American plywood in roof construction: a design guide

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a design guide

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BR 369
ISBN 1 86081 291 0

First published 1999

Published by
Construction Research
Communications Ltd
by permission of
Building Research
Establishment Ltd

Cover photograph
courtesy of APA—The
Engineered Wood
Association

Contents

US softwood plywood panels can be manufactured to conform to several voluntary as well as proprietary end-use standards. Trademarking is the responsibility of the individual agency performing the quality assurance services. Several independent agencies provide these services to US manufacturers.

This guide describes common uses of the most widely available plywood grades from United States production. For additional information or assistance in using or specifying US manufactured plywood, contact any of the following offices:

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1 Introduction

Plywood is a construction material which has characteristics that make it ideal in today's construction market where performance, process and price are main drivers. Plywood is easy to handle, low in weight, consistent in size and performance, low in cost and available in sheet form. This has led to a UK consumption of over 1 million m^3 of plywood in 1996. Most of this comes from North America.

This guide is intended to help the users of American plywood to derive the maximum benefits from plywood in roof constructions in terms of performance, durability and cost-effectiveness. It provides carefully written information to help users to make the right decisions when specifying, selecting, designing and fabricating roof constructions using plywood. It has been written by BRE, who are the UK authority on construction-related issues, in partnership with APA–The Engineered Wood Association.

What is plywood?

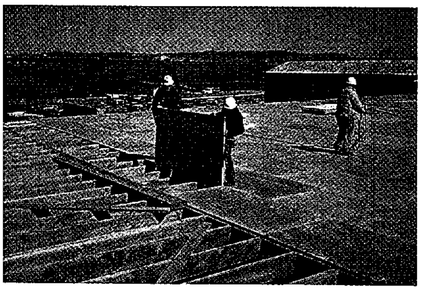
Plywood consists of thin layers ('veneers' or 'plies') of timber bonded together. The simplest plywood consists of three layers with the grain direction of the middle veneer at right angles to the two outer ones. Usually an odd number of veneers is used so that the number and grain direction of the plies is mirrored around the middle veneer. This gives a 'balanced' board. Some American plywoods contain four or six layers and the same stability is achieved by the two central veneers having the same grain direction. The plywood is then symmetrical around the middle glue-line.

The properties of solid timber are very different along the grain and across the grain. Alternating the grain directions of the veneers means that the high tensile strength of timber parallel to the grain direction is used in both directions of the plywood. This is also true for strength and stiffness in bending. The dimensional stability of plywood is almost equal in both directions. Plywood also has improved resistance to splitting along the grain and high resistance to impact loads. Like solid timber, plywood generally has high strength relative to its weight. On a weight-for-weight basis the stiffness of plywood can be greater than that of steel sheet. Plywood does have a main strength axis which needs to be used correctly to maximise the panel's potential.

The USA has forests on around one-third of its land surface. Two-thirds of these forests could be used for timber production but restrictions on logging mean that only 50% are used. America has a long-term forest management programme which aims to harvest wood in a sustainable manner that will protect and enhance the environment. The annual growth increment exceeds extraction by 37%, after taking into account losses arising from fire, hurricanes and natural wastage such as rot and insect attack.

Timber is a natural biological material which can be produced sustainably. Growing trees take up carbon dioxide from the atmosphere and convert this into wood. Carbon accounts for about half the mass of completely dry wood from any tree. Timber acts as a carbon store unless the carbon is released by decay or by burning.

2 Materials



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A wide range of American plywoods is available which gives the wide range of performance and cost attributes required to meet the many applications for which they are used. Performance specifications and design values for using plywood in roofing can be obtained from national and international standards but these must be set within the context of the Building Regulations of England and Wales, the Building Standards for Scotland, and the Building Regulations for Northern Ireland.

This user guide briefly examines the property requirements for plywood used in roofing, what to include in a specification, and a list of relevant American plywoods. Relevant areas are considered in more detail in subsequent sections.

2.1 Performance requirements

The use of structural plywood is controlled through the requirements for bond quality given in European Standard BS EN 314-2. Grade stresses are given in British Standard BS 5268-2 for different lay-ups, timber species and board thicknesses. Roofing is classified as an environment where humidity may be high and it is categorised as Service Class 2 of DD ENV 1995-1-1:1994 (Eurocode 5) and Biological Hazard Class 2 of BS EN 335-3. Only boards meeting the requirements set for performance under humid conditions (BS EN 636-2) or under more extreme conditions (BS EN 636-3) can be used for roofing.

For the majority of cases American plywood complying with BS EN 636-2 will be sufficient: the requirements are given in Table 1.

Supplementary properties can be specified as given in Table 2.

An approximate guide which equates US Product Standard PS1-95[1] veneer grades with those of BS EN 635-3 is given in Table 3.

Table 1 BS EN 636-2 requirements for properties of plywood

Property	Standard and level required
Bonding quality	BS EN 314-2; Class 2
Biodurability	'appropriate for prevailing climatic conditions'. Risk of attack is outlined in Hazard Class 2 of BS EN 335-3. Guidance on factors affecting durability and precautionary measures is in DD ENV 1099 and BS EN 335-3
Mechanical characteristics	Structural data for established products from BS 5268-2 or prEN 12369 (characteristic values) Values can be determined using EN 789 and characteristic values (prEN 12369) and then calculated in accordance with BS EN 1058
Formaldehyde release class	To be designated as Class A, B or C according to BS EN 1084 (Class A having the lowest level). American Exterior and Exposure 1 plywood has the lowest level of Class A

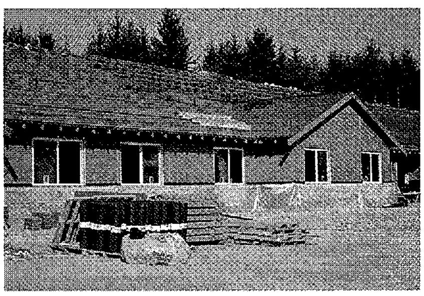
Table 2 Supplementary properties for plywood

Properties		Test method	Reference document
Physical properties	Dimensional changes	BS EN 318	
	Classification by surface appearance		BS EN 635-1, -3
Mechanical properties	Tension properties	BS EN 789	BS 5268-2
	Shear properties	BS EN 789	
	Compression properties	BS EN 789	
	Resistance to screw withdrawal	BS EN 320	
Performance properties	Roofing	prEN 12871-3	prEN 12871-1 prEN 12871-2

Table 3 Equivalent veneer grades of US Product Standard PS1-95 and European Standard BS EN 635-3

PS1-95	BS EN 635-3
N	I
A	I
B	I/II
C plugged	II/III
C	III
D	IV

Requirements for fire behaviour are governed by Approved Document B of the Building Regulations and refer to material performance defined in BS 476. This is covered in a later section of this guide as are aspects relating to the durability of the timber species.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2.2 Specification

The specification for a structural plywood, based on the performance requirements of BS EN 636-2 or 636-3, should cover the following parameters:

- type
- grade
- nominal panel thickness
- number of plies

2.3 Selection

The important property requirements for a roofing material are strength and stiffness. The environmental conditions where the material will be used must also be accounted for. If the material will be in an atmosphere of high humidity, it must have resistance to moisture and decay. The durability of both the timber and the resin must be considered.

The American plywoods which should be considered for selection are listed in Table 4.

2.4 Quality assurance

Plywood manufactured in accordance with US Product Standard PS1-95 is quality assured. The material is intended for use in load-bearing floors, walls and roofing. The main focus of the quality assurance is the structural uses particularly in timber frame construction. The structural grades of American plywood used in roof construction must undergo rigorous prescriptive inspection or performance tests to qualify for certification in accordance with PS1-95. Once a mill is qualified for panel production to PS1 specification, a quality assurance procedure ensures the continued high standard of production. Quality assurance tests are conducted on behalf of the mill during which the following properties may be checked:

- **Mechanical:** panel stiffness and strength in flexure
- **Lay-up and Dimensional:** grade of veneers, veneer and panel thickness tolerance, length, width and squareness
- **Durability:** adhesive bond in shear

In addition to sampling for quality assurance testing, random auditing of mill quality control records is conducted by an independent auditor.

