BS 476-10:2009

BSI British Standards

Fire tests on building materials and structures –

Part 10: Guide to the principles, selection, role and application of fire testing and their outputs

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Publishing and copyright information

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 40, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 476 is published by BSI and came into effect on 1 January 2009. It was prepared by Technical Committee FSH/21, *Reaction to fire tests*, and FSH/22, *Fire resistance tests*. A list of organizations represented on these committees can be obtained on request to their secretaries.

Supersession

This part of BS 476 supersedes BS 476-10:1983, which is withdrawn.

Relationship with other publications

This part of BS 476 describes the general principles and application of the methods in the series of standards for fire testing.

Fire tests are used extensively in support of national fire safety legislation, primarily in the context of prescriptive regulations (or regulatory guidance). The outputs of these tests may also be used, with caution, to support a fire safety strategy that has been generated using the functional approach to regulations. Any of the tests used to characterize the reaction to fire, or fire resistance of a material/construction, only represents one of many possible fire scenarios.

Outputs from fire tests are used in the assessment of fire risks and, similarly to using the results in the context of a fire safety strategy, the limitations on the validity of the results need to be considered when applying them. Guidance on the use of fire tests in the context of hazard assessment is found in BS 6336.

Because of the UK's membership of the EU and its adoption of the Construction Products Directive (CPD) [1], UK legislation now fully embraces the range of European test and classification standards produced by CEN. These standards are required to support the harmonized Product Standards and European Technical Approvals (ETAs) used for the purpose of CE marking of construction products. These European Standards sometimes measure similar characteristics to the British Standards, but some of them measure totally different fire characteristics. Where there are ''equivalent'' standards to those within the British Standards, these are identified and the differences are discussed.

Similarly, with the growth in world trade, the International Standards Organization (ISO) has taken on a more important role. Under the Vienna Agreement, much effort has been allocated to harmonizing CEN and ISO tests. This has resulted in the production of a number of identical EN ISO fire test standards. Additionally, a range of ISO fire test methods is also available that reflects the more diverse requirements of the international market. Where possible, the equivalent ISO test method is identified and the differences are given. However, for the avoidance of doubt, it needs to be understood that the use of ISO fire test methods (except when they have been adopted by CEN) is only voluntary in the UK, and the results obtained cannot be used for the purpose of CE marking of construction products.

The titles of the parts are as follows:

a) Fire tests for (products) materials:
   - Part 4: *Non-combustibility test for materials*;
   - Part 6: *Method of test for fire propagation for products*;
   - Part 7: *Method of test to determine the classification of the surface spread of flame of products*;
   - Part 11: *Method for assessing the heat emission from building materials*;
   - Part 12: *Method for measuring the ignitability of products using direct flame impingement*;
   - Part 13: *Method of measuring the ignitability of products subjected to thermal irradiance*;
   - Part 15: *Method of measuring the rate of heat release of products*;
   - Part 33: *Full-scale room test for surface products*.

b) Fire resistance tests for elements of building construction:
   - Part 20: *Method for determination of the fire resistance of elements of construction (general principles*;
   - Part 21: *Methods for the determination of the fire resistance of load bearing elements of building construction*;
   - Part 22: *Methods for the determination of the fire resistance of non-loadbearing elements of construction*;
   - Part 23: *Methods for the determination of the contribution provided by components and elements to the fire resistance of a structure*;
   - Part 24: *Method for determination of the fire resistance of ventilation ducts*.

c) Fire test for external fire exposure:
   - Part 3: *Classification and method of test for external fire exposure to roofs*.

d) Miscellaneous fire tests:
   - Part 31.1: *Methods for measuring smoke penetration through doorsets and shutter assemblies at ambient temperatures*;
   - Part 32: *Guide to full scale fire tests within buildings*.

The results of tests performed in accordance with BS 476 are not be used to demonstrate conformity to Essential Requirement 2 (ER2) of the European Construction Products Directive (CPD) [1] or any associated classification system, and therefore are not to be used for the purposes of CE marking of products.

Information about this document

This is a full revision of the standard, taking into account changes in legislation and new standards published since 1983.

This part of BS 476 is not intended to be used for determining the conformity of any product or construction to Essential Requirement 2 of the European Construction Product Directive [1].

Hazard warnings

WARNING. This British Standard calls for the use of substances and/ or procedures that can be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage.

Use of this document

As a guide, this part of BS 476 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

Fire in buildings produces a scenario that puts lives at risk either directly, by exposure to the fire conditions, or indirectly, as a result of the response of the building to exposure to fire. Potential responses of the building that could represent a risk to life safety include:

a) ease of ignition, resulting in early involvement;

b) high rates of heat release;

c) rapid spread of fire on surfaces;

d) production of excessive volumes of smoke;

e) excessive heat flow through separating elements of structure;

f) excessive distortion of the structure;

g) collapse of the structure under self-weight or imposed loads;

h) other unspecified behaviour, e.g. melting and dripping.

These characteristics are established by the engineering application of data generated by well-targeted fire tests. Generally, characteristics that relate to the response of the materials are established by means of reduced scale "bench" tests, and those characteristics that control the behaviour of elements of construction are determined by larger scale tests on specimens of the structural elements.

It is important that these tests are repeatable and reproducible and have some relationship with a reference scenario. Product or construction characteristics determined against ad hoc tests have limited applicability outside the testing parameters that were modelled by the test arrangements, e.g. ignition source, fuel quantity and rate of heat release and oxygen availability. The intention of standard test methods derived by a representative body is to achieve repeatability and reproducibility (albeit many tests are now published as desk studies without the desired "round robin" testing taking place), but this is notoriously difficult to demonstrate for fire resistance, in particular, because of variations in conditions and test furnaces from one test facility to another. Reproducibility and repeatability of individual product performance can only be adequately demonstrated for that particular product by repeat testing in different test facilities.

Historically, the tests used within the design/regulatory framework were national tests designed for evaluating products and/or constructions generated in the country in which the final structure was being built because these reflect both the indigenous building forms and the national acceptance of risk (either stated or inferred). In the UK, the methods of test that most reflected these national aspects were British Standards generated by Technical Committees that included most stakeholders, e.g. regulators, manufacturers, designers, and end-users, who produced testing standards by consensus.

Major changes have taken place in the recent past, including:

1) the single European market for construction products has come into being;

2) the growth in world trade has increased significantly giving any designer a wide choice of products;

3) there is now a greater awareness of the field of application of fire tests: direct, extended and project-specific field of application, partly as a result of 1).

These changes unltimately led to the generation of the Construction Products Directive (CPD [1]), which laid down common objectives that materials and elements had to satisfy if they were not to compromise the perceived levels of safety that exists in the individual member states.

