermittent nature of the first water supply led to the practice of storing water in cisterns. At first, these cisterns, which were often made of lead, were located outside the house. Later, the storage cisterns were moved inside.

In the eighteenth century, wealthy households often had stone sinks in the kitchen with water supplied by a hand pump. In this example, the pump (on the right of the sink) lifts water from a tank in the basement, which collected water from the roof via a lead down pipe. The taps are a later Victorian addition.

Later still, the practice developed of placing storage cisterns higher up in the house in order to allow gravitational supply to the fittings. Although there are advantages and disadvantages to having a stored supply of water, the early experience of intermittent service emphasised the value of having a store of water and this has influenced the approach taken to domestic water supply ever since.

A more efficient and widespread piped supply of water was a result of advances in technology which occurred during the nineteenth century. The ability to pump water by harnessing the power of steam was an important development. However, when the first steam pumps were first used on water distribution systems, the sleeved joints of the original wooden pipe systems often failed. This was because they could not withstand the pressure required to push water up to high-level storage tanks. Leaking pipes led to flooding in the streets – a problem not resolved until the introduction of cast iron pipes in the early 1800s.



The introduction of beam engines enabled water to be pumped into towns from reservoirs. This, together with the use of cast iron pipes, provided sufficient water pressure to serve the upper storeys of houses.

Historically, the provision of water varied from town to town and from area to area, with some households receiving a piped supply while others were reliant on a standpipe shared between a terrace or a group of houses. Even where there was a piped supply, this would often only be to a single sink, either in the kitchen, the scullery or even outside in the yard. Charges for water supply were relatively high and were based on such factors as the size of the house, the number of sanitary fittings, and whether or not the supply had to be pumped above ground floor level; this consideration influenced the location of bathrooms and water closets.

The cantilevered back-additions shown on the left are early water closets. They are Victorian additions to Georgian houses in Bath and are typical examples of how such houses were 'modernised'.

Towards the end of the Victorian period, there were significant advances in the quality of water and its delivery, such as the development of water filtration and water treatment as well as the construction of reservoirs.

The fitness of the water for drinking was often questionable, and this played its part, along with poor sanitary conditions, in the propagation of disease. Water-borne diseases, such as typhoid and cholera, were often the result of contamination from cess pits. Once the connection was established, the fact that such diseases spread rapidly among people from all social classes was instrumental in the development of techniques which sought to deliver uncontaminated water to the whole population. The availability of a better supply of water for personal washing also fitted in well with the Victorian penchant for cleanliness. This desire was in stark contrast to previous generations when, for all classes, personal cleanliness was not always a priority.

Regulation of the water supply and installation

Until recently, water was supplied by publically-owned local water authorities, whose regulations were based on the Model Water Bye-laws. Following privatisation in 1988, water has been supplied by a range of private water suppliers (officially known as undertakers).

The supply of water, its installation and its efficient use are regulated by the Government. This is achieved by statute and a number of regulations including the Building Regulations and various Water Regulations. Some rural households still make use of a private supply, such as an artesian well or a spring, and these are regulated as well.

There is an emphasis within the Regulations on the responsibility of both the installer and the consumer to take responsibility for damage, waste and contamination. For example, the Regulations are concerned with issues such as the size of baths, the drawing power of pumps, the use of automatic watering systems and the prevention of backflow – the flow of water from appliances back into the supply system. Double-check valves are used to prevent this on some apparatus, such as outside taps. Domestic appliances, such as washing machines, usually have an integral device to stop backflow and baths, basins and sinks should be designed to stop this occurring by ensuring that the outlets from taps cannot be submerged when the bath or basin is filled. The water suppliers have to be notified before certain items are installed, e.g. larger baths and certain types of larger ponds and swimming pools, and they may decide to impose compulsory metering as a result of such notification. The Regulations are also concerned with the efficient use of water (a maximum target per person per day is set) and with the use of 'grey' (recycled) water (see later).

Water quality: the characteristics of the water supply

The Building Regulations and the Water Regulations require water to be wholesome if supplied for the purpose of drinking. It should also be as clear as possible and contain no substances harmful to materials used in the cold and hot water supply systems. Attention should also be paid to the hardness of the water.

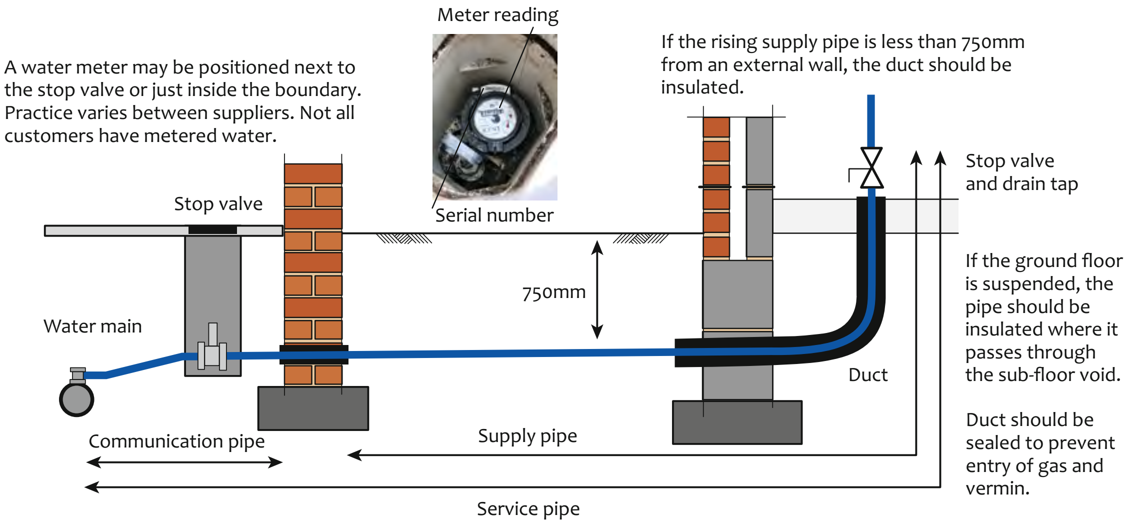
The effects of hard and soft water

The water supplier in each area extracts water from a variety of sources. These include rivers, reservoirs and aquifers (deep water-bearing rocks). The sources are influenced by the type of sub-soil or rock that the water has originally come from. Rocks such as sandstones and granite result in soft water, while limestone produces hard water. While both soft and hard water are perfectly acceptable, hard water can be a problem when it is heated. This is because salts (mainly calcium and magnesium) can be deposited as 'fur' or scale.

There are two categories of hardness; one is referred to as permanent hardness because it is not removed by boiling, the other is referred to as temporary hardness and this can be removed by boiling. It is the latter type that causes most problems because it may deposit salts in the hot water pipework, storage vessel or boiler. These salts can build up over a period of time, restricting the flow of water and potentially causing an explosion. Various water softeners and scale inhibitors can be fitted to the water system to overcome these problems, as long as the supply remains wholesome.

Soft water can also cause problems as, in some cases, it can 'dissolve' lead. In houses which still have lead pipes, this can increase the danger of lead getting into the bloodstream of the occupants.

The incoming supply



A water meter may be positioned next to the stop valve or just inside the boundary. Practice varies between suppliers. Not all customers have metered water.

If the rising supply pipe is less than 750mm from an external wall, the duct should be insulated.

If the ground floor is suspended, the pipe should be insulated where it passes through the sub-floor void.

Duct should be sealed to prevent entry of gas and vermin.

Water is brought into a house from the water supplier's pipe, which is probably situated under the road. The supplier's water supply is brought up to a point just outside or just inside the boundary of the house where a small pit to contain the stop cock (stop valve) is formed. This allows the supply to the individual house to be shut off without interfering with the provision for other properties. The supply up to this point is the responsibility of the water supplier and the pipe, which is usually made of blue polyethylene, is referred to as the communication pipe. It is at this point that a water meter is normally fitted (when one is installed). A water meter tends to prevent excessive water use by the householder. Their installation is standard practice for new houses and encouraged by suppliers for all existing properties where one has not been installed.

From the supplier's stop cock, the service pipe carries the water below ground level into the house. Just above the lowest floor, a stop cock and drain cock will be installed (see next section). The pipework then rises vertically, to supply the various kitchen and sanitary fittings. This first section of internal pipework is usually referred to as the rising main and is normally made of copper, although plastic pipes are increasingly being used. There will usually be horizontal connections off the rising main, the number dependent on whether a direct or an indirect system is used (see later diagrams). The first internal stop cock is often located at the junction between the service pipe and the rising main.

The pipework should be designed to be as short and direct as possible, partly because of cost, but also to reduce the amount of water sitting in the pipes – particularly where it serves appliances that provide drinking water. Cold water pipework should, where possible, run below hot water pipework in order to reduce the risk of the cold water being warmed.

Pipework should generally not be embedded in a solid wall or floor unless it is contained within a purpose-made duct which is easily accessible. It should also not be located in the cavity of a cavity wall or below a suspended (or solid) ground floor as it may freeze. Pipe runs should be adequately supported to ensure efficient flow, to reduce the risk of damage to joints and to restrict noise.

The pipework, both inside and outside, should be protected from frost. This is done by laying the communication and service pipe at a minimum depth of 750mm below ground level. At this level, the warmth of the ground should ensure that, except in extreme conditions, the pipe does not freeze (the maximum depth of the pipe is 1,350mm, unless it is contained within a duct to allow easy access).

To protect the rising main from freezing, it should:

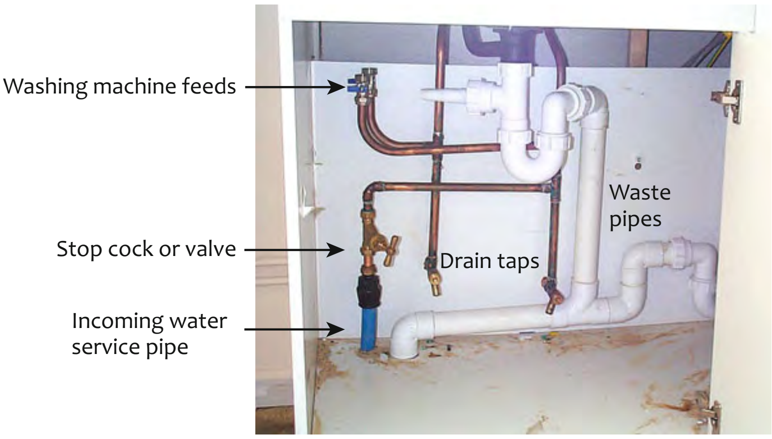
- *not be fixed to the external wall*
- *not pass through or near the eaves*
- *be insulated (lagged) if it passes through an unheated space (e.g. the void under a suspended ground floor) or enters the house as shown in the diagram above.*

Pipework in areas that are unheated, such as the roof space, or in rooms that are not normally heated, such as utility rooms or cloak rooms, should be insulated.

The photographs above show the compression fitting where the incoming main (polythene) is joined to a copper rising main. The stop tap allows the supply to be isolated for maintenance purposes. A drain cock will be fitted just above the stop tap to enable the rising main to be drained.

Stop cocks and valves

For maintenance purposes, stop cocks or stop valves (also known as service valves) are used to isolate parts of the pipework. These should be located as near as possible to the appliance which they serve and should obviously be easily accessible. It is also good practice to label these devices to indicate which parts of the installation they serve. In addition, a drainage tap should be fitted just above the point where the rising main enters the house. In many cases, the service pipe will enter the building below a sink unit. The photograph below shows a typical arrangement of the hot and cold pipework. The pipes have yet to be earth bonded (see Chapter 22 Electrical installations).



Connecting the pipework to the taps can be a bit 'fiddly'. Flexible connectors (the right-hand one with an integral isolation valve) make things a little easier.

A small selection of fittings

Distribution pipework

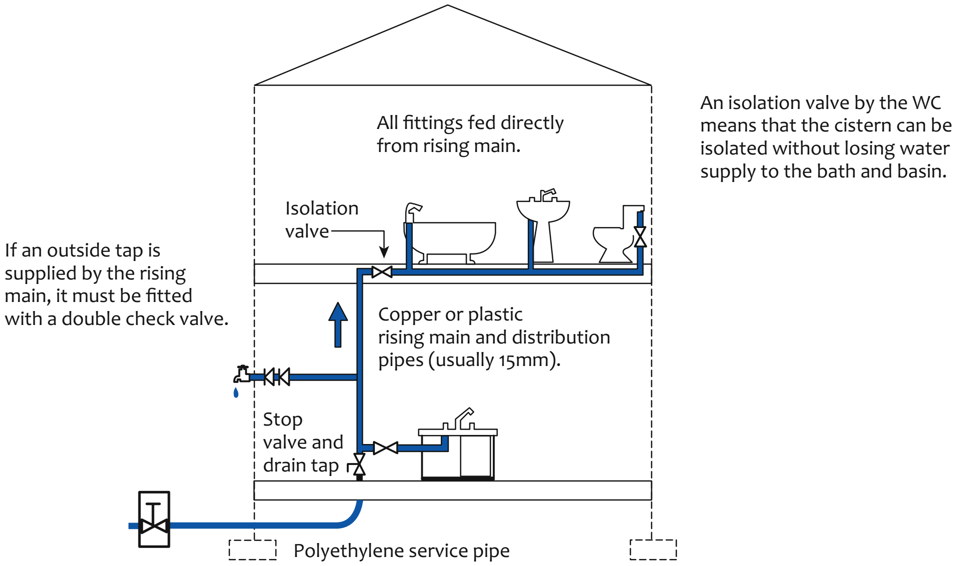
In modern housing, the distribution pipework is mostly hidden in the floor void(s). It can also be concealed behind dry-lining (see the photograph below). If walls are plastered, the pipework is usually surface-mounted. Hiding pipework may seem desirable, but good access should be provided for repairs and maintenance.

Note the chased recess for the horizontal pipework, i.e. the pipework is not actually embedded. Access points will need to be provided when the plasterboard is installed.

There are two approaches to cold water distribution within a dwelling; direct and indirect.

Direct

This is the most commonly adopted system in modern construction. All fittings are supplied directly by the rising main, i.e. there is no storage facility for cold water. This approach is more likely to be found where the mains supply is at a good, constant pressure.

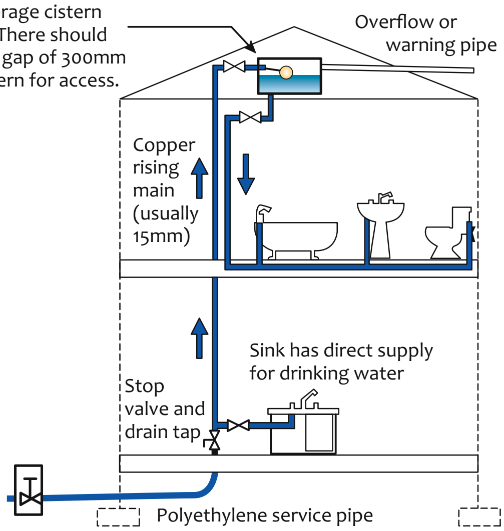


If an outside tap is supplied by the rising main, it must be fitted with a double check valve.

An isolation valve by the WC means that the cistern can be isolated without losing water supply to the bath and basin.

Indirect

The indirect system was commonly installed until comparatively recently, but it is now relatively rarely installed. In the indirect system, the rising main fills a storage cistern which, in turn, provides the water for the individual fittings. As stored water may become contaminated, it is usual to have a direct feed to the downstairs cold water tap and, increasingly, to the cold water supply to bathroom and shower room wash-hand basins, in order to provide drinking water. Indirect systems are most likely to be found in some of the large metropolitan areas where, at peak times, supply may be intermittent due to heavy demand. In these cases, cold water storage will be a reserve against a failure in the mains supply to the house.



Cold water storage cistern in roof space. There should be a minimum gap of 300mm above the cistern for access.

The warning pipe should be inclined downwards and should discharge outside the house at a point where it will be noticed.

The distribution pipes from the cistern are normally of increased diameter, 22 or 28mm.

This is because water pressure is lower than the direct system due to the cistern.

The pressure is determined by the relative height of the cistern and fittings. Fittings near to the cistern will be at a lower pressure.

Lid and insulation removed to show water and ball float.

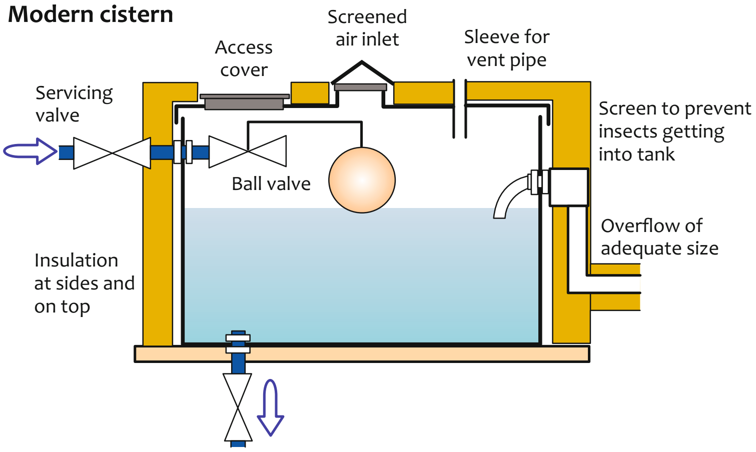
In addition, the storage cistern provides a 'break' in the pipework supplying the sanitary fittings. This lessens the likelihood of back siphonage (back flow), which may occur if water from a wash-hand basin or other appliance is accidentally siphoned back into the mains water supply, thus causing contamination. (This should not occur with modern fittings where the outlet of the tap will be above the rim of the sanitary fitting.) Water from a storage cistern supplies the sanitary fittings and the hot water cylinder (where one exists). The pressure is lower than the mains supply and this places less stress on the various taps and valves, thus reducing wear. Reduced pressure also usually means that there is less noise than with a direct system.

There are, however, disadvantages to storage. For example, stored water may become contaminated and may then be drunk. Also, the cistern occupies space and the load that it imposes has to be taken into account. Finally, the cistern requires protection against frost. When positioned in the roof space, the possibility of frost attack is increased if roof insulation is laid underneath the cistern.

The cold water storage cistern

Thirty years or so ago, it was common to find storage cisterns made of galvanised steel or asbestos cement, but in modern construction they are normally made of plastic or fibreglass. The size of the cistern is based on providing enough stored water for a family for 24 hours (usually 225 litres for a house). The water in the storage cistern is vulnerable to contamination by insects, bacteria and other organisms and so must be designed to prevent contamination of the water supply. A fitted cover excludes insects and daylight, there is a screened air inlet and the warning/over-flow pipe has an integral insect screen. Insulation to the sides and top of the cistern will help prevent the water temperature from rising above 20°C to limit the growth of bacteria. The same insulation will also protect the water from frost.

Modern cistern



The tank should be insulated at the sides and top, but not underneath – the insulation avoids overheating as well as freezing. The distribution pipe can be taken from either the side or the bottom of the cistern. The latter is preferable to limit the amount of sediment gathering at the bottom (it will flow through the pipework and out of the taps). The sediment is harmless but, if it settles at the bottom of the cistern, can provide nutrients which might encourage the growth of bacteria and other organisms.

The supply of water to the cistern is controlled by a valve. Usually this is a float-operated valve, which is opened and closed by the action of a plastic or copper ball floating on the surface of the water. As the water reaches the correct level, the ball rises and slowly closes the valve. (A similar ball valve performs the same function in a cistern serving a WC – see photograph below.) A possible alternative is to have an electrically operated solenoid valve connected to a (water) level switch.

A typical ball valve used in a modern WC. The float controls the water level. The siphon tube is in the centre of the cistern. An overflow or warning pipe (just out of picture on the left) allows water to escape if the float or ball valve becomes defective.

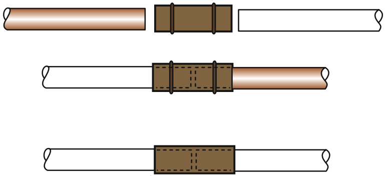
Materials for pipes and fittings

It is important that, in addition to being effective in distributing water, the materials used for water supply and distribution in the house do not cause any contamination of the water supply. Until the 1960s, lead was used for both the supply and distribution of water and lead pipes may still be present in older houses (it should not be used now because of its known harmful effects on human health). Less common was galvanised steel, which almost invariably rusted over the years. Stainless steel overcame the problem of rusting, but was (and is) an expensive alternative.

In new housing, copper is probably the most common material, although plastic is becoming increasingly popular. Copper's main advantages are that it has high tensile strength, while being thin, light and easy to manipulate. It also has a smooth bore, which allows for an efficient flow of water, and it is generally resistant to corrosion. Copper pipes can easily be jointed. This can be done by soldering or by using compression fittings. Simple push-fittings are also available.

It is important to avoid mixing some metals together as electrolytic action can cause corrosion. For example, in older houses, copper pipework was often attached to an existing lead communication pipe or a galvanised iron storage tank which gave rise to the corrosion problem. It is generally advisable to use either only one type of metal pipe or plastic pipes. The latter are available in long lengths and, therefore, require fewer joints. Where joints are required, they are provided by special couplings with rubber ring seals.

Joining copper pipes



Fitting contains two small rings of solder.

End, or capillary feed fittings (above and below)

Flux is applied, pipe is inserted into fitting and blowtorch is applied.

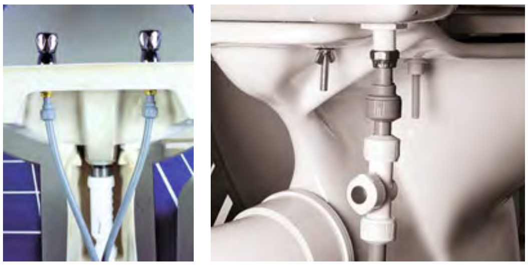
When fitting is hot, solder is introduced as shown and is drawn into fitting by capillary action. The solder must be lead free.

Pipe and fitting cleaned with flux, blowtorch melts solder and forms joint

Compression fitting

As the nut is tightened onto the thread, it squeezes the compression ring onto the pipe.

Plastic pipes have become quite popular in recent years. No soldering is required (most of them are 'push-fit') and the flexible pipework is easy to install in floor and partition voids.



The connector contains a small synthetic rubber ring which grips the pipe and seals the joint.

The use of modern plastic pipes and metal web joists makes the water installation quick and simple. Such joists do not require notching and the long lengths of plastic pipework reduce the number of pipe joints. Long-term reliability is, as yet, unknown.

When metal was the only material used for supply and distribution pipework, the rising main provided a convenient means of establishing a connection to earth for the electrical supply. The use of non-metallic pipes for water supply and distribution has changed this practice and the water mains, whether metal or not, should no longer be seen as providing this function.

Water, the Code for Sustainable Homes and green technology

Introduction

The UK Government introduced the Code for Sustainable Homes in 2006. It sets out mandatory requirements for the construction industry in terms of sustainable housebuilding practice. Its general details are discussed elsewhere (see Chapter 2 Sustainability) as it focuses principally on reducing carbon footprint, but its requirements do have an impact on water provision and usage in homes. This is because the current level of water consumption in 2006, of approximately 150 litres per person per day, was considered to be unsustainable.

It sets a series of Code levels linked to increasing sustainable performance of a building (Code levels 1–6), with Code level 1 being the least efficient and Code level 6 the most efficient. The Code sets out specific requirements for future personal water consumption, together with target dates, and these are detailed in the following table (overleaf):

CODE LEVELS AND TARGET DATE(S) FOR APPLICATION	TARGET FOR AVERAGE MAINS-WATER CONSUMPTION IN LITRES PER PERSON PER DAY (PPPD) (CONSUMPTION IN 2006 = APPROX. 150 LITRES PPPD)	EXAMPLES OF HOW TO ACHIEVE TARGET IN NEW DEVELOPMENTS, I.E. THE USE OF 'GREEN TECHNOLOGY'
1–2 From 2007	120	Install water-economising technologies, e.g. aerated taps and shower-heads. Make use of dual-flush toilet cisterns.
3–4 From 2010 for all developments	105	Install smaller baths or a rainwater harvesting system.
5–6 From 2013 for housing associations From 2016 for all developments	80	Use of reclaimed water, including by means of greywater and rainwater harvesting systems.

Apart from the specific impetus given by the Code to the construction industry, in recent years other factors have led to greater interest in the use of 'green' technologies in terms of water supply and use. They include:

- *the increasing costs of the provision of water services due to updating of the basic infrastructure and the improvements in water quality*
- *the adverse influence of environmental factors (including climate change) on the sourcing of water*
- *the pressure of an ever-rising UK population (now in excess of 60 million).*

Water charges for the consumer are likely to increase for the foreseeable future and the use of green technologies is becoming more attractive as they offer savings in water use and drainage, both of which attract charges for the individual householder from the water industry.

It is important to note that any water installation involving green technology must comply with the standards set out in the statutes and regulations already discussed. The Building Regulations require that a 'risk assessment be carried out together with appropriate testing to demonstrate that any risks have been suitably addressed'.

Greywater

One type of green technology that is becoming increasingly popular involves the use of recycled wastewater, which is known as greywater. Currently, one-third of the average household water consumption in England and Wales is for toilet flushing. This means that some two-thirds is used for other purposes, such as drinking and washing. The one-third used for toilet flushing cannot be recycled, but the greywater from the other two-thirds can be.

The sustainable approach to water usage involves the recycling of all greywater wherever possible, e.g. from baths, showers, wash-hand basins, sinks and washing machines. The greywater is then used for non-potable purposes, i.e. for anything other than for drinking. Examples of such use include toilet flushing, garden watering and washing machines.

Greywater systems range from the wholly unsophisticated (e.g. using a hand-pump to remove water from a sink and discharge it onto a garden) to the more complex (e.g. treatment processes involving large systems of removal and delivery and, possibly, more than one house). Although there are currently no water quality standards in place for treated greywater, such a system should generally comply with the requirements and guidelines of the Building Regulations and Water Regulations.

Most greywater systems have the following features:

- *storage tank or cistern*
- *pump*
- *treatment facility*
- *distribution system.*

Where the system incorporates any form of storage facility, it also has to involve some level of treatment. This is because untreated greywater will deteriorate rapidly when stored longer than a few hours. The untreated water will almost certainly be contaminated by human bacteria and organic debris as well as the residues of soaps, detergents and other products. This means that it will be high in bacteria. If left untreated and allowed to multiply, this will lead to odour problems and poor quality water. Without treatment, some of the bacteria may also be harmful to humans. The level of treatment will depend on ultimate use, e.g. greywater used only for flushing a toilet will not be required to meet a high level of quality.

There are a number of possible systems that can be used, as detailed below.

- **Direct re-use systems:** *These are straightforward and inexpensive methods that involve the use of very simple devices to discharge greywater onto a garden or into a collection tank. At its most basic, such a system might involve using a hand-held pump and hose to discharge greywater from a bath or sink via an open door or window onto a garden. A slightly more sophisticated approach might involve the use of a hand-controlled diverter valve inserted into a bath or shower waste that diverts the greywater to a water butt when required. However, such systems do not include any treatment process so any water collected should be utilised within a matter of hours.*
- **Short retention systems:** *These are treatment systems, in which greywater is delivered to a collection tank and then has a very basic filtration or treatment technique applied. This might involve skimming debris from the surface of the water and allowing particles to settle to the bottom of the tank. The water cannot be stored for a long period, but such processes do reduce the likelihood of odour and water quality becoming a problem.*
- **Basic physical/chemical systems:** *Debris is removed via a filter and chemical disinfectants such as chlorine or bromine are used to prevent bacterial growth during storage. However, such systems do have questionable reliability – the filter requires regular cleaning and odour problems can arise.*
- **Biological systems:** *The basic principle of these systems is that aerobic or anaerobic bacteria are used to digest any unwanted organic material. Oxygen is introduced into the greywater, either via a pump or by means of a reed bed. The oxygen enables the bacteria to 'digest' the organic matter.*
- **Bio-mechanical systems:** *These combine biological and physical treatment and are considered to be the most advanced for domestic greywater use. They remove organic matter by microbial cultures and solid material by settlement. Oxygen is passed through the collected greywater to encourage bacterial activity.*
- **Hybrid systems:** *These use a mixture of any of the previous systems.*

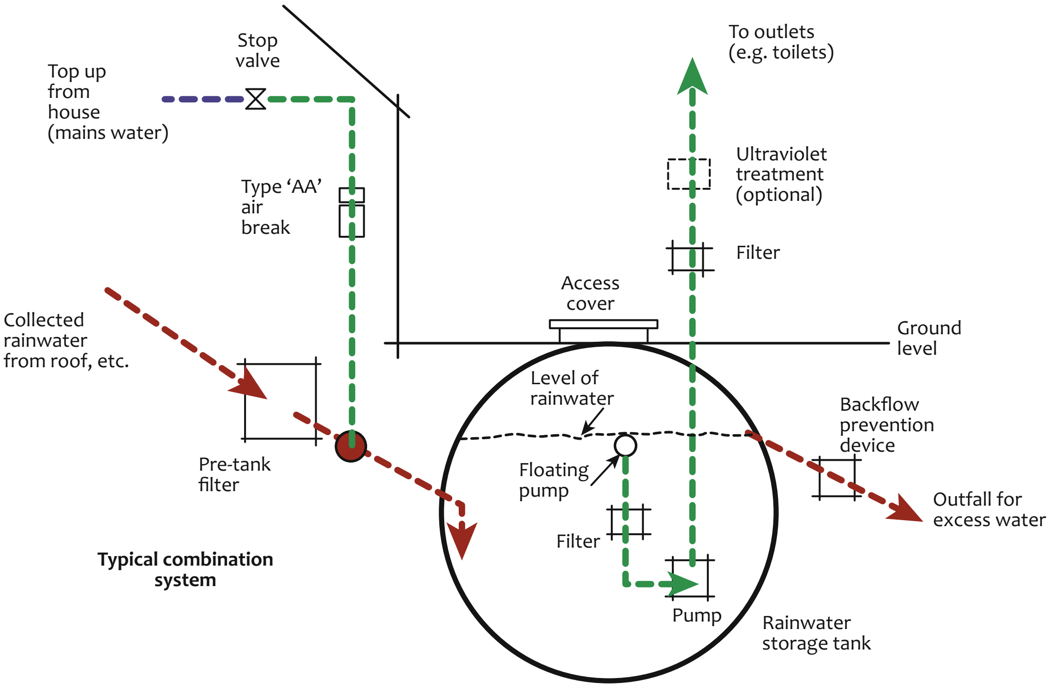
One key point about greywater systems is the need to avoid the risk of cross-contamination with the drinking water supply within a house. Greywater systems nearly always include mains water back-up; this is to allow the system to be topped up when the demand for greywater is greater than its supply. Avoidance of cross-contamination is achieved by ensuring that there is always an air gap between the greywater in a tank and the mains water supply point. All pipework and discharge points on a greywater service should be clearly identified, e.g. pipework should be marked and appropriately coloured in accordance with Water Regulations Advisory Scheme (WRAS) Guidelines and fittings labelled.

Rainwater harvesting

Historically, the construction industry and householders (except keen gardeners) have considered rainwater to be a problem and much effort has been put into removing it as efficiently as possible to a drainage system. However, the recent approach, as a result of the Code for Sustainable Homes, and also because of increasing consumer awareness of the financial and environmental costs of water, is to make use of rainwater harvesting as one of the green technology strategies aimed at reducing overall water consumption.

There are three basic types of rainwater harvesting system:

- **Gravity (or non-pressurised) system:** *Rainwater is collected in a holding tank at or below ground level and pumped up to a high-level header tank (often in the roof) from which it is supplied by gravity to connected fittings or appliances.*
- **Direct (or pressurised) system:** *Rainwater is pumped direct from the holding tank to each fitting or appliance.*
- **Combination system:** *Rainwater is pumped or gravity-fed to a low-level break tank. From here, it is fed by gravity to a booster pump system which distributes the water to the various fittings and appliances.*



Based on information supplied by Polypipe Terrain

Rainwater harvesting systems are complex and their design involves consideration of a wide range of criteria including: the type and area of any roof and other rainwater collection surface; the geographical location of the building and related annual rainfall; the size and location of the main storage tank (e.g. above or below ground); filtration to avoid stagnation and contamination of the collected water; overflow requirements during periods of excess rainfall; top-up from the mains in periods of drought.

Hot water supply

18

Introduction

This chapter explains how hot water is provided and distributed within a house.

History

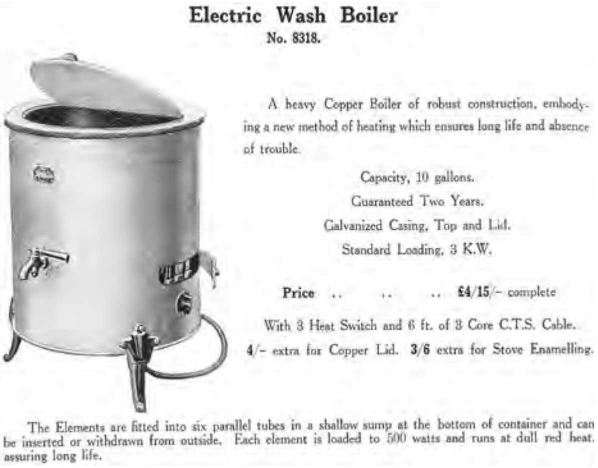
Until the late Victorian period, most of the hot water supplied for bathing and washing would have been heated by fire. At its simplest, this would involve suspending a pot or a kettle over flames. Up until the mid-1800s the normal way of taking a bath, even for relatively wealthy people, would be in a portable tin bath placed in front of the fire. An alternative to this would have been to take the fire to the water and, for instance, light a fire under the large internal cold water storage cistern. A more sophisticated approach to heating water included the ranges that were introduced in the Georgian period, and which have since evolved into multi-purpose elements (the present day 'Aga' for example).

