

3.1 Fire performance

3.1.1 Legislation, guidance and insurance

Building Regulations – Fire Safety

Building Regulations Approved Document B (AD B) is one of a series of documents approved by the Secretary of State as practical guidance on meeting the requirements of Schedule 1 and Regulation 7 of Building Regulations 2000 (England and Wales). AD B Volume 1 covers dwelling houses and AD B Volume 2 covers buildings other than dwelling houses. Scotland is covered by Technical Handbook 2, Domestic and Non-domestic.

The documents classify the use of a building into purpose groups and specify minimum periods of fire resistance to be achieved by the building elements. The periods of fire resistance vary according to the use and the size of building. The greater the fire hazard a building presents then the greater the period of fire resistance required to protect the elements within the building. The materials used to form the internal surfaces of the building are also controlled to reduce the risk of fire growth and internal fire spread.

HTM 05 Firecode – Healthcare Buildings

Hospitals and healthcare environments, by their very nature, contain people who are at risk from fire. The recommendations given in the suite of HTM 05 Firecode includes internal fire spread, elements of structure, compartmentation, fire hazard areas, hospital streets, penetrations, protected shafts, ceiling membranes, cavity barriers and fire-stopping.

Building Bulletin 100 (BB100) - Educational Buildings

The design of fire safety in schools is covered by BB100. Building Regulations will typically be satisfied where the safety guidance in BB100 is followed.

Loss Prevention Council (LPC) Design Guide for the Protection of Buildings – Commercial and Industrial

Provides guidance on the general principles of passive fire protection - contribution to fire growth, fire resistance, compartmentation and external fire spread. It presents insurers with standards of fire protection for industrial and commercial buildings and is intended to assist building designers and other professional advisors in reconciling the provisions of national legislation standards with the recommendations of the insurance industry. It also gives guidance regarding how fire protection measures can be used to augment passive protection.

Fire Protection for Structural Steel in buildings, ASFP Yellow Book

Publication prepared by the members of the Association for Specialist Fire Protection (ASFP). Presents the theory behind, and methods for, fire protection of structural steelwork to comply with Building Regulations. It provides a comprehensive guide to proprietary materials and systems all of which are manufactured, marketed or applied on site by members of ASFP.

3.1.2 Principles of fire performance

Fire growth

The choice of materials for walls and ceilings can significantly affect the spread of fire and its rate of growth, even though they are not likely to be the materials first ignited. The specification of linings is particularly important in circulation spaces where surfaces may offer the main means by which fire spreads, and where rapid spread is most likely to prevent occupants from escaping. Two properties of lining materials that influence fire spread are the rate of flame spread over the surface when it is subject to intense radiant heating, and the rate at which the lining material gives off heat when burning. AD B gives guidance on the classification of linings. The following table is taken from AD B Volume 2:

Table 1 - Classification of linings

Location	National class ¹	European class ^{1 3 4}
Small rooms ² of area not more than: a. 4m ² in residential accommodation b. 30m ² in non-residential accommodation	3	D-s3, d2
Other rooms ² (including garages) Circulation spaces within dwellings	1	C-s3, d2
Other circulation spaces, including the common areas of blocks of flats	0	B-s3, d2

^{1, 2, 3, 4} - Please refer to AD B Volume 2 for explanation.

A detailed explanation of the relevant classifications is given later in this section.

Compartmentation

The spread of fire within a building can be restricted by sub-dividing it into compartments separated from one another by walls and / or floors of fire resisting construction. Two key objectives are:

- To prevent rapid fire spread, which could trap occupants in the building.
- To reduce the chance of fires becoming large, which are more dangerous - not only to occupants and fire service personnel, but also to people in the vicinity of the building.



Loaded timber stud wall failing in respect of loadbearing capacity

The appropriate degree of sub-division depends on:

- The use and fire loading of the building, which affects the potential for fires and their severity, as well as the ease of evacuation.
- The height to the floor of the top storey in the building, which is an indication of the ease of evacuation and the ability of the fire service to intervene effectively.

