Building Design using Cold Formed Steel Sections

Light Steel Framing in Residential Construction

P J GRUBB BSc (Hons), CEng, MICE

M T GORGOLEWSKI BSc, MSc, PhD, Dip Arch RIBA

R M LAWSON, BSc(Eng), PhD ACGI, CEng MICE, MIStructE

SCI PUBLICATION P301

Published by:

The Steel Construction Institute
Silwood Park
Ascot
Berkshire SL5 7QN

Tel: 01344 623345
Fax: 01344 622944

Why use light steel frames?

Light steel framing uses galvanized cold formed steel sections as the main structural components. These sections are widely used in the building industry and are part of a proven technology. Light steel framing extends the range of steel framed options into residential construction, which has traditionally been in timber and masonry.

The Egan Task Force report called for improved quality, increased use of off-site manufacture, and reduced waste in construction, and the Egan principles have been adopted by The Housing Corporation and other major clients in the residential sector. Light steel framing satisfies these Egan principles and it combines the benefits of a reliable quality controlled product with speed of construction on site and the ability to create existing structural solutions.

Steel is a quality assured, dimensionally accurate, high strength, long life, adaptable, reusable and recyclable product. There is an established infrastructure of manufacture, supply, design and detailing, that is well covered by British Standards, type approvals and publications.

Architects and specifiers are now able to extend the successful application of steel by using light steel frames as an economic and versatile form of construction for residential buildings.

This publication provides guidance on the design and detailing of light steel framing in modern residential buildings in ways which comply with the Building Regulations in England and Wales.

Front cover illustration: Adrian James's House (an architect's riverside house).
Architect: Adrian James Architects.

Publication Number: SCI P301

ISBN 1 85942 121 0

British Library Cataloguing-in-Publication Data.
A catalogue record for this book is available from the British Library.

FOREWORD

This publication was prepared by Mr P J Grubb and Dr M Gorgolewski with assistance from Dr R M Lawson. The help of the following individuals and organisations in supplying information, details and for commenting on the draft report, is gratefully acknowledged:

Mr N Cooper	National House-Building Council
Dr G Couchman	The Steel Construction Institute
Mr P Davis	Zurich Building Guarantees
Mr S Driscoll	District Surveyors Technical Committee
Mr A J Hall	Local Authority National Type Approval Confederation
Mr J Mason	Alan Baxter and Associates (DETR project manager)
Dr R Pedreschi	The University of Edinburgh
Dr S O Popo-ola	Imperial College of Science Technology & Medicine

and also the members of the Light Steel Framing Group:

Mr J Baker	The Forge Llewellyn Company
Mr R Burns	Metsec Framing Ltd
Mr R Colver	Ayrshire Steel Framing
Mr I McCarthy	Metsec Framing Ltd
Dr R Ogden	Consultant
Mr D Phillips	Corus Colors
Mr J Robinson	Corus Colors
Dr A Rogan	Oxford Brookes University
Mr R Stark	Knauf Ltd
Mr D Varley	Terrapin Ltd
Mr C Walker	Lafarge Plasterboard Ltd
Mr P Watkins	Metsec Framing Ltd
Mr G Webb	Consultant Architect
Mr C Westbrook	Corus Framing
Mr N Whitehouse	Terrapin Ltd

Acknowledgement is given to the following for their endorsement of this publication:

Mr N Cooper	National House Building Council
Mr P Davis	Zurich Building Guarantees
Mr S Driscoll	District Surveyors Technical Committee
Mr A J Hall	Local Authority National Type Approval Confederation

The work in preparing this publication was carried out under a contract funded by Corus Colors (formerly British Steel Strip Products) and the Secretary of State for the Environment, Transport and the Regions, placed on 8 May 1998. Any views expressed are not necessarily those of the Secretary of State for the Environment, Transport and the Regions.

CONTENTS

SUMMARY

This publication provides information and guidance on the construction of light steel frames in general applications for residential construction, which includes single family houses and apartments. Light steel framing systems use galvanized cold formed steel sections as the primary structural components, which can be assembled as prefabricated panels.

The publication addresses aspects of design within the scope of the Building Regulations (England and Wales). It also covers construction practice and detailing of light steel frames and their interfaces with other materials and components. The information is generic and focuses on general construction principles.

Detailed design information is given on structural design and robustness, serviceability of floors, thermal and acoustic performance, and fire resistant design. A list of manufacturers is presented.

Dimensionnement de constructions utilisant des profils a froid en acier : Ossatures legeres pour immeubles residentiels

Résumé

Cette publication fournit informations et guidances relatives à la construction d'ossatures légères en acier pour des immeubles résidentiels, depuis la maison familiale jusqu'aux immeubles à appartements. Les systèmes d'ossatures légères en acier utilisent des profils à froid en acier galvanisé comme éléments structuraux principaux, qui peuvent être assemblés en panneaux préfabriqués.

L'ouvrage couvre les aspects relatifs au dimensionnement en se basant sur les réglementations relatives aux bâtiments (Angleterre et Pays de Galles). Il couvre aussi les aspects pratiques de construction ainsi que les détails de constructions des ossatures et leurs interfaces avec les autres matériaux et composants.

Cette information est de nature générale et insiste sur les principes de construction.

Des informations détaillées sont données quant au dimensionnement structural et à la robustesse, au comportement en service des planchers, aux performances thermiques et acoustiques et à la résistance au feu. Une liste des fabricants est également jointe.

Gebäudeentwurf mit Kaltprofilen aus Stahl: Stahlleichtbau im Wohnungsbau

Zusammenfassung

Diese Publikation vermittelt Information und Anleitung zum Bau von Stahlleichtbauten allgemeiner Art im Wohnungsbau hinsichtlich Einfamilienhäusern und Appartementhäusern. Stahlleichtbau-Systeme bestehen *aus verzinkten Kaltprofilen aus Stahl als Primärtragwerk, das aus vorgefertigten Elementen zusammengebaut werden kann.*

Die Publikation widmet sich Aspekten von Entwurf und Berechnung innerhalb der Bauvorschriften (England und Wales). Sie behandelt ebenso die Baupraxis und Details von Stahlleichtbauten und deren Interaktion mit anderen Materialien und Komponenten. Die Information konzentriert sich auf allgemeine Konstruktionsprinzipien.

Ausführliche Information zu Berechnung und Widerstandsfähigkeit, Gebrauchstauglichkeit von Decken, thermischem und akustischem Verhalten und bransicherem Entwurf wird vermittelt. Eine Liste von Herstellern wird vorgestellt.

Proyecto de edificios utilizando perfiles de acero conformados en frío: estructuras ligeras de acero en edificios de habitación.

Resumen

Esta publicación reúne información y consejos para la construcción de entramados ligeros de acero aplicados a edificios de habitación tanto familiares como de apartamentos. Los entramados ligeros de acero usan perfiles de acero galvanizados y conformados en frío como componentes estructurales primarios, que pueden ser montados como paneles prefabricados.

La publicación trata aspectos de proyectos en el marco de las Building Regulations (Inglaterra y Gales). También cubre las prácticas de construcción y detalles de las estructuras ligeras y sus interfases con otros materiales y componentes. La información es genérica y concentrada en principios generales de construcción.

Se incluye información detallada sobre el proyecto estructural, la capacidad de servicio y la resistencia al fuego. Se presenta también una lista de fabricantes.

Progettazione di edifici realizzati con elementi sagomati a freddo: Telai leggeri in acciaio per costruzioni residenziali

Sommario

Questa pubblicazione fornisce informazioni e costituisce una guida alla costruzione di telai leggeri in acciaio per applicazioni generali nelle costruzioni residenziali, con riferimento alle case unifamiliari e agli appartamenti. I sistemi di telai leggeri in acciaio impiegano per le parti portanti elementi zincati in acciaio sagomato a freddo, i quali possono essere assemblati come pannelli prefabbricati.

La pubblicazione tratta gli aspetti progettuali all'interno delle esplicite finalità del "Regolamento per gli Edifici" (in vigore in Inghilterra e Galles) e copre anche la pratica costruttiva e di dettaglio delle strutture intelaiate leggere in acciaio e le loro interfacce con altri materiali e componenti. Le informazioni *presentate sono di carattere qualitativo sui principi costruttivi generali.*

Sono riportate dettagliate informazioni sulla progettazione strutturale e sulla solidità, sulle condizioni di servizio dei piani, sulle prestazioni termiche e acustiche e sulla progettazione per la resistenza al fuoco. Viene inoltre presentata una lista di produttori.

Lättbyggnad med stål; konstruktionsdetaljer och utförande i bostadshus

Sammanfattning

Denna publikation ger information och vägledning inom lättbyggnadstekniken med stål för småhus och flervåningshus. Lättbyggnad med stål använder i huvudsak tunnplåtsprofiler i bärande stommen eller skelettstommen och är till hög grad prefabricerad.

Denna publikation behandlar byggregler och normer i England och Wales vid design av husbyggnader i Lättbyggnad med Stål. I denna publikation behandlas utförande av byggdetaljer och praktiska anvisningar med hänvisning till byggregler och normer gällande i England och Wales. Fokus ligger på allmännyttiga konstauktionsprinciper.

Detaljerad designinformation att hämta från denna publikation är bärandekonstruktionslösningar, bjälklaget och dess funktion, akustikegenskaper och termiska egenskaper samt brandtekniska egenskaper.

1 INTRODUCTION TO LIGHT STEEL CONSTRUCTION

Light steel framing is generally based on the use of standard C or Z shaped steel sections produced by cold rolling from strip steel. Cold formed sections are generically different from hot rolled steel sections, such as Universal Beams, which are used in fabricated steelwork. The steel used in cold formed sections is relatively thin, typically 0.9 to 3.2 mm, and is galvanized for corrosion protection.

Cold formed steel sections are widely used in many sectors of construction, including mezzanine floors, industrial buildings, commercial buildings and hotels and are gaining greater acceptance in the residential sector. Light steel framing is already well established in residential construction in North America, Australia and Japan. This publication presents general guidance and details on the use of light steel framing in residential construction, in ways which meet the requirements of the Building Regulations in England and Wales.

1.1 Methods of construction

The basic building elements of light steel framing are cold formed sections which can be prefabricated into panels or modules, or assembled on site using various methods of connection. The different forms of construction are reviewed in the following sections and are illustrated in Figures 1.1 to 1.3.

Figure 1.1 *Light steel framing using discrete members ('stick-build' construction)*

Figure 1.2 *Light steel framing using prefabricated panels*

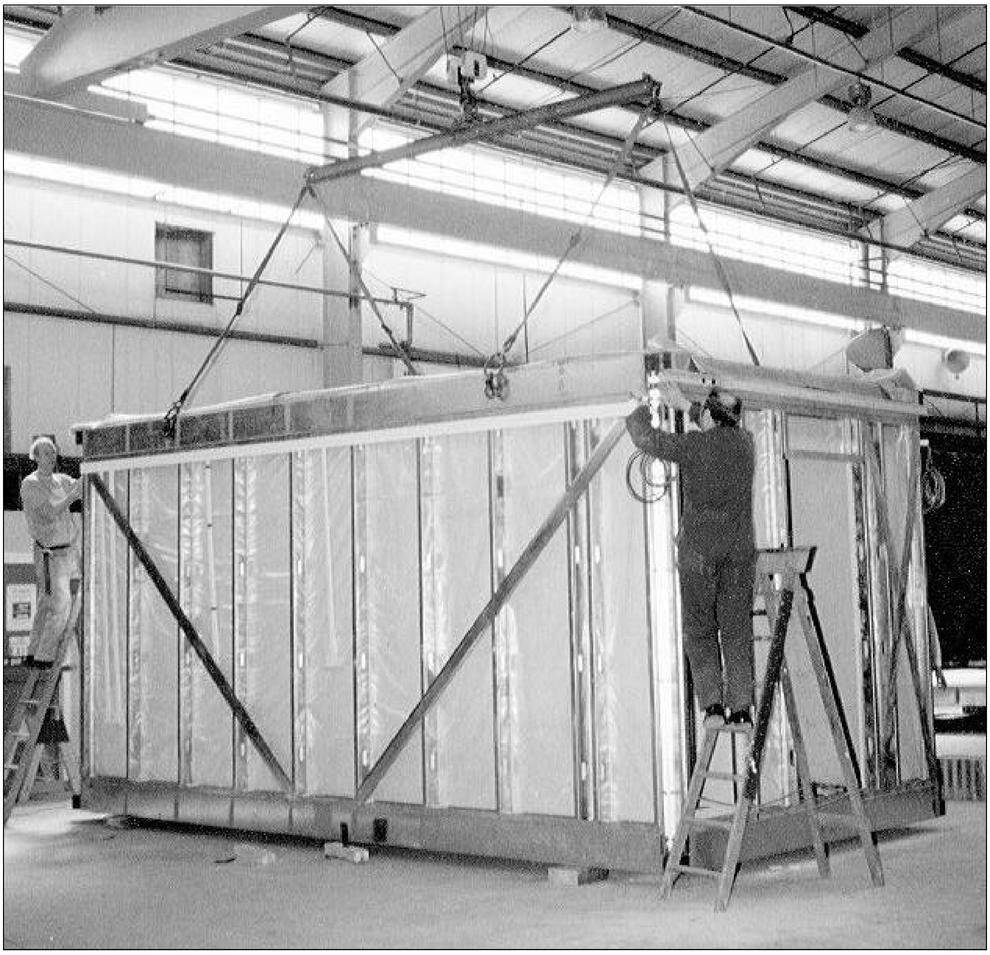


Figure 1.3 *Modular construction using light steel framing*

1.1.1 'Stick-build' construction

In this method of construction (illustrated in Figure 1.4), discrete members are assembled on site to form columns, walls, rafters, beams and bracing to which cladding, internal lining and other elements are attached. The elements are generally delivered cut to length, with pre-punched holes, but connections are made on site using self-drilling self-tapping screws, bolts, or other appropriate site techniques.

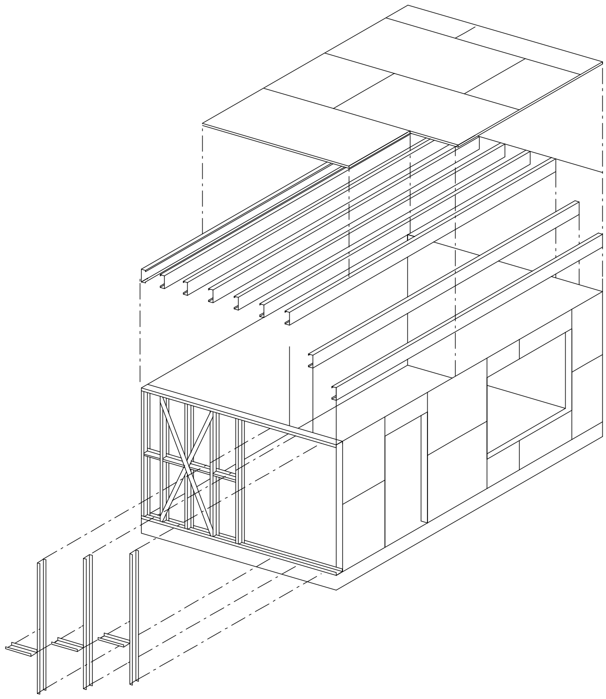


Figure 1.4 *'Stick-build' site construction using wall studs and floor joists*

The main advantages of 'stick-build' construction are:

- construction tolerances and modifications can be accommodated on site
- connection techniques are relatively simple
- manufacturers do not require the workshop facilities associated with panel or modular construction
- large quantities of light steel members can be densely packed and transported in single loads
- components can be easily handled on site.

'Stick-build' construction is generally labour intensive on site, compared to the other methods but can be useful in complex construction, where prefabrication is not feasible. This form of construction is widely used in North America and Australia, where there is an infrastructure of contractors skilled in the technique. This stems from a craft tradition of timber frame construction that now uses many power tools. In these countries, traditional timber contractors have changed to light steel framing with little difficulty.

1.1.2 Panel construction

Wall panels, floor cassettes and roof trusses may be prefabricated in a factory and later assembled on site, as in Figure 1.5. For accuracy, panels are manufactured in purpose-made jigs. Some of the finishing materials may be applied in the factory, to speed on-site construction. Panels can comprise the steel elements alone or the facing materials and insulation can be applied in the factory. The panels are connected on site using conventional techniques (bolts or self drilling screws).

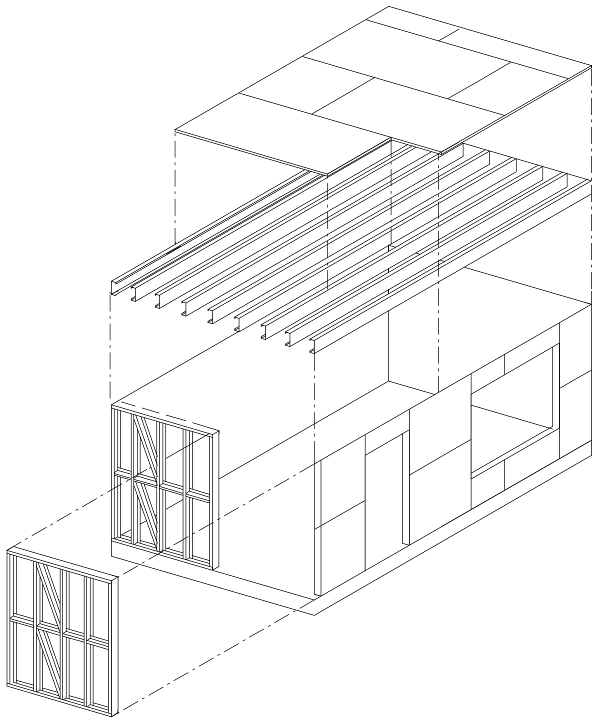


Figure 1.5 *Site assembly of light steel wall panels*

The main advantages of panel or sub-frame construction are:

- speed of erection of the panels or sub-frames
- quality control in production
- reduced site labour costs
- scope for automation in factory production.

The geometrical accuracy and reliability of the panels and other components is better than with stick-build construction because panels are prefabricated in a factory environment. The accurate setting out and installation of foundations is a key factor to achieve rapid assembly of the panels and to obtain the maximum efficiency of the construction process.

1.1.3 Modular construction

In modular construction, units are completely prefabricated in the factory and may be delivered to site with all internal finishes, fixtures and fittings in place, as illustrated Figure 1.6. Units may be stacked side by side, or one above the other, to form the stable finished structure.

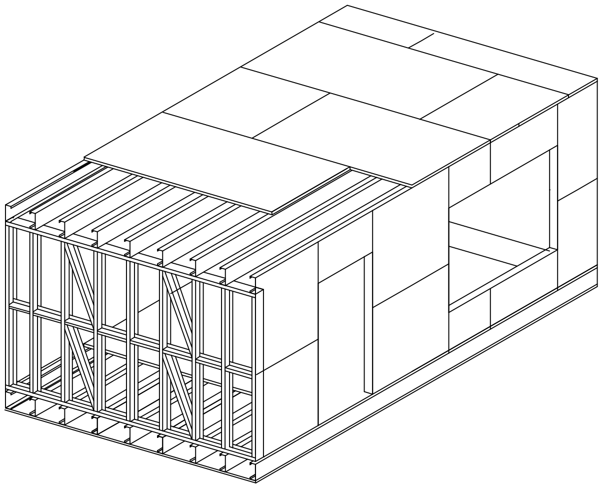


Figure 1.6 *Modular construction using light steel framing.*

Modular construction is most cost-effective where large production runs are possible for the same basic configuration of modular unit. This is because prototyping and set-up costs, which are essentially independent of scale, can be shared across many units.

A complementary SCI publication *Modular construction using light steel framing: Design of residential buildings*[1] addresses the use of modular construction in residential construction.

1.1.4 Platform and 'balloon' construction

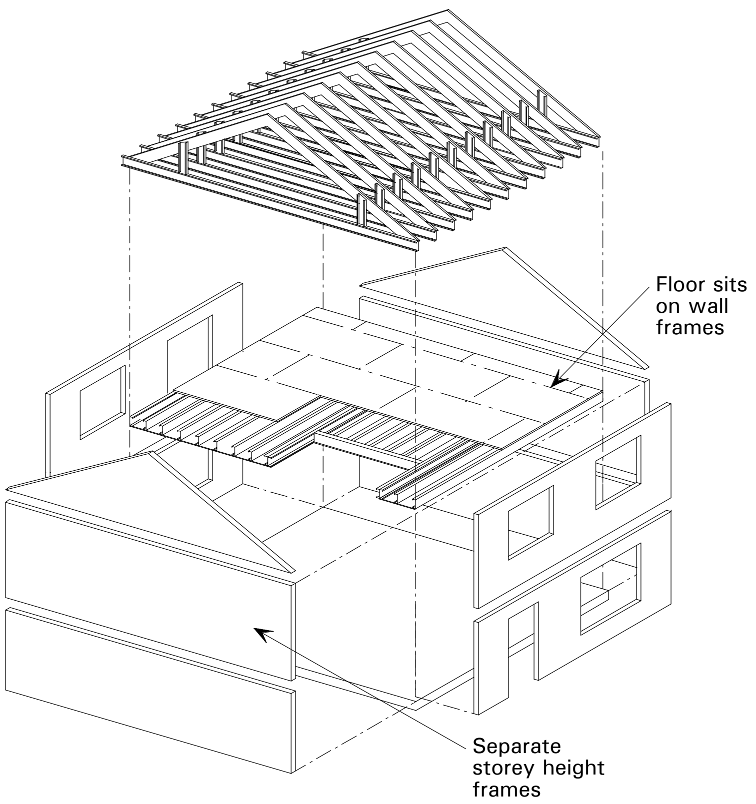
'Stick-build' or panel components may be assembled in either 'platform' or 'balloon' construction, as illustrated in Figure 1.7. In platform construction, walls and floors are built sequentially one level at a time, so the walls are not structurally continuous. In some forms of construction, loads from the walls above are transferred through the floor joists to the wall below.

In 'balloon' construction, the wall panels are often much larger and are continuous over more than one storey. Such panels are more difficult to erect than single storey height panels and have to be temporarily braced whilst the floors are installed. The main advantage of this approach is that loads from the walls above are transferred directly to those below.

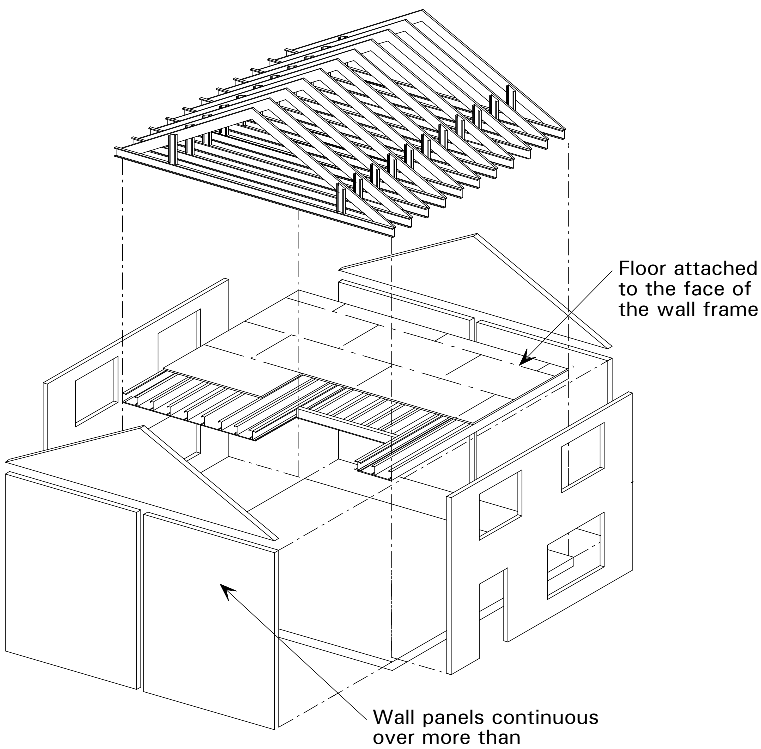
In both forms of construction, the external cladding or finishes are generally installed and attached to the frames on-site.

1.1.5 Material properties

The galvanized strip steel, from which the light steel framing is formed, is usually designated as either grade S280GD or grade S350GD to BS EN 10147[2] (formerly Fe E 280 G or Fe E 350 G). These designations indicate the yield strength (280 or 350 N/mm^2) and that the material is galvanized with a minimum G275 coating. Cold formed steel sections are usually rolled from galvanized sheet steel that is typically 0.9 to 3.2 mm thick. The normal thickness of zinc coating (275 g/m^2) has excellent durability for internal applications. Heavier coatings are available for more aggressive external environments.



a) Platform construction



b) Balloon construction

Figure 1.7 *'Platform' and 'balloon' forms of panel construction*

1.2 Building Regulations 1991

Recent trends towards introducing new legislation in the UK focus on a combined approach where legislation forms one part of an integrated set of measures which include regulation, economic instruments, guidance, demonstration and setting targets.

Increasingly, many of the UK regulations arise as a result of the requirements of the European Union. These requirements which generally take the form of 'directives' which result in the member countries of the EU modifying their own laws.

In England and Wales, a single set of Building Regulations applies. Different regulations apply in Scotland and Northern Ireland. This document principally addresses the English and Welsh regulations.

The Building Act 1984 and the Building Regulations

The *Building Act 1984* forms the statutory framework for controlling the standards of building construction. The Act is implemented by means of the Building Regulations 1991[3], together with a number of formal amendments to the Regulations. The Building Regulations generally set performance requirements for building work, including the erection of new buildings and material changes of use of existing buildings. Practical guidance on ways of meeting these requirements is given in separate *Approved Documents*[4]. The Approved Documents (ADs) also refer to materials and product standards for technical requirements. There is no obligation to adopt the solutions shown in the ADs, if the designer wishes to demonstrate compliance in some other way.

The Approved Documents to the Building Regulations have been revised at various times since 1991. There are currently 13 'Parts'.

Part A*	Structure	1992
Part B*	Fire Safety	2000
Part C*	Site Preparation and Resistance to Moisture	1992
Part D	Toxic Substances	
Part E*	Resistance to Range of Sound	1992
Part F	Ventilation	1995
Part G	Hygiene	1992
Part H	Drainage and Waste Disposal	
Part J	Heat Producing Appliances	
Part K	Protection for Filling, Collision and Impact	1998
Part L*	Conservation of Fuel and Power	1995
Part M	Access and Facilities for Disabled People	1999
Part N	Glazing - Safety in Relation to Impact, Opening and Cleaning	1998

The date in brackets indicates the latest revision. The sections marked with an * are particularly relevant to the use of light steel framing in residential applications and are addressed in this publication.

1.3 Scope of publication

This publication addresses the design of houses and residential buildings in the context of the Building Regulations in England and Wales. It presents means of satisfying the Regulations when using light steel framing and gives appropriate design tables and details.

It is not an Approved Document to the Building Regulations but gives best practice in this developing technology. The publication is supplemented by other SCI publications in the series listed in Section 11.

Sections 2 and 3 present general principles and the later sections demonstrate details which satisfy these principles.

2 GENERAL REQUIREMENTS OF THE BUILDING REGULATIONS THAT AFFECT LIGHT STEEL FRAMING

2.1 Structural performance

2.1.1 Building Regulations Part A: Structure

In Schedule 1 of the Building Regulations, Part A sets out requirements that buildings shall transmit dead and imposed loads to the ground safely and without excessive deformation that could impair stability.

Approved Document A gives guidance on the requirements for loading in buildings and provides information on acceptable designs in masonry and timber construction. There is currently no information which is specifically about light steel framing.

The dead and imposed loads from wind and snow should be taken from BS 6399[5], *Design Loads for Buildings*. A typical dead weight for timber boarded, light steel floor is 0.33 kN/m^2. The design imposed loads given in the Approved Document are shown in Table 2.1.

Table 2.1 *Imposed loads as specified in the Approved Document to Part A of the Building Regulations*

Element	Loading
Roof	Distributed load 0.75 kN/m^2 or concentrated load 0.9 kN
Floors	
Above ground storey	Distributed load 1.5 kN/m^2 or concentrated load 1.8 kN
Communal areas	Distributed load 2.0 kN/m^2 or concentrated load 2.7 kN
Corridors, staircases, etc.	Distributed load 3.0 kN/m^2 or concentrated load 4.5 kN
Ceilings	Distributed load 0.25 kN/m^2 and concentrated load 0.9 kN

The Approved Document also lists Codes of Practice and British Standards for structural design and construction, which can be used to meet the requirements for structural stability. For light steel framing, the structural performance should satisfy BS 5950-5[6], when subject to these loads.

2.1.2 Member resistance

The structural design of all cold formed steel sections is currently covered by the provisions of BS 5950-5: 1998. In future, Eurocode 3 is likely to be applicable; for light steel, the prestandard DD ENV 1993-1-3 has been issued[7]. BS 5950-5 is a limit state design code and the principal design requirements concern:

- Effective section properties.
- Design of members in compression or tension.
- Design of members in bending.

- Design of members subject to combined bending and axial load.
- Web crushing due to local point loads.

The design of floors is generally controlled by serviceability limits rather than bending resistance. BS 5950-5 does not give specific recommendations for residential floors, but, as explained in Section 6.2, serviceability limits should be stricter for these floors than for general applications. Light steel C section members are relatively weak in buckling, unless restrained by the flooring or walling material at points along their length. At the supports or under high local loads, additional stiffening cleats are normally required to prevent web crushing.

2.1.3 Stability

All load bearing structures must have adequate stiffness to prevent movement under horizontal loads.

There are three principal means of providing stability of frames in the vertical plane: integral bracing, X bracing and diaphragm action. The two bracing configurations are shown in Figure 2.1:

Integral bracing

C sections are fixed diagonally between vertical studs within the depth of the stud walls. The diagonal bracing members must be securely connected to the vertical studs to ensure the transfer of their forces in tension and compression.

X bracing

Crossed, flat straps of thin strip steel are fixed on the external faces of the studs. These straps act only in tension and may sag unless pre-tensioned during installation. The crossed flats may be fixed to every vertical stud.

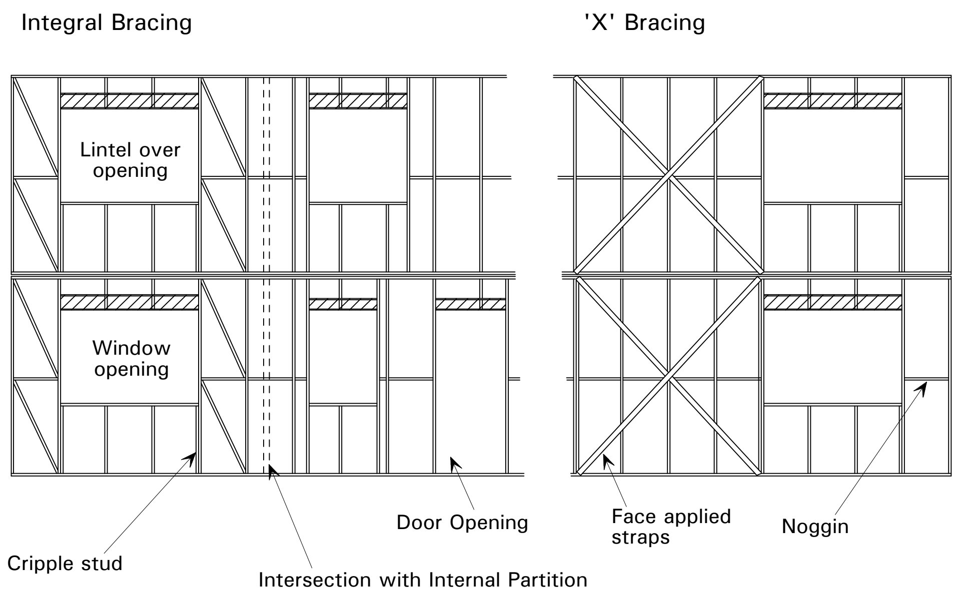


Figure 2.1 *Typical braced frames*

Diaphragm action

Walls, floors and roofs are often sheathed with suitable board materials (plywood, chipboard, cement particleboard and / or plasterboard) for use as structural diaphragms for the transfer of forces to bracing or to the foundations. Effective diaphragm action is achieved by fixing these board materials to the light steel members with self-drilling self-tapping screws, or the equivalent, at a maximum spacing of 300 mm. The screw spacing should not exceed 150 mm at the edges of the panels.

Diaphragms may also be used in the horizontal plane of the floor and in the plane of the rafters. The floor should be designed for the transfer of shear loads to the braced walls. Where large openings are provided in the diaphragm, it is important to ensure that load paths can be maintained. Eurocode 5[8] provides a method for the detailed design of a diaphragm and, although written primarily for use with timber framing, the principles may be adopted for light steel framing. Regarding the limits on the proportions of diaphragms, Eurocode 5 suggests that a deep beam analogy may be assumed, provided that the span is less than six times the width of the diaphragm.

The above three methods of providing stability of frames are all valid means by which wind loads can be transferred to foundations. Provided that the eccentricities of loads applied to holding down points are minimised, loads can be transferred to the foundations without causing excessive deformation of the bottom rail or sole plate. In domestic-scale structures, the sole plate is often a light C section through which the holding-down bolts are inserted directly to the foundations.

When using C section studs, bridging pieces or straps may be fixed horizontally between the vertical studs to improve the buckling capacity of individual studs in their minor axis direction. Double C sections are much more resistant to buckling than single C sections, and generally no intermediate restraints are required.

2.1.4 Serviceability requirements

Serviceability performance concerns the limits on deflections due to loading and the control of vibrations, due to regular activities. Appropriate limits are specified, depending on the application (see Section 6 and 7).

2.1.5 Robustness of light steel frames

The Building Regulations require that structures of 5 or more storeys should be designed to localise the effects of accidental damage. There is currently no published guidance on the 'robustness' of light steel frames to accidental effects, within the context of the Building Regulations. BS 5950-5:1998 refers to BS 5950-1:2000[9], which provides guidance for the design of hot rolled structures to ensure robustness or structural integrity. The 'tying' option in BS 5950-1 requires minimum forces of 75 kN (floor) and 40 kN (roof) to be accommodated. The direct application of this guidance to light steel structures would prohibit the economic use of light steel. This is an anomalous situation, since light steel multi-storey structures are generally constructed using a large number of regularly distributed structural elements, with a high degree of connectivity and structural integrity. In most applications, the provision of continuous ties between the components is straightforward because of the multiple inter-connections.

The following general rules for robustness have been established for light steel frames and are consistent with the principles of BS 5950-1 and BS 5950-5.