These targets were transformed into criteria which, in turn, became the basis for differentiating between products within a new pan-European range of fire tests generated by CEN (Committee European de Normalisation). As with British Standards, these European Standards were derived by representative groups of stakeholders, mainly regulators and testing authorities from across the European Union, and accepted by weighted voting. Whilst the European Standards attempted to incorporate procedures and apparatus that were in use throughout Europe, they invariably required major adaptations, or the design of new apparatus to achieve the agreed objectives.

Tests on structural elements to determine the fire resistance of constructions always had a fairly common basis (ISO 834, first published in 1965) around the world. Therefore, harmonization of the larger scale tests generated less radical changes to the procedures than was the case with material tests. European tests developed to determine the ''reaction to fire'' of materials required the generation of new apparatus and procedures, whereas most of the changes were either procedural or related to the instrumentation in the field of fire resistance.

World trade evolved a need for a range of standards to be available around the world to allow international trade in construction products. As in Europe, there are a number of regional trading alliances that allow the free passage of products within those areas but which have little or no relevance in other parts of the world. The International Standards Organization (ISO) was set up to generate standards for use across the globe.

This has a double objective: when multi-national bodies procure products they can be specified against procedures and standards that are available worldwide, and the standards can be adopted quickly and economically by nations that do not have their own standards in place for any product or procedure. As with CEN, these standards have been drawn up with stakeholder input, this time drawn from the whole of the world.

International Standards are not intended to have a divisive influence: they are required to reflect existing national and regional standards as much as possible. As a consequence, a number of the available ISO standards are a fusion between European, American and Pacific Rim Standards.

To reduce the amount of deviation between standards, agreements have been reached, e.g. the Vienna Accord between CEN and ISO. It imposes a need to consider the suitability of each other's existing standards on both organizations, adopting them where possible, rather than generating new tests or product standards.

The final change in relation to the development and use of standards relates to the validity of the application of the results. In prescriptive regulations, it was enough to pass the test prescribed in the legislation. With the move away from prescriptive to functional legislation, much greater responsibility stays with the design team who have to assure that the building will satisfy the fire objectives against which it was designed.

When dealing with most tests, results established at test scale will not be reproduced at the as-built size. However, most standard fire tests (BS, EN and to a lesser extent ISO) have been developed to classify construction products. This provides a basis against which products can be bench-marked. Depending on the specific test, some might provide data that can be used in engineering analysis, but some will simply pass/fail or classify the product. Where data is available, it can be fed into models and algorithms to predict what might happen at larger scale.

To some extent, the details of a test, i.e. the instrumentation and the procedures, are not very important. Minor differences between British Standards, European Standards and International Standards are of lesser importance than knowing, for example, the mode of failure, the distortion during fire exposure and expansion when establishing by how much the size may be varied. The test conditions specified in any British Standard, European Standard or International Standard that are used to prove a product can have a significant result on the classification that it achieves but make little or no difference to the factors used to determine the extended size. Whilst test methods can vary between CEN and ISO for the sake of harmonization, fire and the response of materials and constructions to it is the same the world over. In certain aspects of engineering judgement, the data needed to demonstrate fire safety are independent of the method that generated the information, albeit any extended application process needs to take into account any differences in the test conditions.

Characterizing the behaviour of a material/product for engineers in order to predict the fire performance of a structure might not always need the product to be tested. It is common practice for a construction to have its fire performance "assessed" in lieu of the testing. This is based upon the results of tests on variations of the material or construction, or by using public domain/generic data, which permits the result to be predicted. Indeed, if the field of extended application is to be established, the performance will have to be assessed using justified methods of interpolation and extrapolation where the onus is on the end user to determine whether the method is technically robust.

The full characterization of a material or construction will generally require a well-planned testing programme designed to evaluate some of the critical parameters in order that the others or the interaction between them can be derived by assessment. It is important that the primary evidence used for establishing the field of extended application of a construction is generated using the test for which the extended application is being derived. However, supporting, or secondary evidence to be used in quantifying the performance may be generated using tests that vary slightly in exposure or criteria as long as the potential influence of the variation test conditions is known and quantifiable.

Part of the concept of the European single market is the ability to mark products with a symbol that identifies that the product conforms to the essential (safety) requirements, including fire, in an unambiguous manner. This CE mark may only be awarded to a product if it conforms to any appropriate EN Product Standard or European Technical Approval. The product(s) have to satisfy the criteria in the European Standard or ETAG (European Technical Approved Guideline) related to the product. The field of direct or extended application is expected to encompass the parameters of the product as installed, hence the need for such assessments.

In anything other than a very simple prescriptive legislative framework, performance claims need to consider the field of application of the results, which is covered in this part of BS 476. This includes the use of direct and extended application as derived from the results of the European Standards as part of the way of expressing the result in the context of the Construction Products Directive (CPD) [1].

The family of tests used to characterize the fire performance of a material have unquantified levels of reproducibility and repeatability, partly due to the uncertainty of measurement that accompanies some of the tests, in particular fire resistance tests where the application of some of the instrumentation is operator dependent.

This subject is addressed in this guide. It sets out to identify the scope and role of the British Standard fire test procedures that form part of the British Standard series of fire tests. It also relates them to European and International Standards test methods for characterizing that specific parameter of the product.

1 Scope

This part of BS 476 describes the general principles of fire testing and identifies the specific objectives/outputs of the BS 476 series of test methods and their related European (EN) and International (ISO) Standards.

It provides guidance as to which test should be used for which purpose and how the results from those tests generally define the role of the test in any prescriptive or functional regulatory regime.

It is not intended to be used for determining the conformity of any product or construction to Essential Requirement 2 of the European Construction Product Directive [1].

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 476-3, *Fire tests on building materials and structures – Part 3: Classification and methods of test for external fire exposure to roofs*

BS 476-4, *Fire tests on building materials and structures – Part 4: Non-combustibility test for materials*

BS 476-6, *Fire tests on building materials and structures – Part 6: Method of test for fire propagation on products*

BS 476-7, *Fire tests on building materials and structures – Part 7: Method of test to determine the classification of the surface spread of flame of products*

BS 476-11, *Fire tests on building materials and structures – Part 11: Method for assessing the heat emission from building materials*

BS 476-12, *Fire tests on building materials and structures – Part 12: Method of test for ignitability of products by direct flame impingement*

BS 476-13, *Fire tests on building materials and structures – Part 13: Method of measuring the ignitability of products subjected to thermal irradiance*

BS 476-15, *Fire tests on building materials and structures – Part 15: Method for measuring the rate of heat release of products*

BS 476-20, *Fire tests on building materials and structures – Part 20: Method for the determination of the fire resistance of elements of construction (general principles)*

BS 476-21, *Fire tests on building materials and structures – Part 21: Methods for determination of the fire resistance of loadbearing elements of construction*

BS 476-22, *Fire tests on building materials and structures – Part 22: Methods for determination of the fire resistance of non-loadbearing elements of construction*

BS 476-23, *Fire tests on building materials and structures – Part 23: Methods for determination of the contribution of components to the fire resistance of a structure*

BS 476-24, *Fire tests on building materials and structures – Part 24: Methods for determination of the fire resistance of ventilation ducts*

BS 476-31.1, *Fire tests on building materials and structures – Part 31: Methods for measuring smoke penetration through doorsets and shutter assemblies – Section 1: Method of measurement under ambient temperature conditions*

BS 476-32, *Fire tests on building materials and structures – Part 32: Guide to full scale fire tests within buildings*

BS 476-33, *Fire tests on building materials and structures – Part 33: Full-scale room test for surface products*

BS 4422, *Fire – Vocabulary*

3 Terms and definitions

For the purposes of this part of BS 476, the terms and definitions given in BS 4422 and the following apply.