Table 4 American plywood types to be considered for selection

Panel type	Standard manufactured to	Bond durability class of adhesive	Equivalent European bond class
C-D grade (grade C group 1 face veneer, grade D group 1 back veneer: unsanded)	PS1-95	Exposure 1 *	2 (humid conditions)
C-C grade (grade C group 1 veneers throughout: unsanded)	PS1-95	Exterior	3 (unprotected exterior conditions)
A-C and B-C grade (grade A or grade B face veneer, grade C group 1 veneers throughout: sanded)	PS1-95	Exterior	3 (unprotected exterior conditions)
Underlayment (grade C plugged face veneer, grade C and D inner veneer, grade D back veneer: touch sanded)	PS1-95	Exposure 1 *	2 (humid conditions)

* Exposure 1 boards are manufactured with the same phenolic adhesives used for Exterior boards, but owing to other compositional factors Exposure 1 boards should only be used in applications where their ability to resist moisture and weather during long construction delays is required prior to protection.

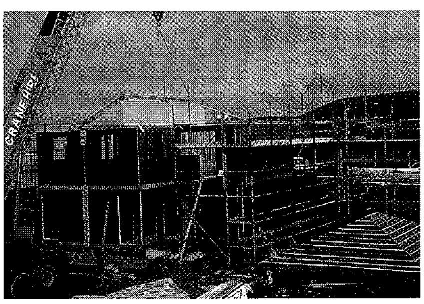
3 Design

3.1 Different roof types

As with other aspects of architectural design, trends in roof design have produced a variety of construction types throughout the years. These may be classified into three main categories of pitched, flat and domed. The majority of housing stock utilises pitched roof construction with recent trends for framing based on prefabricated trussed rafters. A trussed roof structure produces a solution with very efficient use of material, and can be constructed at very low cost to the client. Furthermore, specialist trussed rafter manufacturers generally produce a full set of design calculations that comply with and satisfy local authorities' requirements, building regulations and relevant standards such as BS 5268-3.

Around the 1920s, the modernist movement greatly influenced architectural roof design, turning fashion away from pitched roof construction towards flat roof construction. Different designs of flat roof have been developed over the years to two generic types that are termed 'cold deck' and 'warm deck' construction. Both types require a flat deck placed on top of the structural roofing members for which plywood is ideally suited. The progressive decline in popularity of other decking materials such as asbestos cement sheet, and the virtual elimination of compressed strawboard, has placed more traditional panel products at the forefront of the decking industry.

BRE found from the English House Condition Survey[2] that the largest proportion of flat roof construction has been designed as cold deck. A cold deck roof (Figure 1(a)) has the roof insulation placed between roof joists and below the timber decking, thereby reducing the overall depth of the roofing system but placing the timber decking in a relatively cold environment, hence the generic term 'cold deck'. To avoid moist air migrating from the building and causing condensation to form in the roof void, a vapour check should be installed immediately below the roofing members. This should be installed with weatherproof joints including overlaps. Moisture that penetrates into the roof void needs to be dissipated by adequate ventilation. This is usually achieved by allowing for a sufficiently large unobstructed void between the decking and insulation in each cavity and ventilating this void to the outside air. Openings at the eaves are usually sufficient for small roof areas whilst larger flat roofs may require roof vents placed at select distances. Services, if required in the roof void, should preferably be accommodated below the vapour check membrane by battening out below joists. This avoids penetrations through the vapour check. If, however, penetrations are unavoidable, any holes should be tightly sealed.



There are two types of warm deck commonly used for flat roof construction that do not require ventilating. These are termed 'sandwich' and 'inverted'. The sandwich roof carries that description because thermal insulation is sandwiched between the vapour control layer laid on the deck and the weatherproof membrane laid above it, as shown in Figure 1(b). The

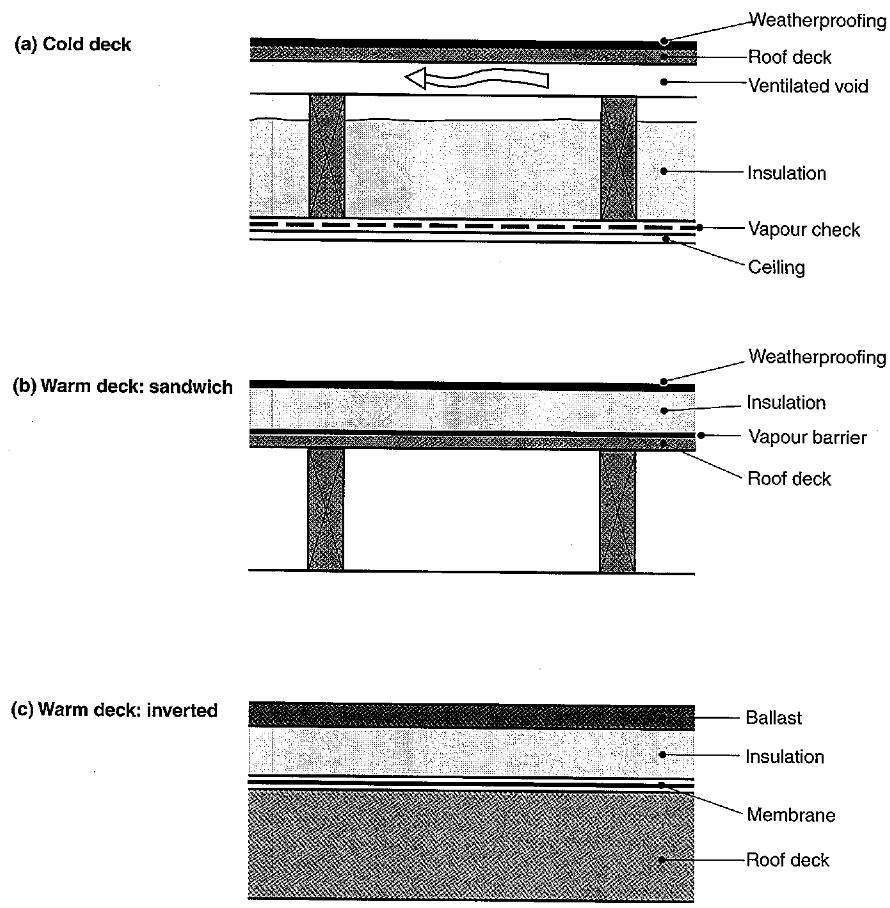


Figure 1 Generic flat roof construction types

inverted roof deck is so-called because the weatherproof layer, which also acts as the vapour control layer, is not in its usual position (see Figure 1(c)), being placed beneath the thermal insulation and ballast.

3.2 Structural design methods

An increasing number of design tools have been available to the engineer through codes of practice for the structural use of timber. The basis for design, up until recently, has always been Permissible Stress despite the trend towards Limit State Design adopted in codes of practice for other materials. One of the initiatives from the European Community (EC) in 1985 was to provide a new set of standards (Structural Eurocodes), technically harmonising codes from all members of the EC* as an aid to lifting barriers to trade in the community. The timber Eurocode is a Limit State Design document which is currently released as a Draft for Development (DD ENV 1995-1-1) and may be used instead of the British Permissible Stress based code of practice BS 5268-2. Other supporting European Standards for wood-based products are BS EN 636, covering the requirements for the use of plywood under various conditions, and BS EN 1058, which gives the method of calculation for determining the characteristic values for use in design.

In the interim period before 2005, when UK codes are due to be withdrawn, the designer has a choice of using a Permissible Stress or Limit State Design code. Although for simple elements permissible stress calculations are quicker, limit state calculations allow an alternative basis for analysis with flexible load combination rules. Many designers will probably opt for using current British Standards at present, but as supporting European material and product standards are introduced the use of Eurocodes will increase.

