## Contents

Acknowledgements ................................................. x
Preface .......................................................... xii
Foreword ........................................................ xiv

### PART 1  Introduction to house construction  1

<table>
<thead>
<tr>
<th>1</th>
<th>Functions of buildings  3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Physical and environmental functions of buildings  4</td>
</tr>
<tr>
<td></td>
<td>Introduction .............  4</td>
</tr>
<tr>
<td></td>
<td>The building as an environmental envelope  4</td>
</tr>
<tr>
<td></td>
<td>Performance requirements of building fabric  9</td>
</tr>
<tr>
<td>1.2</td>
<td>Forces exerted on and by buildings  12</td>
</tr>
<tr>
<td></td>
<td>Introduction .............  12</td>
</tr>
<tr>
<td></td>
<td>Loading forms ............  13</td>
</tr>
<tr>
<td>1.3</td>
<td>Structural behaviour of elements  17</td>
</tr>
<tr>
<td></td>
<td>Introduction .............  17</td>
</tr>
<tr>
<td></td>
<td>The nature of forces acting on buildings  17</td>
</tr>
<tr>
<td></td>
<td>The influence of shape – building components  22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2</th>
<th>Preparing to build  25</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Selection of sites for building  26</td>
</tr>
<tr>
<td></td>
<td>Introduction ..........  26</td>
</tr>
<tr>
<td></td>
<td>Overview ..............  26</td>
</tr>
<tr>
<td>2.2</td>
<td>Site investigation  27</td>
</tr>
<tr>
<td></td>
<td>Introduction ..........  27</td>
</tr>
<tr>
<td></td>
<td>Overview ..............  27</td>
</tr>
<tr>
<td></td>
<td>Nature of the survey  28</td>
</tr>
<tr>
<td></td>
<td>Method of extracting information  29</td>
</tr>
<tr>
<td></td>
<td>Data generated by a site investigation  30</td>
</tr>
<tr>
<td></td>
<td>Contaminated land  33</td>
</tr>
<tr>
<td>2.3</td>
<td>Overview of statutory control of building  35</td>
</tr>
<tr>
<td></td>
<td>Introduction ..........  35</td>
</tr>
<tr>
<td></td>
<td>Overview ..............  35</td>
</tr>
<tr>
<td></td>
<td>Building control  35</td>
</tr>
<tr>
<td></td>
<td>Town and country planning  37</td>
</tr>
<tr>
<td></td>
<td>Health and safety  38</td>
</tr>
<tr>
<td></td>
<td>Environmental legislation  39</td>
</tr>
<tr>
<td>2.4</td>
<td>Overview of utilities and infrastructure  40</td>
</tr>
<tr>
<td></td>
<td>Introduction ..........  40</td>
</tr>
<tr>
<td></td>
<td>Overview ..............  40</td>
</tr>
<tr>
<td></td>
<td>Cold water supply  40</td>
</tr>
<tr>
<td></td>
<td>Electricity supply  42</td>
</tr>
</tbody>
</table>
3 The building process

3.1 Methods of building
- Introduction
- Overview
- Traditional building
- Post-traditional building
- Rationalised and industrialised building
- Accuracy in building

3.2 Modern methods of construction
- Introduction
- Overview
- Background to the development of MMC
- Procurement and programming of projects using MMC
- Volumetric construction
- Panelised construction
- Sub-assemblies and components

3.3 Building sequence
- Introduction
- Overview
- Building sequence – the phases or stages of construction
- Building sequence – the stages in the construction of a house

3.4 Expenditure on building
- Introduction
- Overview
- Building costs
- Expenditure profile
- Financing the building process

3.5 Sustainable house construction
- Introduction
- Overview

PART 2 Building substructure

4 Foundations

4.1 Foundations
- Introduction
- Soils and their characteristics

4.2 Functions of foundations and selection criteria
- Introduction
- Overview
- Functions of foundations
- Selection criteria
### Contents

- Durability  
  - Acoustic insulation  
  - Selection of external walls  
- 7.2 Traditional external wall construction  
  - Introduction  
  - Overview  
  - Masonry walls  
- 7.3 Timber frame construction  
  - Introduction  
  - Overview  
  - Principles of timber frame construction  
  - Timber frame alternatives  
  - Assembly of timber frame buildings  
  - Claddings to timber frames  
  - Timber frame and fire  
  - Movement accommodation  
- 7.4 Light steel frame construction  
  - Introduction  
  - Overview  
  - Principles of steel frame construction  
  - Assembly of steel frame buildings  
  - Steel frame construction and fire  
- 7.5 Panelised construction  
  - Introduction  
  - Overview  
  - Structural insulated panel construction  
  - SIP construction process  
  - Cross laminated timber frame  
  - CLT construction process  
- 7.6 Openings in external walls  
  - Introduction  
  - Overview  
  - Openings in external walls: terminology  
  - Evolution of the lintel form  
  - Volumetric construction  

### 8 Upper floors and stairs  
- 8.1 Timber upper floors to dwellings  
  - Introduction  
  - Overview  
  - Timber floor construction  
- 8.2 Stairs: design solutions and construction forms  
  - Introduction  
  - Staircases in timber  

### 9 Internal division of space: walls and partitions  
- 9.1 Functions of partitions and selection criteria  
  - Introduction  
  - Overview  
  - Division of space  
  - Durability
## 9.2 Options for internal walls and partitions in dwellings

**Introduction**

**Overview**

- Alternative construction forms
- Solid partitions
- Hollow partitions

## 10 Roof: structure and coverings

### 10.1 Functions of roofs and selection criteria

**Introduction**

**Overview**

- Strength
- Weather resistance
- Durability
- Insulation
- Aesthetics

### 10.2 Pitched roof forms

**Introduction**

**Overview**

- Rafter and purlin pitched roofs
- Trussed rafter pitched roofs

### 10.3 Pitched roof coverings

**Introduction**

**Overview**

- Slates
- Plain tiles
- Interlocking tiles
- Dry roof details

### 10.4 Flat roof forms

**Introduction**

**Overview**

- Cold deck flat roof

### 10.5 Flat roof coverings

**Introduction**

**Built-up felt roofing**

### 10.6 Roof drainage and roof chimneys

**Introduction**

**Drainage of pitched roofs**

**Rainwater harvesting and recycling**

**Roof chimneys and flues**

### 10.7 Thermal insulation and condensation prevention

**Introduction**

**Overview – the mechanism of condensation**

**Internal temperature and condensation**

**Control of generated water vapour**
11 Windows, doors and ventilation

11.1 Ventilation and dwellings
  Introduction
  Overview
  Providing effective ventilation
  Alternative approaches to ventilation