Interpretation of the tying and continuity option for light steel structures

Floors and roofs:

1. Horizontal tying arrangements, generally similar to those described in Clause 2.3.5.2 of BS 5950-5, should be arranged in continuous lines wherever practicable throughout each floor and roof level in two directions approximately at right angles.

2. Light steel members acting as ties and their end connections, should be capable of resisting the following factored tensile loads, which need not be considered as additive to other loads acting on the members:

C For floor ties (or joists as ties):	$0.5\ (1.4g_k + 1.6q_k)L_a$ but not less than 5 kN/m (3 kN/m at roof level)
C For internal ties:	$0.5\ (1.4g_k + 1.6q_k)\ s_tL_a$ but not less than 15 kN (8 kN at roof level)
C For peripheral ties:	$0.25\ (1.4g_k + 1.6q_k)s_tL_a$ but not less than 15 kN (8 kN at roof level)

where:

g_k is the specified dead load per unit area of the floor or roof (kN/m^2)

L_a is the largest value, anywhere within the length of the tie, of the mean of any two adjacent spans between vertical supports (m)

q_k is the specified imposed floor or roof load per unit area (kN/m^2)

s_t is the mean transverse spacing of the ties (m)

Note: The distributed tie force applies to the end connections of floor joists, roof trusses or rafters and should be multiplied by the spacing of the component to give the end connection tie force. For example, the minimum tie force for floor joists placed at 400 mm centres is 5 × 0.4 = 2 kN.

Walls:

3. A tying member at the periphery of the building should be connected back to the rest of the structure. If the vertical loads are resisted by a distributed assembly of closely spaced elements, the tying members should be similarly distributed to ensure that the entire assembly is effectively tied. The forces for anchoring the vertical elements at the periphery should be based on the spacing of the elements and taken as 1% of the factored vertical load in the element.

   The minimum values of 15 kN or 8 kN do not apply to the wall studs. However, the floor to wall connections should be designed for the tying forces in 1 and 2.

4. If the main structural elements are discrete columns, the horizontal ties anchoring the columns nearest to the edge of a floor or roof should be capable of resisting a factored tensile load, acting perpendicular to the edge, equal to the greater of the load for an internal tie (given in 2), or 1%

of the factored vertical dead and imposed load in the column acting at that level.

5. All splices in primary vertical elements should be capable of resisting a tensile force of not less than two-thirds of the factored design vertical dead and imposed load applied to the vertical element from the floor level(s) below the splice.

6. Unless the steel frame is fully continuous in at least one direction, the primary vertical load bearing structural elements, whether discrete columns or panel walls, should be continuous at each beam-to-column connection.

7. The system of bracing, whether discrete members or diaphragm panels providing resistance to horizontal forces, should be distributed throughout the building such that, in each of two directions approximately at right angles, no substantial portion of the building is connected to a means of resisting horizontal forces at only one point.

Interpretation of the removal of columns option for light steel structures

8. If the conditions for *tying and continuity* cannot be met, the designer should check each storey to ensure that disproportionate collapse would not be precipitated by the notional removal of vertical load bearing elements, considered one at a time.

   If the light steel frame has discrete columns, the approach is identical to that in BS 5950-1 :2000. However, many *stick-built* structures, and even some *framed* structures, use distributed assemblies of vertical load bearing elements rather than columns.

   For *panel* and *volumetric/modular* structures, the situation is considered to be similar to that of masonry, and requires consideration of the notional removal of a wall panel of 2.25 times the storey height. This length of panel is conservative because of the one-way spanning characteristics of the light steel components.

   In this check, as in BS 5950-1: 2000, only one-third of the normal imposed load need be considered, together with the dead load, except that in the case of buildings used predominantly for storage or where the imposed load is of a permanent nature, the full imposed load should be used. A reduced partial factor $(_f$ of 1.05 should be applied, except that, when considering overturning, the dead load supplying the restoring moment should be multiplied by a partial factor $(_f$ of 0.9.

   Note on the form of construction: *Volumetric/modular* construction differs from other forms of construction in that there is far more connectivity, such that a stack of modules may tolerate the notional removal of a whole module. It is better to use a "scenario-based" approach to review such cases, such as the removal of one support member. Eurocode 1-2-7[10] provides a method for this approach.

9. In all cases, the test for localisation of damage is that the portion of the building at risk of collapse should not exceed 15% of the area of the storey or 70 m^2 (whichever is less) within that storey and the immediately adjoining storey above. A similar area of the immediately adjoining storey below could be loaded with debris from above. Hence, up to a total of 140 m^2 of floor area may be assumed to be at risk of collapse.

Interpretation of the key element option for light steel structures

10. If the notional removal of a vertical load-bearing element would risk the collapse of a greater area than that specified in item 9, then that vertical load-bearing element should be designed as a *key element*. For *key element* design the following loading/assumptions should be adopted:

C A blast pressure of 34 kN/m^2 should be applied to the width of the stud or column (as in the Building Regulations).

C Reduced axial load (dead load+ ⅓ imposed load), may be taken from the floors above, or as defined in 8.

C No lateral restraint is provided by the plasterboard.

C No wind pressure is applied.

C No P-* effects are considered as "prescriptive equivalent".

C The design strength of the steel in the key elements may be taken as 1.2 times the nominal yield strength (P_y). This takes accounts of the actual strength that is normally achieved (as shown by mills certificates) and the high strain rate in the steel when exposed to blast pressures.

Requirements for structures clad with masonry

11. In general, light steel structures only offer lateral support to masonry cladding and the self weight of the masonry is transferred directly to the foundations. Disproportionate collapse of the masonry cladding during an accidental event is unacceptable and special measures are to be taken to ensure this does not occur.

2.2 Fire resistance

Steel does not add to the combustible contents of a building and therefore the fire safety measures are largely concerned with prevention of structural failure and with means of escape.

2.2.1 Building Regulations Part B: Fire safety

Part B requires that buildings must be constructed so that if a fire occurs:

C The occupants are able to escape to a safe place.

C Fire spread over the internal linings of the walls and ceilings is inhibited.

C Stability is maintained for a sufficient period to allow evacuation of the occupants and access for fire fighting.

C Fire spread within the building and from one building to another is kept to a minimum and satisfactory access and facilities are provided for fire fighters.

Guidance in Approved Document B is given for:

C The design of means of escape for dwellings.

C The choice of lining materials for walls and ceilings.

C Measures to ensure that the load bearing elements of the structure of a building remain stable for an appropriate period of time during a fire.

- Sub-division of the building into compartments by fire-resisting construction, such as walls and floors.
- Sealing and sub-division of hidden voids to inhibit the unseen spread of fire and smoke.
- Protection of openings and fire stopping in compartment walls and floors.

Generally, there is no requirement for fire resistance of the structure of single-storey dwellings, unless they affect other buildings, i.e. resistance to internal fire spread. For houses and apartments of 2 to 3 storeys, 30 minutes fire resistance must be achieved for all elements of the structure. This requirement generally increases to 60 minutes for walls and floors separating two dwellings. Any residential buildings with storeys that are more than 5 m above the ground floor require at least 60 minutes fire resistance for the structure and, in this case, separating walls must also be constructed of materials of limited combustibility. A fire resistance of 90 minutes, or even 120 minutes, may be required for taller apartment buildings. Any basement storey may require additional fire separation.

Further recommendations of the Approved Document relate to the use of materials for internal linings which have Class 1 (or better) for rate of flame spread, other than in small rooms below 4 m^2 (in residential buildings). Cavity barriers are required in any concealed cavities within the construction at junctions with compartment floors and walls and at intervals not greater than 20 m.

The Approved Document states that for a building located within 1 m of the site boundary, the fire resistance of an external wall must be provided by non-combustible cladding such as brickwork. Due regard should be taken of unprotected areas and openings.

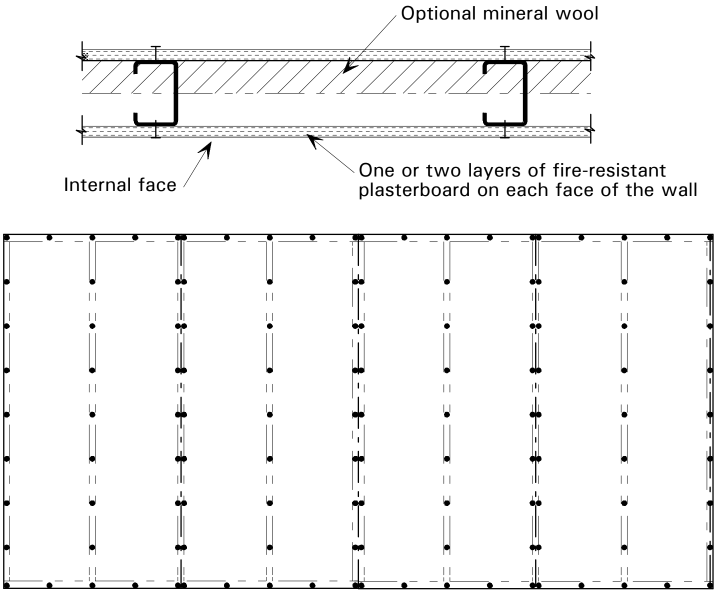
2.2.2 Fire protection of light steel framing

Fire protection to the structural elements in light steel floors and walls is usually provided by fire resistant plasterboard, as illustrated in Figures 2.2 and 2.3. Plasterboard offers the following protection:

- For walls, 30 minutes fire resistance is achieved by a single layer of 12.5 mm fire resistant plasterboard on each face of a steel stud wall.
- For walls, 60 minutes fire resistance is achieved by one layer of 12.5 mm fire resistant plasterboard on a layer of 12.5 mm wallboard, with staggered joints, on each face of a steel stud wall.
- For floors, 30 minutes fire resistance is achieved with 18 mm T&G boarding on light steel joists and 12.5 mm fire resistant plasterboard beneath the joists. The joints are taped and filled.
- For floors, 60 minutes fire resistance is achieved with one layer of 12.5 mm fire resistant plasterboard on a layer of 12.5 mm wallboard with staggered joints beneath the joists and at least 18 mm T&G board on top.

Lining materials are constantly developing and individual manufacturers may use alternative, more economic materials and configurations to achieve the above levels of fire protection.

For further information, see Table 4 in *Building design using cold formed steel sections: Fire protection*[11].



Fixings of boards to wall studs:

For single layer of plasterboard, screws at 300 mm centres (maximum)

For two layers of plasterboard:
First layer of fixings at 600 mm centres (max.)
Second layer fixings at 300 mm centres (max.)
Joints staggered by half a board

Plasterboard should always be laid with long side vertical
Plasterboard plank, always placed as the first layer, with long side horizontal

Figure 2.2 *Fire protection to members in walls*

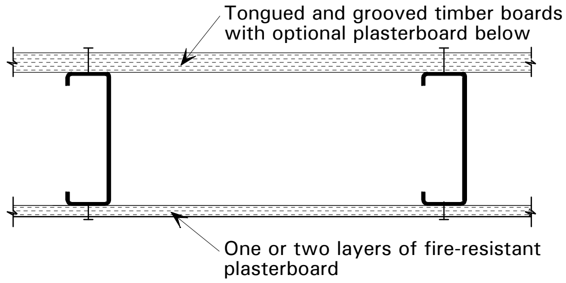
Cement-particle boards can also be used and they are very effective in providing insulation in fire conditions. When multiple layers of board are used, their joints should be staggered to maximise integrity in fire. The boards, which may be 12.5 or 15 mm thick, should be attached to framing members with fixing screws spaced at not more than 150 mm centres at the edges of the boards and at maximum 300 mm centres internally for walls and 230 mm internally for ceilings.

Compartment walls and floors

In residential construction, each dwelling forms a separate fire compartment. A fire resistance of 60 minutes is required for all walls and floors that separate compartments. In hotels and similar multi-occupancy residences, only the floors have to be compartmented.

Compartment walls and floors will usually also act as acoustic separating constructions. The measures for fire protection will also help achieve enhanced acoustic performance.

Cavity barriers or fire stops must be provided around any penetrations through fire resisting walls, in accordance with Building Regulations. 50 mm thick wire reinforced (or polyethylene sleeved) mineral wool fire stops are usually used, installed in any cavities around compartment floors and walls to prevent spread of smoke between compartments.



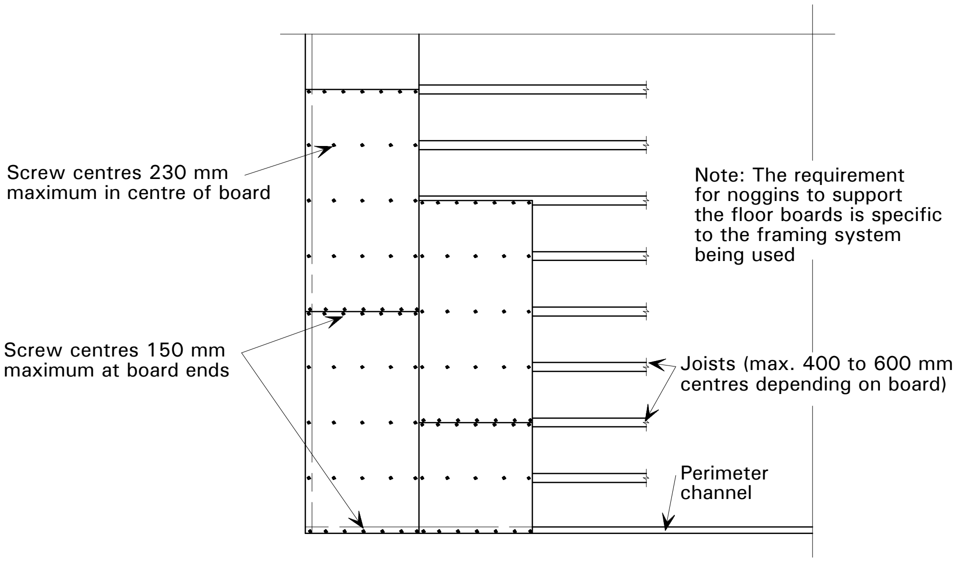


Figure 2.3 *Fire protection to members in floors*

Surface flame spread

External claddings, with limited combustibility and Class 0 flame spread, are required for external walls within 1 m of a site boundary and for buildings over 20 m tall. There are also limitations on opening areas. Surface spread of flame ratings are based on tests to BS 476-7[12]. Table 2.2 shows typical flame spread ratings for cladding and lining materials.

Table 2.2 *Fire resistance classification of materials to BS 476-7*

Classification	**Material**
Class 0	Brickwork Cement render Tile and slate hanging Cement bonded particle board Cement fibre board Wood based materials treated with flame retardant finish to class 0
Class 1	Wood based materials treated with flame retardant finish to class 1

2.3 Acoustic performance

2.3.1 Building Regulations Part E: Resistance to the passage of sound

The requirements of Part E of the Building Regulations apply to floors and walls that separate one dwelling from another, or a dwelling from a communal space. There are no statutory requirements for acoustic insulation of the external envelope, or for other walls and floors within dwellings.

The simplest way to satisfy the requirements is to follow one of the *deemed to satisfy* approved constructions that are identified in the Approved Document E. However, there are currently no light steel frame constructions in this Approved Document. Alternatively, it is possible to show by tests that a given construction meets the requirements presented in the Approved Document, or to repeat a construction that has been used previously and shown in tests to perform acceptably. The acoustic performance of a floor or wall will be acceptable if the values given in Table 2.3 are demonstrated in tests. These tests should be carried out in accordance with BS EN 20140-9[13] (and the performance calculated in accordance with BS EN ISO 717[14]).

Table 2.3 *Sound insulation values for separating floors and walls*

Separating Element	Individual Value (dB)	Mean (dB)
Separating wall - airborne sound insulation (D_{nTw})	49	53
Separating floor - airborne sound insulation (D_{nTw})	48	52
Separating floor - impact sound transmission (L_{nTw})	65	61

Most light steel framing manufacturers have had their typical constructions tested to demonstrate compliance with the Regulations.

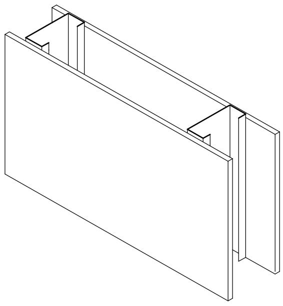
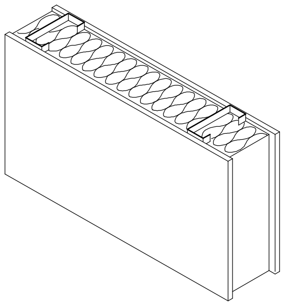
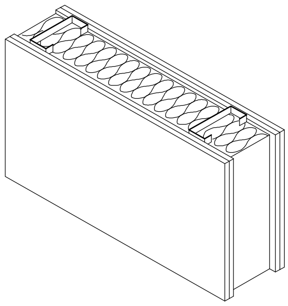
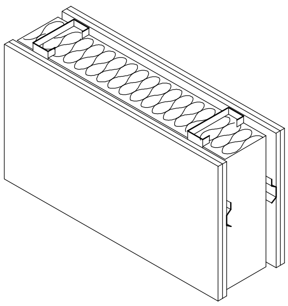
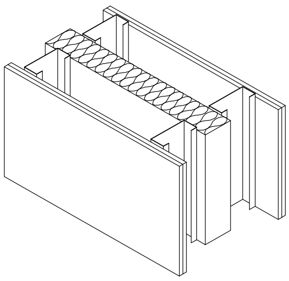
Currently, the DETR is carrying out a review of Part E of the Building Regulations. It is expected that improved criteria will form the basis of new standards to be adopted in future regulations. A 3 dB increase of the above requirements may be introduced.

2.3.2 Acoustic insulation in lightweight construction

Framed construction relies on the presence of a cavity between the various layers and a degree of structural isolation to achieve good acoustic performance. In separating walls, double skin construction is used with minimal inter-connections. Table 2.4 illustrates a range of wall constructions with their respective acoustic insulation. Table 2.5 compares measured acoustic performance of residential buildings using light steel framing with the current requirements, as given in Table 2.3.

Floor constructions achieve good acoustic insulation by multiple layers rather than by the use of heavyweight components. Resilient bars, in the form of small Z sections or ‘top hat’ sections attached to the floors or walls, add to the insulation by reducing direct transfer of sound.

Table 2.4 *Light steel wall constructions giving indicative acoustic insulation and fire separation*

	Material specifications	Acoustic insulation D_{nTw}	Fire resistance
	C 12.5 mm plasterboard C Light steel studs C 12.5 mm plasterboard	35 dB	30 min
	C 12.5 mm plasterboard C Light steel studs with mineral wool between C 12.5 mm plasterboard	45 dB	30 min
	C 2 layers of 12.5 mm plasterboard C Light steel studs with mineral wool between C 2 layers of12.5 mm plasterboard	50 dB	60 min
	C 2 layers of 12.5 mm plasterboard C Resilient bars C Light steel studs with mineral wool between C Resilient bars C 2 layers of12.5 mm plasterboard	58 - 60 dB	60 min
	C 2 layers of 12.5 mm plasterboard C Light steel studs C Mineral wool between stud walls C Light steel joists C 2 layers of12.5 mm plasterboard	60 - 65 dB	60 min

The acoustic insulation properties of walls or floors vary with the frequency of the noise. BS 2750 requires measurement at 1/3 octave bands between 100 Hz and 3150 Hz. Certain frequencies are likely to be attenuated (reduced) more effectively than others by any given construction. Low pitched sounds are usually attenuated less than high pitched sound. Double skin construction performs well above a certain frequency, depending on the cavity width. To maximise the benefit of double skin construction. It is generally recommended that a minimum distance of 200 mm is maintained between the plasterboard layers in adjacent internal rooms.

Lightweight construction uses dry assembly processes. Wet plastering will tend to seal cracks and joints. When using dry lining board, it is important to ensure efficient sealing of air paths that can lead to local sound transfer. Furthermore, flanking at the floor-wall junctions should be minimised by good detailing at these positions. General guidance on acoustic insulation in light steel construction is given in *Building design using cold formed steel sections: Acoustic insulation*'[15].

Table 2.5 *Comparison of the acoustic performance of separating floors and walls in light steel framed dwellings*

	Acoustic Performance		
	Floor D_{nTw} (dB)	**Floor L_{nTw} (dB)**	**Wall D_{nTw} (dB)**
1995 Building Regulations Part E	>52	<61	>53
Measured values in light steel framed dwellings			
Oxford Brookes University demonstration building	57	54	65
Orr Square Church, Paisley	63	50.5	60.5
Northampton Lane, Swansea	58.5	55	63
Chequers Way, Enfield	53.5	57	60
Holiday Inn, Peterborough (modular)	52.5	47.5	59.5
Terrapin modular building	62.5	52.5	73

For symbols, see Table 2.3.

2.3.3 Separating walls

In separating or party walls using light steel framing, two walls are constructed alongside one another. Each skin should be structurally and physically independent of the other, in order to provide the necessary acoustic insulation.

In a double skin wall, the sound insulation of individual components combine together in a simple cumulative linear relationship, provided that the two skins remain largely structurally separate. Therefore, the overall performance can generally be approximated by simply adding together the sound insulation ratings of its constituent parts. Thus, if each skin has a 30 dB sound reduction, the acoustic separation of the combined wall will approach a 60 dB sound reduction.

The essential requirements for good acoustic insulation of separating walls in lightweight dry construction are:

- A double skin separating wall construction.
- An independent structure for each skin with minimal connections between
- A minimum weight of 25 kg/m^2 in each skin (two layers of 12.5 mm plasterboard, or equivalent).
- Wide cavity separation between the two plasterboard skins (200 mm is recommended).
- Good sealing of all joints.
- A mineral fibre quilt within one or both of the skins or between the skins.

Resilient bars, used to attach the plasterboard to the light steel framing, can further reduce the direct transfer of sound into the structure and lead to enhancement of acoustic insulation.

2.3.4 Separating floors

For a separating floor construction between dwellings, both airborne and impact sound transmission must be addressed. High levels of acoustic insulation are achieved in lightweight floors by using a similar approach to that described in Section 2.3.3 for walls. It is important to separate (as far as possible) the top surface layer from the ceiling dry lining layer. This is usually done by the use of a resilient layer between the top floor finish and the structure below, and by resilient bars used to isolate the ceiling. A series of typical floor constructions is presented in Table 2.6.

Impact sound transmission in lightweight floors is reduced by:

- Specifying an appropriate resilient layer with correct dynamic stiffness under imposed loading.
- Ensuring that the resilient layer has adequate durability and resonance.
- Isolating the floating floor surface from the surrounding structure at the floor edges. This can be achieved by returning the resilient layer up the edges of the walking surface.

Airborne sound insulation in lightweight floors is achieved by:

- Structural separation between layers.
- Appropriate mass in each layer.
- Sound absorbent quilt.
- Minimising flanking transmission at floor-wall junctions.

Further improvements in the design of lightweight floors can be achieved by complete separation of the floor structure from the ceiling structure, in a similar way to the double skin walls described above.

The resilient layer beneath the floor finish contributes to insulation against both airborne and impact sound. Generally, mineral fibre with a density between 70 and 100 kg/m^3, provides sufficient stiffness to prevent local deflection but is soft enough to function as a vibration insulator. At the underside of the steel joists, resilient bars partially isolate the dry lining layer from the structure. A mineral wool quilt in the cavity between the steel joists provides sound absorption.

The precise specification of each layer needs to be considered to optimise the floor performance. Increasing the mass of the top (floating) layer can have a significant improvement on the airborne sound insulation. Limited evidence suggests that floor joists at 600 mm centres have slightly better sound insulation than joists at 400 mm centres. Thicker plasterboard layers and gypsum fibreboard will have a higher mass, thus reducing sound transmission.

2.3.5 Flanking transmission

Flanking transmission occurs when airborne sound travels around the separating element of structure through adjacent building elements. Flanking transmission is difficult to predict, because it depends on the details of the floor and wall junction and the quality of construction on site. It is possible for a building to have separating walls and floors built to a high specification, but for sound to be transmitted through side walls which are continuous across the separating elements.

Flanking transmission is dependent on:

- The properties of the surrounding structure, and whether it allows for indirect passage of sound.
- The size of the wall or floor and, therefore, the proportionate effect of flanking losses.
- The details of the floor/wall connections.

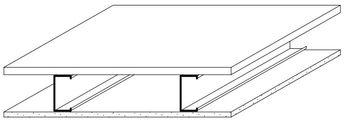
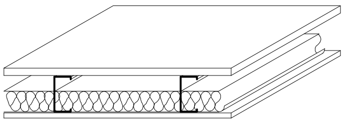
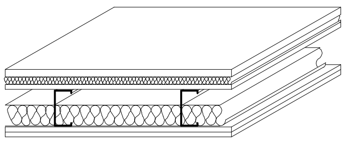
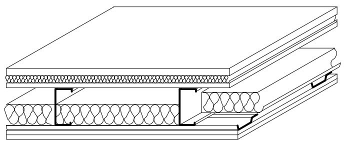
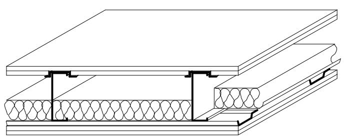
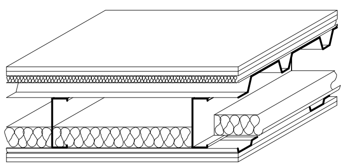
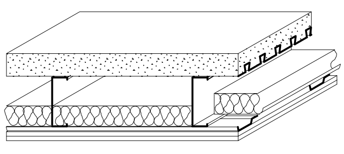
Flanking transmissions can add 3 to 7 dB to the sound transfer of real constructions in comparison to those tested acoustically in the laboratory.

To reduce flanking transmission, it is important to prevent the floor boarding from touching the wall studs by including a resilient strip between the wall and floor boarding (see Figure 4.7). Furthermore, the air space between the wall studs should be filled with mineral wool insulation to a height of 300 mm above the floor level in separating and external walls.

2.3.6 Penetration of linings

Since sound attenuation can be particularly affected by air paths between spaces, special care should be taken around openings for service pipes and other penetrations. Electrical sockets penetrate the plasterboard layer and should be carefully insulated by quilt at their rear. Back to back electrical fittings should be avoided (see Section 9). In panelised and modular construction, electric wiring can be installed in preformed ducts in the factory, which facilitates commissioning on site and allows additional precautions to be made to ensure that it does not compromise acoustic performance.

Table 2.6 *Sound insulation (indicative) and fire resistance characteristics of lightweight steel floors*

	Specification	Acoustic insulation dB		Fire resistance
		D_{nTw}	L_{nTw}	
	C 18 mm chipboard C Light steel joists C 12.5 mm Plasterboard	33	83	30 min
	C 18 mm chipboard C Light steel joists C 100 mm mineral wool between joists C 12.5 mm Plasterboard	42	76	30 min
	C 19 mm cement particle board C 10 mm resilient layer (min) C Chipboard, OSB or plywood C Light steel joists C 100 mm mineral wool C 2 layers of Plasterboard (total thickness 30mm)	52	61	60 min
	C 18 mm T&G chipboard C 19mm plasterboard C 25-30mm mineral wool or glass wool C Chipboard, OSB or plywood base C Light steel joists C 100 mm mineral wool between joists C Resilient bars C 2 layers of Plasterboard (total thickness 30mm)	57 - 60	54 - 57	60 min
	C 18 mm T&G chipboard C Proprietary top hat isolating section C Plasterboard between the top hat section C Light steel joists C Mineral wool between joists C Resilient bars C 2 layers of Plasterboard (total thickness 30mm)	55	59	60 min
	C 18 mm T&G chipboard C 19mm plasterboard C 25-30mm mineral wool or glass wool C 30 mm profiled steel decking C Light steel joists C Mineral wool between joists C Resilient bars C 2 layers of Plasterboard (total thickness 30mm)	55	59	60 min
	C Composite steel decking and concrete slab C Light steel joists C Mineral wool between joists C Resilient bars C 2 layers of Plasterboard (total thickness 30mm)	55 - 59	53 - 59	60 min

2.4 Thermal performance

2.4.1 Building Regulations Part L: Conservation of fuel and power

Part L requires that reasonable provision shall be made for the conservation of fuel and power in buildings by:

- Limiting the heat loss through the fabric of the building.
- Controlling the operation of the space heating and hot water systems.
- Limiting the heat loss from hot water vessels and hot water service pipework.
- Limiting the heat loss from hot water pipes and hot air ducts used for space heating.

Approved Document L sets out the minimum requirements for thermal insulation of new buildings and extensions that comply with Part L. The insulation properties are expressed in terms of U-values. Light steel construction can achieve a high level of thermal insulation economically and without leading to excessive wall thicknesses. Walls with U-values below 0.2 W/m^{2}k are easily achievable.

Part L of the Building Regulations is due to be revised in 2001, with further revisions planned in 2003 and 2005. It is expected that there will be progressively increased thermal performance requirements for buildings. In particular, U-values are expected to fall significantly from the current 0.45 W/m^{2}K for external walls to 0.31 or 0.35 W/m^{2}K (depending on heating system), in 2001, and to 0.27 or 0.3 W/m^{2}K, in 2003; similar improvements are expected for other parts of the building envelope. Requirements for control of air infiltration may be introduced.

SAP rating of buildings

The *Standard Assessment Procedure* (SAP)[16] is an energy rating method for new dwellings. A rating of 1 (poor) to 100 (good) is awarded. The SAP rating can be calculated by computer program or manually. SAP energy ratings of 80 to 100 are readily achievable using light steel framing construction The energy rating will depend principally on the level of insulation and the heating and hot water system specified. In future, when the Part L revisions come into effect the SAP will be converted to a Carbon Index which will be used as one method of satisfying the requirements of Part L.

The National Home Energy Rating (NHER) assessment method[17] is a commonly used alternative energy rating to SAP. This provides an energy rating of 0 (poor) to 10 (good). Light steel frame dwellings can readily achieve NHER scores of between 8 and 10.

Alternatively, the *Elemental Method* specifies U-values of the elements of the building fabric which should be met. The existing and proposed maximum U-value requirements are shown in Table 2.7. In future it is proposed that he maximum U-values will be more onerous for buildings with electric or inefficient gas or oil heating system compared to buildings with efficient gas heating system. The U-values achieved by light steel framing systems generally exceed the existing requirements and can readily meet the proposed new requirements.

A more flexible *Target Method* sets out a calculation procedure that defines a target U-value for the whole dwelling, which should not be exceeded. This allows more flexibility of trade-off between elements. The resulting target will give a heat loss for the whole building close to that which would be achieved if complying by the Elemental Method.

Table 2.7 *Review of current and proposed U-values (W/m²K) in the Approved Documents and typical U-values achieved by light steel construction*

U-values in W/m²K	Walls	Floor	Roof	Windows
Approved Document L (1995)				
Current Approved Document	0.45	0.45	0.25	3.3
Proposed phase 1 changes (expected in 2001)				
Carbon efficient heating	0.35	0.30	0.2	2.2
Carbon inefficient heating	0.31	0.27	0.18	2.0
Proposed phase 2 changes (expected in 2003)				
Carbon efficient heating	0.30	0.25	0.16	2.0
Carbon inefficient heating	0.27	0.22	0.16	1.8
Light steel framing				
Light steel framing - typical	0.35	0.35	0.25	3.0
Light steel framing - best practice	0.20	0.25	0.2	1.8

Further provisions specify control of thermal bridging around windows, doors and other openings. Standard details are included in the Approved Document but, currently, these details do not include examples of light steel framing.

There are also limited requirements for controlling air infiltration through the building envelope (see Section 2.4.5). Unintentional air paths through the fabric must be reduced, as much as is practicable. These will be extended in 2001.

2.4.2 Location of insulation

The effect of cold bridging through the envelope is considered in the U-value calculation.

In light steel framing, thermal insulation is usually placed outside the steel studs to create a 'warm frame' construction (see Figure 2.4). In this way, thermal insulation is avoided and a continuous insulating layer is provided. Alternatively, where condensation risk is low, supplementary insulation can be placed between the steel studs with an insulating sheathing board on the outside of the frame (see Figure 2.5). The supplementary insulation should be placed in contact with the studs to minimise air gaps and to prevent local condensation.

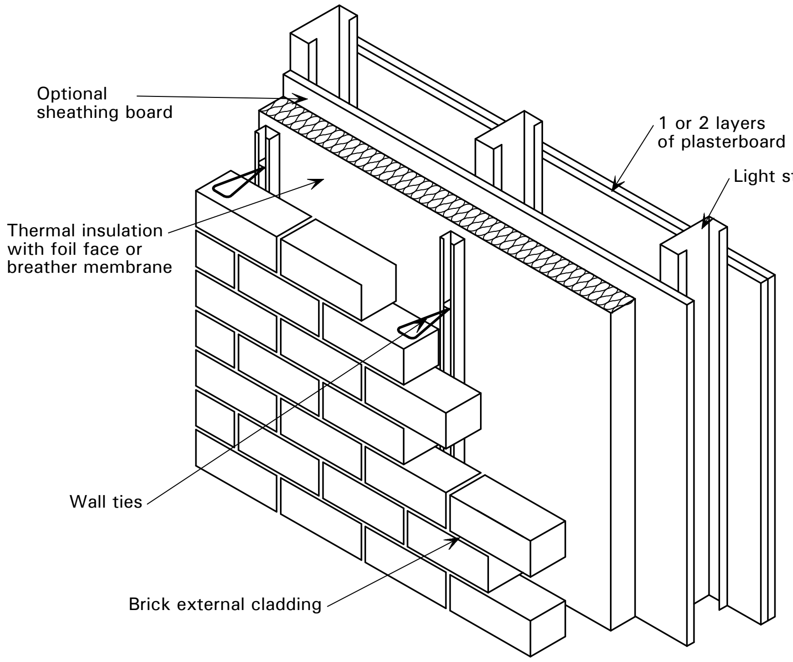


Figure 2.4 *'Warm frame' construction on light steel framing with external insulation*

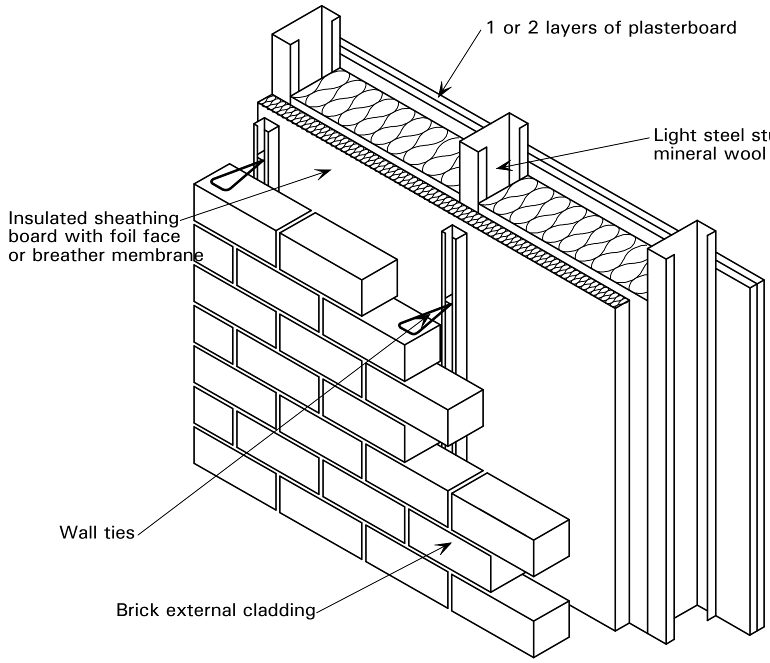


Figure 2.5 *External wall using an insulated sheathing board, with insulation between the studs*

The perimeter of openings should be detailed to minimise cold bridging. In traditional construction, thermal bridges are most common around window and door openings and at the junction of walls with floors and roofs, and can significantly increase heat loss. The 'warm frame' principle ensures that the full thickness of insulation is continuous right up to the window or door frame. This avoids the cooler wall surfaces that occur around openings (see Section 5.1.2).