3.1 assessment

opinion of the likely performance of a component or element of structure if it were to be subjected to a standard fire test

NOTE In a majority of cases, an assessment is the evaluation of a product in lieu of a fire resistance test that could be carried out in a standard size furnace, e.g. 3 m × 3 m for wall furnaces. Examples of such assessments are assessing modest size increases in doors, changes in fixing centres etc. For the product to be given this type of assessment, no significant redesign or reengineering needs to be undertaken. This type of assessment is not limited by furnace design – size increases beyond standard furnace sizes can be included provided there is a valid technical argument given. However, large size increases and complex assessments are the subject of engineering appraisals. Assessments of this type and engineering appraisals can be used for the purpose of demonstrating compliance with the national building regulations[1)], but cannot be used within the context of the CE marking.

3.2 element of construction

part of a building or structure with its own functional identity

3.3 expert opinion

results of a dialogue between a group of experts who are accepted by their peers as being knowledgeable in a particular fire test and the performance of products in that test, in order to derive the extended application rules

NOTE Such dialogue takes place within a recognized and properly constituted forum for an institution of the European Union (EU), such as CEN TC/127. These agreed expert opinions are then transformed into rules that can form the basis of extended application.

1) In the UK, these are the Building Regulations 2000 [2], the Building (Scotland) Regulations 2004 [3], and the Building Regulations (Northern Ireland) 2000 [4].

3.4 expert judgement
view of a recognized expert in a particular fire test and the performance of products in that test that can be used for the purpose of interpreting or applying results of that test in connection with the application of the particular product into parts of works for the purposes of satisfaction of national regulations

NOTE Expert judgement cannot form any part of extended application for CE marking.

3.5 material
physical substance used in manufacturing a product

3.6 product
that which is produced for permanent incorporation in construction works as well as those temporary items of furniture and fittings installed in the completed building

3.7 fields of application

3.7.1 direct field of application (of test results)
outcome of a process (involving the application of defined rules) whereby a test result is deemed to be equally valid for variations in one or more of the product properties and/or intended end use applications

3.7.2 extended field of application (of test results)
outcome of a process (involving the application of defined rules that may incorporate calculation procedures) that predicts, for a variation of a product property and/or its intended end use application(s), a test result on the basis of one or more test results to the same test standard

4 Selection of the appropriate test method

When utilizing test evidence to demonstrate the acceptability of a material/product or element of construction in the context of the envisaged fire hazard, it is important that the correct test is selected to evaluate the appropriate fire performance characteristic(s).

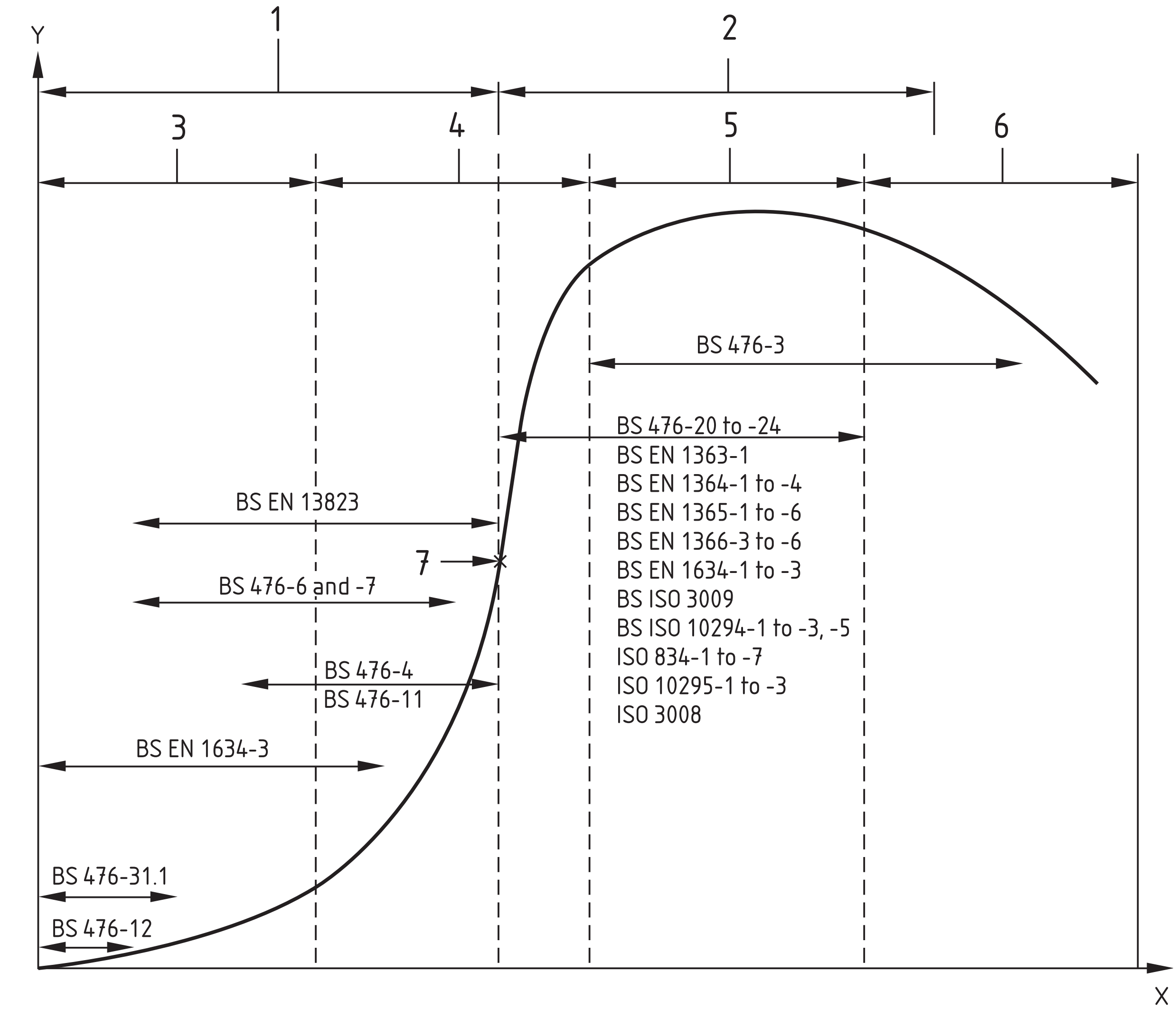
Fire tests set out to measure the following fire characteristics:

- propensity of a material/product to ignite/burn;
- propensity of the material/product to spread fire;
- propensity of material/product to release heat;
- propensity of a material/product to produce smoke;
- ability of an element of construction to contain fire or protect structures;
- ability of an element of construction to contain smoke (doors only).