11.2 Functional performance of windows
  Introduction
  Overview

11.3 Window options
  Introduction
  Overview
  Timber windows

11.4 Orientation and glazing
  Introduction
  Overview – orientation
  Glass forms
  Glazing techniques

11.5 Door types
  Introduction
  Overview
  Panelled doors
  Flush doors
  Matchboarded doors
  Frames and linings
  Engineered and composite doorsets

12 Internal finishes

12.1 Functions of finishes and selection criteria
  Introduction
  Overview
  Criteria

12.2 Wall finishes
  Introduction
  Wall finish options
  Plaster accessories
  Dry lining walls with plasterboard
  Wall tiling
  Wet rooms
  Splashbacks and glass/steel alternatives

12.3 Ceilings and ceiling finishes
  Introduction
  Ceiling finish materials

12.4 Floor finishes
  Introduction
  Overview
  Timber finishes
### 13 Overview of alternative sustainable construction methods

#### 13.1 Sustainable construction
- Introduction
- Overview
- Foundations
- Structural frames

#### 13.2 'Natural green' technologies and ICF
- Clay wall construction
- Straw bale wall construction
- Hemp lime/hempcrete
- Insulated concrete formwork (ICF)
- Green roofs

Index
 FUNCTIONS OF BUILDINGS

AIMS
After studying this chapter you should be able to:

- Appreciate the main physical functions of buildings
- Describe the factors that must be considered in creating an acceptable living environment
- Discuss links between these factors and the design of modern dwellings
- Recognise the sources and nature of loads applied to building elements and the ways in which they affect those elements
- Appreciate the influence of the choice of materials and the selection of design features on building performance

This chapter contains the following sections:

1.1 Physical and environmental functions of buildings
1.2 Forces exerted on and by buildings
1.3 Structural behaviour of elements

INFO POINT
- BS 648: Schedule of weights of building materials (1964 – withdrawn)
- BS EN ISO 7730: Moderate thermal environments. Determination of the PMV and PPD indices and specification of the conditions for thermal comfort (2005)
1.1 Physical and environmental functions of buildings

Introduction

- After studying this section you should be aware of the nature of buildings as environmental enclosures.
- You should appreciate the nature of the building user's need to moderate the environment and understand how built form has evolved to allow this to be achieved.
- You should have an awareness of the link between environmental needs and the form of the building fabric.
- You should be able to recognise the key features of building form that affect the internal environment.
- You should understand the nature of physical forces exerted on and by buildings and you should be familiar with the terminology associated with this aspect of building performance.
- You should have comprehension of the implications of the need to satisfy these requirements upon building design.
- Given a variety of scenarios you should be able to recognise the key features of the building structure and fabric and should be able to relate these to the building's physical and environmental performance.

Included within this section are the following areas:
- The building as an environmental envelope
- Performance requirements of building fabric

The building as an environmental envelope

Overview

The ways in which the internal environments of buildings are controlled have become very sophisticated as the needs of occupiers have evolved. The degree to which we are able to moderate the internal environmental conditions using the building enclosure and building services is great. However, it is easy to take for granted some of the features of buildings that affect the internal environment and to overlook the basis of the evolution of these features. Dwellings are generally designed to be aesthetically pleasing. Many of the details that we associate with building style and aesthetics have their origins in the need to satisfy functional needs. As buildings have developed, the role of building services to control heat, light and ventilation has become more significant. It is easy to forget that these services rely on the existence of an appropriate building envelope in order to achieve the required level of performance. The dwelling as we now know it has its origins in the simplest form of building enclosure, created by people to protect themselves from the extremes of the environment. The factors that led people to develop such enclosures in historic times are still evident today, and the function of dwellings, although now much more sophisticated, is still essentially the same as it was then. One of the primary functions of the building fabric is to create an environmental envelope.
Buildings and the control of the internal environment

Historically people have sought to modify and control the environment in which they live. In prehistoric times caves and other naturally occurring forms of shelter were used as primitive dwellings, providing protection from the external environment. As civilisation has developed, so the nature of people’s shelter has become more refined and complex, developing from caves and natural forms of shelter to simple artificial enclosures, such as those used throughout history by nomadic peoples worldwide. The ways in which the structures created by humans have depended upon the nature of the climate in specific locations and the form of building materials available locally. This resulted in the development of vernacular forms of building, based on the use of readily available local materials. As a consequence, identifiable styles of buildings developed in different areas, each adapting the form of the building to satisfy functional requirements with available materials and technologies. The ability to transport building materials over relatively large distances is a recent development. In Britain, for example, this was limited prior to the Industrial Revolution by the lack of effective transport networks. The advent of canals and rail links allowed materials to be transported over relatively large distances. Hence the extent of vernacular architecture has reduced, with materials from a wide variety of locations being incorporated into more modern buildings to satisfy functional requirements in the most efficient and cost-effective way possible.

Examples of vernacular architecture are found in the UK and throughout the world. In areas such as the Middle Eastern desert regions, where diurnal temperatures vary considerably, being very hot during the day and cool at night, buildings of massive construction are common. Such buildings are referred to as ‘thermally heavy’ structures. The intense heat of the day is partly reflected by the use of white surface finishes, and that which is not reflected is absorbed by the building fabric rather than being transmitted into the occupied space. As a result of the slow thermal reaction of the building this stored heat is released at the times of day when the external temperatures may be very low, acting as a form of storage heater. The effects of direct solar gain are reduced by the use of a limited number of small window openings.

In areas where the climate is consistently warm and humid, such as in South East Asia, a very different approach to building design is required. In such situations, rare breezes may be the only cooling medium that can remove the oppressive heat and humidity of the internal environment. Since this cooling and dehumidifying effect takes place in a short period, the building must be able to react quickly to maximise any potential benefit. Hence, a ‘thermally light’ structure is essential to transmit external changes to the interior with minimal delay. The nature of buildings in such areas reflects these requirements, with lightweight building fabric and many large openings to allow cooling breezes to pass through the building.