The two images above show examples of ranges.

Ranges, and later 'Kitcheners', were designed around an open fire which, as well as heating the room, also provided a means of cooking and heating water. Towards the beginning of the twentieth century the use of back boilers became more widespread and these were often situated behind the kitchen fire feeding a galvanised steel tank situated in the room above. They were not very efficient and certainly would not be capable of providing the large quantities of hot water required by a modern family.

Another familiar device was the 'copper' (see left-hand bottom corner of photograph overleaf). This provided hot water for washing clothes and consisted of a vessel (originally made of copper, later of galvanised iron) which was contained within a brick structure built into the wall. The structure contained a 'hearth' within which a fire could be lit in order to heat the water.

Built-in coppers were still being constructed in houses in the 1920s but by the 1930s freestanding metal versions, usually referred to as a 'boiler' and using electricity as a heat source, were commonplace. The model shown (right) dates from the 1930s.



Electric Wash Boiler
No. 8318.

A heavy Copper Boiler of robust construction, embodying a new method of heating which ensures long life and absence of trouble.

Capacity, 10 gallons.
Guaranteed Two Years.
Galvanized Casing, Top and Lid.
Standard Loading, 3 K.W.

Price .. .. .. **£4/15**/- complete

With 3 Heat Switch and 6 ft. of 3 Core C.T.S. Cable.
4/- extra for Copper Lid. **3/6** extra for Stove Enamelling.

The Elements are fitted into six parallel tubes in a shallow sump at the bottom of container and can be inserted or withdrawn from outside. Each element is loaded to 500 watts and runs at dull red heat, assuring long life.

Gas-fired geysers, which could produce hot water at the point where it was required, or deliver it to a storage vessel, were in use in the late Victorian period. The examples (right) date from about 1935.

Geysers with Porcelain Enamelled Casings
Separate Outer Casing, White Porcelain Enamelled on Steel.
Base and Fittings Chromium Plated. White Porcelain Enamelled Bracket.

Bodies made of strong Copper. Interlocking Taps, reversible by removing outer casing.
Height, 30 in.; Flue Outlet, 4 in.; Gas Supply, ⅝ in. bore; Heat 2½ gallons per minute (raised 40°).

The "Rusmac."
A Closed Type Geyser of attractive appearance at a moderate price.
Price .. .. **£6/10**/- each

The "White Chief."
A Closed Type Geyser of high efficiency with special access base to facilitate cleaning.
Price .. .. **£8/14**/- each

In the twentieth century, as the use of electricity spread, immersion heaters became commonplace, placed within, say, a hot water cylinder, and this had obvious advantages in the summer months when a fire was not required.

Modern systems

Energy efficiency

The Building Regulations require that hot water systems are designed and installed so that they operate in an energy-efficient manner. Performance, design and installation guidance for systems either installed in new-build dwellings or as replacement systems is provided in the *Domestic Services Compliance Guide*, which supports the Building Regulations. This guide provides information on how the functional requirements of the Building Regulations may be achieved. It gives information on boiler, hot water heater or heat exchanger efficiencies for different fuel types, as well as information on vessels, controls, zoning of systems, treatment of hard water and insulation of vessels and pipework.

In addition to these performance requirements, if a system is installed in a new dwelling, then the energy efficiency, controls, zoning and insulation, etc. of the system will also need to achieve the efficiencies used in the SAP calculation, which could be greater than those given in the guidance document, for the dwelling to achieve the necessary SAP rating and show compliance with the requirements of the Building Regulations.

Local water heaters

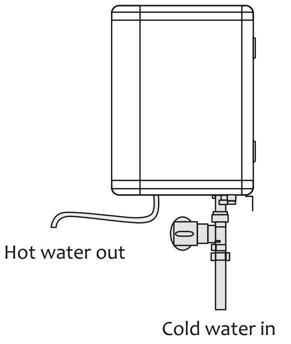
Modern versions of geysers are usually referred to by the more prosaic term 'local water heater'.

These can be sited over the sanitary appliance they supply and can be powered by gas or electricity. Gas-fired local water heaters are 'instantaneous', and have the advantage of bringing water up to a relatively high temperature 'in an instant'. When a tap is turned on, the gas jets ignite and heat the water as it flows through a simple heat exchanger. They can be very efficient as there is no stored heat, but they are slow at providing large volumes of water. In some dwellings, multi-point gas heaters are used. In this system there is one instantaneous heater situated in the bathroom or kitchen, with distribution pipes to the other hot water taps. They are sometimes used in flats where there may be difficulties with the provision of storage tanks (multi-points are mains fed).

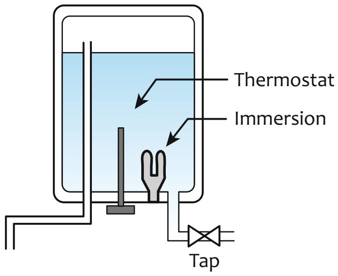
Gas multi-point water heater (right-hand image with cover removed).

Electrical local heaters are not instantaneous as they contain a small amount of stored water, the temperature of which is controlled by a thermostat. Electrical local heaters have the disadvantage of being relatively expensive to run and there is also a time delay while water is reheated. They are generally unsuitable for baths because of the quantities of water required.

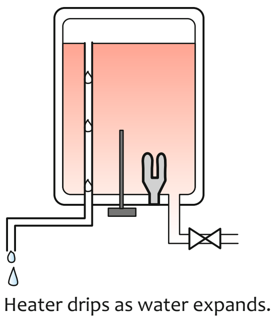
Local water heater – electric



Heater switched off



Heater switched on



In new houses, hot water provision may use a storage system, where the water is stored in a copper cylinder or, alternatively, the boiler which provides the space heating may also act as an instantaneous water heater. This latter approach, which is probably the most common solution in new houses, uses a boiler which is usually referred to as a 'combi ' – because it combines a water heater and a central heating boiler within a single unit. Combi boilers are discussed in Chapter 19.

Centrally stored hot water

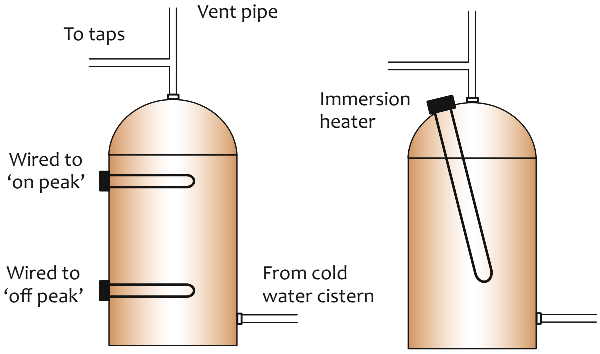
The hot water storage cylinder

Until relatively recently when the use of combi boilers became the norm, a system where the hot water is stored in a copper cylinder would have been the most frequently adopted approach in modern houses. The copper cylinder is sized in relation to its ability to provide sufficient hot water for the day-to-day activities of the household (usually 114 litres). If the cylinder is too small it will not provide enough hot water for, say, a bath and if it is too large the water will take too long to reheat. This will be uneconomic in capital and energy costs. The water in the cylinder can be heated by an electric immersion heater and/or by a boiler which, in most cases, also provides hot water for central heating radiators.

Heating the water

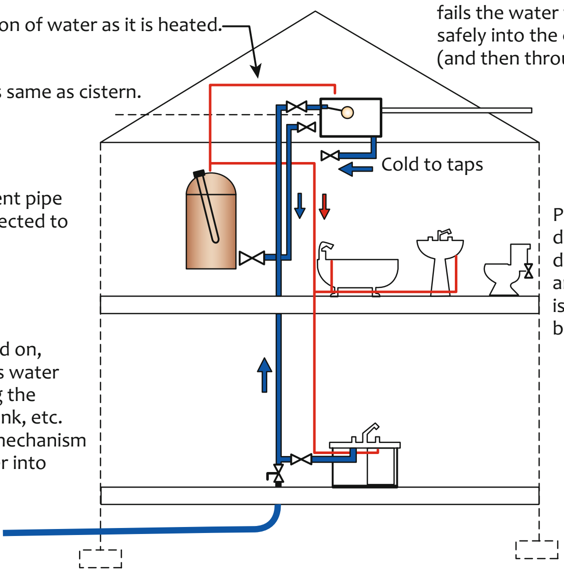
Immersion heaters

Cold water is fed from the cold water storage cistern into a hot water cylinder where it is heated by an electric immersion heater. Even if heat for the water can be produced by some other means, such as a boiler, there will usually be an immersion heater located in the hot water storage cylinder to act as a standby. The immersion heater can be top or bottom mounted, or there can be one at each location. If located at the top, the heating of water is quick for small amounts, and if located at the bottom it is more efficient overall. It is also possible to incorporate a circulator which encourages the transfer of heat by convection.



Most cylinders are still handmade out of copper sheet.

If the immersion heater is not a standby but the main means of providing hot water, it should be linked to the off-peak electricity supply. The cylinder in this case should have a dual immersion heater. The one at the bottom heats the whole tank during the night (off peak), and the one at the top (on peak) heats a small amount as required, as a 'top-up'.



Vent pipe allows for expansion of water as it is heated.

Level of water in vent pipe is same as cistern.

If the thermostat in the immersion heater fails the water will boil and discharge safely into the cistern via the vent pipe (and then through the overflow).

Because of the need for a vent pipe the cylinder cannot be connected to the rising main.

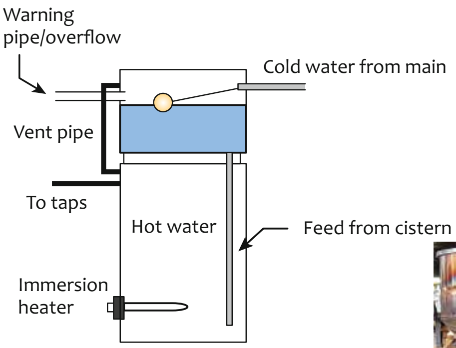
Pressure at the taps is determined by the vertical distance between cistern and taps. Cylinder position is not critical. It could even be sited downstairs.

When the hot taps are turned on, pressure in the cistern forces water out of the cylinder and along the hot water pipework to the sink, etc. At the same time the valve mechanism opens and allows fresh water into the cistern and cylinder.

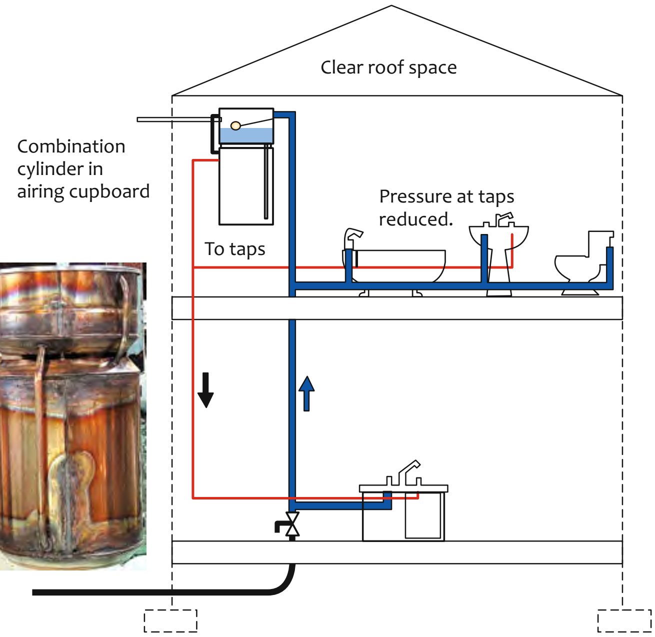
For reasons of energy economy, the hot water cylinder should be lagged with an insulating jacket as shown in the photographs below.

Combination cylinders

These consist of a cold water storage cistern mounted directly above the hot water cylinder. They do not require a water storage cistern in the roof space and are, therefore, particularly useful in flats or properties with a direct cold water system.



The top part of the cylinder fulfils exactly the same function as a cold water storage cistern.



Copper combination cylinders.

The main disadvantage of combination systems is that there is often insufficient water pressure because of the lack of height between the storage tank and the highest sanitary fitting (showers pose a particular problem).

Heating water with a boiler

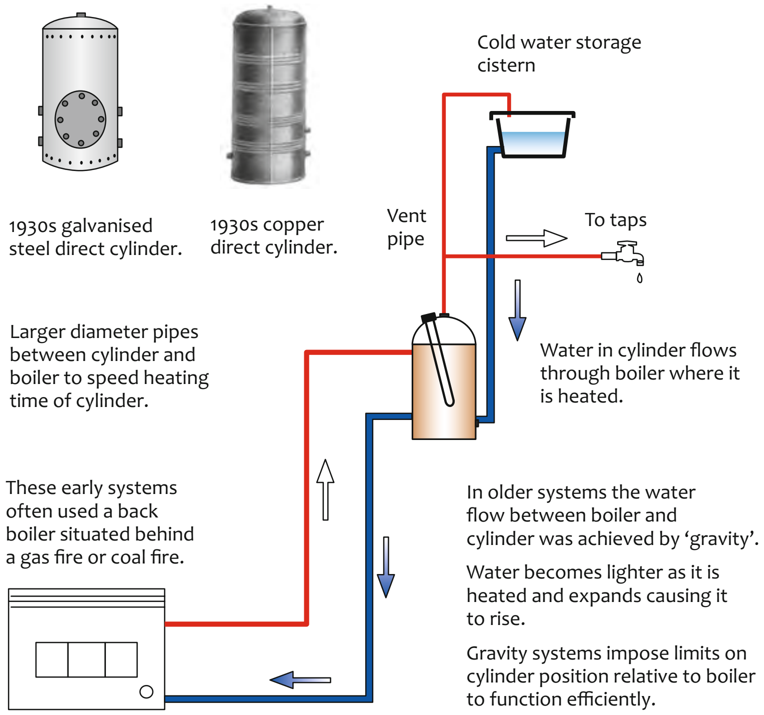
In this approach, cold water is heated in a boiler and stored in a hot water storage cylinder. There are two basic types of cylinder, direct and indirect.

The Building Regulations require that safety measures are incorporated into all hot water systems, so that if the system malfunctions, it does so in a safe manner. Any tank or vessel that contains or could receive hot water, either in normal operation or as part of the fail-safe system, must be adequately supported on a suitability sized base and be capable of withstanding any anticipated rises in temperature or water pressure without failing or collapsing. Hot water tanks and vessels, in addition to any normal controls or thermostats etc., are also required to be provided with independently operating safety devices to ensure that the temperature of the stored water does not exceed 100°C. These can typically include vent pipes, pressure or temperature release systems and non-automatic re-setting energy or thermal cut-outs to the vessel or heat source (see later). Any pipework from a safety system must also be able to withstand high temperatures or pressures, be adequately sized to cope with the associated flow rates and discharge in a safe visible position, without injuring anyone.

Note: The Building Regulations also require that, where baths are provided in new dwellings and some dwellings formed by a change of use, the temperature of the hot water supply to the bath does not exceed 48°C. This would normally be achieved by the provision of a thermostatic safety or mixer valve to the bath hot water supply pipework.

Direct

In the past, when it was less common to find room (space) heating carried out by central heating, hot water was often stored in a direct cylinder. The distinguishing feature of this approach is that water that has been passed between the cylinder and the boiler is the same water that is finally taken out of the taps. Therefore it has to be continually replaced.


1930s galvanised steel direct cylinder.

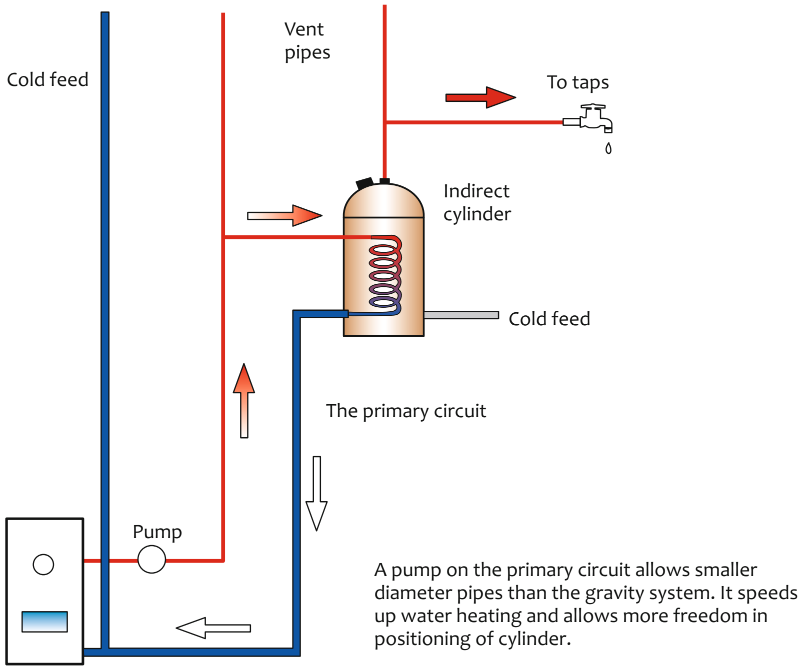
1930s copper direct cylinder.

The direct cylinder had two major disadvantages:

- *Water is constantly drawn into the system, heated, drawn off and then replaced. The constant introduction of fresh water means that, in hard-water areas, there is likely to be a build-up of salt deposits (as 'fur' or scaling) as the boiler heats the water. Such scaling can eventually block up the pipes, the boiler and the hot water cylinder. In addition, it is more likely that air will be introduced into the system, which will increase the likelihood of corrosion.*
- *Some early central heating systems used direct cylinders, but as water was drawn off at the taps the radiators were denied heat. In addition, the water which flows out of the taps in these systems can contain small particles of rust and sludge from the radiators.*

Indirect

In this approach a heat exchanger, usually in the form of a copper coil, is required in the hot water storage cylinder. Hot water from the boiler flows through the heat exchanger, thus heating up the water in the cylinder. The hot water which flows through the taps has therefore been heated indirectly. The water flowing between the boiler and the hot water storage tank is referred to as the primary circuit. The water that is heated by the heat exchanger, and which then emerges from the taps, is referred to as the secondary circuit.

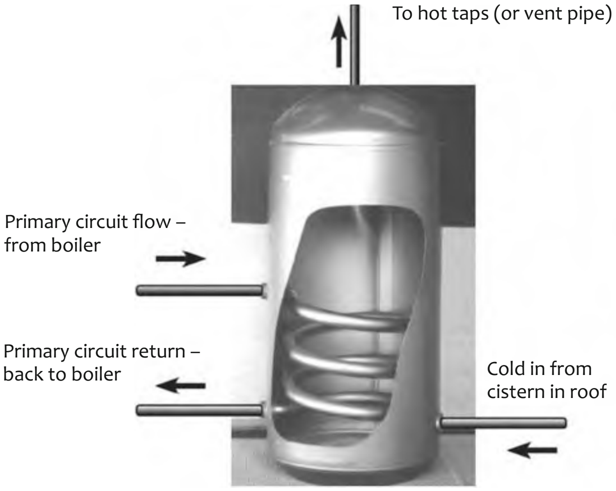


A pump on the primary circuit allows smaller diameter pipes than the gravity system. It speeds up water heating and allows more freedom in positioning of cylinder.

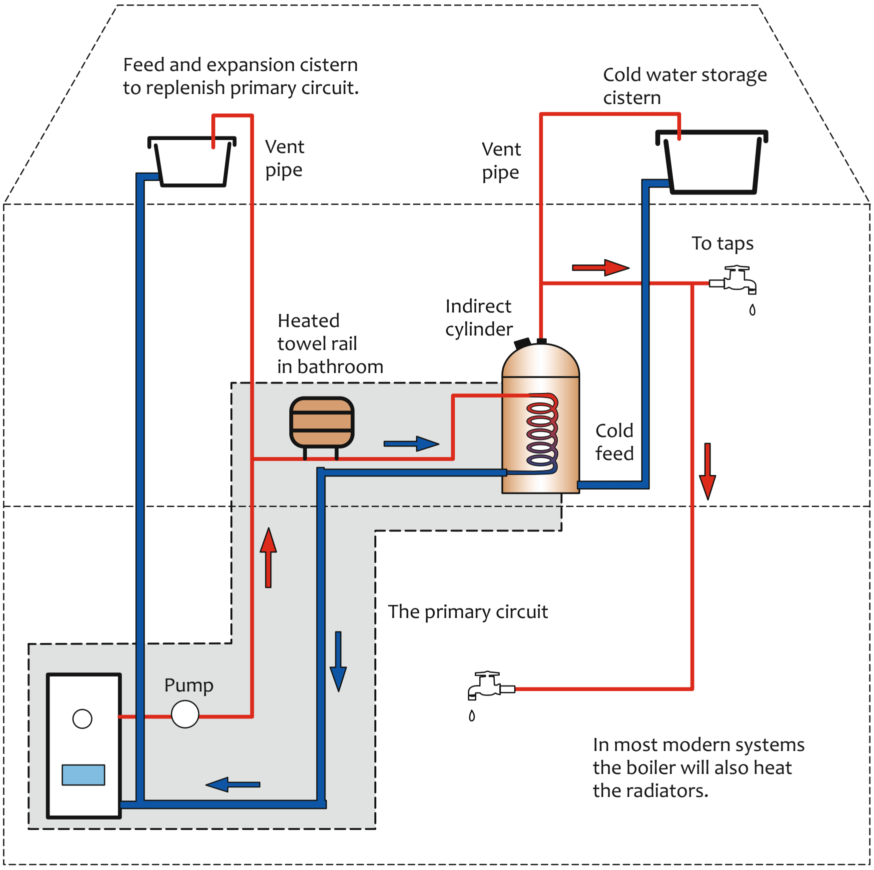
A copper coil or heat exchanger.

This approach avoids the problem of 'furring up' because the water in the primary system remains constant (except for small amounts which may be lost by evaporation). As any volume of water contains only a given amount of salts, furring is limited. In theory, salt deposits may still form in an indirect storage cylinder but, because the stored water is at a lower temperature than the water in the primary circuit, the furring is minimal. Indirect cylinders are the norm in modern houses.

An indirect cylinder is shown in the photograph below, as is a typical indirect installation, including pipework to the taps.



Cylinder during manufacture



For clarity the warning pipes, incoming water main, valves, drain taps and immersion heater are not shown.

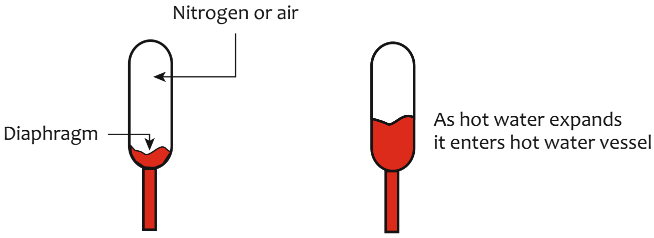
For reasons of economy and efficiency, it is important to plan the layout of the hot water supply system to avoid long runs of pipework. This will affect the positioning of the boiler in relation to the hot water cylinder and the distance from the cylinder to the sanitary appliances. Where long runs of pipework are unavoidable they should be insulated (lagged) to prevent heat loss.

Unvented domestic hot water storage systems

Until 1989, water by-laws (now referred to as Regulations in England and Wales) would not allow hot water storage equipment to be supplied directly from the rising main (except for small electric local heaters). Changes to these by-laws made storage of pressurised hot water acceptable (pressurised means in this case that the water is supplied directly from the mains, i.e. it is under mains pressure). This, in turn, made it possible to do away with the cold water storage cistern altogether. Because these systems will not have a vent to the atmosphere, safety features have to be incorporated. They are normally installed as a package, with a number of safety features set up in the factory before delivery to site.

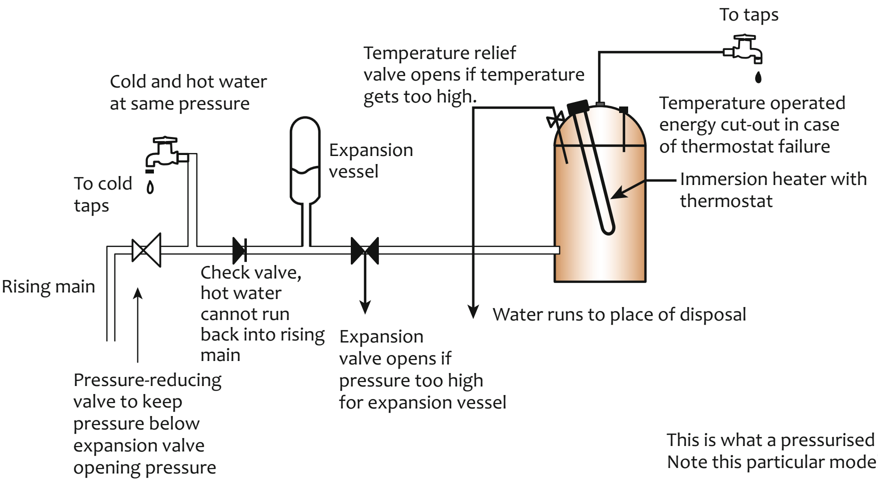
The safety features should include:

- *A pressure-reducing valve:* This provides a constant mains pressure, at a pressure level which will not activate the other safety features.
- *An expansion vessel on the hot water circuit:* This replaces the open vent, and takes the increased volume of water when it is heated. The size of the vessel is based on it accommodating at least 4 per cent of the system's overall water content. Heating water causes it to expand.



The expansion vessel is often fitted on top, or next to, the cylinder. Some cylinders have space for expansion located within the cylinder.

- *Pressure-relief valves:* These are incorporated in case the expansion vessel or the pressure-reducing valve fails. If this should happen, they open and allow the water to flow to a point of disposal. The disposal point should be visible, in order to draw attention to the problem, but designed to ensure that people in or around the building are not injured by the hot water.
- *Check valve:* This prevents hot water being siphoned back into the mains supply.



This is what a pressurised cylinder looks like in practice. Note this particular model has two immersion heaters.

The diagram on the previous page shows, for simplicity, the water being heated in an immersion heater. The water can, and usually would be, heated by a boiler, in which case the primary circuit will need similar protection, i.e. safety features, unless it is vented. Although a vented primary circuit is quite acceptable, it makes little sense to have a non-vented hot water system heated by a vented boiler. See Chapter 19 Space heating for more information.

In this system, water is heated and stored in a vessel which is enclosed (i.e. the hot water cylinder), so additional safety precautions have to be taken to avoid the risk of explosion which could occur if the water accidentally rose above 100°C.

The following are some of the precautions which should be fitted directly onto the storage cylinder to avoid an uncontrolled rise in temperature.

Thermostat

There should be a thermostat in the hot water storage cylinder. If the thermostat should fail, a number of back-up precautions are included, which are designed to operate in sequence should the water continue to rise in temperature. They include:

- *Temperature-operated energy cut-off: This is set at a temperature higher than the thermostat. If the temperature reaches this point, the cut-off will stop the supply of hot water to the cylinder. If this cut-off comes into operation then, obviously, there is a problem and the thermostat has failed. The cut-off can only be reset manually, which will hopefully draw the attention of the user to the fact that there is a fault.*
- *Temperature-operated relief valve (or combined temperature and pressure relief valve): This is a temperature-operated probe. It will react if the thermostat fails, so it will be set at a higher temperature. It operates a valve, which will open and allow hot water out of the vessel. At the same time it will allow cold water to flow in from the mains, therefore lowering the temperature.*

Unvented hot water systems have the advantage of removing the need to provide cold water storage for hot water cylinders. They also allow for the use of smaller water supply pipes because the water is supplied under higher pressure than in a system that utilises storage cisterns, and they reduce the amount of pipework that is required. They do, however, require a larger incoming supply pipe and there is no reserve supply of water in the event of a mains failure. The other disadvantage, of course, is that they require the extra safety precautions referred to above and, as a consequence, maintenance becomes particularly important.

An unvented cylinder in situ.

Solar water heating

Solar water heating absorbs heat energy from the sun to heat water for domestic use. This is achieved through collectors containing a liquid medium (heat transfer fluid) which transfers the absorbed heat to a hot water storage cylinder where it indirectly heats water for use within the building.

Solar water heating systems are usually estimated to be able to supply between 30 and 70 per cent of the annual hot water requirements for a house. This will be influenced by the size, orientation and efficiency of the system as well as the overall hot water demand of the household. Additionally, output will vary according to the season; the supply during winter months will meet a smaller percentage of a household's requirements than in the summer, and therefore some form of back-up system for heating water is normally used.

One reason why solar hot water systems can be effective is that the demand for hot water is relatively constant throughout the year and so unlike, say, a solar-based space heating system, they are responding to a more or less constant demand.

As with other devices which capture energy from the sun – such as photovoltaic (PV) cells – in order to maximise the potential of a solar water-heating system, panels should ideally be tilted to an angle between 30° and 45°, on a roof which receives direct sunlight for most of the day, i.e. essentially south facing but not necessarily directly south. Some authorities are more specific and suggest that the optimal position for a collector is at an incline of 35° to horizontal and facing south. The collector should be free from shadows created by vegetation, buildings or other obstacles. Also, as with PV cells, panels are dependent on available roof space as well as building orientation, domestic systems typically requiring between 2 and 5m² of roof space.

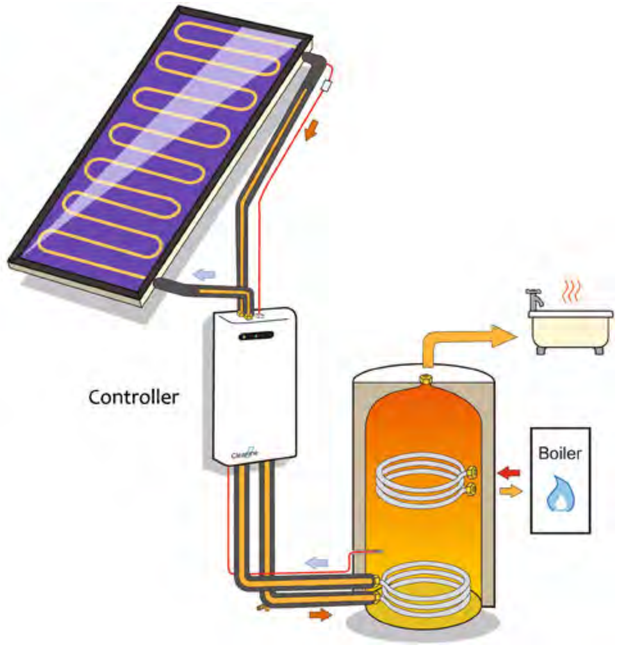


Image courtesy of Viridian Solar.

The diagram above shows a simplified version of an indirect system. The heat transfer fluid is circulated through the system and absorbs heat from the sun as it runs through the collector. It then heats the water in the cylinder via the heat exchanger – in this case a copper coil similar to that discussed in the earlier section on indirect central heating systems. The controller shown in the diagram is an electronic device which senses the temperature in the solar collector and compares it with the temperature of the water in the storage cylinder. When the water in the collector is hotter than the water in the cylinder, the controller switches on the pump in order to run the solar-heated water through the coil heat exchanger. Back-up heating is provided by a boiler which usually feeds hot water through a heat exchanger in the same storage cylinder (via a second heat exchange coil).

An 'active' solar thermal system uses a pump to circulate the heat transfer medium. An alternative is a passive solar thermal system. These rely on gravity and convection, i.e. the tendency for a warmer, less dense fluid to rise, cool and sink. They do not incorporate any electrical components, such as a pump, and therefore benefit from being relatively cheap to run. However, due to the lack of a pump the system can be susceptible to performance extremes, i.e. either overheating or slow response.

There are two main collector types: flat plate collectors and evacuated tube collectors.

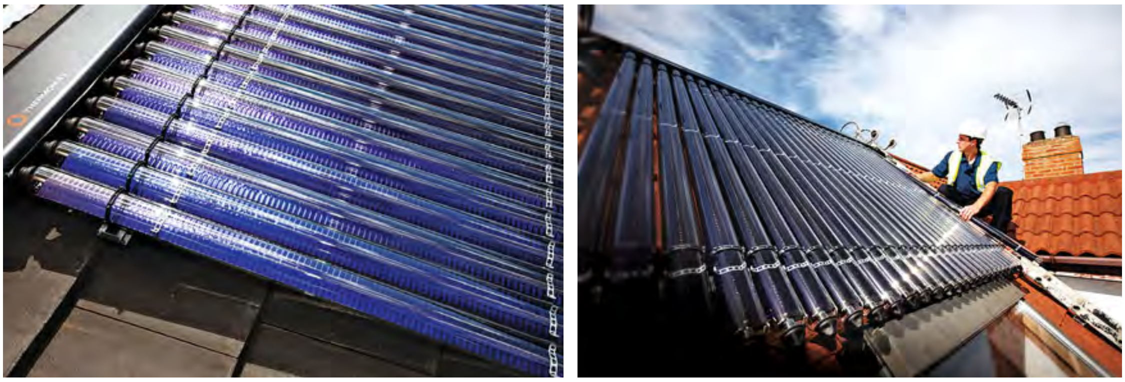
Flat plate collectors. Photographs courtesy of Viridian Solar.

In flat plate systems, the liquid medium absorbs heat by passing through the whole plate. It is then returned to the hot water storage cylinder where it can heat water for domestic use. The system consists of a flat absorber plate which contains copper (or possibly aluminium) tubing through which the liquid medium runs in order to be heated by the sun. The collector is insulated and covered in glass.