Figure 1 shows the typical fire development of an unsprinklered, conventionally furnished, modest sized compartment fire. Superimposed on it are the times and temperatures where the fire tests are relevant.

Tests that characterize the ignitability, surface spread of flame, release of heat and production of smoke are known as ‘‘reaction to fire’’ tests, and these are discussed in Clause **5**.

Figure 1 **Typical temperature/time relationship of a fire with the various fire tests superimposed on it to show their limits of applicability**



Key

1	Reaction to fire	6	Decay
2	Fire resistance	7	Flash-over
3	Initiation	X	Time
4	Growth	Y	Temperature
5	Steady state		

Tests that characterize the fire containment properties of an element of construction, including those designed to protect the frame from collapse and to restrict the spread of smoke, are referred to as ''fire resistance'' tests, and are discussed in Clause **6**.

There is an increase in the use of semi-natural fire tests. These expose the interaction between elements and the BS 476 semi-natural tests, and are discussed in Clause **7**.

Since the 1983 edition of BS 476-10 was published, there has been an increase in the understanding of how the tests' outputs are used. All European Standards incorporate a field of application statement, which is necessary if the scope of the performance is to be defined for

CE marking purposes. The need for the output from tests to be subject to a defined field of application is not restricted to European Standards. All fire test results need to be considered in this context.

Broadly, there can be considered to be three sub-categories of field of application:

- *direct* field of application;
- *extended* field of application; and
- *project-specific* field of application.

Direct and *extended* have been defined within CEN in relation to European fire test methods for the purposes of CE marking (see Clause **3**). These definitions are explicit and are intended to ensure that the process of extended application of test results within Europe is transparent.

It is important to understand the roles of *expert opinion* and *expert judgement* within the context of CE marking and the process of standardizing extended application rules. Expert judgement does not form any part of the extended application process for CE marking.

When carrying out an extended application, it is necessary to identify all of the parameters that might change or, in the case of a project-specific field of application extension, the actual parameters that have changed, and to identify the factors that will change for each parameter in turn. It is then necessary to consider the influence of the factors on each of the relevant criteria in turn.

In some cases, the influence on the criteria can be quantified using appropriate mathematical techniques, or can be based upon rules developed and agreed by industry consensus. In many cases, the influence can be resolved solely by expert judgement.

These differences are significant when extended application is carried out for the purposes of CE marking of construction products. In such cases, in an attempt to ensure that extended applications are generally accepted across the Member States of the EC, expert judgement is excluded from the process. However, expert judgement is accepted for purposes outside of CE marking and might be accepted when demonstrating conformity to the requirements of the national building regulations[2)].

Field of application is discussed in greater detail in **5.3**, **6.7** and **8.3**.

2) In the UK, these are the Building Regulations 2000 [2], the Building (Scotland) Regulations 2004 [3], and the Building Regulations (Northern Ireland) 2000 [4].

5 Reaction to fire tests

5.1 Principles of the tests

Reaction to fire tests are used to characterize the performance of construction products and/or materials in terms of their contribution to the initiation and growth stages of a fire, leading up to flashover (see Figure 1). The initiation and growth stages of a fire can be broadly divided into a series of important contributory characteristic parameters:

- ignition;
- flame spread;
- heat release rate;
- smoke production rate;
- area of fire involvement;
- time to flashover.

It is as a result of the need to characterize these parameters for construction products and/or materials that the BS 476 series of reaction to fire test standards evolved over the years. The initiation and growth stages of a fire are fundamental to the life safety of building occupants. The underlying philosophy is that, if a fire starts, its rate of growth should be such that there is adequate time for the building occupants to escape to a place of safety without being injured.

The specific requirements in terms of acceptable levels of fire growth will vary depending upon factors including:

- building types;
- building use;
- building design;
- environmental influences;
- potential ignition sources and locations;
- fire load.

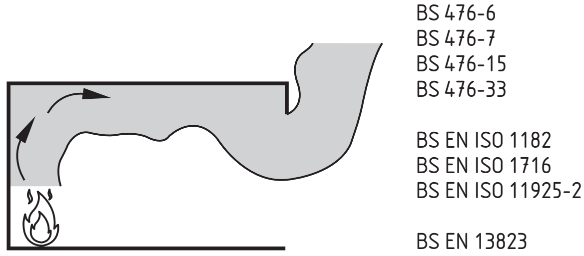
These factors are important in defining the fire scenario relevant for each test.

Each of the fire test methods seeks to assess a specific characteristic parameter of the construction product and/or material within the details of the specific test scenario. Comparative levels of performance are defined in some of the methods of test as classes of performance. These tend to be the test methods that are used to demonstrate conformity to the requirements of regulations, e.g. the building regulations in the UK[3]. For other test methods, there are no associated classifications. Some of these test methods are used within the areas of fire safety engineering and/or forensic fire studies.

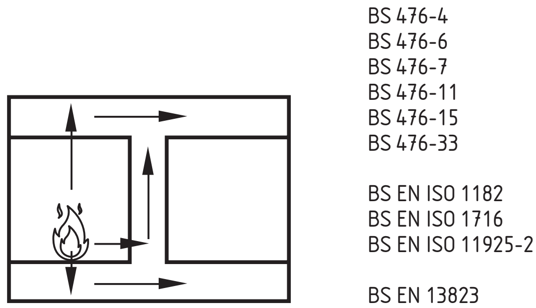
Figure 2 shows a series of schematic illustrations of fire growth mechanisms that commonly occur in buildings. For each case, the test methods available for characterizing the fire performance have been listed.

[3] Building Regulations 2000 [2], Building (Scotland) Regulations 2004 [3], and Building Regulations (Northern Ireland) 2000 [4].