*All the countries in EFTA and the European Union – 18 national standards bodies

Flat roof construction

Deck type	Advantages	Disadvantages
Cold deck	Low-tech insulation materials may be used and are easily positioned. The overall depth of roof construction is reduced by placing insulation between joists. Any remedial repairs may be carried out easily.	Sufficient ventilation is required. Leaks in the waterproof membrane may go undetected as water will be trapped above the vapour check. The uninsulated roof deck is more susceptible to temperature-induced movements.
Warm deck: sandwich	The plywood decking is contained within the insulated building and is not subject to temperature extremes. A good vapour check is relatively easy to achieve. Services may be routed through the roof void without penetrating the vapour barrier.	High thermal stress in the weatherproof membrane arising from a low rate of heat transfer through the underlying insulation. Local roof traffic could cause damage to the waterproof membrane if insufficient support is offered by the insulation. Both a vapour check and waterproof membrane are required.
Warm deck: inverted	Components of the roofing system are all protected from extremes of temperature by the top ballast layer. Services may be routed through the roof void and are insulated from the cold. The waterproof layer is protected from roof traffic.	The decking may become chilled by rainwater percolating below the insulant, causing condensation on the underside of the plywood decking. Roof dead weights are greatly increased by the use of ballast above the insulation. Span-to-depth ratios will be reduced for structural roofing members. If ballast is used for the top layer, increased drainage may be required to avoid blockages.

3.3 Service loads

One of the basic functions provided by roofs and their component materials is to resist any loads applied, from the outset of construction and throughout its useful life. Both dead loads (material self weights) and imposed loads (any other loading that may be envisaged throughout the building life) must be considered during the design stage of the roof structure. The type and intensity of both dead and imposed loads applied to the plywood in roof constructions will vary depending on its usage and the type of construction envisaged.

For all types of pitched roof construction, be it trussed rafter or others, the plywood has very good structural characteristics for provision as sarking board. In this instance, the plywood's function is to stiffen the roof structure and resist longitudinal loading to the gable ends of the building (ie wind loads). Plywood decking in flat roof construction adopts a similar role in bracing roof members and resisting horizontally applied loads by membrane action, but also transfers vertical roof loads (both dead and imposed) to the supporting joists.

Dead weights of roofing material may be easily calculated from manufacturers' specifications or taken from the unit weights given in BS 648 (Schedule of weights of building materials). The effect of live load on the roofing structure and components must also be considered from the following:

- **People**
  Two main categories of roof access are provided in BS 6399-1 for determining the loads due to people: general cleaning and maintenance access provided, and general access not provided. BS 6399-1 should be consulted for roof with access for specific usages.
- **Wind**
  This load effect is derived in a similar manner to snow loads in that a basic wind speed is first determined and then adjusted using various coefficients to derive the design wind speed. The coefficients account for topography,

height above ground, cladding size and a statistical factor for building design life. These are all covered by BS 6399-2 along with the derivation of pressure coefficients and wind loads for calculating uplift forces.

- **Snow**
  The loads stated in BS 6399-3 allow for the effects of snow. The basic snow load for undrifted snow in an unsheltered area at an assumed ground level datum of 100 m above sea level may be modified according to the site altitude, surrounding topography or redistribution of snow due to drifting or removal. The Building Regulations Approved Document A gives simplified values of snow load for most small housing construction.

To derive a design load for checking the resistance of a roof component, both dead and relevant imposed loads from the above must be considered in likely combinations. Individual loads are factored according to the combination and the most onerous combination is used for design.

From the three types of imposed loading highlighted above, it is necessary for designers to consider fully the action of loads on roof structures and to design for both strength and rigidity accordingly. Typical designs for roofs in Scotland commonly adopt roof sarking as part of their design against wind loading.

3.4 Minimum allowable load levels

American plywood comes in various grades and thicknesses to provide a suitable product for the loads it is intended to resist in its function as either roof sarking or decking. Permissible values for Grade Stress and Modulus are given in BS 5268-2 along with section properties for the variety of thicknesses available. Design loads, which the roofing must resist, are provided in BS 6399-1, -2 and -3.

For American plywood used as sarking in pitched roofs, the minimum thickness for resisting vertical loads is 9.0 mm as stated in BS 8103-3. This thickness is sufficient to provide full bracing to rafter members. Additional thickness may be necessary for other construction cases or to meet the durability requirements.

Thicknesses of American plywood for decking in flat roof construction are given in Table 5.

These values should be used for low-rise domestic buildings, as described in BS 8103-3 provided that:

- Orientation of the grain of and face of the board is perpendicular to supports
- Boards span three or more joists
- Access to the roof is for maintenance and inspection only for the case of no permanent access
- Fixing of the boards is carried out in accordance with recommendations in section 5.2 of this guide

Table 5 Thickness of plywood for flat roof decking

	Maximum centres of support members		
Plywood type	400 mm	450 mm	600 mm
No permanent access to roof			
American construction and industrial plywood: C-D Exposure 1, C-C Exterior grade or Sturd-I-Floor (underlayment)	12.0 mm	12.0 mm	15.0 mm
Access provided to roof			
American construction and industrial plywood: C-D Exposure 1, C-C Exterior grade or Sturd-I-Floor (underlayment)	15.0 mm	15.0 mm	18.0 mm

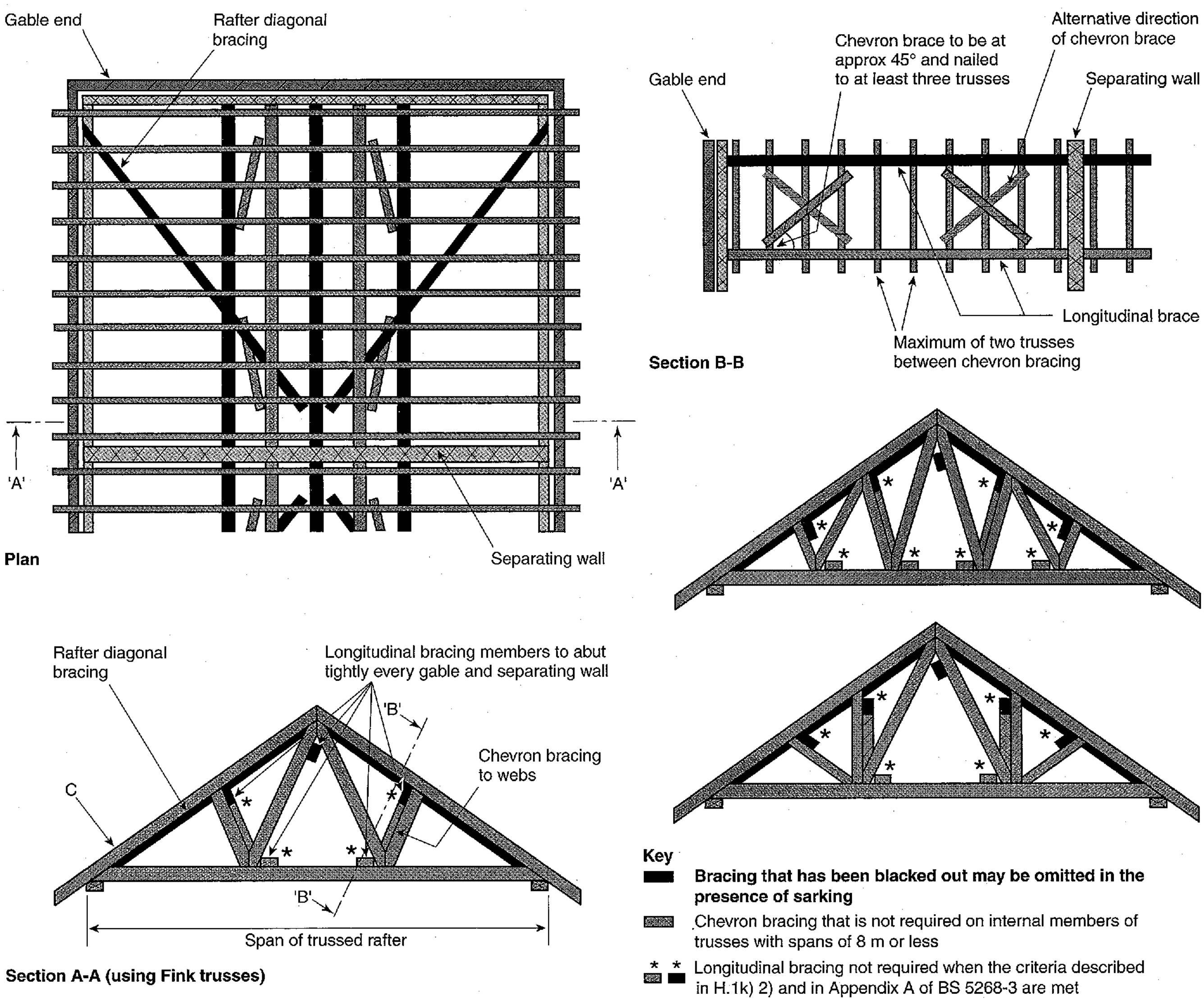


Figure 2 Bracing requirements for pitched roofs with sarking: bracing in BS 8103-3 that may be omitted is shown blacked out *(Original drawings from BS 8103-3:1996 are reproduced with the permission of BSI under licence number PD\ 1999 0792. Complete copies of the standard can be obtained by post from BSI Customer Services, 389 Chiswick High Road, London, W4 4AL)*