There is a great difference in the properties of thermally light buildings and thermally heavy buildings. The fabric of the thermally light building is generally light in weight, with little capacity to absorb and store heat. Thus these buildings display fast response to external temperature changes. Thermally heavy buildings, in contrast, tend to be massive in their construction form, with dense walls that absorb heat readily. This construction form insulates the interior from external changes as a result of slow reaction times. The selected construction form must be matched to climate, user needs and the building services that are present to actively modify the internal environment.
The use of protective structures or enclosures is not the only method utilised in the moderation of people’s environments. Since fire was first discovered and used by primitive people to provide light and heat, the use of energy to aid in environmental moderation has been fundamental. Although the use of built enclosures can moderate the internal environment and reduce the effects of extremes in the external climate, the active control and modification of the internal environment require the input of energy. The use of buildings to house people, equipment and processes of differing types, exerting differing demands in terms of internal environment, has resulted in the development of buildings and associated services capable of controlling the internal conditions within desired parameters with great accuracy.

The nature of people’s perceptions of comfort within buildings has also developed. The simple exclusion of rain and protection from extreme cold or heat are no longer sufficient to meet human needs. The provision of an acceptable internal condition relies on a number of factors, which include:

- **Thermal insulation and temperature control**: The fabric of a modern dwelling must ensure that the levels of heat transfer between the interior and the external environment are within acceptable limits. In some cases this is aimed at minimising heat loss during cold periods; in others the aim is to minimise heat gain. In both of these situations the fabric must possess good levels of insulation in order to fulfil its functional requirement.

- **Acoustic insulation**: In most situations it is desirable to shield the internal environment within a dwelling from the noise of the external surroundings. In addition, the need to maintain levels of privacy demands that the external envelope of the building be capable of insulating against the passage of noise to a reasonable level.

- **Provision of light**: The interior of a dwelling must be provided with sufficient levels of natural or artificial light to allow the users to undertake their daily activities without hindrance. In addition, the levels of lighting maintained affect the perceptions of the comfort of the internal environment. Areas that are not provided with natural lighting would not be considered fit for human habitation.
Control of humidity and ventilation: In any building environment there is an acceptable range of relative humidity within which most people will feel comfortable. If the environment is subject to humidity levels above or below this range the occupants will feel discomfort; hence the humidity levels must be controlled. This is normally achieved in dwellings by the provision of appropriate levels of ventilation. The daily activities undertaken within a dwelling produce significant amounts of water vapour from cooking, washing and so on. Ventilating the interior to allow this vapour to migrate to the exterior is an effective method of humidity control. The provision of opening window areas facilitates ventilation and air movement within the dwelling, providing a constantly changing air supply to the interior.

Exclusion of contaminants: One of the functions fulfilled by the provision of appropriate levels of ventilation is the effective removal or exclusion of contaminants. Smoke, odours and other contaminants that are present in the air will be removed as a result of providing appropriate levels of air movement and, more importantly, air change through ventilation.

The extent to which each of these plays a part in the creation of an acceptable environment varies from situation to situation. As the construction industry seeks to develop a more sustainable approach to its activities there is a move towards more natural mechanisms for environmental control. Many new buildings are designed to maximise natural light and ventilation, with the aim of reducing energy costs. Similarly, the benefits of solar gain may be maximised in the design of dwellings with differing sizes of window on different elevations depending on orientation. Large windows on southerly elevations maximise solar gain, while small openings on northerly elevations minimise heat loss. In the Northern Hemisphere the sun shines from the south. Hence most solar gain is on south-facing elevations. This affects the design of buildings such that larger windows tend to be placed to maximise heat gain, with small windows on north-facing walls to reduce heat loss. Factors such as this will play an increasing part in the design of buildings as we move towards a more sustainable approach to the built environment.

Figure 1.2 on the next page illustrates these requirements and the ways in which they are met in modern construction forms.

The construction of buildings using materials that were readily available locally was common in Britain prior to the Industrial Revolution. After this the ability to transport materials via the canal and railway systems resulted in more widespread use of some materials. The adoption of slate for roof coverings is a good example of this. In the UK the local availability of slate is limited to quite restricted areas, such as North Wales and the Lake District. However, the use of slate as a roofing material was widespread. In some countries the use of local materials and techniques is still commonplace and the wide variety of vernacular building styles reflects this. As previously noted, the form of these buildings is also affected by the nature of the local climate and the need to moderate the internal environment. Figure 1.3 on the next page shows an example of a regional vernacular style.

The sustainability agenda is growing in acceptance and prominence worldwide. As a consequence of this, the impact of construction and urban development is under scrutiny. One of the results of this scrutiny is an increased awareness of a building’s environmental footprint. This is driving a return to the use of locally sourced materials and materials that have been sourced in an environmentally responsible manner.
Figure 1.2
The building as an environmental modifier.

External fabric provides insulation against extremes of temperature, including solar gain

Weather-resistant external fabric excludes moisture, wind etc.

Provision of windows allows natural lighting and ventilation

Air conditioning and mechanical vent. aid temperature and humidity control
Heat-producing appliances aid internal temperature control

External fabric insulated against noise

Figure 1.3
Vernacular forms of architecture.

These dwellings are located in Thailand. The lightweight construction form is created by the use of locally available materials. The large openings allow air to pass through the building to cool the interior quickly.

REVIEW TASKS

- What performance differences do we expect from thermally light buildings compared with thermally heavy buildings?

- Undertake an Internet search using the terms ‘vernacular building’ and ‘modern house construction’. Identify the key differences in the images that you locate. How do these relate to the performance requirements that we have previously identified?

- Visit the companion website at www.macmillanihe.com/companion/Riley-Construction-Technology-1 to view sample outline answers to the review tasks.
Performance requirements of building fabric

Overview
The requirement to provide an acceptable internal environment is merely one of the performance requirements of modern buildings. The level of performance of buildings depends upon several factors and the emphasis placed upon individual performance requirements varies from situation to situation. Statutes and guidelines, such as the Building Regulations, set out minimum standards. These standards must always be satisfied irrespective of perceptions of the performance of the building fabric. The increasing role of the building as an asset has also affected the ways in which buildings have been designed to maximise the long-term value and to minimise the maintenance costs of the structure and fabric. House construction is linked strongly to ‘marketability’ in some countries.

The performance requirements of buildings include:

- Structural stability
- Durability
- Thermal insulation
- Exclusion of moisture and protection from weather
- Acoustic insulation
- Flexibility
- Aesthetics
- Buildability
- Sustainability.

Each of these performance requirements is important, although in certain instances some aspects of performance may take on more significance than others. A good example of this is the issue of durability. The level of durability required is linked to the required lifespan of the building. In some cases the intended functional life of the building may be short. In these situations the level of durability required clearly takes on less importance than in a situation where the lifespan is intended to be longer. Notwithstanding this, the relative importance of the various requirements is generally considered to be equal, and each of the requirements must be addressed to some extent. It is therefore worthwhile considering each in turn.