Structural fire precautions

Premature failure of the structure can be prevented by the provision for loadbearing elements to have a minimum period of fire resistance to failure of loadbearing capacity. The purpose in providing the structure with fire resistance is:

- To minimise the risk to the occupants, some of whom may have to remain in the building for some time (particularly if the building is a large one), while evacuation proceeds.
- To reduce the risk to fire fighters engaged on search and rescue operations.
- To reduce the danger to people in the vicinity of the building who may be hurt by falling debris, or because of the impact of the collapsing structure on other buildings.

Fire limit state

In structural design terms, fire is considered to be an accidental limit state, i.e. an accidental occurrence, and one for which the structure must not collapse. Loads and their factors of safety used in design at the fire limit state reflect the low probability of occurrence.

Typically, structural members that are designed to be fully stressed under normal conditions would be subject to a load ratio of 0.5 to 0.6 under fire conditions. Within this book loadbearing floors and partitions are quoted with respect to a stated load ratio. Many constructions have been tested at a conservative load ratio of 1.0 (100%) despite the fire state being an accidental load.

Structural behaviour of timber in fire

Timber has a low thermal expansion coefficient, which minimises the possibility of protective layers and charred materials becoming displaced. It also has a low thermal conductivity, which means that undamaged timber immediately below the charred layer retains its strength. Generally, it may be assumed that timber will char at a constant rate when subjected to the standard heating conditions of the test furnace. The rate of reduction in the size of structural timber can be taken as 15mm to 25mm (depending on species) in 30 minutes for each face exposed, different rates apply where all faces are exposed. The undamaged timber can be assessed for structural stability using standard design guides in conjunction with stress modification factors.

For partitions tested with high load ratios it should be noted that when the timber is exposed to fire, the exposed face will shrink causing differential thermal movement. This can be important for axially loaded sections, as it introduces a degree of eccentricity, which may cause a loss of loadbearing capacity.



Charred timber joists after a test

Structural behaviour of steel in fire

Steel generally begins to lose strength at temperatures above 300°C and eventually melts at about 1500°C. Importantly for design, the greatest rate of strength loss is in the range of 400°C to 600°C.

Using fire design codes such as *BS 5950-8* or the Structural Eurocodes *EC3-1.2* and *EC4-1.2* (designated *ENV 1993-1.2* and *ENV 1994-1.2*), the load on the structure at the time of the fire can be calculated by treating it as an accidental limit state. If used, this will allow designers to specify to the fire protection contractor a limiting or failure temperature for a given structural section. The fire protection contractor will then be able to use the required thickness of material to ensure that the steel section does not exceed this temperature within the fire resistance period. This process could be simplified by the designer specifying a maximum steel temperature, based on the worst case, for all beams or columns on one floor level.

Buildings that are not primarily used for storage, e.g. offices, residential units, schools and hospitals, have a high percentage of non-permanent loads. For this type of building, the structural codes *BS 5950-1* and *ENV 1991-1-1* assume that a proportion of the design load will not be present at the time of the fire. Other types of buildings, such as warehouses and libraries, are primarily used for storage, so a high percentage of the load is permanent, and the codes allow for no reduction in design load for the fire condition.

The fire testing standards effectively base the failure criteria for loadbearing elements on strength. However, beams are often designed for deflection requirements, which mean that their strength is not fully utilised in the cold state and they would therefore have an additional reserve of strength at the fire limit state.

Columns are frequently designed so that a single length will be two or three storeys high. The lowest storey will be loaded the highest and the upper storey will be lightly loaded.

In buildings with a degree of non-permanent load (in terms of duration and magnitude), the load ratio of the structural members is unlikely to be greater than 0.6. In storage buildings, where the majority of load is permanent, the load ratio would normally be higher, but is unlikely to be greater than 0.65.