3.5 Bracing in pitched roofs

The provision of plywood as sarking in pitched roof construction negates the requirement for a number of bracing members normally found as standard members in pitched roofs. It is possible to omit the diagonal bracing, chevron bracing and longitudinal bracing but only at rafter level as shown in Figure 2. In order to ensure the integrity of the plywood sarking, the following conditions must be met:

- The plywood must be directly fixed to the top face of the rafter members
- Adjacent sheets should be laid with staggered joints and nailed, at not more than 200 mm centres, to every truss that they cover.
- Galvanised round wire nails (3 mm diameter by 50 mm long) should be used to fix the plywood to rafters. These may be either common smooth or ring shank. If splitting of the rafters occurs, nailing should be in a staggered pattern between plywood sheets and driven in a skew direction.

The plywood sarking must be moisture resistant with a required minimum thickness of 9 mm. Suitable plywood to meet this recommendation would need to be grade C-C (CDX for flat roofs) or better and have a nominal sanded or unsanded thickness of at least 9.5 mm.

3.6 Weathertightness

To combat the effects of driving rain in windy conditions, pitched roofs adopt a layered principle such that all direct paths from the underside to the outer surface are lapped by the adjacent surface. The outer covering for a pitched roof is usually one of two kinds: permeable or impermeable to air. The former category includes components such as tiles or slates which overlap each other to direct rain to the eaves. These are not weathertight, and although measures have been taken in their design to prevent the ingress of rain and wind by providing interlocking mechanisms and overlaps, driving rain may still penetrate tile or slate edges through to the sarking felt. This second layer of defence should have sufficient overlaps between successive sheets to prevent further penetration of water by wind action. By installing plywood sarking behind the felt, additional airtightness may be achieved as well as providing a third barrier for penetrating rain. Plywood sarking has particular benefit in non-ventilated warm roofs, typical of industrial buildings and some loft rooms. In this instance the greatly increased airtightness, which is comparable to that of brickwork for 9.5 mm sheathing-grade plywood, enables simple and efficient construction detailing solutions.

3.7 Thermal efficiency

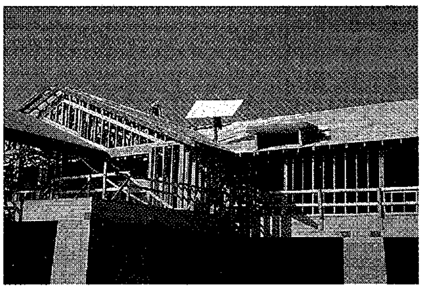
Energy ratings should be calculated for every roof type governed by the Building Regulations 1991, be it pitched, flat, residential or industrial. There are three methods recommended that demonstrate compliance with Part L of the Building Regulations:

- Elemental
- Target U-value
- Energy Rating

All three methods enable the heat losses through building fabric to be limited within target values expected for compliance. The Government's preferred method, the Standard Assessment Procedure (SAP), is adopted for the Energy Rating method. This method ranks the energy efficiency of a building on a scale of 1–100 (poor–excellent) based on the thermal insulation, heating system and fuel type, ventilation and solar gain and is most likely to be requested by local housing authorities for all new housing stock. Builders, unless directed otherwise, will probably opt for the more simplistic Elemental or Target U-value methods.

With the Elemental method, the design U-value for roofs is relaxed from 0.2 to 0.25 if the building SAP rating is greater than 60. In the example given in Appendix A of a typical roof construction, the plywood sarking could make the difference between this Target U-value being satisfied or not.

4 Planning: Building Regulations and other legislation



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Mandatory regulations, which must be complied with for all new-build, are stated in the suite of Building Regulations for England and Wales, the Building Standards for Scotland, and the Building Regulations for Northern Ireland. Compliance with these regulations is the responsibility of the building designer, who may be the owner of the building, his appointed architect, a structural engineer appointed by the owner or his architect or, in the case of small buildings, the actual builder. The increasing complexity of roof construction and the codes that govern their design has led many building designers to request the specialist services of a roof designer. In the case of pitched trussed rafter roofs, design or design-and-build, sub-contracts may also be let to a trussed rafter designer. British Standard BS 5268-3 provides information on the responsibilities of these parties.

In ensuring compliance of the roof structure to relevant legislation regarding health and safety of building occupants, documents approved by the Secretary of State should be referred to for practical guidance on meeting the requirements. The relevant Approved Documents are:

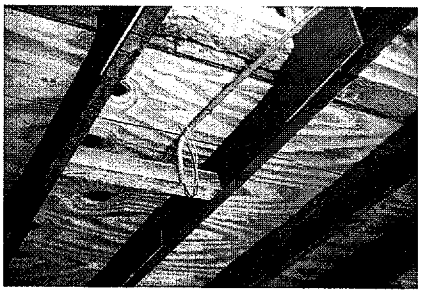
England and Wales	Scotland	Northern Ireland
A: Structure	Part C: Structure	C: Site preparation and resistance to moisture
B: Fire safety	Part D: Structural fire precautions	D: Structure
C: C4 – Resistance to weather and ground moisture	Part G: Preparation of sites and resistance to moisture	E: Fire safety
F: Ventilation	Part K: Ventilation of buildings	F: Conservation of fuel and power
L: Conservation of fuel and power	Part J: Conservation of fuel and power	

Apart from ensuring a reasonable standard of health and safety for persons in or around buildings, in accordance with Regulation 7 any new-build 'should be carried out with proper materials in a workmanlike manner'. By following an appropriate technical specification, as defined by the Construction Products Directive (89/106/EEC), plywood manufactured in accordance with US Product Standard PS1-95[1] is deemed suitable for use in construction and thereby complies with Regulation 7 if used for its intended purpose. Further guidance may be found in the Approved Document to support Regulation 7: Materials and workmanship.

To ensure safe working practices during construction, the designer should consider relevant safety regulations. These include the Construction (Design and Management) Regulations[3] and the Health and Safety Executive's approved code of practice for management of health and safety at work[4].

Other regulations, which may apply but are not covered herein, are The Building Regulations (Northern Ireland) 1973 and The Inner London Building Act. Certain advisory bodies such as the National House Building Council (NHBC), Building Research Establishment Ltd (BRE) and Timber Research and Development Association (TRADA) also produce guidance on roof construction which should be considered.

5 Construction methods



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5.1 Coverings

The following pitched roof coverings are suitable for use in conjunction with plywood sarking: tiles, both concrete and clay; slate and stone; and fully supported built-up bitumen felt and felt strip slates.

For all types of roof covering, underlay must be fixed to the plywood using felt nails or hot-dip galvanised steel nails of 3 mm diameter, thus providing a weather shield. The effectiveness of the underlay will depend on the pitch of the roof, overlap lengths between sheets and at roof hips and valleys, and sufficient mechanical fixing to the plywood sarking. To afford adequate protection to the plywood and avoid condensation forming, the underlay should have adequate strength and a vapour permeability of not less than 0.36 g/m^2 per 24 h at 25 °C and a relative humidity of 75%, tested in accordance with BS 3177. If insulated underlay is used to place the dew point outside the plywood sarking then the insulating material should be durable and damp resistant and should not cause obstruction in the batten and tile space.