Structural stability
In order to satisfactorily fulfil the functions required of it, a building must be able to withstand the loads imposed upon it without suffering deformation or collapse. This necessitates the effective resistance of loads or their transfer through the structure to the ground. In dwellings of traditional structure the mechanisms for dealing with these loads are rather different from those of a timber frame or modular building. The principles of each are dealt with later in this book and will not be explored in detail here. However, it is important to note that whatever the form of the building structure, the loads must be dealt with effectively. Generally this is achieved either by transferring them to some intermediate supporting element or to the supporting strata. Individual elements or components of the structure must also possess sufficient strength to cope with the forces that are established within them as a result of the various forms of load that exist within buildings.
**Durability**

The long-term performance of the structure and fabric demands that the component parts of the building are able to withstand without deterioration the vagaries and hostilities of the environment in which they are placed. The ability of the parts of the building to maintain their integrity and functional ability for the required period of time is fundamental to the ability of the building to perform in the long term. This factor is particularly affected by the occurrence of fires in buildings. The issue of durability affects the design of the building fabric and the selection of building materials and components. Great care must be taken in the specification of materials and components, as well as in the detailed design of the building, if premature failure is to be avoided. Durability is generally considered to be a variable benchmark of building performance in that it is linked to the intended design life of the building rather than being an absolute measure of performance.

**Thermal insulation**

The needs to maintain internal conditions within fixed parameters and to conserve energy dictate that the external fabric of a given building provides an acceptable standard of resistance to the passage of heat. The level of thermal insulation that is desirable in an individual instance is, of course, dependent upon the use of the building, its location and so on. As the costs of energy increase and the awareness of environmental issues becomes more widespread, so the issue of energy consumption increases in importance. The Building Regulations set down minimum requirements for thermal performance of building enclosures. These requirements will undoubtedly increase in the future, and the design of the building fabric will evolve accordingly.

**Exclusion of moisture and protection from weather**

The passage of moisture from the exterior, whether in the form of ground water rising through capillary action, precipitation or other possible sources, should be resisted by the building envelope. The ingress of moisture to the building interior can have several undesirable effects. These include the decay of timber elements, deterioration of surface finishes and decorations and risks to the health of the occupants, in addition to effects upon certain processes carried out in the building. Hence, details must be incorporated into the design of the building structure and fabric to resist the passage of moisture to the interior of the building from all undesirable sources. The exclusion of wind and water is essential to the satisfactory performance of any building fabric. In addition, the associated issue of exclusion of contaminants is increasingly recognised. One example of this is the potentially deleterious effect of radioactive radon gas upon the occupants of buildings. In areas where this is likely, specific design details must be introduced to minimise the potential risk associated with ingress of the gas.

**Acoustic insulation**

The passage of sound from the exterior to the interior, or between interior spaces, should be considered in building construction. The level of sound transmission that is acceptable in a building will vary considerably, depending upon the nature of the use of the building and its position. In the case of dwellings this is of particular
concern where individual dwelling units are adjacent or contained within the same building enclosure. In fact, this is the case for the vast majority of dwellings in the UK. Free-standing or detached dwellings are far less common than semi-detached and terraced houses or flats. The transmission of noise between linked dwelling units can be a major problem, and all new buildings take this into account. There is also an issue associated with the transfer of sound between the exterior and the interior of the building. This can be of particular concern in locations where there is likely to be significant noise, as in the case of dwellings close to airports, for example.

**Flexibility**

In industrial and commercial buildings in particular, the ability of the building to cope with and respond to changing user needs has become very important. Hence the level of required future flexibility must be taken into account in the initial design of the building. This is reflected, for example, in the trend to create buildings with large open spaces that may be subdivided by the use of partitions which may be readily removed and relocated. In reality, although the structural form of dwellings may well lend itself to flexibility in layout, this is rarely exploited by occupiers.

**Aesthetics**

The question of building aesthetics is subjective; however, it should be noted that in some situations the importance of the building’s aesthetics is minimal, whereas in others it is of course highly important. For example, the appearance of a unit on an industrial estate is far less important than that of a city centre municipal building. The extent to which aesthetics are pursued will have an inevitable effect on the cost of the building. In the UK and other places there has been a tendency for house building to follow traditional design, as this is most readily marketable.

**Buildability**

In recent years developers and constructors have made greater progress in reducing the number of defects in buildings. A link has been recognised between the complexity of details and the probability of failure. Hence great efforts are now made to ensure that buildings and their component details are physically ‘buildable’ in true site conditions.

This summary is not a definitive list of the performance requirements of all building components in all situations; however, it is indicative of the factors which affect the design and performance of buildings and their component parts (Figure 1.4).

**Sustainability**

There is now a widespread acceptance of the need to undertake all construction activity, including the construction of dwellings, in a sustainable way. This is supported by legislative controls and drivers such as the Building Regulations and a raft of specific environmental legislation. In the UK the introduction of energy ratings for new homes and the requirement to include energy information in the sales details of existing homes have ensured that sustainability is an issue that is recognised not just by constructors but also by dwelling owners and occupiers.
1.2 Forces exerted on and by buildings

Introduction

After studying this section you should be aware of the differing forces that act upon the structure of buildings.

You should have developed knowledge of the origins of these forces and the nature in which they act upon the structural elements of the building.

You should have an intuitive appreciation of the relative magnitude of various forces.
You should be able to distinguish between the forces exerted on the building and the forces exerted by it.
■ You should understand the terminology associated with the forces active within buildings, and, given a variety of scenarios, be able to recognise the different types of forces and appreciate their implications.

Loading forms
Overview
Forces acting upon the structural elements of buildings derive from a variety of sources and act in many different ways. However, there are a number of basic principles of structural behaviour, and these can be applied in considering the application and effect of the various forces that act upon buildings. The ways in which the structure and fabric of a building behave will depend upon their ability to cope with a range of inherent and applied loads or ‘dead’ and ‘live’ loads. If the building is able to withstand the loading imposed upon it, it will remain static; in such a state it is considered to be stable. Any force acting upon a building is considered as a loading, whether it arises as a result of external factors, such as the action of wind on the building, or from the use of the building, such as the positioning of furniture, equipment or people. We must also recognise that the building itself is a source of loading simply as a result of the effect of the self-weight of the structure.