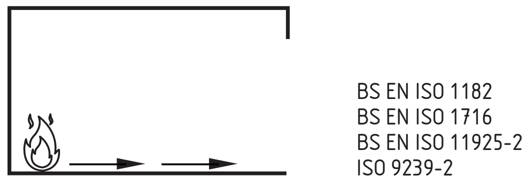
Figure 2 **Possible fire growth mechanisms**



a) Fire growth on internal linings leading to flashover



b) Concealed spaces (e.g. ceiling voids, floor voids, shafts or cavities)



c) Flame spread on floorings

When a construction product has to demonstrate conformity to the Essential Requirements laid down in the Construction Products Directive [1] and for the purposes of CE marking, this can only be accomplished by the construction product conforming to a European Technical Specification (hEN or ETAG), in which case only the European (EN) fire tests and relevant European classification standard will be specified.

5.2 Specific reaction to fire tests

5.2.1 BS 476-4

This standard specifies a test method for determining whether building materials are non-combustible by measuring the temperature rise caused by heating of a specimen in a tubular furnace or observing the duration of any specimen flaming. It can be used for classifying the performance of:

- internal surface linings (e.g. ceilings and walls);
- internal surfaces of concealed spaces and cavities;
- external surfaces of buildings (excluding roofs);
- insulation materials.

The following test methods are published by CEN and ISO, but are not equivalent to BS 476-4. They may be used to determine European classifications in accordance with BS EN 13501-1 equivalent to the national classes for use within the context of the building regulations in the UK[4)]:

- BS EN ISO 1182;
- BS EN ISO 1716.

5.2.2 BS 476-6

This standard specifies a method of test for determining a comparative measure of the contribution to the growth of a fire by a flat material, composite or assembly. It is intended for assessing the performance of:

- internal surface linings (e.g. ceilings and walls);
- internal surfaces of concealed spaces and cavities;
- external surfaces of buildings (excluding roofs).

The following test methods may be used for deriving European classifications in accordance with BS EN 13501-1 equivalent to the national classes that require BS 476-6 for use within the context of the building regulations in the UK[4)].

- BS EN 13823;
- BS EN ISO 11925-2.

These reaction to fire European Standards are not equivalent to BS 476-6 because they measure different fire characteristics. However, a classification system based upon these test methods has been developed and adopted within Member States of the EC, as have national classifications for a range of construction products. As a consequence, a table of equivalent classification requirements was produced within the context of the guidance in support of building regulations in the UK[5)].

The following International Standard is used to assess similar fire characteristics:

- ISO 5660-1.

5.2.3 BS 476-7

This standard specifies a test method for determining the lateral spread of flame over the surface of an essentially flat material, composite or assembly. It is intended for assessing the performance of:

- internal surface linings (e.g. ceilings and walls);
- internal surfaces of concealed spaces and cavities;
- external surfaces of buildings (excluding roofs).

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4) Building Regulations 2000 [2], Building (Scotland) Regulations 2004 [3], and Building Regulations (Northern Ireland) 2000 [4].

5) These are Approved Document B (ADB) [5] for England; Technical Handbook, Section 2 [6] for Scotland; and Technical Booklet E [7] for Northern Ireland.

The following test methods may be used for deriving European classifications in accordance with BS EN 13501-1 equivalent to the national classes based upon BS 476-7 for use within the context of the building regulations in the UK[6]:

- BS EN 13823;
- BS EN ISO 11925-2.

The following International Standard is used to assess similar fire characteristics:

- BS ISO 5658.

5.2.4 BS 476-11

This standard specifies a method of test for assessing the heat emission from building materials in a furnace at a temperature of 750 °C. The method is intended to be used for reasonably homogeneous materials. It may be used for non-homogeneous materials if it is possible to obtain a test specimen representative of the material as a whole. It is usually not suitable for materials composed of discrete layers that are glued together and/or have surface coatings or veneers.

The results of the test can be used for classifying the performance of:

- internal surface linings (e.g. ceilings and walls);
- internal surfaces of concealed spaces and cavities;
- external surfaces of buildings (excluding roofs);
- insulation materials.

The following test methods are standards published by CEN and ISO, but they are not equivalent to BS 476-11. They may be used to determine equivalent European classifications in accordance with BS EN 13501-1 equivalent to the national classes for use within the context of the building regulations in the UK[6]:

- BS EN ISO 1182;
- BS EN ISO 1716.

Finally, the following test method is also required for obtaining a European classification of construction products in the context of the definition of ‘‘materials of limited combustibility’’ provided in the supporting guidance to the building regulations[6]:

- BS EN 13823.

5.2.5 BS 476-12

This standard specifies a test method for the determination of ignitability of materials, composites and assemblies subjected to direct impingement of flames. A range of seven different ignition sources are included within the standard, which are intended to be representative of a number of real ignition sources. The test procedure does not include any imposed external radiation other than from the ignition source itself.

[6] Building Regulations 2000 [2], Building (Scotland) Regulations 2004 [3], and Building Regulations (Northern Ireland) 2000 [4].

The results of the test are used for determining the ease of ignition of, for example:

- internal surface linings (walls and ceilings);
- external surfaces;
- floorings;
- temporary sheeting materials used during refurbishment and construction works.

The following test method is not explicitly used within the context of the building regulations in the UK[7]. However, it could be used to assess similar fire characteristics:

- BS EN ISO 11925-2.

5.2.6 BS 476-13

This standard specifies a test method for examining the ignition characteristics of exposed surfaces of essentially flat materials, composites or assemblies. Specimens are orientated horizontally and subjected to externally imposed irradiances at fixed levels.

The results of the test are used for determining comparative ignitability performance of, for example:

- internal surface linings, materials, composites or assemblies;
- internal surfaces of concealed spaces and cavities;
- external surfaces;
- floorings;
- services including pipes and cables.

This test method is identical to ISO 5657.

5.2.7 BS 476-15

This standard specifies a method for assessing the heat release rate of essentially flat products exposed to controlled levels of radiant heating with or without an external igniter. The specimens may be tested in either the vertical or horizontal orientation and are subjected to externally imposed irradiances at fixed levels.

The results of the test are used for determining comparative heat release rate performance for different types of products, including:

- internal surface linings, materials, composites or assemblies;
- internal surfaces of concealed spaces and cavities;
- external surfaces;
- floorings;
- services including pipes and cables.

This test method is identical to ISO 5660-1.

5.3 Field of application

Within the field of reaction to fire, direct field of application is the application of the test results for a material or product in accordance with the details of how they were tested. Specifically, this means that

[7] Building Regulations 2000 [2], Building (Scotland) Regulations 2004 [3], and Building Regulations (Northern Ireland) 2000 [4].

the mounting and fixing arrangement used in the test method is applied directly to the use of the material or product in real end use conditions. Any variation in the physical properties or thickness of material or product in the end use application, or variations in the mounting and fixing arrangements, should be either quantitatively determined through a carefully designed test programme or, in some cases, be the subject of an assessment or expert judgement by an expert. EN test methods give clearly defined rules for direct field of application. The standard used for classifying products using test data from reaction to fire tests, BS EN 13501-1, is currently being revised to enable the use of extended application rules.