Roofs with tiles or slates require counter battening before tiles may be fixed. This ensures that there is an unobstructed vertical path for water to run off which penetrates past the top roof covering such as tiles. In this case the underlay may be either fully supported by the plywood sarking or unsupported between the battens and counter battens. Additional air flow behind unsupported underlay will help to increase the overall permeability of the roof construction and reduce the likelihood of condensation forming.

All tile, slate and felt roof coverings should be lapped, both in the horizontal and vertical direction, according to the recommendations in BS 5534-1. Mechanical fixing of the roof covering should be to the battens and not directly to the plywood sarking. Special attention should be paid to the construction of valleys, which are a particularly vulnerable part of the roof as its pitch is several degrees less than that of the general roof surface. Construction of this problematic detail is made easier by the presence of plywood sarking, which may provide full support for formed sheet metal channels.

If a bitumen felt roof covering is specified, sheets should be bonded to the roof and built up as two to three layers in accordance with BS 8217.

Flat roof coverings rely more heavily on workmanship and material quality than their counterpart pitched roof coverings since gravity works against the roofing system rather than being utilised. Great care must be taken to ensure that bonded sheets provide a waterproof seal and unbonded sheets allow for movement of the underlying material at discontinuities. Because of the greater use of adhesives and to avoid water being trapped in the constructed roof, sheet membranes should not be handled, laid or jointed when any rain, sleet or snow is falling.

5.2 Layout and fixing

British Standard BS 8103-3 Annex L covers the fixing of plywood for use as a flat roof decking. Specifications for contractors should include the following:

- Plywood should be laid such that the face grain lies perpendicular to the supports.
- Fixing nails should be located at centres not exceeding 150 mm along edges and 300 mm along intermediate supports.
- Expansion gaps of 3 mm should be provided at board edges and noggings or counter battens inserted beneath any unsupported edge (unless tongued-and-grooved boarding is used)
- Either plain wire nails or annular-ringed shank nails may be used to the specification in BS 8103-3 Annex L. The relevant clauses of BS 1202 must also be met.

Plywood should ideally be installed with moisture contents within the range that will be experienced in service, especially for warm deck construction where ventilation is not provided to dissipate excess water. The moisture content at time of erection or fixing of plywood decking or sarking should not be more than 18%. The final moisture content will vary according to the type of roof construction and prevailing conditions. Generally, for sarking and flat roof cold decking, the moisture content will not exceed 18% provided that the roof is ventilated. Warm deck construction, both sandwich and inverted, will produce decking moisture contents in the range of 9 to 14%.

5.3 Ventilation

To help to control condensation, ventilation of the roof space is covered by recommendations in BS 5250 (Control of condensation in buildings). Plywood can arrive on site with a low moisture content (not more than 8 to 10%) because of the high temperatures used for gluing the veneers. This makes the product suitable for installation in unventilated roof structures such as warm deck constructed flat roofs.

Adequate ventilation of plywood sarking in timber pitched roof constructions may be achieved in practice by providing ventilation gaps of 25 mm minimum continuous opening at the eaves on opposite sides of the building. Where this is not possible in lean-to, mono-pitch or multi-bay pitched roofs, high-level ventilation should be provided equivalent to a continuous opening of 5 mm in addition to the low-level provision. Ventilation gaps at the eaves are usually provided in the soffit board with a small-gauge metal mesh to prevent the access of insects and birds. High-level ventilation may be provided by special tiles. A clear airway between the sarking and any roof insulation of at least 25 mm (50 mm for a room-in-the-roof) must be provided during construction and throughout the service life of the building. This is best achieved by separating the two elements using continuous boarding attached to the underside of the rafters.

5.4 Details

In addition to the plywood sarking, which provides a very good bracing solution for trussed rafter roofs, the roof should be fixed to the supporting walls and to gable end walls. This braces the walls as well as preventing uplift of the roof structure and transmitting wind loading on the gable ends into the roofing members. This may be achieved, as shown in Approved Document A, clause 1C37, using galvanised mild steel or other durable metal straps which have a minimum cross-section of 30 mm × 5 mm. Fixing should be incorporated at not less than 2 m intervals; details are shown in Figure 3.

The provision of plywood sarking (see section 3.5) allows many of the roof

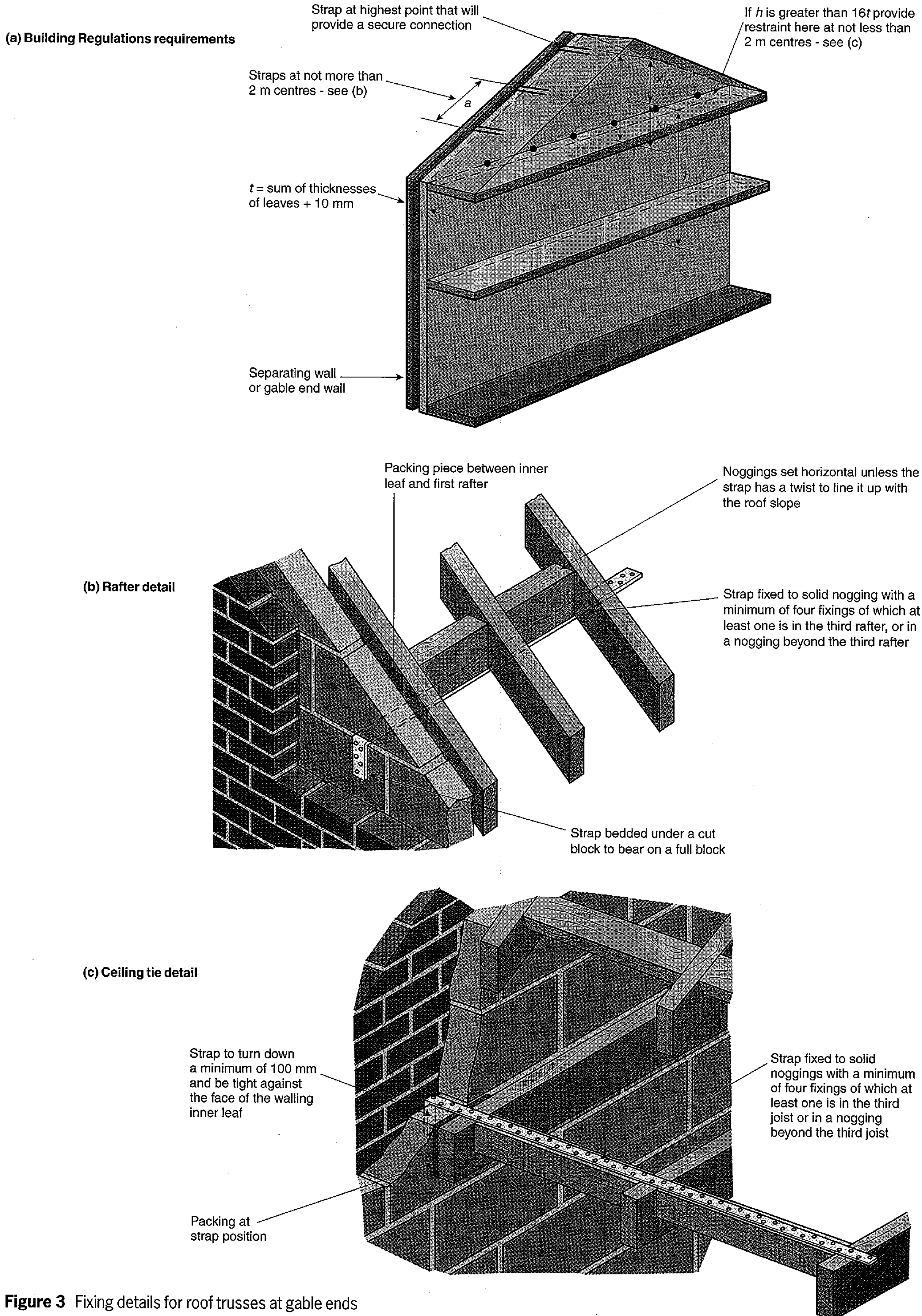


Figure 3 Fixing details for roof trusses at gable ends
(Redrawn from Approved Document A. Original drawings Crown copyright, used with the permission of DETR)