2.4.3 Control of condensation

Condensation in buildings can occur on a cold internal surface, or as interstitial condensation within the thickness of the wall. This can be more serious as it can go unnoticed, leading to damage of the fabric of the building.

Water vapour will pass between spaces or across envelope elements wherever there is a vapour pressure difference. Where vapour-laden air percolates into a wall, floor or roof construction, it will lead to interstitial condensation if it is cooled to its dew point temperature. In light steel construction, interstitial condensation on the steel is avoided by keeping the steel frame fully within the insulated cavity, or ensuring that there is an effective vapour barrier to prevent water vapour reaching the cold part of the envelope. The increased thermal conductivity of steel studs means that the temperature of the steel along the web and at the outer flange is greater than in the insulation alongside, which reduces the likelihood of condensation on the wall studs.

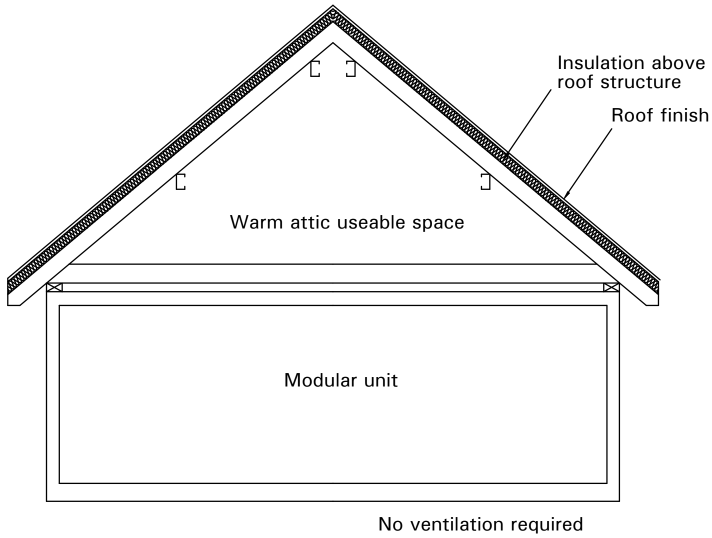
In the worst case, 'thermal bridging' through the studs can cause local cool spots in the vicinity of the stud, leading to "ghosting" where local condensation causes staining of the wall surface along the lines of the studs. 'Warm frame' construction ensures that the internal surface temperatures along the steel framing elements do not fall to below the dew point temperature. Alternatively, insulated sheathing boards can be used with some insulation between the studs. In this case, a vapour control layer should be used. To avoid surface condensation and "ghosting", the Building Research Establishment suggests that internal surface temperatures should not fall below 15.5°C when the internal air temperature is 21°C. Particular attention must be paid to:

- Detailing to ensure continuous insulation at window and door openings.
- Detailing at wall junctions with floor and roof.
- Penetration by services.
- Mechanical venting of spaces subject to high humidity, e.g. bathrooms.

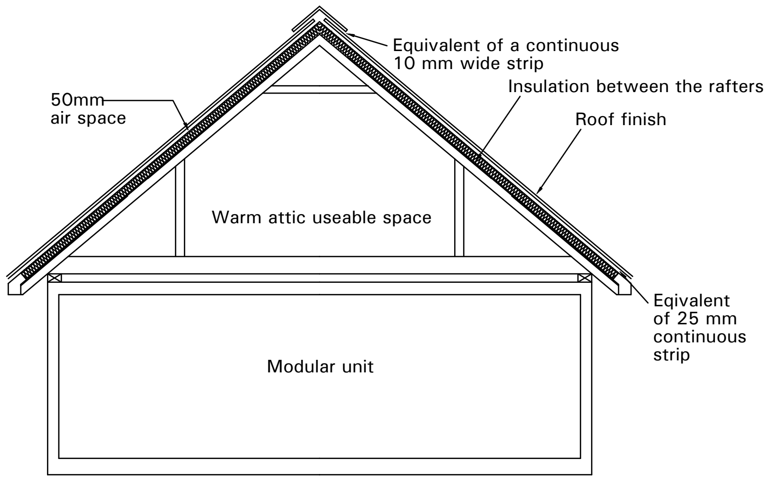
2.4.4 Ventilation of roof space

Part F2 of the Building Regulations defines the requirements for the avoidance of condensation in the roof of buildings. This requires that adequate provision should be made to prevent condensation in the roof or roof void. This requirement can be satisfied by providing sufficient cross-ventilation into the roof space, or placing the insulation above the roof structure. The following options are available as illustrated in Figure 2.6:

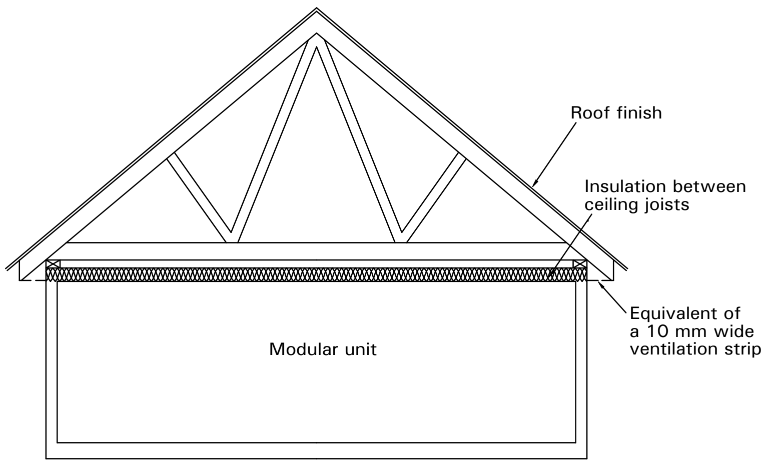
- For a pitched roof with a ventilated cold roof space, a ventilation gap equivalent of a 10 mm continuous open strip should be provided along each eaves. This requirement is illustrated in Figure 2.6(c).
- Where insulation follows the pitch of the rafters and is between or below the rafters, a 50 mm air gap must be left between the top of the insulation and the underside of the roof covering, with the equivalent of a 25 mm ventilation grill at the eaves and the equivalent of 5 mm of continuous ventilation at the ridge.
- No ventilation is required for flat and pitched roofs where the insulation is placed above the roof structure.



a) 'Warm roof' with insulation above the rafters



b) 'Warm roof' with insulation between the rafters



c) 'Cold roof' with no external insulation

Figure 2.6 *Roof space ventilation measures*
(Note: The wall insulation has been omitted for clarity. In all cases the insulation at the head of the wall should be continuous with the roof insulation)

2.4.5 Air-tightness

The 1995 Building Regulations do not specify targets for air infiltration and the proposed revisions for 2001 do not require air infiltration testing for dwellings. However, it is expected that these will soon become a requirement of new construction in the UK. Other countries such as Sweden and Canada already have strict air infiltration standards. The new regulations for 2001 will require some additional steps to be taken to avoid air infiltration.

Heating demand is significantly affected by infiltration of cooler outside air through cracks and gaps in the building envelope. Furthermore, air flows within the structure can increase the risk of interstitial condensation. Air infiltration is best dealt with by creating an air barrier on the warm side of the insulation, which is well sealed at all joints. This may be the vapour barrier or some other element of the construction, such as the plasterboard. It must be well sealed, and penetrations should be avoided or appropriately detailed.

Achieving sensible air-tightness requires attention to detailing both in design and during construction, ensuring a good overall standard of construction. Many of the air-leakage paths can be designed during the design phase by careful consideration of the details. Airflows through the structure can be prevented or reduced by means of an air barrier, which can be the vapour barrier or some other layer in the envelope. The air barrier should be continuous, as far as is practical, with seals at overlaps and edges around openings such as windows and doors. Details should prevent penetrations of the air barrier for services or other reasons or, alternatively, there should be an effective seal around all penetrations.

2.5 Radon gas infiltration

The requirement in Part C of the Building Regulations that precaution shall be taken to avoid changes to health and safety caused by substances in the ground covers the precautions to prevent radioactive radon gas from entering the building from seepage from the ground. In the UK, the degree of exposure varies with location.

There are two common methods of protecting dwellings from radon gas infiltration:

- The passive system consists of an airtight barrier that runs across the whole building including the ground floor and walls. This barrier is usually a polyethylene membrane placed above the floor structure and lapped under the cavity tray at the wall intersections. Where a suspended floor is used, secondary protection is also provided with the introduction of air bricks to provide ventilation of the void beneath the floor. Openings of at least 1500 mm^2 per metre run of wall on two opposite sides are required.
- Alternatively an active approach requires the installation of a powered radon extraction system that needs to be maintained throughout its life.

A composite suspended groung floor using steel decking and in-situ concrete provides an impermeable barrier to these gases.

Good design should ensure that service pipe and cable entry points do not permit leaks in the radon-impermeable membrane. Airtight seals should be provided, where necessary.

The guidance in Approved Document C refers to *Radon guidance on protective measures for new dwellings*, published by BRE[18].

3 OTHER PERFORMANCE REQUIREMENTS FOR LIGHT STEEL FRAMING

3.1 Durability and design life

The hot dip galvanizing coating provides adequate durability of light steel frame construction in internal applications not directly exposed to moisture for long periods. The standard coating is G275 (275 grams/m^2 summed over both surfaces), which is suitable for internal applications.

As for traditional construction, attention to design and construction details is essential. Control of moisture ingress and condensation, including the correct positioning of thermal insulation and use of damp proof courses, membranes and flashings will ensure good performance, and long design life.

When using galvanized steel, damaged areas of corrosion protection, e.g. at weld zones, must be reinstated by treatment with an appropriate zinc-rich paint. For this treatment to be fully effective, these areas must be thoroughly cleaned by wire brushing, primed and coated with two coats of a zinc rich paint having a zinc content of at least 96%, or an equally effective alternative protection system.

In the following situations, sacrificial loss of zinc coating in local areas occurs and this protects the exposed edges of steel against corrosion. No further attention is required for:

- member ends, which have been cut in the factory
- holes for bolts or services, which have been punched in the factory
- penetrations made by self-drilling self-tapping screws.

A number of buildings, using standard galvanized steel components, have been monitored to assess the loss of zinc, leading to predictions of their design life (to major maintenance).

A design life of over 200 years can be achieved in 'warm frame' construction (see *Durability of light steel framing in residential building*[19]). In 'cold frame' construction, such as in uninsulated lofts, a design life of over 60 years is achieved. In all cases, the building envelope should be properly maintained.

3.2 Dimensional discipline

3.2.1 Structural grid

For the effective use of materials, regular spacing of studs, floor joists and trusses is desirable. The spacing of these components should be compatible with standard floor, ceiling and wall boards. A structural grid of 400, 600 or 1,200 mm is usually adopted to suit the use of 1,200 mm wide plasterboard.

3.2.2 As-built tolerances for light steel framed structures

Light steel framing is very accurate and dimensional variations are largely due to the inaccuracy of the other components, particularly the foundations. Light steel framing may be used with all foundation types but care must be taken to ensure that target line and level tolerances are achieved, in order to assemble the wall panels accurately (see Section 4).

Compliance with normal accuracy of construction can be achieved easily, but the actual location of external brickwork in cavity walls, compared to the theoretical location, is a common practical problem. Here, the courses of brickwork below the DPC are laid before the DPC is in place. Any deviations in the brickwork at this level clearly affect the cavity space between the brickwork and the frame.

It is essential that the main contractor and the light steel framing supplier agree a hand-over procedure and ascertain the accurate position of the brickwork **before** the steel frame is erected.

The nominal cavity between the insulation and the brickwork is 50 mm, although the Approved Documents illustrate cases where the 'actual' cavity when using partial-fill insulation between two masonry skins can be reduced. NHBC recommend that the **minimum** cavity width that is achieved on site is 50 mm between the insulation and the internal face of the brickwork.

The construction tolerances for light steel frames are as shown in the following figures. The verticality (plumb) of the frame may deviate by up to 5 mm per storey, as shown in Figure 3.1 (+ indicates outward movement of the frame).

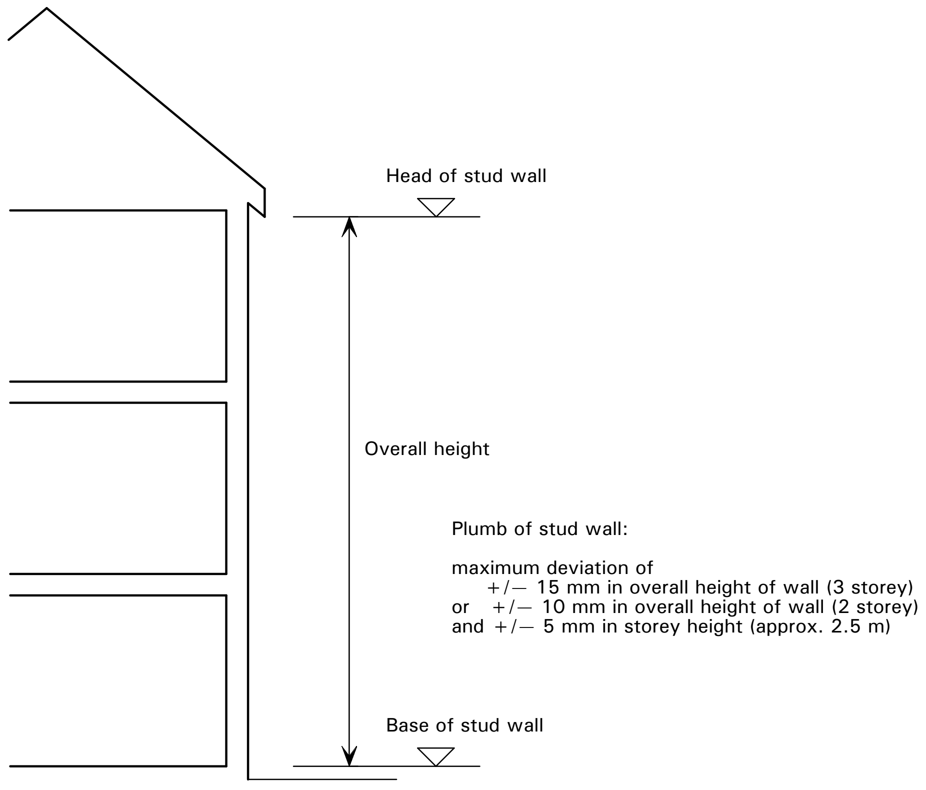


Figure 3.1 *Verticality of frame (relative to base)*

There are additional requirements for masonry clad walls. In determining the nominal cavity width, the following construction tolerances should be considered:

Out of verticality of brickwork +/- 10 mm total or +/- 5 mm per floor

Deviation in the surface of the insulation +/- 5 mm

It is unreasonable to consider that the 'worst' tolerances of all the components occur together at the same position. The normal method of considering a sensible probability of occurrence is either:

Expected maximum deviation = 2/3 × sum of individual maximum deviations

or = SQRT (Sum of squares of individual max deviations)

The figures quoted are for tolerance only and take no account of permissible deflections of the structure.

Tolerances in foundation levels are presented in Section 4.1.

Frames are manufactured as flat components to tight tolerances (< 3 mm) but, when installed, may be forced to align with other irregular components. Figure 3.2 shows a method of checking straightness on plan. A maximum deviation of 5 mm in a length of up to 10 m is reasonable.

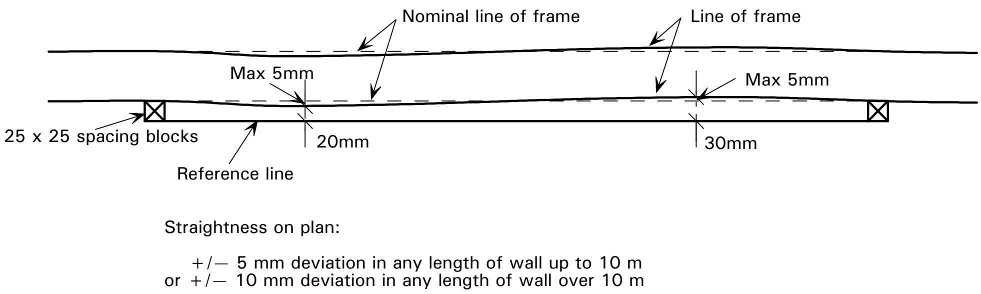


Figure 3.2 *Horizontal position of frame (at base)*

The level of floors is dependent on the level of the end supports. In this case, a deviation in level of ± 5 mm is acceptable, as shown in Figure 3.3.

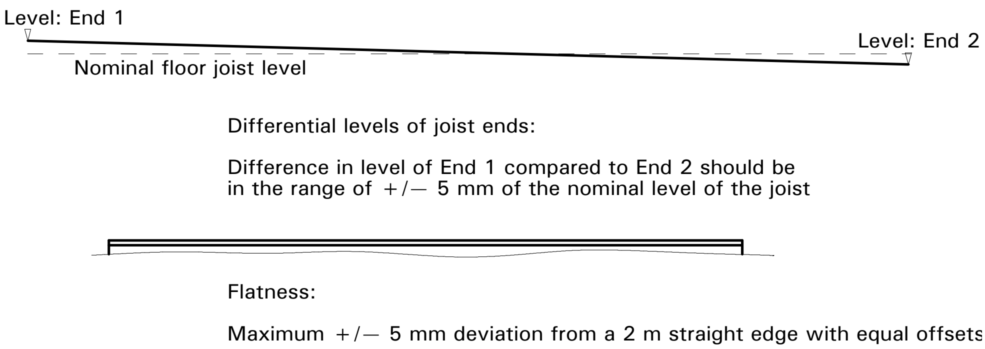
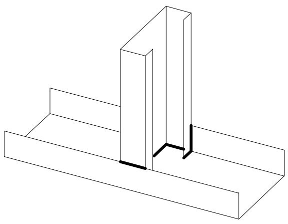
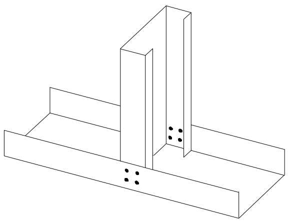
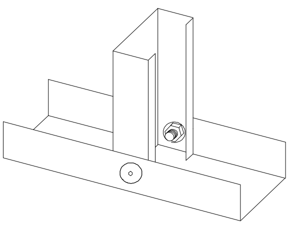
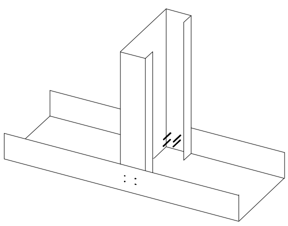


Figure 3.3 *Level of floors*

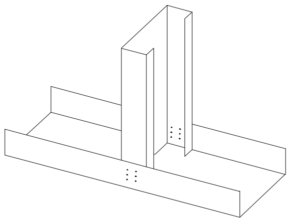
3.3 Connections

There are several techniques available for connecting light steel components; some of these are presented in Table 3.1. Guidance on the design and detailing of the most common connection types is given in BS 5950- 5. Manufacturers use the method which best suits their own framing system, taking into account design, detailing and construction issues and for which appropriate test data are available.

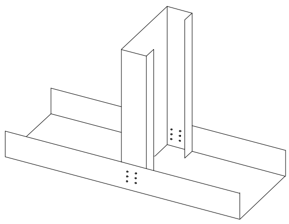
Table 3.1 *Typical connections used in light steel construction*

Welded connections	Typical shear capacity: by test (can be as great as shear strength of section)
	**MIG welding:** Light steel sections may be joined by continuous MIG welding. Care is required to ensure that the welding process does not cause damage to the components being connected, because the parent metal is very thin. The welding of galvanized steel requires special care (see Section 3.4.3). To maintain the durability of the steel, the affected areas should be protected after welding with a zinc rich paint.
	**Spot welding**: Spot welding is primarily used for workshop fabrication. An arc is created between the tips of the welding tool on either side of the steel elements to be joined. It is most appropriate where the welding tool can be supported and easily moved into position to form the weld. A minimum of 3 spot welds should be used for each connection.
Bolted connections	Typical shear capacity: 12 mm bolt: 8 -12 kN
	**Bolts** are a common choice for connecting light steel sections because of the ease with which holes in the sections can be punched during the roll forming process. The connections are usually arranged so that the bolts are primarily subject to shear and the capacity of the connection is generally governed by the bearing strength of the thinner material.
Screwed connections	Typical shear capacity: 5.5 mm screw: 5kN
	**Self-drilling, self-tapping screws** are commonly used for connecting light steel components. The drill part of the screw forms a hole in the steel section and the tapping part forms the thread in a single operation. This technique is commonly used to inter-connect either wall panels or stick built frames on site, although care must be taken to ensure that the protruding head of the screw does not interfere with the finishes. 2 or more screws should be used for each connection. Self-drilling self-tapping screws are also used extensively to attach finishing materials, such as plasterboard, sheathing, floor boarding, insulation and decking, to light steel structures. Stand-off screws, where the screw thread is discontinuous, may be used to fix cellular insulation boards to light steel components without the risk of crushing the insulation.

Riveted connections Typical shear capacity: by test



Blind rivets are fitted into pre-drilled holes and a mandrel is pulled by a special tool so that the rivet expands into and around the hole. These rivets provide a relatively robust form of attachment with good pull out resistance. They are useful for thin-thin attachments such as the seams of profiled decking and sheeting.

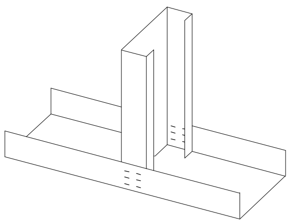


Self-piercing rivets do not require pre-formed holes in the components since the rivet is designed both to pierce and to form a permanent fastening within the materials being joined in one single operation. This requires a hydraulic operated tool with access to both sides of the fixing. The riveted connection is formed in two phases:

Piercing: The rivet shank acts as a shearing punch which cuts a hole through the top layers of material and partially through the lower layer until coming under the influence of the reacting die.

Flaring: During the final stages of punch travel in the lower sheet, the sheet material is displaced into the die and causes the shank of the rivet to flare out, locking itself into the material.

Press joining or clinching Typical shear capacity: by test



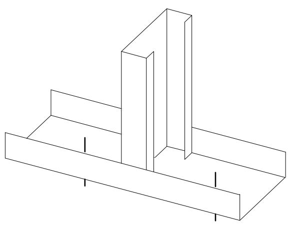
Clinching is a combination of drawing and forming that locks two or more layers of thin gauge steel together. Clinching involves a hydraulically operated punch that drives the layers of metal into a die to make an impression. Additional force is then applied to spread the top layer of steel into the bottom layer. This prevents the top layer from being pulled out of the bottom layer.

There are two basic **clinching** methods:

(a) Cut clinch: This type of clinch is formed by shearing the metal on two sides, drawing the top layer through the slits in the bottom layer and expanding the width to form a lock on both sides.

(b) Button or round clinch: This type of clinch is characterised by a "button" formed on one side of the metal. The layers of metal are simply formed by drawing them into a circular dovetail; the diameter is then expanded to lock the sheets together.

Powder actuated fastenings Typical shear capacity: related to brick or concrete strength in typical applications.



Powder actuated fasteners are used to connect light steel members to concrete and masonry or to thick steel members. However, it is not possible to connect thin steel members, because of the flexibility of the connected parts to the driving force.

Site connection details are specific to the system being used but, in general, site steel-to-steel connections are made with either self-drilling self-tapping screws or 10-12 mm diameter, Grade 4.6 bolts. Details of the different types of self-drilling self-tapping screws and their common applications are presented in Appendix D of *Construction Detailing and Practice*[20]. In general, panel-to-panel connection uses a minimum of three 10 mm bolts, evenly distributed through the storey height, or seven 4.8 mm diameter self-drilling self-tapping screws, 1 at the base, 1 at mid-height and 5 at the head. The grouping at the head of the panel is to enable the sharing of wind loads between adjacent braced panels or to transfer the tie forces required for robustness.

Panels will be attached at the ground level with bolts, at braced panel points, or powder actuated fasteners, along the length of the base track.

Between storeys, the base of the second lift of wall may be attached to the head of the lower storey wall with either self-drilling self-tapping screws or bolts. If self-drilling self-tapping screws are generally used, it is likely that bolts will be used locally at points of high stress, for example, where braced bays interconnect.

3.4 Health and safety requirements

A risk assessment and method statement are required to satisfy the requirements of the Construction Health and Safety Plan. These are site and design specific and therefore need to be dealt with on an individual project by project basis.

3.4.1 Welding of galvanized steel

Welding of galvanized steel is a hazardous activity, because of the harmful gases that are given off and which should be mechanically extracted. Consequently, welding on site should be avoided, unless the zinc coating is removed locally beforehand and work is carried out in accordance with an H&S/COSHH method statement. Weld affected areas should be 'made-good' with a zinc rich paint or similar corrosion inhibiting material.

3.4.2 Erection procedure

The erection procedure for a light steel frame used in housing is illustrated in Figure 3.4. In Stage 1, the slab dimensions are checked because an accurate starting point is essential to minimise geometrical inaccuracy and alignment problems.

At Stage 2, the panels at ground floor are aligned and levelled, temporarily braced, and fixed to the foundations.

At Stage 3, the individual floor joists or prefabricated cassettes are supported on the wall beneath. In platform construction, the floor boarding provides a working platform for the erection of the upper wall panels, as in Stage 4.

At Stage 5, the roof trusses are lifted individually and positioned on the upper walls. Roof bracing is installed and the structure is stable.

Storey-high panels and roof trusses can be man-handled into place, although it may be more economic to use a crane to lift larger panels. In some cases, roofs can be prefabricated, sheathed and lifted into place to provide a rapid weather-tight envelope.

3.4.3 Temporary bracing

Wall frames are unstable until floor members are fixed in position. As with any type of building, it is unsafe practice to leave a partially erected structure in an unstable state. Therefore, temporary side supports or bracing may be required, particularly when the structure is left overnight in a partially erected condition. The requirements of every individual case should be separately considered but it may be appropriate to use a scaffold 'cage' for extra restraint.

The addition of other loads, such as stacking of plasterboard on suspended floors, is not acceptable until the framework has been completed and fully braced. These loads should be checked by the designer.

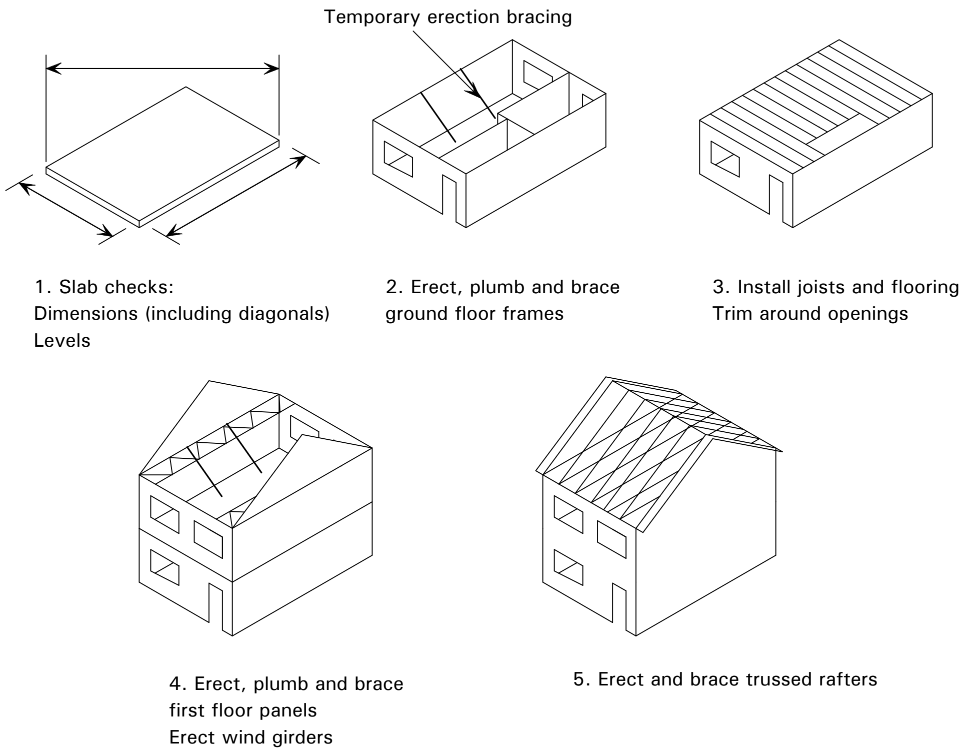


Figure 3.4 *Erection procedure for light steel frames*

4 FOUNDATIONS

Foundations to light steel framing are essentially the same as for any other form of construction, although the dead loads applied by the light steel frame will be much lower than in concrete or masonry construction.

The foundation size will be determined either by the vertical load or by the requirement to resist wind uplift.

4.1 Site tolerances

All forms of frame construction require an accurate 'starting point'. Therefore, the foundations or ground beams must be finished accurately in order to be acceptable for 'hand-over' to the frame erector. For accurate erection of the frame, the following tolerances are required at the level of the base of the wall frame.

- Length of wall frame	+/- 10 mm in 10 m.
- Line of wall frame	+/- 5 mm from outer face of plate.
- Level of base of wall frame	+/- 5 mm over complete wall line.

As a simple check on squareness, if the walls are of the correct length and location, the diagonals of a rectangular plan form will be equal.

A special steel member may be incorporated into the foundations to facilitate accurate later attachment of the steel sub-frames or panels, see Section 5.

If the specified tolerances are not achieved, a number of problems may arise affecting the quality of the finished structure:

- Insufficient bearing for sole plate.
- Variations in cavity width.
- Cavity "ledge" at sole plate.
- Insufficient fixity of superstructure to foundations.

In practice, the foundation or ground beam will have local deviations in level along its length and some packing will be required to achieve the required tolerances and to provide for effective load transfer.

It is suggested that the following packing methods should be used, although individual systems may vary from this:

< 10 mm	pack under each stud with thin pre-galvanized steel shims
10-20 mm	pack under each stud with steel shims and grout over the length of the sole plate
> 20 mm	obtain advice from the frame designer / manufacturer. In this situation it is likely that the steel frame erector will not accept the sub-base and remedial work will be required.

4.2 Foundation types

Light steel frames may be designed to suit a range of foundation types, depending on the ground conditions that are encountered. Strip or trench fill foundations are currently the most common but raft, pile or pre-cast pile foundations may be suitable in some instances.

An SCI publication *Composite ground floors and mini piling for housing*[21] presents guidance on the design of composite ground floors and mini-piles for housing.

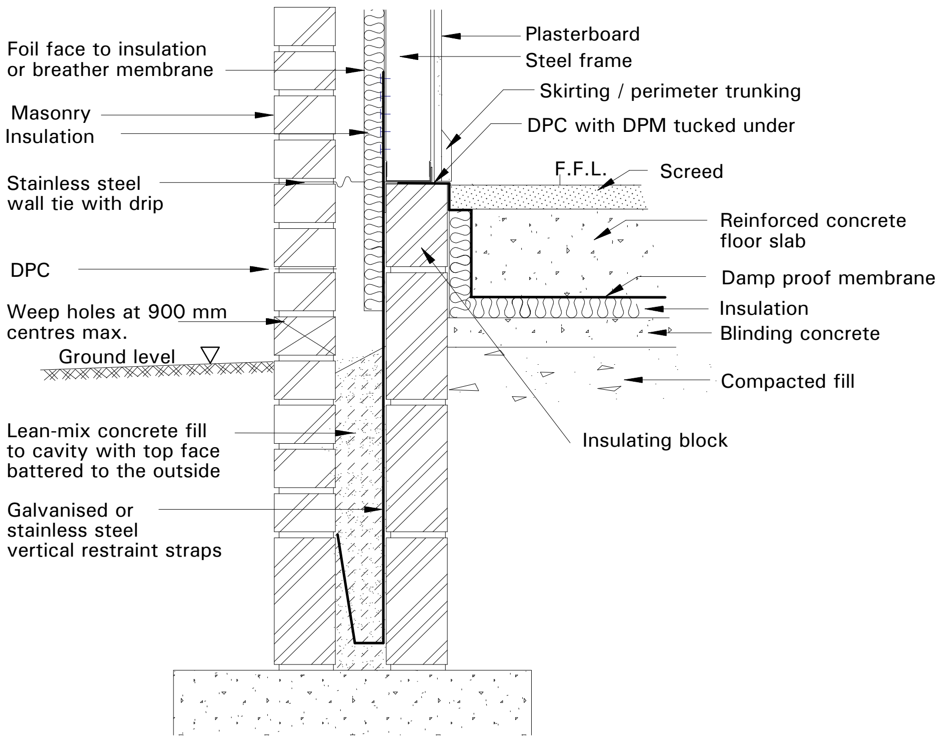


Figure 4.1 *Foundation - generic interface detail for ground-floor slab*

Note: The insulation may be positioned above the ground slab with a floating timber floor boarding over, as shown in Figure 5.1.