In order to withstand these forces two basic structural properties must be provided by the building. First, the component parts of the building must possess adequate strength to carry the applied loads. Second, the applied forces must be balanced in order to resist the tendency for the building to move. Thus the building must remain in equilibrium. In order to understand how these factors are achieved we must first examine the nature of the loads that act upon buildings.

The nature of loads
The forces, or loads, applied to buildings can be considered under two generic classifications: dead loads and live loads. Dead loads would normally include the self-weight of the structure, including floors, walls, roofs, finishes, services and so on. Live loads would include loads applied to the building in use, such as the weight of people, furniture, machinery and wind loads. Such loads are normally considered as acting positively on the building. However, in the case of wind loads (Figure 1.5) suction zones may be created (that is, negative forces); this effect is often illustrated by the action of roofs being lifted from buildings in high wind conditions. Hence buildings must be designed to cope with forces acting in a variety of ways.

The ability of the materials used in the construction of buildings to withstand these loads is termed ‘strength’. In considering whether a building has sufficient strength, the different types of load must be considered. Their direction is also important: they may be oblique (at an angle) or axial (along the axis of an element).

Stress
When subjected to forces, all structural elements tend to deform. This deformation is resisted by stresses, or internal forces within the element. The stresses which are established in components fall into four basic categories: shear stress, tensile stress, compressive stress and torsional stress.
Shear stress
Shear stress (Figure 1.6) is the internal force created within a structural member which resists a tendency, induced by an externally applied loading, for one part of the member to slide past another.

Tensile stress
Tensile stress (Figure 1.7) is the internal force induced within an element which resists an external loading that produces a tendency to stretch the component. When such a force is applied the member is said to be in tension.
Compressive stress
Compressive stress (Figure 1.8) is the internal force set up within a structural component when an externally applied force produces a tendency for the member to be compressed or squashed. Such an element is said to be in compression.

![Figure 1.8 Compressive stress.](image)

Torsional stress
Torsional stress (Figure 1.9) is the internal force created within a structural element which resists an externally applied loading which would cause the element to twist.

![Figure 1.9 Torsional stress.](image)

Strain
The effect of a tensile or compressive stress on an element is to induce an increase or decrease in the length of the element. The magnitude of such a change in length depends upon the length of the unit, the loading applied and the stiffness of the material. The relationship between this change in length and the original length of the component gives a measure of strain (denoted by \( e \)):

\[
e = \frac{l}{L}
\]

where \( l \) = change in length and \( L \) = original length.

This effect is also evident in materials subject to shear stress, although the deformation induced in such cases tends to distort the element into a parallelogram shape.

The relationship between stress and strain (subject to loading limits) is directly proportional and is a measure of the material stiffness. The ratio of stress/strain is known as the modulus of elasticity.

Moments
The application of a force can, in certain instances, induce a tendency for the element to rotate. The term given to such a tendency is moment. The magnitude of
such a moment depends on the extent of the force applied and the perpendicular
distance between the point of rotation and the point at which the loading is applied.
As a result of the effects of leverage, relatively small loads applied at considerable
distances from the point of action can induce rotational forces. Moments upon
structures must be in equilibrium in order for the structure to remain stable; that
is, clockwise moments (+) must be equalled by anticlockwise moments (−). The
magnitude of a moment is the product of the force applied and the distance from
the point of action at which it is applied (the lever arm) and is expressed in Newton
millimetres (Figure 1.10).

Figure 1.10
Moments applied to a
building element.

For equilibrium: moment caused by load = Moment applied by support

\[ LM = IR \]

REVIEW TASKS
- In as few words as possible distinguish between the following forms of stress:
  1. Tensile
  2. Torsional
  3. Shear.
- Identify examples of where each of these are found in buildings.
- Consider the shape and form of typical building components such as floor
  joists, lintels and roof members. How are these influenced by the forces that
  they are designed to cater for?
- Visit the companion website at www.macmillanihe.com/companion/Riley-
  Construction-Technology-1 to view sample outline answers to the review tasks.

REFLECTIVE SUMMARY
- Stress is the term used to refer to the internal force within an element that is
  subjected to an external force or loading. Stress may be: shear, compressive,
tensile or torsional.
- Strain is a measure of the tendency of an element to suffer deformation under
  loading.
- Moment is the result of a force applied perpendicular to an element at a
distance from a point of rotation.
1.3 Structural behaviour of elements

Introduction

- After studying this section you should be aware of the implications of the loads applied to structural building elements.
- You should understand the terminology associated with the structural behaviour of buildings and the elements within them.
- You should appreciate the implications of the structural performance upon the selection of materials.

Included in this section are the following areas:

- The nature of forces acting on buildings
- The nature of building components

The nature of forces acting on buildings

Overview

The effects of the types of loads or forces exerted on a building depend on the way in which those forces are applied.

Maintaining the integrity and structural stability of a building relies on its ability to withstand inherent and applied loads without suffering undue movement or deformation. Nevertheless, it is possible to allow for a limited amount of movement or deformation within the building design, as is common in mining areas for example. Resistance to movement and deformation results from an effective initial design of the structure as a unit and the ability of materials used for individual components to perform adequately.

Limited movement, of certain types, is inevitable in all structures and must be accommodated to prevent the occurrence of serious structural defects. The effects of thermal and moisture-induced changes in building materials can be substantial, producing cyclical variations in the size of components. This dictates the inclusion of specific movement accommodation details, particularly when dealing with elements of great size, such as solid floors of large area. Additionally, the period shortly after the erection of a building often results in minor consolidation of the ground upon which it is located; however, this will generally be very minor in nature. These forms of movement and deformation are acceptable; other forms, however, must be avoided. Their nature and extent depend upon the nature and direction of the applied forces. Three main categories of applied forces combine to give rise to all types of building movement.

Vertical forces

Vertically applied forces, such as the dead loading of the building structure and some live loads, act to give rise to a tendency for the structure to move in a downward direction – that is, to sink into the ground. The extent of any such movement depends upon the ability of the building to spread the building loads over a sufficient area to ensure stability on ground of a given loadbearing capacity. The loadbearing capacities of different soil types vary considerably; the function of foundations to buildings is to ensure that the loading of the structure does not exceed the bearing capacity or safe bearing pressure of the ground. In most instances the bearing...
The term slenderness ratio relates to the proportional dimensions between height and thickness of structural elements.

Part 1: Introduction to house construction

Figure 1.11
Reduction of pressure applied to the ground resulting from the use of foundations.