Evacuated tube collectors are more advanced, efficient and expensive. They contain a number of glass tubes through which the liquid medium runs. The tube has had some of the air removed from it and the vacuum created reduces convective heat losses.

In both cases, low emissivity coatings to the glass (covering or tube) can increase efficiency (see Chapter 15).

Evacuated tubes have some advantages over flat plate collectors. They are capable of performing, albeit at a reduced level, on overcast days and in colder weather. Additionally, in terms of repair there is the possibility of replacing individual tubes rather than the whole panel.



Evacuated tube collectors. Photographs courtesy of Kingspan Renewables Ltd.

Space heating 19

Introduction

As with hot water supply, space heating can be provided by either a central source, or locally at the point where it is required. The detailed design and maintenance of heating systems is very much a task for specialist engineers and, as such, is beyond the scope of this book. However, this chapter introduces the reader to some of the more common installations and more recent developments and briefly explains how they work.

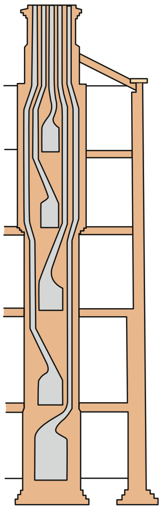
History

Until relatively recently, the most common means of space heating was in the form of open fires. Wood was the most common fuel until the eighteenth century when coal became more and more widely available.

Coal fires presented a number of practical problems. Besides being dirty and labour intensive they were inefficient, with most of the heat produced going up the chimney instead of into the room. Nineteenth century advances in the design of flues and grates, together with more efficient provision of air for combustion, went some way towards improving energy efficiency. In the streets outside, the dirt and smog associated with coal burning were becoming problematic in some towns and cities as early as the Georgian period. This problem was not effectively addressed until the implementation of the Clean Air Act in 1956. This legislation was a direct response to a large number of cases of serious ill health, and even death, in urban areas in the early 1950s. Despite these problems, open coal fires remained popular into the1960s.

For countries that had developed other forms of heating this attachment to the open coal fire appeared to indicate both eccentricity and backwardness. In fact, central heating systems, using steam, water and air, were developed by the Victorians. Some of the technical advances were driven by a desire to find effective ways to heat greenhouses containing tropical plants. However, although central heating was installed in some public buildings, it was not generally developed for housing until the mid-twentieth century. Open fires were also of symbolic importance in defining the idea of a home; a feeling that was encapsulated by the phrase 'hearth and home'. The open fire was usually the focal point in a room, a factor that was emphasised by the use of electric fires, in the 1960s and 1970s, and gas fires in the 1980s and 1990s, which simulated a 'coal effect'. (In fact, gas fires in use as early as the 1920s also employed this effect.) The value of these later 'coal effect' appliances was not primarily as a heating source but rather for reasons of visual focus and psychological comfort.

Most houses prior to the 1960s would be built with fireplaces in every room. This required complex flue arrangements to get rid of the exhaust gases. The chimney structure was therefore a significant part of the building, with its size, in part, being dictated by the need to have separate flues for each fireplace.



In many larger houses chimneys were significant visual and structural elements.

In the past, houses tended to be rather draughty. This was partly due to gaps in the structure and around windows, doors, etc., but a lot of the air movement was caused by air rising up the chimney. Draughty houses were associated with the Victorian idea that there was a strong link between adequate ventilation and good health. This link is something that we have been relearning in modern houses: where a requirement to reduce levels of natural and casual ventilation has led to increasingly sealed buildings. Without sufficient ventilation, condensation, associated moulds and off-gassing of certain manmade materials have created significant ill health for some occupants. This desire to seal houses is principally linked to concerns regarding energy efficiency of space heating. While this potentially reduces the incidence of fuel poverty, carbon emissions and waste, we should be vigilant about the link between reducing ventilation and the potentially negative effects on human health.

Gas fires, or rather stoves, were developed in the latter part of the nineteenth century. However, it was not until the years following the First World War that gas and electric fires became more commonplace. This was clearly due to technical advances, although social changes, which meant that fewer people had servants, were also a factor.

The 'Popular'

Three examples of fires/boilers from the early 1930s. The left-hand picture shows an early coal-fired central heating boiler. At this time only a tiny percentage of houses were centrally heated. The middle picture shows a modest 'range'. This contained a small oven above the fire and space to heat one or two saucepans in front of it. The range also contained a back boiler (to heat a water cylinder). The right-hand picture shows a typical fireplace suitable for a lounge or dining room.

During the later 1920s electric and gas fires became popular - the former due to the increased spread of electricity, the latter due to the newly competitive costs of gas. The middle picture shows an early (1932) 'flame effect' electric fire.

Central heating systems started to become more commonplace in the 1930s, but only on a limited scale, and it was not until the late 1960s that this approach began to replace open fires in new housing. The provision of local or individual heating appliances for each room, while less popular perhaps than central heating, may still be an economic, and efficient alternative, particularly in the highly insulated houses increasingly required by the Building Regulations, where even a single heat source can be sufficient. The provision of local heat sources may also be more appropriate in awkwardly shaped dwellings where long pipe runs for a central system may be difficult to justify. Nevertheless, until recently it was rare to find modern houses built without some form of central heating, and public perception considered it to be an essential element in a new house.

In the past few years a great deal of attention has been given to alternative 'low carbon' approaches to domestic space heating, and this will be an increasingly vital consideration in the coming decades. This is unsurprising as space and water heating is responsible for a significant proportion of the UK's carbon emissions. The increasing attention to energy efficiency, thermal insulation and reduction of casual ventilation in housing has occurred at a time of steeply rising energy costs. It also coincides with a number of Government targets for carbon reduction and associated initiatives to encourage the adoption of 'low-carbon' technologies, not least for the services for new and existing housing.

This chapter examines the most commonly installed space heating system – gas central heating. It also considers electrical heating systems. These were quite common in the past but are used far less now – mainly because they are generally more expensive and less efficient than gas central heating. The chapter finishes by considering heat pumps, which are being installed in increasing numbers.

Central heating installations

Central heating is an approach in which heat is produced by a central source and then distributed around the house utilising heated air and, most commonly, hot water. Central heating installations almost universally provide for domestic hot water as well as space heating. Such installations usually consist of four main parts:

- *a boiler to generate heat (for space as well as hot water)*
- *a medium through which the heat travels to its destination – this will usually be in the form of ducts (carrying air) or pipework (carrying water)*
- *an element which emits the heat once it reaches that destination – this will usually be in the form of radiators, convectors or underfloor systems*
- *a system of controls which enable the system to operate efficiently and conveniently.*

Typical central heating installations are sometimes referred to as 'wet'. This refers to the fact that the heat generated by the boiler is transported around the house by water. These installations remain the most common approach to central heating in UK housing. Water is heated in a central boiler and then sent via a network of pipes to a heat emitter, usually a series of radiators. The water is cooled as it gives off its heat, and returns to the boiler to be heated again. The water is usually heated in the same boiler that provides domestic hot water.

Fuels

The fuels which are generally available include: gas, oil, coal, biomass, liquefied petroleum gas (LPG) and electricity. Some of the factors affecting the choice of fuel are set out below.

Cost

The cost of the fuel can change over time in relation to market conditions, and should be considered in conjunction with the type of heating appliance. This is because some heating appliances are more expensive than others in terms of capital cost, and also because some appliances are more efficient than others in the way that the fuel is used.

Availability

In some areas there may be a restricted choice of fuels. An obvious example is mains gas, which is not available in some rural areas. In this case, LPG, which is stored on site in a large cylinder, may be considered as an alternative. In urban areas obtaining and storing biomass can be difficult and expensive.

Convenience/cleanliness

Fuels such as mains gas and electricity do not require the provision of storage facilities, unlike oil, coal and biomass. This is an obvious advantage, except in circumstances where supply might be cut off. Solid fuel boilers may need to be hand fed, although there are a number of coal and wood pellet boilers which have an integral storage hopper with an automatic feeding system and these have reduced some of the inconvenience associated with these fuels.

Control

Coal and certain forms of biomass boilers are less easy to control than oil or gas, as the burning fuel cannot be turned on and off.

Carbon emissions

Government attention and emissions targets to regulate and incentivise reductions in carbon emissions will increasingly impact on the relative cost and availability of some fuels and their respective heating systems. All the above fossil fuels including electricity, which is largely produced by burning fossil fuels, produce significant quantities of carbon emissions. Biomass (logs, wood chips and pellets), just like all other commonly used fuels, gives off carbon as it is burned. However, unlike all the alternatives, growing replacement biomass draws the same quantity of carbon out of the atmosphere as is put into it when it is burned (i.e. it is carbon neutral). This has made it an increasingly popular fuel.

Boilers

Boilers are the heart of a wet central heating system as they provide the heat energy for the hot water and the radiators. There are various types of boilers.

Free-standing

This is simply a boiler that stands on the floor (taking up floor space) and is connected to a vertical flue, such as a chimney or a balanced flue (see below).

Wall mounted

This is smaller than a freestanding boiler. It is mounted on an external wall and, generally, uses a balanced flue. It is the most common type in modern houses and has the advantage of not taking up floor space.

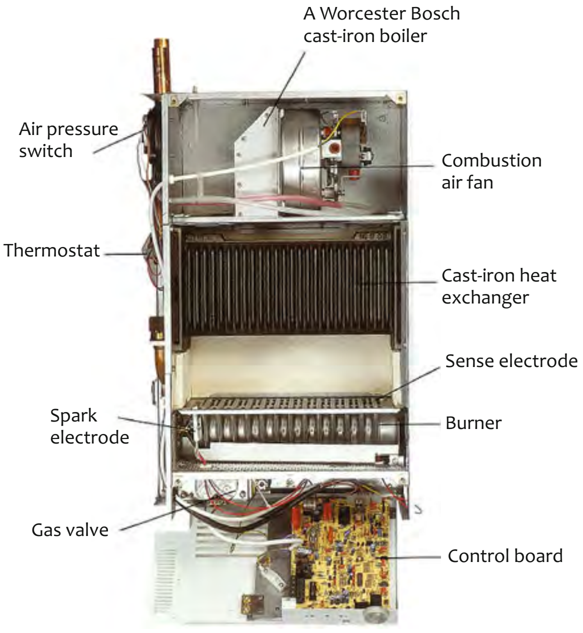
Back boilers

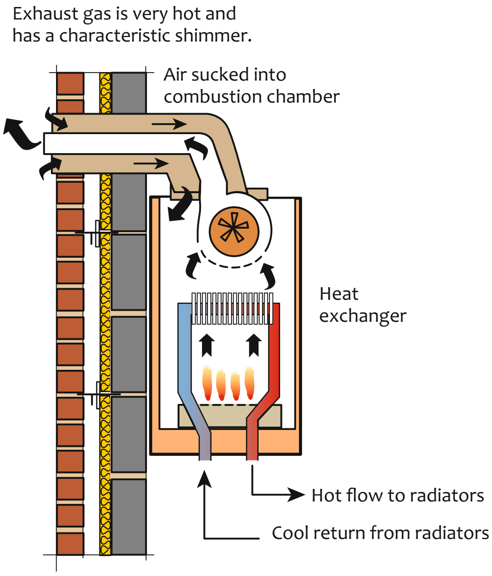
This is a boiler placed at the back of a room heater and connected to a flue. Traditionally, with, say, a coal fire, it would be a small steel or cast-iron water container fitted behind the fire and heated by it. Some gas back boilers have a room heater which can be used independently of the boiler. Wood-burning stoves can also be fitted with an integral boiler, which can heat a primary circuit for water and/or space heating.

Condensing boilers

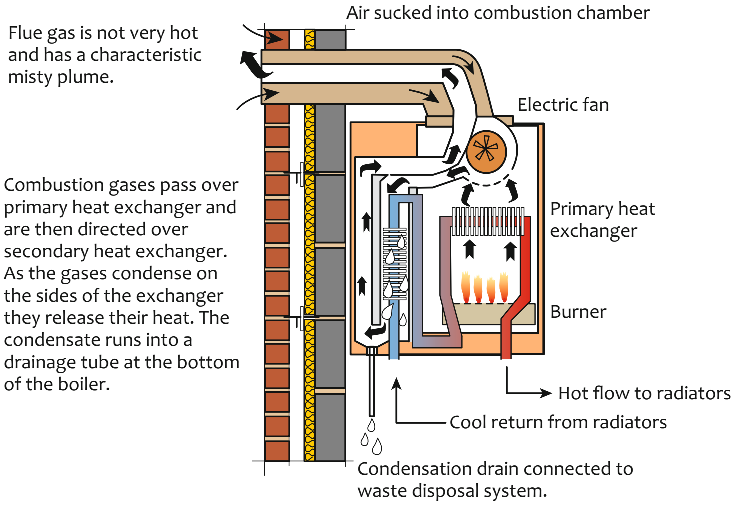
Condensing boilers are now the most common boiler for new housing and as a replacement for existing boilers. The reason for this is that they have proved to be more efficient than standard boilers because of their ability to recover heat which would otherwise have been lost up the flue. Research has shown condensing boilers to be 80–90 per cent efficient, compared to an efficiency figure as low as 60 per cent for a non-condensing boiler. Because of the energy efficiency of the installations, the Government has used campaigns to encourage their use and the Building Regulations' energy-efficiency performance requirements stipulate that all new boilers, whether they are new installations or replacements, are to be condensing boilers. However, if in exceptional circumstances, such as an existing dwelling with a traditional back boiler that is being replaced and no other suitable position or location is possible within the dwelling for a condensing boiler, provided that an approved installation and evaluation process is followed, it may be possible to install a non-condensing boiler.

The first picture (overleaf) shows a 'traditional' or regular non-condensing boiler. The graphic below that shows a condensing boiler.





Combustion gases pass over heat exchanger and into flue. About 30 per cent of the heat is wasted.



Combustion gases pass over primary heat exchanger and are then directed over secondary heat exchanger. As the gases condense on the sides of the exchanger they release their heat. The condensate runs into a drainage tube at the bottom of the boiler.

Because they extract more heat than non-condensing boilers, the exhaust gases in a condensing boiler are cooled to a temperature at which water vapour will condense. This condensate is acidic and will have to be removed by a drain connected to the household waste disposal system. If the condensate is not drained it can cause corrosion and damage to the boiler and flue. All condensing boilers have fan-assisted flues to help disperse the cold gases.

Flues

Boilers which burn oil, gas, coal or biomass require a flue to exhaust the gases produced by combustion. There are a number of rules in the Building Regulations regarding chimneys and flues, and these are aimed at the safe functioning of appliances. The Regulations cover adequacy of combustion air, as well as its safe discharge. Air, or rather oxygen, is required for safe and efficient combustion. In addition to combustion air, sufficient ventilation air is required to ensure that the products of combustion move quickly up the flue. This is necessary in order to reduce the likelihood of condensation occurring or soot building up. More importantly, sufficient ventilation air is necessary to ensure that carbon monoxide fumes do not seep back into the house. Ventilation air must be provided by permanent means that cannot be easily obstructed by the occupier. The Regulations also require that in rooms where solid fuel appliances are installed or replaced, a proprietary fixed carbon monoxide alarm is provided.

In early construction, flues or chimneys were simply built of brickwork, but nowadays it is normal to use some form of internal lining. The linings may be made from a number of materials, including concrete, stainless steel or fireclay. Pre-formed blocks, which incorporate the chimney structure and the lining in one element, are also available.

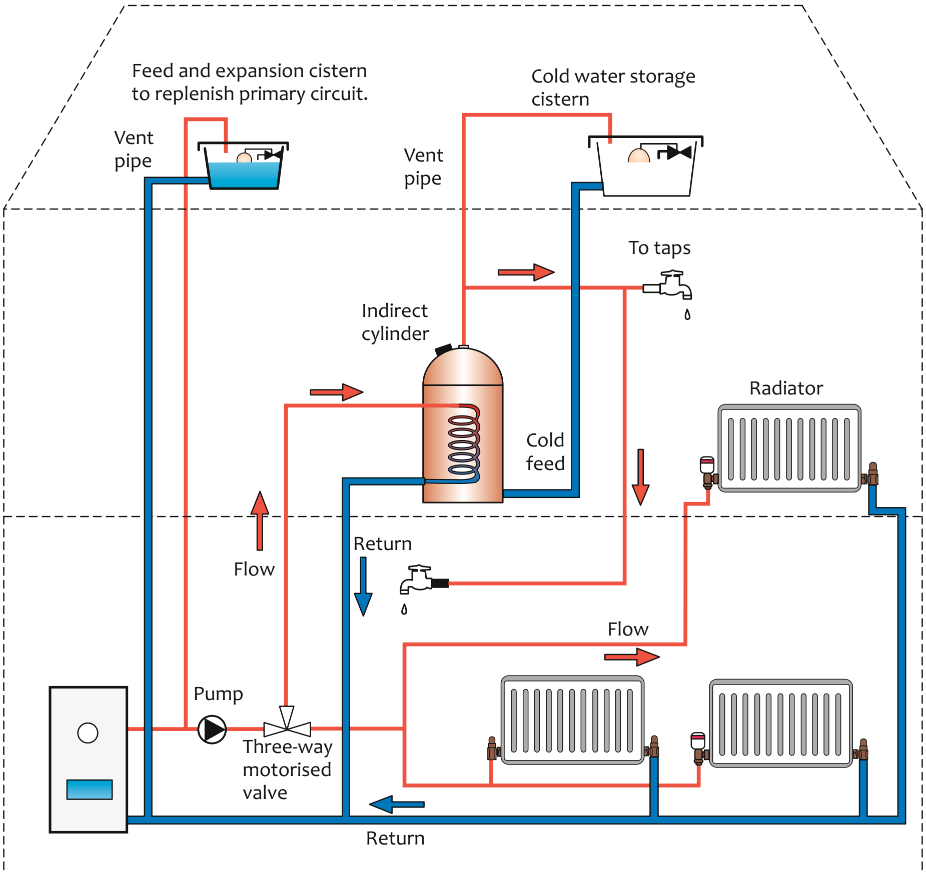
In some circumstances the fuel being used may influence the choice of liner. For example, flexible stainless steel liners, which are sometimes used on existing chimneys, should only be used with the specific combustion appliances and fuels for which they are designed. The Regulations also require flues to be accessible for inspection and maintenance and that sufficient information, typically in the form of a notice plate adjacent to the hearth, is provided with new or replacement flues, so that it is clear to which appliances and fuel types the flues are suited. The linings should be airtight, to ensure that no gases escape into rooms or the roof space, and also waterproof, as some fuels produce water vapour, which can condense in the upper part of the chimney. This condensed water may be absorbed into the brickwork and, depending on the fuel being burnt, acids or salts in solution may be transferred as well. The acids or salts in solution may also find their way back into the boiler. The problem of condensation can be resolved, to some extent, by the use of insulated linings to the flue.

Balanced flues

Most wall-mounted boilers use a balanced flue. Unlike a traditional flue it both draws air for combustion and disposes of flue gases through the same unit. The flue should not be placed near an opening window, nor where the heat from it may cause damage (for example, melting plastic rainwater goods). It should also, of course, be placed out of the reach of people, or enclosed by some form of durable guard. In the past, balanced flues used to be rather large to enable sufficient air and exhaust flow; nowadays fan-assisted balanced flues are significantly smaller and more effective.

Vented central heating

Many older central heating installations are vented. A vented installation means that, as explained in Chapter 18 on hot water supply, the pipework to both the hot water storage cylinder and the boiler is vented to the atmosphere. Vented installations require non-mains pressure water to supply both the boiler and the hot water cylinder and thus require two separate cold water storage cisterns. A 'feed and expansion' cistern provides cold water to the boiler's 'primary circuit'. This is a pipe network which takes the hot water heated by the boiler to the heat exchanger in the hot water cylinder and to the radiators. This half of the circuit is known as the 'flow'. The heat is drawn off by the radiators and heat exchanger, and then the water returns to the boiler for re-heating. This half of the circuit is known as the 'return'. Ideally, the water in the primary circuit would remain there forever. However, if there were a fault which caused the water to boil and expand, this would be safely vented to the cistern. This also regulates the water level in the primary circuit, hence the term 'feed and expansion' cistern. As the water in the primary circuit is intended to be re-circulated, re-heated and not to be drawn off to taps, it is commonly treated with a chemical additive to reduce the effect of salt deposition or furring. A separate, and much larger, cold water cistern is required for the hot water circuit. This also allows for any excessive water expansion to be safely vented. The diagram below illustrates the principles and key components of a typical vented installation.



Note: If any of the cisterns receive overflow water from the hot water system, such as via the expansion pipe, the Building Regulations require that the cistern is designed, manufactured and installed to remain stable and resist the anticipated increase in water temperature without failing or collapsing and injuring anyone.

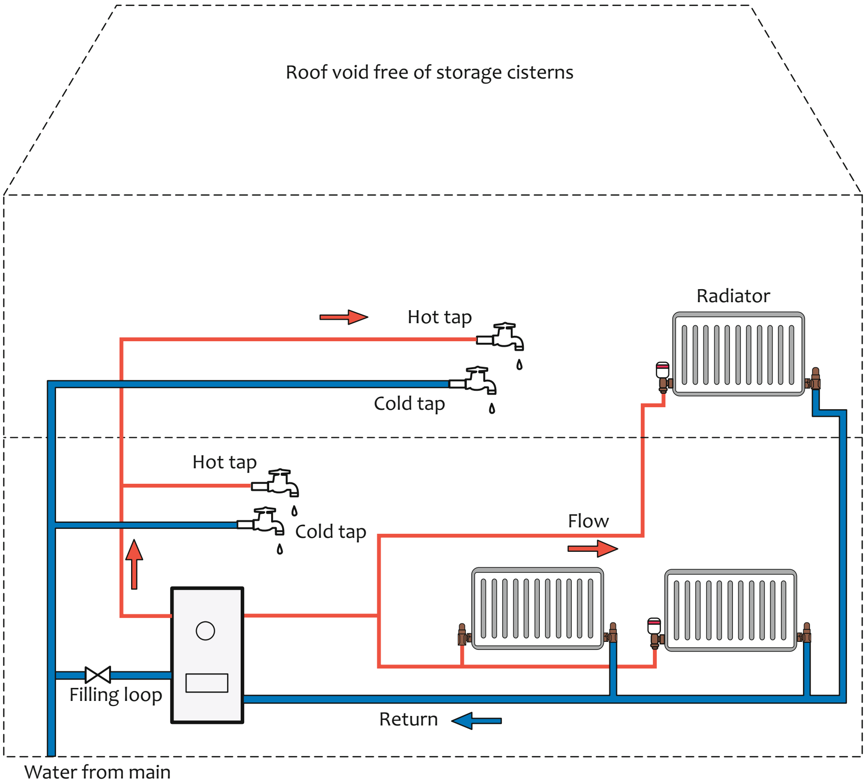
Unvented central heating

An alternative to the vented installation, is a sealed or unvented boiler. The most common form of this is often called a 'combi', or combination boiler. These have become very popular and currently dominate new gas and oil-fired boiler installation.

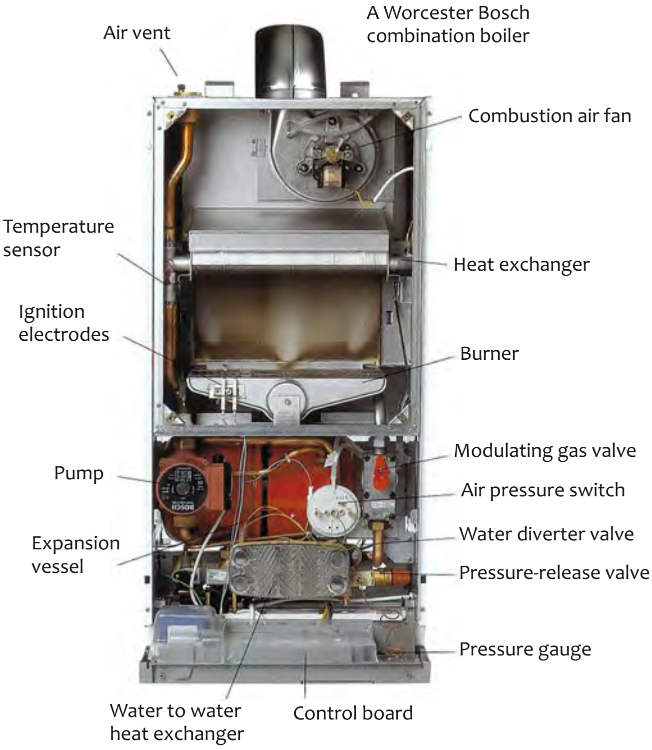
Unvented installations use sophisticated mains pressure boilers which produce space heating as well as instantaneous hot water supply. They provide both without the need for either hot water storage or cold water storage cisterns, which are necessary in vented installations.

The primary circuit heated by the boiler goes to the radiators to provide space heating. However, within the boiler itself, there is a special heat exchanger which enables the primary circuit to transfer some of its heat indirectly to mains pressure cold water. This avoids a storage requirement and provides mains pressure hot water on demand.

The boiler itself is more complex. A number of the components and controls – the pump and motorised valves – which are separate items in vented systems, are incorporated within the boiler. Additionally, because the boiler is not vented, and works solely on mains pressure, it requires additional safety features, such as an expansion vessel and automatic discharge valves, similar to those used in an unvented hot water installation (described in Chapter 18). These safety components are also incorporated within the boiler.



Boiler is connected to the main through a filling loop. A tap on the loop allows the boiler to be filled to the right pressure. A gauge on the boiler can then be monitored. In a combination boiler all the safety features required (because it is not vented) are contained within the boiler.



There are some significant advantages of unvented systems, they:

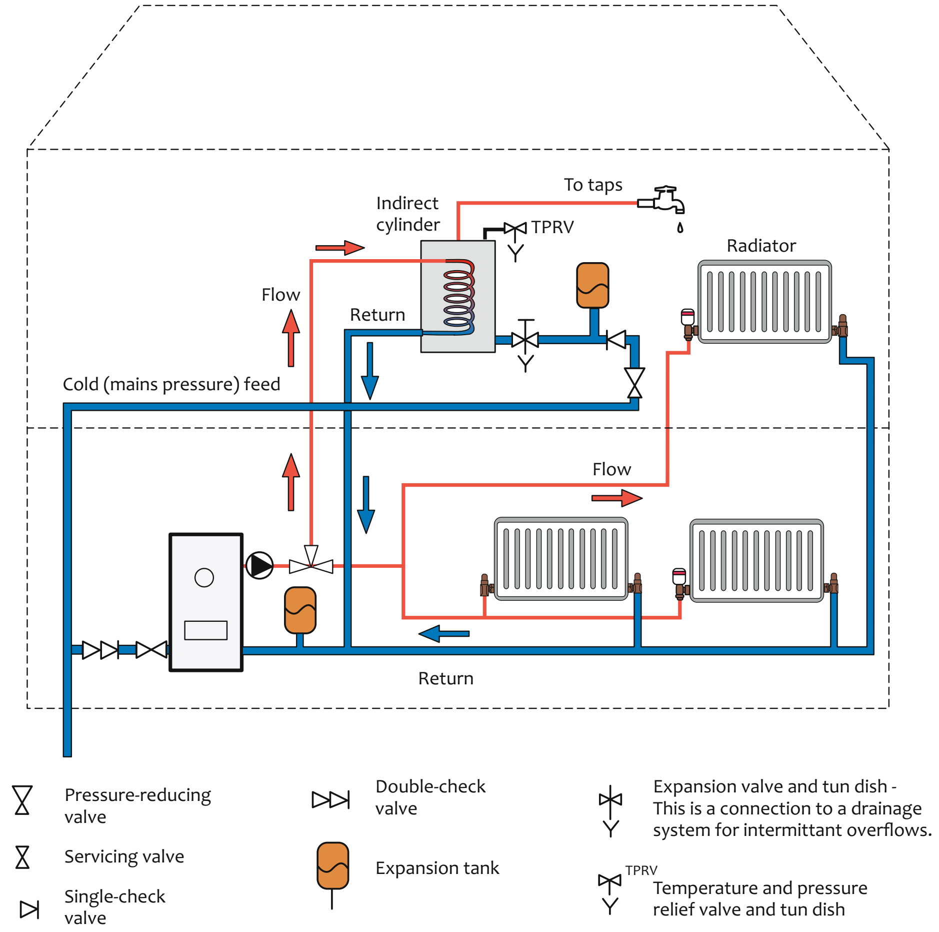
- *are compact, relatively simple to install and do not require storage cisterns or cylinders*
- *should save energy as there is no loss of heat from stored hot water, and the water is only heated as it is needed*
- *are good for showers, because hot water is at mains pressure*
- *are compact, and as such they are particularly useful in medium-sized houses where space is at a premium, as well as in flats where access to the roof space is restricted.*

They also have some disadvantages:

- *there can be a conflict between space heating and hot water production and they can be slow to fill a bath; however, there is no waiting time while a hot water cylinder reheats*
- *the maintenance required to ensure function and safety may mean that this aspect of their running costs may be higher than for other installations*
- *there is an increased risk of furring because mains pressure cold water is constantly drawn through the boiler to provide hot water, and in hard water areas it may be necessary to use a water softener.*

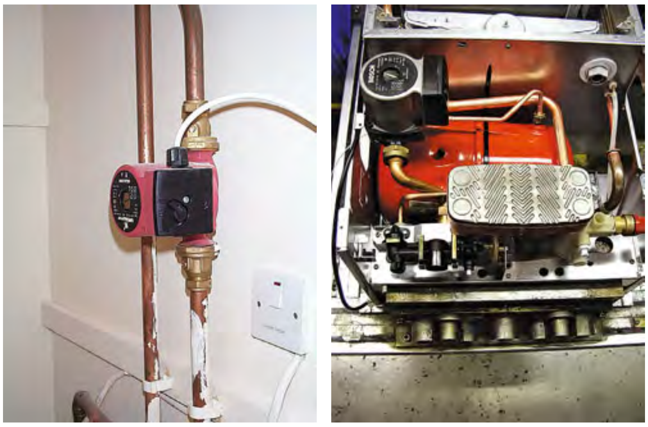
System boilers

A system boiler is designed along similar lines to a regular (vented) boiler but is designed for use with an expansion vessel rather than a feed and expansion cistern and an open vent. In some boilers the expanding water is accommodated in an expansion vessel fitted inside the boiler. In others it is not part of the boiler but is usually located near to it. This boiler is almost a 'halfway house' between a regular vented boiler and an unvented boiler. To provide hot water for washing, a system boiler heats water in a separate hot water cylinder. This can be either a vented (traditional) cylinder or a modern pressurised one. The advantage of the system boiler is that there is no feed and expansion tank in the roof – it is efficient to follow the same approach for the hot water cylinder, and these are usually pressurised, as illustrated in the diagram below.



Central heating installation components and controls

Small-bore pumped systems



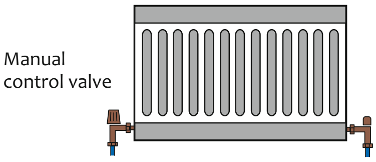
An electric pump ensures good and quick circulation. Some manufacturers fit the pump inside the boiler. The right-hand picture shows a Worcester Bosch combination boiler with an integral pump.

Some older systems were gravity-fed – this led to inefficiencies and constraints in pipe size and layout and required pipes to be laid to a fall. Nowadays, providing a pump to either push or pull the water around the system is the norm. In a pumped system the water will circulate at a higher speed than in a gravity system, which allows a more flexible layout. Better control of the heating and cooling process results from the fact that less water is used, which means that the system heats up and cools down more quickly than a gravity system. The use of a pump also means that the pipework can be of small diameter, and this gives a neater, more efficient installation. The pipework, which transports the water to the radiators, is usually formed in copper or plastic, usually with a diameter of either 15 or 22mm.

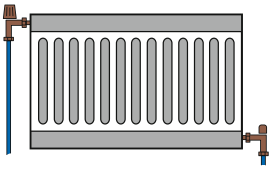
In vented systems, the pump is a standalone component located on the primary circuit. In unvented systems it is integrated into the boiler.

Radiators

The usual method of releasing the heat into a room is by means of a radiator. Despite the name, radiators operate mainly by convection, i.e. by the movement of air across the surface of the radiator.



Water enters at bottom of radiator – neater



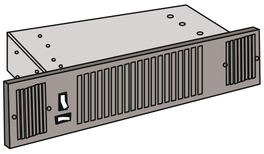
Water enters at top of radiator – more efficient in large systems.

Because the majority of heat from a radiator is convected heat, shelves or other obstacles should not be placed over the top of the radiator; this interferes with the flow of air and hence the distribution of heat. Radiators can be made of pressed steel or aluminium, although older cast-iron ones may still be in use.

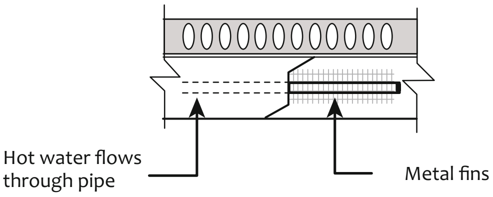
The amount of heat that the radiators emit depends on their size as well as on the temperature of the water. Enlarging the surface area of the radiator can, therefore, increase the heat output. This can be done simply by making a single radiator larger or by using double or triple layers sandwiched together, or by the addition of metal fins.

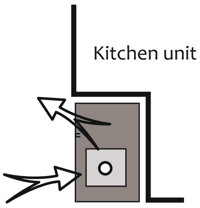
Convectors

Instead of radiators, a convector emitter may be used on a wet system. These have hot water flowing through a series of pipes in the convector. Fins are usually attached to the pipes in order to give off more heat by increasing surface area. Air passes over these fins by natural convection or with assistance from a fan. This process extracts heat which is given out into the room. The fan can be fitted to a thermostat.