Installation of a steel frame on a typical trenchfill foundation is illustrated in Figure 4.1. The over-site damp proof membrane (DPM) should be attached to the side of the slab and returned under the damp proof course (DPC) on which the frame is placed. To comply with Part M of the Building Regulations, Approved Document M suggests level threshold details, shown in Figure 4.2. In this case, the external leaf DPC may be placed two courses above the internal DPC. The DPC/DPM detail requires careful execution, as in practice the DPM often billows out and may bridge the cavity, providing a ledge for mortar droppings to rest upon. The external wall at this position is below the DPC and will increase the risk of dampness crossing the cavity to the sole plate.

4.3 Holding down requirements

For lightweight structures, there may be a combination of wind and dead loading which leads theoretically to uplift on the foundation. In such cases, it is necessary to provide holding down anchorages at various positions, for example, at braced bays. Holding down anchorages may take various forms;

- Steels straps fixed to the stud wall and attached to the masonry supports or to the concrete foundations.
- Holding down bolts fixed to the concrete ground slab.

Where stainless steel holding down straps are used, as shown for the suspended beam and block floor in Figure 4.3(a), they should be in Grade 1.4301 steel to BS EN 10088[22]. They should also be isolated from the studs by use of neoprene gaskets, or similar attachments, in order to minimise the risk of galvanic action. Non-stainless connectors should also be isolated from the straps by the use of suitable grommets and washers.

In concrete raft construction, walls are bolted to the concrete using the type of fixing shown in Figure 4.3(b). Resin or expanding anchors are suitable for use in an in-situ concrete raft of minimum C20/GEN 3 grade concrete to BS 5368-2.

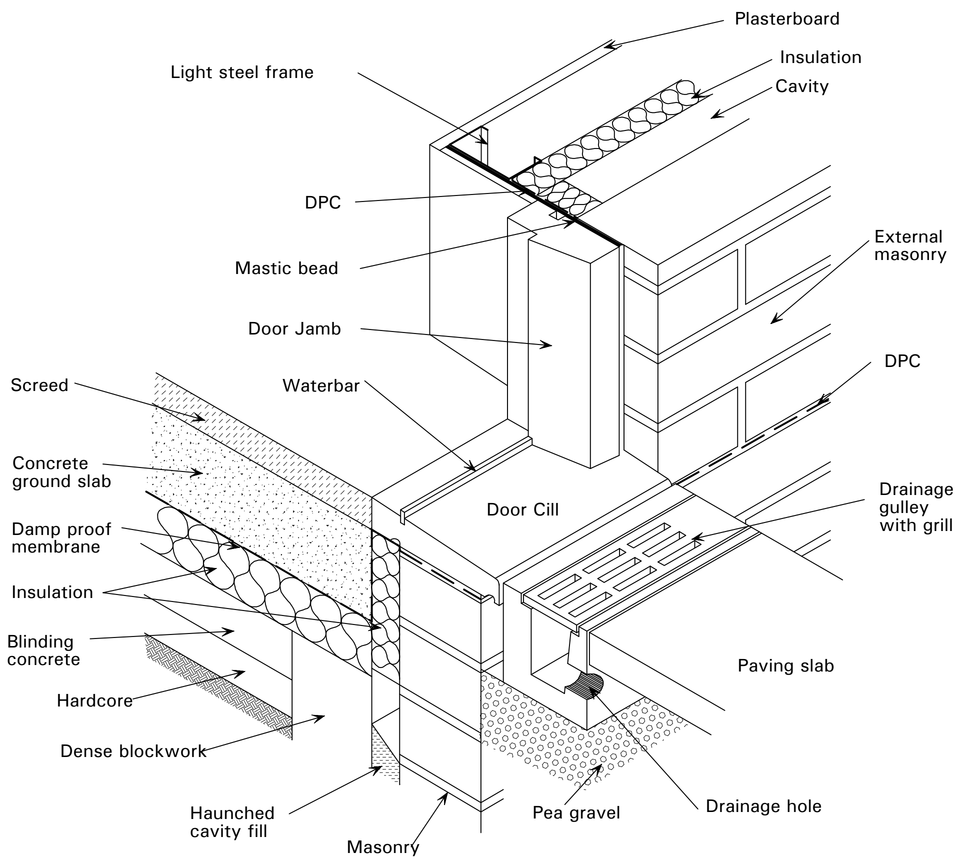
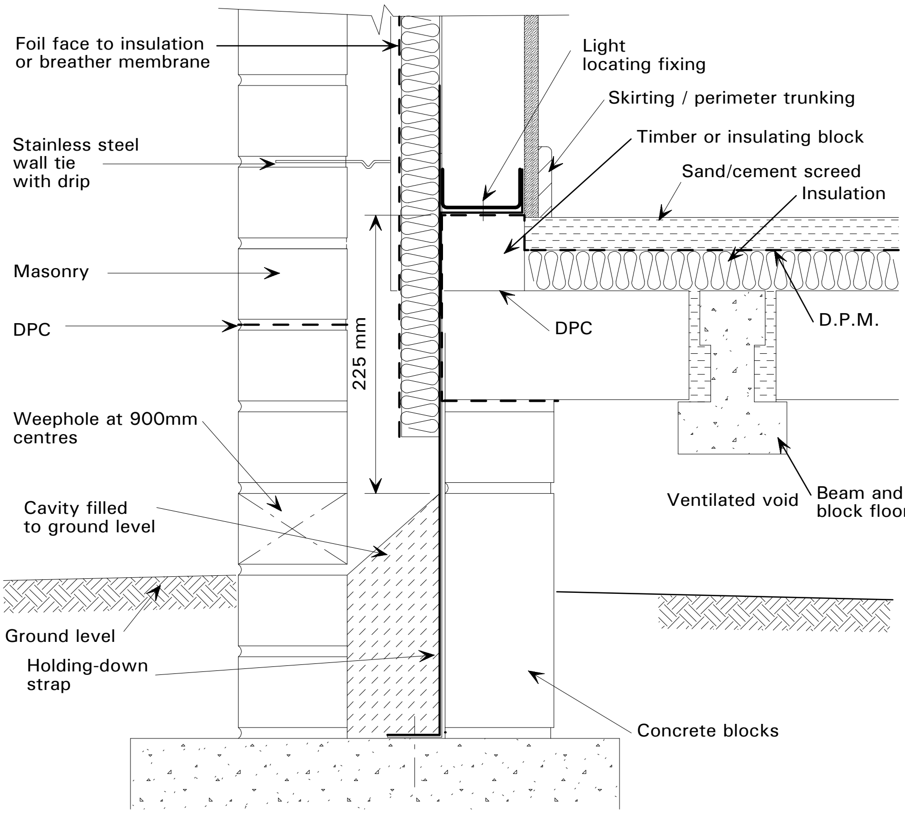


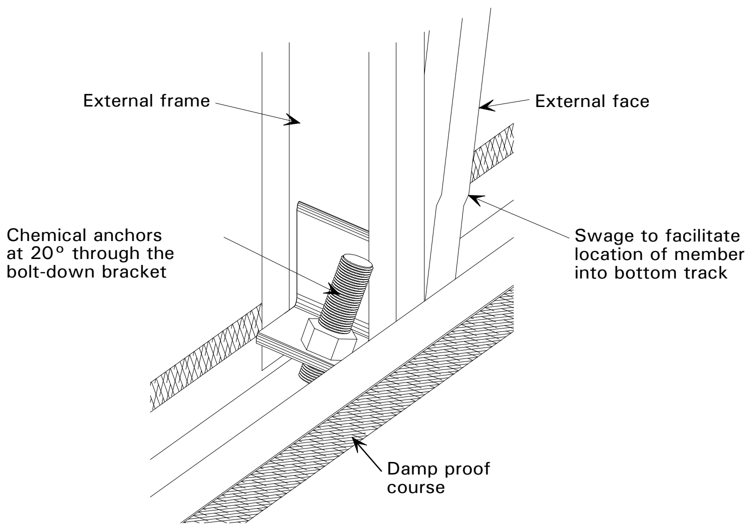
Figure 4.2 *Accessible threshold to meet Part M of the Building Regulations*

Particular attention must be paid to the details at the interface between the super-structure and the foundation to minimise the risk of corrosion. The light steel frame should be located entirely above the DPC level of the brickwork.

In circumstances where this cannot be achieved, particularly at openings providing wheelchair access, a thickness of corrosion protection equivalent to Z460 galvanizing, or a suitable bituminous coating, should be applied to all components below DPC level.



a) Holding-down detail for light steel frame on a suspended ground floor



b) Bolt-down bracket detail for light steel frame on insitu concrete slab/edge beam

Figure 4.3 *Different forms of anchorage of light steel frames to foundations*

5 GROUND FLOORS

Ground floors may be of two generic types: ground bearing (i.e. raft), or suspended floors. Suspended ground floors are increasingly used, especially when the ground conditions are poor.

Suspended ground floors may comprise light steel floor joists, as shown in Figure 5.1, or steel decking and in situ concrete, or a more traditional beam and block floor. Light steel frames can be readily used with both light steel joists and concrete floor slabs. The beam and block floor can be adapted to light steel frame construction, provided the steel elements are properly protected from moisture.

The ground below a suspended ground slab must be covered by a layer of blinding concrete or a damp proof membrane, to prevent plant growth. A ventilated air space is required beneath the floor; this must be at least 150 mm from the top of the ground cover to the underside of the floor boards and at least 75mm below the underside of any wall plate. The external walls should have ventilation equivalent to openings of 1500 mm^2 per metre run of wall.

For lightweight construction, it may be necessary to provide additional holding down anchorages or straps but it is not sufficient to tie them only to the ground floor (see Section 4.3).

5.1 Steel joist floor

A suspended ground floor may be constructed using light steel joists as shown in Figure 5.1. In this figure, the floors are embedded in a masonry stub wall. The galvanizing layer on the joists provides sufficient protection against corrosion due to the ambient air, provided a membrane is placed over the ground, or the floor joists are insulated from below. The first layer of floor boarding is attached directly to the floor joists and provides lateral restraint to the joists and diaphragm action. The preferred location of the insulation is under the joists, so that a 'warm frame' can be maintained but, alternatively, insulation may be placed on the floor and a final layer of boarding placed on the insulation.

The joists must be laid on a damp proof course at the support points. Where the joists are built into masonry, additional corrosion protection will be required in the form of bitumen paint or a pre-formed closure. Where loads are transferred from the wall through the joists to the foundation, additional strengthening sections or web stiffeners may be required to support the loads from above.

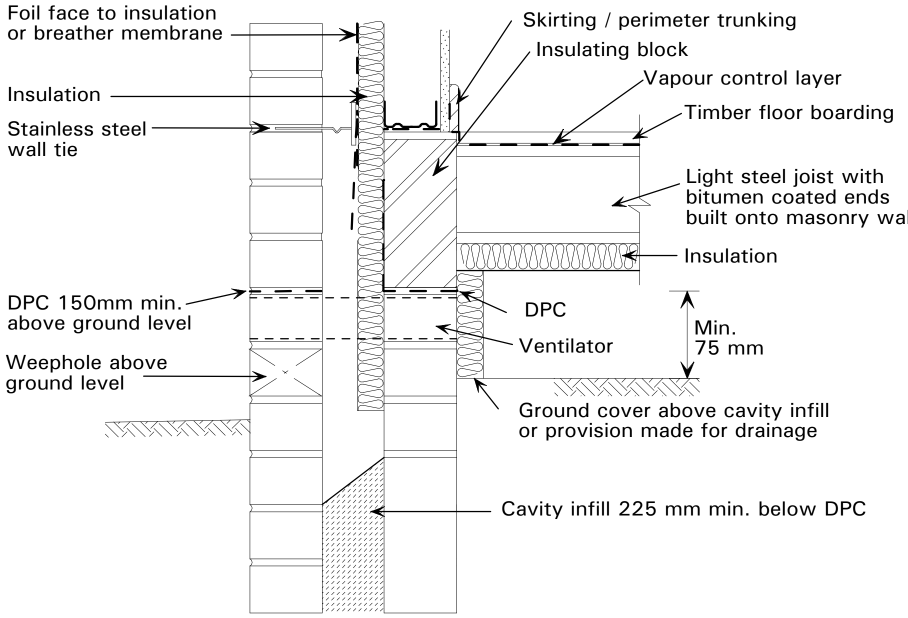


Figure 5.1 *Ventilation and insulation detail for suspended ground floors using steel joists*

5.2 Beam and block floors

Precast concrete beam and block floors are commonly used in domestic-scale construction. Figures 5.2 and 5.3 show details suitable for this form of construction when used with light steel framing.

The holding down straps, as shown in Figure 5.2, are plugged and screwed to the face of the foundation masonry and must be installed prior to the erection of the light steel frame. This work must be carried out before the frame is erected and the straps should be properly installed within tolerance, in the correct position, since the flexibility for further adjustment is very limited. The protruding section of the strap is screw-fixed to the face of the wall studs.

As an alternative, the hook detail shown in Figure 5.3, may be used and is installed by the frame erector. Communication with the ground worker is essential to ensure that the cavity fill is not placed before the hooks are installed. To resist high uplift forces, a reinforcement hoop can be embedded in the mass concrete footing and the restraint strap can be hooked through it. This system overcomes the problems of the horizontal alignment with the wall studs associated with the previous system.

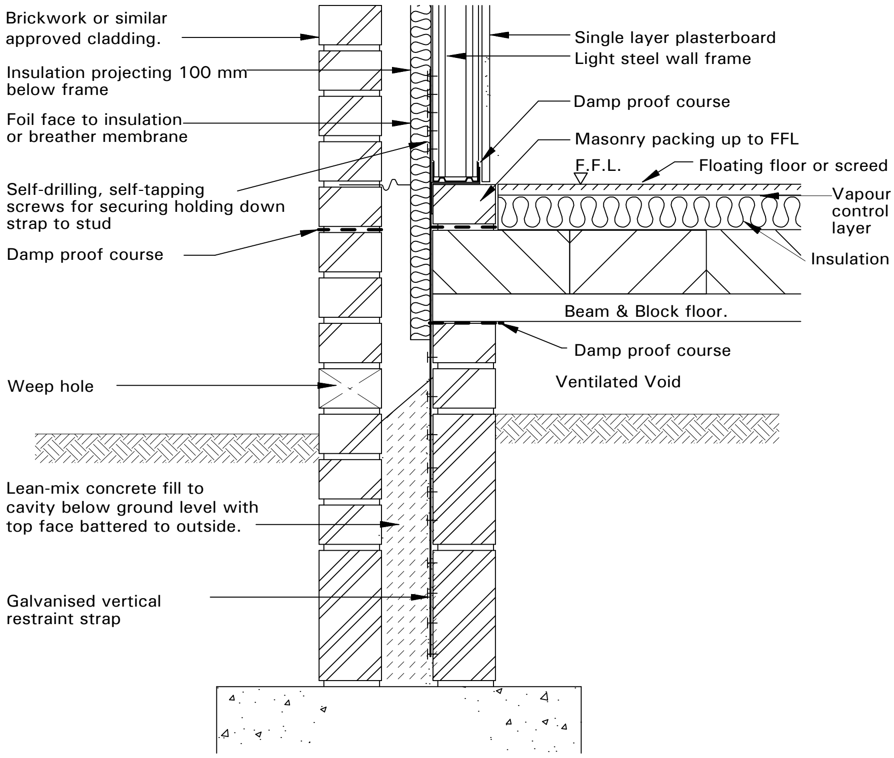


Figure 5.2 *Fixing down details for the light steel walls on beam and block ground floors using steel straps*

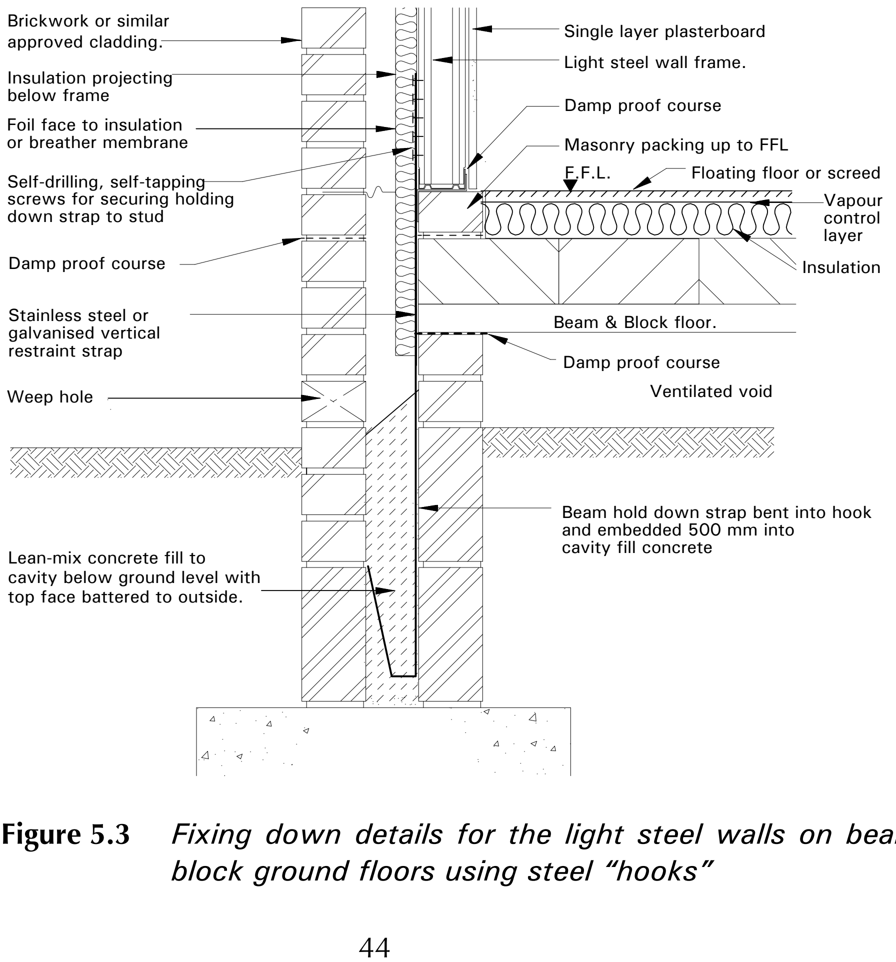


Figure 5.3 *Fixing down details for the light steel walls on beam and block ground floors using steel "hooks"*

5.3 Composite ground floor slab

A composite suspended ground floor slab may be constructed using steel decking acting compositely with the in-situ concrete slab placed on it. In this case, the clear span during construction is limited to about 3.5 m for steel decking thicknesses up to 1.2 mm. Spans of up to 4.5 m can be readily achieved for composite slabs in residential applications if an internal temporary support is provided to support the decking during construction. This may take the form of a sleeper wall on a modest foundation. Subsequently, the composite slab is able to resist imposed loads on the floor without requiring this intermediate support. Light mesh reinforcement is required in the slab topping to prevent cracking. Again, a DPC is required to protect the ends of the decking where it sits on the foundation.

The decking and slab may rest directly on the masonry foundation or a galvanized steel ring beam may be used to facilitate the erection of the wall frames and to evenly distribute the loads to the foundations. Figure 5.4 shows a purpose-made G section as a ring beam which can be used to support both the decking and the wall frame. The G section as a ring beam can be aligned and levelled prior to the installation of the ground slab and provides an accurate template for the wall frames and a tamping rail for the power-floated floor. This G section beam should be bitumen coated for durability.

The G section is vertically supported by masonry and tied to the steel decking with lateral support straps at not greater than 1.2 m centres. When the slab is concreted, it is important to place the concrete in the area of the G section first and to vibrate the concrete thoroughly to minimise the risk of air pockets beneath the top flange. As an aid, vent holes should be provided in the top flange of the G section.

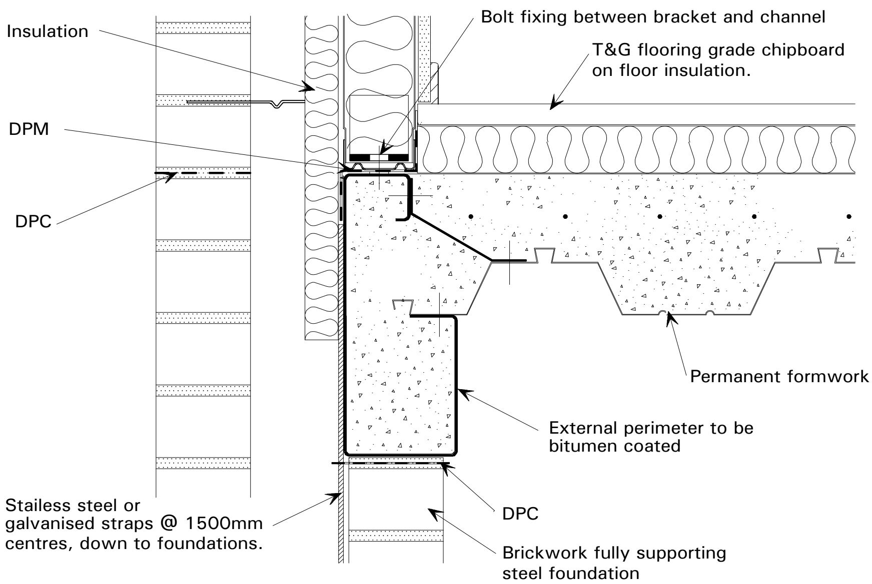


Figure 5.4 *Steel ring beam and composite slab in a suspended ground floor*

6 INTERMEDIATE FLOORS

The construction of a suspended floor comprising cold formed steel floor joists is similar to that for a floor using timber joists. Figure 6.1 shows a suspended floor arrangement using C section joists. The strength to weight ratio of light steel joists is higher than that of timber joists of similar size. Steel joists are dry, stable and do not suffer the long term problems of drying out, creep or shrinkage. Joists are generally positioned at 400 or 600mm centres, depending on the spanning capabilities of the floor boarding.

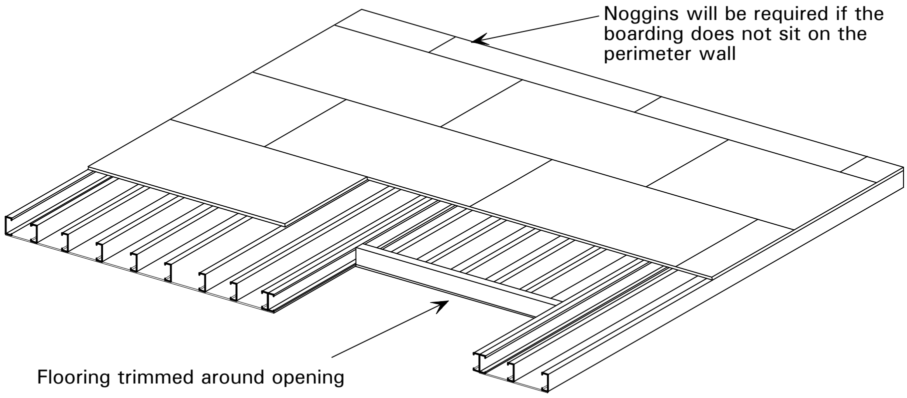


Figure 6.1 *Typical suspended floor using C section joists*

Figures 6.2 and 6.3 show typical floor/wall junctions for floor joists orientated parallel and perpendicular to the wall. If the positions of joists perpendicular to the wall do not coincide with wall studs, special components, such as the Z section shown in Figure 6.3, may be required in order to transfer the vertical loads. When using this type of section, the joists are fixed by web cleats to the perimeter Z section.

6.1 Floor finishes

6.1.1 Flooring materials

For floors in domestic-scale buildings, moisture resistant, type P5 chipboard to BS EN 312[23] should be used. When improved moisture resistance is required, WBP grade plywood to BS EN 1072:1995[24], or cement particle board to BS EN 634-1[25], should be specified. Installation should comply with the appropriate clauses of BS 5268-2[26], BS 8000-5[27] and BS 8201[28].

To prevent squeaking due to small movements of the flooring, tongue and grooved joints should be glued, using adhesives complying with BS 4071[29]. Square edge board should be supported on all sides on joists or noggins.

6.1.2 Ceilings

Plasterboard or other ceiling linings may be fixed directly to the bottom flange of joists and perimeter Z sections, provided they are spaced at not greater than 600 mm centres. When the joist centres exceed 600 mm, or where a high level of acoustic insulation is important, resilient bars or furrings are fixed to the joists and the ceiling is fixed directly to them. These resilient bars improve the acoustic insulation of the floor significantly (see Section 2.3.4). Noggins are required when plasterboards of up to 12.5 mm are attached to joists or trusses at 600 mm centres.

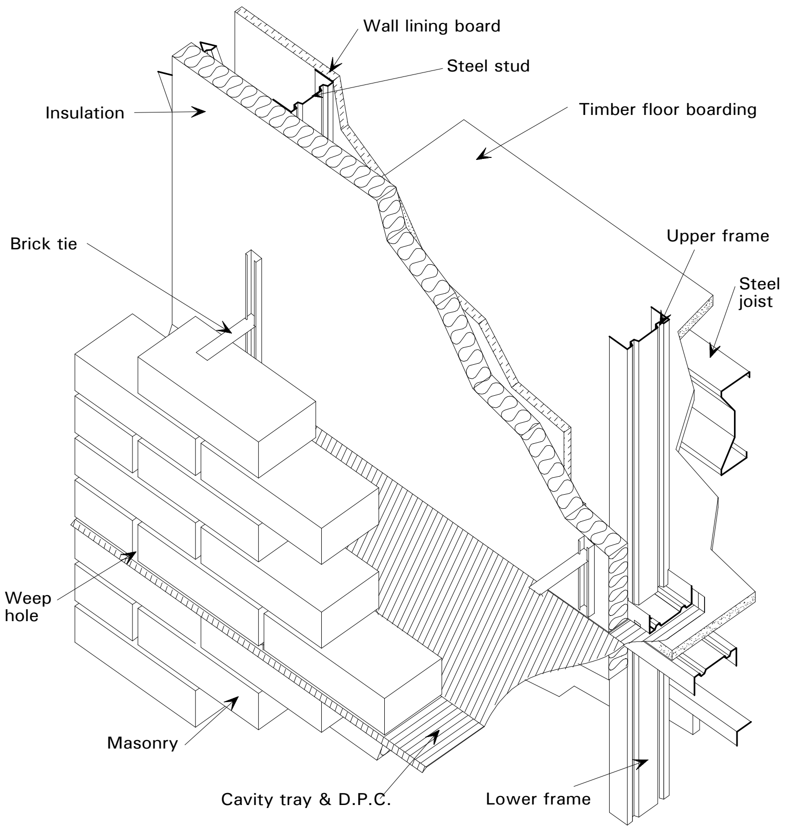


Figure 6.2 *Junction of walls to first floors - single family dwelling (joists parallel to walls)*

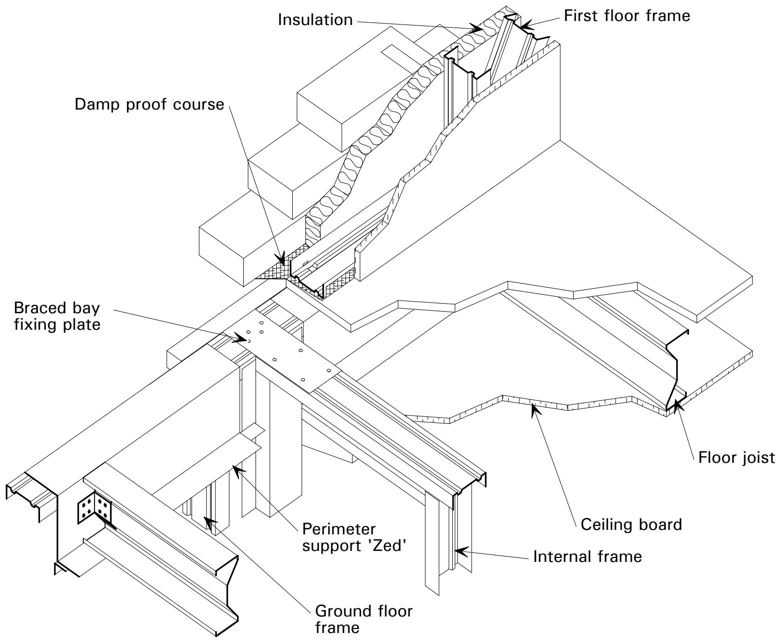


Figure 6.3 *Junction of walls to first floor - single family dwelling (joists perpendicular to walls)*

6.2 Design of light steel floor joists

6.2.1 Serviceability performance of light steel floor joists

For user comfort, floors should be sufficiently stiff that vibration due to normal activities do not cause annoyance. Suitable end connections and flooring materials will improve to the overall performance in service. The SCI's recommendations for the serviceability performance of light steel floor joists supporting a boarded floor are:

Static criteria:

(a) The maximum deflection for a single joist subject to dead and imposed loads is limited to the smaller of span/350, or 15 mm.

(b) The maximum deflection for a single joist subject only to imposed load is limited to span/450.

Dynamic criteria:

(c) The natural frequency of the floor should be limited to 8 Hz for the uniformly distributed load case of dead plus 0.3 kN/m^2, which represents the nominal load on a lightly loaded floor. This is achieved by limiting the deflection of a single joist to 5 mm for this loading condition.

(d) The deflection of the complete floor (i.e. series of joists plus the flooring material) when subject to a 1 kN point load, should be limited to the values presented in Table 6.1 (Virginia Polytechnic[30] criterion).

For domestic floors with a characteristic imposed load of 1.5 kN/m^2, the governing criterion is most likely to be b) (i.e. span/450) for spans to 3.5 m, or (d) (floor vibration) for longer spans.

For other floors subjected to imposed loads in excess of 1.5 kN/m^2, the governing criterion is most likely to be (a) (span/350 or a maximum of 15 mm).

For separating floors and other floors with high dead load, criterion (c), (i.e. 8 Hz limit), may become critical.

For floors constructed using floor boarding (timber boards, chipboard, plywood or cement particle board) that are screw fixed to the top flange of light steel joists, criterion (d) may be applied as follows to determine the required second moment of area of the individual floor joists.

$$I_{\text{required}} = \frac{L^3 \times 10.16}{N_{\text{eff}} \times *_{\text{j}}} \quad cm^4$$

where : L is the joist span (m)

N_{eff} is the number of effective joists acting with single point load, or may be taken as in Table 6.1

$*_{\text{j}}$ is the limiting deflection (mm) obtained from Table 6.2

Table 6.1 *Value of N_{eff} for different flooring configurations*

Floor configuration	Joist centres	
	400 mm	600 mm
Chipboard	2.5	2.35
Cement particle board	3	2.75
Built-up acoustic floor	4	3.5

Table 6.2 *Limiting deflection of floors y_{crit} subject to a 1kN point load at mid-span*

Span (m)	3.5	3.8	4.2	4.6	5.3	6.2
Deflection (mm)	1.7	1.6	1.5	1.4	1.3	1.2

Note: Tables 6.2 to 6.5 are provided as an aid to assessing the floor joist properties required for estimating purposes. The tables are for joists at 400 or 600 mm centres and for imposed loads of 1.5 kN/m^2 or 2.5 kN/m^2. Although a heavier dead load has been used for the 2.5 kN/m^2 situation, the criterion (d) has not been assessed for an 'acoustic' floor. The limiting spans listed under this criterion have been calculated from the full formula, not the simplified formula which appears in this publication.

Table 6.3 *Maximum span (m) for joists at 400 mm centres for G_k=0.32 kN/m^2, Q_k=1.5 kN/m^2*

I of individual joist (cm^4)	Maximum span (m) for limiting criterion				
	L / 450 under imposed load	L / 350 under total load (or 15 mm)	8Hz under self weight + 0.3 kN/m^2	y_{crit} +10% under 1 kN	
				18 mm chipboard	22 mm chipboard
50	3.08	3.14	3.56	**3.04**	3.08
100	3.88	3.95	4.24	**3.57**	3.61
150	4.44	4.53	4.69	**3.97**	4.03
200	4.89	4.98	5.04	**4.30**	4.36
300	5.59	5.59	5.57	**4.82**	4.89
400	6.15	6.00	5.99	**5.23**	5.30
500	6.63	6.35	6.33	**5.57**	5.65
600	7.04	6.64	6.63	**5.87**	5.95
700	7.42	6.90	6.89	**6.13**	6.22
800		7.14	7.12	**6.37**	6.46
900		7.35	7.34	**6.59**	6.68
1000		7.55	7.53	**6.80**	6.89
1100				**6.98**	7.08
1200				**7.16**	7.26
1300				**7.33**	7.43
1400				**7.49**	7.59

Note: The limiting span is shown in bold. Slight increases in the limiting span result from using 22 mm rather than 18 mm chipboard. A 10% increase in y_{crit} is permitted for residential buildings in Reference 30

Table 6.4 *Maximum span (m) for joists at 400 mm centres for G_k=0.72 kN/m^2, Q_k=2.5 kN/m^2*

I of individual joist (cm^4)	Maximum span (m) for limiting criterion				
	L / 450 under imposed load	L / 350 under total load (or 15 mm)	8Hz under self weight + 0.3 kN/m^2	y_{crit} +10% under 1 kN	
				18 mm chipboard	22 mm chipboard
100	3.27	**3.27**	3.74	3.57	3.61
150	3.74	**3.74**	4.14	3.97	4.03
200	4.12	**4.12**	4.45	4.30	4.36
300	4.72	**4.71**	9.92	4.82	4.89
400	5.19	**5.19**	5.29	5.23	5.3
500	5.39	**5.50**	5.59	5.57	5.65
600	5.94	**5.76**	5.85	5.87	5.95
700	6.26	**5.99**	6.08	6.13	6.22
800	6.54	**6.19**	6.29	6.37	6.46
900	6.80	**6.37**	6.48	6.59	6.68
1000	7.05	**6.54**	6.65	6.80	6.89
1100	7.27	**6.70**	6.81	6.98	7.08
1200	7.49	**6.85**	6.96	7.16	7.26
1300	7.69	**6.99**	7.10	7.33	7.43
1400		**7.12**	7.23	7.49	7.59
1500		**7.24**	7.36		
1600		**7.36**	7.48		
1700		**7.47**	7.59		

Note: The limiting span is shown in bold text.
See notes under Table 6.3.

