BRE Building Elements series

ROOFS AND ROOFING

Performance, diagnosis, maintenance, repair and the avoidance of defects

THIRD EDITION

H W Harrison, P M Trotman and G K Saunders

IHS

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CONTENTS

PREFACE TO THE THIRD EDITION

The third edition of this book is being published at a time when the UK construction industry is facing a significant reduction in its work load, and nearly a decade after the second edition was prepared. That decade has seen massive changes in public awareness of the need for sustainability in construction, and the introduction of the Code for Sustainable Homes in November 2006, which since May 2008 has formed a basis for assessment of the acceptability of the design of new housing in England and Wales.

But similar needs exist for the whole of the UK's future building programme, new-build hospitals, factories, educational buildings and other long-life buildings which will provide challenges to designers in meeting the conditions brought about by anticipated climate changes and the need to be carbon-neutral and to conserve our dwindling natural resources. There have also been significant changes in British Standards which increasingly reflect those taking place in Europe.

However, the UK cannot afford year-on-year to renew more than a very small percentage of the stock of existing buildings, and the need for intelligent conservation and upgrading of the old stock is arguably of equal if not more importance.

It is against this background that this third edition of *Roofs and roofing* has been prepared. In addition to thorough revision of the chapters on the more traditional forms of construction, such as tiling and slating, completely new chapters have been prepared on:

- extensive lightweight green roofs,
- modern methods of construction,
- roof-mounted photovoltaic systems,
- thermal insulation in lofts,
- loft conversions,
- single-layer membranes.

New sections have been introduced as appropriate into existing chapters, including:

- new forms of metal roofing,
- siphonic roof drainage,
- new materials technologies,
- improved protective finishes for timber, metals and concrete.

Where appropriate, each chapter now contains a section dealing with provisions that may become necessary to accommodate climate change (eg increased rainfall, stronger winds and higher temperatures).

There have been considerable changes too in the standards covering roof drainage which have been reflected in the revised text.

Approximately one-quarter of the photographs are new to this edition.

HWH
PMT
GKS
June 2009

3 SHORT-SPAN DOMESTIC PITCHED ROOFS

Short-span roofs are normally defined as being of less than 8–9 m span. Pitched roofs are conventionally defined as those roofs with slopes greater than 10°, whereas roofs of slope 10° or less are defined as flat.

For the purposes of this book, pitched roofs have been categorised into those covered in relatively small overlapping units, dealt with in Chapters 3.1, 3.2 and 3.6, those covered in sheet materials, dealt with in Chapters 3.3–3.5, and thatch, which forms a category of its own, dealt with in Chapter 3.7.

Small overlapping units consist of the following types:

- clay tile,
- concrete tile,
- natural slate,
- manmade slate,
- shingles.

Figure 3.2 shows the current market share held by the first four categories. Following increased appreciation of the need to protect the environment, there has been limited use of recycled materials such as rubber. The increased popularity of PV systems is envisaged which will affect the type of roofing chosen to support them.

Some general information about defects in pitched roofs in housing can be found in *Assessing traditional housing for rehabilitation*[1].

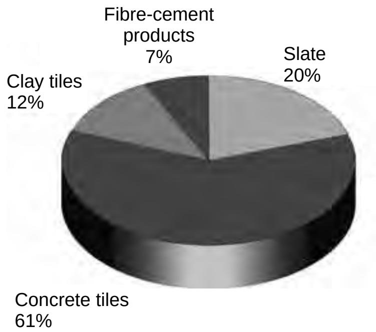

Figure 3.2: Roof tile market by value, 2006. Data from *Roofing Market Report*[2]

Figure 3.1 This steeply pitched plain tiled roof was built in 1880 but re-covered after bomb damage in the 1939–45 war

Box 3.1: Calculations of rainwater run-off from short span domestic roofing and gutter size

Using Figure 3.25, the effective catchment area that will discharge to each gutter is:

- for the slope of a pitched roof, the plan area, A (m^2), plus half the elevation area, B (m^2) (Figure 3.25a),
- for a pitched roof abutting a wall, the plan area, A, plus half the elevation area, B, plus half the wall area, C, above the roof slope (Figure 3.25b),
- for a flat roof, the relevant plan area.

The run-off rate to each gutter is the total catchment area for the gutter divided by 48. This produces the run-off in litres per second using the recommended rainfall (thunderstorm) rate of 75 mm/hour.

The size of the guttering is shown in Table 3.5 using the flow capacity that will accommodate the run-off rate. As part of this process, the number of outlets should be considered: more outlets from a run of guttering spreads the total loading on the gutter, but the loadings will vary according to where the outlets are positioned (Figure 3.26).

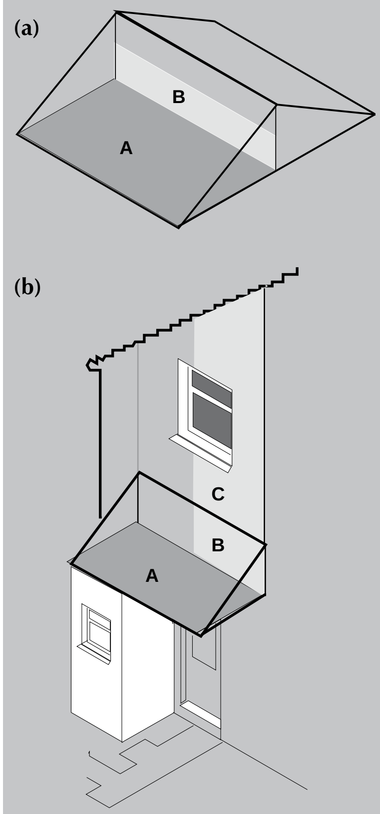

Figure 3.25: Catchment areas for calculating rainwater run-off

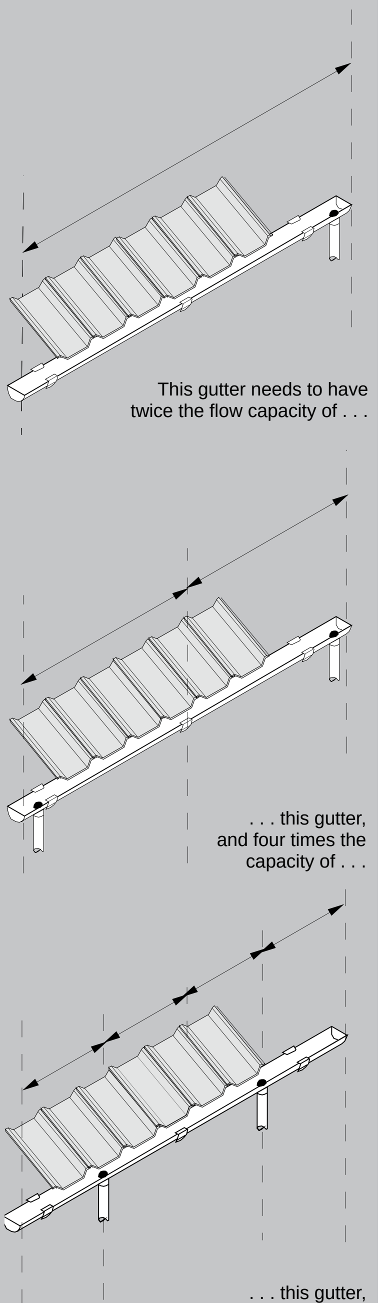

Figure 3.26: Spacing between outlets to reduce water load on gutters

Table 3.5: Flow capacities of standard eaves gutters (when level)

Size of gutter (mm)	Flow capacity (litres/sec) True half round	Nominal half round
75	0.38	0.27
100	0.78	0.55
115	1.11	0.78
125	1.37	0.96
150	2.16	1.52

BRE site inspections. Drawings have been seen that specifically state that the design of gutter systems should be left to the site staff to sort out! The pitch of valley gutters is less than the pitch of the roof they join, and valley gutters on pitches of less than 20° are particularly prone to leaking. Poor detailing was commonly found in the BRE quality assessments.

BRE site inspections revealed a number of cases where gutters had not been installed on porches and bay windows: decisions which may be marginal where the drips cause no inconvenience to the occupants, but less acceptable for doorways (Figure 3.27).

A room in the roof

Where a room is formed within a pitched roof void, it is sometimes difficult to achieve adequate ventilation for the roof to the outside (Figure 3.28). BRE Defect Action Sheets 118[22] and 119[23] deal with this problem, particularly where it involves the careful placing of thermal insulation to ensure an adequate ventilation gap. *Thermal insulation: avoiding risks*[24] is also helpful. The most important points to watch are:

- that a vapour control layer (eg of at least 500-gauge polyethylene) is installed in the sloping part of the roof under the insulation,
- that a vapour permeable sarking is used in new construction,
- that cupboards should be within the insulated envelope, ensuring continuity of the lining.

MAIN PERFORMANCE REQUIREMENTS AND DEFECTS

Choice of materials for structure

Timber has been used as the main structural material in the vast majority of tiled roofs: those dating from before the early 1960s for the most part designed with strutted purlins (Figure 3.29), more recent designs using trussed rafters. The structure of most of these is in good condition (only 1 in 8 of these structures being reported as faulty[5]), provided attention has been paid to routine maintenance of the covering.

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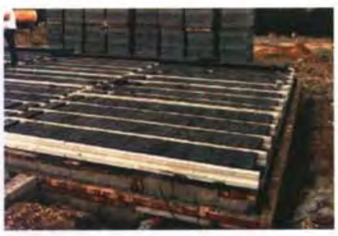
BRE Building Elements

Floors and flooring



P W Pye
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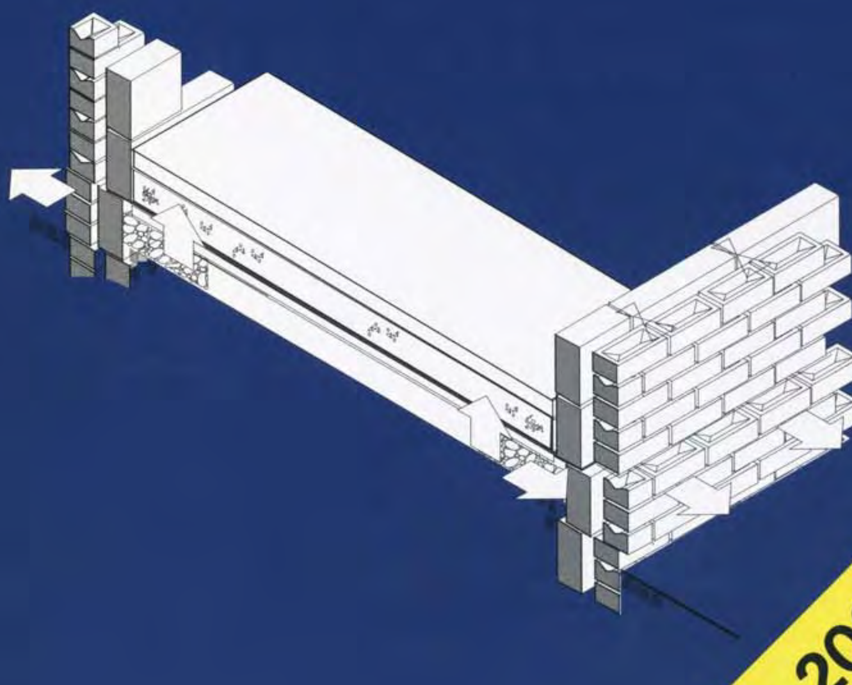
H W Harrison

Performance, diagnosis, maintenance, repair and the avoidance of defects



BRE

New edition 2003

BRE Building Elements

Floors and flooring

Performance, diagnosis, maintenance, repair and the avoidance of defects

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Contents

Preface

First edition

It has been said that most problems with floors occur because people insist on walking on them, pushing trolleys over them, placing large objects on them and dropping things on them – if only they were ceilings they would never wear out! A small witticism that reflects the way some people, including professionals in the construction industry, see floors. Or, rather, don't see them! After all, what is there to a floor: floorboards nailed to joists. What can go wrong with that? And if it happens to form a ceiling, even better. But the facts belie this perception.