Convector may be fan assisted





Small linear convector heaters can be placed at low level and encased in a manner which emulates skirting.

Underfloor heating

Underfloor heating has become increasingly popular and, although it currently represents a relatively small proportion of current installations, its use is set to rise. It essentially consists of a plastic pipework system laid on an insulated concrete slab and covered with a cement-based screed. There are also systems which can be covered by timber-based flooring – though these can compromise the efficiency of such installations by placing a relatively good insulator on top of the heat source. Heated water from the boiler's primary circuit, or from a heat pump installation, is circulated through the pipework network and gives off its heat to the screed into which the pipes have been embedded. It is possible to zone areas of the floor using zoning valves which restrict the flow rate of hot water to specific areas and this can provide greater flexibility of operation. Although underfloor heating can be installed in concrete upper floors, most installations are restricted to the ground floor.

As the whole area of the floor acts as a convector, the temperature of the circulating water can be relatively low. This suits condensing boilers and heat pumps in particular, both of which operate efficiently at relatively low temperatures. It also has the advantage that such installations match the human preference for warm feet and cool head. Additionally, no wall radiators are required so there is no adverse impact on room layouts and radiators can be used on upper floors if required.

On the downside, maintenance and repair costs can be very high and disruptive. Additionally, speedy response to heating demand can be difficult to achieve and, without a suitably designed control system, it can be difficult to control the exact amount of heat delivered to individual rooms.

Plastic pipes are laid onto retaining sheet which in turn is laid on top of significant insulation. The pipes will be embedded in a screed, which will be laid once the whole system has been pressure tested.

Plastic pipe manifold. This separates and controls the hot flow and cooler return water throughout the installation, connecting back to the heat source's flow and return.

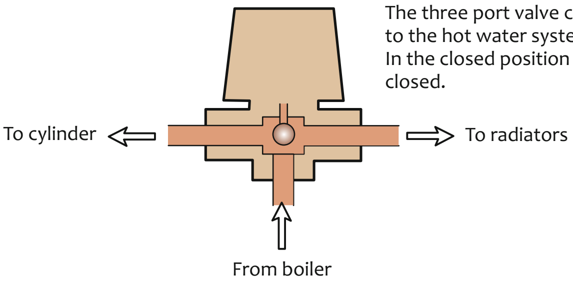
Two-pipe system

Where radiators are used, a two-pipe circuit is universal: one a flow pipe and the other a return pipe, and each radiator is connected to both. The water that leaves the radiator flows into a return pipe, which goes back to the boiler. The same process occurs in all the other radiators, with all of them receiving water at more or less the same temperature.

Two- and three-way valves

In vented systems these valves, which are linked to the central heating controls, open and close in response to signals from thermostats in the control system. By so doing, they send the hot water to the radiators or the hot water cylinder, or to both at the same time, in response to demand. These valves should be wired back to the boiler in order to prevent it from firing when it is not needed for either circuit (see the section on short cycling below).

It is important to ensure that these valves are not fitted on or before the feed and expansion or vent pipes, as this may interfere with the expansion capacity of the system.



The three port valve can direct water to the hot water system and/or radiators. In the closed position both circuits are closed.

Two-way valves may be used, with one on the heating circuit and one on the hot water circuit. If a three-way valve is used then only one is necessary to control both the heating and the hot water. The three-way valve would be positioned at the T-junction where the flow divides to serve the radiators and the hot water storage cylinder (see the diagram on p. 368).

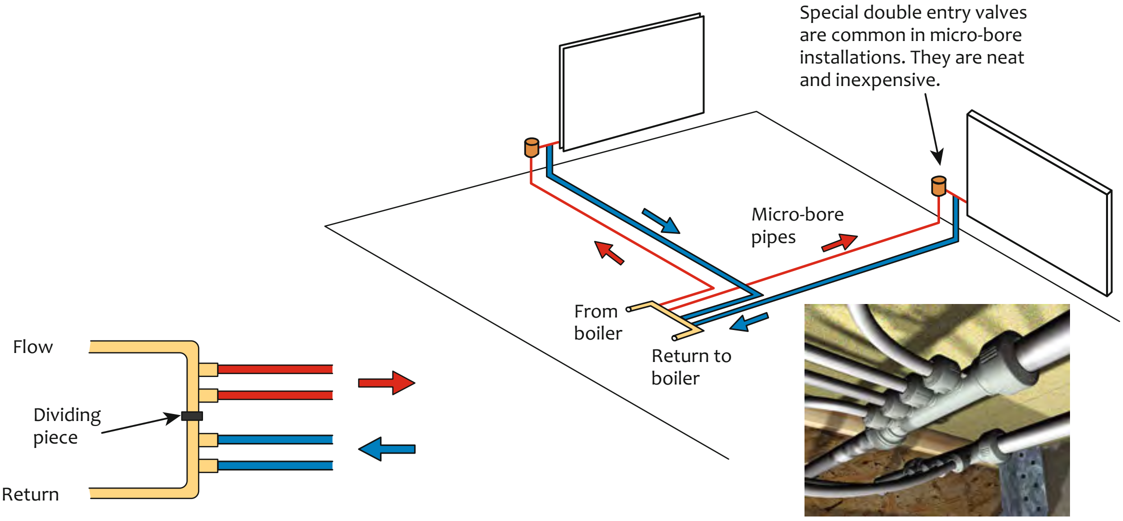
Such valves are included within the boiler in unvented boilers.

Micro-bore (mini-bore)

A development of the small-bore system is the micro-bore. This again is a two-pipe system, but with smaller pipework sizes. The pipework which circulates the water to the radiators is divided into two sections:

- *flow and return from the boiler to a device known as a manifold*
- *flow and return from the manifold to each radiator.*

The main circulation pipes are 15 or 22mm diameter, as with a small-bore system, but they feed via the manifold into micro-bore pipes with diameters of 8, 10 or 12mm, which supply the individual radiators in the manner shown below.



Special double entry valves are common in micro-bore installations. They are neat and inexpensive.

Plastic manifold – looking from below.

These systems are mechanically pumped but the pump will be more powerful than with a small-bore system because of the smaller pipe diameter. Until recently, the main material for micro-systems was copper but plastic is also now common.

The principal advantage of micro-bore systems is that the pipes are very flexible and easy to manipulate. This reduces installation time and causes less disruption to the structure. Additionally, there is less water in the system and therefore less heat loss and a faster response. The disadvantages primarily relate to the relative thinness of the pipes: they are more susceptible to blockage and, if they are copper, they are more vulnerable to impact damage.

Controls on central heating systems

On a wet central heating system, controls are necessary to provide safety, comfort and energy efficiency. For increased energy efficiency the controls might take into account:

- *changes in outdoor temperature*
- *variance in room temperature requirements between different rooms*
- *diurnal, and perhaps seasonal, heating requirements.*

Boiler thermostat

A thermostat is required in order to control the temperature of the water heated by the boiler and to stop the boiler from overheating. It will normally be set at between 70 and 80°C and will switch off the boiler when the pre-set temperature is reached. If the temperature is set higher than this, the radiators will be too hot to touch.

Hot water cylinder thermostat (only on vented systems)

This will usually be set at about 60°C. When this temperature is reached the flow of hot water to the heat exchanger in the storage cylinder will be switched off by the motorised valve (see photograph below). The temperature setting is based on the need to ensure that bacteria are killed off, set against the need to ensure that energy is not wasted and that people are not at risk of being scalded.

Timers and programmers

A simple time switch can be used to turn the heating on and off at predetermined times. However, if separation of heat and water is required, a more sophisticated programmer is needed. Programmers can be set for daily or weekly sequencing, while allowing different settings each day. They can also be used to switch motorised valves to divert heat to the heating circuit or hot water cylinder as required. Controllers are slightly more sophisticated and use detectors to sense temperature changes.

Boiler managers are even more sophisticated. They can carry out a variety of energy-saving and convenience-related functions. For example, sensing outside and inside temperatures in order to work out the correct time to switch on the boiler to ensure that the house can be at the right temperature when the household rises. They are quite expensive to install and not everyone is convinced of their value.

Room temperature

It is possible to control room temperature by altering the boiler thermostat and individual radiator valves, but this would be very inefficient and time consuming. A modern heating system would incorporate a room thermostat and/or a series of individual radiator thermostats.

Room thermostat

Room thermostats can easily be set by the occupier to turn off the heating system at a temperature of their choosing. They work by breaking an electrical circuit when the temperature around the device reaches the pre-set point.

Room thermostats are easily adjustable and can be linked to various parts of the system, such as the pump, programmer or motorised valves, in order to divert or cut off the flow of heat. They should also be linked to the boiler in order to prevent short cycling (see below).

Perhaps the main disadvantage of room thermostats is that they shut down the whole of the system in reaction to local temperature conditions (including draughts or direct sunlight), which may not be a reflection of the needs of the whole house. Because of this, some thought is necessary in positioning the thermostat so that it reflects an ideal temperature for the whole house.

In some situations, due perhaps to size or layout, it might be more efficient to divide a house into different temperature zones according to different heating requirements and have a thermostat, connected to motorised zone valves, for each area.

Programmable room thermostats, which allow a selection of different temperatures at different times of day, are also available.

Thermostatic radiator valves

Thermostatic radiator valves (TRV) reduce the heat flow to individual radiators when a pre-set temperature has been reached. Therefore different rooms can be kept at different temperatures. TRVs take the place of the handwheel valve on the flow side of the radiator. They are set manually for each radiator by reference to a numbered system indicated on the individual valves.

TRVs may be particularly useful in rooms that might be prone to overheating (for example, south-facing rooms or kitchens). They would normally be used in conjunction with a room thermostat but they should not be used on any radiator located in the same space as the thermostat because they will override the thermostat's function.

If TRVs are fitted to all the radiators in a circuit a situation might arise where the boiler is continuing to heat water and it is being pumped around a system that has been effectively closed down. Such a situation is wasteful but it could also cause damage, perhaps at the very least to the pump. The problem can be overcome by the use of additional controls and diverting valves, or, as implied, by not fitting TRVs to every radiator.

Remote sensors can be used with TRVs. They are placed in a position within the room which might reflect the desired temperature better than the fixed position of the actual valve.

Preventing short cycling (dry cycling)

Short cycling is when the boiler 'fires up' in order to maintain its own temperature irrespective of whether or not heat is required by the radiators or the hot water cylinder. It can be reduced or eliminated by the use of appropriate control systems and the manner of their design and fitting. For example, room and cylinder thermostats plus any motorised valves can be wired to override the boiler thermostat when heat is not required (this is known as boiler 'interlock').

Further add-on controls are available but their cost effectiveness and efficiency is questionable, particularly for systems with the 'standard' controls mentioned above.

User understanding

If they are to be used effectively the occupier must understand the controls on a heating system. Many people find time clocks difficult to understand, for example, and there is significant anecdotal evidence to suggest that many people do not understand the function of the various control devices commonly used – examples include:

- *thermostats being used in a way which assumes that they function in a similar manner to a car accelerator, i.e. turned up to maximum to get the house 'warmed up quickly'*
- *using the thermostat as an on/off control for the boiler*
- *setting the thermostat at its highest point and turning the boiler control on or off.*

In addition, digital control systems are often difficult to understand and TRVs have a numbering system of 1 to 5 that has no obvious connection to actual desired temperatures.

The Building Regulations require that sufficient information is provided to the owner/occupier for new or replacement boilers or heating systems, so the system can be maintained and operated correctly, ensuring that it works in an energy-efficient manner throughout its life.

Biomass boilers

Biomass boilers are currently more common in commercial and industrial settings where very large volumes require heating and where building operators can currently benefit from Government subsidies on installation and running costs. There have been several examples of the use of such boilers in providing a centralised heat source for space and water heating for a group of houses as a form of district heating system. For individual dwellings, biomass boilers represent a very low proportion of domestic central heating installations. However, they are beginning to grow in popularity. A number of the real and perceived disadvantages of solid fuels have been resolved by technical and market developments.

There is an increasing number of suppliers responding to the developing market for biomass. In the past, logs from felled or coppiced trees were the mainstay of the biomass market. However, a range of new forms of timber and other agricultural products, both by-products and material grown specifically for the market, have appeared. Wood chips, compressed wood-waste logs and crop waste have been developed as fuels. Perhaps the most convenient form of biomass currently used are wood pellets. These are compressed wood waste from forestry, sawmill and other timber industries. The waste is squeezed at high pressure through a press with 6–8mm holes. The process produces a uniformly dense, easily storable fuel. They take up significantly less space than logs, produce the same calorific value and can be easily moved around – blowing them from the delivery truck into the storage hopper is a commonly adopted measure for delivery. Bulk delivery is possible, and if stored in the dry, the pellets can last indefinitely.

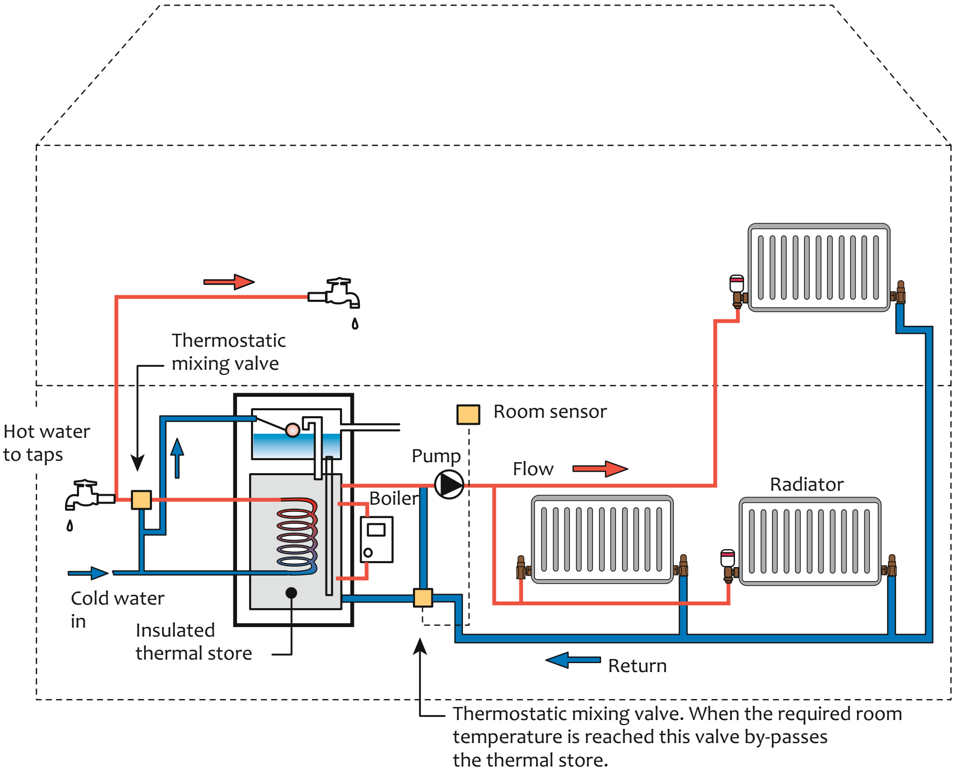
While having sufficient and convenient storage remains an issue for some, automated feeders (using a hopper and automatic auger-fed supply) have made the continuous and relatively controlled burning of biomass possible. However, because of their nature – where instantaneous turning on and off of such fuels is very difficult – a different approach to exploiting biomass has to be adopted. Biomass boilers are best suited to a more continuous heating cycle than gas or oil-based central heating installations. For example, unvented systems using biomass are currently impossible and even the typical vented system approach has to be significantly adapted.

In order to be efficient, some biomass boilers should be continuously combusting – i.e. mostly in tick-over mode. The thermal store exploits this trickle of heat, enabling it to be stored as hot water and efficiently used for space heating and hot water. Heat is drawn out of the thermal store via a series of heat exchangers (usually one for hot water and one for the space heating circuit – i.e. to radiators or to underfloor heating). Generally, the temperature of water from the store will be too high for space and water heating and mixing valves will introduce cooler water. As the heat is drawn off, the store's thermostat senses a drop in temperature and signals increased demand back to the boiler. This automatically moves from tick-over to firing mode and feeds more biomass into the boiler until the heat demand is satisfied. Clearly, a number of sophisticated controls and mechanical devices are required for such a system to be effective and efficient.

Some biomass boilers effectively exploit the improved controllability of wood pellet and wood chip, enabling a more intense and intermittent combustion, more akin to gas and oil-fired boilers. However, unlike the installations exploiting these fuels, a thermal store arrangement is common for biomass. A thermal store (sometimes called a buffer or accumulator tank) is a highly insulated hot water cylinder, significantly larger that a typical copper hot water cylinder. For example, a 10kW wood biomass boiler requires a thermal store of 800 litres – so space storage for both fuels and the thermal store is an issue. In addition, the boilers themselves are quite large compared to their gas or oil-fired equivalents.

Some installers recommend biomass boiler installations with photovoltaic cells for the necessary electrical power (hopper feed augurs, pumps, etc.) and a complementary solar water heating installation for the summer non-heating period. Currently, domestic systems are more suited to large single houses or groups of dwellings. They become particularly cost effective if the occupier has a ready source of biomass (e.g. a large, well-insulated rural dwelling with its own woodland biomass source) and/or where mains gas is unavailable.

The Principles of Thermal Store Installation



Electrical heating systems

Electric storage radiators

These are heaters which work by heating a thermal storage block contained within a radiator. As explained in Chapter 22 Electrical installations, storage radiators run off separate ring mains supplying 'cheap rate' off-peak electricity. The heating element warms up special bricks which release their heat during the day.

Storage radiators present a problem in respect of control. This was particularly true with older versions, where virtually the only control was on the amount of heat that was going into the storage radiator. This meant that energy was being put into the system based on anticipation of conditions the next day.


Fused connection box wired to off-peak supply.


A storage radiator from the 1970s showing the heating elements and some of the clay bricks.


Modern storage radiators can respond to changes in external temperature when charging, and respond to varying temperatures during the day. Some of them are fan assisted.

Modern storage radiators are better insulated to retain heat when necessary, and usually have a damper which can be opened to allow air to flow through the heater. A fan linked to a thermostat can further improve this arrangement. Sensors that adjust the electrical charge in relation to overnight changes in temperature can also control the input of heat. Although these controls reduce unwanted heat losses and afford greater control, they do, of course, increase capital costs. Even with improved controls, storage radiators are not as responsive as wet systems either to changing conditions (e.g. taking account of solar gain) or occupancy requirements.

Modern storage radiators are simple and cheap to install and they are much less bulky than their predecessors. In small well-insulated buildings they can be relatively cost effective and the constant background heat can be useful. Maintenance costs can be low compared to a wet central heating system, although the more efficient fan-assisted heaters will be more expensive. A separate arrangement for the production of hot water will be necessary, a factor which by itself may mean that the overall 'package' of heating and hot water may be more costly and less effective than a gas-fired central heating system.

Ducted warm air

In this approach air rather than water is the medium for distributing heat around the house.

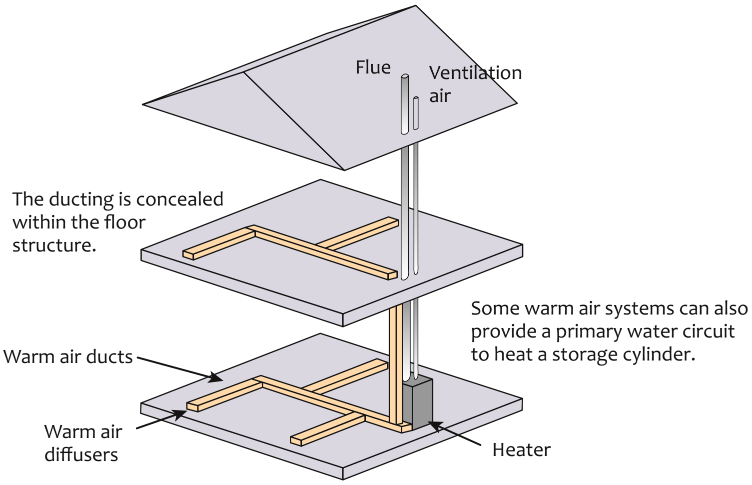
Air is drawn into the system where it is heated by electricity, gas, a heat pump or oil. The heated air is moved around the house through a series of ducts, before being emitted into the rooms by grilles in the wall or floor. This movement can be achieved by natural convection or by the use of fans. The ducting may be installed on the ground floor level only or on both floor levels. In the former system, heat travels upstairs by natural convection and by conduction through the floor.

Fresh air can be introduced into the heating cabinet and mixed with the return air, which is extracted from the rooms via return grilles. This combined air is then filtered and reheated for further circulation. The layout of the return air grilles requires careful consideration. Problems have arisen, for instance, with inlets near bathrooms and kitchens circulating condensate around a house. Another problem can be caused if the outlet and inlet grilles are placed too close together, and the air comes out of one grille and into the other without circulating around the room.

Control can be exercised by opening and closing the grilles as required, either manually or in relation to a room thermostat. The thermostat should also be wired to the heating element.

Warm air systems have been the source of complaints in the past because of the air movement causing draughts, and the fact that some people find the dry air produced uncomfortable. Also, in less sophisticated systems, as the same air is re-heated and distributed around the house there have been problems with the circulation of dust, moisture and smells.

More sophisticated systems are available which can be combined with mechanical ventilation systems and heat exchangers. These are sometimes used in a relatively airtight building that requires mechanical ventilation. A heat exchanger extracts heat from warm stale air and uses it to pre-heat incoming cold fresh air.



Heat pumps

These have been around for many decades but, given the rise in fuel costs and concerns about carbon emission, they have become more widely used and promoted as an alternative to both gas-fired central heating and electrical heating systems.

A heat pump space heating system requires three components:

- *an external heat-collection mechanism*
- *the heat pump itself: this device is reliant on the chemical properties of a refrigerant – a liquid which has a very low boiling point*
- *an internal means of heat distribution and emission.*

Heat pumps use low temperature heat, collected from the ground, the air or even bodies of water, which have been warmed by the sun. The heat pump itself is a sealed device which converts the low temperature heat to high temperatures and then enables this higher temperature to be distributed as a heat source within buildings for space heating, hot water or both.

External heat collection

There are two external heat-collection methods commonly used in the UK: ground sourcing and air sourcing – hence the terms *ground source heat pumps* (GSHP) and *air source heat pumps (ASHP)*.

Ground sourcing

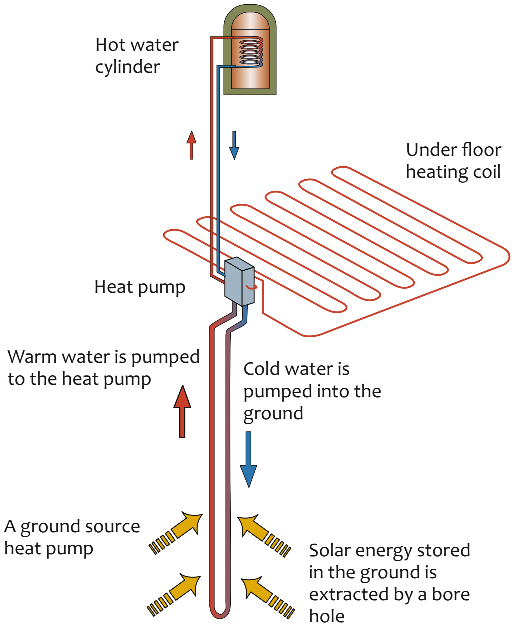
Throughout daylight hours solar radiation hits the Earth's surface. The effect of this is that at 1m or so beneath the ground surface, temperature becomes stable and consistent at 8–12°C throughout the annual and diurnal cycle. In order to exploit this low temperature heat, a pipe is located in direct contact with the ground. This can be in the form of a pipe laid horizontally at 1.5–2m depth or it can be placed vertically in a borehole. Three factors dictate which system is adopted:

- *the available space – a rule of thumb is that three times the internal area of a house is required for horizontal ground collection*
- *the nature of the sub-soil – clays and water-retaining soils are better than thinner, lighter and drier soils*
- *the relative cost – trenches are the cheaper method.*

Systems for collection can be *direct*, where the refrigerant which is used by the heat pump also runs through the ground collection pipes underground, picking up and transferring ground heat directly to the heat pump. The alternative – *indirect* systems, which are far more common – have ground collection pipes which contain a mixture of water and anti-freeze. This liquid is circulated around the ground collection pipes and transports the absorbed heat to the heat pump. The heat is transferred to the heat pump. The cold liquid is then re-circulated around the ground collection pipes.

In both systems the fluids used are sealed-in and are continuously re-circulated.

Once installed, ground collection pipes have virtually no visual impact.



Within the building the heat from a heat pump is often distributed via an under floor heating coil.

Very thick floor insulation is required if underfloor heating is to be efficient. This insulation is 75mm thick.

Air sourcing

This form of heat collection avoids the significant disruption and cost of excavation and provides an opportunity for heat collection if the available land is unsuitable or insufficient for ground sourcing. An air source collector is an air handling unit which draws heat out of the external air and transfers this to the heat pump either via air or, more commonly, via a liquid refrigerant. Although some collectors have been successfully located within the roof void (accessing external air via a vent), most units are located on an external wall. Some have been placed adjacent to the house, but sufficiently close to make pipe runs efficient. Some air source collecting units have the heat pump built into the unit itself rather than as a separate unit.

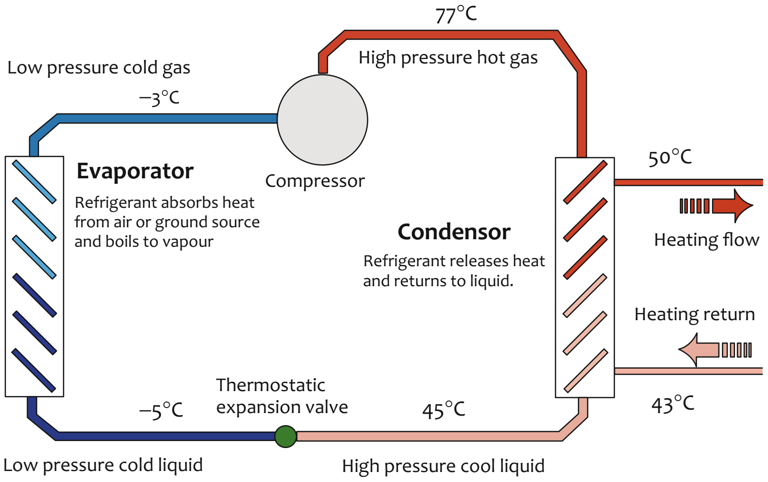
Air handling units located on a gable end.

The heat pump

The pump is the heart of these systems. Heat pumps make use of refrigeration technology. Fridges work by extracting heat out of items placed within them. This extracted heat is then deposited into the air outside the fridge. This technology has been exploited and reversed. A heat pump makes use of low grade heat energy drawn out of the external environment, converting this to higher temperatures to be transferred to the interior of a building. Clearly, the heat collected externally is often at a different temperature from that which is desirable to provide thermal comfort inside a building. The heat pump uses a liquid refrigerant – a liquid with a very low boiling point (i.e. it will evaporate and condense with little energy input) – to convert low temperatures to high temperatures. In order to exploit the refrigerant's properties, the heat pump requires four components, connected together in a sealed circuit:

- **The evaporator:** *this is the interface with the selected collection method (i.e. ground or air source). The heat drawn from the source will boil the refrigerant, evaporating it and turning it into a gas. The gas then moves to the compressor.*
- **The compressor:** *this is where the refrigerant vapour is compressed, which significantly boosts the temperature of the refrigerant (similar to the way that heat builds up when using a bicycle pump). The refrigerant then moves into the condenser.*
- **The condenser:** *as the refrigerant condenses from a vapour to a liquid, it cools dramatically, releasing significant heat. The condenser is the point in the pump where boosted heat is transferred, via a heat exchanger, to be used in space heating and/or in hot water production. Having condensed, the refrigerant is now very cold. However, it is still under high pressure.*
- **The expansion valve:** *this is the last component in the sealed heat pump circuit. This releases the pressure and temperature, and the cold liquid refrigerant moves back to the evaporator to start the cycle of heat exchange and temperature boosting again.*

The refrigerant is sealed within the heat pump circuit and should re-circulate continuously over the life of the heat pump itself. Typically, a heat pump used for domestic installations is about the size of a large fridge and will generally be located within the house.



The operation of the heat pump requires electricity. However, because the heat pump exploits free, low-grade heat, the heat pump has significant potential efficiency. Dependent on the variables of each specific installation, heat pumps can produce up to four times their direct energy input (i.e. 1kWh electrical energy use for 4kWh heat output). This ratio is often expressed as the coefficient of performance (CoP) and will vary over the year and between installations.

There is some evidence that an annual CoP of 4 is relatively rare and many heat pumps are operating at lower efficiencies.

Heat pump installations operate most efficiently if the output temperature is low (particularly in comparison to gas and biomass-fired central heating). For heat pumps, an ideal output temperature would be 40–50°C. Typically, heat output from central heating boilers is around 70°C. This lower temperature output favours a more continuous heating cycle, i.e. an all-day trickle of heat, rather than the intensive morning and evening heating bursts more favoured by both typical current lifestyles and more traditional heating systems. This also has an impact on the form and design of the internal heat emission systems.

Internal heat emission

The radiators described earlier for gas-fired central heating systems are not ideally suited to low-temperature heat pump installations. The most common and ideal form of heat emission for heat pumps is to use underfloor heating (see earlier in the chapter). These installations expand the effective heating area to the entire ground floor.

With low heat output, the larger the area available for convection of heat, the greater the efficiency of the emitter. In order to achieve this, an installation incorporating lots of pipes to maximise the flow rate of the circulating water is recommended for underfloor heating with heat pumps. In open plan buildings, particularly where they are tightly sealed and highly insulated, underfloor heating should provide effective and consistent heat without the need for zoning valves, which are used to control heat output in specific areas. However, zoning valves may well be necessary in houses with complex plan form and lower levels of insulation. These valves deliberately constrain flow rates to specific areas of the floor and, in order to maintain the efficiency of the system, a buffer tank, which provides a temporary reservoir enabling flow rates to be maintained throughout the rest of the floor, may be required.

It is possible to use radiators instead of underfloor heating; however, in order to ensure that sufficient heat is convected from the radiator, they will need to be significantly larger than those used with a boiler-based central heating system. There are a number of radiator designs specific to low heat output systems like heat pumps and, as previously mentioned, if heating is required in areas of a house which do not have concrete floors, then such radiators become a necessity.

Hot water production

Heat pumps can be used to provide both space heating and hot water. Problems can arise with satisfying both heating and hot water demand from heat pumps in extreme conditions. However, as far as hot water production is concerned there is a requirement for additional heat input: this is because the typical heat output of heat pumps is too low and falls short of the required 60°C for hot water storage. This requirement aims to reduce the incidence of legionella and provide sufficiently hot water, but not so hot that it scalds. Some additional form of water heating will be required (i.e. a boiler, immersion heater, solar water heater, etc.).

Some heat pump installations have an additional space heating source (for example, a gas or biomass-fired boiler or a wood-burning stove) to provide additional heating in exceptional weather conditions.

Controls

The controls for heat pumps vary from installation to installation. However, all heat pumps have their own integral programmer and temperature control. These provide a digital display and enable a variety of functions, such as timing, zoning, switching modes on and off, etc. They will all provide 'systems information' related to the efficiency of the pump, monitoring output temperatures and providing electrical input records.

Heat pumps will also often have a number of room thermostats controlling the entire space heating system. If radiators are fitted as part of the installation, then thermostatic radiator valves can also be used.

Some pumps have a 'weather compensator'. This device reduces or increases the heat pump activity automatically according to monitored external weather conditions. In theory, these devices can replace room thermostats and should satisfy the thermal comfort requirements of both the occupant and the system's efficiency. Some concerns have been expressed at how effective these devices have been in certain conditions when used with air source heat pumps – they have effectively over-compensated for very cold night-time temperatures, leading to excessive electrical input.

Installation efficiency and other issues

Heat pumps are not ideal for all houses. There is greater opportunity for newer, well-sealed and highly insulated houses to benefit most from this low temperature, continuous heating cycle system. There is increasing evidence that installations in such buildings, when combined with underfloor heating, supplementary solar water heating and renewably produced electricity (to power the heat pump), can potentially provide very efficient low-carbon and cost-effective space and hot water heating over a number of decades. They can be relatively maintenance-free during that period too. There are potentially more problems, issues and constraints where they are retro-fitted to existing buildings, particularly those which are poorly insulated and of solid wall construction.

Heat pumps are significantly different from other common forms of space heating currently encountered in the UK. Some of these differences can create problems related to expectations and in terms of the behaviour of occupants. Heat pumps provide relatively low-temperature heat compared with a biomass or gas-fired boiler. As such, they will provide a longer, more continuous level of heating than would be the case with the aforementioned heating systems. This can lead to some issues with the responsiveness of heat pumps to increased demand: in gas-fired central heating systems increased demand can be satisfied very quickly. This is not the case with heat pumps. This can be further exacerbated by the commonly adopted underfloor heating, where zoning can be difficult to achieve and can affect the efficiency of the system itself.

Ventilation 20

Introduction

The provision of adequate and appropriate levels of ventilation is primarily important for reasons of the health and comfort of the occupants of a house. However, because ventilation also allows warm air to leave the house, and colder air to enter it, attention needs to be paid to how that ventilation (i.e. changes in the volume of air) takes place, and the extent to which it can be controlled in order to reduce heat losses. The ability of the occupiers to control ventilation so that it provides a level of air change which is effective, yet allows the occupier to feel comfortable, is an important consideration.