Table 6.5 *Maximum span (m) for joists at 600 mm centres for G_k=0.32 kN/m², Q_k=1.5 kN/m²*

I of individual joist (cm^4)	Maximum span (m) for limiting criterion				
	L / 450 under imposed load	L / 350 under total load (or15 mm)	8Hz under self weight + 0.3 kN/m²	y_{crit} +10% under 1 kN	
				18 mm chipboard	22 mm chipboard
100	3.39	3.45	3.83	3.50	3.63
150	3.88	3.95	4.24	**3.88**	4.06
200	4.27	4.35	4.55	**4.20**	4.40
300	4.89	4.98	5.04	**4.71**	4.93
400	5.38	5.42	5.41	**5.12**	5.34
500	5.79	5.73	5.72	**5.45**	5.69
600	6.16	6.00	5.99	**5.75**	5.99
700	6.48	6.24	6.22	**6.01**	6.26
800	6.78	6.45	6.44	**6.24**	6.50
900	7.05	6.64	6.63	**6.46**	6.73
1000	7.30	6.82	6.8	**6.66**	6.93
1100	7.53	6.98	6.97	**6.84**	7.12
1200		7.14	7.12	**7.02**	7.31
1300		7.28	7.27	**7.19**	7.48
1400		7.42	7.40	**7.34**	
1500		7.55	7.53	**7.49**	

Note: The limiting spans are shown in bold text.
See notes under Table 6.3.

Table 6.6 *Maximum span (m) for joists at 600 mm centres for G_k=0.72 kN/m^2, Q_k=2.5 kN/m^2*

I of individual joist (cm^4)	Maximum span (m) for limiting criterion				
	L / 450 under Imposed load	L / 350 under total load (or 15 mm)	8Hz under self weight + 0.3 kN/m^2	y_{crit} +10% under 1 kN	
				18 mm chipboard	22 mm chipboard
100	2.86	**2.86**	3.38	3.50	3.63
150	3.27	**3.27**	3.74	3.88	4.06
200	3.60	**3.60**	4.02	4.20	4.40
300	4.12	**4.12**	4.45	4.71	4.93
400	4.54	**4.53**	4.78	5.12	5.34
500	4.89	**4.88**	5.05	5.45	5.96
600	5.19	**5.19**	5.29	5.75	5.99
700	5.47	**5.41**	5.50	6.01	6.26
800	5.71	**5.59**	5.68	6.24	6.50
900	5.94	**5.76**	5.85	6.46	6.73
1000	6.16	**5.91**	6.01	6.66	6.93
1100	6.35	**6.06**	6.15	6.84	7.12
1200	6.54	**6.19**	6.29	7.02	7.31
1300	6.72	**6.31**	6.42	7.19	7.48
1400	6.89	**6.43**	6.54	7.34	
1500	7.05	**6.54**	6.65	7.49	
1600	7.20	**6.65**	6.76		
1700	7.35	**6.75**	6.86		
1800	7.49	**6.85**	6.96		
1900		**6.94**	7.05		
2000		**7.03**	7.15		
2100		**7.12**	7.23		
2200		**7.20**	7.32		
2300		**7.28**	7.40		
2400		**7.36**	7.48		
2500		**7.44**	7.56		
2600		**7.51**			

Note: The limiting span is shown in bold text.
See notes under Table 6.3.

6.2.2 Attachment of floors to walls

Joists may be built into walls or supported by joist hangers or cleats. Cleated connections should be made through the web to minimise the risk of local bearing or buckling of the section. For steel joists supported on loadbearing masonry walls, a tight control of masonry tolerances is required on-site to ensure that adequate bearing is provided.

Figures 6.4(a), (b) and (c) show alternative support details at an intermediate floor. Figure 6.4(a) shows platform construction in which the timber floor decking extends through to the external face of the stud wall. The second wall frame is then fixed directly to the floor and loads are transferred through the boarding. The direct attachment of the boards to the walls provides stability and permits the floor to act as a structural diaphragm. In platform construction, alignment of the walls is achieved on each floor, so that there is no accumulation of differential vertical tolerances. The floor joists are supported by the perimeter light steel zeds and each joist should be connected by a cleat to the Z section which is fixed to the wall studs at each intersection. In general, self-drilling, self-tapping screws are used for all connections, although bolts may be used at bracing points.

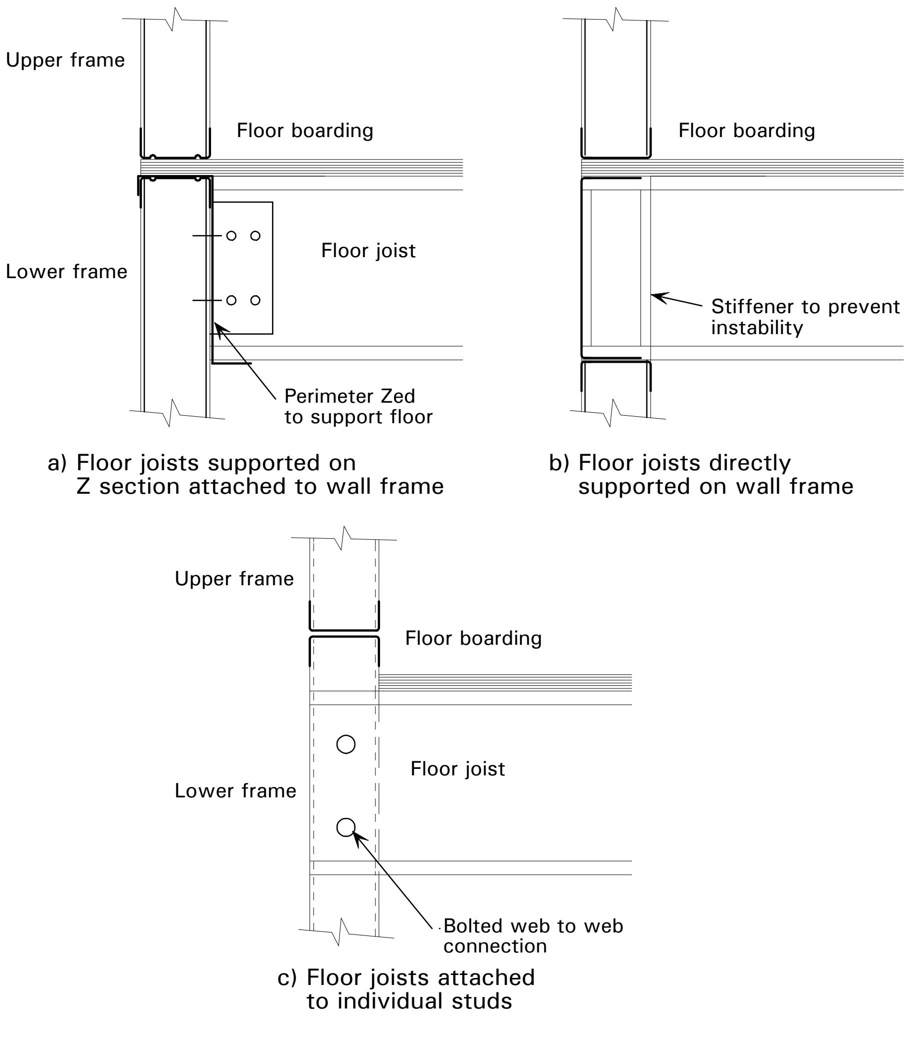


Figure 6.4 *Generic connection details between floors and walls*

Figure 6.4(b) is similar to Figure 6.4(a), but the joists continue over the head of the stud wall. In this configuration, the joists should align with the studs, both above and below the joists. Stiffeners in the form of short sections of stud may be required to transfer concentrated loads from the stud walls above.

Figure 6.4(c) shows an alternative arrangement where the studs continue beyond the floor level and the joists connect into the side of each stud. This affords each frame a degree of continuity to resist horizontal loads. In this configuration the floor boarding is attached right up to the inside face of the stud wall. Only two bolts are required for adequate structural connection.

Joists may also be supported by joist hangers or similar brackets attached to hot rolled steel sections used to provide support over large openings. In this case, the hot rolled steel section is generally designed to be accommodated within the floor depth. The hot rolled steel section should be supported by discrete columns, often in the form of boxed C sections or RHS sections.

6.2.3 Bridging and blocking of joists

To provide lateral stability to light steel floor joists, bridging and blocking pieces may be required, as shown in Figure 6.5. Specific rules cannot be presented here since different joist profiles require different solutions. For example, a 'sigma' section joist is more stable than a lipped C section and requires no bridging or blocking elements for spans of up to 4.5m. Advice should be sought from the manufacturer on the exact requirements for the system being used on a particular contract.

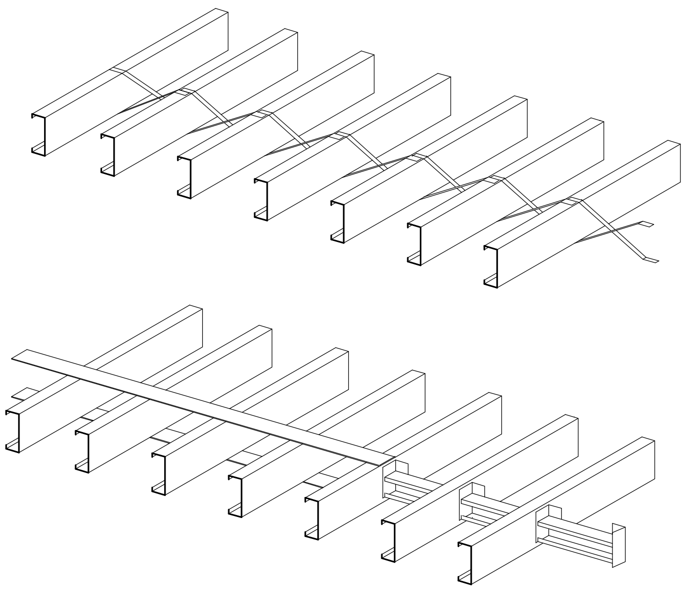


Figure 6.5 *Generic bridging and blocking details*

6.3 Concrete floors

Concrete floors may also be used with light steel framing, or floor joists, although the weight of the construction is a limiting factor to the sizing of the wall studs. For this reason, additional hot rolled steel members may be required. Concrete floors may be constructed using either thin pre-cast units or in-situ concrete placed on steel decking acting as permanent shutter. A composite floor may be created by using steel decking which acts compositely with an in-situ concrete floor. Spans of up to 4.5 m can be achieved if the decking is propped during construction. Otherwise, unpropped spans are limited to 3 to 3.5 m.

Table 6.7 *Typical sizes of concrete and composite floors*

Type of floor	Overall slab thickness	Span condition	Span	Weight kg/m^2
Precast concrete units	100 mm	Unpropped	5.0 m	235
	150 mm		7.0 m	250
Composite slab	130 mm	Unpropped	4.0 m	200
	(60 mm deck)	Propped	4.5 m	200
Composite slab	150 mm	Unpropped	3.5 m	230
	(80 mm deck)	Propped	4.5 m	230

Imposed load of 1.5 kN/m^2.

6.4 Separating floors

The Building Regulations require that a separating floor provides acoustic insulation between dwellings or between a dwelling and a communal space (see Section 2.3).

'Built-up' floors, using resilient layers, are particularly effective in reducing impact sound transmission. Steel decking or floor boarding may be laid over light steel joists and heavy density mineralwool slabs, or similar, are fixed to the decking or boarding using beads of mastic adhesive. Plasterboard planks are then laid over the insulation to provide a firm and level base for the final layer of floor boarding (see Section 2.3).

Steel decking may be used to replace one or more layers of boarding. It is relatively shallow (< 30 mm deep) because it is only required to span up to 600 mm between floor joists.

To avoid acoustic flanking transmission at floor wall connections, the space between the studs should be filled with mineral wool to a height of 300 mm above floor level for separating walls.

A compressible filler strip should be fitted to all perimeters of the floor boarding to avoid the transmission of impact sound from the floor to the light steel frame (see Figure 6.6). The spaces between the floor joists are also filled with a mineral wool sound insulating quilt.

6.5 Compartment floors

For residential construction, the Building Regulations require that a floor between two dwellings acts as a compartment floor, to provide fire separation. In general, a compartment floor will also act as a separating floor and the same measures that achieve the required acoustic performance will provide the necessary fire separation.

Figure 6.7 shows two alternative 'dry-build' floor systems which meet the requirements of the current Building Regulations for compartment floors. The detail also shows an adjacent separating wall where insulation placed between the wall studs reduces flanking losses. Steel decking may also be used and provides for integrity to passage of smoke or flame in fire.

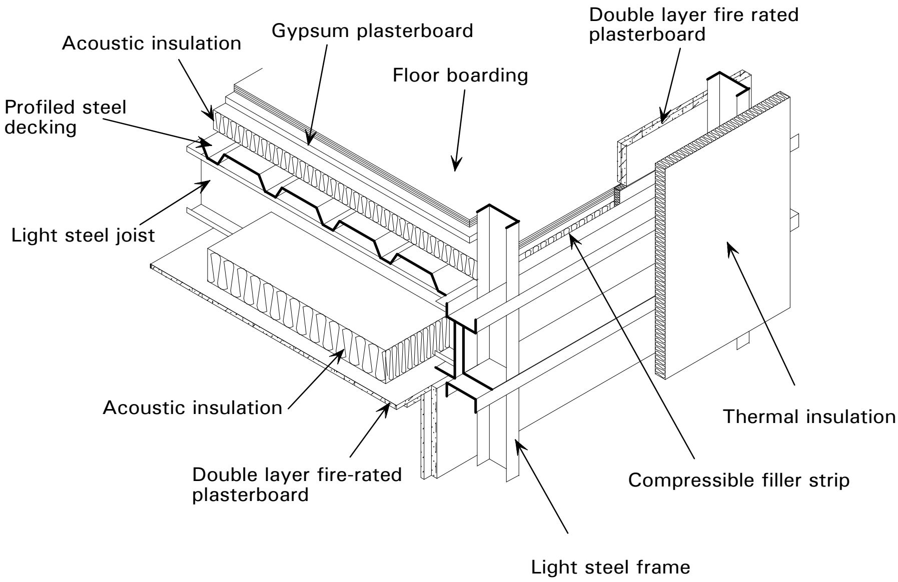


Figure 6.6 *Detail of a typical separating wall / floor junction using profiled steel decking*

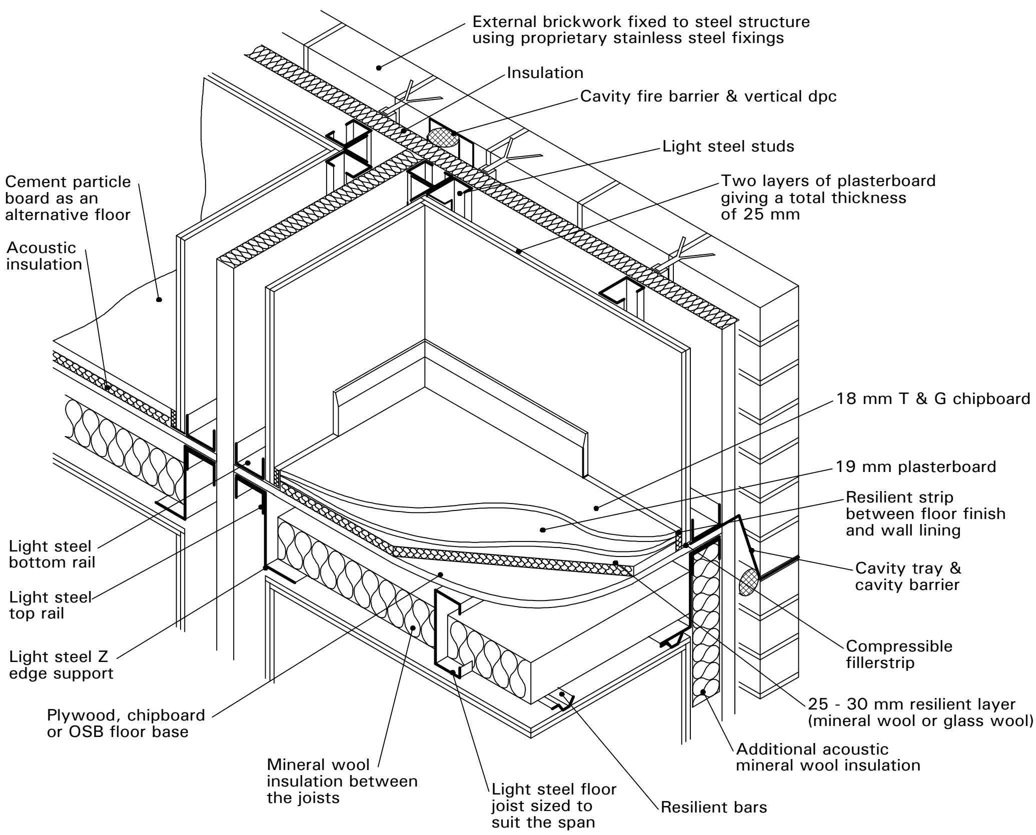


Figure 6.7 *Details of compartment floor at junction with external wall and separating wall*

7 EXTERNAL AND LOAD-BEARING WALLS

Walls are generally categorised as load-bearing if they resist significant axial load from floors or the roof. Non-loadbearing walls are typically demountable partitions or other internal non-structural walls. However, all walls must be designed to resist the loads due to wind pressure acting perpendicular to the plane of the wall. For external walls, pressures are the sum of external and internal pressures; for internal walls, the maximum differential internal wind pressures are used; suction on one side of the wall, pressure on the other.

7.1 Design for wind forces

7.1.1 Deflection limits

Deflection limits for walls depend on the type of cladding that they support. Cladding may be grouped in the following generic forms.

- Glazing
- Masonry cladding
- Board or rendered materials.
- Sheeting.

For glazing and masonry cladding, control of deflections is important to avoid cracking due to wind loads. The SCI proposes that a horizontal deflection limit of height/500 is used when checking stud walls supporting masonry. This limit does not take account of any stiffening action of the brickwork. Actual deflections may be expected to be 50 to 70% of these deflections.

For board or rendered finishes, it is proposed that a deflection limit of height/360 is used.

For steel cladding, a deflection limit of height/250 may be used because of the ability of the cladding to accept greater movement.

Suggested horizontal deflection limits for walls subject to winds loading are summarised in Table 7.1.

Table 7.1 *Suggested deflection limits for external walls subject to wind loading*

Application	Deflection Limit
Full height glazing	Height/600
Masonry walls	Height/500
Board/rendered finish	Height/360
Steel cladding	Height/250
Other flexible finishes	Height/360

To meet the relevant limiting deflection criteria, wall studs may be chosen on the basis of their second moment of area, assuming that they deflect as simply supported beams.

7.1.2 Design for stiffness

Table 7.2 provides guidance on the minimum required second moment of area per metre of wall, since studs may be placed at various centres, typically to suit plasterboard sizes. The tabulated values may be multiplied by the stud spacing (in metres) to obtain the required second moment of area of each stud.

The deflection limit to be considered should be selected on the basis of experience and the type of cladding (see Section 7.1.1).

Table 7.2 *Minimum second moment of area, I, per metre width required for studs resisting wind load only*

Wall height (m)	Characteristic wind pressure (kN/m^2)	I (cm^4/m) for Deflection Limit of:			
		L/250	L/360	L/500	L/600
2	0.5	*6*	*9*	*13*	*15*
	0.75	*10*	*14*	*19*	23
	1	*13*	*18*	25	30
2.5	0.5	*12*	*18*	25	30
	0.75	*19*	*27*	37	45
	1	25	*36*	50	60
3	0.50	21	*31*	43	51
	0.75	32	*46*	64	77
	1	43	*62*	86	103
3.5	0.50	34	*49*	68	82
	0.75	51	*74*	102	123
	1	68	*98*	136	163
4	0.5	51	*73*	102	122
	0.75	76	*110*	152	183
	1	102	*146*	203	244

Note: It is recommended that the minimum section modulus should not be less than 20 cm^4/m width of wall for robust behaviour (values in grey area). Values determined on the basis of stiffness, are indicated in italics.

As an example, consider a 2.5 m stud wall resisting an unfactored wind pressure of 0.75 kN/m^2. If a deflection limit of L/360 is specified, this can be achieved with I_{xx} = 27 cm^4/m; for studs at 600 mm centres; this equates to I_{xx} = 16.2 cm^4 per stud. This would require use of 75 mm × 1.6 mm lipped C section studs at 600 mm centres. (I_{xx} = 25 cm^4 per stud from typical manufacturers' data).

To frame a 1.8 m wide window within this wall, the studs either side of the window would effectively resist load from wind pressure applied to a 1.2 m width of wall. Thus, 75 × 1.6 plain C section studs in pairs would be required on either side of the window opening.

7.2 Design for axial load

7.2.1 Axial compression

In housing, lipped and plain C section studs are commonly used in section depths between 75 and 100 mm and in steel thicknesses between 1.2 and 2.4 mm. The axial load resistance is dependent on the stud slenderness. Noggins are often provided within wall frames to provide lateral restraint to the studs. Without these noggins, the minimum radius of gyration dictates the slenderness of plain C sections. When a mid-height noggin is provided, the slenderness of the studs is reduced by half and the axial resistance increases considerably.

The effect on a lipped C section is less dramatic, since the lips provide more stability to the section and the minimum radius of gyration is much greater than for a plain C section. It is unlikely that noggins will be provided in domestic construction using lipped C studs. Table 7.3 presents typical compression loads that may be resisted by 75 mm plain C sections with mid-storey height restraints (r) and 100 mm lipped C sections that are either unrestrained laterally (u), or restrained laterally (r) at mid-height. Steel with design strength of 280 N/mm^2 has been assumed in these tables.

7.2.2 Bending and compression

In studs subject to combined bending and axial load, the limiting combination of axial load and moment varies with stud length, stud type and restraint conditions. To comply with the requirements of Clause 6.4 of BS 5950-5, the ability of a stud to resist moment reduces as the axial load increases. In a typical house, the storey height is 2.5 m and Figures 7.1, 7.2 and 7.3 are presented for walls of this height. These figures are based on the detailed requirements of Clauses 6.4.2 and 6.4.3 of BS 5950-5.

The intercepts on each axis are for pure compression and for pure bending in the major axis direction respectively. A slight improvement can be seen when studs are restrained at mid-height. Figures of this type allow interpolation between tabulated values. These figures should not be used for studs subjected to biaxial bending.

Loads transferred from beams may be assumed to be applied at the face of the column or stud wall, and the moment due to this action is calculated for an eccentricity of half the member depth or width, depending on the orientation of the members.

Table 7.3 *Load capacity (in kN) of light steel C section studs resisting axial load only*

(a) 75 mm plain C section (restrained at mid-height)

	Factored load (kN) for section thickness		
Wall height (m)	**1.2 mm**	**1.6 mm**	**2.4 mm**
0.00	36.5	57.3	88.2
1.00	35.0	55.2	85.0
2.00	30.0	46.2	71.1
2.25	28.0	42.3	65.1
2.50	25.7	37.8	58.3
2.75	23.3	33.4	51.5
3.00	20.9	29.4	45.3

(b) 100 mm lipped C section stud (restrained at mid-height)

	Factored load (kN) for section thickness		
Wall height (m)	**1.2 mm**	**1.5 mm**	**2 mm**
0.00	58.7	78.1	109.8
1.00	58.0	77.2	108.4
2.00	54.0	71.6	100.2
2.25	52.5	69.6	97.2
2.50	50.8	67.3	93.5
2.75	48.8	64.4	89.0
3.00	46.4	61.0	83.8

(c) 100 mm lipped C section stud (unrestrained within height)

	Factored load (kN) for section thickness		
Wall height (m)	**1.2 mm**	**1.5 mm**	**2 mm**
0.00	58.7	78.1	109.8
1.00	54.0	71.7	100.6
2.00	46.2	61.2	85.2
2.25	44.0	58.1	80.7
2.50	41.6	55.0	76.0
2.75	39.2	51.7	71.1
3.00	(36.8)	(48.4)	(66.2)

Figures in brackets are for studs with a slenderness ratio in excess of 180. All data for S280 steel.

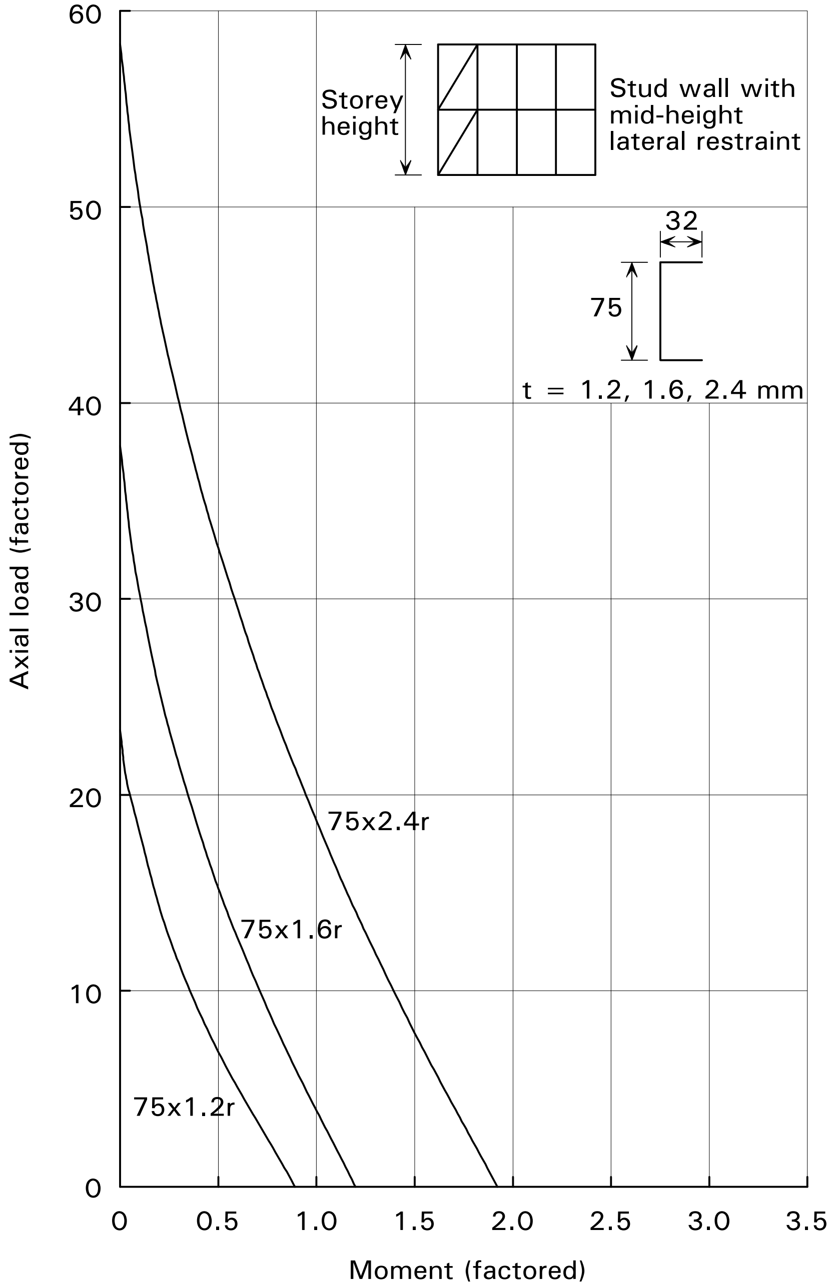


Figure 7.1 *Moment / axial load for 2.5m high, 75 mm plain C stud wall - restrained at mid-height*

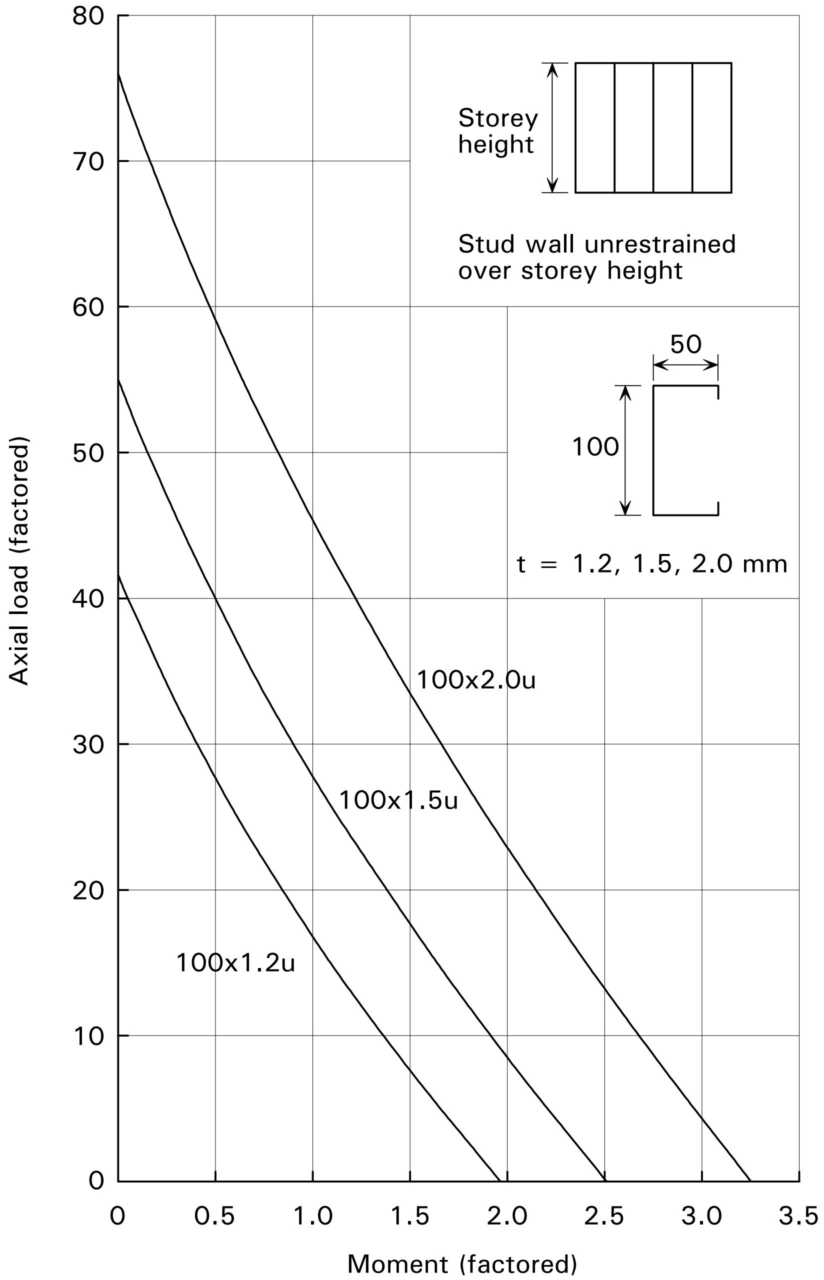


Figure 7.2 *Moment / axial load for 2.5m high, 100 mm lipped C stud wall - unrestrained*

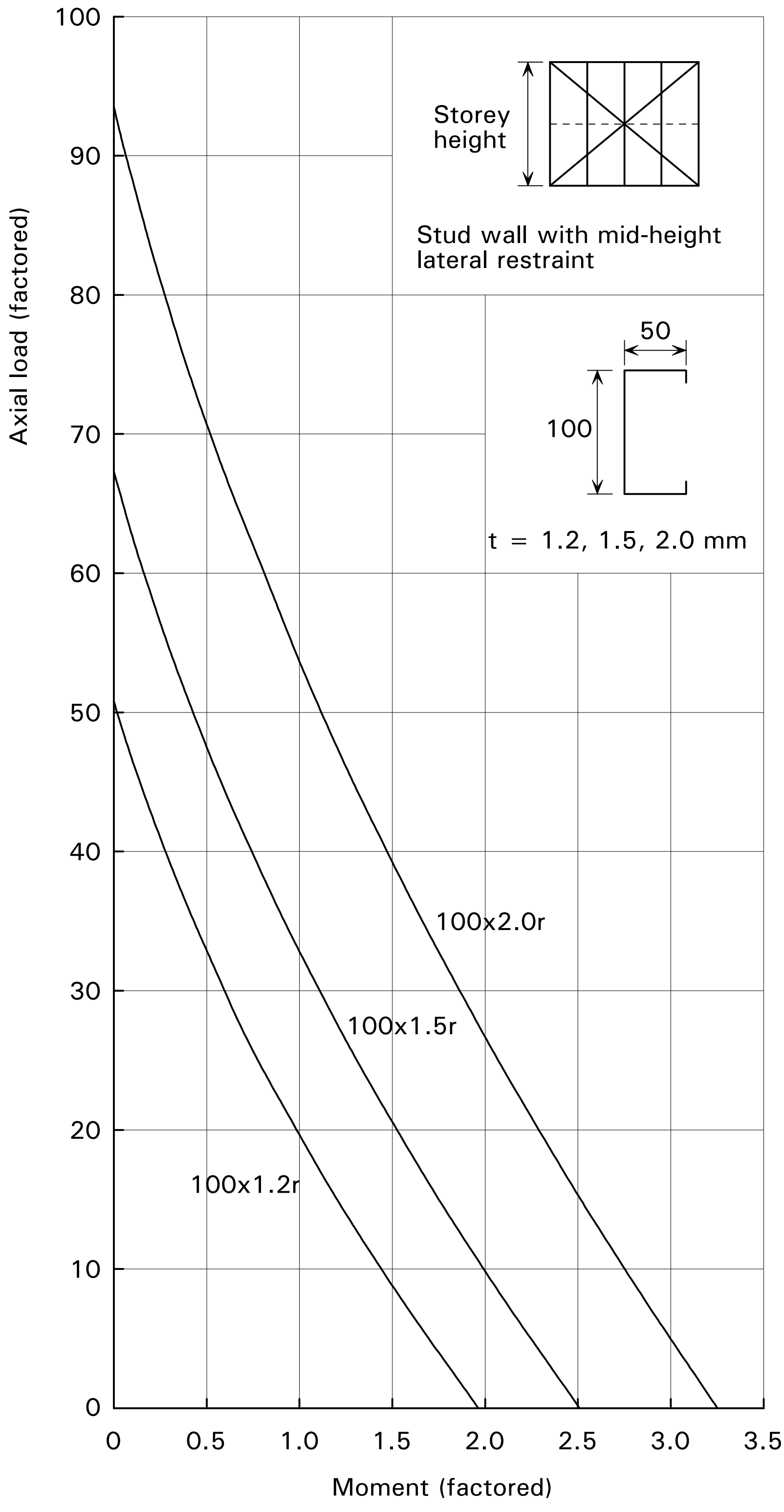


Figure 7.3 *Moment / axial load for 2.5m high, 100 mm lipped C stud wall - restrained* at mid-height

7.3 Details of external wall construction

Typical details for cavity construction of external walls are shown in Figures 7.4 and 7.5. The inner skin, which has a plasterboard lining to the room face, uses C section studs in single lengths between floors, at regular centres of typically 400, 450, or 600 mm. These spacings are chosen, where practical, to ensure the efficient use of plasterboard linings and other cladding materials. Multiple studs are used in heavily loaded applications, such as adjacent to openings or in braced panels.