BRE's figures on faults in buildings of all types (given in greater detail in the introductory chapter which follows) show that a substantial number concern floors. Despite the advice that has been available to the industry from the 1920s, faults in flooring, such as cracking, detachment and entrapped water, recur frequently. If some of the errors appear elementary, this only reflects what happens in the design office and on site. All that we can do is show to those who work in the flooring industry what is being done incorrectly and how to take corrective action – preferably before faults or defects lead to costly damage.

This book describes the materials and products, methods and criteria which are used in the construction of floors and flooring. It draws the reader's attention to those elements and practices which ensure good performance or lead to faults and failure. There is sufficient discussion of the underlying structure to enable an understanding of the behaviour of the whole floor without going very far into engineering design principles. It does not purport, though, to be a book of construction practice; nor does it provide the reader with the information necessary to design a floor, but, mainly through lists and comprehensive illustration, shows him or her what to look for as good and bad features of floors and flooring. It also offers sources of further information and advice.

Readership

Floors and flooring is addressed primarily to building surveyors and other professionals performing similar functions, such as architects and builders, who maintain, repair, extend and renew the national building stock. Lecturers and other educators in the building field will also find it to be a useful adjunct to their course material.

Scope of the book

Although books on flooring are few, there is no shortage of industry guidance on floors and flooring. The problem is that people do not use the guidance that exists.

To try to remedy that situation, the contents of this book are configured so that the principles, features and functions of floors and flooring are described first (Chapter 1). There needs to be sufficient discussion of principles to impart understanding of the reason for certain practices; without that understanding, practitioners will have difficulty following correct procedures – or until they make the mistakes, or overlook precautions, as previous generations have done. The criteria presented in Chapter 1 are then related to the different types of floors and their finishes (Chapters 2–8).

The text concentrates on those aspects of construction which, in the experience of BRE, lead to the greatest number of problems or greatest potential expense if carried out unsatisfactorily. It follows that these problems will be picked up most frequently by maintenance surveyors and others carrying out remedial work on floors. Although most of the information relates to older buildings, surveyors may be called upon to inspect buildings built in relatively recent years. It is therefore appropriate also to include much material concerning observations by BRE of new buildings under construction in the period 1985–95.

Many of the difficulties which are referred to BRE for advice stem from too hasty assumptions about the causes of particular defects. Very often the symptoms are treated, not the causes, and the defects recur. It is to be hoped that this book will encourage a systematic approach to the diagnosis of floor and flooring defects.

The case studies provided in some of the chapters are selected from the files of BRE Advisory Service and the former Housing Defects Prevention Unit, and represent the most frequent kinds of problems on which BRE is consulted. They are not meant to be comprehensive in scope since the factors affecting individual sites are many and varied.

As has already been said, this book is not a textbook on building construction. Hence, the drawings are not working drawings but merely show either those aspects to which the particular attention of readers needs to be drawn or simply provide typical details to support text.

Other more specific aspects of the subject not deemed to be relevant to this book are mentioned briefly in appropriate chapters – usually in the introductory paragraphs.

Passive fire protection measures are those features of the fabric, such as structural frames, walls and floors, that are incorporated into building design to ensure an acceptable level of safety. These measures, so far as they affect floors, are dealt with in outline in this book. Measures which are brought into action on the occurrence of a fire, such as fire detectors, sprinklers and smoke exhaust systems are referred to as active fire protection, and are not dealt with in this book.

The standard headings within the chapters are repeated only where there is a need to refer the reader back to earlier statements or where there is something relevant to add to what has gone before. We have assumed that readers will know many of the more common abbreviations used in the industry – DPC, PVC etc – and we have declined to spell them out.

This book deals with all kinds of floorings (ie floor coverings), including both in situ and manufactured products, and these are covered in detail in Chapters 5–8. A classification of floorings for use internationally has been published by the European Union of Agrément, and this is examined in more detail later in the book.

Ceilings, whether suspended or applied directly to soffits, are treated as integral parts of the element of floors since many aspects of performance, such as fire and sound, affect all parts of both floors and ceilings. Ceilings are mainly dealt with in Chapter 2.

Ramps, landings and stair treads are included as elements of floors, but not staircase enclosures. There is an argument for dealing with staircases in conjunction with walls since, in most cases, it is necessary to consider the enclosures for stairs in conjunction with stair flights; enclosures for staircases, and such matters as protected shafts, are therefore considered as elements of walls.

Much that is relevant to ordinary floor finishes applies also to stair tread finishes.

The weatherproofing aspects of balconies, insofar as they are similar to those of roofs, are dealt with in the book on roofs. Thresholds are handled as parts of external walls.

In many places through the book we have quoted British Standards and codes of practice which have been withdrawn; however they would have been current at the time a particular floor or flooring was laid. We have done this deliberately since they often gave better specifications than those now current. Indeed, in some cases, standards and codes have been withdrawn and not replaced. Copies of old standards and codes are often retained by BRE for use in disputes; they can also be seen in the British Library.

In the United Kingdom, there are three different sets of building regulations: the Building Regulations 1991 which apply to England and Wales; the Building Standards (Scotland) Regulations 1990; and the Building Regulations (Northern Ireland) 1994. There are many common provisions between the three sets, but there are also major differences. Although the book has been written against the background of the building regulations for England and Wales, this is simply because it is in England and Wales that most BRE site inspections have been carried out. The fact that the majority of references to building regulations are to those for England and Wales should not make the book inapplicable to Scotland and Northern Ireland.

We have deliberately not provided more than an outline of the major points which specifiers will need to take into account in the cleaning and maintenance of floorings since this is not a topic which has been studied in depth by BRE or its predecessor, the Building Research Station; in any case there is suitable literature available from industry sources and other publishers.

Some important definitions

Some of the more general terms used in floors and ceilings will be found in Section 1.3, Subsection 1.3.3 of BS 6100-1 (Glossary of building and civil engineering terms: General and miscellaneous).

Since the book is mainly about the problems that can arise in floors, two words, 'fault' and 'defect', need precise definition. Fault describes a departure from good practice in design or execution of design; it is used for any departure from requirements specified in building regulations, British Standards and codes of practice, and the published recommendations of authoritative organisations. A defect – a shortfall in performance – is the product of a fault, but while such a consequence cannot always be predicted with certainty, all faults should be seen as having the potential for leading to defects. The word 'failure' has occasionally been used to signify the more serious defects.

By 'floor' we mean the whole of the horizontal elements of a building (excluding roofs but including ceilings); 'flooring' refers simply to the finish of the upper surface of the floor.

Where the term 'investigator' has been used, it covers a variety of roles including a member of BRE's Advisory Service, a BRE researcher or a consultant working under contract to BRE.

'Topping' has been used to describe an in situ material laid to provide good abrasion resistance and to provide the wearing surface. It has also been used to refer to a cementitious mix used to lock together components of a structural concrete floor, such as hollow pots, where it is called a structural topping.

'Underlay' is a layer used between the structural deck or slab and the flooring, either prefabricated (eg plywood or hardboard) or a thick in situ layer (eg mastic asphalt or aggregate filled latex cement). 'Underlayment' is in situ material used to smooth or level the base prior to laying the flooring. (The term underlay seems to have become restricted to preformed substrates and the term underlayment to those formed in situ, and we have adopted this distinction. However, in other industry publications and documents the former term will be found to apply to both applications.)

'Wear' is the progressive loss from the surface of a material or component brought about by mechanical action.

Acknowledgements

Photographs which do not bear an attribution have been provided from our own collections or from the BRE Photographic Archive, a unique collection dating from the early 1920s.

To the following colleagues – many from the BRE Scottish Laboratory and the Fire Research Station – and former colleagues who have suggested material for this book or commented on drafts or both, we offer our thanks: D R Addison, Dr B R Anderson, R W Berry, Dr A B Birtles, Dr P Bonfield, P J Buller, Dr R N Butlin, A H Cockram, Dr J P Cornish, S A Covington, R N Cox, Dr R C deVekey, Diane M Currie, R J Currie, Maggie Davidson, Dr J M W Dinwoodie, Dr B R Ellis, Dr V Enjily, Dr L C Fothergill, E Grant, G J Griffin, C J Grimwood, J H Hunt, Dr P J Littlefair, T I Longworth, K W Maun, N O Milbank, Dr D B Moore, W A Morris, Dr R M Moss, F Nowak, E F O'Sullivan, R E H Read, J F Reid, M R Richardson, J Seller, A J Stevens, P M Trotman, C H C Turner and Dr T J S Yates, all of BRE.

We have also drawn upon some notes prepared by the late Dr Frank Harper and the late Wilfred Warlow. In addition, we acknowledge the contributions of the original, though anonymous, authors of *Principles of modern building*, Volume 2, from which several passages have been adapted and updated.

PWP
HWH
August 1997

Second edition

This revised edition of *Floors and flooring* embodies a considerable number of changes from the first edition, particularly with respect to changes to standards and codes, and to building regulations.

Major changes will be found to the section concerned with revised guidance for identifying radon affected areas (Chapter 1.5); to the section on tests for sound insulation which has been amended by the introduction of pre-completion testing (PCT) by Approved Document E (2003) of the Building Regulations (Chapter 1.8); and to the chapter on panel products (Chapter 8.5) following the preparation of performance specifications and confirmation of former draft International Standards.

The opportunity has also been taken to update references to the hundred or so British Standards mentioned in the first edition.

PWP
HWH
July 2003

Chapter 1.9 Durability

This is a general chapter which includes information relevant to all kinds of flooring – information relevant to a particular kind of flooring, such as typical wear rates on a particular surface, will be given in the appropriate later chapter.