In a house, fresh air is needed to:

- *provide oxygen for breathing*
- *remove odours, smoke, water vapour and other products of occupancy, including pollutants*
- *enable the efficient operation of heating appliances, etc.*
- *maintain humidity at levels which are comfortable and which minimise the risk of condensation occurring (see Chapter 16)*
- *remove pollutants produced by building materials (and perhaps the buildings contents)*
- *provide cooling – an issue which will probably become more important for housing as climate change continues to have an effect on average and peak summer temperatures in the UK.*

There are important physiological and psychological issues involved in providing for adequate ventilation. For example, in addition to the necessity to have oxygen to breathe, most people have a psychological need for fresh air and to be able to feel a movement of air in the house, yet excessive ventilation, and therefore air movement, can cause draughts. Draughts, which are essentially an undesired movement of air, will make people feel colder than the actual reduction in air temperature caused by the air movement. That is, a draught will cause heat to be lost from the body but will also cause a psychological reaction which will make that person perceive the temperature to be lower than it is.

The aim in a well designed and constructed house would be to ensure that there are sufficient air changes, (i.e. ventilation), with the minimum amount of air infiltration (i.e. unintentional ventilation). Such an approach results in less energy being wasted through direct heat loss and also, because when air speeds are reduced, a lower air temperature can achieve the same levels of thermal comfort.

Infiltration occurs via openings such as vents and flues, through gaps and cracks around openings such as windows and doors, and joints between materials (such as where floor joists are built into the inner skin of a cavity wall). Air leakage can also occur through the porous surfaces of walls, floors and ceilings.

The better a house is thermally insulated, the higher the percentage of energy losses through infiltration become. The Building Regulations and the Code for Sustainable Homes both emphasise the need to deal effectively with infiltration in order to produce a low-energy dwelling. For the higher levels of the Code (see Chapter 2) it is likely that the emphasis on airtightness and the minimisation of infiltration will be such that mechanical or other means of ventilation may be necessary to provide sufficient air changes (while windows are closed).

The Building Regulations and ventilation

The Building Regulations refer to the idea of extract ventilation and purge ventilation.

Extract ventilation is needed to remove moisture and/or odours from particular rooms in a house, usually by means of mechanical extract fans. Minimum recommended extract rates (in litres of air per second) are set by the Building Regulations for the kitchen, bathrooms, utility rooms and sanitary accommodation. The extract ventilation can be continuous or intermittent. Extract fans can be automatic or manually controlled and automatic systems can include fans operated by the light switch or a humidistat. Extract fans operated via the light switch may work well where the room has no natural light (say, a WC without windows) but if the light does not have to be switched on in order to use the room they will be less effective. Humidistats should not be used where the primary need is to remove odours (e.g. where there is a toilet in the room). A cooker hood which is ducted to the outside is a suitable device for a kitchen (provided that it can extract at the minimum rate laid down in the Regulations). Where an automatic device is incorporated it should be capable of being overridden by the occupiers.

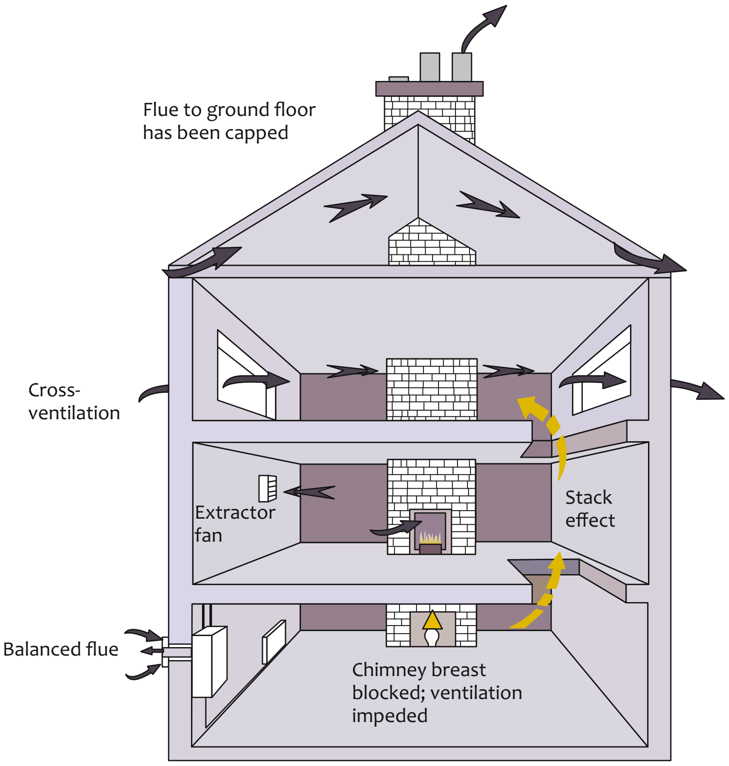
The mechanical ventilator should not be placed too near a source of incoming air (whether a window or door) because it will pull in external air rather than pull out moist internal air.

In addition to specific rates of extract ventilation for the rooms mentioned above, the Building Regulations also require minimum whole house ventilation rates in relation to the supply of air to all habitable rooms within the house, the amount of which is dependent on the number of bedrooms and the internal floor area of the dwelling. This air is typically supplied continuously at a low rate to remove and reduce levels of water vapour and indoor pollutants and to introduce fresh air into the dwelling. This is normally done by the provision of a calculated number of suitability-sized background ventilators (e.g. trickle vents in doors or windows, etc.) to the habitable rooms. Although they can be mechanically operated, trickle ventilators are usually of the 'hit and miss' type (these are hand operated and offer the occupants some control over ventilation by allowing varying degrees of opening and closing). One problem with trickle vents is that once people close them they tend to forget to open them again. This is probably because there is a prompt to close (i.e. a cold draught) but no obvious prompt as a reminder to reopen them. This is a similar situation to the problem with lighting – there is a prompt to turn lighting on (i.e. darkness) but a less compulsive prompt to turn it off.

Although there are other means, background ventilation is often provided by the incorporation of controllable 'trickle ventilators' within the structure of a window. The photograph shows a trickle ventilator in a newly installed window (hence the protective wrapping).

Purge ventilation allows ventilation to occur rapidly. The Building Regulations recommend that, in each habitable room, it should be possible to provide a minimum of four air changes per hour, directly to the outside (i.e. that it should be possible to completely change the volume of air in the room four times in an hour). In most cases this can be achieved by natural ventilation (i.e. by opening windows, skylights and /or external doors). Therefore this requirement, along with the need for adequate daylight provision, will have an effect on the overall size of window provision and, in the case of ventilation, the size and total areas of their openable portions, in relation to the floor area of the room they serve (note: adequate daylight provision is not a requirement under the Building Regulations – though clearly it is an important design issue).

The ability of extraction systems, background or trickle vents, windows and external doors to provide effective ventilation will vary depending on their position (whether on the windward or the leeward side of the house), the height of the dwelling, the number of openings (and the size and design of the openings) and, indeed, the overall design and layout of the dwelling. For natural ventilation to be effective, cross-ventilation is required. The stack effect will also have an influence as when windows are opened upstairs and downstairs, the staircase will act as the stack (see overleaf for an explanation of the stack effect).



Doors and partitions will also have an effect on the adequacy of ventilation so, for example, opening a window to a room on the leeward side of a house with a (closed) tightly fitting door on the windward side may provide very little ventilation. Window types will also have an effect, for example side-hung casements may block wind-driven ventilation paths or redirect them into the house depending on which way they open, or rather which way the wind is blowing. Sliding sashes offer the most control in their ability to vary their opening area by small increments.

The required air changes in a house can also be produced by mechanical means but such an approach should not lead to a situation where window sizes are reduced, as it needs to be borne in mind that there are important psychological aspects to having a good view out of a window in order to maintain contact with the outside. The requirement for adequate levels of daylight is also an important factor in the design of windows, and therefore it is important to consider daylighting and ventilation strategies at the same time.

For non-habitable rooms (such as kitchens and bathrooms), the Building Regulations recommend that where it is not possible to provide a sufficient area of external opening windows and doors, it may be possible to supplement these by other methods, such as mechanical extract ventilation. This does not mean that well-designed and easily openable windows are not important in these rooms for the reasons mentioned earlier.

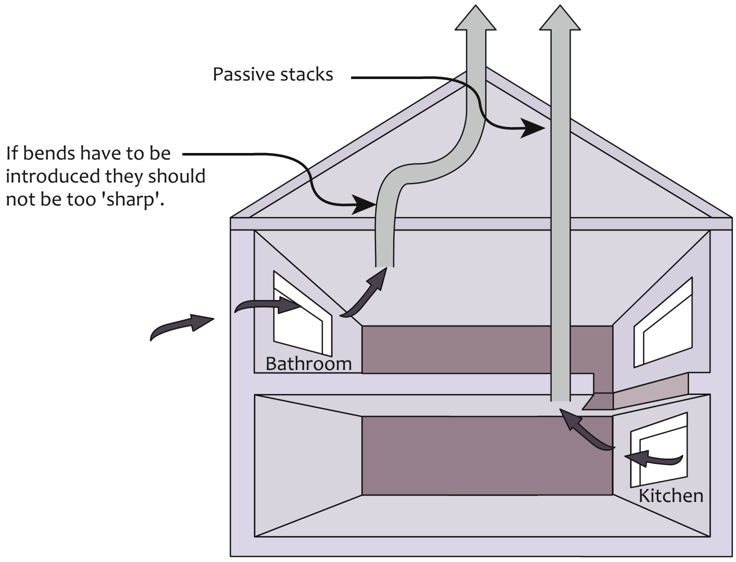
Alternative ventilation approaches

Alternative ventilation systems for new dwellings, which are provided with external windows and doors include:

- *passive stack ventilation*
- *continuous mechanical extract ventilation (MEV)*
- *continuous mechanical supply and extract with heat recovery (MVHR).*

Passive stack ventilation

Passive stack ventilators are vertical ducts (essentially chimneys) and they rely on a combination of the action of wind blowing over and around the dwelling and the 'stack effect' which occurs because of the difference in air temperature, and therefore air density, between the interior and the exterior of a house. Essentially, the stack effect is the result of the action of pressure differences with height: hot air rising will cause cold air to flow in from below to replace it (which is why a draught is felt with a coal or wood open fire). Wind action around a building is not only affected by the direction and strength of the wind but also by the size, shape and profile of the building. Because air flow through a passive stack will increase as air temperature increases, they will remove moist air from cooking and bathing areas when the conditions for moisture generation are created.



Passive stack ventilators are designed with a separate duct for each room or area (to avoid moist air flowing between rooms) and with an outlet above the roof line. They need a reasonably airtight building with adequate controlled air supply – probably through trickle vents. An advantage is that they do not rely on mechanical devices, such as fans, but they have to be carefully designed for the particular situation and may not work efficiently in some wind conditions or where the outlet is incorrectly sited. In some situations air movement could work in reverse with cold air being pushed into the house. Because of this the outlet should ideally be located at ridge level rather than emerging through the slope of the roof – where the duct will need to be extended above the roof line to avoid reverse movement. Because passive ventilators also rely on the action of the wind, account has to be taken of wind patterns and velocities generally and the effect on these of such things as, for example, wind direction, roof slope and configuration, shelter from surrounding buildings, trees, etc., and possibly the effect of tall buildings. Their efficiency also increases with height, which is another reason why a duct from say, the bathroom to the ridge, will work better than from the bathroom to the eaves. Efficiency is also related to the ability to provide a suitable vertical path through the house. However, it is not always easy to extend the ducting to the ridge without introducing too many bends (or bends that are too sharp).

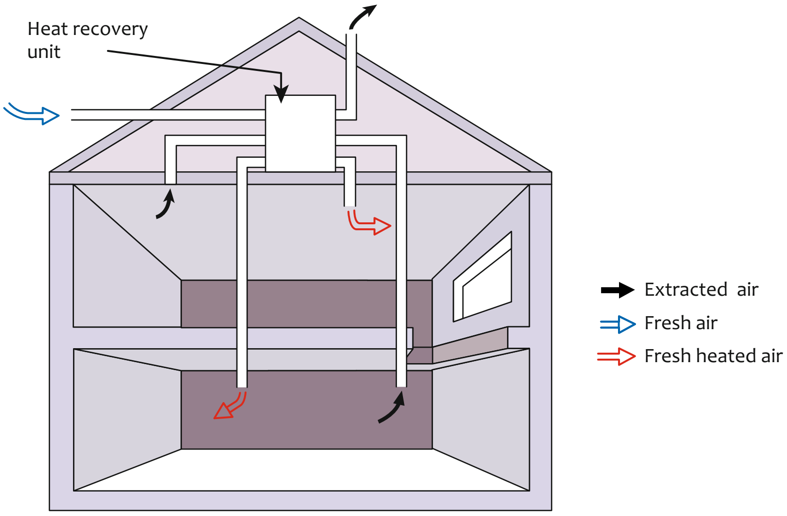
If passive stack ventilators remove air too quickly, and therefore increase air movement, they may cause draughts. Their effectiveness can also depend on room layouts and their position relative to windows etc. They should always be insulated, otherwise condensation may occur.

The term 'passive' is used to denote that no mechanical devices are necessary for their operation. However, there are vertical ventilators which have humidistats fitted, which close the vents when humidity levels fall below a certain level. The idea is to reduce unnecessary heat loss.

Mechanical extract ventilation and mechanical supply and extract with heat recovery

Mechanical extract ventilation (MEV) systems provide a relatively simple approach to the extraction of humid or odorous air (from kitchens, bathrooms, sanitary accommodation and perhaps utility rooms), utilising a system of ducts through which air is moved by fans. MEV relies on fresh air being delivered through background ventilation (by trickle vents, for example).

A development of this basic idea is known as mechanical supply and extract with heat recovery (MVHR). While MEV is purely an extraction system, an MVHR system is more sophisticated, being designed to provide both extract ventilation and fresh air input to all the rooms and spaces within the house (i.e. it is a 'whole house' system). In addition, an MVHR will have a heat recovery device which can remove heat from the warm air which is being extracted and use this to warm the incoming cold fresh air which is pulled in from outside the house. This warmed fresh air is then supplied to the rooms of the house. Because the air coming into the house is warmed, less energy is used in bringing it up to the required temperature; additionally, draughts are avoided.



In an MVHR system there are separate ducts for the stale, humid, odorous, yet warm outgoing air, and the fresh, yet cold incoming air. The heat recovery device, sometimes known as a heat exchanger, is a relatively simple design, usually formed by metal plates. Heat is usually exchanged by the process of the warm extracted air heating the thin metal sheets of the heat exchanger as it passes over them, with this heat then being transferred to the colder incoming air. The heat exchanger is designed so that the incoming and outgoing airflows do not mix at any point. The heat exchanger is often located in the roof space but units that fit easily within living spaces are available.

Control systems for MVHR systems usually include a boost device for rapid extraction.

One drawback of MVHR is that, in addition to the capital costs, it uses two electric fans, one for extraction and one for supply, in its operation (which is designed to be continuous). In comparison, MEV only has one fan. However, MVHR does recover quite a high percentage of the heat which would otherwise be wasted.

An MVHR system does not require any background ventilation; indeed, it relies for its efficiency on the house being very airtight.

MVHR systems are relatively commonplace in many northern European and Scandinavian countries where people have been used to building (and living in) relatively airtight buildings for some considerable time. It is likely that, as noted previously, the requirements in the Code for Sustainable Homes for increasingly airtight buildings will mean that MVHR will become more commonplace in the UK. Indeed, the Passivhaus standard, which is often used as a reference point for low-energy houses, requires such an approach.

Other ventilation Regulation requirements

A fairly recent addition to the Regulations that deal with ventilation systems is the requirement to commission systems where possible (not a requirement for, say, an on/off extract fan) and measure the airflow rates of mechanical ventilation appliances or systems and provide this information in the form of an approved notice to the building control body for the project within a specified time period.

In addition, sufficient information should be provided to the owner of the building, so that the ventilation system can be used correctly and the system maintained to enable it to perform in an efficient manner throughout its life.

Parts of the Building Regulations – other than those previously mentioned – which will affect the design and installation of ventilation systems include:

- *the requirement that sufficient combustion air is provided to heat-producing appliances, such as wood burners, open fires, gas or oil appliances, etc., to ensure that the products of combustion arising from the use of these appliances do not harm the health of the dwelling occupiers (for example, by being drawn out of the appliance by an extraction system or by reducing the levels of oxygen in a room). A separate part of the Regulations that deals with combustion appliances and fuel storage systems sets out these ventilation and other safety requirements*
- *although the opening of external windows, etc. can be used to control thermal comfort for occupiers, thermal comfort is not a requirement of the Regulations, but the prevention of overheating that would necessitate mechanical cooling is controlled by the part of the Regulations that deals with the conservation of fuel and power. Likewise, high levels of airtightness provided to reduce heat loss, may require additional levels of background ventilation depending on the design of the system and building.*

Drainage 21

Introduction

The disposal of foul water and rainwater depends on the proper design of the drainage system and the correct use of appropriate materials. Foul water consists of soil (from toilets), and waste water (from baths, basins and sinks). The drainage system should be able to carry and discharge its contents quickly and efficiently in such a way as to avoid damage to health. The system must avoid leakage, resist the entry of deleterious substances and avoid blockages. This chapter is divided into three sections:

- *above ground drainage*
- *below ground drainage*
- *rainwater disposal.*

Sanitary systems flushed by water were used by the ancient Greeks and the Romans. In this country a water closet was designed in Elizabethan times (sixteenth century) and there were great advances in plumbing and drainage during the Victorian era. Despite this, during the nineteenth century many properties still had cesspits, situated directly under the house, which were emptied at intervals by 'night-soil men'. An alternative to this might be a 'privy' located outside, perhaps in a courtyard, and shared by a terrace of houses.

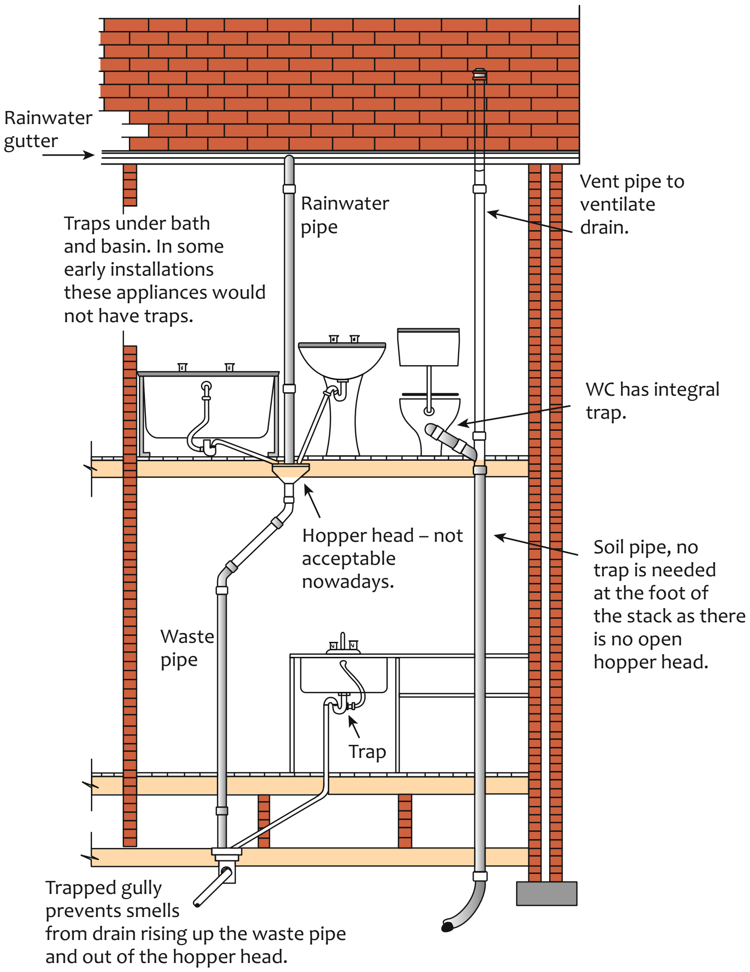
Following frequent outbreaks of typhus and cholera, the relationship between adequate sanitation and the spread of disease was gradually acknowledged. This eventually led to legislation such as the 1875 Public Health Act, which was to have a significant effect on sanitary arrangements in buildings. This was followed by other Public Health Acts, leading up to the present Building Regulations (first produced in 1965).

By the early part of the twentieth century most houses, in towns if not in rural areas, were connected to some form of mains drainage. However, in many cases the effluent discharged straight into rivers or the sea, without treatment. It was not until the end of the twentieth century that sewage treatment became universal.

Section One: above ground drainage

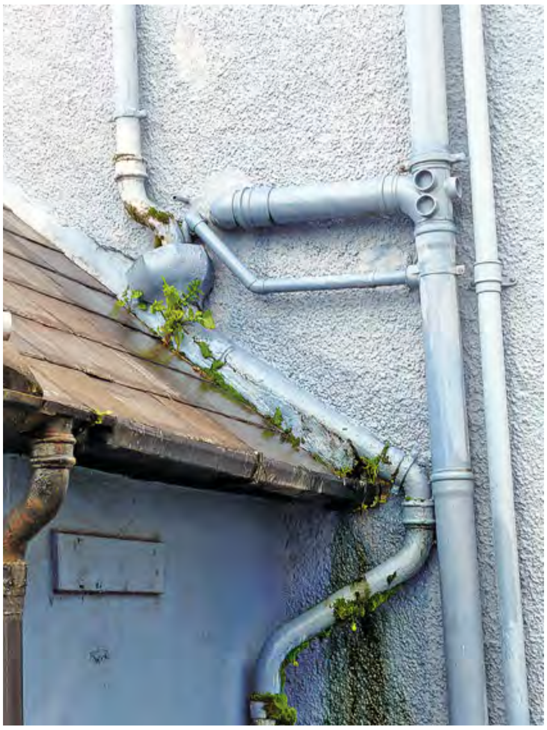
Two-pipe system

Many small terraced houses built at the turn of the twentieth century would have had fairly rudimentary sanitary facilities, and it was not until the end of the First World War that it became common to find new houses with proper bathrooms. The precursor of the drainage we see on new houses today is known as the two-pipe system. The part of this system that was located above ground consisted of a vertical pipe which carried soil from the toilet and a second vertical pipe that carried waste water from the bath, basin and sinks. On many properties the waste pipe also carried rainwater from the roof, usually via a downpipe which discharged into a hopper head.



The diagram above shows key elements in a two-pipe system. The diagram shows the discharge pipes from a bath and basin flowing into a hopper head alongside the discharge from the rainwater downpipe. It is not uncommon for hopper heads to become blocked by material flushed down the sink and, because the hopper head is essentially an open receptacle, by leaves and debris. Such blockages lead to overflowing and possible damp penetration.

Hopper heads were common on two-pipe systems.



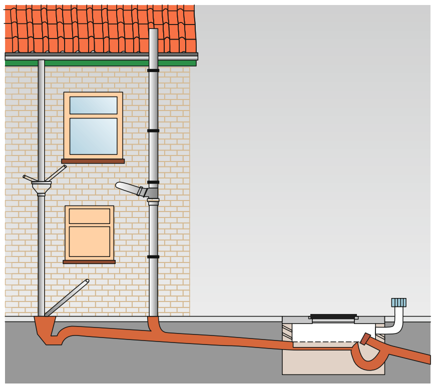
Blockages in this hopper have caused it to overflow.

The photograph shows a house dating from the 1930s served by a two-pipe system. One of the pipes carries the soil from the toilet and the other carries the waste from the bath and basin. On many properties the waste pipe also carried rainwater from the roof (as shown here).

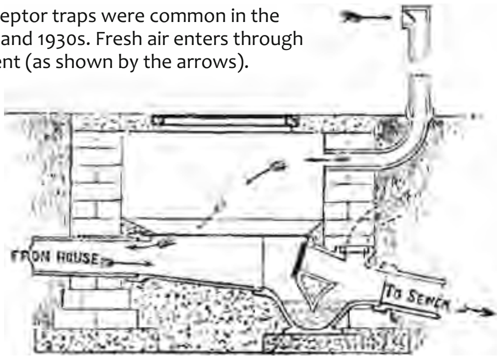
This photograph shows examples of the two-pipe system serving a larger property that has been converted into flats. Over a period of years the system has been adapted and extended, resulting in an unsightly tangle of poorly designed and poorly supported pipes, with associated maintenance problems.

At the bottom of the waste pipe was a trapped gully into which ran the waste water from the kitchen sink. The primary purpose of the trap in the gully was to ensure that no smells or gas from the underground drainage system escaped back up the pipe to emerge at the hopper head. Traps operate by use of a water seal (these are discussed in more detail later). Unlike the waste pipe, the soil pipe was not trapped at its base. Instead, it was ventilated at the top in order to allow sewer gases to escape. The top of the soil pipe was located above the eaves to ensure that sewer gases did not enter the house via openings, such as windows, or by infiltrating the roof space.

As the diagram below shows, the soil and the wastes combined underground to run in a single pipe. This combination of soil and waste is usually referred to as foul drainage. In many ways this system worked well. It was relatively straightforward and the combination of rainwater and waste water meant that the system was well flushed. Ideally, the two pipes would have converged underground at an access point known as a manhole (although this was not always the case). Usually the last manhole before the mains sewerage system in the street was of a type known as an interceptor. This manhole contained a trap which was intended to intercept rats and smells in order to prevent them entering the house. Unfortunately, interceptor manholes tended to suffer from frequent blockages and, because of this, their use was discontinued.



Interceptor traps were common in the 1920s and 1930s. Fresh air enters through the vent (as shown by the arrows).



From *The Plumber and Sanitary Houses*.

Vent to an interceptor trap in adjacent manhole.

Traps

The Victorians were aware of the problems associated with 'foul gases' entering the house through leakage or through air moving backwards through the system. The two examples on the next page are from a book written in 1897 called *The Plumber and Sanitary Houses* by S. Stephens Hellyer (Batsford). They show how gas from a badly designed or sited stack pipe can enter a dwelling.

Traps were developed to prevent this problem of foul air entering the house. Traps are essentially water barriers placed below the outlet of sanitary fittings and, on early systems, at the foot of the discharge pipes.

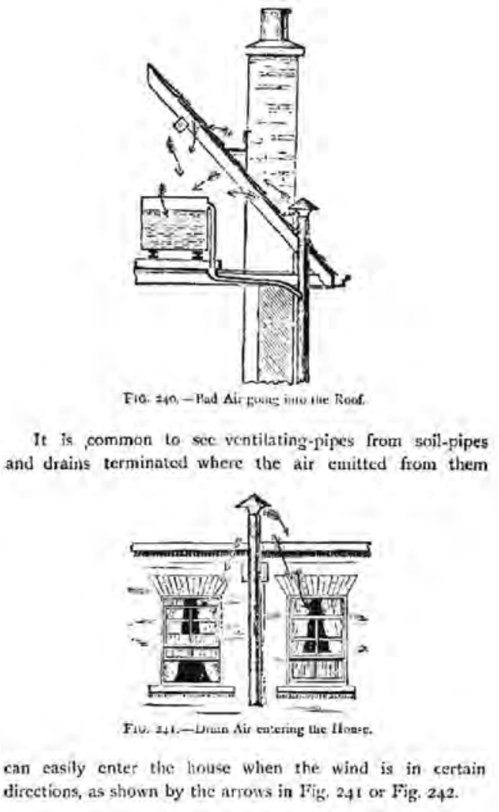
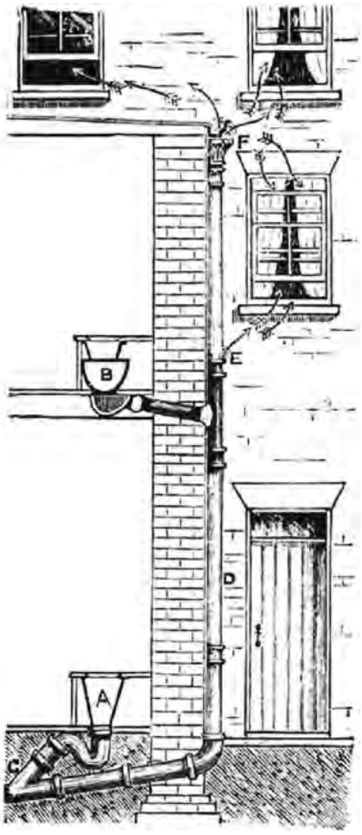


FIG. 240.—Bad Air going into the Roof.

It is common to see ventilating-pipes from soil-pipes and drains terminated where the air emitted from them

FIG. 241.—Drain Air entering the House.

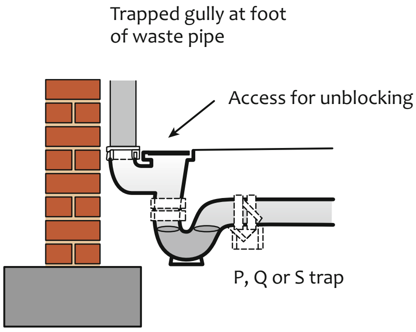
can easily enter the house when the wind is in certain directions, as shown by the arrows in Fig. 241 or Fig. 242.

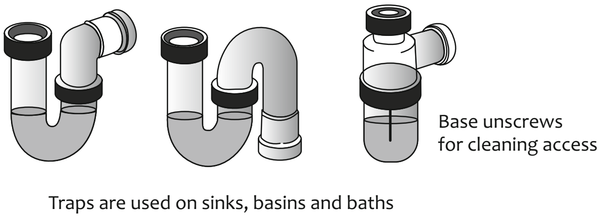


A trap works by retaining water to prevent the passage of odours. Typical traps to sanitary fittings and discharge stacks are shown in the diagrams below.

A WC does not require a separate trap because there is an integral water seal within the design of the pan itself.

Trap design has not changed much over the past hundred years or so. Before this, in the late nineteenth century, drainage was an emerging technology and various trap designs were available.



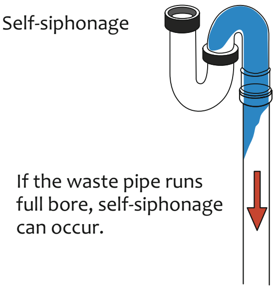


Traps are used on sinks, basins and baths

Siphonage

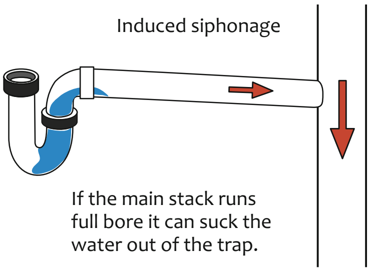
The Victorians realised that the traps could be 'broken'. This happened because the water forming the trap was siphoned out by the action of the water flowing in the pipe. The ways in which siphonage can occur are illustrated in the diagram below.

Self-siphonage

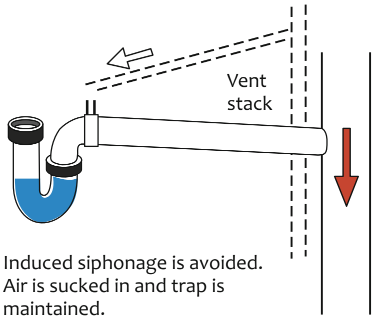


If the waste pipe runs full bore, self-siphonage can occur.

Induced siphonage



If the main stack runs full bore it can suck the water out of the trap.



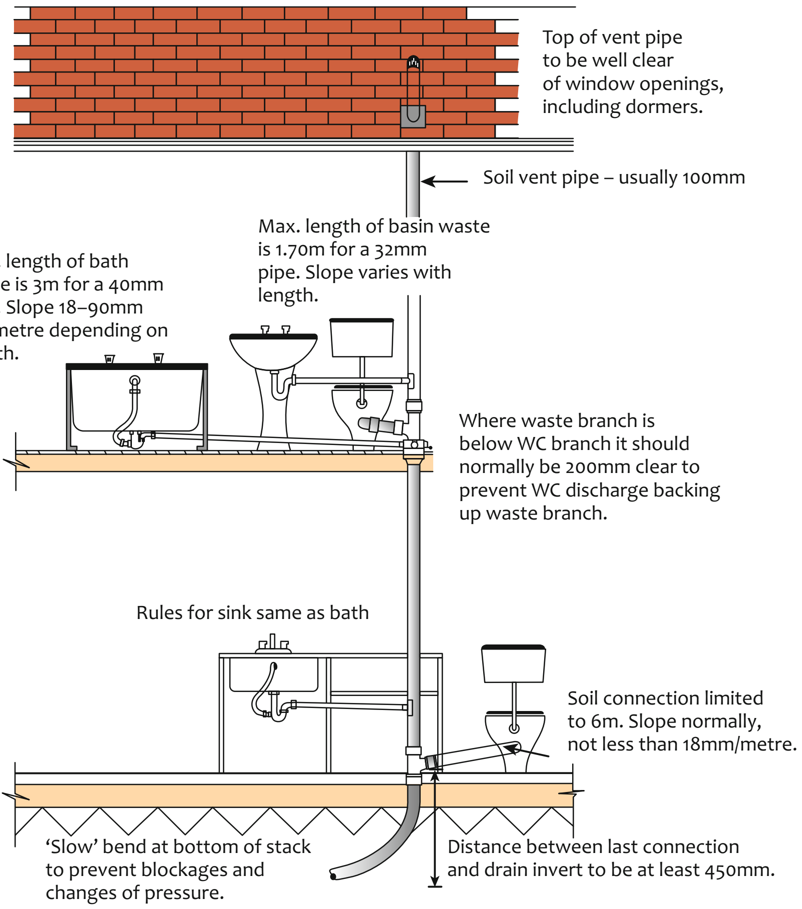
Induced siphonage is avoided. Air is sucked in and trap is maintained.