In **section 9 - Steelwork encasement systems**, the thicknesses of protection required are specified for design temperatures of 550°C, unless otherwise stated. It is the responsibility of the design engineer, using design codes such as *BS 5950-8* or *ENV 1993-1-2*, to specify the appropriate limiting steel temperatures.

The loss of strength of cold-formed steel at elevated temperatures exceeds that of hot-rolled steel by between 10% and 20%. Expert advice should be sought in determining the strength reduction factor at the limiting temperature.

3.1.3a British test standards

BS

Fire resistance test standards

Building Regulations and supporting documentation require elements of structure and other building elements to provide minimum periods of fire resistance, expressed in minutes, which are generally based on the occupancy and size of the building.

Fire resistance is defined in *BS 476: Part 20: 1987* as 'the ability of an element of building construction to withstand exposure to a standard temperature / time and pressure regime without loss of its fire separating function or loadbearing function or both for a given time'.

BS 476: Part 20: 1987

Describes the general procedures and equipment required to determine the fire resistance of elements of construction.

BS 476: Part 21: 1987

Describes the specific equipment and procedures for determining the fire resistance of loadbearing elements.

BS 476: Part 22: 1987

Describes the procedures for determining the fire resistance of non-loadbearing elements.

BS 476: Part 23: 1987

Describes the specific equipment and procedures for determining the contribution made by components to the fire resistance of structures.

Loadbearing capacity

A loadbearing element must support its test load. For floors, flat roofs and beams, allowable vertical deflection is limited to $\frac{1}{20}$ of the clear span.

Integrity

A separating element must resist collapse, the occurrence of holes, gaps or fissures through which flames and hot gases could pass, and sustained flaming on the unexposed face.

Insulation

A separating element must restrict the temperature rise of the unexposed face to below specified levels.

Reaction to fire test standards

Non-combustibility



Non-combustibility testing

To help provide maximum fire safety in buildings, certain building elements need to be constructed of non-combustible materials. A building material is designated as non-combustible if it satisfies performance criteria when tested in accordance with:

BS 476: Part 4: 1970 (1984) Non-combustibility test for materials.

BS 476: Part 11: 1982 (1988) Method for assessing the heat emission from building materials.

Glasroc F MULTIBOARD and Glasroc F FIRECASE are designated as non-combustible materials.

Materials of limited combustibility

- (a) Any non-combustible material (listed in AD B, Table A6).
- (b) Any material of density 300kg/m³ or more, which does not flame or cause a 20°C temperature rise when tested to *BS 476: Part 11*.
- (c) Any material with a non-combustible core at least 8mm thick having combustible facings (on one or both sides) not more than 0.5mm thick. Where a flame spread rating is specified, these materials must also meet the appropriate test requirements.

Gyproc plasterboards are all designated materials of limited combustibility.

Surface spread of flame

Flame spread over wall and ceiling surfaces is controlled by providing materials that are either non-combustible or materials of limited combustibility. Combustible materials (or certain materials of limited combustibility that are composite products) when tested to the standards below, are classified Class 1, 2, 3 or 4. Class 1 provides the greatest resistance to surface spread of flame.

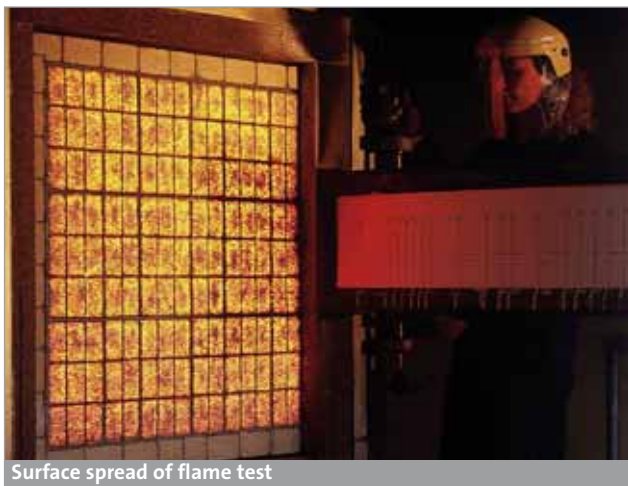
BS 476: Part 7: 1997 Surface spread of flame tests for materials

or

BS 476: Part 7: 1987 Method for the classification of the surface spread of flame of products.