Floor finishes may be considered to provide for the following main functions:

- protection of the structural floor
- better appearance
- increased comfort and safety

The relative importance of these functions varies according to circumstances and budgets. However, one of the most important attributes is the maintenance of the functions over time; in other words, the finishes must be durable. Because of its importance, durability has often been regarded as a basic property of a floor finish, but it represents only the length of time that the chosen properties persist and depends as much on the conditions of use as on the properties of the finish[98].

Many factors influence the life of a floor finish:

- wear
- water and other liquids
- indenting loads and impacts (Figure 1.61)
- sunlight
- insects
- moulds and fungi
- high temperature

as well as the fundamental properties of the materials and adhesives used, and the compatibility of these with other parts of the structure and its behaviour in use.

Figure 1.60
The durability of any flooring is governed ultimately by the kind of use it gets, particularly by heavy wheeled vehicles

Figure 1.61
This industrial floor has suffered very heavy wear in spite of the robust finish. It has been subjected to piecemeal replacement. The wheel tracks of mechanical handling equipment can be seen

The European Union of Agrément (UEAtc) have given priority, in their Method of Assessment and Test covering innovative floorings, to assessing the conditions of service for floorings using what has been called the UPEC system. UPEC is the French acronym for wear (usure) index 1–4, indentation (poinçonnement) index 1–3, water (eau) index 0–3, and chemicals (chimiques) index 0–3 (UEAtc Method of Assessment and Test No 2[25]). Given the existence of an Agrément certificate for a particular product, therefore, a surveyor should be able to make a judgement on its performance. UEAtc and the British Board of Agrément (BBA) have also issued further guidance on the assessment

Figure 1.62
This paint finish is breaking up. There is little substance to resist further wear

of plastics floorings (UEAtc Methods of Assessment and Test No 23[99] and No 36[100], and BBA Information Sheet No 2[101]). These are referred to in greater detail in the appropriate later chapters. Experience has shown that there is a relationship between wear and indentation of PVC floorings; these floorings, invariably, have a C index of 2. For PVC floorings, it has therefore been found possible to omit the C rating, and to combine the U and P ratings into a single G classification (1–5).

Of all the performance factors described above, wear is perhaps the most influential because:

- it is unavoidable in normal use
- it applies to all kinds of flooring
- in many cases, it can be very obvious to users when it occurs

Expected life of floorings

There is a British Standard on durability, BS 7543[102], which applies to floors and flooring. It gives general guidance on required and predicted service life, and how to present these requirements when preparing a design brief.

The service life of a floor covering depends as much on the conditions in the building and the degree of use as on the inherent properties of the material and the techniques adopted in laying it. However, even bearing in mind the comparative ease of replacement of many thin floorings, building users should have a reasonable expectation of a minimum service life for a properly selected flooring, taking all circumstances into account. What that minimum might be is a matter for debate, but UEAtc have decided on 10 years, and BRE would not dispute that figure[25].

Durability is affected by the care and skill with which the floor is laid, and the behaviour of the subfloor, as well as by the choice of material itself. Failure to provide adequate dampproofing and ventilation, and a sound screed, can lead to serious deterioration in finish; for example as buckling of wood block floors or loss of adhesion in tiled or painted finishes (Figure 1.62).

Resistance to wear

All floor surfaces wear to some degree when subjected to foot or wheeled traffic. There may also be other factors including the movement of furniture, which may scrape or cut the surface, and the movement of heavy loads such as in warehouses. However, using the definition of wear as the progressive loss from the surface of a body brought about by mechanical action, it is not just the quantitative loss of material which is important but also the qualitative assessment of the condition of the worn surface. Where changes in appearance are involved, the assessment becomes more and more subjective.

Wear and damage can be considered to arise from a number of causes:

- mechanical action (leading to progressive loss of substance)
- abrasion caused by fine solid particles
- cutting by the action of vehicles (eg trolleys) and furniture
- corrosion from spillages
- degradation from soluble salts rising from the subsoil or entrapped moisture in concrete
- fatigue in the surface material
- movement or rocking from uneven or friable bedding causing chipping of arrises of slabs or tiles

There has been considerable concern since the 1960s with the degree of wear of floors in heritage buildings. This is dealt with in detail in Chapters 5.2 and 5.5. In some cases, depending of course on the material involved, it is evident that wear of around one millimetre in ten years is occurring[103].

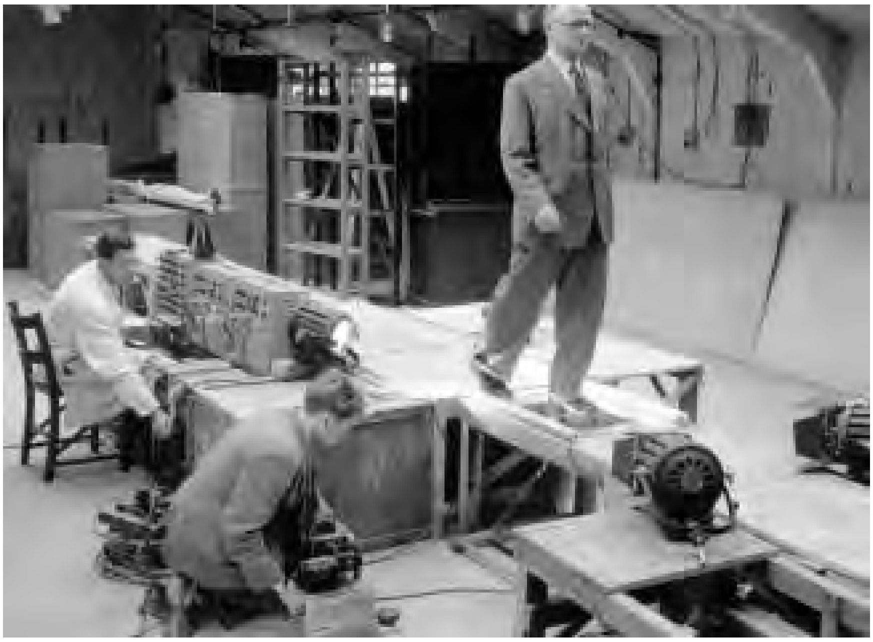

Figure 1.63
Measuring the forces applied by foot traffic to flooring. Although these tests were conducted in the late 1950s, the results still apply

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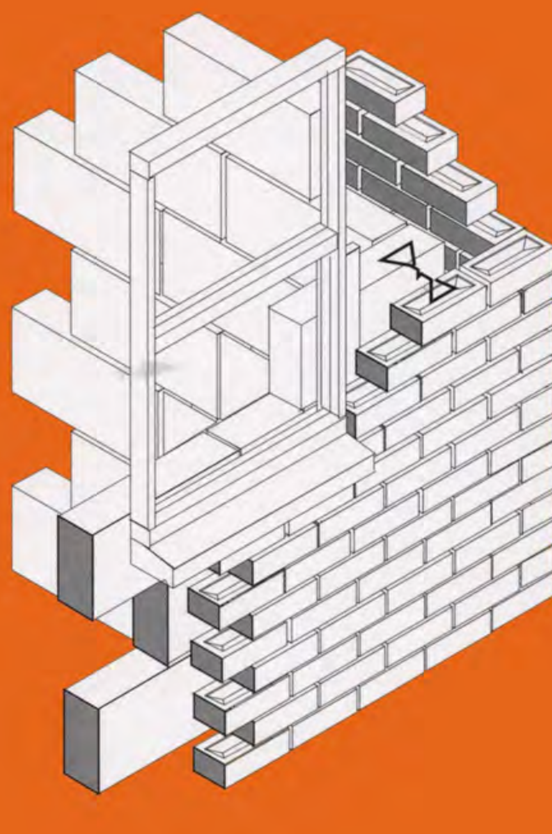
BRE Building Elements

Walls, windows and doors

H W Harrison
and
R C de Vekey

Performance, diagnosis, maintenance, repair and the avoidance of defects



BRE

BRE Building Elements

Walls, windows and doors

Performance, diagnosis, maintenance, repair and the avoidance of defects

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Contents

Preface

This book is about all the main vertical elements of buildings, both external, including walls, windows and doors, and internal, including separating walls, partitions and internal doors. It deals in outline with the achieved performances and deficiencies of the fabric over the whole age range of the national building stock. Of course, many performance requirements are common to buildings of whatever age, the main difference being that occupants tend to make allowances for deficiencies when the building is old.

The construction of a wall and its constituent materials must have adequate strength, be fire resistant, offer the necessary acoustic and thermal properties, and resist erosion and corrosion for the life of the building, so that the occupants can use the building safely and conveniently. In addition, the external envelope should have adequate resistance to the elements, and must allow the maintenance of a suitable indoor environment.

Information on faults in buildings of all types show that nearly half concern walls, windows and doors. Despite the advice that has been available to the industry from the 1920s, faults which formerly occurred on a substantial scale, such as rain penetration through windows and doors, still recur frequently. Some of these faults may appear to be elementary in character, but this only reflects what happens in practice. Recognition of faults before they occur on site is obviously much more preferable to correction after the event. In some cases an underlying cause is lack of knowledge, in others a lack of care.

Readership

Walls, windows and doors is addressed primarily to building surveyors and other professionals performing similar functions – such as architects and builders – who maintain, repair, extend and renew the national building stock. It will also find application in the education field.

In spite of the current explosion of information, or perhaps because of it, people do not use the guidance that exists. In order to try to remedy that situation, the advice given in Chapters 2 to 10 of this book concentrates on practical details. However, there also needs to be sufficient discussion of principles to impart understanding of the reason for certain practices, and much of this information is given in Chapter 1.

Scope of the book

All kinds of external walls, encompassing loadbearing and non-loadbearing, curtain walls, and overcladding are dealt with first; then windows and external doors, including thresholds. Later chapters include separating walls, partitions, and internal doors and stair enclosures including protected shafts. In principle, all types of buildings are included, though obvious practical considerations of space decree that information on heritage buildings is limited in scope.

The book is not a manual of construction practice, nor does it provide the reader with the information necessary to design a wall. Both good and bad features of walls, windows and doors and the joints between them are described, and sources of further information and advice are offered. The drawings are not working drawings but merely show either those aspects to which the particular attention of readers needs to be drawn or simply provide typical details to support text.

Excluded from the scope of this book is consideration of foundations for walls, or basements, which will be dealt with in another publication. Wall-to-roof junctions at eaves and verges, and fabric or flexible plastics sheathings to buildings were dealt with in the companion book, *Roofs and roofing*.

As with the other books in this series, the text concentrates on those aspects of construction which, in the experience of BRE, lead to the greatest number of problems or greatest potential expense, if carried out unsatisfactorily. It follows that these problems will be picked up most frequently by maintenance surveyors and others carrying out remedial work on walls, windows and doors. Occasionally there is information relating to a fault which is infrequently encountered, and about which it may in consequence be difficult to locate information. Although most of the information relates to older buildings, much material concerning observations by BRE of new buildings under construction in the period from 1985 to 1995 is also included.