A solution to this problem was to use ventilation or anti-siphon pipes. This was a system of pipes connected to the traps on the sanitary appliances. They worked by equalising the air pressure on both sides of the trap, thus maintaining the seal. Although this approach overcame the problem of siphonage, the 'spaghetti-like' tangles of pipes which resulted was both unattractive and uneconomical (as shown in the photograph above).

Single stack system

In the 1950s, the Building Research Establishment designed a single stack, above ground drainage system. This carried both soil and waste water in one vertical discharge stack. The design relied on keeping the length ('runs') of branch pipes short, with minimum falls, to avoid the danger of waste pipes running full bore and causing siphonage.

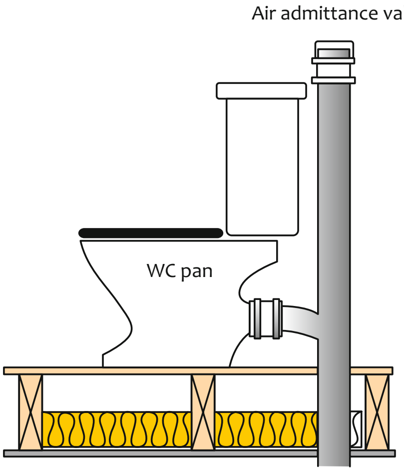
The single stack system is the usual design for the disposal of foul water in modern houses. If the design parameters (see diagram on the next page) are exceeded, ventilating pipes or additional stacks will have to be introduced to ensure that siphonage does not occur. Alternatively, special self-sealing traps can be used, but these can be noisy and relatively expensive.



This diagram shows some of the design parameters for single stack systems.

The soil stack is open to the air at the top to allow ventilation of the underground drainage system and to protect the traps. An alternative is for the soil stack to terminate within the house. This can be done if an air-admittance valve is fitted to the top of the stack. Although not in common use, they avoid the need to penetrate the roof covering. The Building Regulations impose limits on where these 'stub stacks' can be used.

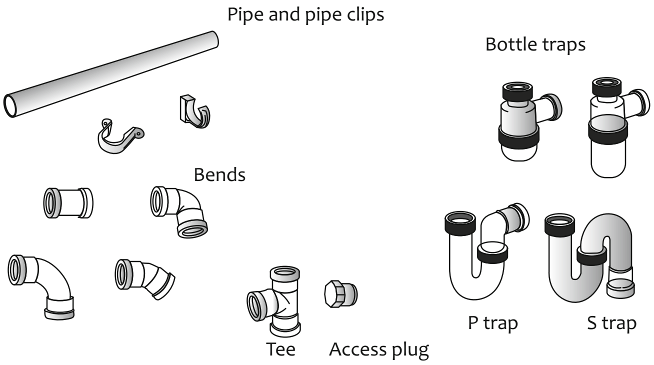
Air-admittance valves protect the traps by allowing air into the soil stack but, at the same time, preventing foul air from escaping into the house. Because an air-admittance valve will not provide adequate ventilation to the drainage system, a stack which is open to the air must be used at the head (start) of the drain run.

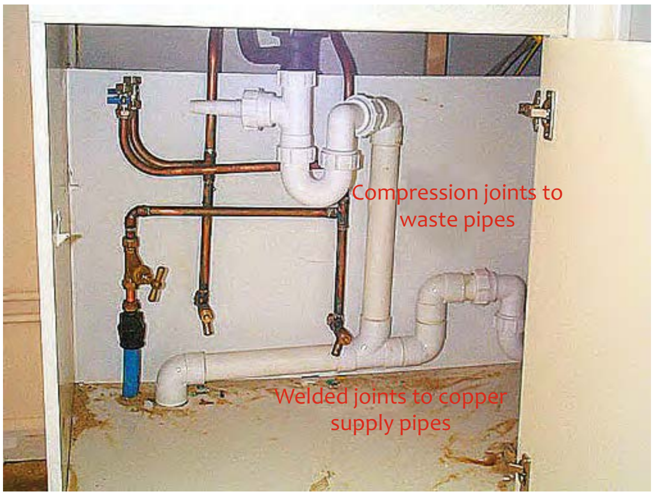


Materials

Materials used for the vertical discharge pipes have included lead, cast iron, asbestos cement and pitch fibre. Lead, galvanised steel and copper have been used for the smaller branch pipes. However, in new houses the most common material is plastic. Plastic has the advantage of being relatively light and easy to handle, and is generally the most economical material.

Plastic waste pipes are jointed by means of a solvent cement or by the use of ring seals made of synthetic rubber. Ring seals are the usual method of jointing for the larger diameter soil stack in order to allow for thermal movement. There are a number of manufacturers, all with their own comprehensive ranges of internal fittings.





The diagram above shows some examples of the pipework associated with waste water disposal and the photograph shows how some of these components are used under a kitchen sink.

Waste and WCs at ground floor level

There is a restriction on the minimum distance between the point at which the lowest fitting enters the soil stack and the bottom (or invert) of the underground drain. This is to avoid the danger of back pressure (and therefore siphonage) produced by the pipe's contents hitting the bottom of the vertical pipe. The restriction also avoids the possibility of soapsuds flowing back into the lowest fittings.

If it is not possible for the lowest sanitary fitting to comply with this requirement it can discharge directly into the underground system. Similarly, this approach may be more practical if the ground floor sink is a long way from the stack.

At ground level it is often easier to connect the WC directly to the underground drainage system.

Section Two: underground drainage

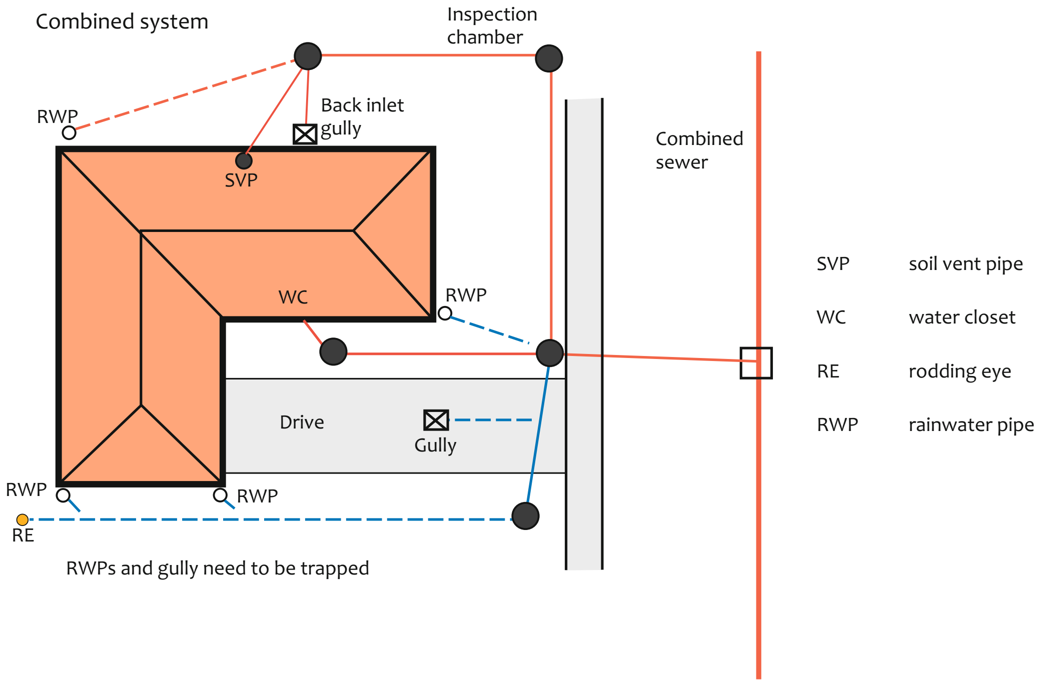
Underground drains carry foul and surface water to the sewer, which is usually located under the road. They should be:

- *laid in straight lines*
- *laid to even gradients, with as few changes in gradient as possible*
- *constructed of materials which will allow a free flow of the contents of the drain*
- *constructed of materials which will not leak*
- *constructed to allow a free passage of air, with ventilation being provided at the head (start) of the drain run*
- *constructed of durable materials which will resist attack by chemicals and other aggressive agents*
- *constructed of materials, and have joints, which will resist forces imposed by movement and loading*
- *provided with access points to allow for the clearance of blockages.*

Underground drainage can be divided into two basic systems: combined and separate.

Combined system

In a combined system the foul water and the rainwater flow in the same underground pipe system before discharging into a combined sewer.

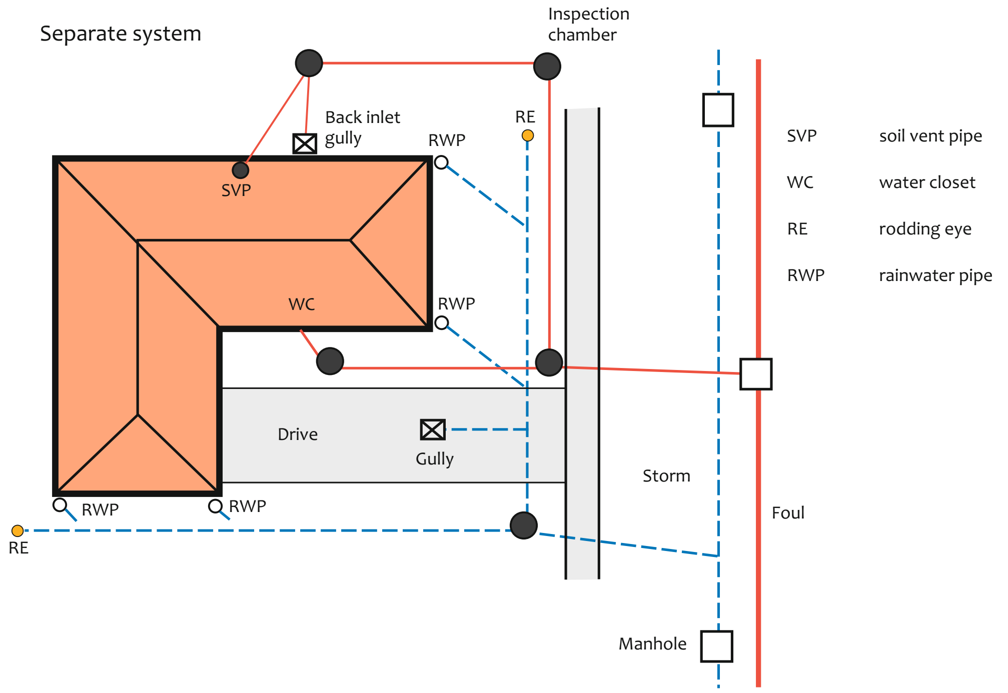


Separate system

In this system the soil and the rainwater flow in separate drainpipes which are connected to separate sewer systems. The rainwater discharges via a stormwater drain into a watercourse or infiltration systems where possible, such as soakaways, while the soil discharges into a sewer that will lead to a treatment plant. The choice of system depends on whether there are separate sewers for foul and rainwater, and this will vary from area to area.

The flow of rainwater in a combined system has a cleansing action and also helps to reduce the incidence of blockages. Combined systems have a further advantage in that the amount of pipework required is less than in a separate system. However, combined systems dramatically increase the workload of the sewerage treatment plants, which are intended to treat foul water only.

In many areas the water authorities are moving to a separate mains sewerage system. Therefore, new developments are required to have a separate system within the curtilage of the development, even though they may flow into a combined sewer.



Partially separate system

This approach is quite common in older houses and might consist of rainwater at the front of the house flowing into the stormwater water sewer in the main road, while at the rear of the house the rainwater flows into a combined sewer.

Rural areas

In some rural areas there may be no accessible mains drainage. If this is the case then the foul water will flow into either a cesspool or a septic tank (or possibly a proprietary treatment plant).

Cesspools

These are simply impervious holding tanks, with no outlets for the effluent, which retain the material until it is collected by the local authority, or a private contractor, for treatment and disposal elsewhere.

Septic tanks

Rather than simply holding the material for collection, a septic tank treats the sewerage that it collects. The manner in which it carries out treatment is similar to a sewage treatment plant. This involves the natural breakdown of the contents of the tank by settlement, bacteria and filtration. Normally, the outlet from a septic tank is discharged into a system of land drainage (a drainage field) which is typically a network of slotted pipework laid to a slight fall on single-sized clean aggregate, that allows the treated effluent to drain into the sub-soil where it undergoes further natural treatment. However, the size and success of the system is dependent on factors such as the size of the tank, flow rates into the tank and the permeability of the soil. It may not be possible to use such a system if the soil is a non-permeable clay. Other alternatives that may be considered suitable depending on the consent of regulatory bodies may be bespoke reed beds, wetlands or drainage mounds.

Proprietary treatment plant

This type of system will vary depending on the manufacturer's design; essentially it does the same job as a septic tank but with mechanical methods of treatment. As such systems can be very effective it is sometimes the case that effluent can be permitted to be discharged to a running watercourse with the consent of the regulatory bodies, or it can be discharged into the ground via a suitability-sized effluent drainage field, as would be the case with a septic tank.

Materials

Clay

Early drainage pipes were made of clay. They were of varying quality until the introduction of salt glazing, which greatly improved their reliability. (Salt glazing is a coating which makes the pipe impermeable.) Salt-glazed pipes and fittings are still in use, although manufacturers can use other techniques to produce impermeable drainage materials. Vitrified pipes are clay pipes that have undergone 'vitrification', a process that occurs at very high temperatures which fuses the clay particles to form a dense, durable and inert material. Clay pipes are manufactured in a wide range of lengths and diameters. They are durable and resist attack from most chemicals.

Plastic

Plastic drainage pipes are a popular alternative to clay because of the ease with which they can be handled. Plastic pipes also have the advantage of being relatively flexible and, therefore, able to withstand some pressure, such as that imposed by ground movement, without fracturing. Excessive pressure may cause deformation (and ultimately cracking), leading to a blockage in the drain run.

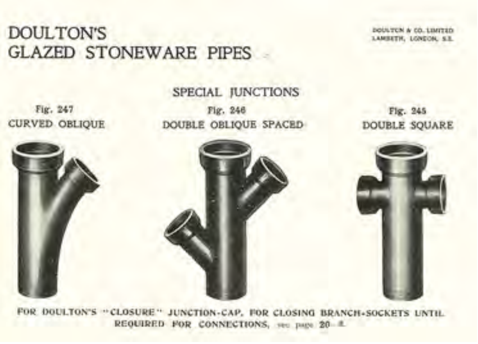
Other materials which have been used for underground drainage in the past include: pitch fibre, cast iron, concrete and asbestos cement. These materials are rarely used nowadays, with the exception of cast iron, which is sometimes specified for pipes running under buildings or when bridging soft ground.

Gradient

The gradient at which a drainpipe is laid must be sufficient to ensure that the contents flow along the pipe, while being shallow enough to ensure that, in a foul pipe, the liquid does not flow too fast and leave the solids behind. The gradient will also be related to the diameter of the pipe. A typical underground pipe serving a house has a diameter of 100mm and should be laid at a gradient of between 1:40 and 1:80. These figures will also be influenced by the amount of waste flowing along the pipe. The greater the flow, the shallower the drain can be.

Jointing of pipes

Although clay pipes are strong, they are also rigid. This makes them prone to fracture if there should be excessive movement in the ground or if excessive loads are placed on them. This can be caused by vehicles or the load imposed from the backfilling of the trench in which they were laid. This rigidity was compounded in earlier clay pipes by the manner in which their joints were made. Until 35 or so years ago the joints were formed in cement mortar, which produced a rigid connection.



DOULTON'S
GLAZED STONEWARE PIPES

DOULTON & CO. LIMITED
LAMBETH, LONDON, S.E.

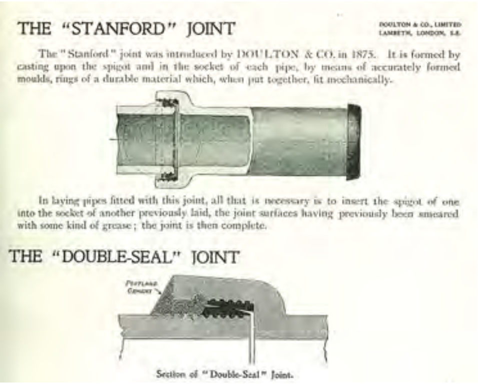
SPECIAL JUNCTIONS

Fig. 247
CURVED OBLIQUE

Fig. 246
DOUBLE OBLIQUE SPACED

Fig. 245
DOUBLE SQUARE

FOR DOULTON'S "CLOSURE" JUNCTION-CAP, FOR CLOSING BRANCH-SOCKETS UNTIL REQUIRED FOR CONNECTIONS, see page 20



THE "STANFORD" JOINT

DOULTON & CO., LIMITED
LAMBETH, LONDON, S.E.

The "Stanford" joint was introduced by DOULTON & CO. in 1875. It is formed by casting upon the spigot and in the socket of each pipe, by means of accurately formed moulds, rings of a durable material which, when put together, fit mechanically.

In laying pipes fitted with this joint, all that is necessary is to insert the spigot of one into the socket of another previously laid, the joint surfaces having previously been smeared with some kind of grease; the joint is then complete.

THE "DOUBLE-SEAL" JOINT

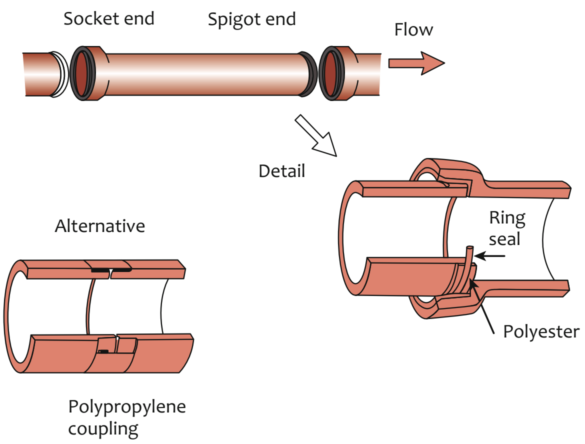
Section of "Double-Seal" Joint.

Images courtesy of Hepworth Clay, Wavin Ltd.

In the middle of the nineteenth century technological development saw the construction of machines which could extrude clay pipes. Their popularity grew quickly and by the end of the century all new underground drainage installations used clay pipes. Until the 1950s or so all pipes had rigid joints (see examples – top left). They were usually formed by wrapping a tarred rope (gaskin) around the socket before it was inserted into the spigot. The joint was then finished with a strong cement mortar. Nowadays all pipes have flexible joints – the pipes are quick to lay and can accommodate quite substantial ground movement without cracking.

Images courtesy of Hepworth Clay, Wavin Ltd

Modern clay pipes are sometimes referred to as vitrified pipes. Vitrification (vitrum is the Latin for glass) occurs at very high temperatures and produces a dense impermeable pipe. It is similar to the process used for producing vitreous ceramics. Earlier pipes were often salt glazed to produce similar qualities of impermeability – common salt was added during the firing process.



Courtesy of Hepworth Clay, Wavin Ltd.

'Densleeve' flexible coupling

Modern clay and plastic pipes have flexible joints which allow for earth movement and, at the same time, accommodate any thermal or moisture movement in the pipe itself. There are a variety of flexible joints available, some examples of which are shown in the diagram above and the photograph below.

With the connector shown above, the outer clamps provide a leak-proof seal, whatever the surface is, and the centre band provides shear resistance in applications where pipes are subject to earth loads. Courtesy of Hepworth Clay, Wavin Ltd.

Pipework being laid with a flexible joint (at an inspection chamber – see later). Courtesy of Hepworth Clay, Wavin Ltd.

Trenches and bedding

Underground drainage pipes are placed in a trench, the depth of which is determined by a variety of factors, including:

- *the point at which the drain enters the main sewer*
- *the layout of the drains*
- *site conditions, such as the slope of the ground*
- *the need for the pipes to be protected from traffic or other accidental damage.*

The Building Regulations provide guidance on the requirement for, and methods of, protection, which will differ depending on the location and depth of the pipes.

Bedding to drainage pipes.

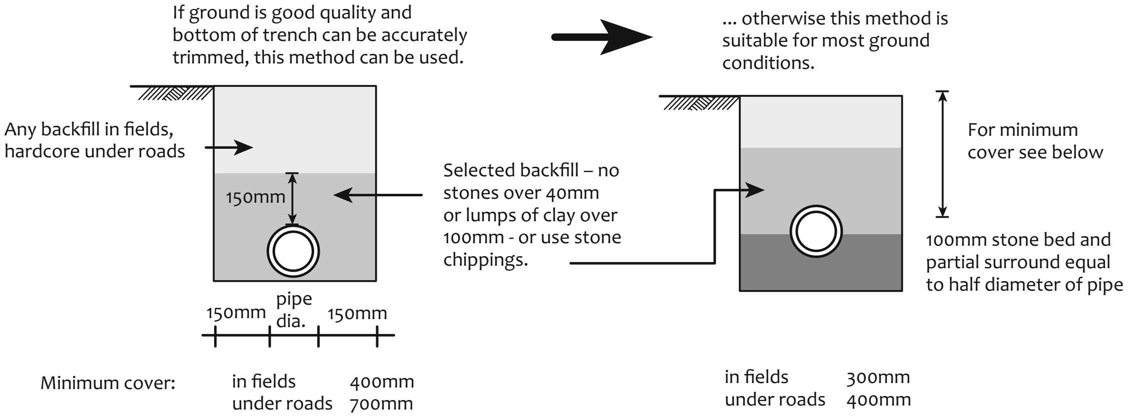
Although in some sub-soils it is possible to trim the ground and lay the pipe directly on the bottom of the trench, it is generally easier to use a bedding material, such as pea gravel or limestone chippings.

The function of this bed is to provide an even gradient to overcome any inaccuracies in the trench. It also provides an adequate and uniform support to the pipes while allowing movement to occur. The amount of bedding and the material which is consequently used to backfill the trench will vary according to the depth of the pipe, its size, its strength and whether the pipe is rigid or flexible.

This image shows a drainage pipe laid on a bed of limestone chippings and the backfill. Courtesy of Hepworth Clay, Wavin Ltd.

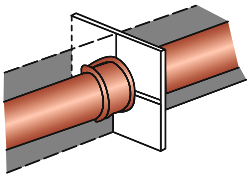
The backfilling to the trench should be selected from the excavated material to avoid stones. It should be carefully placed in order to avoid damage to the pipes.

Examples of possible bedding arrangements which meet the minimum requirements of the Building Regulations are shown below and on the next page. The examples below apply to rigid clay pipes.



Where available cover is less than set out above the pipe should be surrounded in concrete.

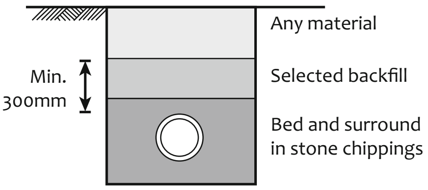
Flexible material at joints allows slight movement.



Thickness at least 100mm or diameter of pipe, whichever is the greater.

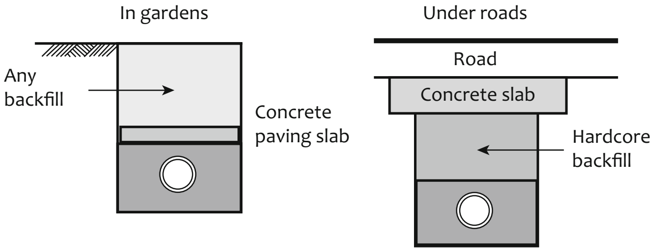
Flexible pipes

As these may deform under load they require more support than rigid pipes.



Minimum cover is 600mm in gardens or fields, 900mm under roads.

If cover cannot be maintained:

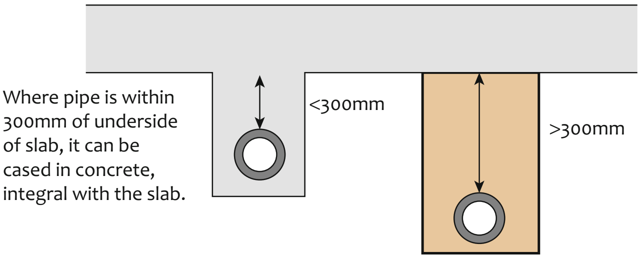


Or surround drain in concrete as shown previously.

Additional protection

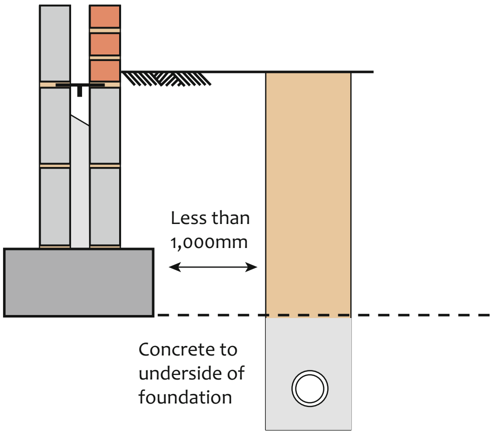
Although granular beds are the normal bedding material, the pipes may need additional protection in certain circumstances. This protection usually takes the form of a concrete surround. The circumstances where this may be required include situations where:

- *there is an anticipation of settlement*
- *pipes run under a building*
- *a pipe runs parallel to and below a foundation*
- *the pipes are laid at a shallow level and there is the danger of crushing from traffic (i.e. under a road).*

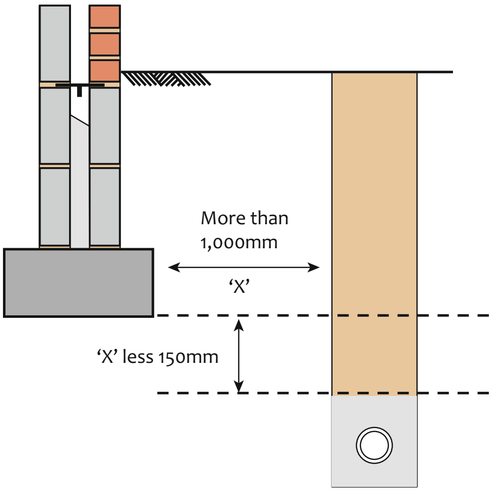


Where pipe is within 300mm of underside of slab, it can be cased in concrete, integral with the slab.

If this distance is 300mm or more, bed and surround in chippings – minimum surround 100mm. Rest of trench filled with hardcore.



Concrete to underside of foundation

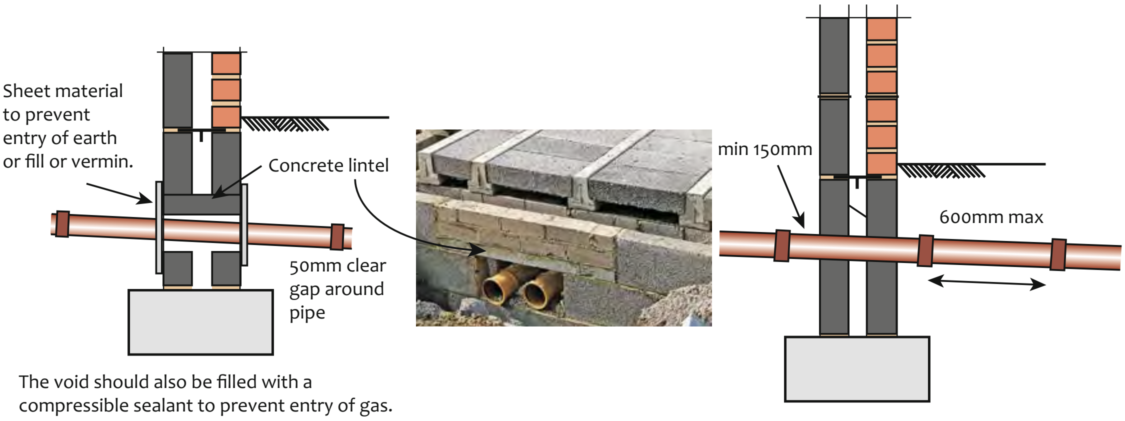


Pipes running through a wall

Where a drainpipe runs through the exterior wall of a house to connect to the underground system (as will occur in most modern houses) precautions must be taken to ensure that movement in the building structure does not fracture the pipe. This is usually done by forming a lintel over the opening.

An alternative to this is to increase the flexibility of the drain run by using short lengths of pipe under the wall. The increased number of joints gives the pipe run extra flexibility and minor building settlement should not fracture the pipe. Particular attention should be paid to the gradient at this point to ensure that settlement does not produce a backfall.

Drainpipes running through wall in gap formed with concrete lintel.



The void should also be filled with a compressible sealant to prevent entry of gas.

Access points

Access to the underground drainage system is necessary to facilitate the clearing of any blockages and to allow for inspection of the system. In a well-designed system there will be access at the following points:

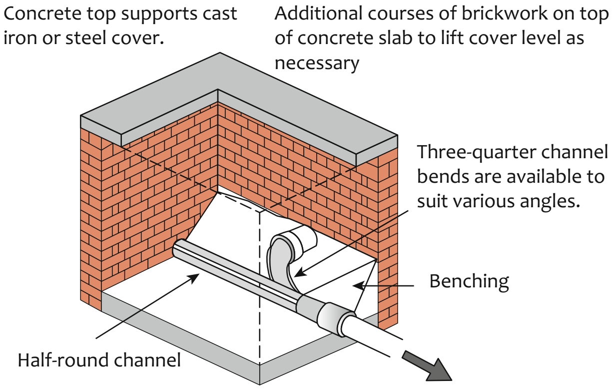
- *the start of a drain run*
- *the change in pipe size*
- *changes of direction*
- *changes in gradient*
- *junctions of different drain runs*
- *intervals along a straight drain run*
- *the outlet of a treatment plant or septic tank.*

The intervals between access points depend on the type and size of access used and guidance is given for their design and spacing in the Building Regulations. The intervals are determined mainly by the ability to effectively utilise equipment for removing blockages. The different types of access are explained below.

Manholes

The term 'manhole' implies that there is working space at drain level and that a person is able to get into it in order to carry out work. This is usually necessary because a manhole is deeper than an inspection chamber (see below).

Although most manholes on a modern development are constructed in a pre-cast material (sometimes plastic but usually pre-cast concrete) brick manholes are still sometimes used. Brick manholes are usually built in engineering or semi-engineering bricks with walls of one brick thickness. Inside the manhole, half or three-quarter round channel sections are used to allow access to blockages. The channels are bedded in a cement/sand mortar (referred to as benching). This is formed on a gradient to ensure that any spillage flows back into the drain.



Thickness of brickwork depends on depth.

Manholes on new housing developments are usually constructed in pre-cast concrete, as shown in the two photographs above.

Inspection chambers

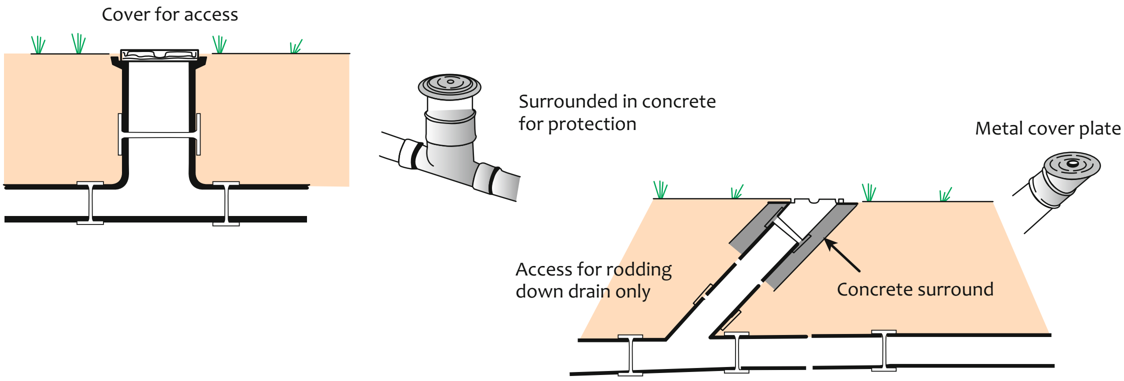
The base of an inspection chamber with pipes connected and trench partially backfilled. Courtesy of Hepworth Clay, Wavin Ltd.

Inspection chambers are shallower than manholes (typically 500mm wide and up to 1,000mm deep). There is no space for working at drain level and it is intended that blockages should be cleared without entering the chamber.

Plastic inspection chambers in position.
(right-hand photograph courtesy of Hepworth Clay, Wavin Ltd.)

Access fittings and rodding points

These permit access to single pipe runs at shallow levels. Rodding points, or rodding eyes, are a type of access point which are basically an extension of the drainpipe itself. A branch from the horizontal drain run is carried up to ground level and sealed with a removable cap; blockages can be cleared by the use of drain rods.



A rodding point. Courtesy of Hepworth Clay, Wavin Ltd.

In practice, a modern development will use a combination of these different types of access point depending on the layout, accessibility and required depth of the proposed drainage system.

Section Three: rainwater (surface water) disposal

At the beginning of the Industrial Revolution many houses had no system of rainwater collection or disposal. With urbanisation, the need to remove rainwater from the vicinity of groups of houses became necessary to avoid flooding. In addition, inadequate rainwater disposal can cause damp penetration of the building and, in some soils, foundation movement. During the eighteenth and early nineteenth centuries, fashionable townhouses usually had parapet walls. The roof behind would drain to side or centre lead-lined gutters and discharge into hopper heads. The hopper heads were made from cast iron or lead; the downpipes were invariably made from lead until the middle of the nineteenth century when iron became more common.