5.4 Relationship between reaction to fire tests and building fires

The BS 476 reaction to fire tests were basically developed to rank products and materials in terms of specific performance characteristics. The outputs of BS 476-4, BS 476-6, BS 476-7, BS 476-11 and BS 476-12 are simply a classification of a derived parameter that has no real physical meaning, other than comparison of one material or product with another. These tests do not provide data that can be related to real building fire performance in a quantitative sense or that can be used as input parameters to modelling approaches.

However, there are two exceptions. BS 476-13 and BS 476-15 provide physical data that are characteristic of the material or product. As such, these data can be used as input data to modelling approaches for predicting fire growth within buildings and as such can be correlated with real fire behaviour. The limitation of these test methods relates to the scale of the specimen that is tested and their inability to adequately represent important factors in determining performance such as joints, fixings and air gaps.

6 Fire resistance tests

6.1 Principles of the tests

Fire resistance tests are used to measure fire behaviour/performance of elements of construction when they are exposed to a fully developed fire (see Figure 1). Simple elements (such as beams and columns) are required to withstand the stresses imposed on them by the use and behaviour of the building whilst they are exposed to developed fire conditions, in order that they do not collapse, in total or in part. Other more complex elements are required to contain the fire to within prescribed areas as well as, if appropriate, carrying the prescribed loads.

A fully developed fire is one that occurs post-flashover. Whilst the elements that are tested for fire resistance also help to contain the fire and the products of combustion in the period between ignition and the point of flashover, this contribution is not taken into account either in the claimed performance or in the test conditions used. The ability of an element to continue to carry a load and/or to contain a fire during the post-flashover conditions, as characterized in the thermal exposure conditions prescribed in the test (see **6.2**), is expressed in terms of the time for which the element meets the prescribed criteria.

When a fire flashes over into the fully developed fire state, the fire dynamics are such that the fire will spread and engulf more of the structure unless barriers are installed that inhibit the natural growth and movement of the fire gases.

There are many routes of potential fire spread (see Figure 3). In principle, tests have been generated to establish the ability of all potential barriers designed to prevent such spread. The current tests have been superimposed on the potential routes of fire spread to help identify which test is most appropriate for protecting against fire spread for the risk under consideration.

6.2 Thermal exposure conditions of the tests

The standard fire resistance tests follow the temperature–time relationship approximated in Figure 1. In theory, this exposure condition is the basis of all fire resistance tests whether they are defined in British Standards, European Standards, International Standards or most of the world's national standards. In practice, whilst the test is controlled to follow these test conditions, the actual thermal dose/heat flux received by the specimen will be influenced by the time constant of the temperature measuring device, the nature of the furnace fuel and the furnace geometry.

There are significant differences between the conditions experienced by a specimen tested to BS 476-20, BS EN 1363-1 or ISO 834-1, solely in respect of the thermal dose, regardless of the other procedural differences that exist between the various standards.

For this reason, the tests should not be automatically considered interchangeable, albeit data and results from one regime may be used to substantiate the performance of an element against another regime, by persons with an adequate detailed knowledge of the differences between the test regimes and of the behaviour of the element or product under fire test conditions. Adequacy in this context is judged from the level of direct experience of fire testing to the two regimes involving the product or element in question.

A more detailed analysis of the influence of differences between furnaces and measuring equipment is found in ISO/TR 22898.

The actual thermal exposure condition utilized in the fire resistance test (as defined in BS 476-20) represents a modest sized, traditionally furnished and fenestrated compartment (sometimes erroneously referred to as a cellulosic curve).

It can be seen from Figure 3 that the fire exposure defined in these standards is not always appropriate, e.g. dampers, lift doors (from the shaft side), external walls (from the outside), penetration seals across riser shafts. Regardless of this, fire resistance is invariably characterized by the same temperature–time relationship, which means that, in any application other than in a regulatory compliant prescriptive solution, there is a need for the user of the output to understand the limits on the application of the results/data obtained.