Although the 1987 version has been superseded by the 1997 version, the 1987 version is still cited in Building Regulations.

The exposed plasterboard surfaces of Gyproc and British Gypsum specialist boards, are all designated Class 1.

**Fire propagation**

Investigations concerned with the growth of fires in buildings show that the surface spread of flame test does not measure all the properties that are relevant for placing combustible materials in the proper order of hazard. Such considerations led to the test which is described in *BS 476: Part 6: 1989 Method of test for fire propagation for products*. This test takes into account the amount and rate of heat evolved by a specimen whilst subjected to a specified heating regime in a small furnace. The standard describes the method of calculating

the results to obtain indices of performance, which help to determine the suitability of combustible wall and ceiling lining materials when used in areas requiring maximum safety.

Class 0

In addition to the degree to which combustible materials used as wall and ceiling linings can contribute to the spread of flame over their surfaces, consideration must also be given to the amount and rate of heat evolved by these materials when used in areas requiring maximum safety. Building Regulations, by means of associated documentation, make provisions that wall and ceiling surfaces must be Class 0 in circulation spaces (which are often escape routes) and in other specific situations. In AD B, a Class 0 material is defined as either:

- (a) composed throughout of materials of limited combustibility (this term includes non-combustible materials)
- or
- (b) a Class 1 material that has a fire propagation index (I) of not more than 12 and a sub-index (i_1) of not more than 6.

The exposed plasterboard surfaces of Gyproc and British Gypsum specialist boards are designated Class 0 in accordance with AD B.

Although Class 0 is the highest performance classification for lining materials, it is not a classification identified in any British Standard.

3.1.3b European test standards**EN**

The Construction Products Directive (CPD) within European legislation is designed to enable free trade across Europe in construction products. To enable free trade, harmonised test standards for technical performance are required. The area of technical performance most affected by this requirement is fire performance. This can be split into two main parameters; reaction to fire and fire resistance.

Reaction to fire and fire resistance are measured differently across Europe. For reaction to fire, new test methods were devised and a new Euroclass classification system introduced. For fire resistance the methods used across Europe were similar but the severity of furnaces varied due to factors such as different fuel sources and furnace geometry. To increase consistency between furnaces, the plate thermometer was introduced. This was designed to measure the heat flux to which samples are exposed and consequently equalises the test furnaces.

EN fire resistance

For the UK, the introduction of the plate thermometer means that our furnaces have become more severe, especially during the first 30 minutes of exposure. Refer to **Figure 1 - Comparison of the BS and EN furnace curves** (page 22), that shows the increased temperature measured with a BS thermocouple when a furnace is controlled utilising the EN plate thermometer.

In addition to the severity of the new EN fire resistance tests, the test standard also imposes strict rules governing the use of tests to cover specific end use scenarios (field of application). This restricted field of application has most effect on partition heights where partitions built at heights above 4m may need to have enhanced levels of fire resistance.

Building Regulations allow EN and BS testing systems to run in parallel so that designers can use either EN or BS test data.

British Gypsum has retested the majority of its systems to present test information in accordance with new EN fire test standards. Since the EN and BS standards are running in parallel, this book shows tables to both EN and BS.

EN fire resistance and its application to British Gypsum systems

The EN fire resistance periods claimed for systems in this document are evaluated in accordance with the relevant EN test standards.