Hopper head to a Victorian butterfly roof.

Hopper head to a parapet wall gutter.

Hopper head to a parapet wall on a Georgian building.

Hopper head to an eaves gutter.


Lead box gutter on a seventeenth-century house.


362 PARKER, WINDER & ACHURCH, LTD., BIRMINGHAM.

From 1928 catalogue

Rainwater Gutters, Sockets, Pipe Clips, etc.

EXCLUSIVE DESIGNS

No. PHO 9440

No. PHO 9441

BOX GUTTERS.

Extreme sizes. Width.	Depth.	Sole.	Thickness.	Facet.		Prices in 6' lengths. Painted. No. PHO 9440	No. PHO 9441
3"	2"	2¾"	Ord.	Inside R. and L.H.	....	9/3 per yard.	— per yard.
4"	3"	3¾"	Ord.	„ „	....	9/10 „	— „
4"	4"	3¾"	Ord.	„ „	....	11/- „	11/- „
5"	4"	4¼"	Ord.	„ „	....	12/- „	12/- „
6"	4½"	5½"	Ord.	„ „	....	16/8 „	16/8 „
6"	6"	5¾"	3/16"	„ „	....	26/- „	26/- „
8"	6"	7"	¼"	„ „	....	29/3 „	29/3 „

Short Lengths.
Up to 2 feet charged as one yard.
Over 2 feet and up to 4 feet charged as 1½ yards.
„ 4 „ „ 6 „ „ 2 „

Connections.

Nozzles, Angles (sq. and obtuse, 135°) are charged as	2 yards of Gutter.
Clips, Stop-ends and Outlet on Bottom „ „	½ yard „
Outlets Cast on back of Gutter „ „	1 yard „
Return Stop-ends cast in „ „ „	½ yard „

For Ornaments see Exclusive Designs below. Architects requiring other sizes than these should communicate with us before specifying.

No. PHO 9442A No. PHO 9442B No. PHO 9442C No. PHO 9442D No. PHO 9442E No. PHO 9442F No. PHO 9442G

ORNAMENTS FOR CASTING ON BOX GUTTERS, SOCKETS, OR RAIN-WATER HEADS.

Any of these Exclusive Ornaments can be cast on the above Box Gutters, and on Sockets and Rain-Water Pipe Heads, at a cost of 1/3 each. Any existing design on such Gutters, etc., can be replaced by any other design free of charge. Ornaments spaced at any desired centres, but when less than 18" apart, a small extra will be charged.

EXCLUSIVE DESIGNS

No. PHO 9443 Socket.
No. PHO 9444 Ears.

No. PHO 9443 Socket.
No. PHO 9446 Ears.

No. PHO 9445 Socket.
No. PHO 9448 Ears.

No. PHO 9445 Socket.
No. PHO 9450 Ears.

PIPE SOCKETS WITH EARS. (Cast-on or Loose Dovetail).
All Ears and Ornaments are interchangeable. Angled Ears will be charged extra.

Modern installations

Rainwater flowing off a roof is usually collected at the eaves in a gutter fixed to the fascia. The gutter is fixed at a very shallow gradient to ensure that the water flows to the vertical rainwater pipes. The size of the gutter, and the size and number of downpipes, is determined by the amount of rainwater they will have to deal with. Generally, it is best to have the gutters sloping towards a downpipe in the centre of a roof elevation rather than a long length of gutter sloping to the end. This arrangement halves the amount of water that the lower part of the gutter has to carry and, in addition, keeps the gap between the gutter and the tiles to a minimum. If there is a large gap between the gutter and the tiles some of the rainwater may not be collected. This is a particular problem in high winds.

For most houses, a 75, 100 or 112mm gutter will usually be adequate, depending on the number of downpipes which are used. Downpipes are usually 50, 65 or 100mm diameter.

Gutter profile

Nowadays, gutters are usually half-round or box-shaped, although traditional profiles are still available. A box-shaped gutter and a half-round gutter are shown in the images below, as well as a traditional Ogee gutter.

Ogee gutter.

Materials

Gutters and downpipes in modern houses will usually be made of plastic, although aluminium rainwater goods are also available. In the past, a variety of materials has been used, including wood, lead, cast iron and asbestos cement.

Plastic has become the most popular material because:

- *it is lightweight*
- *it is relatively inexpensive*
- *it requires very little maintenance, i.e. painting*
- *it is easy to fix*
- *the smoothness of its finish enhances the flow of rainwater and, therefore, the efficiency of the system.*

In the early days of plastics, rainwater goods were always grey, but nowadays a greater range of colours is available including white, black and brown.

Underground rainwater disposal

As mentioned previously, rainwater should be removed from the vicinity of the building, and this is done by taking it into the underground drainage system. If the underground system is a combined one, then a trapped gully is necessary to prevent smells from the drain rising up the downpipes. The rainwater downpipe should enter the gully from the top or behind – this avoids the problem of splashing which might occur if the downpipe merely discharges over the gully (see the photograph below).

If there is a separate drainage system a trap is not required, and the downpipe can be taken directly into the underground system. At ground level, an access fitting or rodding point should be incorporated, and similar fittings can be used at regular intervals or changes of direction along the drainage run. On small sites the surface water drain does not usually require manholes or inspection chambers as blockages are comparatively rare.

Surface water

Rainwater that falls on hard surface areas, such as pavements and roads, enters the underground drain via trapped or untrapped gullies in the manner referred to above.

Additional precautions are required in car parking areas, where special gullies known as petrol interceptors are sometimes installed. The purpose of these is, as the name implies, to prevent petrol and oil entering the sewerage system.

Rural areas

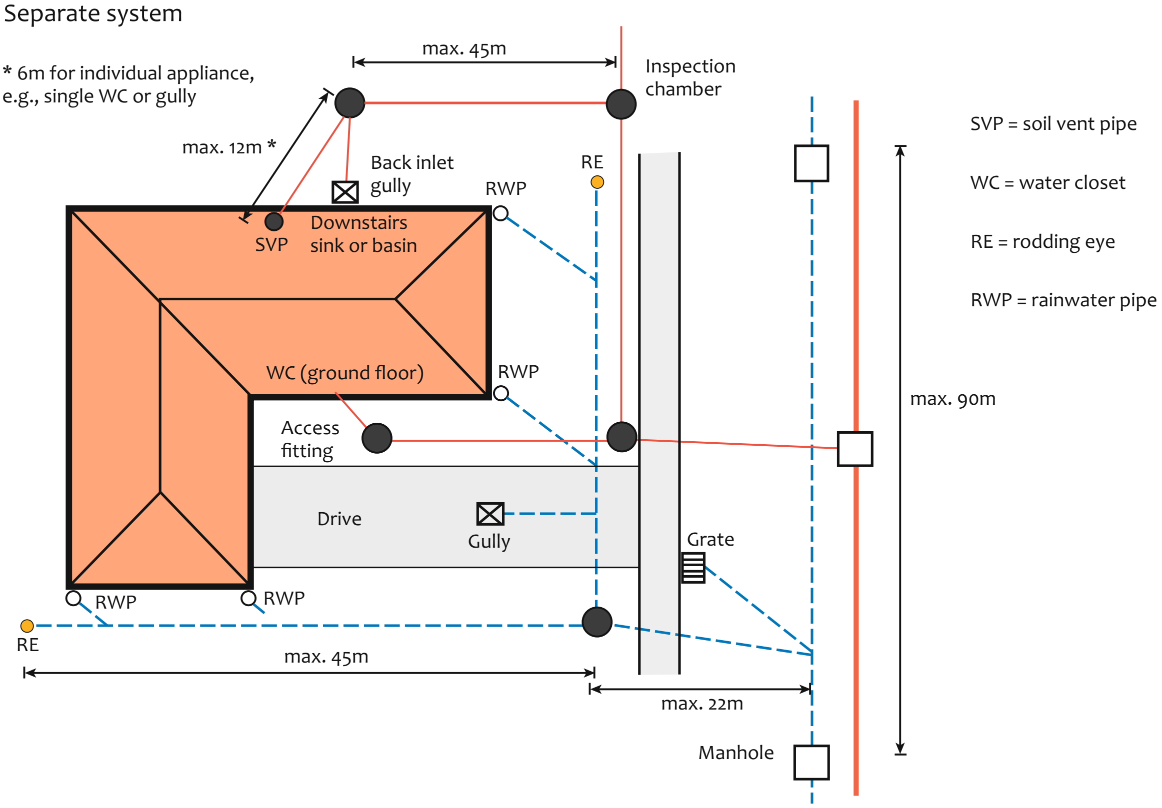
In rural areas where main drainage does not exist, rainwater can be piped directly into streams or disposed of via soakaways. However, sometimes regulatory bodies may require consent to do this and restrict the amount of rainwater that can enter the waterway over a period of time to help prevent flash flooding. Therefore it may be necessary to provide some means of restricting the flow of water, such as a soakaway, swale, pond or tank, before water is finally discharged into a watercourse.

A soakaway can be either a proprietary chamber to hold water or a large pit dug in suitable porous ground and filled with broken bricks or stone. The rainwater enters the soakaway and gradually percolates into the surrounding ground. The Building Regulations recommend that they are positioned far enough away from buildings so as not to present problems with foundations due to the softening of the soil, heave or subsidence caused by the washing out of soil particles.

A typical underground drainage system

The drawing (opposite) shows a typical (separate) drainage installation for a modern house. The Building Regulations impose limits on the spacing of access and inspection points to facilitate clearing or rodding the drain runs. These are related to the nature of the fitting. So, for example, manholes, because of their good access, can be 90m apart. Inspection chambers can be up to 45m apart and 22m from a junction. Further details can be found in the Building Regulations. The system shown is a separate system and there are, therefore, no requirements to trap the rainwater downpipes. In a combined system, of course, traps will be necessary.

Separate system



* 6m for individual appliance, e.g., single WC or gully

Alternative disposal of rainwater

As we have observed, one of the problems with combined underground drainage systems is that they can unnecessarily overburden sewerage treatment plants. There is, however, another issue with both systems in that neither make adequate (re)use of rainwater as a resource. In recent years there has been more emphasis on the sustainable use of water in houses in terms of how much is used by occupants, but the possible use of rainwater is only now beginning to be seen as an element in a more coordinated and sustainable approach – an approach usually referred to as sustainable urban drainage (SUDs). Considering SUDs in its wider sense is beyond the scope of this book but key aspects of it are discussed in Chapter 17 Cold water supply (see the section on Water, the Code for Sustainable Homes and green technology).

Electrical installations 22

Introduction

This chapter covers the basic design and layout of a typical electrical supply to a house and explains the devices which are used to protect against the possibility of electric faults and electric shock. It also discusses the principles of fire alarm systems and home security systems.

History

The first successful demonstration of the potential of electricity was quickly followed by the first public supplies in the early 1880s. Despite this, the installation of electricity in houses was slow. Although in the early part of the twentieth century, it was common to find most large new houses supplied with electricity, the majority of homes at the outbreak of the First World War still did not have a supply. One reason for the initial slowness of the take-up was the cost associated with installation and supply, but another reason was related to concerns raised by a number of bodies about potential dangers to health – a perspective that was encouraged by some of the suppliers of rival energy sources. As with other innovations, electricity was taken up first by the middle classes, who could afford it and who saw it as a desirable status symbol.

Initially, electricity was used mainly for lighting purposes, although many people did not like electric light in their houses as they considered it to be harsh when compared to gas, oil or candle light. It ultimately became popular because it was seen as cleaner and, after the initial scare about health, safer than the town gas that had been replacing candles and oil lamps from around the mid-nineteenth century. It gradually became obvious that this was a power source with enormous potential and, during the 1920s and 1930s, there was a steady increase in the number of electrical appliances that we take for granted today. However, many rural areas were not connected to mains electricity until after the Second World War.

The images below are taken from a 1930s electrical catalogue.

Side Entry (Metal)
Pol. Brass on White

3-Pin Surface

No. 8183. One Way
Two Way
No. 8190B. Brown Bakelite
,, 8940B. White Bakelite

No. 8792. Two way.
Switch Adaptor.
4/6 each

Bayonet Cap.

The "Wylex"
For Tough Rubber Cable.

The **" Wylex " Box** serves two purposes, that of a joint box, or when piece " C " is knocked away, a ceiling rose.

The Box is universal both in number of ways and sizes of cables.

The **" Wylex " Box** is made of " Bakelite " and has a superb finish can be fixed anywhere.

No. 8549 .. .. .. **16**/- doz.

The key units of measurement of electricity (without getting too involved in the principles of electro-dynamic physics) are volts and amps (or amperes), where volts are the 'pressure' or 'force' that causes electrical current to move from one point to another and amps are the flow rate of the moving charge. In recent years, there has been a movement towards harmonising national voltages throughout Europe and the UK is gradually moving towards the European standard of 230 volts from its previous standard of 240 volts.

Modern installations

Regulations

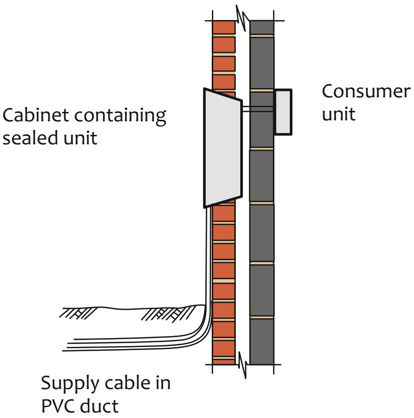
In modern construction, electrical supplies to houses should be designed and installed in accordance with the current edition of the IEE Wiring Regulations (published by the Institute of Electrical Engineers). These Regulations, which are periodically updated, are concerned with the design, installation and proper testing of electric circuits, with particular emphasis on safety requirements. They are meant for guidance and are not statutory requirements as, for instance, are the Building Regulations. However, they do set out the procedures that are considered to be 'good practice' in the industry, they are referred to in the Building Regulations and can be cited in a court of law as the standards to which a house should be wired. Most electricity suppliers will not supply electricity to a house unless it has been wired to at least the standard set out in the IEE Wiring Regulations.

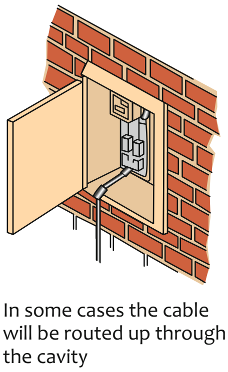
In accordance with these Regulations, the following factors are checked to ensure the correctness of an electrical installation:

- *polarity: to ensure that the various elements, such as sockets, lights, etc., are wired up correctly*
- *earthing: to ensure that a proper and continuous earth has been established*
- *insulation resistance: to ensure that insulation of the cables is in good order*
- *wiring circuit continuity: to ensure that the earth, neutral and live wires are all properly connected and continuous.*

Entry into the house

The local electricity supplier will bring the electric service cable up to the house. In the past, the electrical supply might have entered the house at high level. This still occurs in some rural areas, but nowadays a house will usually receive its power via an underground cable. Generally in the past, the meter, the supplier's master switch and the consumer unit (which contains the householder's master switches) were placed inside the dwelling. Nowadays, the incoming supply cable will usually terminate in a cabinet placed on the outside of the dwelling. This makes it easier for the electricity supplier to read the meter (and cut off the supply as the supplier's master switch is also located in the external box). The householder's consumer unit, however, will be positioned inside the house.

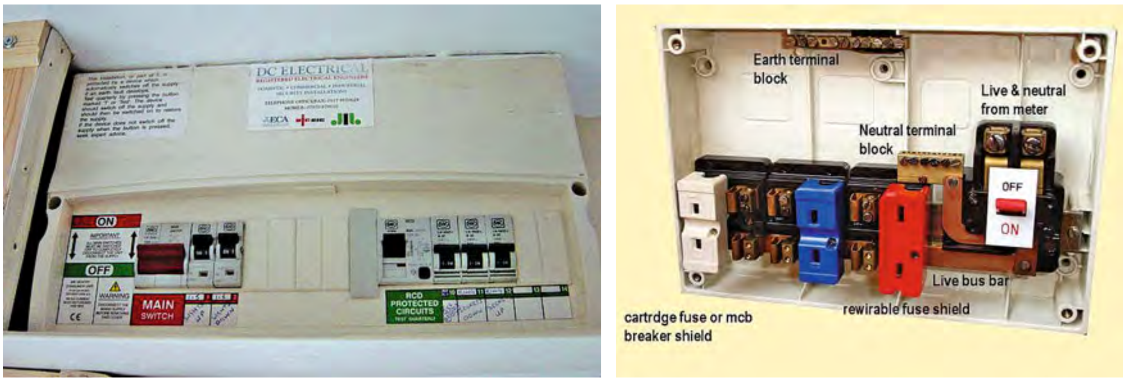




The incoming service cable terminates in a sealed unit (the service head) which contains the electricity supplier's fuse. The fuse is designed to 'blow' if there is a serious fault and the fuses/circuit breakers in the consumer unit have failed to operate. This fuse is not accessible to the householder. There is usually a terminal near the sealed unit, which is the earth connection (the purpose of which is explained later). The supply is extended into the house and connected to the occupier's consumer unit.

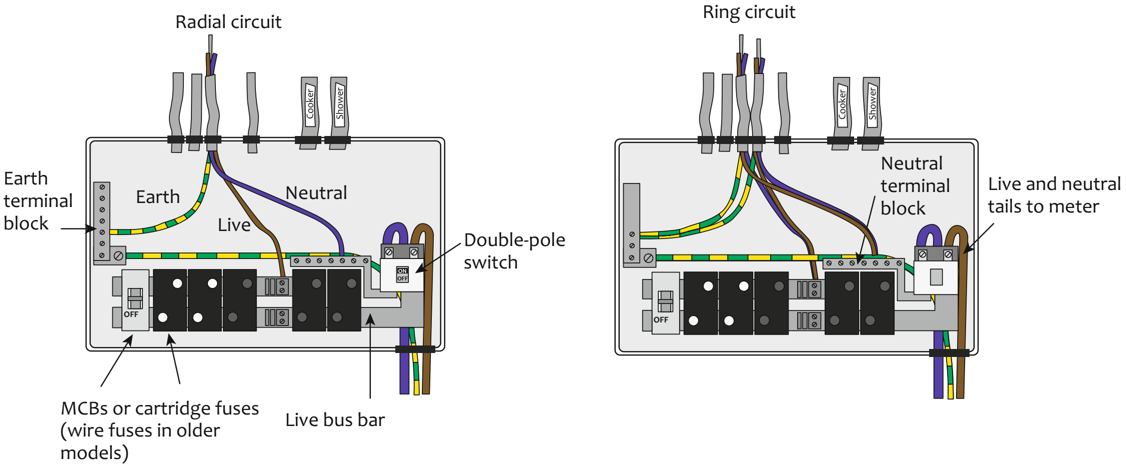
The consumer unit

The consumer unit (which is sometimes still referred to as the fusebox – its historical description) contains the householder's mains switch, which can isolate all of the circuits in the house. It also contains either miniature circuit breakers (MCBs) or fuses (these are explained later in this chapter). It is from the consumer unit that the individual circuits providing light and power are distributed. Each circuit will have its own MCB/fuse, the size of which will depend on the anticipated load.



A modern consumer unit with MCBs is shown on the left. On the right is a 1980s consumer unit with cartridge fuses.

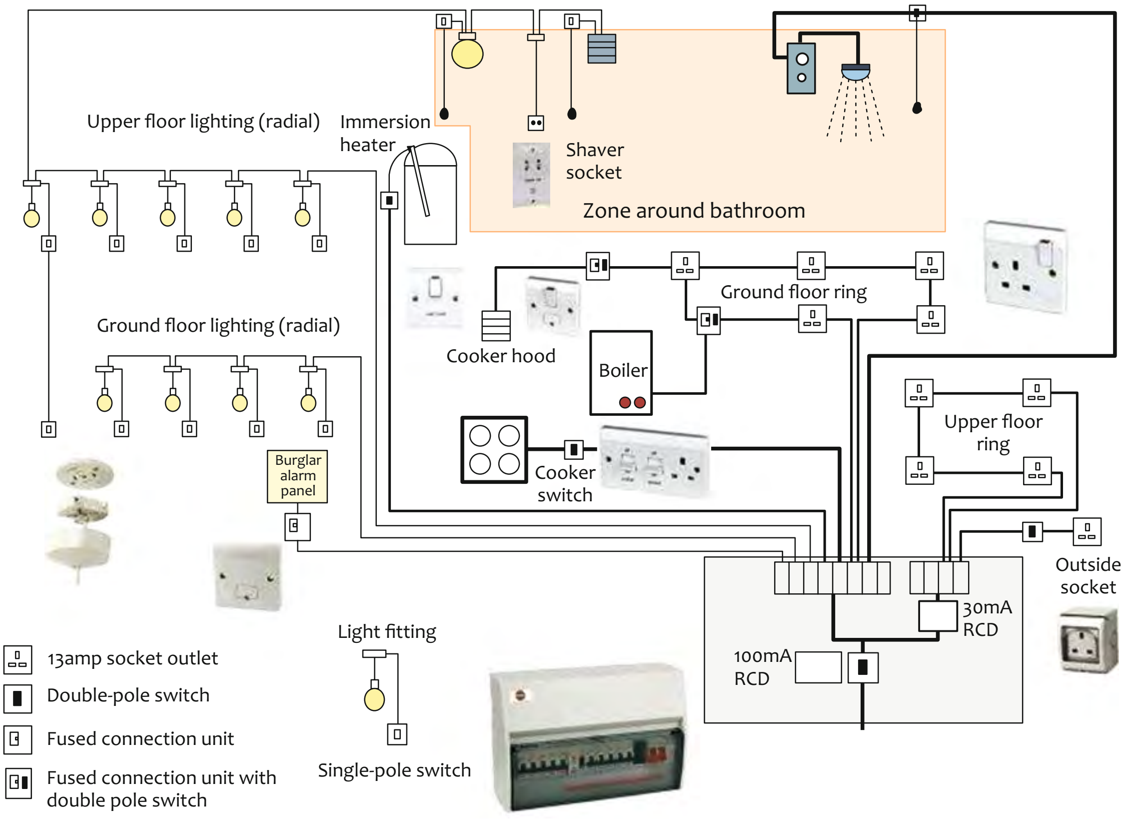
Schematic drawing of a consumer unit from the 1990s showing typical wiring



There will usually be only one consumer unit per dwelling. An exception might be where space heating is provided by electric storage radiators, in which case there will be a separate consumer unit for this system, as well as a separate meter (as the electrical supply is via 'off peak' electricity). Electric storage heaters are discussed in the Chapter 19 Space heating.

The diagram below shows a typical electrical installation for a modern house.

Schematic layout of a modern installation



Power circuits

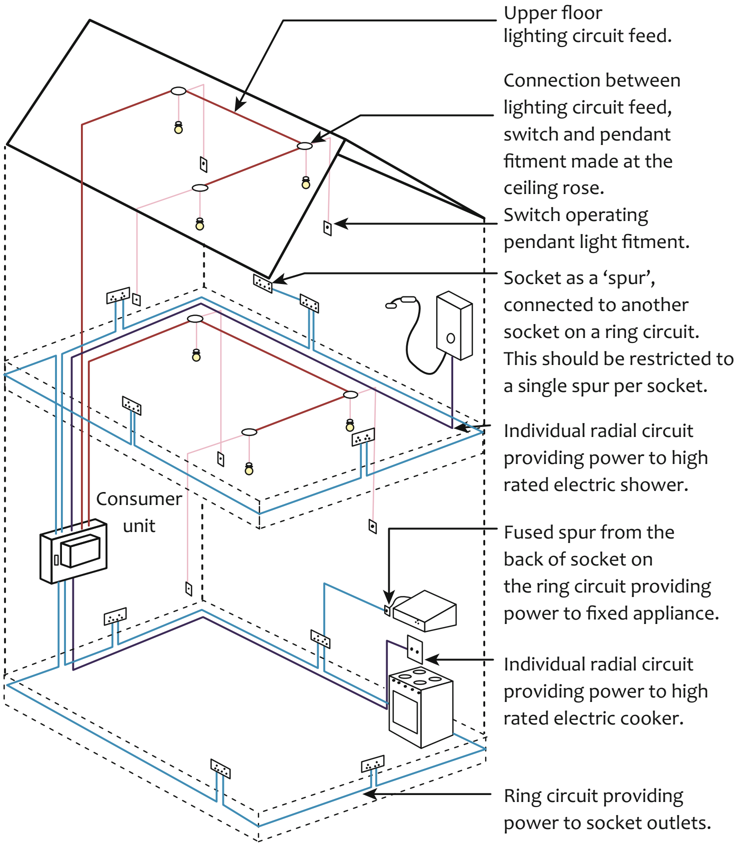
Until the 1940s, the power circuits to a house were generally arranged in what was described as a radial system. In this arrangement, individual cables were fed from the consumer unit (or fuse box, as it was known then) to one or more socket outlets. These circuits would be wired and fused for differing purposes (e.g. one circuit intended for small electrical equipment, one circuit for larger equipment).

Since the 1950s, installations have employed what is referred to as a ring main to distribute electric power to the sockets in the house. This approach was developed to allow the larger number of electrical appliances, both portable and stationary, which are found in a modern house, to be run off one circuit. The electric cable, comprising the live, neutral and earth wires, runs from the fuse in the consumer unit, serving each socket or appliance in turn, and returning in a ring to the consumer unit. Usually, there is a separate ring for each floor. As the power can flow either way around the ring, the load on the cable is reduced and this permits the use of a smaller cable size.

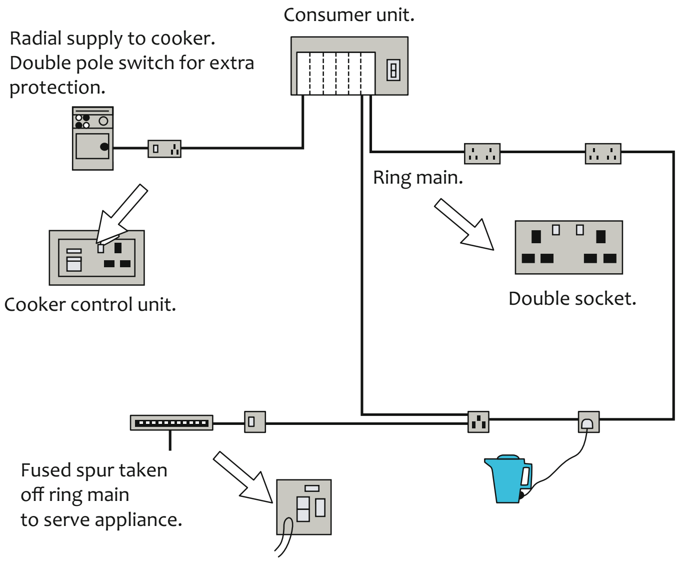
The total load for an individual ring main or ring circuit is usually 30amps. It is unlikely that all the power sockets will be used at any one time, but if this load is exceeded the MCB or fuse in the consumer unit will blow (i.e. cut the electricity off).

Individual electrical appliances are supplied with electricity by being plugged into a socket outlet which is connected to the ring main. There can be any number of socket outlets running off one ring circuit, although the floor area that can be served by one circuit should be no more than 100m². Ring mains have the advantage over the older radial circuits in that additional sockets can be added at any time.

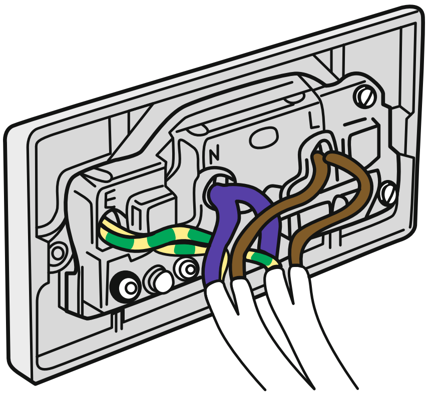
Typical modern electrical installation



Apart from the ring mains, there are usually separate radial circuits – where the cable terminates at the last outlet rather than returning in a ring. These run from the consumer unit to supply appliances which are permanently connected and which take a relatively high load (and, therefore, require a higher rated cable – as explained below). Examples of these appliances include cookers, electric showers and, where installed, immersion heaters fitted to hot water cylinders. A double pole switch (which isolates both the neutral and the live wires) is used to allow these appliances to be isolated from the mains supply during servicing.



To avoid the possible expense of diverting the ring to isolated areas, sockets or appliances may also be served by a radial supply taken off the ring circuit. This is referred to as a spur. There are restrictions on the number of spurs on one ring (to avoid overloading), and a spur can only supply one socket, which can be a twin outlet or one fixed appliance. Fixed appliances (such as a wall-mounted heater) are fed from a fused connection unit. This can be part of the ring main or, as shown in the diagram above, a spur. On a simple ring main, the cable 'loops in' and 'loops out' of each socket. A spur would only 'loop in'.

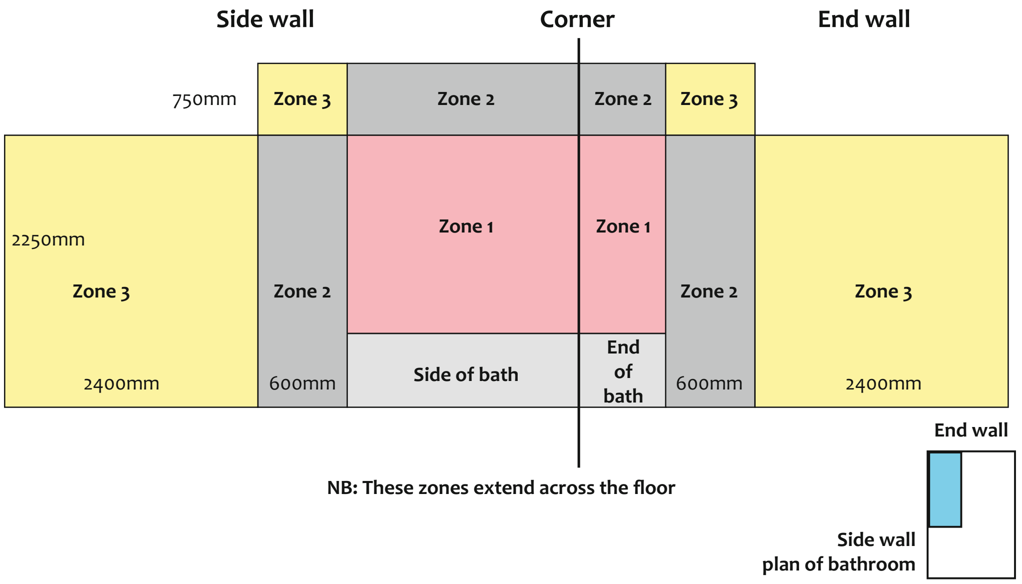


Cable loops in from previous fitting and then loops out to next

Bathrooms and kitchens

In bathrooms and shower rooms, special protection measures are required. They are achieved by means of a zoning system involving restrictions on the types of devices and controls that can be installed close to baths and other 'wet' fittings and the use of safe devices/controls, such as insulated pull-cords instead of switches.

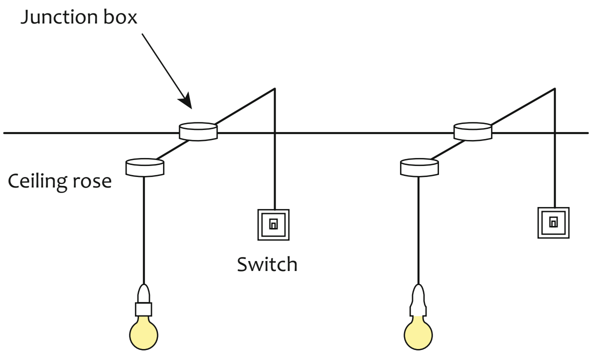
The IEE Wiring Regulations set out a number of rules for installations in bathrooms and shower rooms as well as for bedrooms containing showers. The room is divided into zones – Zones 0 to 3, where Zone 0 is the interior of the bath or shower, Zone 1 is next to the bath and Zone 3 furthest away (see diagram below). The rules are linked to the zones and are complex. They set out the fittings that can be installed in each zone, e.g. in Zone 0, there cannot be any electrical installation; in Zone 1, an instantaneous shower or water heater is permitted as long as it is splash-proof; in Zone 2, Zone 1 appliances plus light fittings, extractor fans, space heaters and shaver sockets are permitted; in Zone 3, all the previous fittings are permitted plus fittings such as heated towel rails (which must be protected by a 30amp residual-current device (RCD)). The rules also control where pull-cord switches can be installed (this depends on ceiling height).