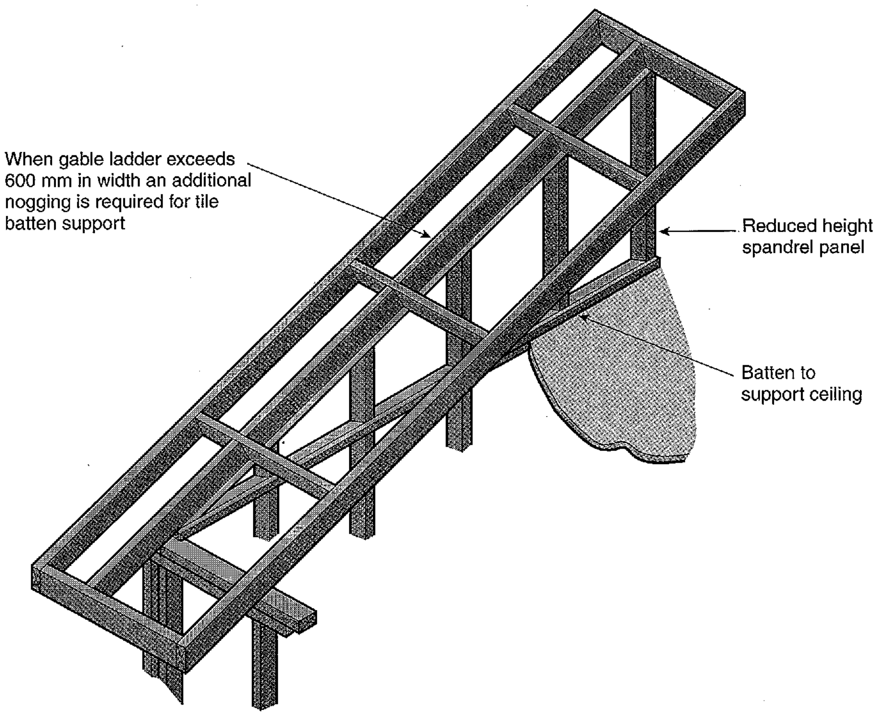


Figure 4 Gable ladder and detail at gable ends

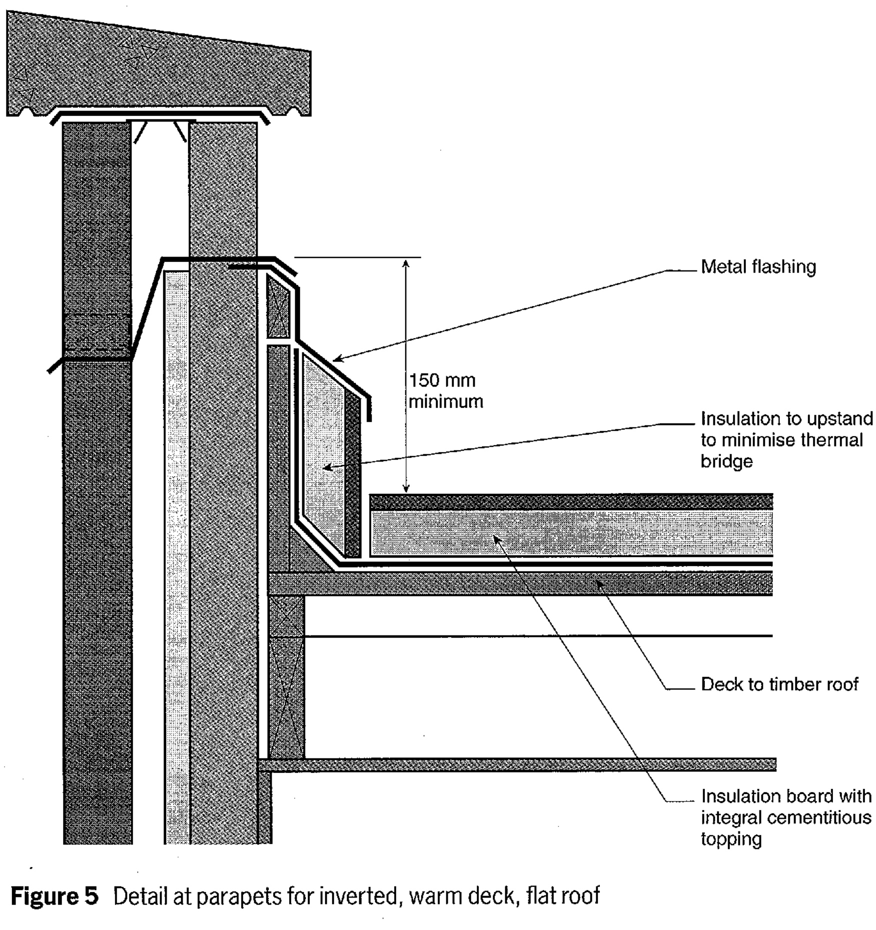


Figure 5 Detail at parapets for inverted, warm deck, flat roof

bracing members to be omitted, although web chevron bracing and some longitudinal bracing will still be required by the designer, as shown in Figure 3. Gable ends require special detailing of the roof construction. Figure 4 shows the provision of a gable ladder for fixing soffits on the external underside and inter-nogging to support roofing battens where the distance from the last truss to the end of the roof exceeds the truss spacing. Additional detailing is also required around openings in the roof for chimneys, air vents or roof lights.

The type of detail required in the construction of flat roofs is mainly focused on two points: the smooth transition of membranes over discontinuities, and continuity of the weatherproof membrane at parapets to ensure a weathertight system. Figure 5 shows wooden chamfers to ease the transition of the weatherproof membrane from a horizontal to a vertical plane and the level of detail required at parapet walls. Cold bridging should be avoided by insulating the roof from both parapet walls and all external walls, as well as insulating around any services or drains that penetrate the roof surface. Details for services and drains are shown in Figure 6.

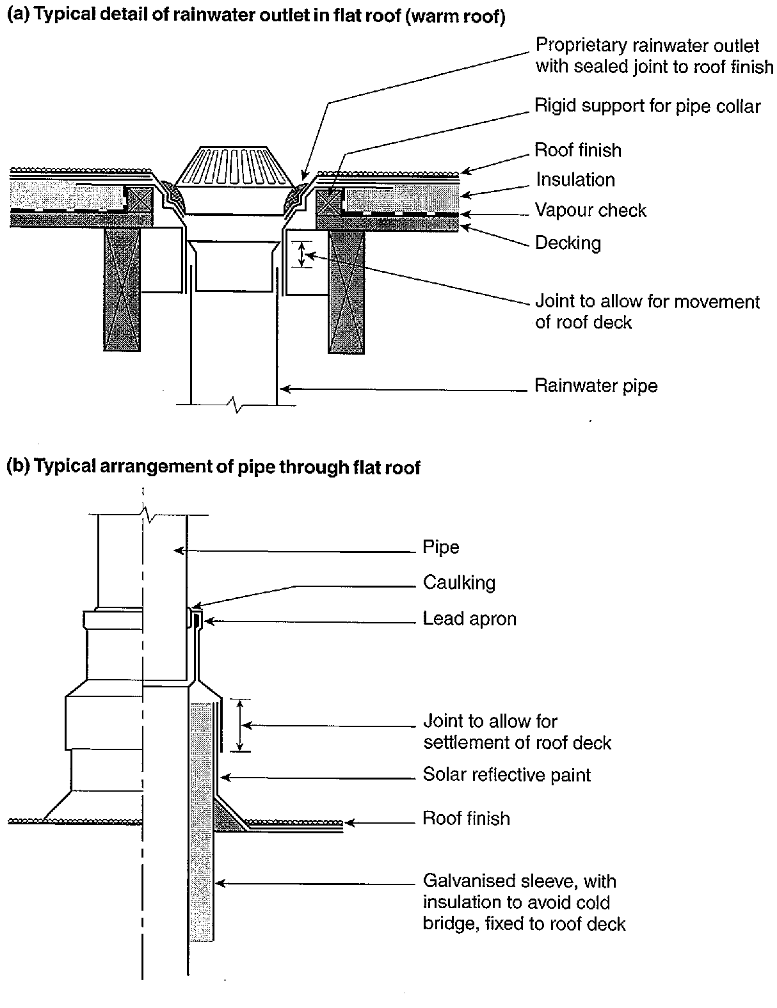


Figure 6 Details of penetrations through a flat roof
(Drawings reproduced courtesy of Timber Research and Development Association)