A wall sub-frame or panel consists of a head rail, a base rail and possibly horizontal noggins at mid-height. C sections used as noggins, may require at least one end tapered to fit into the adjacent C section wall stud. These lateral restraints ensure that the design of walls in most applications is governed by major axis rather than minor axis buckling of the studs. For the normal storey heights used in housing, intermediate noggins are not required when using lipped C section studs.

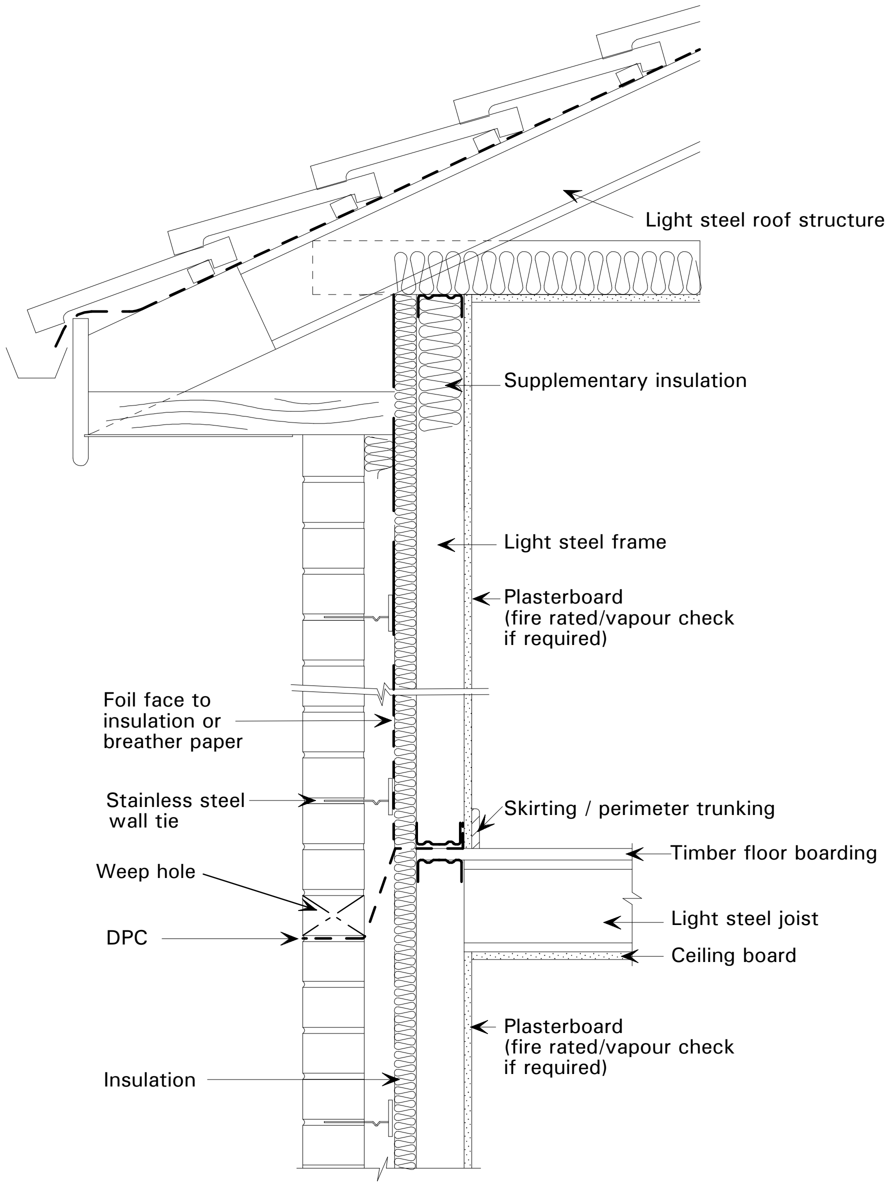


Figure 7.4 *Generic detail - external wall connection with eaves and intermediate floor*

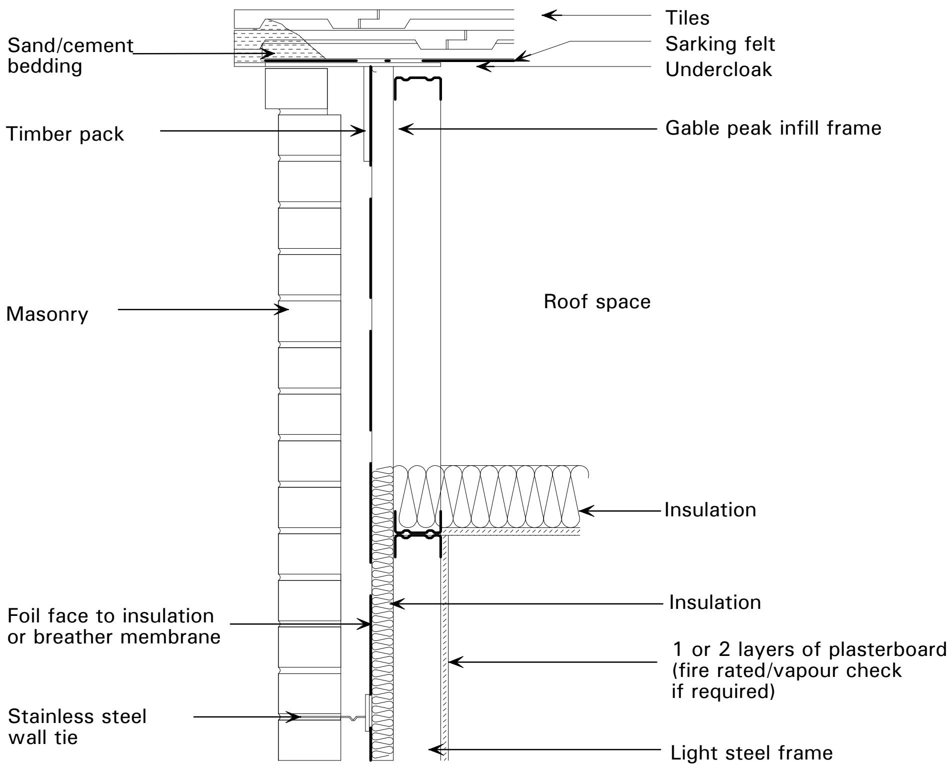


Figure 7.5 *Generic detail - Gable wall*

7.3.1 Masonry cladding

Masonry cladding supports its own weight on the foundations and transmits only lateral loads to the steel structure. For domestic-scale construction, joints to allow horizontal movement will not normally be required. However, movement joints may be required in structures above four storeys to accommodate differential movement of the brickwork and steel.

The cavity face of the inner skin may be sheathed and should always be insulated with a suitable board material. Some insulation may be placed within the depth of the stud, provided that the risk of interstitial condensation has been assessed and shown to be negligible.

When installing the light steel framing on an in situ concrete ground slab, the base rail should be placed on a DPC. For heavy load conditions, or an uneven slab, it may be necessary to use a thicker base rail and/or packings.

7.3.2 Lintels

Openings larger than 600 mm wide in external walls will generally require a frame lintel in the plane of the stud wall to transfer loads from above, as illustrated in Figure 7.6. C shaped lintels are recommended at, or just below, floor level where restraint can be properly afforded by the floor joists. Separate lintels are also required within the external brick skin.

Cavity trays should be provided above horizontal cavity barriers and above window and door openings. Attention should be paid to the local details in these areas (see Figure 7.6) to ensure that water is effectively shed to the outer skin of the wall. To ensure that water will not run back and penetrate at the reveal, cavity trays should extend 150 mm either side of a door or window opening and have stopped ends.

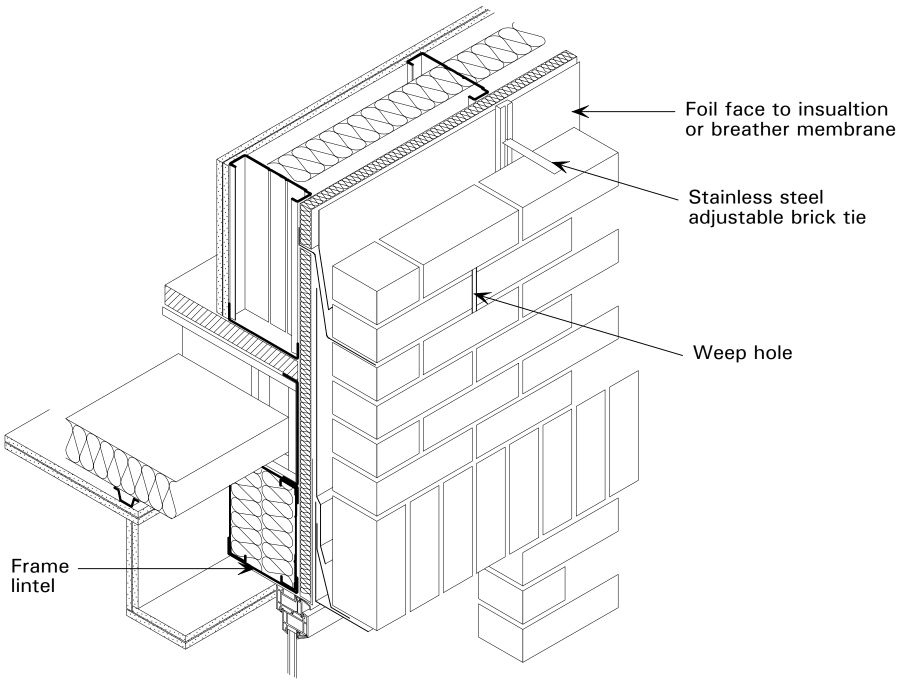


Figure 7.6 *Detail of lintel at opening*

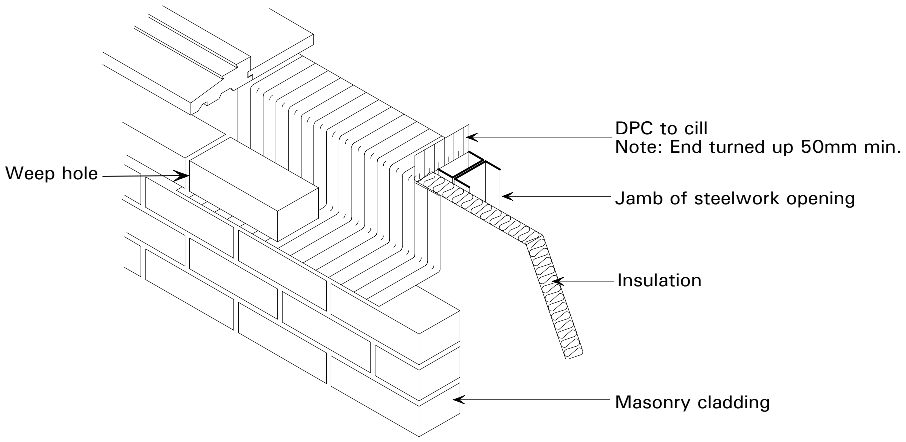


Figure 7.7 *Damp proof course (DPC) detail at cill*

7.3.3 Wall ties

The majority of details in this publication show how light steel framing interfaces with brickwork. When used with masonry cladding, the external skin should be attached to the light steel frame with either epoxy coated galvanized ties, or austenitic stainless steel ties (to DD 140[31], BS 1243[32], BS 5628[33], BS 8200[34] or approved by independent assessment). The ties provide lateral restraint whilst accommodating vertical movement. To accommodate movement and tolerances, brick ties are normally fixed in vertical channels. These channels can be attached directly to sheathing boards or, they may be attached through soft insulation boards using stand-off screws. The stand-off screws should be isolated from the channels with neoprene or similar washers to minimise cold bridging and bi-metallic action.

A minimum distribution of 2.5 wall ties per m^2 of wall is required according to BS 5628 for double skin masonry walls. For areas of high wind suction, the density of ties should be increased. Figure 7.8 shows an arrangement of brick ties achieving a distribution of 4.44 wall ties per m^2 when studs are spaced at 600 mm centres. Horizontal centres can be increased to 1200 mm, provided that the vertical centres of the ties are reduced accordingly.

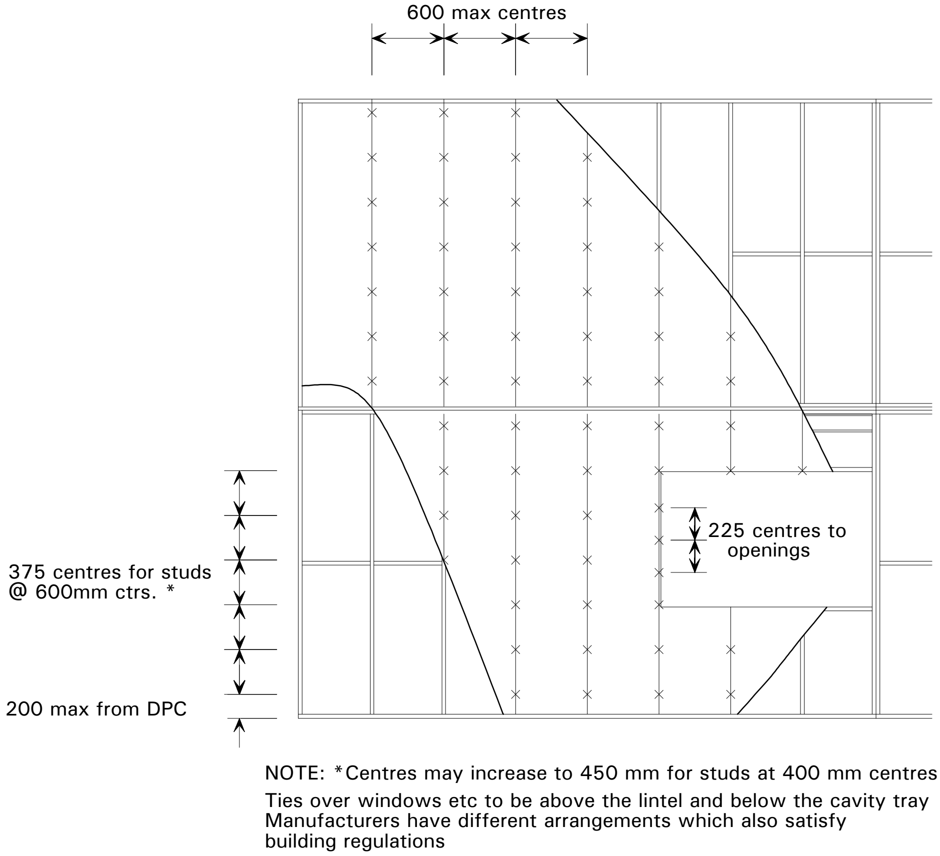


Figure 7.8 *Wall tie spacing and fixing*

7.3.4 Details at windows

The details at windows and doors depend on the precise masonry detail adopted, such as flush or check reveals.

Figure 7.9 shows typical head, cill and jamb details for insulated and uninsulated cavity closers in flush reveals with masonry cladding (where the window is set into the brickwork). Proprietary cavity closures are used around the opening to provide insulation and a barrier to moisture.

Figure 7.10 shows the alternative details for a checked reveal (where the window frame aligns with the cavity).

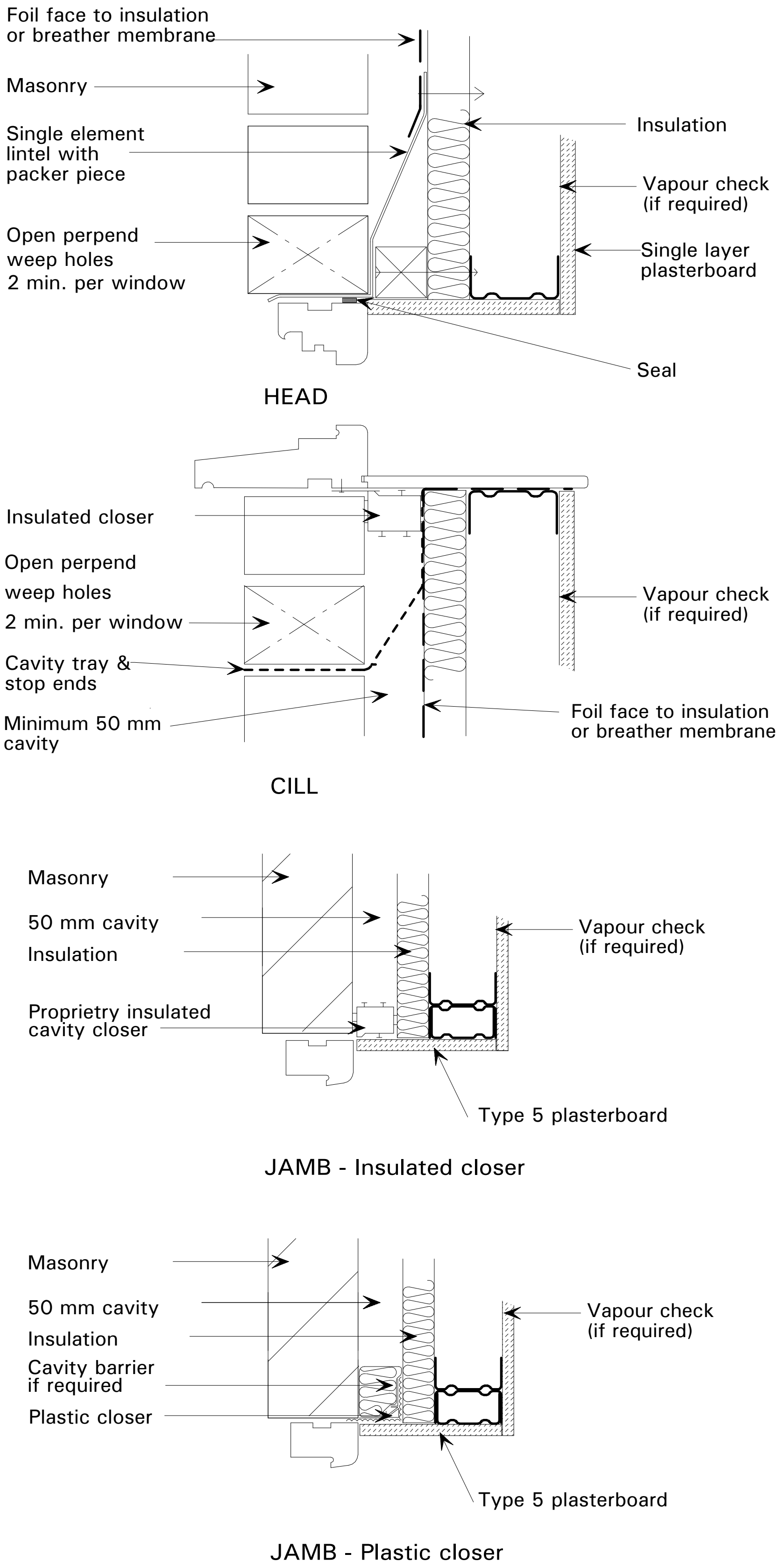


Figure 7.9 *Window details: Flush reveal*

Note: For severe or very severe exposures a cavity tray with stop ends may be required above the lintel.

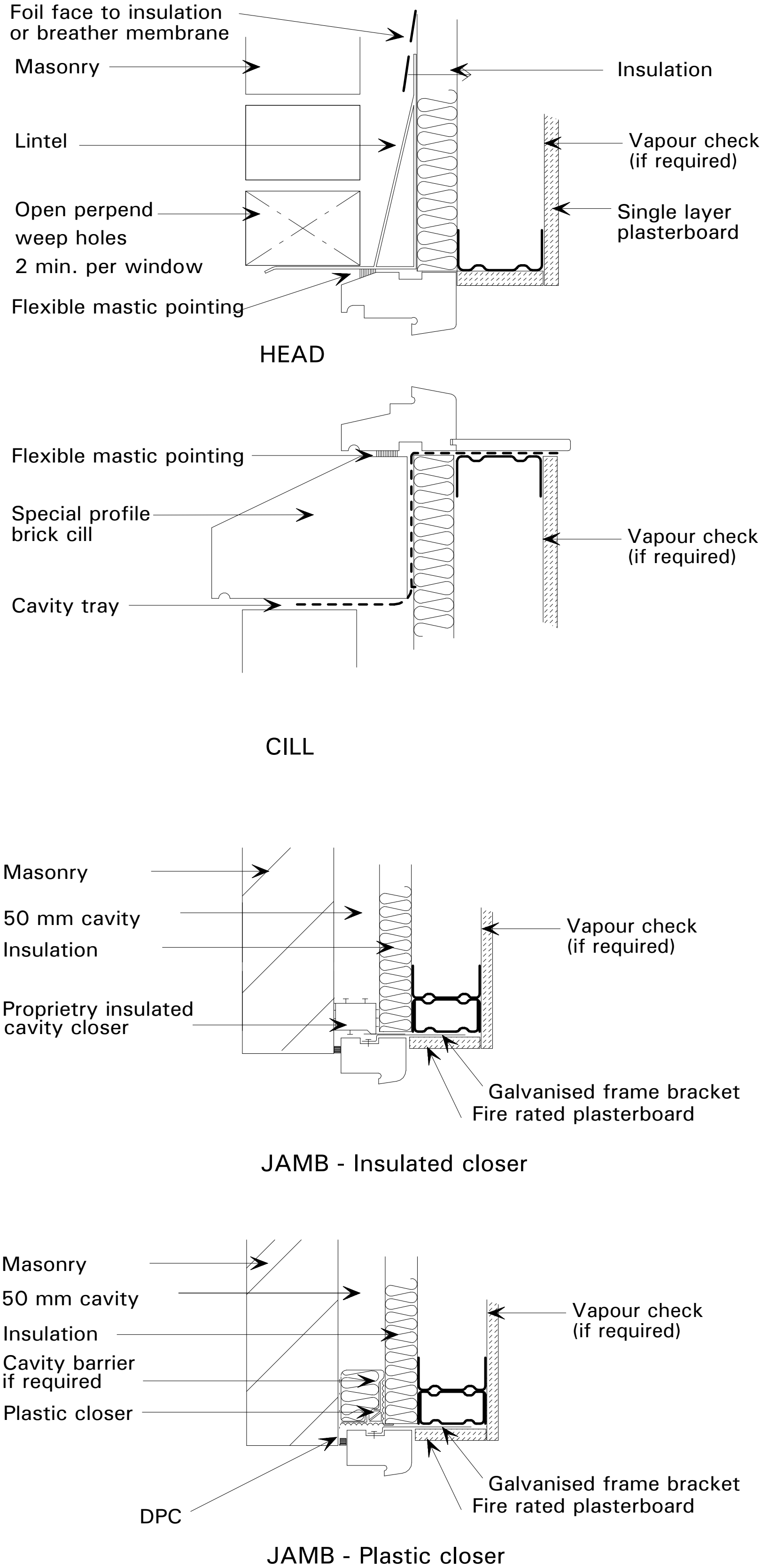


Figure 7.10 *Window details: Checked reveal*

Note: For severe or very severe exposures a cavity tray with stop ends may be required above the lintel.

7.3.5 Other forms of cladding

Vertical tile hanging

Figure 7.11 shows how vertical tile hanging is fixed in the traditional manner using battens and counter battens. The detail at steps and staggers shown in Figure 7.12 is similar to that used in more traditional forms of construction. Head, cill and jamb configurations are shown in detail in Figures 7.13(a), (b) and (c). A sarking layer should be fixed between the battens and counter-battens.

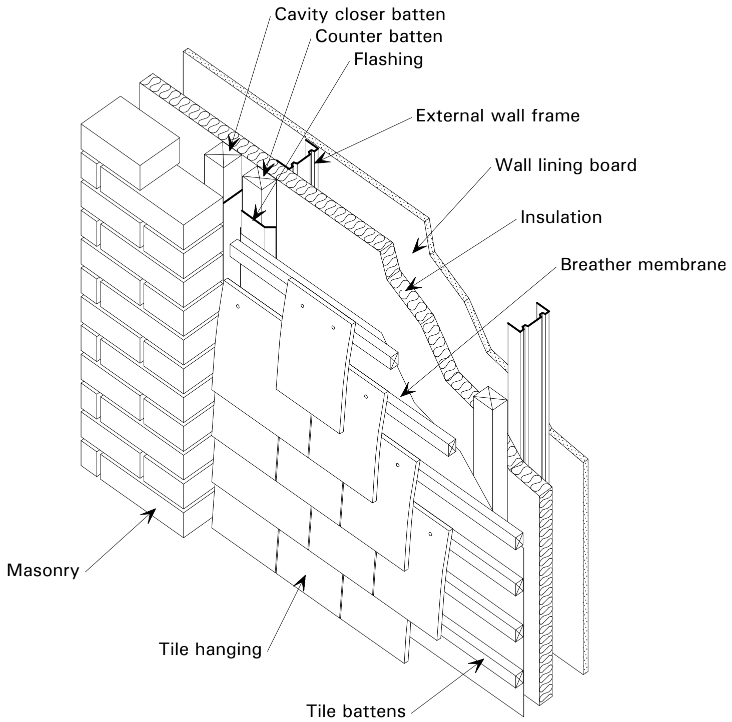


Figure 7.11 *Tile hanging detail*

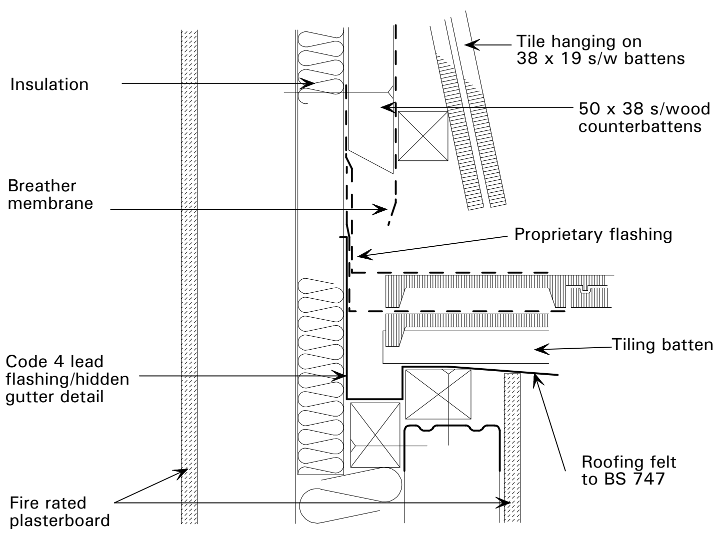


Figure 7.12 *Tile hanging - step and stagger detail*

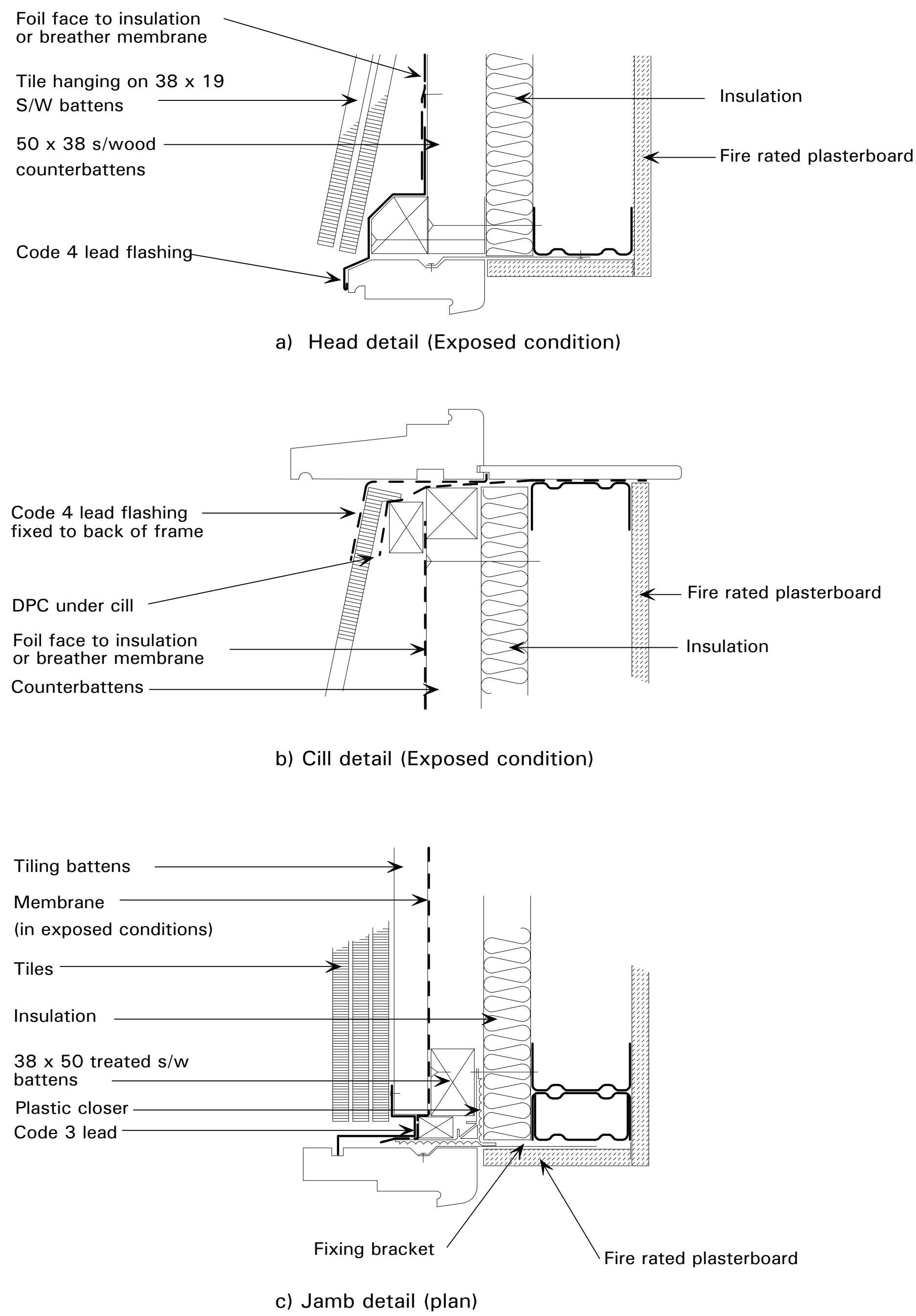


Figure 7.13 *Tile hanging details of windows and doors*

Render on metal lath

Figure 7.14(a) shows how vertical battens are fixed in locations to coincide with vertical studs. A combined metal lath / breather membrane is then attached to the battens and the render coat is applied directly to the lath. The finished face can then be sealed with a proprietary sealant and an external paint finish applied.

Timber boarding

Figures 7.14(b) and (c) and 7.15(a) to (c) show how a traditional boarded finish can be achieved with a light steel frame. The arrangement shows vertical battens attached at the stud positions and the boards are attached to these battens. In exposed situations, a breather membrane is required; this should be located between the vertical battens and the boarding.