Figure 1.11 shows the reduction of pressure applied to the ground resulting from the use of foundations. The load is reduced by using foundations to increase the interface area between the building and the ground, thus reducing the pressure applied to the ground (Figure 1.11).

The need to withstand such vertical loads is not exclusive to the lower elements of the building structure, although such loads are greater in magnitude at the lower sections owing to the effects of accumulated loads from the structure. All structural components must be of sufficient size and strength to carry the loads imposed upon them without failure or deformation. Columns and walls, often carrying the loads of floors, roofs and so on from above, must resist the tendency to buckle or to be crushed by the forces exerted. The way in which columns and walls perform under the effects of vertical loads depends on the slenderness ratio of the component (Figure 1.12). In simple terms, long, slender units will tend to buckle easily, while short, broad units will resist such tendencies. In long, thin components the risk of buckling can be greatly reduced by incorporating bracing to prevent sideways movement; this is termed 'lateral restraint'.

If overloaded significantly even short, broad sections may be subject to failure; in such instances the mode of failure tends to be crushing of the unit, although this is comparatively rare.

Horizontal components, such as floors and beams, must also be capable of performing effectively while withstanding vertically applied loads (Figure 1.13). This is ensured by the use of materials of sufficient strength, designed in an appropriate
manner, with sufficient support to maintain stability. Heavy loads on such components may give rise to deflection, resulting from the establishment of moments, or in extreme cases puncturing of the component, resulting from excessive shear at a specific point. When subjected to deflection, beam and floor sections are forced into compression at the upper regions and tension at the lower regions. This may limit the design feasibility of some materials, for example concrete, which performs well in compression, but not in tension. Hence the use of composite units (and composite sections) is common, such as concrete reinforced in the tension zones with steel.

As shown in Figure 1.5, illustrating the effects of wind loads, the vertical forces applied to buildings may be in an upward direction. These must also be resisted, usually by making the best use of the mass of the building. Upward loads may also be generated from the ground, in zones of shrinkable clay or those which are prone to the actions of frost, for example. The upward force exerted by the ground in such cases is termed ‘heave’.

Some structural elements are referred to as composite sections. They are made up of two or more materials acting in such a way that they maximise the performance of the composite by combining the best characteristics for the individual materials.
Horizontal forces acting on buildings derive from many sources and it is difficult to generalise upon their origins and effects. Typically, however, such loads may be exerted by subsoil pressure, as in the case of basement walls, wind or physical loading on the building. The effects of such forces are normally manifested in one of two ways:

- Overturning, or rotation of the building or its components
- Horizontal movement, or sliding of the structure.

These forms of movement are highly undesirable and must be avoided by careful building design. The nature of the foundations and the level of lateral restraint or
buttressing incorporated into the building design are fundamental to the prevention of such modes of failure. Additionally, particularly in framed structures, the use of bracing to prevent progressive deformation or collapse is essential; this could be described as resistance of the ‘domino effect’ (Figure 1.14).

**Oblique forces**

In some areas of building structures the application of forces applied at an inclination is common (Figure 1.15). This is generally the case where pitched roofs are supported on walls. The effects of such forces produce a combination of vertically and horizontally applied loads at the point of support. These effects are resisted by the incorporation of buttressing and/or lateral restraint details. The horizontal effects of these loads are sometimes ignored, with disastrous effects.

**REVIEW TASKS**

- Explain the value of foundations in dissipating the forces experienced by a wall.
- Identify examples of horizontal, vertical and oblique forces in buildings with which you are familiar.
- Visit the companion website at www.macmillanihe.com/companion/Riley-Construction-Technology-1 to view sample outline answers to the review tasks.
PART 1 Introduction to house construction

This section is included to extend in a brief way the earlier material concerning the forces experienced by the components of a building. The bulk of the forces experienced by a house would be compression and tension. These tend to translate directly into the use of certain materials suited to these forces – we know that concrete, for example, is excellent in resisting compression and that reinforcement steel is used to counteract tension because of its elasticity. At this stage it may be useful also to consider why the components used in housing are not only of a certain material but also of a certain shape.

We can use the example of a ruler to explain the value of placing material in direct opposition to the forces that they will experience. If the ruler is laid flat and loaded centrally it will bend with relative ease (Figure 1.16).

It will also be seen that if we now rotate the ruler through 90 degrees and load it again, the resistance to bending is dramatically improved, even though its material content is exactly the same. The reason for this is that the body of the material has been placed directly in opposition to the loads to be carried.

This same effect has led to the development of certain shapes of components, such as steel beams. When we think of steel, the I-section generally comes to mind. If we examine the forces experienced by a beam spanning a gap, we know that there is a tendency to bend in a ‘smile’ fashion. Earlier in this chapter we discussed how this sagging leads to maximum compression at the top of beams and maximum tension at the bottom (Figure 1.13).

If we now look at the I-shape which has evolved for steel beams, Figure 1.17 shows how the beam has been arranged to place material where it is really needed. The web of the beam (like our ruler) is vertical and therefore directly opposes the direction of bending, providing efficiency in resistance to loads. Also, we have just said that when a beam bends, the maximum compression and maximum tension are in the top and bottom of the beam. Here we have the flanges of the beam, again
Corrugated materials attempt to place material closer to the vertical plane in order to counteract bending. The effect may be best illustrated by trying to make a flat piece of paper span between your fingers: it sags easily and the paper collapses.

However, if you were to introduce a series of folds as shown in Figure 1.18, the reorganisation of the material and the movement of material towards the vertical help the paper to span the gap successfully.
This principle is found in corrugated roof sheeting and in materials such as wall cladding, which is used extensively on light industrial and industrial premises.

**REVIEW TASKS**

- We have accounted for the popular sectional shape provided for steel beams. Now consider the shapes of other building elements and consider how their shapes are driven by the loads that they are intended to resist.

- Consider the following key locations in the structure of houses:
  - foundation/wall junction
  - upper floor/wall connection
  - eaves at roof level
  - ridge at roof level.

  What loads/forces are present at these locations and how are the various components and connections designed to transfer or resist these?