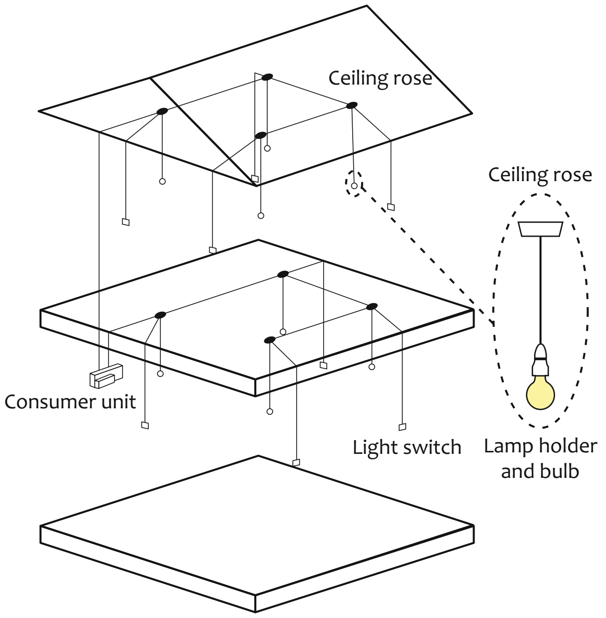


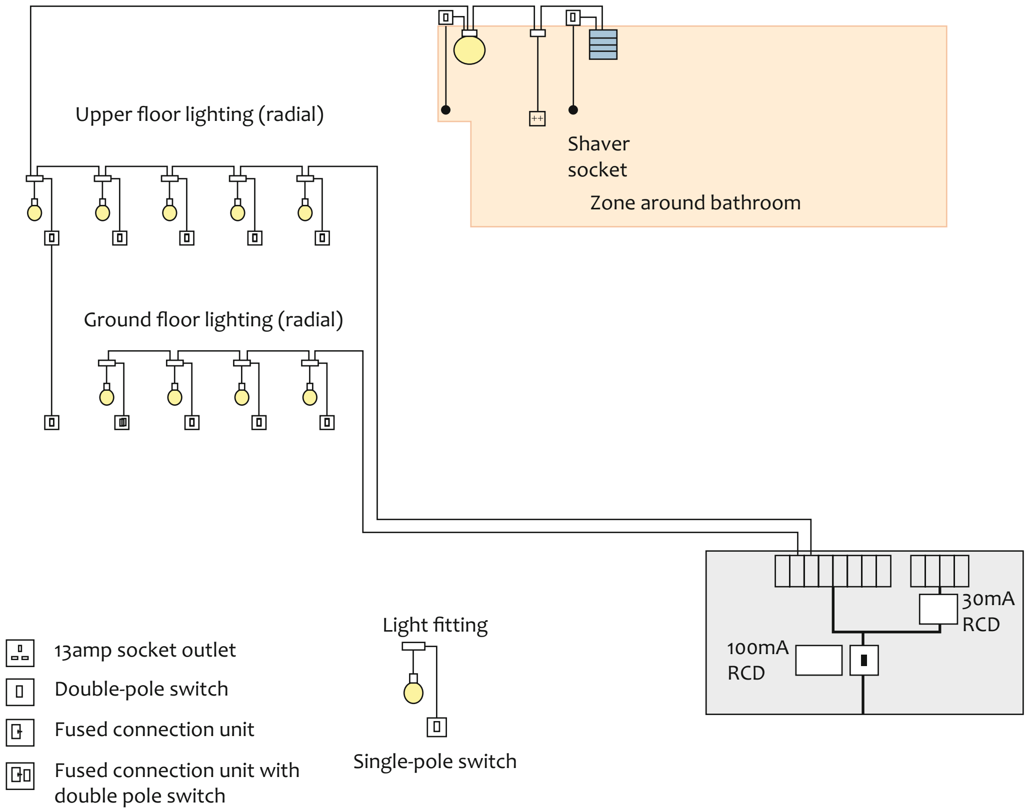
There are no similar rules for kitchens, but the layout should be designed so that it is not possible to touch a wall socket while touching a metal sink.

Lighting circuits

The lighting circuit of houses used to be arranged in what is known as a junction box system. In this approach, the cable was run from the fuse box to a series of (junction) boxes. A cable was then run to the light switch and another to the light. There was usually one box for each light and its switch. A detail is shown in the left-hand diagram overleaf.


Junction box
Ceiling rose
Switch

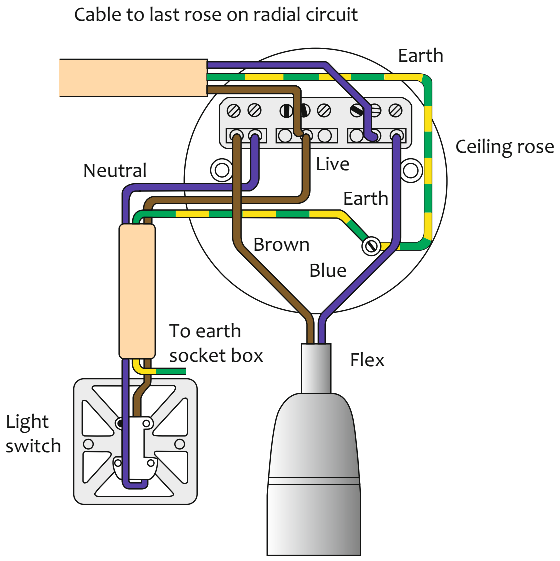

Ceiling rose
Ceiling rose
Consumer unit
Light switch
Lamp holder and bulb


Upper floor lighting (radial)
Shaver socket
Zone around bathroom
Ground floor lighting (radial)
30mA RCD
100mA RCD
13amp socket outlet
Double-pole switch
Fused connection unit
Fused connection unit with double pole switch
Light fitting
Single-pole switch

In a modern house, the lighting is kept separate from the power circuit. As with a ring main, there are usually two circuits, typically one for each floor, so that if a fuse blows the whole house is not plunged into darkness. This is shown in the right-hand diagram above. The wiring is taken to the lights in a 'loop in' system. The cable runs from the consumer unit to each lighting rose in turn, where it is looped into the terminal of each light (instead of a junction box). A length of the same size cable then connects to the switch, which in turn operates the light.

Unlike the power circuit, the cable does not normally return to the consumer unit as lights do not consume a lot of power and, in this sense, it can be considered to be a radial system. Lighting circuits are normally protected by a 5amp fuse or MCB in the consumer circuit and such a fuse will carry the load of 12 × 100W bulbs. However, the current UK move towards the use of low-energy or 'eco' bulbs is resulting in a much lower electricity requirement for lighting circuits.

The drawing below shows the last ceiling rose on a radial circuit. The metal socket box is earthed for safety (in case brass or similar switch plates are used). The live wire is diverted to the switch. Only when the switch is 'on' is the circuit complete. If the live wire were connected directly to the bulb-holder (and the neutral routed through the switch), there would be a risk of electrocution when changing a bulb.



Electrical safety

Perhaps, the major concern with electricity is safety and, in particular, the prevention of electrocution or fire. Electric shock is caused by electric current moving through the nervous system of the body. The effect of shock ranges from a mild tingling sensation to a disruption of the regular contractions of the heart or respiratory muscles – and this can cause death. Because human tissue acts as a resistance to electricity, heat is generated when contact is made and this may result in burns. The other safety problem is that fire might be caused by a short circuit or as a result of overheating caused by the system being overloaded, which is why electrical installations to dwellings and associated outbuildings and outside areas have been controlled by the Building Regulations since 2005.

The methods of guarding against fire and shock are discussed below.

Fuses

Fuses were the traditional method of protecting appliances and cables from damage in case of a fault occurring. They operated by having a lower current rating than the cable or appliance they were intended to protect. If too great a current flowed through the circuit, the fuse reacted by melting and therefore breaking the circuit. This reduced the risk of fire occurring in cables which were overloaded with electric current.

As discussed earlier, fuses were located in the consumer unit and there was one for each circuit in the house. They were also located in some outlet points, such as fused socket outlets and fused spurs, as well as the plug of every moveable appliance. Fuses were designed to be the 'weak link in the chain', and were meant to fail before anything serious occurred to the electrical circuit, i.e. overload or short circuit.

There were two different types of fuse: rewirable and cartridge fuses.

Rewirable fuse

Although outdated, these may still be found in older houses. They usually consist of an expendable tinned-copper wire in a plastic or (originally) Bakelite frame and metal pins. One advantage of these fuses is that it is obvious when they are blown. They do, however, have a number of disadvantages, perhaps the main one being the fact that the point at which the fuse wire melts can be erratic. Similarly, the general temperature of the surroundings can affect its efficiency. The fuse wire itself can deteriorate over time and blow without reason. Another problem is the possibility that householders can use a higher rating fuse wire, or indeed, a metal wire that is not a fuse wire at all (metallic bottle tops and aluminium foil are also used improperly). If a fault occurs or if, as sometimes happens, a substitute 'wire' is put in place because a fault has occurred, there is an increased safety risk.

Cartridge fuse

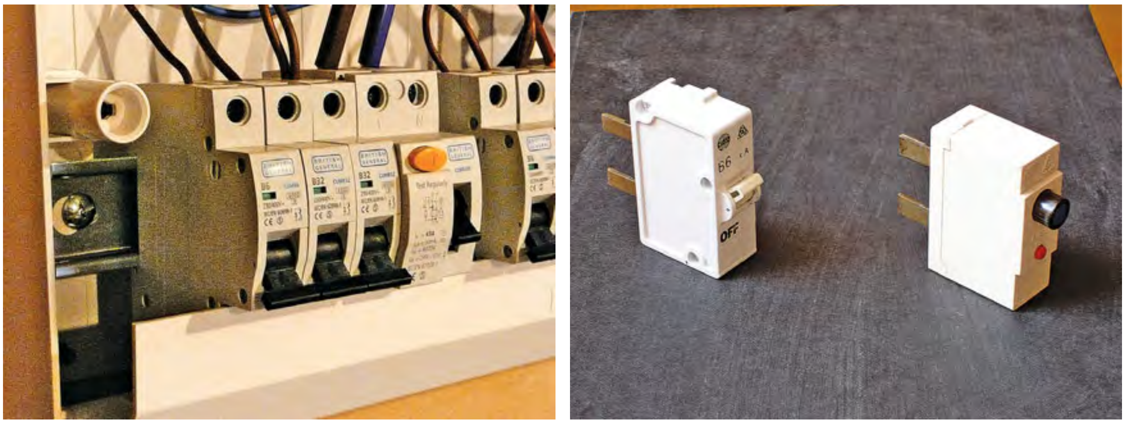
Once again, although outdated, these may be found in older houses. They consist of a wire element encased in a glass cartridge which is filled with particles of sand or a similar mineral. The wire element is secured to metal caps at each end of the cartridge in order to continue the electrical contact. A cartridge has the advantage of being easier to replace than fuse wire. Perhaps more importantly, it reacts more quickly to excess current than fuse wire. The cartridges are colour-coded: red for 30amp (power ring and radial circuits, cooker/shower); blue for 15amp (immersion heater); white for 5amp (lighting). Typical cartridge fuses can be seen in the photograph.

This type of fuse is also found in plugs. To aid correct selection, the fuses are also colour coded. For example, a red (3amp) fuse is suitable for a plug connected to a radio or fridge, but a brown (13amp) fuse is required for electric fires, washing machines and electric kettles.

Miniature circuit breaker (MCB)

In modern circuits, a device known as a miniature circuit breaker has superseded traditional fuses. An MCB performs the same function as a fuse, but when a fault occurs a switch is turned off, thus isolating the circuit. Once the fault has been remedied, the MCB can be switched back on to complete the circuit again. Examples are shown below.

MCBs are more expensive than fuses, but are more reliable and are quicker to respond to an electrical fault. They are installed onto a buzz-bar within a modern consumer unit (the buzz-bar is a metal bar in a consumer unit that is connected to the incoming main).



On the left, three MCBs have been installed onto the buzz-bar of a modern consumer unit while, on the right, the two MCBs are for installing into older consumer units as replacements for rewirable or cartridge fuses.

Earthing system

The earthing of an electric circuit is a very important part of its safe design. If a live wire comes into contact with a metal object, it can become charged and any person touching that metal object will receive an electric shock or be electrocuted. A metal object may become live for a number of reasons, such as a wire coming loose or its protective insulation being damaged. If a person touches that metal object, the electricity will flow through that person's body to the ground, with the possibility of causing death. To avoid this, metal parts of electrical appliances should be connected to earth by means of the earth wire, which is incorporated into the power or lighting circuit.

If the earth wire is in position, this will be the line of least resistance and the current will flow through the wire, rather than the person. As this is happening, the flow of electricity through the earth wire will increase the amount of current flowing through the circuit. This will, in turn, blow the fuse or trip the MCB.

Types of earthing system

In early electrical installations, the earthing was commonly carried out by connecting an earth wire to the rising water main as this was usually made of lead. In the past, this would normally be sufficient to provide a good earth; however, this has not been permitted since 1966 as modern water mains are made of plastic rather than metal. A further problem to note is that an existing metal water main may be changed to a plastic-based material without anyone realising the effect this will have on the earthing arrangement.

In modern houses, the earthing system will usually be provided by the electricity supplier and normally will be either TN-C-S or TN-S. Occasionally, it will be TT.

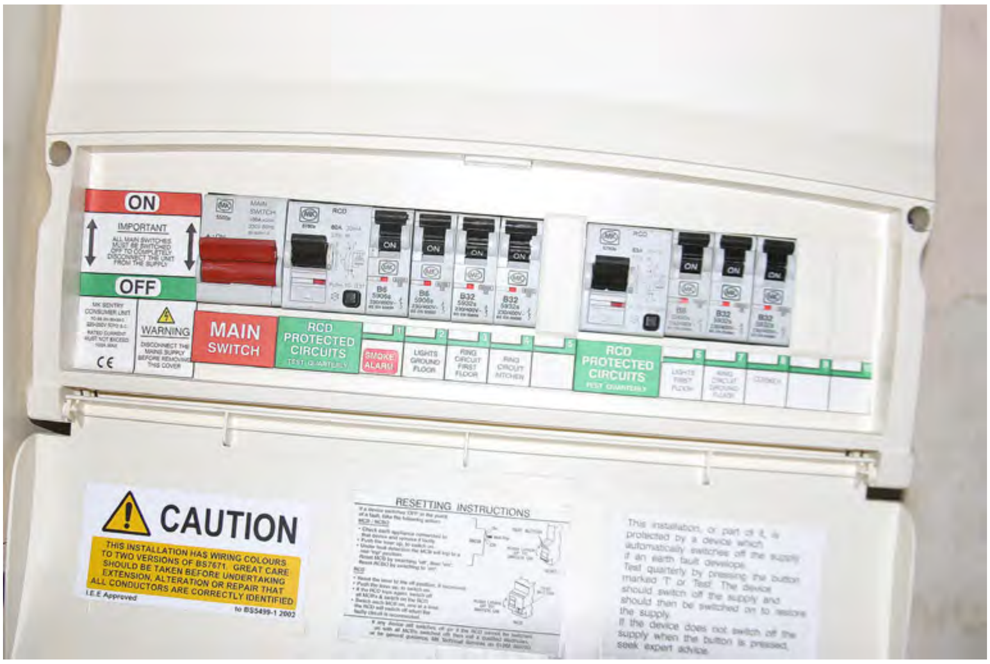
- *TN-C-S: This is an earthing system which has a combined protective earthing and neutral conductor. It is commonly referred to as protective multiple earthing (PME) and is the system most commonly used today. It uses the fact that the neutral pole of mains electricity is connected to earth at the supplier's sub-station via the local supply transformer. In this method, the neutral conductor of the supply network is used as an earth fault return path, as well as performing its normal function of carrying a load current.*
- *TN-S: In this earthing system, which may be found in older houses, the earth wires are taken back to an earth terminal located near the service head and then connected to the metal sheath surrounding the mains cable of the supplier. In this case, the metal sheath would form the earth fault return path to the neutral pole at the nearby sub-station.*
- *TT: This system can be used in cases where the electrical supply company has not provided a system for earthing. With this approach, the consumer must provide their own earth connection through a suitable earth electrode, such as an earth rod, earth tape or earth plate. An earth rod, for instance, is essentially a metal stake, usually copper, which is driven into the earth and the earthing terminal is connected to it. One of the key problems with earth rods as a means of earthing is that their effectiveness can be affected by such factors as the type of soil and how firm it is. This is because the rod needs to be driven into the ground and, if it is rocky, this may be difficult. On the other hand, if the soil is not firm (for instance if the ground is backfilled soil), sufficient contact may not be achieved. In addition, changes to the nature of the soil and the possibility of the rod corroding need to be taken into account. Earth rods are now usually used with a 'back-up' protective device such as a residual-current device (RCD).*

Residual-current device (RCD)

This is similar to, but should not be confused with, a miniature circuit breaker (MCB). It is a mechanical switching device and is used to reduce the risk of electrocution by reacting quickly to earth fault currents, i.e. within 25–40 milliseconds – before electric shock can cause a cardiac arrest. It works by switching off the flow of electricity when an imbalance is detected between live conductors. RCDs are available with different sensitivity ratings.

Current Wiring Regulations require RCD protection to all new power and lighting circuits. For existing housing, they should, at the very least, be installed on power circuits; this is because of the dangers associated with portable appliances, e.g. powered garden tools, which may be used outside the house.

The whole of the electrical system to a house should not be protected by a single RCD as, when 'tripped', there will be neither power nor lighting. Clearly this lack of lighting can itself be dangerous, especially if someone has just received an electric shock. New installations make use of split-load consumer units, where power and lighting circuits are split between two or more RCDs, so that power and lighting will, at the very least, be present on one floor if an RCD 'trips'. It is also usual practice not to provide RCD protection to fire and burglar alarm systems.

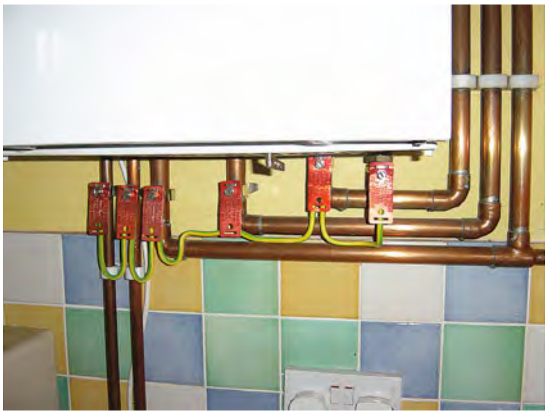


This consumer unit has a red main switch and two sets of MCB protected circuits, each set is further protected by a RCD (identified by a green tab). The RCDs offer complete protection to all lighting and power circuits in the house.

An RCD on its own does not provide protection against over-currents, but a residual current circuit breaker with overload (RCBO) can be used. This combines the role of RCD (earth fault protection) with an MCB (overload and short-circuit protection) and can be installed on each circuit. However, it is a very costly method of protection and not much used.

Bonding

It is not just the metal surrounds of electrical appliances that can become live and cause a shock. The problem may arise where someone may be touching two separate conductive elements at a time when a fault occurs. Because of this possibility, all metal objects, such as copper pipework which might accidentally come into contact with an electric current, should be connected firmly (bonded) to the main earth terminal. This is particularly important in a bathroom, because a wet body is less resistant to shock, and the bonding will often be to a radiator.



Bonding (a boiler in a bathroom) using earth clamps to connect copper pipework.

Wiring

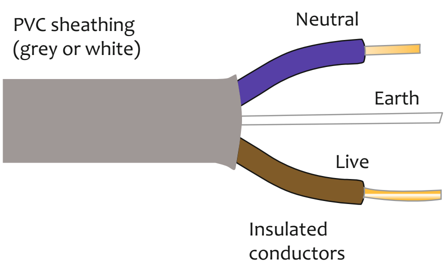
Modern cables

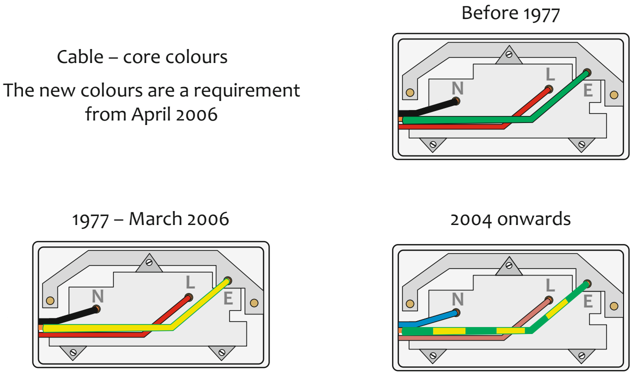
The main wiring carrying the supply to the outlets is referred to as cable. In order to ensure safety, the cables that carry the electric current must be related to the load of the current that they carry. They must also be protected against damage. All new wiring must comply with Part P of the Building Regulations which refers to British Standard 7671 and the IEE Wiring Regulations.

The cable consists of conducting wire(s) and a protective insulation. The conductors, which carry the electric current (the live and neutral wires carry the same current, but in the opposite direction), are usually made of copper, although sometimes aluminium is used. Cables are given a rating for the current that they can carry safely without becoming too hot. If the cables overheat, there is a danger that they will be damaged and may cause a fire. The rating is based on the cross-sectional area of the wires that carry the current. So, for instance, the cable used in a power ring circuit may be rated as 2.5mm^2. Cables with a cross-sectional area of 2.5mm^2 are single stranded, but above this size they are usually made up of multiple strands of copper. The earth conductor is slightly smaller in cross-sectional area than the other two and only carries an electrical load when there is a fault.

Circuits carrying a heavy current, such as cookers, have a thicker cable made up of several strands of conductor with a cross-sectional area of $6\text{–}10\text{mm}^2$. Within the cable, the conductors are protected and separated from each other by an insulating material, which also serves to protect against direct contact and, therefore, shock. The insulating material is usually polyvinyl chloride (PVC).

As the insulation plays an important role, it, in turn, requires protection against mechanical damage, moisture or chemicals. This is achieved by surrounding the insulated conductors in sheathing. This type of cable is referred to as PVC/PVC because it consists of copper conducting wires insulated in PVC, and the insulated conductors are themselves wrapped in a protective PVC sheath. PVC is chosen because it is relatively tough, incombustible and inert. It does not deteriorate with age, although it does soften at temperatures around 70°C. Because of these characteristics, PVC can be buried in most wall plasters. The live (brown) and neutral (blue) wires within the cable are covered in PVC of different colours (as indicated below left); the earth wire is left bare within the PVC sheath. However, in flexes that connect appliances to a socket, the earth is covered in green and yellow PVC (as seen below right).




Cable – core colours

The new colours are a requirement from April 2006

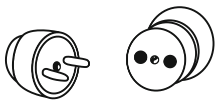
There is also a mineral-insulated, metal-sheathed cable, but this is less often used in houses due to its high cost.

Older types of cable

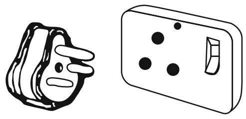
PVC/PVC cable has been in use since the 1960s. Prior to this, it was common to find cloth-covered, rubber-insulated cable. The rubber could perish for a variety of reasons, leading to short circuits and risk of fire. Another old type of cable, that was in use until the late 1940s, used rubber to insulate the wires, but with a sheathing of lead. The lead sheath acted as the earth as well as protecting the cable from impact damage. This type of cable was often used for surface wiring. It was very expensive and not always effective, as a good earth connection could be lost if the lead sheathing was damaged. A point to note is that modern sockets and switches are sometimes fitted to older cabling, masking the age and integrity of the wiring in a dwelling.

Sockets and switches

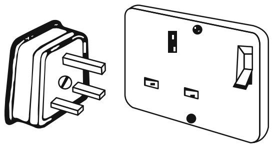
Socket outlets have also changed over the years, with early systems often using round, two-pin sockets. These did not have earth protection and there were no fuses in the plugs. In the 1930s, they were replaced with round three-pin sockets which were earthed, but still did not have fuses in the plugs. The modern, square-pin, 13amp sockets have been in use since the 1950s. However, when inspecting old buildings, as stated previously, it should not be taken for granted that a modern socket is necessarily connected to modern wiring.



Early round 2-pin socket



1930s–50s round pin socket
(switched or unswitched)



Modern square 3-pin socket

A variety of switches for lighting and other purposes are installed. Most lighting is controlled by a wall-mounted switch; some include dimmer or timer controls. Ceiling pull-cord switches must be used where switches for lighting and other apparatus are in close proximity to bathroom and kitchen fittings.

The Building Regulations (Part M) require that reasonable provision is to be made for all people to use a building and its facilities. This means that consideration needs to be given to disabled access and use. The Regulations offers design guidance on appropriate heights of sockets and switches in habitable rooms that will enable use by the disabled. Provision should be made between 450mm and 1200mm from finished floor level, e.g. power sockets, TV sockets and telephone jack points between 450mm and 1000mm; lighting and other switches, such as cooker and immersion switches, door bells and entry phones between 900mm and 1200mm.

Fixing and protecting PVC cables

Instead of burying a cable, e.g. in a solid floor or in wall plaster, cables should be laid in a conduit or in trunking. Conduit consists of metal or PVC tubes which protect insulated cables from being damaged. At the same time, it allows access to the cables in order to withdraw or renew them without affecting the fabric of the building. Trunking performs a similar function, but provides continuous access to the cable.

Cables can be fixed on the surface of a wall, but it is better for them to be buried in the wall. This is done by cutting a chase or groove in the masonry so that the cable is protected by the full thickness of the plaster. Cables which travel down walls can be afforded further protection by the use of channelling, which is made of plastic or metal.

It is important to note that when cables are hidden by plaster, they should be installed vertically (in case of future alteration works or maintenance). Any horizontal runs necessary should be made in floors or ceiling voids. Cables run through a solid floor should be placed in a duct. The Building Regulations and British Standard 7671 give guidance on the positioning of concealed cables.

The manner and method of running and fixing cables is also important in terms of safety. The following are some of the points which should be borne in mind:

- *If a cable is to be run at right angles to a timber joist, the joist should be drilled as near to its centre as possible, and at least 50mm from the top of the joist. This is to ensure that nails in the floorboards do not accidentally pierce the cable. A notch cut in the top of the joist is not acceptable.*
- *If the cable is run parallel to the joists, it should be adequately fixed to them and supported at regular intervals. It should not be run diagonally across floors or ceiling, nor bent sharply, nor be fixed to the top of joists in the roof space.*
- *If a cable has to pass through a masonry wall, it should be protected by a conduit.*
- *The layout of the cables should be designed to avoid contact with materials which may damage the cables and/or present a safety problem. This might include obvious points such as avoiding contact with water, but also includes avoiding contact with, for instance, cement and polystyrene which can damage the PVC coating.*
- *Problems can also occur if the cables overheat. This can occur through contact with hot surfaces or where they are covered with insulation (e.g. roof, wall or floor thermal or acoustic insulation).*
- *It should be kept in mind that rodents have been known to cause electrical fires by biting through the insulation.*

Solar electricity – photovoltaic (PV) systems

Solar electricity is based on the principle of the direct conversion of light into electricity, which is known as photovoltaics. The technology of photovoltaic or PV systems has been around for over 40 years and used for domestic purposes for at least 30 years, but it is only in the past five years or so that the systems have become increasingly installed in UK domestic property. This is as a result of rapidly rising energy costs, allied to greater public awareness of the need to make use of sustainable sources of energy (i.e. renewable energy systems). Another key factor is the reduction of a user's carbon footprint as there are no CO_2 emissions with the use of a PV system.

After the initial capital cost of the installation, the electricity provided costs nothing and there are also further financial incentives, such as the opportunity to sell electricity back to the National Grid when the system is producing more electricity than the householder needs. Currently, the UK Government's Feed in Tariff (FIT) scheme sets out minimum payments to be made by electricity supply companies to individual householders who make use of micro-generation, such as a PV system.

To set against these benefits, however, it should be borne in mind that PV systems use a significant amount of energy in their manufacture. Also, there may be disposal problems when a system is removed or replaced as they are highly toxic. They also degrade at a rate of about 1 per cent per year, resulting in a decrease in performance as a system ages.

A PV system is comprised of either individual cells or panels made up of a series of cells. Each cell is made from one or two layers of semi-conducting material, usually silicon, and works by converting solar radiation into direct electrical current. Sunlight contains photons and, when these strike the surface of the PV cell or panel, they dislodge electrons in each individual cell which flow through it to create an electric current. As the electricity produced is direct current (DC), a device called an inverter is required within the system to convert it into the alternating current (AC) used in domestic buildings. PV technology is developing fast and the latest systems make use of thin-film PV cells which are lighter and use much less raw material in their manufacture. These can also produce electricity from daylight and not just sunlight.

The stronger the sunlight, the more electricity produced. However, a PV system can produce limited electricity even on an overcast or cloudy day. In the UK, a conventional PV system needs to be installed on a south-facing elevation or roof in order to capture maximum sunlight. In domestic applications, façade systems are unusual and PV systems are normally installed on a south-facing roof, although roofs facing south-west or south-east are also acceptable. Shading by trees and other buildings needs to be avoided.

Specialist roof tiles incorporating single cells or larger multi-celled panels may be used, either as part of the initial construction or added at a later date. PV panels are often installed above the existing roof covering, the only limit to their number often being the area available on the roof. A key point is that the roof structure must be capable of supporting the extra load of the PV system used and for existing buildings this may involve adding extra structural members. Because there is increased strength in sunlight that falls on an angled (or tilted) panel rather than on one that is horizontal, a pitched roof provides a more efficient base than a flat roof. PV panels on the latter should be installed at an angle.

The house on the left, built in the mid-1990s, had a PV system installed in 2011. The panels are fixed to stainless steel rails that run across the roof above the existing roof tiles and are secured to the timber structure beneath. Note the individual cells within each panel. The right-hand bungalow has recently had integrated PV tiles installed at the same time as a new slate roof.

The systems are fairly expensive to install and, therefore, in terms of capacity they are tailored to a household's demand. The strength of a PV cell is measured in kilowatt peak (kWp) and PV systems are similarly measured. Most installations are between 1.5kWp and 3kWp. A 2kWp system would provide an average household with approximately 40–50 per cent of its electricity demand, but would require 16m^2 of panels, an area which may be difficult to install on smaller houses. The lifespan of PV systems is about 25 years, although early PV panels have exceeded 30 years. They have a long financial payback period, in excess of 100 years, but incentives such as selling electricity back to the National Grid can drastically reduce this period.

Fire and smoke alarm systems

The Building Regulations (Part B) require either individual smoke alarms or an automatic fire detection and alarm system to be installed in all new dwelling houses. Part B recommends that the system shall be in accordance with British Standard 5839, but where the occupants are at a special risk from fire a higher standard may be appropriate.

Detection and alarm systems make use of smoke detectors in high-risk areas (e.g. cupboards under communal staircases) and/or in circulation spaces (such as halls and landings) as well as heat detectors in kitchens, where a smoke detector might be overly sensitive to normal everyday occurrences (such as overdone toast). The Building Regulations recommend that smoke detectors are provided within 7.5m of doors to all habitable rooms and a heat detector is provided in the kitchen if it is open-plan or not provided with a door. The system should be connected to the property's consumer unit either as a single independent circuit or via a single regularly used lighting circuit (although, in this case, isolating the supply to the alarms and to the lighting should be separately achievable). A stand-by power supply should be installed as well; normally, this is by means of a rechargeable or non-rechargeable battery.

Smoke detectors are normally one of two types – either an ionisation chamber (working by physical process) or an optical chamber (working via photoelectric process). In the former, any smoke entering the ionisation chamber interrupts a small current between two electrodes and sets the alarm off. The optical chamber is basically a light sensor; when smoke enters the chamber, some light is scattered by the smoke particles, interrupting the sensor and triggering the alarm. This type is generally considered more reliable than an ionisation detector as the latter is likely to give more false alarms. Combination alarms incorporating both types of detection are also available and are considered to offer the best protection.

A typical smoke detector: the button is for the occupier to test the system to ensure that it is working.

Once smoke is detected, the device sets off an alarm. Normally, this is an audible alarm and triggering any single detection unit should set off all alarms in the system. Special alarms are also available for the hard-of-hearing which set off a flashing light as well as an audible alarm.

Recent research indicates that approximately 85 per cent of all dwellings in the UK have some form of fire alarm, although these may not all be full detection systems. One of the problems of all fire alarm systems is that occupiers do not always replace 'dead' batteries or, in some cases, they remove the batteries from detectors where they are 'too sensitive' and cause false alarms. Smoke detectors are the standard devices that are installed; heat detectors should always be used in conjunction with smoke detectors and never as a stand-alone device.

Home security systems

Increasing numbers of dwelling houses are having home security systems installed as they have been proven to reduce the likelihood of a property being burgled. Often referred to as burglar alarm systems, the choice of such systems and fittings is considerable. They range from hard-wired to wire-free systems and the protection devices include: motion detectors, such as passive infra-red (PIR) detectors, ultrasonic detectors, microwave detectors and photoelectric beams; door and window alarms; exterior motion-detecting lights; surveillance cameras; personal attack alarms.

Most systems are connected to a clearly visible external alarm box that contains an audible alarm device and, usually, a flashing or strobe light. Alternatively, the system can incorporate a remote connection via telephone or radio network to an approved central monitoring station linked to the police or via broadband to any computer. It is also possible to have a cheaper alternative, a speech dialler. This is linked to the control unit and automatically dials pre-set telephone numbers and leaves a pre-recorded message.

On the left can be seen a typical external burglar alarm box (note: normally when this type is triggered, a blue light flashes and an alarm bell sounds for a fixed period). The right-hand photograph shows a typical passive infra-red (PIR) detector (note: it has detected movement, so flashes red).

Internally, the detection and alarm devices will be linked to a programmable control unit and the dwelling will normally be divided into a number of zones, which can be selected and armed by the householder, e.g. bedroom zone unarmed, all other zones armed at night.

The programmable control unit, showing a number of zones on the left, is linked to the external alarm box shown previously. The external security light has an in-built PIR detector at the bottom.

One common problem experienced by these systems in the past was that of false alarms – some can be so sensitive that a fly crossing a sensor can set off the alarm. Modern systems are designed to turn off the alarm after a pre-set period (maximum of 20 minutes) if the householder is not present.

The most effective burglar alarm system should also be combined with appropriate physical security measures to all external doors and windows. These include five-lever dead-bolts, sash or casement locks, hinge protectors and anti-lifting devices for sliding doors.

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