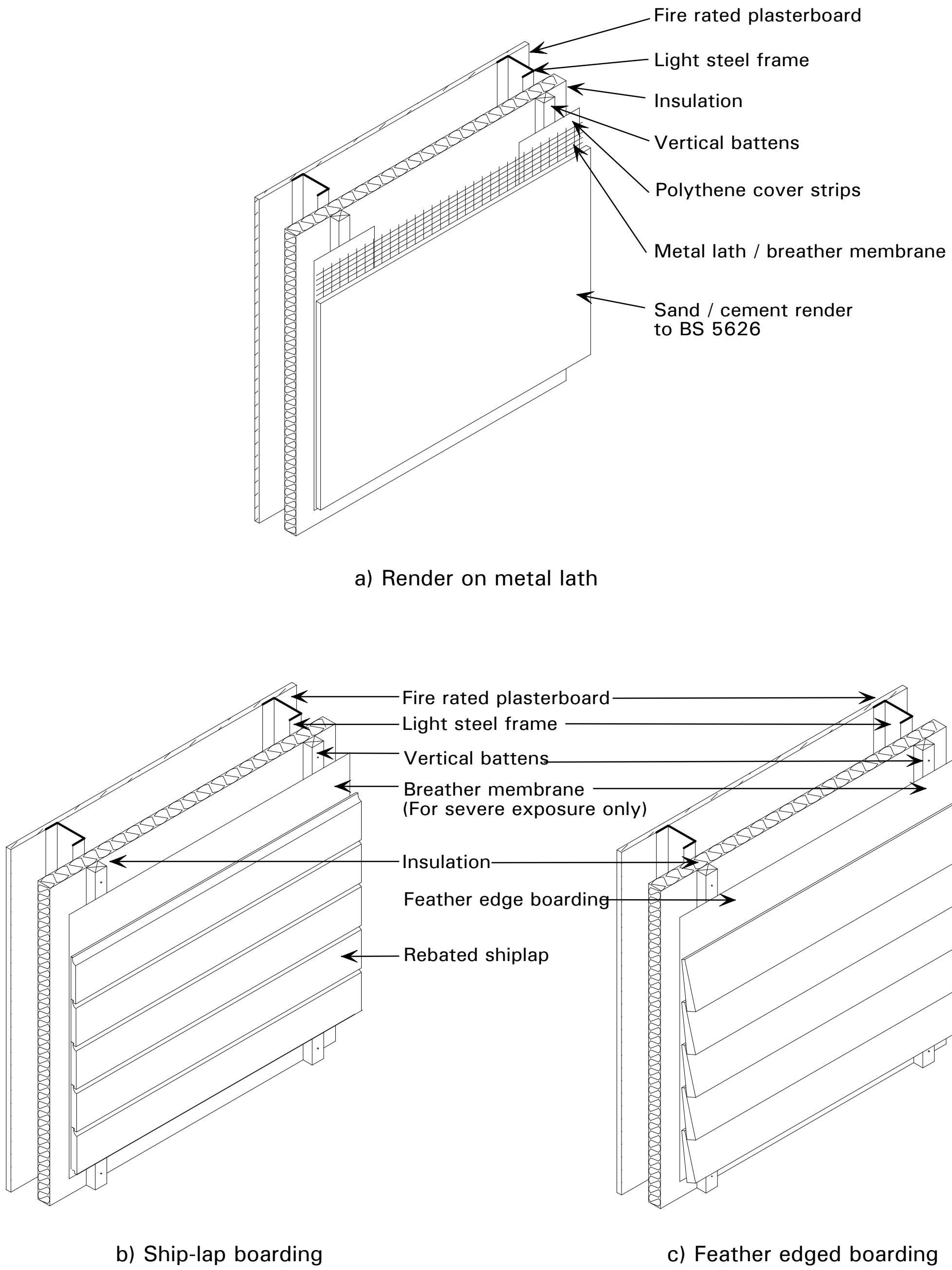


Figure 7.14 *Alternative forms of cladding supported by light steel framing*

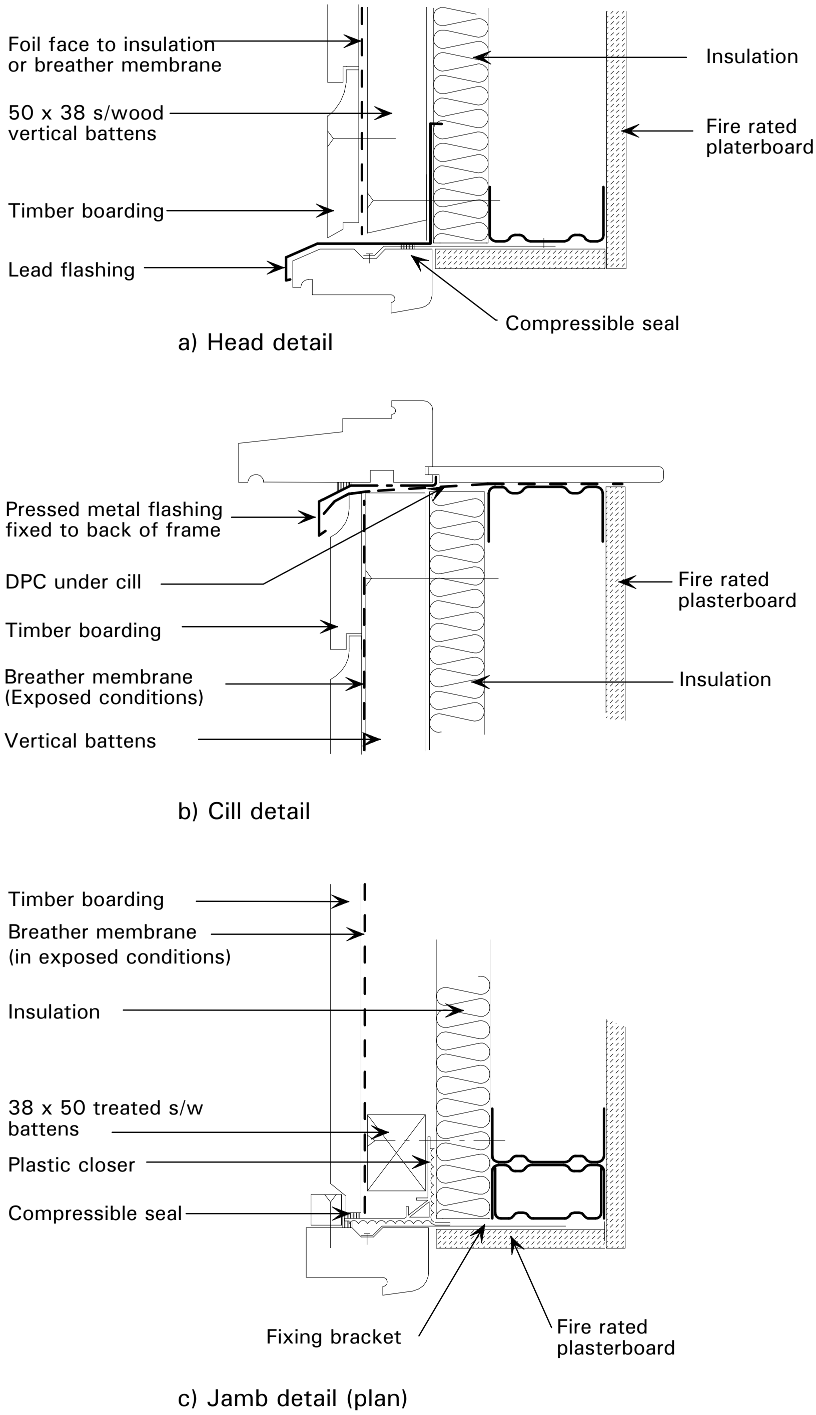


Figure 7.15 *Timber boarding details at windows and doors*

7.4 Internal wall construction

7.4.1 Loadbearing walls

Loadbearing walls can resist lateral loads when they are suitably braced by integral bracing or by flat straps. Loadbearing internal walls are generally clad on each side with one layer of plasterboard or special fire resistant board. Multiple layers of plasterboard may be used to provide impact resistance, or rigidity for tiling, or where good acoustic insulation or high fire resistance is required.

Attention should be paid to local details at the head and base of the wall to ensure that loads can be adequately transferred without local deformation of the joists or studs. In particular, where joists are continuous over such walls, bearing and buckling of the joists should be checked. The connection can be stiffened by inclusion of a short length of stud, or other measures.

7.4.2 Non-loadbearing walls

The construction of non loadbearing walls is similar to that of loadbearing walls except that noggins and diagonal bracing are not required to stabilise the studs. As axial loads only arise from the self weight of the walls, a regular pattern of smaller or thinner studs may be used. Figure 7.16 shows alternative forms of head detail to non-loadbearing walls.

Long-spanning light steel joists reduce the number of load-bearing walls. Consequently, the internal partition walls can be non loadbearing and this will simplify construction.

7.4.3 Junctions between intersecting walls

Figure 7.17 shows junctions of an external wall and a separating wall. Some of the details use purpose-made light steel sections, whilst others use a particular configuration of C section studs. Special corner studs may be required to ensure that plasterboard can be attached to both walls.

7.4.4 Separating and compartment walls (party walls)

Separating walls generally comprise double skin construction with insulation in the cavity between the skins. Separating walls should continue into the roof space. The requirements for acoustic insulation of separating walls satisfy the minimum fire resistance requirements for compartment walls. Therefore, where a separating wall is required also to act as a compartment wall, the acoustic insulation requirements will control.

For separating walls, each skin should have at least two layers of plasterboard on the room side, and a minimum thickness of 30 mm. For example, one layer of 19 mm plasterboard plank, and one of 12.5 mm fire rated plasterboard, will achieve 60 minutes fire resistance, provided that the stud wall is continuous into the roof space. In the roof space, the plasterboard may be reduced to a single 19 mm plank with cover strips, or two 12.5 mm plasterboards. Alternative configurations may be adopted with 15 mm plasterboard replacing the 12.5 mm boards.

Cavity barriers or fire stops should be provided around any penetrations through fire resisting walls, in accordance with Approved Document B.

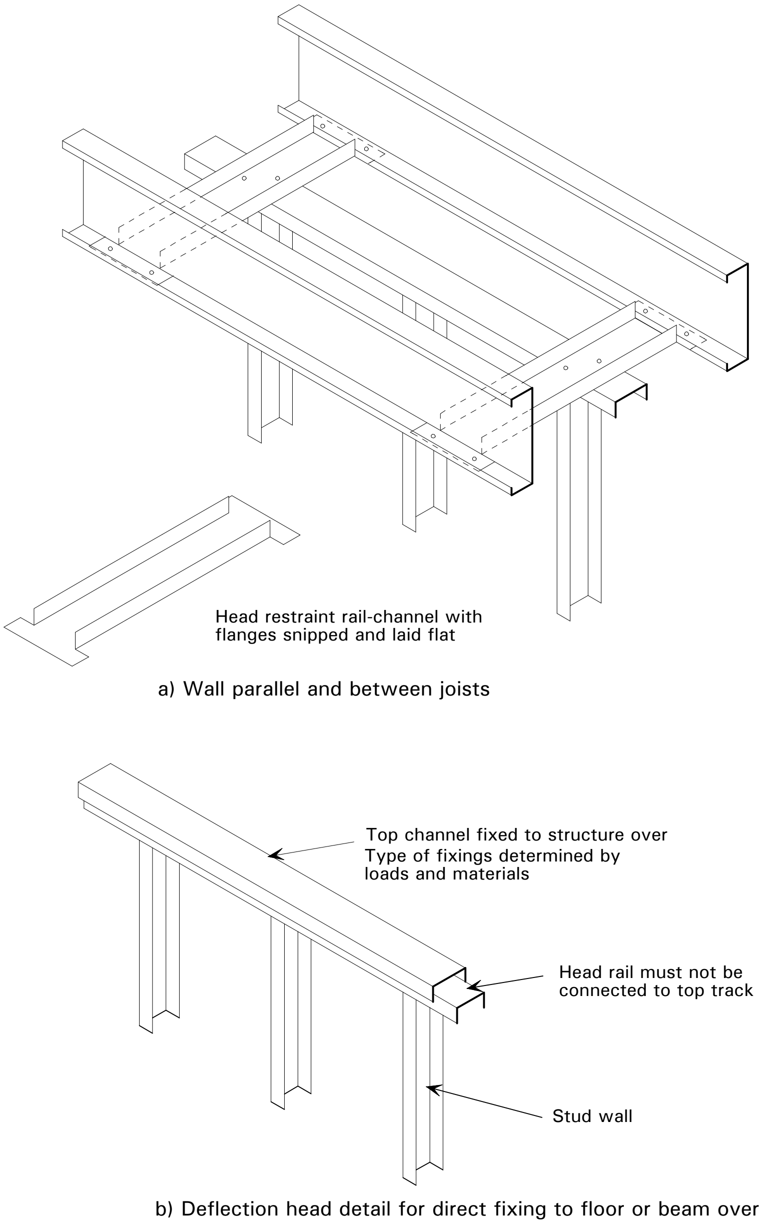


Figure 7.16 *Head restraint to interior non-loadbearing wall*

Junctions (roof, eaves, external walls, internal, steps and staggers)

Cavity barriers consisting, for example, of 50 mm thick wire-reinforced (or polyethylene sleeved) mineral wool should be provided at the junction of a compartment wall with any external wall void which would otherwise be continuous. These barriers are required in a compartment wall or floor, or any element that is required to be fire resisting. Typical locations would be:

- Horizontally at junctions with floors and roof.
- Vertically at a maximum lateral spacing of 20 m.

Figure 7.17 shows a typical detail at the junction of an external wall and a compartment wall. A 9 mm thick non-combustible board may be used as an alternative and should be fastened to one skin only, in order to reduce sound transmission.

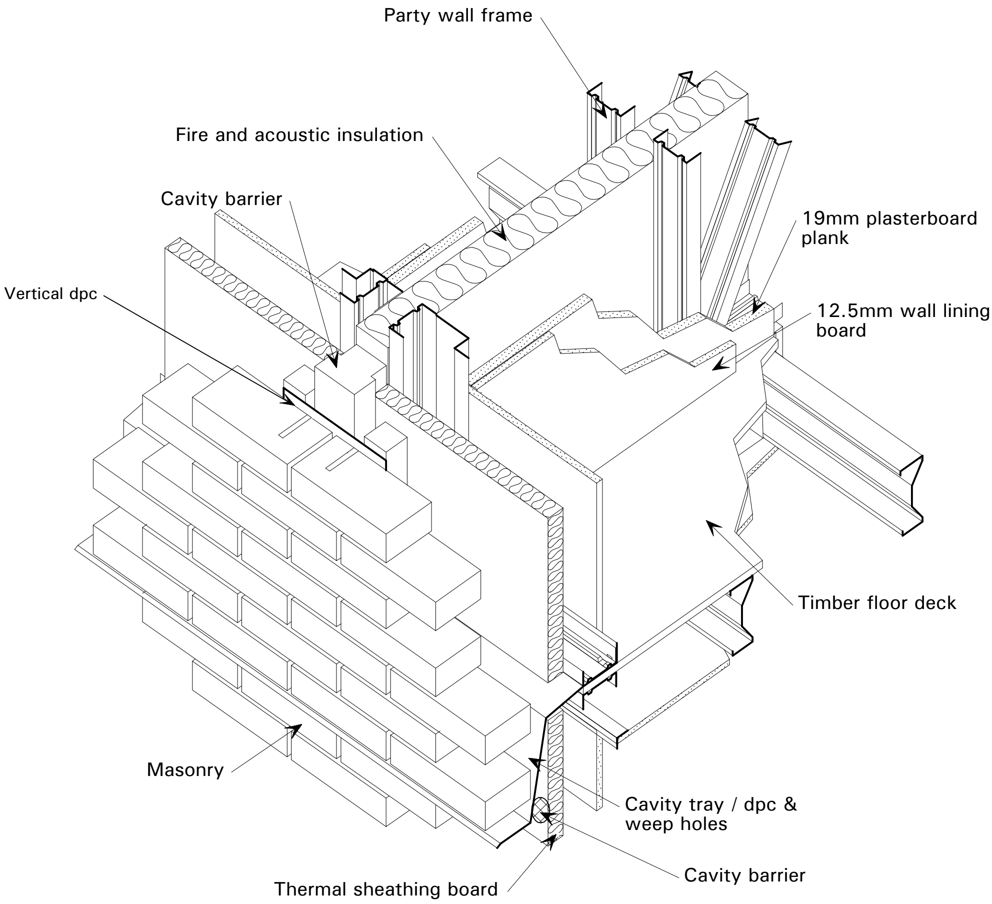


Figure 7.17 *Party wall detail at an external wall*

A section through a typical separating wall is shown in Figure 7.18. On sloping sites, the roof lines may step, which leads to the step/stagger detail shown in Figure 7.19.

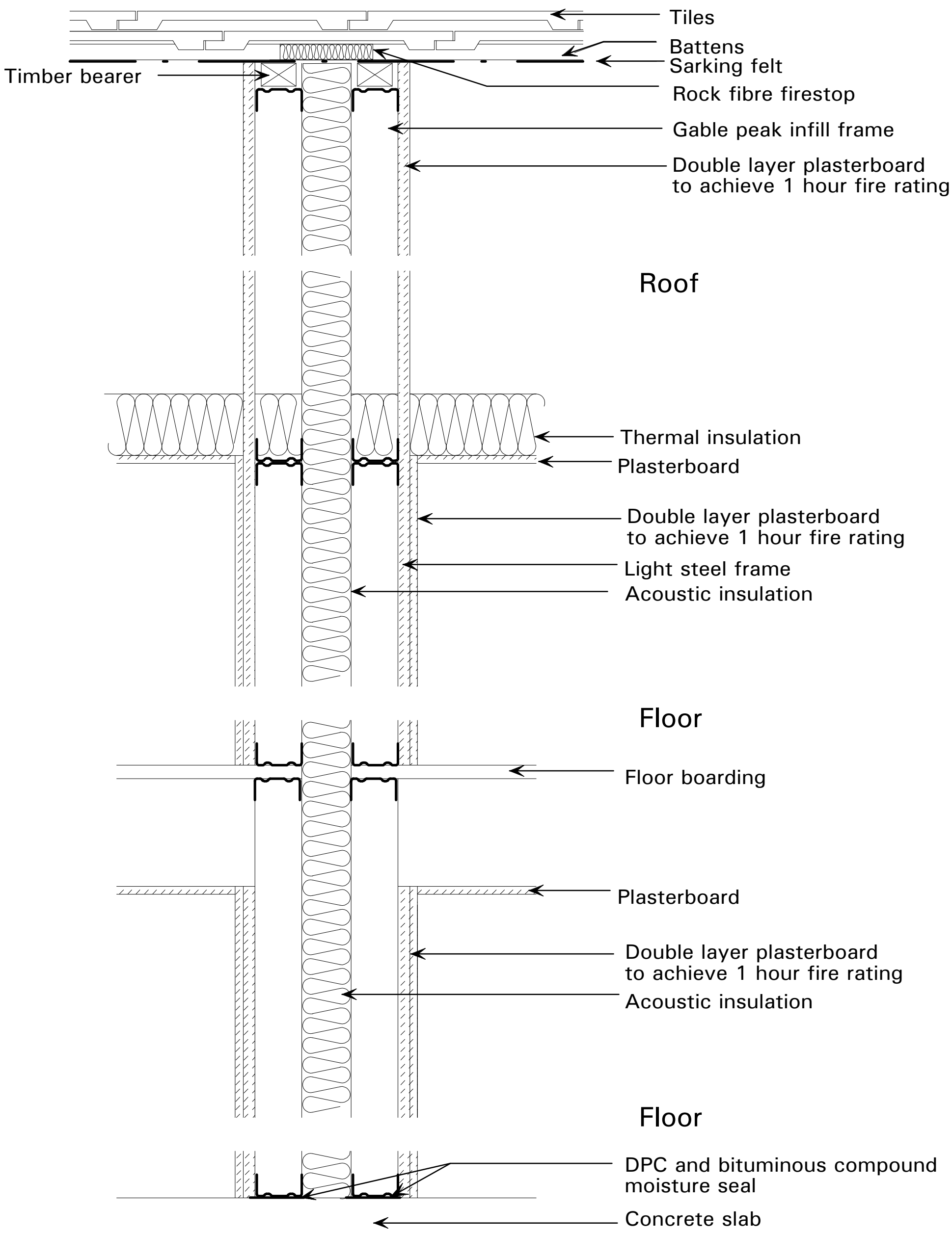


Figure 7.18 *Separating wall detail*

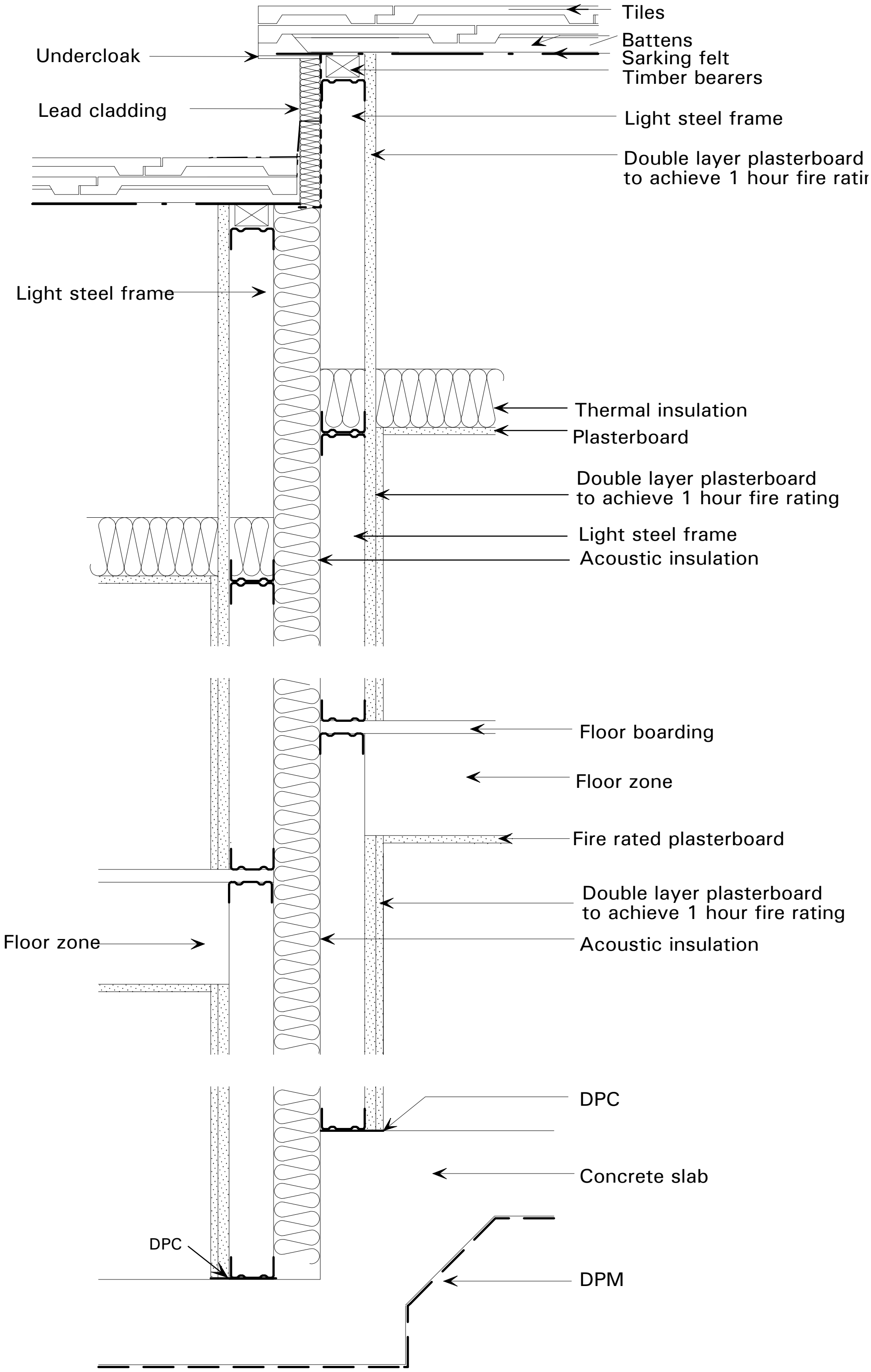


Figure 7.19 *Separating wall - step / stagger generic detail*

Sound insulation

Provided that the details described in this Section are followed, airborne sound reductions will be achieved which comply with the requirements of the Building Regulations. Particular care should be taken to minimise the physical connection between adjacent properties since this will help to reduce noise transfer.

Further guidance may be noted as follows:

- The location of electric sockets and switches should be carefully considered; back-to-back installations should be avoided between dwellings. Approved Document B allows wall linings to be penetrated so that services pass through the void, provided that the fire and acoustic integrity is maintained. Wherever possible, it is recommended that services should be routed away from separating walls. If services and penetrations in separating walls are avoided, then the problem of back-to-back fittings will not arise.
- The joints of successive layers of boarding should not be coincident.
- Acoustic quilt or cavity barriers should be used where appropriate to seal air gaps and to minimise flanking sound transmission, including that from floor to floor.
- There are no restrictions on the proximity of windows for acoustic requirements.
- All air gaps in linings should be avoided or sealed.

There are no requirements in the Building Regulations for sound insulation between rooms in dwellings. However, the NHBC requires that 38 dB sound reduction for airborne sound is provided around bathrooms and WCs, in accordance with BS 8233[35]. For this purpose, mineral wool insulation is often introduced between the studs in walls surrounding bathrooms, or in other areas where improved acoustic insulation is required.

7.5 Fixing wall linings

Plasterboard linings are attached using bugle-headed self-drilling self-tapping screws to minimise the risk of popping of the fixings. In all cases, the vertical edges of the boarding must be supported on studs. The horizontal edges will require secondary supports, unless 15 mm or thicker plasterboards are used on studs at not more than 600 mm centres. Purpose-made components are available for all such junctions. Fixings should be spaced at a maximum of 300 mm.

8 ROOF CONSTRUCTION

The structure of roofs in housing using of light steel framing is generally based on conventional timber *fink* roof trusses that span between front and rear facades. Where required, timber trusses can be used in conjunction with light steel framing.

Light steel roof trusses using C and Z sections can be used as an alternative, particularly where they are designed for long span applications with greater potential for usable roof space. Flat, pitched and mansard roofs may also be designed using standard steel components. Special roof trusses have been developed which provide an 'attic' or open roof structure with modestly size components and minimal self weight. Alternatively, open roofs may be formed by spanning light steel purlins between closely-spaced cross-walls.

Where roof truss/joist centres do not coincide with the light steel studs in the supporting wall frame, a spreader beam of adequate strength must be used to transfer the vertical load from the roof into the wall.

8.1 Loading on roofs

Roof loads are affected by the use of the roof space, the slope of the roof and the roofing materials. The following loads should be considered:

Dead loads: Concrete or clay roof tiles weigh approximately 0.5 kN/m^2. Natural slates can be heavier. The dead loads on plan should also take account of the slope of the roof. Other finishes, such as battens, felt insulation and plasterboard should be included (allow 0.2 kN/m^2).

Imposed load: This load depends on whether the roof space is occupied. A minimum of 0.25 kN/m^2, plus any well defined loads, such as water tanks, is required. For occupied roof space, an imposed load of 1.5 kN/m^2 is used.

Snow load: A basic snow load of 0.6 kN/m^2 is used in England and Wales. This can be reduced for roof slopes greater than 30**E**. BS 6399-3 requires a separate check where snow may build up on the roof. The intensity of snow is a function of location and altitude of the building.

Wind load: In BS 6399-2, wind pressures are based on the mean wind speed which depend on the geographical location and is modified for various effects, including altitude and proximity of other buildings. Negative pressures due to wind uplift are applied normal to the plane of the roof slope.

Loads are combined using the load factors in BS 5950. Serviceability limits are not normally critical, except for habitable uses of roofs.

8.2 Pitched roofs

Pitched roofs may be designed in cold or warm construction, depending on whether the enclosed roof space is to be habitable. Typical ridge, eaves and verge details for warm roofs which utilise truss or purlin-based roof constructions are presented in the following sections.

8.2.1 Roof trusses

An 'attic' or open roof truss, as shown in Figure 8.1, creates useable roof space, uses fewer components than a *Fink* truss and provides an economic solution, since it utilises the high bending strength of the steel members. Additional useable space is provided at a minimal extra cost.

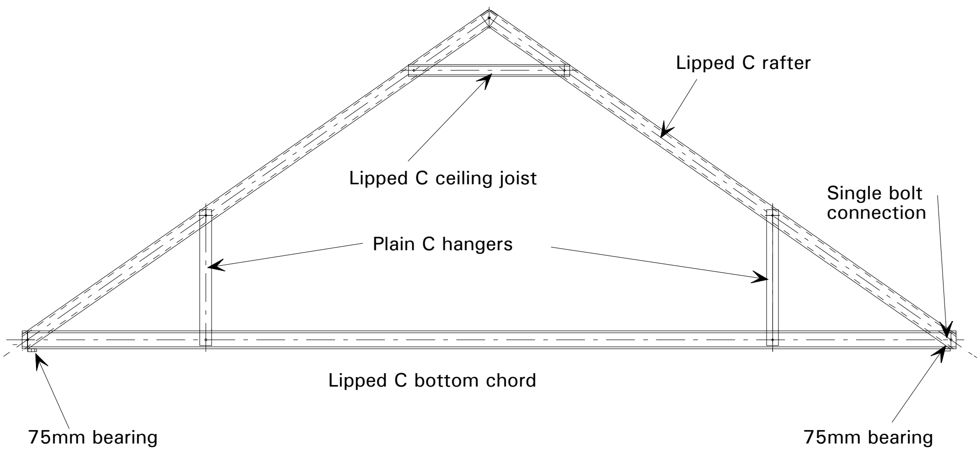


Figure 8.1 *Open roof structure using C sections*

The attic truss consists of six components: 2 rafters, a bottom chord, a ceiling joist and 2 vertical hangers, which are all in the form of lipped C sections with a single bolt at each connection. The bottom chord supports the occupied floor. The trusses are placed at 600 mm maximum spacing and are battened and tiled in a conventional manner, as shown in Figure 6.2. Since the roof space is designed to be habitable, the insulation is located above the light steel rafters; anti-slip battens and counterbattens are incorporated as shown.

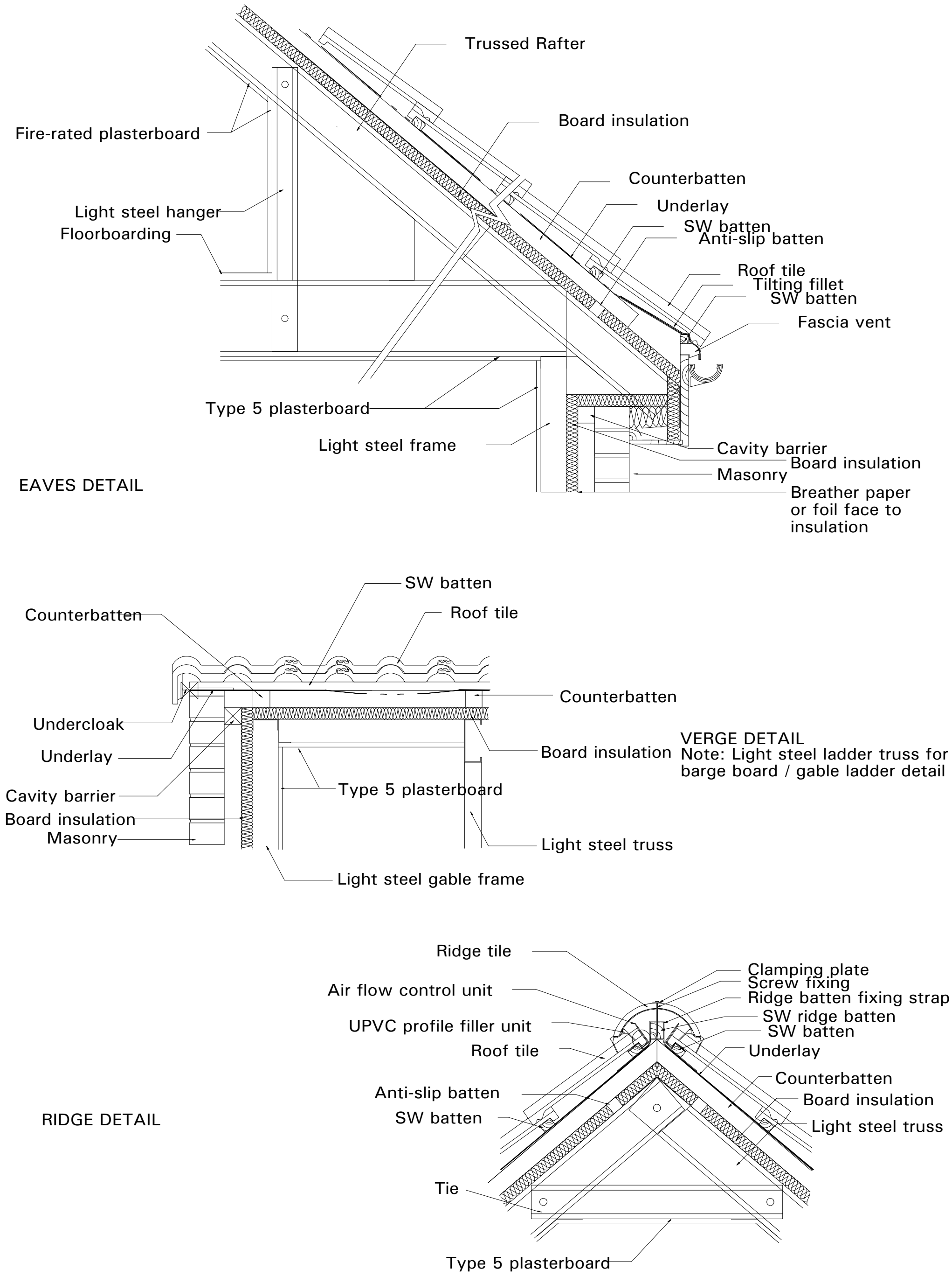


Figure 8.2 *Attic truss – Eaves, verge and ridge details for 'warm roof'*

8.2.2 Mansard roofs

Mansard roofs may be created to increase the useable roof space. A mansard has a steep portion, which generally incorporates 'dormer' windows, and a shallow pitch upper portion over the space. A 'warm roof' is achieved by the details illustrated in Figure 8.3.

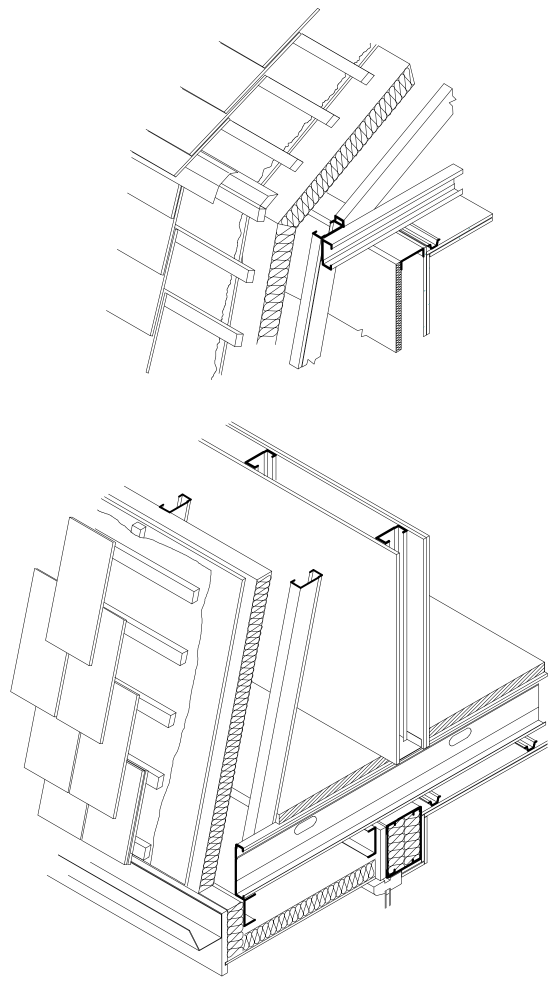


Figure 8.3 *Mansard details*

8.2.3 Purlins supported by trusses

An economic approach for larger buildings is to use light steel 'Fink' trusses placed at much wider centres and to span steel purlins between them. However, roof tiles and plasterboard ceilings should be supported on battens at close centres and to achieve this with purlin-based systems, secondary members such as counterbattens are required (see Figures 8.4 and 8.5). Ceiling and floor boarding can be supported from joists spanning between the trusses.

When widely spaced steel trusses are used, purlins are required to span between trusses in a direction parallel to the tiling battens. Counter-battens, a sarking board (the favoured solution in Scotland), profiled roof sheeting or structural liner trays, will be required to provide direct support to the roof tiles.

8.2.4 Purlins supported on cross-walls

Timber rafters (typically 100 mm × 38 mm at 600 mm centres), or roof sheeting, can be laid over and fixed to the purlins and can support traditional felt and battens. Profiled steel sheeting or structural liner trays may be used to span across the purlins.

The details appropriate to purlin roofs with structural liner trays are shown in Figure 8.4.