- Visit the companion website at [www.macmillanihe.com/companion/Riley-Construction-Technology-1](http://www.macmillanihe.com/companion/Riley-Construction-Technology-1) to view sample outline answers to the review tasks.
Index

Acoustic insulation  6, 9, 10, 62, 164, 176, 230, 267, 359
Aesthetics  4, 9, 11, 164, 178, 211, 274, 277, 305, 320–1, 332, 340
Air leakage  54, 86–7, 290, 321
Airborne sound transmission  176, 270
Airbrick  154, 157
Apron lining  250, 259
Architrave  270, 338, 344–5
Asphalt  128, 148–9, 306
Auger  29, 115–16, 121
Axial  13, 213, 264
Axial loading  264
Batten  167, 188, 199, 200, 289, 292–3, 298
Beads  330–1, 333
Bearing capacity  17, 27, 31, 93–100, 103–4, 107, 109, 111, 116–18, 121, 123, 126, 148, 160, 259, 272
Bending  22–4, 100, 107–9, 123, 219
Bentonite  115
Bituminous felt  303–5
Blocks  63, 71, 107, 126–7, 130, 132, 155, 157, 167, 177–8, 180–1, 186, 255, 259, 267, 270, 309, 310, 340–1, 359, 361
Bonding, brick  232–3
Bonnet hip tiles  297
Boot lintel  236
Breather paper  188, 204
Bricks  32, 71, 107, 127 130, 133, 154, 157, 163, 177–81, 186, 236, 267, 361
Bricks, clay  163, 178–80
Bricks, concrete  180
Broadband  36, 44, 138–9
Brownfield sites  34
Buckling  18, 178
Buildability  9, 11, 164, 320
Building paper  188
Building, industrial  57, 154, 206, 261, 264, 328
Building, rationalised  57
Building, traditional  55–7
Building, post-traditional  56–7
Building, vernacular  7–8
Butt jointed  293
Buttress  21
Calcium silicate bricks  180
Capillarity  146, 167
Capillary action  10, 146
Carbon dioxide  77–8, 81–2, 85–6, 98, 317–18, 360
Carriage  46, 258
Casement  323–5, 328
Catchpit  51–2
Cavities, close  170
Cavity barriers  189, 200, 222, 233
Cavity closure  189, 234–5
Cavity fill  130, 132, 182
Cavity tray  221, 236, 241
CDM  see Construction (Design & Management) Regulations
Ceiling joist  264, 279–80, 283–6, 313, 350
Ceilings  341–3, 349
CFA piles  116, 121
Chimneys  273, 307, 309–10
Cladding, lightweight  197, 199
Cladding, masonry  198, 201, 219, 221
Clay wall  356–9, 367
Closed string  257
Closed systems  57–9
CLT (see cross-laminated timber)
Cohesionless soils  94, 96–7, 123, 133
Cohesive soils  94, 96, 107, 123, 133
Cold bridging  150–1, 155, 170, 175, 177, 234, 236, 241, 328
Combined drainage  45, 48
Common rafters  280, 282
Compression  15, 19, 22, 95, 274–5, 285–6
Compressive stress  13, 15
Concrete, mass  103, 119, 148, 202, 361
Construction, cavity  130–1, 133, 166–7, 177, 186, 221
Construction, filled cavity  130–1, 133
Construction, foundation block  130–1
Construction, panelised  65–6, 163, 209, 212, 224
Construction, porous solid  167
Construction, steel frame  65, 163, 206, 213, 219, 222–4, 232
Construction, sustainable house  54, 77–80
Construction, volumetric  63–6, 207, 210, 237, 240–1
Construction (Design & Management) Regulations  38–40, 54
Contaminants  7, 10, 25, 31–3, 36, 40, 87, 97, 146–7, 149, 309, 318, 320–1
Contaminated land  25, 27, 33
Continuous flight auger (CFA)  115–6, 121
Contractors  38–9, 69, 75
Cover technology  98
Cross-laminated timber (CLT)  65–6, 225, 230–2, 243
Cross-ventilation  154, 293, 300, 302, 313, 318

369
Index

Dado 348–9
Damp-proof course (DPC) 70–1, 91, 124, 127–8, 133, 142, 149, 157, 163, 167, 178–9, 193–4, 202–3, 213, 221, 234–6, 351
Damp-proof membrane (DPM) 72, 127, 129, 149, 213

DBA scale 276

Dead loads 13, 144
Deleterious 10, 126
Developer’s equation 26–7, 40, 73–4, 76, 187
Dew point 312–13, 315
Dewatering 32, 52
Diagonal bracing 291
Differential movement 28, 136, 198, 201
Differential settlement 92
Dimensional coordination 58, 186
Disabled access 152
Diurnal range 5
Door, flush 332, 335, 338
Door, matchboarded 336–7
Door, panelled 332–6
Door, types of 332–3
Door frame 338–9
Door lining 339, 345–7
Dormer 175, 281, 290
DPC (damp-proof course) 70–2, 127–8, 133, 149, 157, 194, 202–3, 213, 234–6
DPM (damp-proof membrane) 72, 127, 129, 149, 213
Drones (See UAVs) 25, 28–9
Dwelling Emission Rate (DER) 85, 87, 173

Earthwork support 107
Eaves course 293
Environment Act 39, 98
Environmental Protection Act 39
Equilibrium 13, 16, 97
Exclusion of moisture 9–10, 125, 127–8, 147, 149, 164, 166–8, 221
Expanded metal lathing 344
Expenditure profile 74
External fabric 10, 87, 145
Fair faced finish 178
Finishes, wall 342
Finishes, ceiling 196
Finishes, floor 72, 352