BS EN 1364-1: 1999

Specifies a method for determining the fire resistance of non-loadbearing walls.



Fire resistance test – integrity testing on 3m high partition

BS EN 1365-1: 1999

Specifies a method of testing the fire resistance of loadbearing walls.

BS EN 1365-2: 2000

Specifies a method for determining the fire resistance of loadbearing floors and roofs.

BS EN 1364-2: 1999

Specifies a method for determining the fire resistance of non-loadbearing ceilings.

ENV 13381-4

Test methods for determining the contribution to the fire resistance of structural members: Applied protection to steel members.

Partition height

The most significant difference between the EN and BS tables is maximum partition height. Within the *BS 476: Part 22* testing regime, the partition height in the fire state was not considered, and if a partition passed the fire test at 3m it was deemed to be suitable in fire resistance terms for any possible heights. Under the BS system, the cold state height would be the maximum height claimed regardless of the fire duration required. The more sophisticated EN test standard considers partition height and fire resistance performance in the end use condition, ensuring a greater level of fire safety.

Within the field of application section of *BS EN 1364-1: 1999* there is a limitation on the height that can be claimed for a partition based on a given test. To claim up to 3m the partition has to be tested at a height of 3m in the fire resistance test. To claim up to 4m, the partition has to pass the test with a partition test height of 3m and deflect laterally by not more than 100mm during the test. To claim above 4m the partition has to undergo an engineering appraisal where the thermal bow and strength loss of the steel studs is taken into account. This means that the same partition may have different quoted heights at different fire resistance durations. The only alternative to using an engineering appraisal is to conduct a test at the height under consideration. British Gypsum has conducted an extensive series of tests on partitions with heights up to 6m, and data from these tests are used within the performance tables.

Insulation materials, such as glass and stone mineral wool, can affect the fire resistance of a partition. These materials can provide additional insulation / integrity performance but can also increase the thermal bow of the partition and therefore reduce the partition height that can be claimed. Consequently, within the performance tables, there are instances for which the partition height is reduced when a quilt is included within the cavity of the partition. It cannot be assumed that adding a quilt to a partition specification will not impact on its fire resistance.

EN reaction to fire

The European Classification System (Euroclass), devised for the classification of 'reaction to fire', has been introduced as part of the ongoing harmonisation of European standards. Reaction to fire has traditionally been assessed using at least 30 different national standards across Europe. The Euroclass system includes tests designed to better evaluate the reaction of building products to fire.

The Euroclass system predicts the performance of building materials in a real fire more accurately than the old British Standard classification system. Gypsum products are intrinsically fire safe products and generally fall into the higher Euroclass classifications.



Failure of 6m high partition

The Euroclass test methodology is built around the Single Burning Item (SBI) test method (*BS EN 13823: 2002*), which is an intermediate scale test to evaluate the rate of fire growth from a waste paper basket fire positioned in the corner of a room. Other tests used in the classification system are the non-combustibility test (*BS EN ISO 1182: 2002*), heat of combustion test (*BS EN ISO 1716: 2002*) and direct flame impingement test (*BS EN ISO 11925-2: 2002*).

BS EN 13501-7: 2002

Fire classification of construction products and building elements, should be followed to determine the Euroclass rating.

Plasterboard is subject to a 'classification without further test' decision. This means that any type of plasterboard can be classified



Non-combustibility furnace

as A2 so long as the paper grammage of the liner does not exceed 220g/m². Any plasterboard product with a paper liner in excess of this grammage is required to be tested. Classification A2 is the second best Euroclass category, see **Table 2** (page 21). All British Gypsum plasterboard products manufactured in accordance with *BS EN 520* are designated Euroclass A2.

Building Regulation equivalence

AD B allows the Euroclass classification system to be used for demonstrating compliance. **Table 2** (page 21) gives the requirements and the equivalent Euroclass category.