Many of the difficulties which are referred to BRE for advice stem from too hasty an assumption about the causes of a particular defect. Very often the symptom is treated, not the cause, and the defect recurs. It is to be hoped that this book will encourage a systematic approach to the diagnosis of walls and walling defects.

The case studies provided in some of the chapters are selected from the files of the BRE Advisory Service and the former Housing Defects Prevention Unit, and represent the most frequent kinds of problems on which BRE has been consulted.

The standard headings within the chapters are repeated only where there is a need to refer the reader to earlier statements or where there is something relevant to add to what has gone before.

Since it is necessary to consider the enclosures for stairways in conjunction with stair flights, enclosures for stairways (including such items as protected shafts) are therefore considered as elements of walls and are dealt with in this book in Chapter 6.3.

In the United Kingdom, there are three different sets of building regulations: *The Building Regulations 1991* which apply to England and Wales; *The Building Standards (Scotland) Regulations 1990*; and *The Building Regulations (Northern Ireland) 1994*. There are many common provisions between the three sets, but there are also major differences. This book has been written against the background of the building regulations for England and Wales since, although there has been an active Advisory Service for Scotland and Northern Ireland, the highest proportion of site inspections has been carried out in England and Wales. In addition, the technical aspects of the book are affected more by exposure due to location and height above sea level than by national or administrative boundaries. The fact that the majority of references to building regulations are to those for England and Wales, should not make the book inapplicable to Scotland and Northern Ireland.

There is insufficient space in this book to deal with the highly sophisticated new forms of external walls, such as the so-called ‘smart’ or intelligent skins, employing variable external fabric, to improve solar control and daylight utilisation. It is intended that these form part of a further book in this series. Information relating to these techniques may be sought from BRE.

Some important definitions

Since the book is mainly about the problems that can arise in walls, windows and doors, two words, ‘fault’ and ‘defect’, need precise definition. Fault describes a departure from good practice in design or execution of design: it is used for any departure from requirements specified in building regulations, British Standards and Codes of practice, and the published recommendations of authoritative organisations. A defect – a shortfall in performance – is the product of a fault, but while such a consequence cannot always be predicted with certainty, all faults have the potential for leading to defects. The word failure has occasionally been used to signify the more serious defects (and catastrophes!).

Where the term 'investigator' has been used, it covers a variety of roles including a member of BRE's Advisory Service, a BRE researcher or a consultant working under contract to BRE.

Because the term ‘separating wall’ has been used in the construction industry from the earliest days, and is still in current use, we prefer to use it in this book as a generic term despite the comparable term ‘compartment wall’ which is found in the national building regulations.

Acknowledgements

Photographs which do not bear an attribution have been provided from our own collections or from the BRE Photographic Archive, a unique collection dating from the early 1920s.

To the following colleagues, and former colleagues, who have suggested material for this book or commented on drafts, or both, we offer our thanks:

M J Atkins, P Bonfield, R Cox, E J Daniels, Maggie Davidson, C Grimwood, W H (Bill) Harrison, C Holland, M Howarth, Dr P Littlefair, Penny Morgan, F Nowak, Dr R Orsler, M Pound, P W Pye, R E H Read, J Reid, Justine Redshaw, B Reeves, J Seller, A J Stevens, C M Stirling, N Tinsdeall, P M Trotman, P Walton, and Dr T Yates, all of the BRE.

We wish to acknowledge a special debt to P M Trotman for providing the majority of the information in Chapter 2.6.

In addition, acknowledgement is given to the original though anonymous authors of *Principles of modern building*, Volume 1, from which several passages have been adapted and updated.

H W H
R C de V
July 1998

Chapter 1 The basic functions of the vertical elements

Figure 1.1
Tay House, Glasgow (Photograph by permission of Stoakes Systems Ltd)

This first chapter deals in turn with the basic functions which affect all of the vertical external envelope of a building, whether large (Figure 1.1) or small, and all of its vertical internal subdivisions. In later chapters each of these functions is considered in greater detail where relevant to a particular component. The chapter takes its cue from a passage in *Principles of modern building*: '*It will be convenient to consider the whole range of wall functions together, even though any given wall, external or internal, loadbearing or non-loadbearing, may not have to perform all of them*'.

Chapter 1.1 Strength and stability

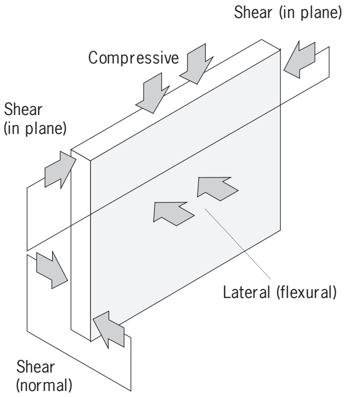

Figure 1.2
Different loadings on a wall

The predominating factor in the design of a wall is whether it has to carry an imposed load, for example from floors and roofs. Ever since Roman times the loading on a non-framed wall has largely governed its thickness, and over the years conventions became established for their construction.

However, it is only comparatively rarely that the wall can stand by itself without receiving support or restraint from the remainder of the building. Even the smaller domestic scale building of loadbearing brick often relies on the floor to provide lateral restraint to the external wall. All that this chapter can do is to draw attention to some of the more important considerations in relation to the contribution which walls make to the structure as a whole, but not to provide sufficient information to allow the structural design of walls to be carried out.

All walls need to be sufficiently strong to carry the self weight of the structure, together with imposed loads; for example those due to furniture, equipment or the occupants of the building.

Current requirements as far as the structure of walls is concerned are embodied in the various national building regulations. Taking the England and Wales Regulations[15] as an example:

'(1) The building shall be constructed so that the combined dead, imposed and wind loads are sustained and transmitted by it to the ground

(a) safely; and

(b) without causing such deflection or deformation of any part of the building, or such movement of the ground, as will impair the stability of any part of another building

(2) In assessing whether a building complies with sub paragraph (1) regard shall be had to the imposed and wind loads to which it is likely to be subjected in the ordinary course of its use for the purpose for which it is intended.'

Structural design of walls for buildings is covered by the main British Standard Codes of practice for the various materials:

- steel to BS 5950-1 to 9[16]
- concrete to BS 8110-1 to 3[17]
- timber to BS 5268[18]
- masonry to BS 5628[19], Approved Document 1/2[20] or BS 8103[21]

Loads

There is a wide range of structural considerations that may be required of a walling system, ranging from purely non-loadbearing cladding to the cellular masonry or concrete walling system which ultimately carries all the actions on a structure. The forces are illustrated by Figure 1.2.

Dead loads

The dead weight of any floors, partitions, ceilings, roofs and claddings must be carried to the ground (foundations) via a structural frame or a loadbearing wall. The design dead load at any point is the sum of all the individual dead loads acting at that point from above factored up to allow for the variability of materials. The partial factor of safety is normally around 1.2–1.4 for unfavourable loads and 0.9 for favourable loads. Eccentric loads

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BRE Building Elements

Foundations, basements and external works

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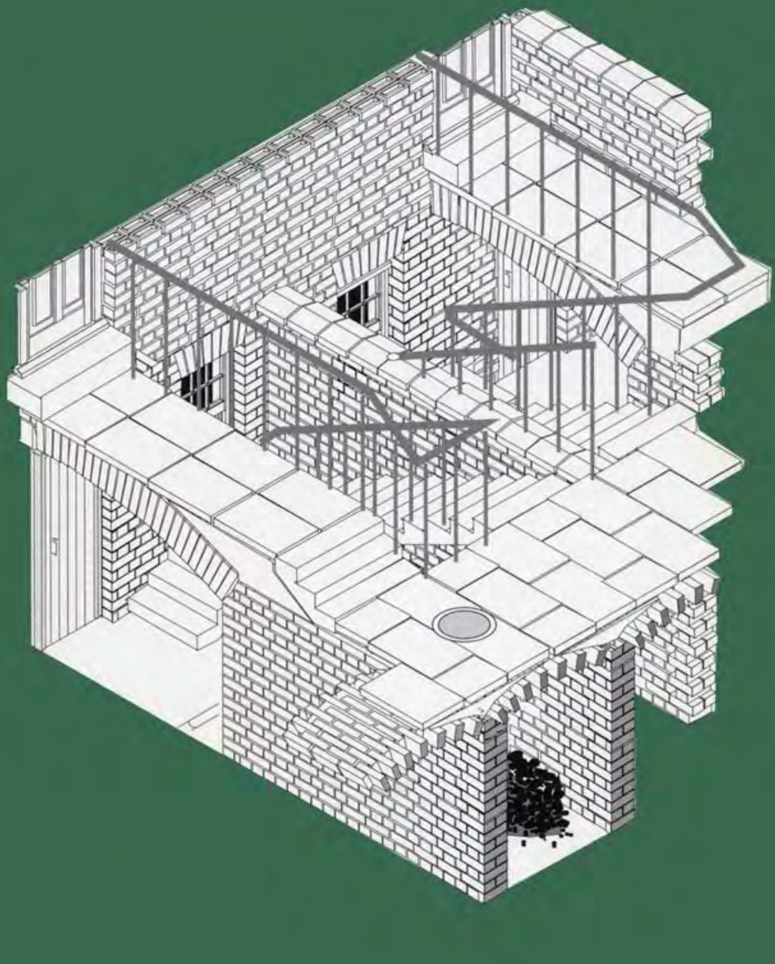

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Performance, diagnosis, maintenance, repair and the avoidance of defects

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Contents

Preface

This book is the fifth of the BRE Building Elements books and completes the planned series which was begun in 1996. The first four books are *Roofs and roofing* (first published in 1996), *Floors and flooring* (1997), *Walls, windows and doors* (1998) and *Building services* (2000).

Readership

As with the other books, *Foundations, basements and external works* is addressed primarily to building surveyors and other professionals performing similar functions; for example, architects and builders who maintain, repair, extend and renew the national building stock. Surveyors and architects undertaking routine surveys of existing buildings may identify site problems or issues – in particular concerning the behaviour of foundations – which need to be referred to specialists for advice. The larger non-domestic buildings built in the second half of the twentieth century, and perhaps even some in the first half of the century – the standard textbooks of the time were quite explicit – will most likely have had the benefit of adequately designed foundations. In the case, though, of relatively small buildings such as houses, many decisions concerning ground and foundations will have been made by building professionals who had little or no training in geotechnical engineering.

Some topics, such as deterioration in drainage installations, may often be amenable to straightforward rectification, but other aspects, such as the installation of dampproofing in basements, may be outside the experience of individual surveyors. Clients need to be advised on when to call in other consultants to rectify existing problems. The book is certainly not addressed to the geotechnical engineer or the landscape architect, though it will in all probability find application in the education field.

Scope of the book

The descriptions and advice given in this book concentrate on practical details. But there also needs to be sufficient discussion of principles to impart understanding of the reason for certain practices. In previous books in this series, some of the information which applied generally to the subject matter of the book was given in Chapter 1, but here the topics, though all closely related to the site, are rather more disparate, and the principles which govern practice will in consequence be found dispersed in individual chapters.