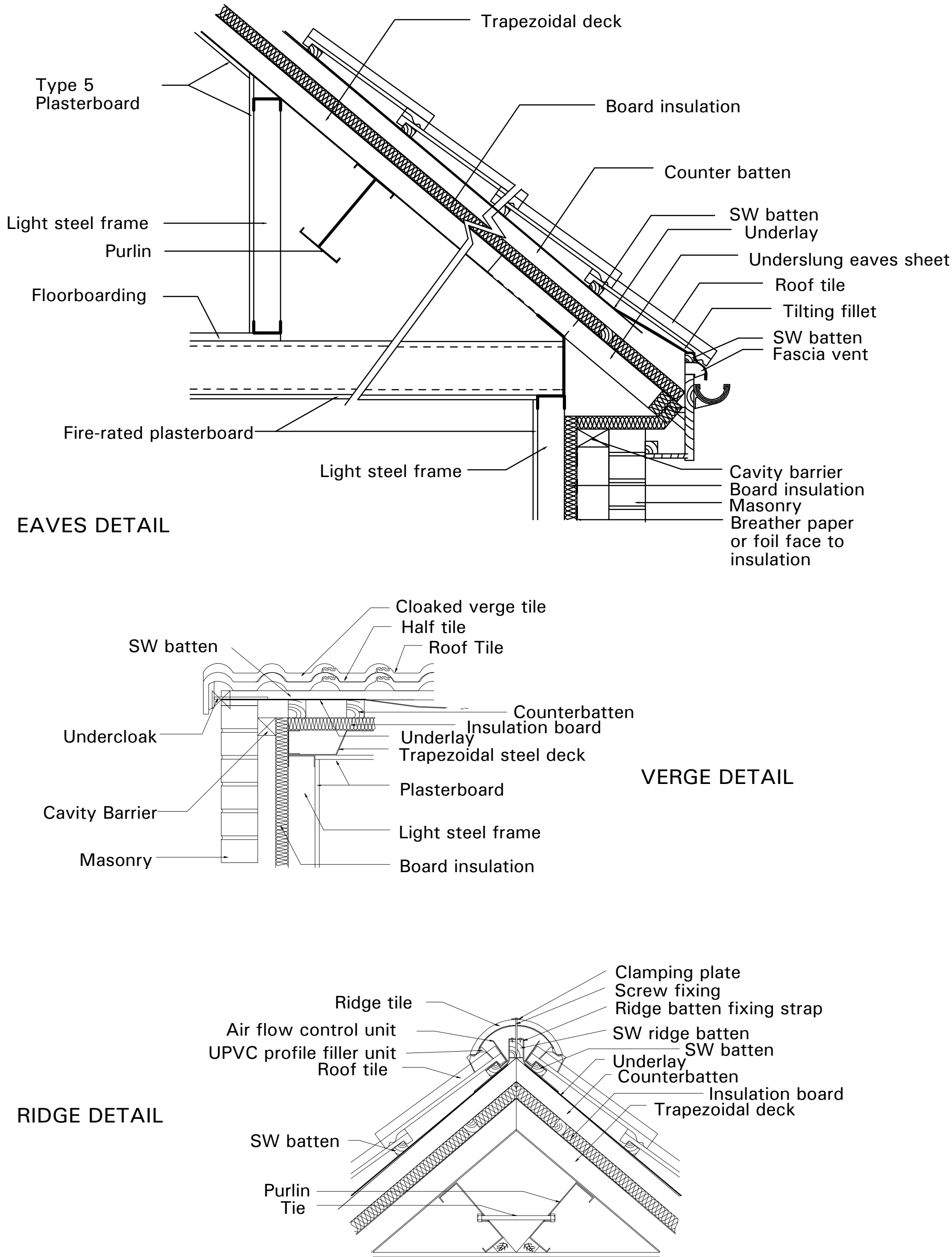


Figure 8.4 *Purlins and structural liner tray – Eaves, verge and ridge details for warm roof*

8.2.5 Panel roofs

In domestic applications, panel roofs use an insulated sandwich board spanning from eaves to ridge or intermediate purlins. The panels are provided with counter battens attached for the support of felt, battens and tiles. The details appropriate to purlin roofs with insulated panels are shown in Figure 8.5.

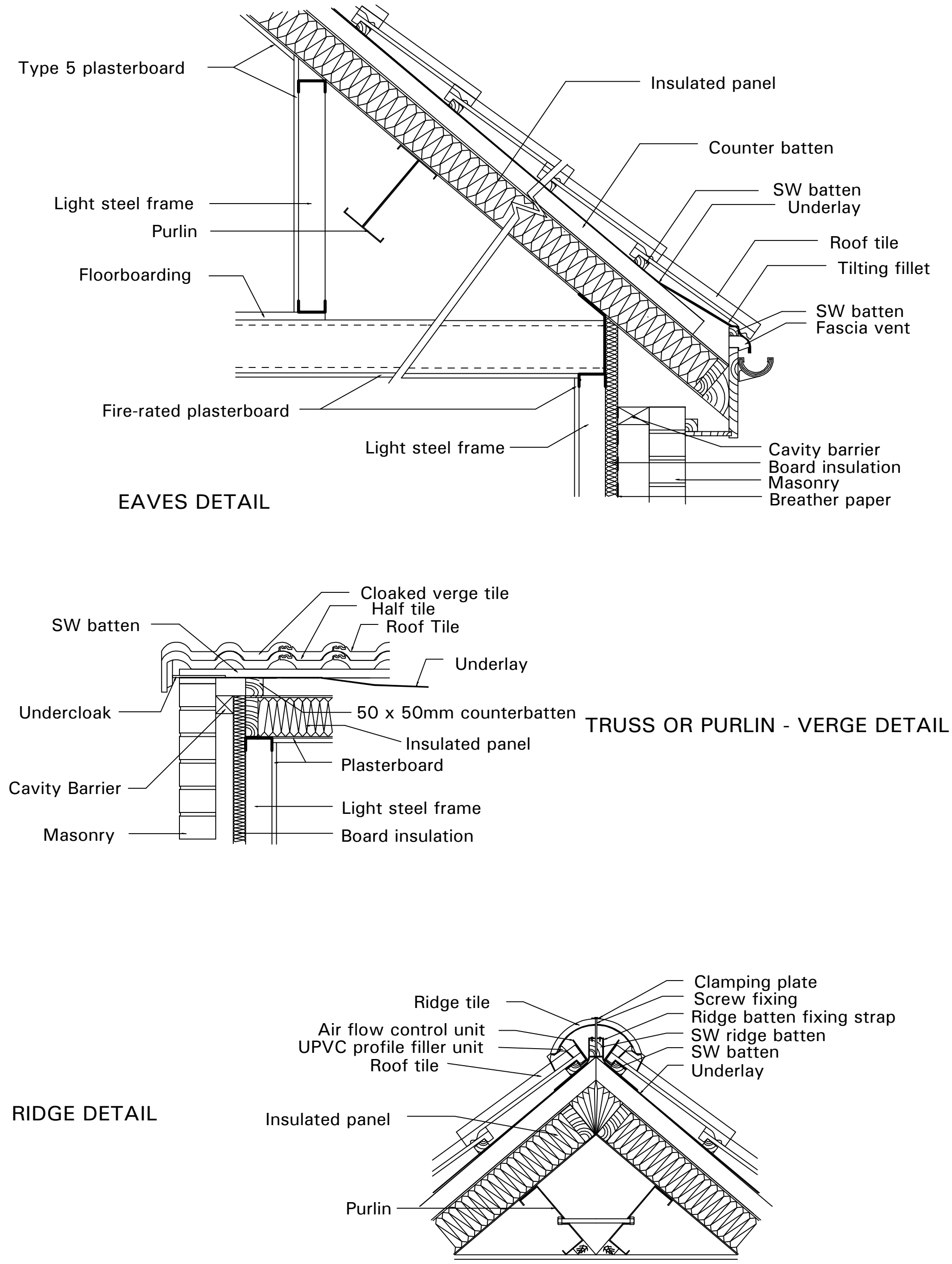


Figure 8.5 *Purlins and insulated panels – eaves, verge and ridge details for warm roof*

8.3 Construction details

8.3.1 Eaves

Several eaves styles can be achieved with light steel sections. If a 'warm roof' is specified, the insulation should completely enclose the light steel sections, as shown in Figures 8.3 to 8.5. An alternative approach is to cut the steel members short at the eaves to minimise the risk of cold bridging. Timber inserts are then used to extend the rafter members and to attach the barge boards, soffits and guttering.

For 'cold roofs', it may be necessary to introduce a timber wall plate to isolate the light steel trusses thermally from the stud walls.

8.4 Flat roofs

Flat roofs constructed from light steel components do not suffer from the shrinkage and creep problems associated with timber roofs. However, there are certain principles to be followed to ensure that other problems do not occur. For example, where steel decking forms a flat roof, a minimum fall of 1:40 should be introduced to ensure that any moisture runs off. To avoid local ponding of rain water, the pitch may need to be increased to overcome the effective reduction in roof angle caused by the deflection of long span roof purlins or decking.

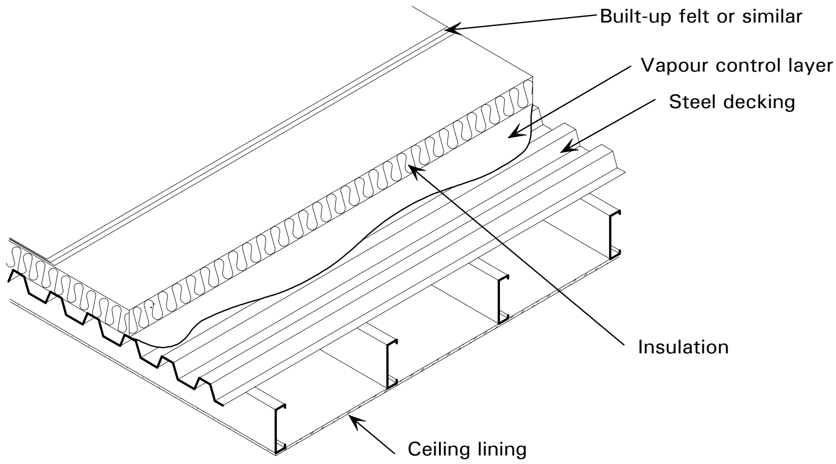
8.4.1 'Warm deck'

In 'warm deck' construction, the insulation is laid above the decking and a vapour control layer is placed between it and the decking (see Figure 8.6). The roof structure is therefore kept warm and, provided that the heating is reasonably constant, this eliminates the risk of condensation in the roof void. Air flow would cool the void and, therefore, this form of construction must not be ventilated.

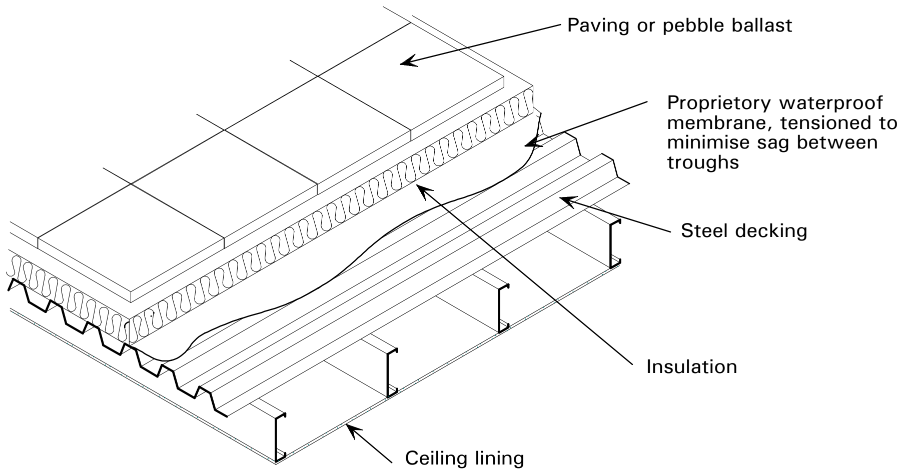
8.4.2 'Cold deck'

In this form of construction, the insulation is placed immediately above the ceiling. In cold weather, the temperature of the deck and the roof void is lower than that of the internal spaces, making it susceptible to condensation from moist air penetrating the void. A vapour control layer should therefore be included beneath the insulation, and good ventilation to the roof void should be provided (see Section 1.2.4).

Good air flow requires at least 50 mm of clear space between the top of the insulation and the roof deck and the equivalent of a continuous 25 mm opening along both sides of the roof. Cold roof designs require careful detailing; light steel components should be used with caution in these applications.



a) Warm deck sandwich design



b) Inverted roof

Figure 8.6 *'Warm deck' construction in roofs*

9 SERVICES

In light steel framing used in housing, it is standard practice to provide holes at regular centres through the webs of light steel joists and studs for the incorporation of service cables and pipes. Floor boarding can be installed in advance of the services and provides a safe working platform at an early stage. Services are installed from below and the risk of cutting notches out of the section is eliminated. This is different from traditional construction where the service installation in the floor is usually carried out from above and is complete before the floor boarding is laid.

9.1 Details for service openings in floors

Figures 9.1 and 9.2 show typical details of floor joists for service openings. These generally allow small diameter pipes and electrical cables to be threaded through the structure, although the lattice joist can accommodate much larger services. Rubber or polyethylene grommets that line the inner face of the openings are used to prevent damage to cables and eliminate contact between the steel and other metals which could cause bimetallic action, leading to possible corrosion.

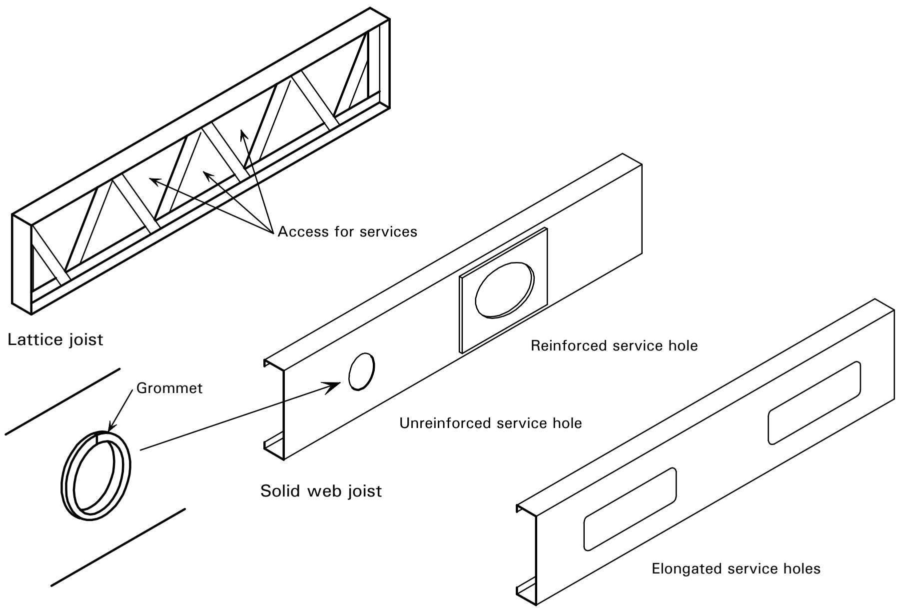


Figure 9.1 *Service penetrations in joists*

As an approximate guide, the maximum depth of unstiffened rectangular hole or slot in a light steel framing member, should not exceed 40% of the overall depth of the member. Its length should be less than three times the depth of the hole. The diameter of circular holes should not exceed 60% of the depth of the member. Unstiffened holes should be at least the depth of the member apart and should be at least 1.5 times the depth away from the end of the member. In these cases, the holes have negligible influence on the structural properties of the member. Larger openings in the steel joists and studs may require some reinforcing by the addition of an additional steel plate.

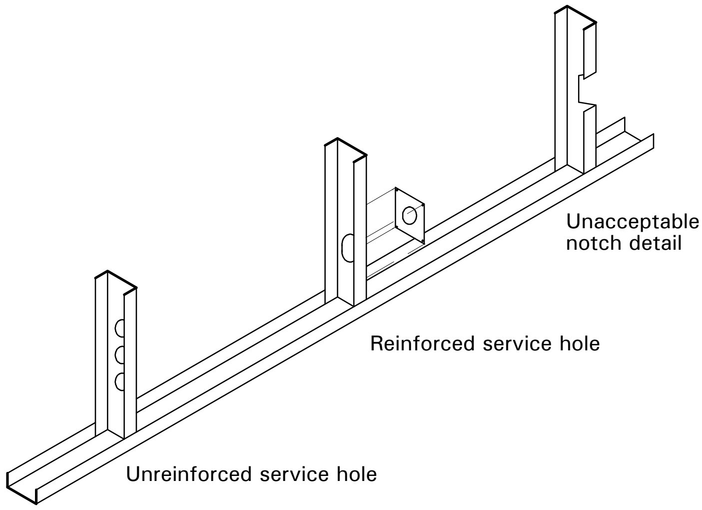


Figure 9.2 *Service penetrations in studs*

Cutting holes in the light steel webs on site is not recommended but, where necessary, the holes should be formed with specialist tools to minimise the risk of leaving rough edges and causing damage to the galvanized surface. The steel sections should never be cut by burning. Proprietary grommets and sleeves can be modified to fit non-standard penetrations.

Larger pipes are usually located in the spaces between or below the joists. Where latticed floor joists are used, the installation should be planned to allow the alignment of the diagonal lacings and thus service pipes, ducts and cables can be easily accommodated.

The electrical services design should bear in mind that electrical cables that are surrounded by thermal insulation have an increased risk of overheating and the cable rating should be selected to compensate. Generally, electrical services should be installed in accordance with BS 7671 [36].

9.2 Separating and compartment walls and floors

It is advisable not to place plumbing services within separating or compartment walls, as any future access may damage the integrity of the walls and penetrations through the linings may affect their performance.

When vertical service ducts such as drainage pipes have to pass through compartment floors it will be necessary to take additional precautions to avoid compromising the fire and acoustic integrity of the compartment. Figure 9.3 illustrates how this should be accommodated. It is important to ensure that an effective fire barrier is maintained and that there is clearance between the service ducts and the steel structure, with effective flexible fire stopping around the services.

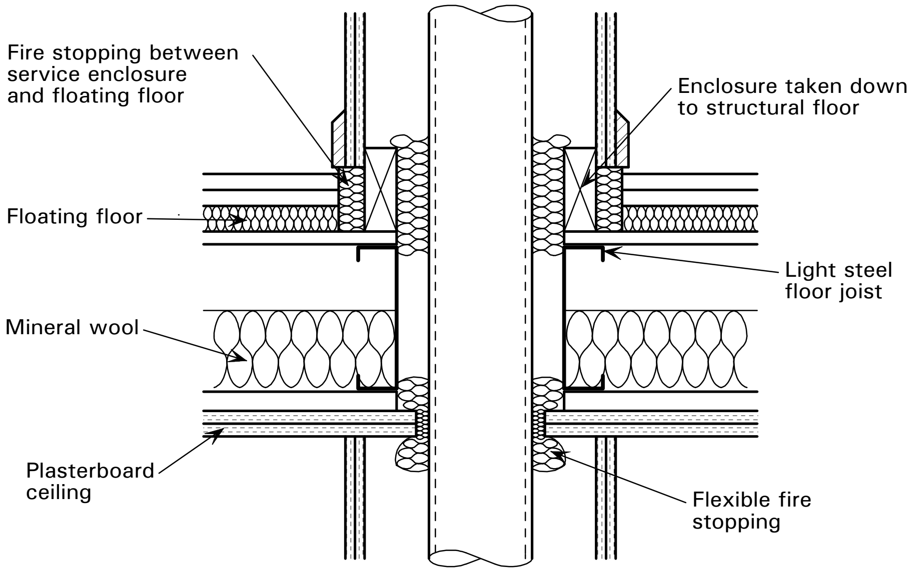


Figure 9.3 *Detail of the trimming of vertical risers in separating / compartment floors.*

Any electrical fittings in separating walls should be protected at their rear with two layers of plasterboard and a mineral wool quilt, as illustrated in Figure 9.4.

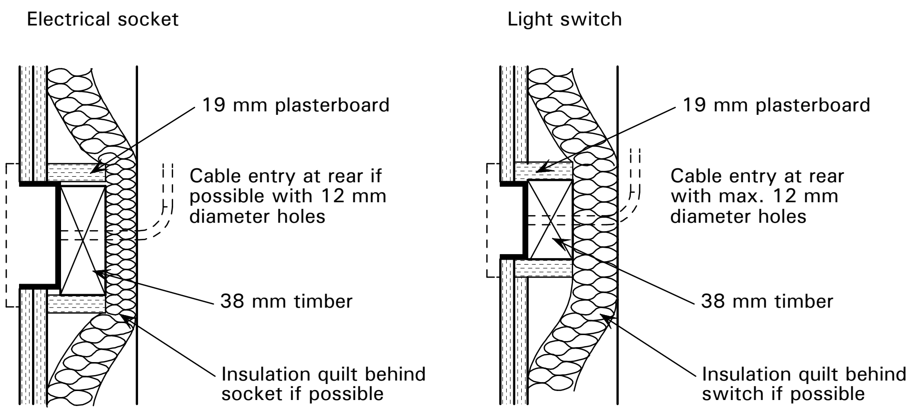


Figure 9.4 *Detail of a typical electrical fitting*

In multi-occupancy accommodation with separating floor constructions, access to services through the floor is not practical. Figures 9.5 and 9.6 show how services can be incorporated in a separating floor. The services are effectively installed in a duct above the structural floor within the acoustic insulation zone. Care must be taken not to compromise the acoustic insulation performance. Thus, it is important for the pipes to touch neither the floor finish nor the duct walls and base. The duct should be filled with resilient material, with some resilient material also being maintained beneath the duct. Sealant should be used to prevent air paths being formed. Any electric installation penetrating the plasterboard ceiling below should be detailed to prevent direct air paths through the plasterboard by sealing around any penetrations with flexible acoustic sealant.

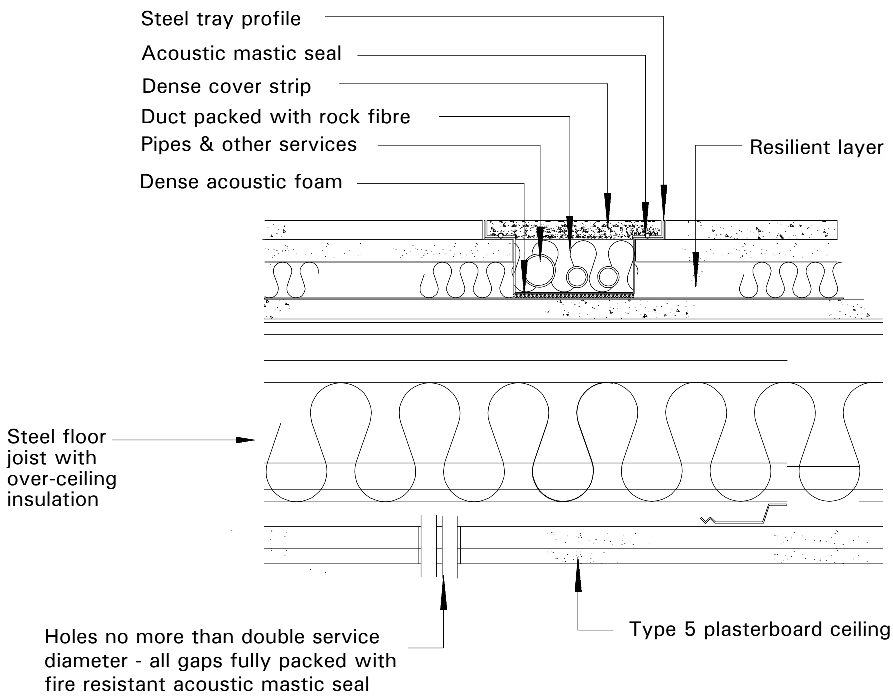


Figure 9.5 *Detail of a service duct within the resilient layer of a separating floor*

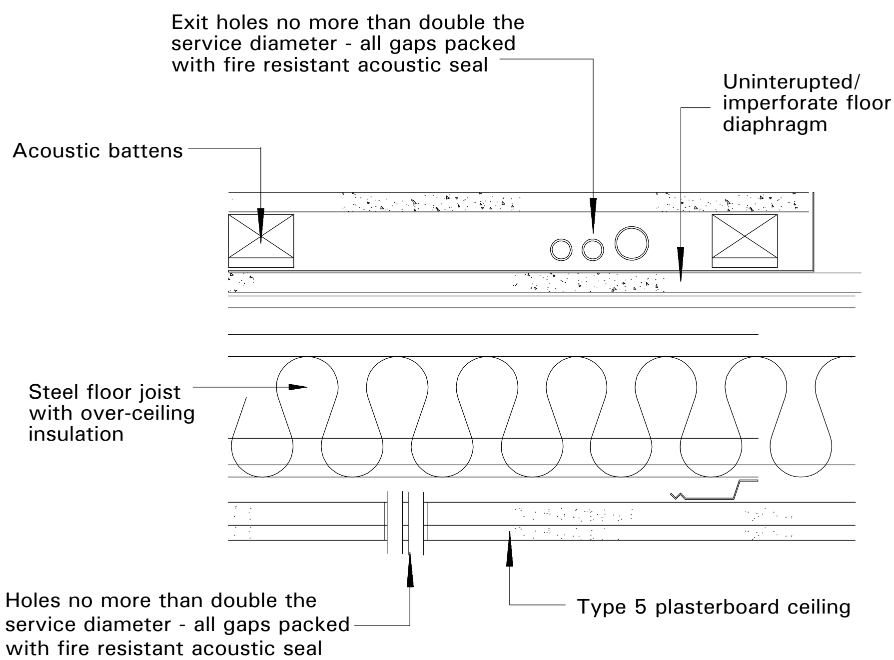


Figure 9.6 *Detail of services integrated into a separating floor using acoustic battens to support the floor boarding.*

Compartment floors and walls are required to minimise the risk of the spread of fire and can only be penetrated by services if the fire integrity can be maintained.

9.3 Installation of gas appliances

Domestic gas installations should be in accordance with BS 6400[37]. The Institute of Gas Engineers publishes guidance on the installation of gas services to framed residential buildings. Generally, domestic gas installations can follow a conventional pattern. Gas entry must be detailed to avoid leakage into an unventilated void to minimise the risk of explosion.

Wall hung boilers can be used with balanced flues. Balanced flues or other ducts to central heating boilers and air-conditioning units and overflow pipes, may penetrate the external wall. The location of these horizontal penetrations should be planned to miss any structural diagonal bracing. Additional holes or slots must not be cut through any steel member without the prior approval of the structural engineer responsible for the overall design of the structure.

Furthermore, in multi-storey construction, where the external masonry finish has independent vertical support from the ground, adequate provision must be made for differential movement between the external masonry skin and any penetrations through it, such as balanced flues, that are rigidly fixed to the internal structure. This movement is due to the vertical expansion of the masonry that is in the opposite direction to the elastic shortening of the light steel walls. An oversized hole in the external finishes should be provided and sealed with a material, generally mastic, which will tolerate movement to prevent the ingress of water.

9.4 Attachment to walls

When heavy items, such as wall hung boilers or kitchen units are to be attached, additional light steel plates or noggins can be included to strengthen the stud walls. Furthermore, self-drilling self-tapping screws can be used to fix directly into the steel studs and joists. Lightly loaded fixings can be made to plasterboard walls with proprietary fixing devices, many of which are readily available. As an alternative, gypsum fibreboard can be used for wall linings, as this enables higher loads to be supported by fixings directly to the wall lining.

10 REFERENCES

1. GORGOLEWSKI, M.T., GRUBB, P.J. and LAWSON, R.M.
Modular construction using light steel framing: Design of residential buildings (SCI-P302)
The Steel Construction Institute, 2001

2. BRITISH STANDARDS INSTITUTION
BS EN 10147: 1992: Specification for continuously hot-dip coated structural steel sheet and strip.

3. Building Regulations 1991
Statutory Instrument 1991 No 2768
The Stationery Office

4. Building Regulations
Approved Documents (Parts A to N)
The Stationery Office (see page 7 for full list)

5. BRITISH STANDARDS INSTITUTION
BS 6399 Loading for Buildings
BS 6399-1:1996: Code of practice for dead and imposed loads
BS 6399-2:1997: Code of practice for wind loads
BS 6399-2:1998: Code of practice for imposed roof loads

6. BRITISH STANDARDS INSTITUTION
BS 5950-5:1998: Structural use of steelwork in buildings
Code of practice for design of cold formed thin gauge sections

7. BRITISH STANDARDS INSTITUTION
ENV 1993:Eurocode 3: Design of steel structures
DD ENV 1993-1-3: 1999 General rules. Supplementary rules for cold formed thin gauge members and sheeting (includes UK NAD)

8. BRITISH STANDARDS INSTITUTION
ENV 1995: Eurocode 5: Design of timber structures
DD ENV 1995-1-1: 1995 Part 1.1 General rules for buildings

9. BRITISH STANDARDS INSTITUTION
BS 5950: Structural use of steelwork in buildings
BS 5950-1: 2000 Code of practice for design in simple and continuous construction: hot-rolled sections

10. BRITISH STANDARDS INSTITUTION
ENV 1991:Eurocode 1: Basis of design and actions on structures
DD ENV 1991-2-7: 1991: Actions on structures - Accidental actions due to impact and explosions.

11. LAWSON, R. M.
Building design using cold formed steel sections:
Fire protection (SCI-P129)
The Steel Construction Institute, 1993

12. BRITISH STANDARDS INSTITUTION
BS 476: Fire tests on building materials and structures,
BS 476:1997: Method of test to determine the classification of the surface spread of flame of products.

13. BRITISH STANDARDS INSTITUTION
BS EN 20140: Acoustics. Measurement of sound insulation in buildings and of building elements.
BS EN 20140-9: Laboratory measurement of room to room airborne sound insulation of a suspended ceiling with a plenum above it.

14. BRITISH STANDARDS INSTITUTION
BS EN ISO 717: Acoustics. Rating of sound insulation in buildings and of building elements.
BS EN ISO 717-1:1997: Airborne sound insulation
BS EN ISO 717-2:1997: Impact sound insulation

15. CLOUGH, R. H. and OGDEN, R.G.
Building design using cold formed steel sections:
Acoustic insulation (SCI-P128)
The Steel Construction Institute, 1993

16. BUILDING RESEARCH ESTABLISHMENT
The Government's Standard Assessment Procedure for Energy Rating of Dwellings
Published by BRE on behalf of the Department of the Environment, Transport and the Regions, 1998

17. NATIONAL HOME ENERGY RATING (NHER)
NHER Introduction
National Energy Services

18. BUILDING RESEARCH ESTABLISHMENT
Radon guidance on protective measures for new dwellings,
BRE Report BR211, 1991.

19. POPO-OLA, S. O., BIDDLE, A. R. and LAWSON, R. M.
Durability of light steel framing in housing (SCI-P262)
The Steel Construction Institute, 2000

20. GRUBB, P. J. and LAWSON, R. M.
Construction detailing and practice (SCI-P165)
The Steel Construction Institute, 1997

21. BIDDLE, A.R.
Mini-piling and composite ground floors and for housing (SCI-P299)
The Steel Construction Institute, 2001

22. BRITISH STANDARDS INSTITUTION
BS EN 10088:1995:Stainless Steels

23. BRITISH STANDARDS INSTITUTION
BS EN 312: Particleboards. Specifications
BS EN 312-1:1997: General requirements for all board types

24. BRITISH STANDARDS INSTITUTION
BS EN 1072:1995: Plywood. Description of bending properties for structural plywood

25. BRITISH STANDARDS INSTITUTION
BS EN 634-1: Cement Bonded Particle Boards
Specification - General Requirements

26. BRITISH STANDARDS INSTITUTION
BS 5268: Structural use of timber
BS 5268-2:1996: Code of practice for permissible stress design, materials and workmanship

27. BRITISH STANDARDS INSTITUTION
BS 8000: Workmanship on building sites
BS 8000-5:1990: Code of practice for carpentry, joinery and general fixings

28. BRITISH STANDARDS INSTITUTION
BS 8201:1987: Code of practice for flooring of timber, timber products and wood based panel products

29. BRITISH STANDARDS INSTITUTION
BS 4071:1996: Specification for polyvinyl acetate (PVA) emulsion adhesives for wood

30. KRAUS, C.A. and MURRAY, T.M.
Floor vibration criterion for cold-formed C-shaped supported residential floor systems
CE/VPI-ST 97/04
Virginia Polytechnic Institute and State University, February 1997

31. BRITISH STANDARDS INSTITUTION
DD 140: Wall ties
DD 140:Part1:1986: Methods of test for mortar joint and timber frame connections
DD 140: Part2:1987: Recommendation for the design of wall ties

32. BRITISH STANDARDS INSTITUTION
BS 1243:1978: Specification for metal ties for cavity wall construction

33. BRITISH STANDARDS INSTITUTION
BS 5628: Code of practice for use of masonry
BS 5628-1:1992: Structural use of unreinforced masonry
BS 5628-2:2000: Structural use of reinforced and prestressed masonry
BS 5628-3:1985: Materials and components, design and workmanship

34. BRITISH STANDARDS INSTITUTION
BS 8200:1985: Code of practice for design of non-loadbearing vertical enclosures of buildings

35. BRITISH STANDARDS INSTITUTION
BS 8233:1987: Code of practice for sound insulation and noise reduction in buildings.

36. BRITISH STANDARDS INSTITUTION
BS 7671: 1992: Requirements for electrical installations. IEE Wiring Regulations. Sixteenth edition.

37. BRITISH STANDARDS INSTITUTION
BS 6400: 1997: Specification for installation of domestic sized gas meters (second and third family gases)

11 OTHER PUBLICATIONS IN THIS SERIES

LAWSON R. M., GRUBB, P. J., PREWER, J. and TREBILCOCK, P.
Building Design using modular construction: An architect's guide (P272)
The Steel Construction Institute, 1999

ROGAN, A. L. and LAWSON, R. M.
Value and benefit assessment of light steel framing in housing (P260)
The Steel Construction Institute, 1998

LAWSON, R. M., PEDRESCHI, R., POPO-OLA, S. and FALKENFLETH, I.
Over-cladding of existing buildings using light steel (P247)
The Steel Construction Institute, 1998

HILLIER, M., LAWSON R. M. and GORGOLEWSKI, M.
Over-roofing of existing buildings using light steel (P246)
The Steel Construction Institute, 1998.

GRUBB, P. J. and LAWSON, R. M.
Building design using cold formed steel sections:
Construction detailing and practice (P165)
The Steel Construction Institute, 1997

TREBILCOCK, P. J.
Building design using cold formed steel sections:
An architect's guide (P130)
The Steel Construction Institute, 1994

LAWSON, R. M.
Building design using cold formed steel sections:
Fire protection (P129)
The Steel Construction Institute, 1993

CLOUGH, R. H. and OGDEN, R. G.
Building design using cold formed steel sections:
Acoustic insulation (P128)
The Steel Construction Institute, 1993

CHUNG, K. F.
Building design using cold formed steel sections:
Worked examples (P125)
The Steel Construction Institute, 1993

BIDDLE, A.R.
Minipiles and composite ground floors for housing (P299)
The Steel Construction Institute, 2001, *to be published*