3.1.4 Why gypsum is so effective in fire



Glass fibres within the core of a Glasroc F specialist board

Fire resistance

Gypsum plasters, plasterboards and British Gypsum specialist boards provide good fire protection due to the unique behaviour of gypsum in fire. When gypsum-protected building elements are exposed to fire, dehydration by heat (calcination) occurs at the exposed surface and proceeds gradually through the gypsum layer. Calcined gypsum on the exposed faces adheres tenaciously to uncalcined material, retarding further calcination which slows as the thickness of calcined material increases. While this continues, materials adjacent to the unexposed side will not exceed 100°C, below the temperature at which most materials will ignite, and far below the critical temperatures for structural components. Once the gypsum layer is fully calcined, the residue acts as an insulating layer while it remains intact.

Table 2 - AD B categories and relevant EN test requirements

National classification	Euroclass category	Safety level	BS EN ISO 13501-1: 2007 test requirements
Non-combustible	A1		BS EN ISO 1182: 2002 and BS EN ISO 1716: 2002
Material of limited combustibility	A2		BS EN ISO 1182: 2002 or BS EN ISO 1716: 2002 and BS EN ISO 13823: 2002
Class 0	B		BS EN ISO 13823: 2002 and BS EN ISO 11925-2: 2002
Class 1	C		BS EN ISO 13823: 2002 and BS EN ISO 11925-2: 2002
Class 3	D		BS EN ISO 13823: 2002 and BS EN ISO 11925-2: 2002
N/A	E		BS EN ISO 11925-2: 2002
N/A	F	No performance determined	

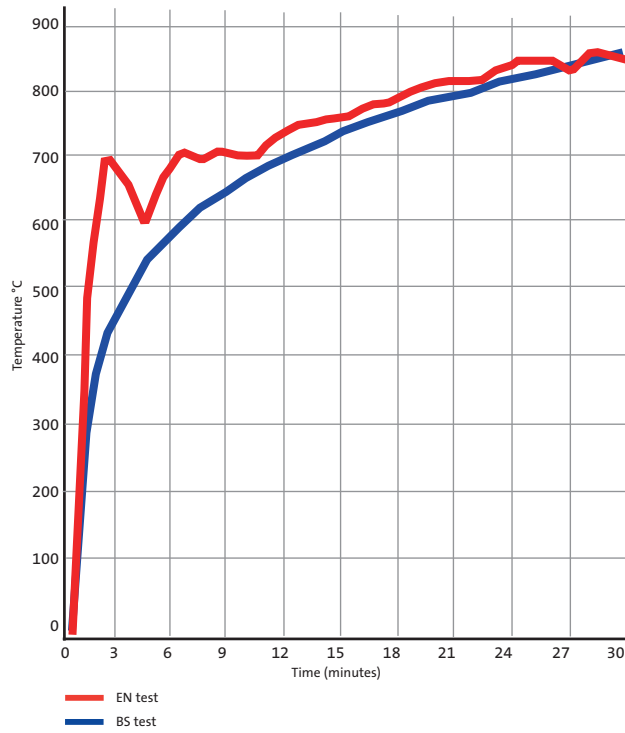
Figure 2 - Temperature profile on the unexposed face of a partition system (page 22), shows a typical unexposed temperature profile for a plasterboard lined partition. The graph shows that there is a significant plateau in the temperature rise, while the plasterboard is undergoing calcination. After this period the temperature gradually rises until the boards lose their integrity and fall away.

The inclusion of glass fibres and shrinkage inhibitors within the gypsum core of certain plasterboards improves the cohesive properties and fire integrity performance. This enables a much higher fire protection performance to be achieved compared to standard wallboard.

In terms of reaction to fire, gypsum products are excellent performers as the endothermic hydration reaction requires energy to be taken from the fire, so gypsum is a negative calorific contributor.

Figures

1 Comparison of the BS and EN furnace curves



2 Temperature profile on the unexposed face of a partition system