Included in foundations and basements is all work below DPC level, including strip foundations, piles, retaining walls to basements; but not including ground floor slabs or rafts, which were included in *Floors and flooring*, and building services within the footprint of the building, which were included in *Building services*.

Many points relating to the use of particular materials in close proximity to the ground, such as the durability of brick, block and concrete have been dealt with in *Walls, windows and doors* to which reference can be made.

Large civil engineering structures such as port installations, bridges and tunnels, underground car parks and very large non-building structures such as storage tanks are excluded from the scope of this book.

Included in external works are all items outside the building footprint but inside the site boundary, encompassing wastewater and surface water drains, supply of utilities (eg gas, electricity and cabled services), footpaths, and access for vehicles including car parks and hard standings to be found in the vicinity of buildings. Perimeter and freestanding boundary walls are also dealt with, as is security fencing and, in outline only, lighting; CCTV surveillance systems, though, are normally left in the hands of specialist consultants and contractors, and are therefore not covered in detail.

With such a broad scope, it will be apparent that only brief reference can be made to most topics, and the text therefore concentrates on those aspects with which BRE has been most heavily involved, whether in laboratory research, site investigation or development of legislation.

In principle, all types of buildings are included. However, it is inevitable that the nature of foundations becomes very sophisticated in some building types such as those which are very tall, and these installations rarely lend themselves to simple guidance for use by non-specialists. Indeed, there may well be no professional role whatsoever for them in this respect. However, even the relatively simple systems used in the majority of domestic construction provide adequate potential for improvement.

Foundations, basements and external works is not a manual of construction practice, nor does it provide the reader with the information necessary to design foundations, basements or external works. Both good and bad features of these elements are described, and sources of further information and advice are offered. The drawings are not working drawings but merely show either those aspects to which the particular attention of readers needs to be drawn, or simply provide typical details to support text. The discussion, for the most part, is deliberately neutral on matters of style and aesthetics and is wary of suggesting that there is ever a unique optimum solution.

In a similar fashion to the other books in this series which deal with other building elements, the present text concentrates on those aspects relating to the subject matter of the book, in this case the site, and which, in the experience of BRE, lead to the greatest number of problems or greatest potential expense if carried out unsatisfactorily. It follows that these problems will be picked up most frequently by maintenance surveyors and others specifying and carrying out remedial work. Occasionally there is information relating to an item, perhaps a fault, which is infrequently encountered, and about which it may be difficult to locate information. Although most of the information relates to older buildings, much material concerning observations by BRE investigators of new buildings under construction in the period from 1985 to 1995 is also included.

The case studies provided in some of the chapters are selected from the files of the BRE Advisory Service, and the former Housing Defects Prevention Unit, and represent the most frequent kinds of problems on which BRE has been consulted.

The standard headings within the chapters are repeated only where there is a need to refer the reader to earlier statements or where there is something relevant to add to what has gone before. An exception to the sequence of standard headings occurs in Chapter 2.1 where the amount of material to be described requires a further breakdown into diagnosis, monitoring and remedial work. Chapter 3 also does not follow the standard headings; it was found to be more appropriate to deal separately with structure and waterproofing of basements which is reflected in the sub-chapter headings.

In the United Kingdom, there are three different sets of building regulations: The Building Regulations 1991 which apply to England and Wales; The Building Standards (Scotland) Regulations 1990; and The Building Regulations (Northern Ireland) 1994. There are many common provisions between the three sets, but there are also major differences. The book has been written against the background of the building regulations for England and Wales, since, although there has been an active Advisory Service for Scotland and Northern Ireland, the highest proportion of site inspections has been carried out in England and Wales. The fact that the majority of references to building regulations are to those for England and Wales should not make the book inapplicable to Scotland and Northern Ireland.

Although practically all topics relating to the construction of buildings are encompassed in the Construction (Design and Management) Regulations 1994, the ramifications for each of the topics covered in this book are quite different. It is therefore not practical to spell them out, beyond noting that there must be a Health and Safety Plan and File for all construction work which should include information on how to manage health and safety issues after the installation is completed and throughout its life until demolition[1].

Design criteria

While this book is mainly about existing buildings and not specifically about the design of new buildings, it has been necessary in several circumstances to give some design criteria so that subsequent performance of the completed building may be assessed against what was required or intended.

Some important definitions

The term ‘footprint’ has been used to describe the area actually covered by the building fabric. Note that this term is not synonymous with the term curtilage, as used in legislation, which in its normally accepted meaning includes any ground forming a part of the enclosure within which the building stands.

The term ‘surcharge’ as used in this book has two distinct meanings: a preloading of the ground (eg to induce consolidation), and a condition in which water is held under pressure within a gravity drain, but which does not escape to cause flooding.

So far as water terms are concerned, there has been a significant change in usage since the 1980s. The term ‘potable water’ to describe water of a quality suitable for drinking is now no longer popular though it is still contained in current Standards, and the words ‘drinking’ and ‘wholesome’ to describe water are preferred.

The use of the term ‘foul water’ in relation to sewage has fallen out of official use, being superseded by the term ‘wastewater’ which is often more closely defined as ‘greywater’ or ‘blackwater’; ‘greywater’ is wastewater not containing faecal matter or urine, ‘blackwater’ is wastewater that contains faecal matter or urine. However, for the purposes of this book, we tend to retain the term foul water when referring to greywater and blackwater; wastewater, though, can include surface water (eg run-off from car parks).

The term ‘aerobic’ indicates conditions in which free oxygen is present, and ‘anaerobic’ in which it is not present.

Since the book is to a considerable extent about the problems that can occur in the below-ground fabric of buildings, two words, 'fault' and 'defect', need precise definition. Fault describes a departure from good practice in design or execution of design; it is used for any departure from requirements specified in building regulations, British Standards and codes of practice, and the published recommendations of authoritative organisations. A defect – a shortfall in performance – is the product of a fault, but while such a consequence cannot always be predicted with certainty, all faults have the potential for leading to defects. The word failure has occasionally been used to signify more serious defects and catastrophes.

Where 'investigator' has been used, it covers a variety of roles including a member of BRE's Advisory Service, a BRE researcher or a consultant working under contract to BRE.

Particular terms relating to topics under discussion will be found in the various chapters which follow.

Acknowledgements

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To the following colleagues, and former colleagues, who have suggested material for this book or commented on drafts, or both, we offer our thanks:

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We are particularly grateful to Richard Driscoll, who contributed much of Chapters 1.1 to 1.3, 1.5, and the majority of Chapter 2; to Ron and Lesley Bonshor who prepared historical and other material on foundations and geotechnics, and on cracking; to Mike Lillywhite who prepared some of the historical studies on foul drainage upon which we have drawn; and to John Ramsay, Member of The Landscape Institute, who commented on Chapters 1.4 and 1.5 from the point of view of the landscape architect, and also contributed much of Chapter 6.2.

HWH
PMT
December 2001

Chapter 2.2 Old brick and stone footings

Before the introduction of concrete strip foundations for masonry walls, it was common practice to provide masonry footings wider than the wall above in order to spread the imposed load on the soil. Where the ground was of poor bearing capacity, with high water tables leading to boggy areas, there may even have been brushwood faggots or fascines placed beneath the footings in the hope of improving bearing capacity.

As well as describing the lower courses of corbelled brickwork, this chapter deals with masonry below DPC level – particularly its durability.

Characteristic details

Basic description

In Georgian and Victorian times the foundations of small buildings tended to be very shallow in depth, often no more than half a dozen or so courses of bricks. This brickwork below ground level was often stepped in order to spread the load, as shown in Figure 2.24. Before the widespread introduction of concrete in footings towards the end of the nineteenth century, unless the walls were founded on rock, progressively wider courses of bonded masonry were absolutely necessary to spread loads over adequate widths of subsoil. It was common practice to use as many bricks as possible laid as headers, that is to say, normal to the line of the wall so that the corbelling action was maximised. Where the wall was of stone, the same principle would apply, with the maximum use of through stones (Figure 2.25).

Local authority byelaws in the last years of the nineteenth century required the course above the concrete to be twice the width of the wall to be carried, with successive courses above that reducing by quarter brick width each side until the required thickness of wall was achieved. In modern construction, this stepped profile has been dispensed with as a simple mass concrete strip adequately distributes the load.

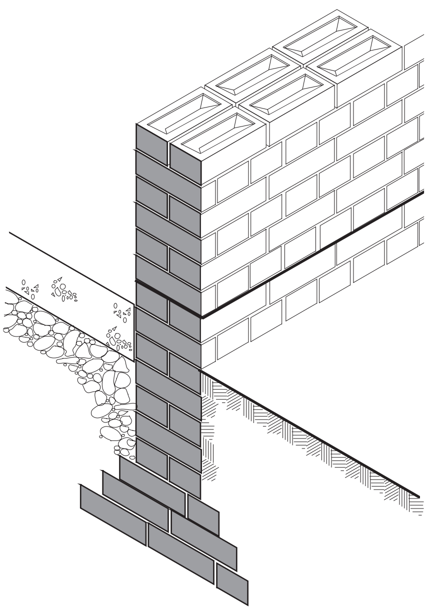

Figure 2.24 Maximum use of brick headers in footings gives the best loadbearing qualities

Main performance requirements and defects

Strength and stability

There is an important difference between the behaviour of brickwork built in lime mortar, and brickwork built in cement mortar. Masonry footings which used lime mortars are much more tolerant of movement than are those built with cement mortars, the ductile nature of the lime mortar allowing the bricks to move slightly relative to each other when under stress. In consequence, footings of buildings built before the 1930s, before lime mortars began to be superseded by cement mortars, are much less likely to crack when the soils on which they are founded shrink or heave.

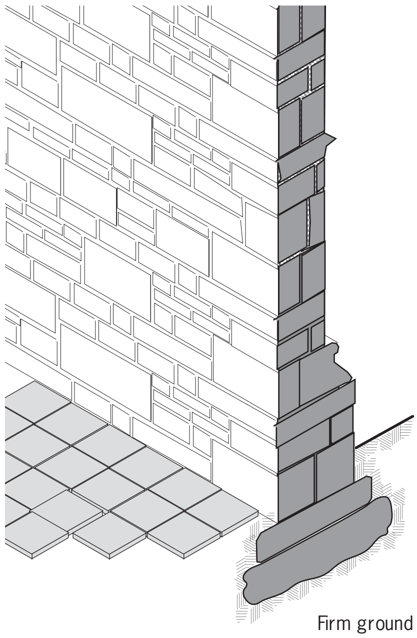

Figure 2.25 Typical stone footings widely used until the end of the nineteenth century

Figure 2.26 A narrow diameter hole has been excavated in a confined space alongside a one brick solid external wall to establish the depth and width of what turned out to be brick footings. Both depth and width had to be established by probing with a long crowbar. The footings were on shrinkable clay, and were unusually deep for an Edwardian house. Tree roots are visible in the sides of the excavation

Figure 2.27 A variety of contaminants has obviously been in contact with this 100 year old clay brickwork below DPC level, but only minor damage has resulted. There is also evidence of previous alterations and some repointing

Where alterations are to be made to an old building, it is crucial to expose and measure any masonry footings, and to carry out an assessment of the loadbearing capacity of the soil on which they are carried (Figure 2.26).