6 Durability

6.1 Introduction

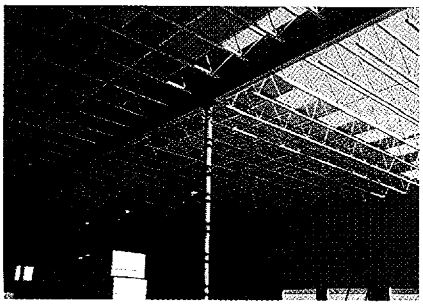
Wood and wood-based panel products can be attacked by both fungi (rot) and insects. Wood-destroying fungi can cause deterioration of susceptible timbers and wood-based products if the wood remains at moisture contents of 20% or more for significant periods. Most timbers, and especially wood-based products, used in buildings are below these moisture contents when installed. Good design and care in construction can prevent or minimise the occurrence of these moisture conditions and thus reduce subsequent opportunities for attack by wood-destroying organisms. In particular, good ventilation systems can reduce high moisture contents. Insects, while more tolerant of low moisture contents, can be discouraged by the glues used in modern plywood construction and by the high temperatures achieved in insulated roof spaces. However, where the risk of attack is seen as unacceptable, the specifier should take steps to reduce or remove the risk. This can be achieved by incorporating wood preservatives into the panel product.

The risk of attack and, therefore, the need to use plywood of enhanced durability can be determined by its intended service environment. Service environments are defined in European Standards as hazard classes of biological attack. BS EN 335-3 relates these hazard classes to the use of various panel products, including plywood. For roofing timbers, only hazard classes 1 and 2 need be considered. These describe a service environment which is above the ground and covered (ie indoors); for hazard class 1 the environment remains dry while for hazard class 2 there is a risk of wetting from high humidity or condensation.

6.2 Exposure classes

Eurocode 5, which covers the use of plywood in roof construction, states that 'only in exceptional cases would covered structures be considered to belong to service class three', the most onerous of the three classes. This logically places plywood for use in both flat and pitched roof construction in service class two, for materials whose average moisture content will not exceed 20% at a temperature of 20 °C and relative humidity not exceeding 85% for a few weeks per year. The accompanying National Application Document for the UK goes further in clearly stating that timber used in cold roof construction may be termed a service class two material. Furthermore, for warm roof construction where the plywood decking is within a heated environment and protected from damp conditions, the plywood and other roofing members may be upgraded to service class one.

Plywoods manufactured in accordance with US Product Standard PS1-95[1] are suitable for both service classes one and two as stated in BS 5268-2; a European Standard has not yet been produced for the grade stresses and



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service classes of plywood*. If the plywood is to be used as decking for flat roofs, especially cold decking, it is recommended that CDX grade or better should be used since the decking may be subjected to condensation.

Exposure of the plywood to wetting in the finished roof is highly dependent on both the adequacy of roof design and the standard of workmanship during erection. If either of these two factors are in doubt, then the designer should consider treating the outer plies with a suitable preservative. Suitable treatment would require a 10-minute dip in an organic solvent preservative to Type F/N of BS 5707-1, or use of any of the preservatives complying with section 8 clause 63 of BS 5589 so that the outer veneers are completely penetrated. British Standard BS 6566-7 (soon to be replaced by DD ENV 1099) for the treatment of plywood should also be consulted. Plywood that has been treated with a water-borne preservative should be dried to a moisture content of less than 20% before installation in a structure whose design has been based on use in service classes one and two.

6.3 Fungal decay

When the risk of fungal attack is assessed, only hazard class 2 need be addressed since the continuous dry conditions of hazard class 1 preclude the development of fungi.

BS EN 460, which relates the need for preservative treatment to hazard class, states that the natural resistance (durability) of all timbers against wood-destroying fungi is normally sufficient for hazard class 2 usage, but that treatment may sometimes be advisable for timbers of durability class 4 or 5. Reference should be made to BS EN 350-2 to determine the durability class of the wood species included in the plywood. It should be noted that durability class 5 includes the sapwood of all timbers. Clearly it is difficult to assess the proportion of sapwood present in plywood because its method of production, in effect, reorganises the distribution of sapwood and heartwood found in solid timber. Where sapwood and heartwood cannot be readily differentiated, for example as with spruce, the whole of the plywood must be considered to be of sapwood for the purposes of treatment decisions.

6.4 Insect attack

In the UK, attack by the house longhorn beetle is possible in the area to the south of London and defined within the Approved Document to support Regulation 7. Here it is strongly recommended that treatment against attack by this insect is carried out on all susceptible timber and wood-based products. Reference to BS EN 350-2 should be made to determine susceptibility of the timber species used in the plywood. Where mixed species are used or sapwood is present, the most susceptible wood should be used as a guide for treatment. However, because of the size of the insect, for plywood in which all veneers are 3 mm or less in thickness, no preservative treatment is necessary. Where it is deemed necessary to prevent attack by the common furniture beetle, reference again should be made to BS EN 350-2 but any durability requirements should be ignored if the veneers are 1.5 mm or less in thickness.

6.5 Roof components

Panel products incorporated into roof structures can be used either as sarking in pitched roofs or as flat roof decking. The British Standard BS 5268-5, although principally concerned with solid timber, provides an indication of the need for enhanced durability in roof components. Pitched roof sarking in most domestic buildings is regarded as safe from fungal attack (hazard class 1)

*An Interim Technical Data Sheet[5] is available from TRADA providing converted grade stresses for use with Eurocode 5.

and therefore plywood of any timber species can be used without the need for treatment. Where the specifier concludes that there is a significant risk of insect attack, treatment may be necessary (see clause 3), especially where sapwood is present or the timber used in the panel construction is one where differentiation between heartwood and sapwood is difficult. Where there is a risk of wetting, eg from condensation (hazard class 2), treatment against fungal attack is regarded as desirable.

For flat roof decking, the recommendations for higher durability against fungal attack are related to the opportunity for the boards to become wet in service. A ventilated cold deck construction or a warm deck that will only experience low humidity may be regarded as hazard class 1 and requires no enhanced durability; any plywood will perform satisfactorily. For decking in warm roofs that will experience intermittent or continuous high humidity (hazard class 2), the need for resistance to biological degrade becomes progressively greater and a decision on treatment will have to be made based upon perceived risk. Considerations on insect attack are the same as for pitched roofs.

6.6 Treatment methods

Treatment of American plywood can be achieved by treating the finished board material. BS 1282 provides guidance on the types of preservative formulations available and their method of application (see also BRE Digest 378[6]). For preservation in hazard classes 1 and 2, both organic solvent and waterborne preservatives are available. Formulations should be selected to prevent insect attack, fungal attack, or both, depending on circumstances. BS 5707 provides information on organic solvent formulations and BS 4072 on copper/chromium/arsenic waterborne formulations. Waterborne boron compounds (defined in the BWPDA Manual[7]) may also be used.

Wood preservative treatment schedules for plywood are not so well established as for solid timber and treatment facilities may be restricted. To help with deciding on a preferred treatment process, advice should be obtained from the preservative manufacturer. In general, the procedures described in BS 5268-5 can be used. However, since it is likely that plywood will be treated in whole sheets and then cut to size during installation, it is essential to ensure that any cut edges are sealed or treated at the time of cutting.

Further guidance on pre-treatment processes and wood preservatives for various end-uses can be found in BS 5589.

7 Fire

Fire performance is regulated by Approved Document B (Fire safety). This calls up national standards for performance levels but these will be replaced by harmonised European Standards as they are produced. Currently, ISO 834 covers the agreed European fire resistance tests. The British Standard for fire performance is BS 476 (Fire tests on building materials and structures). This contains 33 parts, and parts 4 to 7 inclusive are directly relevant for plywood, parts 20 to 22 for the whole roof. The performance areas these parts of the standard address are: non-combustibility; ignitability; fire propagation; surface spread of flame; fire resistance of the elements of a structure.

The performance of plywood in these areas is shown in Table 6.