Figure 3 **Routes of potential fire spread**

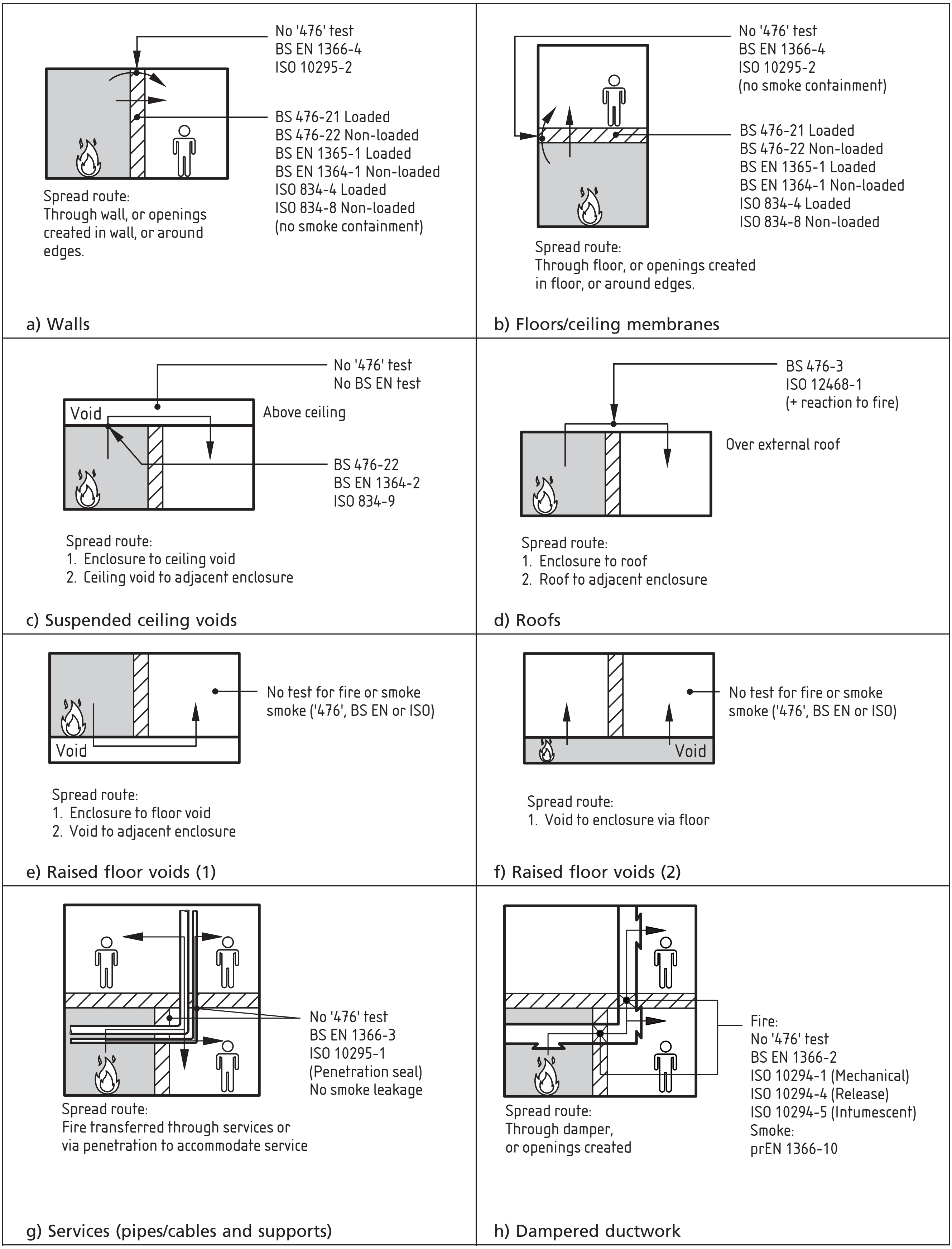
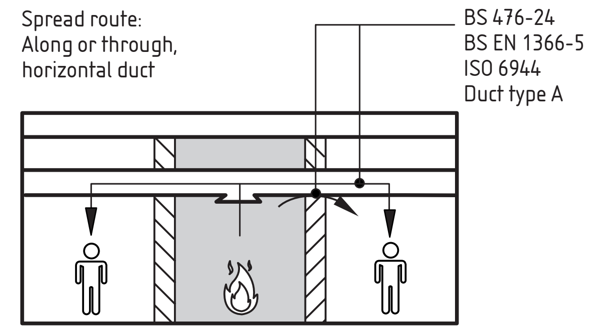
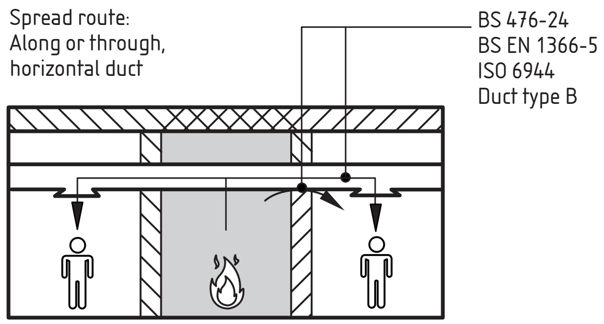


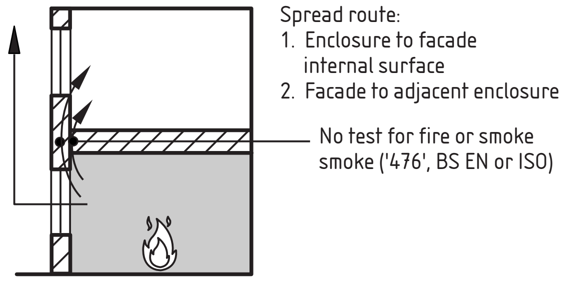
Figure 3 **Routes of potential fire spread** *(continued)*



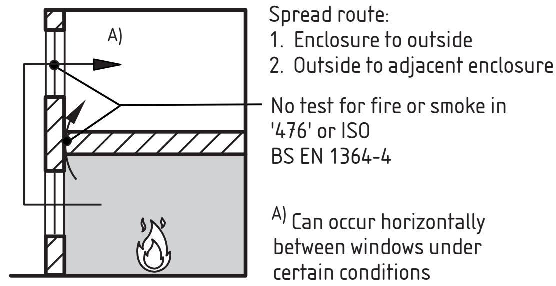
i) Undampered horizontal ductwork (1)



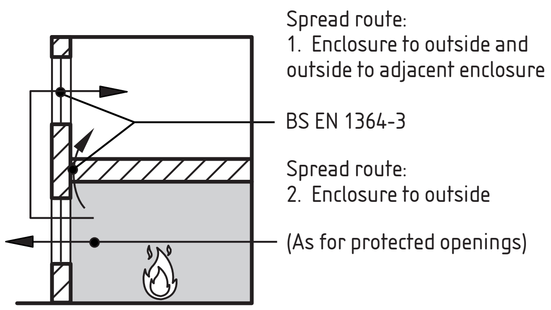
j) Undampered horizontal ductwork (2)



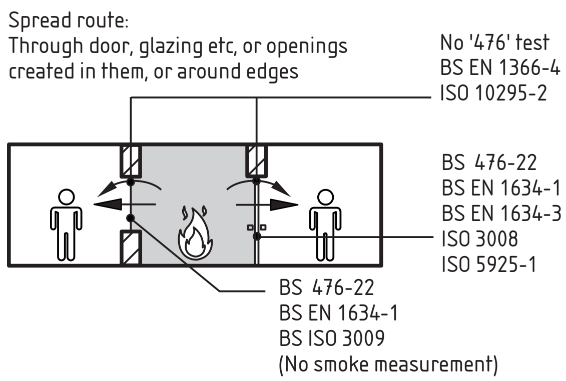
k) External walls/windows (1): non-fire-resisting spandrel and glazing



l) External walls/windows (2): fire-resisting spandrel; non-fire-resisting glazing



m) External walls/windows (3): fire-resisting spandrel and glazing



n) Protected openings

6.3 Pressure differential conditions in the test

In addition to the prescribed temperature–time conditions, the fire resistance test embodies a prescribed pressure differential between the exposed and non-exposed faces of separating elements. There is no pressure differential when the element under test only has a loadbearing function.

As with the temperature–time scenario described in **6.2**, the pressure differential specified in BS 476-20 is representative of a conventionally fenestrated and furnished space of normal, 2.5 m to 3.5 m storey height. For specific tests, e.g. BS 476-23 for suspended ceilings protecting steel beams (in lieu of cladding them) and BS 476-24 for ventilation ducts, the pressure conditions are varied from those given in BS 476-20.

However, in BS 476-21 and BS 476-22, it is normal for separating elements to have a neutral pressure axis set at 1.0 m above the "notional" floor level and to assume a pressure differential that increases with height at a rate of 8.63 Pa/m. Note that this is an assumption that only holds true at 30 min because a major component in this assumption is the gas temperature which is both lower and higher at different times doing the test, resulting in a controlled pressure differential of 20 Pa just below the top of the furnace.

Even if one ignores that many spaces will have a ceiling or roof to the space that is well in excess of the nominal 3 m, and in which case the position of the assumed neutral axis is incorrect, there are many applications where the prescribed pressure regime is not applicable.