Durability

It should be noted that discussion of this topic in this chapter applies only to those materials used below ground level. Different considerations apply to materials used above ground level, and reference should be made to the appropriate parts of *Walls, windows and doors*[101].

Only a few influences are known to reduce the normally indefinite life of materials recommended for construction of foundations, the most significant of these being sulfate attack and frost. Mortar for brick and blockwork can have very variable durability. Breakdown may be hastened by the use of unsuitable, poor quality or incorrectly prepared materials. The relevant codes give extensive guidance on the preferred specifications for given circumstances. Local building control departments should have information on the presence of aggressive soil or groundwater in particular areas. Where any doubts exist, samples should be taken for analysis.

Washing out mortar from footings or fines from the ground beneath foundations can result from leaking water mains or drains.

Clay bricks

So far as the bricks themselves are concerned, there is a wide range of performance. Engineering bricks are highly durable, the inherently good resistance of these materials being due principally to their low porosity. The deterioration of brick depends on the nature of the contamination to which it is exposed, and can occur as a result of either a chemical interaction with the ceramic materials – leading to the dissolution of the glassy phase, which in some cases can constitute as much as 60% of the brick – or a physical expansion mechanism due to the crystallisation of salts within the brick pores[77]; this is potentially a more serious problem (Figure 2.27). The salts are transported by water to the interior of the brick and can derive from the external environment or from the rehydration of the soluble phase of the brick. The most deleterious salts are those that are readily hydratable (eg sulfates of sodium and calcium).

The site of crystallisation is determined by the dynamic balance between the rate of evaporation of water from the brick surface and the rate of solute migration to the site of crystal growth. If the rate of solute migration is faster then the rate of evaporation, then crystallisation occurs on the surface of the brick (efflorescence). Although efflorescence is unsightly it is not harmful. If the rate of solute migration is slow, or if the salt is relatively insoluble, crystallisation will take place within the pores of the brick. This is usually referred to as sub-florescence or cryptoflorescence, and it can result in delamination, flaking and spalling[77].

A more detailed explanation of the effect of crystallisation of soluble salts on clay bricks is to be found in Chapter 2.2 of *Walls, windows and doors*.

Calcium silicate bricks

Calcium silicate bricks are resistant to attack by most sulfate salts in the soil and groundwater. The durability of calcium silicate bricks under salt crystallisation attack can be attributed to a combination of their very low soluble salt content, and their low porosity and coarse pore structure. However, calcium silicate bricks may be attacked by high concentrations of magnesium and ammonium sulfate. They may also suffer severe deterioration if they are impregnated by strong salt solutions, such as calcium chloride or sodium chloride, and then subjected to frost[77].

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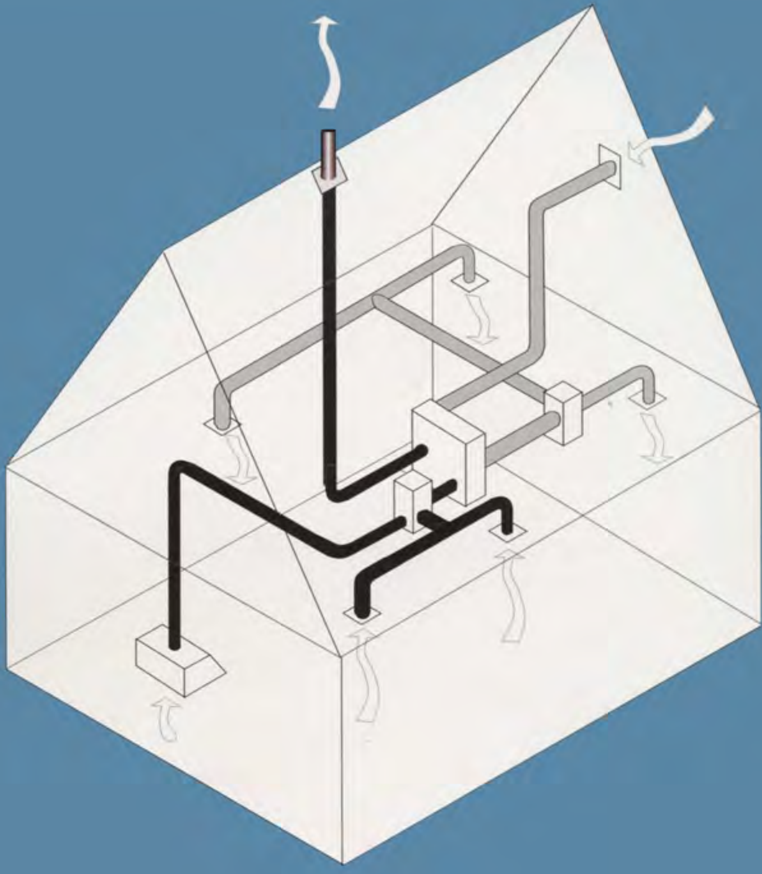

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Performance, diagnosis, maintenance, repair and the avoidance of defects

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Contents

Preface

This book is about building services: the gamut of fuelled, piped, ducted, wired and mechanical facilities which extend over the whole age range of the UK's building stock. In essence, it is the quality of heating, artificial lighting and other services, such as refuse disposal, which makes an otherwise bare carcass habitable – even efficient and enjoyable. However, things do go wrong from time to time – the boiler ceases to function, the television aerial corrodes, the pipes in hard water areas fill with calcium deposits, and, sadly, there is the occasional disaster and tragedy from carbon monoxide poisoning or electrical fault.

Sir John Egan, in his report, *Rethinking construction*[1], has drawn attention to the need, amongst other things, to improve productivity, reduce construction times and cut accidents in the UK construction industry, and he also called for a 20% cut in the number of defects. This book may be seen as a contribution to some of the aims identified in the report, and is drawn from the collective experience of the Building Research Station and its successors, the Building Research Establishment and BRE Ltd, over the years since its foundation in 1921.

Information on faults in buildings of all types shows that a substantial number relate to building services, and some of those are rather elementary in nature. An analysis of the information available to BRE is given in Chapter 0.

Readership

Building services is addressed primarily to building surveyors and other professionals performing similar functions – such as architects and builders – who maintain, repair, extend and renew the national building stock. During the course of routine surveys of existing buildings by surveyors and architects, there will be a need to identify items relating to the services: deficiencies in performance resulting from outdated installations, or breakdown through wear and tear, which demand attention. Bearing in mind the increasing complexity of building services, and of the old adage that a little knowledge can be a dangerous thing, there is still a need for sufficient information to be available to enable building owners to be advised on when to call in specialist consultants to rectify, enhance or replace existing installations. *Building services* is certainly not aimed at the mechanical and electrical engineer nor indeed at the building services engineer, though it will perhaps find application in the education field.

The descriptions and advice given in the pages which follow concentrate on practical details. But there also needs to be sufficient discussion of principles to impart understanding of the reason for certain practices, and some of this information of a general nature is given in Chapter 1.

Scope of the book

All kinds of building services, including space heating and cooling, ventilation systems, piped services of water and gas, refuse disposal, wired services for electricity, telephone and television, and mechanical handling systems such as lifts and escalators are, in principle, covered in the book. It will immediately be apparent that in a production of this limited size the coverage on any particular topic can only be brief. The text therefore concentrates on those aspects with which BRE has been most heavily involved, whether in laboratory research, site investigation or the development of legislation and Standards.

Although lightning protection might possibly be considered as a building service, this topic has already been dealt with in *Roofs and roofing*, Chapter 1.6, and *Walls, windows and doors*, Chapter 1.8; the risk of lightning strikes and detailed discussion of the necessary provision against strikes is not included in this book, though a case study drawing attention to the extent of damage which can occur to a chimney is included in Chapter 2.1. However, since these other volumes were written BRE has issued a new Digest which deals with lightning protection[2].

Building services does not deal with industrial plant engineering, nor in any detail with the design and installation (and faults) of the large scale installations necessary to service larger buildings. Nor can it deal with specialised buildings such as cold stores. There is an almost incredible variety of practices, with corresponding potential for error and breakdown. The saving grace is, of course, the degree of specialisation, competence and professional skills of the larger firms of consultants and contractors in the building services industry who are more usually involved in these larger schemes. It is in the smaller schemes that corners are sometimes cut.

In principle, all types of buildings are included. However, it is inevitable that the nature of installations becomes very sophisticated in some building types such as factories and health buildings, and these installations do not make it easy to provide simple guidance for use of non-specialists on site. The topics differ somewhat in this respect from those which have been covered in the other books in the BRE Building Elements series. However, even the relatively simple systems used in the majority of domestic construction provide adequate potential for improvement.

Both good and bad features of building services are described, and sources of further information and advice are offered. The drawings are not working drawings but merely show either those aspects to which the particular attention of readers needs to be drawn or provide typical details to support text. The discussion is deliberately neutral on matters of style and aesthetics and is wary of suggesting that there is ever a unique optimum solution.

As with the other books in this series, the text concentrates on those aspects of building services which, in the experience of BRE, lead to the greatest number of problems or greatest potential expense, if carried out unsatisfactorily. It follows that these problems will be picked up most frequently by maintenance surveyors and others specifying and carrying out remedial work on building services. Occasionally there is information relating to an item, perhaps a fault, which is infrequently encountered, and about which it may in consequence be difficult to locate information. Although most of the information relates to older buildings, material concerning observations by BRE investigators of new buildings under construction in the period from 1985 to 1995 is also included.

The case studies provided in some of the chapters are selected from the files of the BRE Advisory Service, the Building Research Energy Conservation Support Unit, and the former BRE Defects Prevention Unit, and represent the most frequent kinds of problems on which BRE has been consulted.

An attempt has been made within the chapters to follow the standard order of section headings adopted for the other books in the series. These standard headings are repeated only where there is a need to refer the reader to earlier statements or where there is something relevant to add to what has gone before.

In the United Kingdom, there are three different sets of building regulations: the Building Regulations 1991 which apply to England and Wales; the Building Standards (Scotland) Regulations 1990; and the Building Regulations (Northern Ireland) 1994. There are many common provisions between the three sets, but there are also major differences. The book has been written against the background of the building regulations for England and Wales, since, although there has been an active Advisory Service for Scotland and Northern Ireland, the highest proportion of site inspections has been carried out in England and Wales. The fact that the majority of references to building regulations are to those for England and Wales should not make the book less applicable to Scotland and Northern Ireland.

In addition to the building regulations, there is also other legislation such as the Electricity at Work Regulations 1989, the Electricity Supply Regulations 1989, the Regulations of the Institution of Electrical Engineers, now published by BSI as Requirements for electrical installations, BS 7671[3], the Gas Safety (Installation and Use) Regulations 1998, and the Water Byelaws[4] which were succeeded by the Water Regulations in 1999[5].