Although plywood is rated 'combustible' it achieves a 'not easily ignitable' classification. Plywood ignites at around 270 °C if a flame is present but spontaneous ignition does not occur until a temperature greater than 400 °C is reached. The slow, predictable charring rate of plywood in a fully developed fire, combined with relatively few joints between panels, means that plywood gives better fire performance than might be expected.

Plywood cannot be made non-combustible (all materials containing more than a small amount of organic material are combustible) but its resistance to the spread of flame can be improved. Treatment with a flame-retardant can allow plywood to achieve the Class 1 requirements of BS 476-7:1997. Plywood can be impregnated with flame-retardant chemicals into the finished board. Plywood which has already been installed can be surface treated with a flame-retardant paint or intumescent paint (intumescent materials froth at high temperatures).

These treatments do not make the plywood non-combustible and the fire resistance rating of the structure may not change either.

Table 6 Performance of plywood in the parameters of BS 476

Performance parameter	Relevant part of BS 476	Rating of plywood
Non-combustibility	Part 4 (1970)	Combustible
Ignitability	Part 5 (1979)	Not easily ignitable
Fire propagation (rate of heat release)	Part 6 (1989)	Does not meet requirements for class 0
		Class 3 (density >400 kg m^{-3})
Surface spread of flame	Part 7 (1987)	Class 4 (density <400 kg m^{-3})
Fire resistance of elements	Parts 20 to 22 (1987)	Rating dependent on structure as well as components

8 Acoustics

Approved Document E (Resistance to the passage of sound) sets levels for the performance of walls and floors but not for roofs. Plywood can be used in combination with other materials in a design for sound insulation.

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British Standards Institution (BSI)

British Standards

BS 476:— Fire tests on building materials and structures
-7:1997 Method of test to determine the classification of the surface spread of flame of products
BS 648:1964 Schedule of weights of building materials
BS 1202:1974 Specification for nails
BS 1282:1975 Guide to the choice, use and application of wood preservatives
BS 3177:1995 Method for determining the permeability to water vapour of flexible sheet materials used for packaging
BS 4072:— Wood preservation by means of copper/chromium/arsenic compositions
BS 5250:1995 Code of practice for control of condensation in buildings
BS 5268 Structural use of timber
-2:1996 Part 2. Code of practice for permissible stress design, materials and workmanship
-3:1998 Part 3. Code of practice for trussed rafter roofs
-5:1989 Part 5. Code of practice for the preservative treatment of structural timber
BS 5534-1:1997 Code of practice for slating and tiling. Part 1. Design
BS 5589:1989 Code of practice for preservation of timber
BS 5707:1997 Preparations of wood preservatives in organic solvents
BS 6399:— Loadings for buildings.
-1:1996 Part 1. Code of practice for dead and imposed loads
-2:1997 Part 2. Code of practice for wind loads
-3:1988 Part 3. Code of practice for imposed roof loads
BS 6566-7:1985 (1991) Plywood. Part 7. Specification for classification of resistance to fungal decay and wood borer attack
BS 8103-3:1996 Structural design of low-rise buildings. Part 3. Code of practice for timber floors and roofs for housing
BS 8217:1994 Code of practice for built-up felt roofing

European Standards

BS EN 314-2:1993 Plywood. Bonding quality. Part 2. Requirements
BS EN 318:1993 Fibreboards. Determination of dimensional changes associated with changes in relative humidity
BS EN 320:1993 Fibreboards. Determination of resistance to axial withdrawal of screws
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-3:1995 Softwood
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BS EN 789:1996 Timber structures. Test methods. Determination of mechanical properties of wood-based panels
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BS EN 1084:1995 Plywood. Formaldehyde release classes determined by the gas analysis method
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prEN 12871-2:1997 Wood-based panels. Structural roof decking on joists. Part 2. Performance requirements. *Draft for public comment*
prEN 12871-3:1997 Wood-based panels. Structural roof decking on joists. Part 3. Performance test method. *Draft for public comment*

International Standard

ISO 834:1975 Fire-resistance tests. Elements of building construction

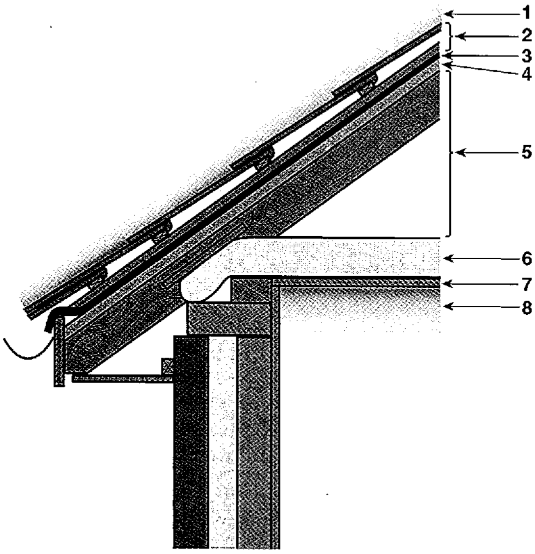
Appendix A: Examples of U-value calculations for roofs

Within the building industry, the U-value is adopted for indicating the level of thermal resistance. Since the U-value is a measure of heat loss, the lower the U-value the higher the resistance to the passage of heat and the more energy efficient the construction is. Building material manufacturers provide energy efficiency values for their products in terms of thermal conductivity (λ). This varies slightly over the range of species groups used in the ply make-up, but a nominal value of 0.115 W/mK may be used for American plywood with minimal error. To determine U-values (U), the reciprocal of the thermal resistance (R) must be calculated. Thermal resistance values for the range of available plywood thicknesses are provided in Table A1 for convenience, or they may be calculated simply by dividing the thickness of material (L) by the material's thermal conductivity (λ).

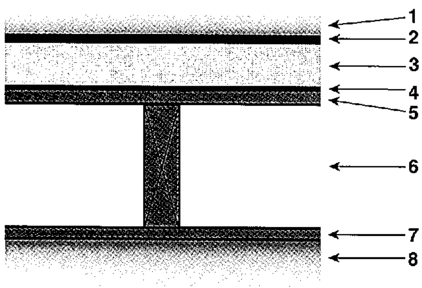
Table A1 Thermal resistance values for a range of plywood thicknesses

Panel thickness		Thermal
inches	mm equivalent	resistance R (m^2K/W)
1/4	6.4	0.06
5/16	7.9	0.07
3/8	9.5	0.08
7/16	11.1	0.09
15/32	11.9	0.10
1/2	12.7	0.11
19/32	15.1	0.13
5/8	15.9	0.14
23/32	18.3	0.16
3/4	19.1	0.17
7/8	22.2	0.19
1	25.4	0.22
1 1/8	28.6	0.25

The two examples on the next page outline a typical calculation for pitched and flat roofs.



Pitched roof			
Roof component	**L (m)**	**λ (W/mK)**	**R (m^{2}K/W)**
1 External surface resistance			0.04
2 Tiles and airspace between battens			0.12
3 Underlay			0.00
4 9.5 mm American plywood sarking	0.0095	0.115	0.08
5 Loft void			0.12
		$\Sigma R_p =$	0.36
Convert 'pitched' resistivity to 'on plan'			
$R_f = \Sigma R_p$. Cos 40° = 0.36 . Cos 40° =			0.28
6 140 mm mineral (glass or rock) wool	0.140	0.04	3.50
7 13 mm plasterboard	0.013	0.16	0.08
8 Internal surface resistance			0.10
		$\Sigma R =$	3.96
		$U = 1/\Sigma R =$	0.25 W/m^{2}K



Flat roof: warm deck			
Roof component	**L (m)**	**λ (W/mK)**	**R (m^{2}K/W)**
1 External surface resistance			0.04
2 3 layer felt (no access)			0
3 100 mm rigid polystyrene sheet	0.100	0.029	3.45
4 Vapour check			0
5 18 mm American plywood deck	0.018	0.115	0.16
6 Unventilated airspace			0.18
7 13 mm plasterboard	0.013	0.160	0.08
8 Internal surface resistance			0.10
		$\Sigma R =$	4.01
		$U = 1/\Sigma R =$	0.25 W/m^{2}K

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BR 369
ISBN 1 86081 291 0