Fink 285
Fire resistance 201, 232, 245, 260, 263, 340, 362
Flange 22, 247–8
Flanking sound transmission 176
Floor, ground 42, 70, 72, 91, 136, 143–6, 148, 150, 153–5, 157, 159, 212–14, 230, 245, 254–5, 264
Floor joists 16, 72, 154, 194, 196, 212, 216, 245, 248–9, 252, 254
Floorboarding 154, 248, 336, 342
Floors, beam and block 158, 255
Floors, timber ground 154
Floors, upper 163, 194, 204, 216, 218, 244–5, 247–8, 251, 253, 255, 257, 259
Flue 16, 22, 25–6, 28, 32, 36, 40, 80, 138, 148, 180, 274, 276, 278, 310, 318, 322, 330
Form factor 174–5
Formation level 70
Formwork 58, 107, 119, 123, 356–7, 359, 361–2
Foundations, deep strip 108, 132
Foundations, pad 109–10
Foundations, raft 109–11, 202, 213
Foundations, strip 70, 103–4, 106–9, 112, 132–3, 202, 355
Foundations, trench-fill 132
Frame, balloon 187, 189–90, 193
Frame, panelised 207–8
Frame, platform 187, 189, 191–3
Frame, stick-build 207
Fuel poverty 315
Gable end 277, 281, 287
Gable ladder 205, 281, 286, 288
Gang nail plate 284
Gauge 206, 292–3, 343, 346
Glazing 36, 316, 322–3, 328–33
Green 34, 54, 78, 187, 303, 330, 353–60, 364–5, 367
Green roofs 353, 364–5
Ground beam 118–19, 123, 213, 355
Ground-supported floor 144, 146, 148
Guard railing 256, 258
Gutter 275, 292–3, 295, 303, 307, 311
Gypsum plaster 201, 265, 269, 341, 343, 345, 350
Half turn stairs 255
Hanger 217, 245, 249
Hardcore 46, 71, 149, 154
Headlap 297
Hemp 19, 94, 97, 104, 118, 136
Hemplime/hempcrete 358–9
Herringbone strutting 245–6, 248
Hip iron 296
Hip rafter 280–3, 296
Hipped end 277–8, 281, 288
Holding-down strap 194, 213, 279
Honeycombed 154, 335
Humidity 5, 7, 199, 312, 358
Hygroscopic 154, 186, 248, 300, 322, 332–3, 351, 358
Impervious cladding 166
Industrial Revolution 5, 7, 55
Infrastructure 25–7, 36, 38, 40, 44, 46, 63–4, 75, 80, 134, 139
Inner string 257
Insulated concrete formwork (ICF) 353, 356, 361–3
Insulation, thermal 6, 10, 81–2, 86, 145, 163–4, 168, 181, 186, 188, 213, 243, 273, 278, 290, 300, 302, 312–13, 320, 323, 346
Integrity 10, 17, 92, 111, 129, 176, 216, 219, 231, 263, 265, 300
Internal environment 4–9, 276, 316–17
Interstitial condensation 188, 312–13
Invert level 45
Inverted roof 300, 306

Jack rafter 277–80, 282, 291
Jamb 233
Joist hanger 245
Kerb 25, 46
Kerfed joint 248
Kingspan 226
Index

Land drains 51
Load, lateral 101, 125, 127-8, 165, 205, 219, 265
Lateral pressure 127
Lateral restraint 18, 20-1, 165, 216-17, 252
Lath and plaster 350
Lazy S 75
Lean-to 282
Light penetration 321
Lintel 16, 72, 74, 113, 137, 141, 163, 178, 216, 220, 223, 232, 233, 235-9, 268, 321
Live loads 13, 17, 144, 165, 187, 275-6, 280
Meter box 43, 137
Middle rail 333
Modern methods of construction (MMC) 54, 58-64, 66-8, 224, 240, 354-5
Modular construction 63, 211, 216
Modulus of elasticity 15
Moisture content 94, 97, 118, 248, 300, 322, 332, 338, 351-2
Moments 15, 16, 19
Monolithic 306
Movement accommodation 17, 183-4, 201
Muntin 333
National grid 42
National Joint Utilities Group (NJUG) 134-5
Natural gas 43
Newel 257
Noggins 188, 216, 246-7, 270
Opaque 329
Open fire flue 310
Open string 257
Open systems 57
Ordinary Portland cement 32, 56, 95, 180
Ordnance datum 49
Orientation 7, 168, 316, 329, 331
Outer string 257
Oversite 106-7, 154, 157
Panelised construction 65-6, 163, 209, 212, 224
Panelled door 332-6
Partitions 11, 69, 72, 159, 179, 203, 254, 260-70, 309
Partitions, demountable 261
Partitions, hollow 270
Partitions, masonry 267
Partitions, stud and sheet 270
Passive stack 87, 319
PassivHaus 54, 87-8, 317
Paving 25, 47, 152
Permeability, air 87-8, 168, 182-3, 225, 318-19, 321, 327-8, 339
Piles 67, 100, 112-3, 115-21, 123, 213, 355
Piles, displacement 113, 115
Piles, end-bearing 113, 116
Piles, friction 113, 116-17
Piles, replacement 113, 115
Plan of work 27, 68-9, 73
Planning permission 37, 64
Plant 28, 45, 49, 56-7, 70, 73-6, 89, 106, 123, 155, 178, 296, 339, 358, 364-5
Plaster accessories 343
Plasterboard 58, 72, 139, 188, 196, 201, 216, 260, 263, 269-71, 279, 289, 300, 302, 341-3, 34, 348, 350-1
Pod (see modular construction) 64, 66, 210, 238, 240-1
Pointing 185
Polished plate glass 329
Positive pressure ventilation 314
Post-traditional building 56-7
Precast 25, 66, 91, 113, 119, 121-3, 142, 154, 157, 163, 213, 355
Preliminary items 74
Pressure 17-8, 20, 30-1, 40-3, 86-7, 95, 97, 99, 125-9, 146, 182, 187, 213, 230, 242-3, 275, 284, 286, 314, 318
Pressure, hydrostatic 125, 129, 147
Pressure, mains 42
Principal contractor 39
Procurement 28, 45, 56-7, 70, 73, 89, 106, 123, 155, 178, 296, 339, 358, 364-5
Rainwater goods 307, 366
Ratio, slenderness 18, 180
Rebates 325
Recycling 78, 80, 84, 309, 355, 367
Reinforcement 22, 103, 107, 111, 114-15, 123, 350-1
Remediation 33, 97-8
Render 64, 167, 178, 186, 197, 199, 221, 224, 226, 232, 267, 341, 357
Repose, angle of 94, 97
RIBA 27, 68, 73
Ridge 24, 83, 88, 114, 117, 150, 153, 170, 219, 226, 234-6, 277-8, 280-4, 289, 293-9, 309, 319
Ridge tile 294-5, 298-9, 309
Riser 256-8
Rising main 42
Rocker pipe 141
Roof covering 7, 224, 273, 275-7, 280-3, 286, 291, 293-4, 296, 298-9, 301, 303-6, 313, 315
Roof drainage 273, 307
Roof outlet 307, 311
Roofing, built-up felt 303
Roofs, cold deck 306
Roofs, collar 278
Roofs, couple 278-9
Roofs, dry 298
Roofs, flat 273, 299, 300, 302-4, 306
Roofs, green 353, 364-5, 367
Roofs, pitched 21, 64, 67, 219, 224, 273, 278-83, 288, 290-2, 298, 300-1, 305, 307, 313
Roofs, rafter and purlin 56, 278, 280-1, 284
Roofs, trussed rafter pitched 283
<table>
<thead>
<tr>
<th>Index</th>
<th>373</th>
</tr>
</thead>
</table>