Although practically all building services are encompassed in the Construction (Design and Management) Regulations 1994, the ramifications for each of the services covered in this book are considerable. It is not practical to spell them out in this book, beyond noting that there must be a Health and Safety Plan and File for buildings constructed after this date which should include information on how to manage health and safety issues after the installation is completed and throughout its life until demolition[6].

Some important definitions

The broad term 'services' usually includes those provisions for meeting the internal environmental requirements that – like heating, lighting and ventilating systems – depend on the consumption of energy and materials. The most common requirements today are for consumable water for life support and for sanitation, for consumable energy (for heating, lighting, ventilation and other purposes), and for means of transportation and telecommunication. All services, of course, require further space for their accommodation within the building, and most, but not all, also require support and enclosure.

For the purposes of this book the word 'chimney' means a structure consisting of a wall or walls containing a flue or flues. This definition includes any part of the fabric of a building or a part separate from it; that is to say, either masonry carcass or metal sheath. The 'flue' is the continuous void which actually carries the products of combustion from the appliance to the terminal. The term 'duct' means an enclosed void which carries one or more pipes from one part of the building to another part. Chimney can also apply to the structure which encloses a vertical ventilation duct. The term duct can also apply to the (usually) sheet metal enclosed void which carries fresh air into the building, or vitiated or exhausted air out of the building.

Since *Building services* is mainly about the problems that occur in building services, two words, 'fault' and 'defect', need precise definition. Fault describes a departure from good practice in design or execution of design; it is used for any departure from requirements specified in building regulations, British Standards and Codes of practice, and the published recommendations of authoritative organisations. A defect – a shortfall in performance – is the product of a fault, but while such a consequence cannot always be predicted with certainty, all faults have the potential for leading to defects. The word 'failure' has occasionally been used to signify the more serious defects (and catastrophes!). The word fault as used here is not synonymous with electrical fault as defined in BS 7671, and defects and unsafe conditions take on a special significance in gas utilisation as controlled by the Gas Safety (Installation and Use) Regulations.

A general requirement for 'safety' arises because many of the means adopted to satisfy the primary user requirements create potential or actual hazards. BRE has been greatly concerned with safety over the years. The most important aspects in the past history of building have been structural collapse and fire. Hazards to health probably come next, though they tend to be more insidious, and less easily recognised and defined. Other aspects include explosion (closely related to fire), and a variety of possible contributory causes of human accidents such as falls. Safety means the reduction of these hazards and risks of accident to tolerable levels since absolute safety is virtually unattainable. A number of accident rates are quoted in this book for various building services. As noted in the companion book *Roofs and roofing*, it is a matter for the collective judgement of society, operating through building regulations and British Standards, whether these accident rates are acceptable, for it could be very expensive to uprate all Standards to provide for better protection.

Where the term 'investigator' has been used, it covers a variety of roles including a member of BRE's Advisory Service, a BRE researcher or a consultant working under contract to BRE.

Particular terms used in connection with energy, central heating and air conditioning will be found listed in later chapters.

So far as water terms are concerned, there has been a significant change in usage since the 1980s. The term 'potable' water to describe water of a quality suitable for drinking is now no longer popular, though it is still contained in current Standards: the terms 'drinking water' or 'wholesome water' are preferred. 'Grey water' is defined as waste water not containing faecal matter or urine, and 'black water' is defined as waste water which contains faecal matter or urine.

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Photographs which do not bear an attribution have been provided from our own collections or from the BRE Photographic Archive, a unique collection dating from the early 1920s.

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H W H
P M T
July 2000

Chapter 1 **Building physics (services)**

This first chapter deals in simplified form with some of the basic underlying scientific and engineering principles which tend to affect the internal environment of the building as a whole. It also concentrates on those uses of energy which seem to be of most consequence to the occupants and which have a direct effect on their comfort, both thermal and visual.

As noted in the introductory chapter, the oldest buildings in the UK building stock have relatively little in the way of building services. In the days when these buildings were built, their occupants had to make do with the crudity of what was currently available. The application of scientific principles to the design of buildings, although receiving some impetus with the technological developments of the Industrial Revolution, did not take off until the 1920s and did not really form a significant part of the education of architects until the middle years of the twentieth century.

'The highest available knowledge of pure science and the most effective methods of research are needed in building as in any other field of research. Building research as a whole, however, is concerned with the principles of an exceptionally wide range of science. Results of past scientific research are not at present fully utilised in building because there is no suitable bridge between the research worker and the architect or designer.' (The Department of Scientific and Industrial Research, 1919).

Although the principles underlying design for user satisfaction might not have changed significantly during the interwar years, the 1920s and 1930s, the application of scientific principles to the design and construction of buildings received a boost when the first volume of the book *Principles of modern building* was published in 1938 (see Chapter 1.1).

There is not the slightest doubt that since that time the increasing sophistication and consequent demands of users for improved standards in all kinds of buildings are driving an accelerating rate of change in the technological development of building services. In consequence, building services plant is getting more and more sophisticated (Figure 1.1), and services are taking an ever-increasing share of the total costs of a building project.

Figure 1.1
Part of the plant room for a small office building. The rate of change of technological development is increasing, and plant rooms can become congested

Chapter 1.1 The building as a whole

At the time that the Building Research Station (BRS) was first established, relatively few houses had bathrooms and water closets, relying instead on outside 'privies'. Central heating was rare, even in non-domestic buildings. Washday for many households began by lighting a gas or coal fire under the 'copper', stirring the clothes with a 'dolly', and 'mangling' them by hand to a semi-dry state. Standards since then have risen out of all recognition.

When the first edition of *Principles of modern building* (13) was published in 1938, it was possible to discuss in physical terms the functions and performances of the types of construction that were then being built, to indicate ways of predicting some of the performances, and to distinguish between good and bad practices. In the revised and expanded editions of 1959–61 this approach was further developed and extended to floors and roofs as well as to walls. But the focus on the building element – the wall, floor, or roof – remained.

This concentration on building elements had the merit that it directly reflected the main interests of the designer at the detailed design stage. On the other hand it offered little general guidance on, for instance, the design of a complete spatial enclosure, the performance of which was of more interest to the user; and, for this reason, it could lead to overemphasis on some features and the relative neglect of others of equal or greater importance. There was a need to think more in terms of the whole system, at least when contemplating any major departure from already proven practice.

Part 1 of the third edition of *Principles of modern building* was entitled 'The building as a whole'. The text dealt with a number of important aspects of the performance of the whole building such as stability, ventilation, thermal and sound insulation, fire protection and daylighting, but there was little examination of the role of building services and the part they played in establishing comfortable conditions for the occupants. Since the 1960s, BRE has put much effort into examining the influence of one services subsystem upon another; for example, the inter-relationship of different forms of heating systems with thermal capacity, thermal insulation and ventilation provision, and the effects of extraneous air leakage. The performance of the whole building ought to be viewed as a complex interaction of all its parts and all its subsystems, and what is in balance for one set of circumstances may not be the same for another. Although the carcass of the building can provide the occupants with some protection from extremes of climate, both winter and summer, it is the servicing subsystems which now provide the fine tuning and correction of any imbalances in comfort levels (Figure 1.2).

Figure 1.2
Simple protection from the weather, which might have sufficed in years gone by, is no longer enough. When this substantial dwelling was built in the nineteenth century, the many chimneys now surviving indicate that the main rooms were heated by open fires; even so, some rooms were unheated. Used since the early 1920s as offices, the servicing systems have needed to change out of all recognition

The UK Climate Change Impacts Review Group have published estimates of the changes to the British climate that are expected to result from global warming over the next 60 years. Climate change has particular relevance to buildings because they last a long time. Buildings now being designed or extensively refurbished are expected to last well beyond the time when significant climate change is expected, and many aspects of buildings are sensitive to climate. Current design procedures rely on historical climate data for the assessment of risk, but, if climate is to change, risk needs to be reassessed. Given the high degree of uncertainty about future climate, the first requirement is to determine the extent to which aspects of buildings are sensitive to climate change. The results form a basis for deciding where changes to design conditions are required. For building services, the greatest changes are likely to be in heating and cooling requirements. In the short term, the most important effects are likely to derive from initiatives to limit global warming by improving energy efficiency, rather than from the direct effects of climate change[30].

BREEAM – the BRE Environmental Assessment Method for buildings – was launched in July 1990. It remains the main working method worldwide for assessing environmental performance, and indeed has become a *de facto* standard for environmental performance[29].

Integration of building services into the overall design process

Although it might be thought that services would always be fully integrated into the carcasses of buildings from the start of the design process, with coordination proceeding through to the site assembly, it is only within recent years that significant progress has been made. When buildings were simple, and had few services other than provision for space heating, a hand pump in the kitchen, and bell wires to summon the servants, coordination of the installations was relatively unimportant, and could be accommodated piecemeal. Some were left exposed in any case.

BRS became more heavily involved in the rationalisation and integration of building services in the late 1950s following the discovery that it was common on site inspections to find that no such planning had taken place. Each specialised contractor would do his own thing. The first one on site had a clear run, and all the others following on had to fit their pipe runs and cables around what was already there. A mechanical and electrical engineer of a brand new hospital under construction in 1960 was asked by a BRE investigator if he could show a drawing of the services at one pinch point in the structure, an underground duct joining two buildings. The engineer produced 24 separate drawings, each showing different installations passing through the same location! No one had thought to coordinate them, and a veritable cat's cradle had resulted on site. The legacy lingers on in many of the buildings of those days, with a few honourable exceptions.

This lamentable state of affairs prompted BRE to include the integration of building services in the series of books aimed at the educational field, and entitled *Designing for production*[31].

In these publications, building services are categorised into three types:

- large self-contained elements with few connections to other services, such as lift installations
- utility services, such as sanitary accommodation, usually grouped into fairly well defined areas of the building, with connections with hot and cold water systems, and to drainage
- environmental services, which by their nature extend on a significant scale throughout a building; these include heating, ventilation, lighting and communications subsystems (Figure 1.3)

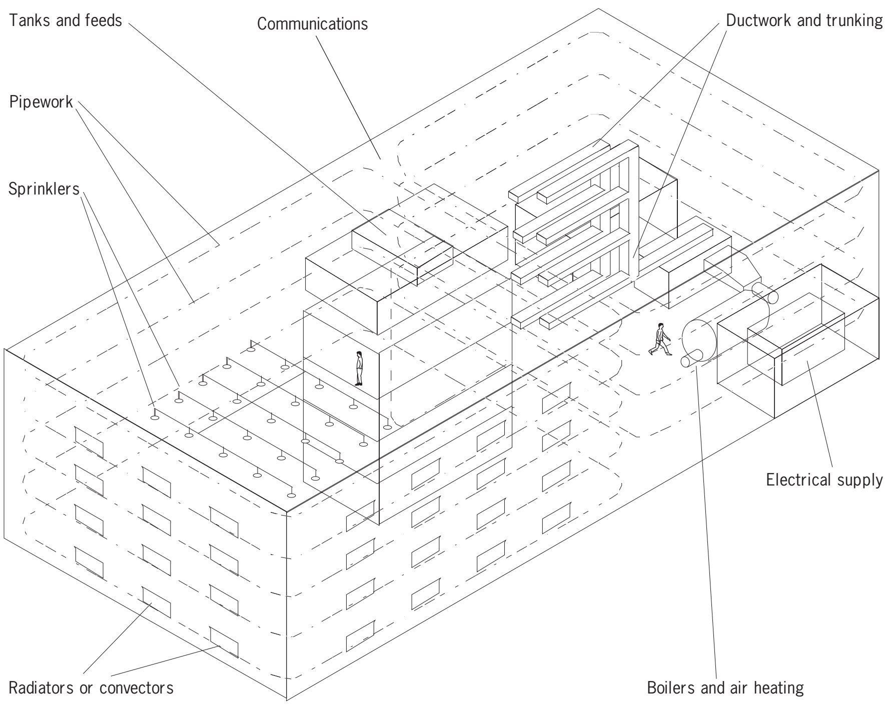
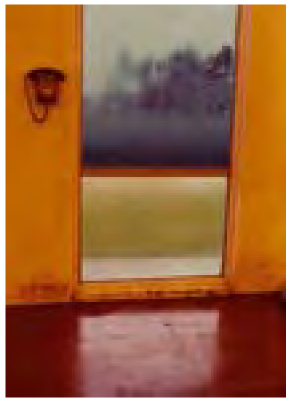
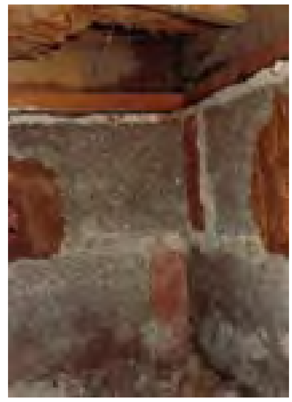
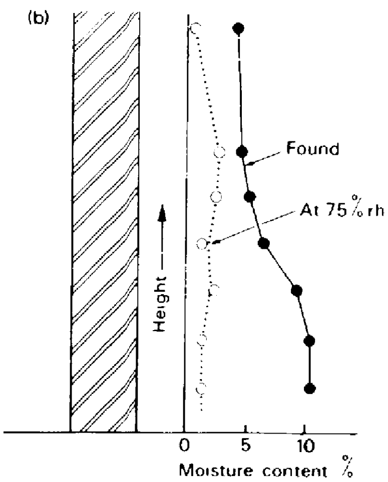


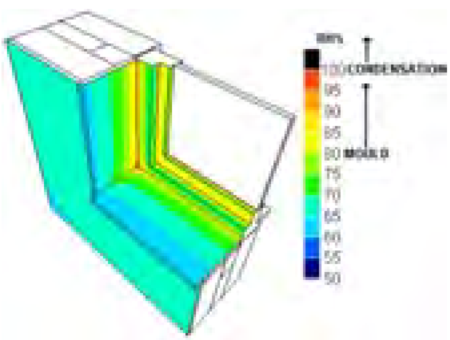
Figure 1.3
A schematic illustration adapted from Designing for production[31] showing some of the environmental services for a large building

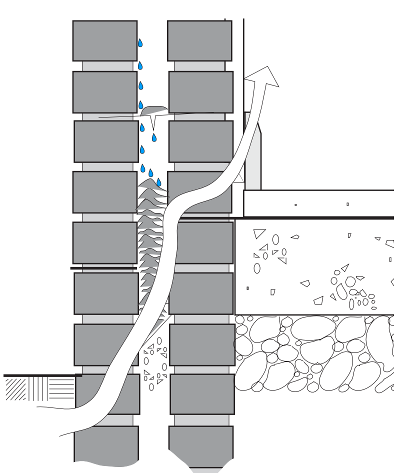




Understanding dampness

Peter Trotman
Chris Sanders
Harry Harrison





Understanding dampness

Effects, causes, diagnosis and remedies

Peter Trotman, Chris Sanders and Harry Harrison

BRE
constructing the future

Contents

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Preface

Many years ago, before the Building Research Station was founded, the British Medical Association asked the Royal Institute of British Architects to investigate the causes of dampness in dwelling houses to help them find the reasons for the prevalence of certain diseases. The RIBA committee found that direct penetration of rain through walls and lack of a damp-proof course (DPC) accounted for nearly two-thirds of all cases; condensation contributed only 2%. The causes may have since changed in relative importance with changes in construction techniques, such as cavity walls and the tendency for houses to be better heated. Unfortunately, though, dampness is a continuing source of distress to occupants. It is possibly a source or a contributor to illness, it encourages deterioration in the building fabric, and it is involved in half of the investigations undertaken over the years by BRE.

As well as damp patches on walls, ceilings and floors, dampness can lead to blistering paint, bulging plaster, rot in building timbers, mould on surfaces and fabrics, and sulfate attack on brickwork. It can also lead to less visible problems, such as reduced effectiveness of thermal insulation or cracking in brickwork as a result of corrosion of embedded metal components. Despite all the technical advice that has been published in the past, there is still a significant set of problems. This book seeks to address them.

Readership

This book is aimed primarily at all professionals involved in the design, maintenance and management of domestic, public, commercial and industrial properties; this includes surveyors, architects, builders and facilities managers. It will also be useful to student members of these professions. Much of the text and many of the illustrations will also be of relevance to householders and other users of buildings.

Scope of the book

The emphasis of this book is on existing buildings with some coverage of the design of new build. It lists the causes of dampness in buildings and explores the consequential effects of that dampness on the fabric, the maintenance of protection against dampness, and the remedies which the detrimental results of dampness will call for.

It is illustrated with photographs of defects from the BRE Advisory Service collection and drawings of construction elements that need careful design and execution. Case studies illustrate some of the more typical problems which have been investigated as well as some interesting but informative non-typical cases, although it must be recognised that it is rare to find two cases which are identical in every detail.

Chapter 1 contains background information. Chapter 2 provides a visual indication of the most common manifestations of dampness to be seen in buildings, tabulated according to building element. When the appearance of the defect under investigation has been matched with the appropriate photograph, a key provides a link to later chapters which give explanations of the physics, further information to confirm the diagnosis, and the remedies which might be specified to put right the defect.

Although this book is mainly about existing buildings, and not specifically about the design of new buildings, it gives some design criteria so that subsequent performance of the completed building may be assessed against what was either required or intended.

Some important definitions

Condensation: the process whereby water is deposited from air containing water vapour when its temperature drops to or below the dewpoint.

Dampness: used here to cover a wide variety of phenomena relating to the unwanted presence of water or water vapour, whatever its cause.

Deliquescent substance: substance which becomes damp and finally liquifies on exposure to the atmosphere, owing to the low vapour pressure of its saturated solution.

Dewpoint temperature of the air: the temperature at which condensation of liquid water starts when air is cooled, at constant vapour pressure.

Hygroscopic substance: usually applied to solids which tend to absorb moisture from the atmosphere without actually becoming liquified.

Psychrometric: Relating to the measurement of water vapour in the air, including the use of the wet and dry bulb hygrometer.

Rain penetration of walls and roofs: results from water entering the structure to such an extent that the resulting dampness or dripping of water becomes a nuisance.

Relative humidity: the ratio, normally expressed as a percentage, of the actual amount of water vapour present to the amount that would be present if the air were saturated at the same temperature.

Reverse condensation (*old term: summer condensation*): interstitial condensation that can occur when moisture within a wall is driven in by solar radiation on south-facing walls.

Rising damp: normally the upward transfer of moisture in a porous material due to capillary action.

Thermal bridge (*old term: cold bridge*): part of a structure of lower thermal resistance which bridges adjacent parts of higher thermal resistance and which can result in localised cold surfaces on which condensation, mould growth and/or pattern staining can occur.

Vapour control layer (VCL): usually a thin sheet material with a vapour resistance greater than 200 MNs/g, used on the warm side of thermal insulation to restrict moisture which diffuses through the insulation from condensing on any colder outer surface.

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Chapter 5
Rain penetration

This chapter tells you how to assess the risk of specific designs in actual locations in the UK using the driving rain index, and deals with rain penetration in solid and cavity masonry walls, cavity wall insulation, cladding systems, DPC detailing principles and well-tried details, rain penetration of pitched and flat roofs, parapets and leaking windows.

Figure 5.1 A disfiguring deposit of carbonate from rain penetrating the sloping brickwork parapet

Figure 5.2 Although much of this results from condensation, there is also some rain penetration

There are regional construction differences throughout the UK as a result of local experience and practice as well as available materials. In more exposed locations, walls may be sand:cement rendered and slate or tile-hung in Cornwall and Scotland. Pitched roofs are given a second line of defence with a sarking material of felt or plastics. In Scotland, boarding is used as the sarking. Windows in Scotland are usually inset to give protection; other parts of the UK use a narrow sill with the window much closer to the line of the outer leaf.

DRIVING RAIN

In the Building Regulations, control of moisture is a functional requirement and the building must be designed to adequately resist such penetration – see Approved Document Part C and Part G.

An International Council for Research and Innovation in Building and Construction (CIB) *Working Commission on Rain Penetration* meeting in the 1950s adopted a definition of rain penetration:
By rain penetration is meant that rainwater penetrates into a wall either through the surface of the wall, or due to leakage at windows or similar installations. It is not necessary that water penetrates so far that it may be discernible on the inside of the wall. More information is in *Rain Penetration Investigations - A summary of the findings of CIB Working Commission on Rain Penetration - Oslo 1963*.

Rain penetration in modern cavity walls tends to show as a well-defined roughly circular area on internal finishes. Sometimes surface salts will define the outer limits of such wetting. If the wetting persists, most of the wall may become visibly damp. In older, solid wall buildings, wetting may not be visible because successive coats of emulsion paint or vinyl wallpaper have masked the effects. The extent of the dampness, or if dry the salts which define it, can be traced with a moisture meter.

Figure 5.3 Severe wetting from driving rain on an exposed wall

Moisture can be deposited on external surfaces in several ways:

- ❒ Gentle rain or drizzle normally falls vertically and will accumulate on flat surfaces. Some splashing may wet adjacent surfaces.
- ❒ Driving rain, which is heavy rain blown by a strong wind on to horizontal and vertical surfaces. Water can also be blown uphill on sloping surfaces.
- ❒ Snowfall and wind-blown snowdrifts have little effect at the time but when the snow melts, it can cause severe wetting, particularly very fine snow blown into pitched roofs.
- ❒ Fog wets external surfaces but in small quantities and has little effect.
- ❒ Condensation can occur on outside surfaces in tropical climates, particularly with air-conditioned buildings. Storms in these climates are more likely to be a test of weathertightness.