In BS EN 1363-1 and its associated standards, the neutral pressure axis is set at only 0.5 m above the notional floor level, producing a pressure differential at the head of the construction 4 Pa greater than in BS 476. ISO 834-1 specifies a neutral axis at the same height as in BS EN 1363-1, as a result of adopting as much of the European Standard as is possible under the Vienna Agreement.

The data generated by the test conditions of BS 476-20 or BS EN 1363-1 will be comparable at the head. The difference in pressure between these tests is unlikely to be the cause of major differences in the outputs, except that a shift in neutral pressure axis can create failures local to the neutral axis when considering combustible constructions, especially if there is a metal interface.

6.4 Criteria of failure in the test

The criteria of failure used in the BS 476-20 series of tests are designed to prevent fire spread as a result of collapse of the structure or as a result of increased heat flow from the exposed to the unexposed face. Criteria have been set in BS 476-20 that define the limiting conditions in respect to the passage of flames and hot gases and the temperature rise on the protected face.

The three main criteria are:

- loadbearing capacity (R);
- integrity (E);
- insulation (I).

The European Standards, based upon BS EN 1363-1, using the European classification system (BS EN 13501-2) have assigned the code letters given in parentheses above to the separate criteria, but are otherwise similar.

The resistance to the passage of flames and hot gases is measured by means of a cotton fibre pad placed in the gas stream immediately over any gap or crack, when there is no risk of the pad igniting as a result of any other mechanism, e.g. radiation, as defined in the appropriate standard, or by means of gap gauges when the cotton pad cannot be used. The ignition of the cotton fibre pad, or the use of the gap gauges, has no reference scenario outside the use of the standard in the context of product approvals or when complying with prescriptive regulations. The risk that such an event represents is difficult to evaluate in conformity to functional regulations and a quantifiable method of evaluating the flow of hot gases would be preferred. Further information can be found in ISO/TR 22898.

The maximum and mean temperature rise criteria on the unexposed face are identical in British, European and International Standards for demonstrating conformity to the insulation criteria (I). The reference scenario supporting the maximum temperature rise of 180 °C and the mean temperature rise of 140 °C would appear to have been lost in the passage of time: it is difficult to relate these temperatures to a particular hazard, especially for the shorter durations of fire separation referenced in modern building codes. The criterion of insulation does have a common failure regardless of which of the standards are used. In BS EN 1634-1 (fire doors), more measurements are made on the temperature of doors than is required in BS 476-22.

Collapse is obviously the ultimate failure criteria for loadbearing capacity but, because this can be very damaging to testing facilities, universal acceptance exists between BS 476-21, BS EN 1365-1, BS EN 1365-2, BS EN 1365-3 and BS EN 1365-4 for the rate of deflection and the magnitude of the maximum deflection, namely:

- a maximum deflection of $L/20$; or
- a maximum rate of deflection of $L^2/900d$ when $L/30$ is exceeded;

where:

L is the span; and

d is the depth of the section.

Radiation is not a requirement specified in BS 476-20, albeit it is recommended that it is measured. In BS EN 1363-1, radiation/heat flux is a requirement and is set at 15 kW/m^2 measured at a distance of 1.0 m on the centre axis of the specimen.

6.5 Use of data and outputs from fire resistance tests

The results of a fire resistance test can be used in a number of ways:

- to satisfy the requirements of a specific part of a prescriptive regulation (not normally concerned with the field of application);
- to permit a product or element of construction to demonstrate conformity to the essential requirement (ER2) by means of an applied CE mark, by reference to an applicable European harmonized technical specification;
- as a way of satisfying a regulatory requirement where conformity is demonstrated by means of a field of application report (see Clause **4**) applied to the test result;
- to provide data in support of an assessment of the fire resistance of an element that cannot be tested due to restrictions on size, unavailability of materials, costs, timescale, etc.;
- to provide data for the purpose of quantifying the probable behaviour of an element to be used as part of a fire engineered safety strategy;
- to provide data (historically) for use in formulating design codes dealing with the predicted performance of elements, e.g. BS 5268-4 and various parts of BS 5950.

When used for the first of these applications, the test specified in the guidance to regulations is expected to have been performed and the test specimen is expected to meet the requisite specified duration of conformity to the relevant criteria. In a simple prescription, there is no requirement for the specimen size, the fixing/restraint conditions, the load (if loaded), etc., to be evaluated for confirmation that the application is correct, i.e. is within the field of application. As a result, the test evidence can be to BS 476, BS EN 1363, ISO 834, or whatever test is specified within the regulations.

When the construction has to demonstrate conformity with the Essential Requirements laid down in the Construction Products Directive (CPD) [1], this can only be accomplished by the construction conforming to a European Standard product standard or an ETAG (European Technical Approved Guideline), in which case these documents will specify only the European (EN) tests and relevant European classification standard. Evidence generated by subjecting the element to other tests, e.g. BS 476, is not useable for the purposes of CE marking.

6.6 Specific fire resistance tests

6.6.1 BS 476-20

This standard specifies the heating conditions, pressure regime, basic procedures, equipment specification and general criteria required for fire resistance testing (possibly excluding some of the equipment and criteria necessary for the performance of BS 476-24, which had not been published at the time of publishing BS 476-20).

Whilst this standard's primary use is for a laboratory to carry out testing, it also provides background information on the use of instrumentation and the design of specimens, which is of value to any organization contemplating a testing programme.

An important aspect of BS 476-20 is an appendix giving guidance information, which gives background to the principles and philosophy of fire resistance testing, and for which no similar publication exists elsewhere.

Equivalent European Standard:

- BS EN 1363-1.

Equivalent International Standard:

- ISO 834-1 (together with the commentary document ISO/TR 834-3).

6.6.2 BS 476-21

This standard specifies methods, instrumentation, monitoring procedures and specific criteria for the determination of the fire resistance of the following loadbearing elements:

- beams;
- columns;
- floors/roofs;
- walls.

This standard is of value to laboratories and sponsors alike and, as with BS 476-20, the appendix gives useful background guidance, although this is not as extensive as that given in BS 476-20.

Equivalent European Standards:

- BS EN 1365-1 (walls);
- BS EN 1365-2 (floors and roofs);
- BS EN 1365-3 (beams);
- BS EN 1365-4 (columns).

Equivalent International Standards:

- ISO 834-8;
- ISO 834-9;
- ISO 834-10 [8)];
- ISO 834-11 [9)].

6.6.3 BS 476-22

This standard specifies the methods, instrumentation, monitoring procedures and specific criteria for the determination of the fire resistance of the following non-loadbearing elements:

- partitions (non-loadbearing walls);
- fully insulated door assemblies;
- partially insulated door assemblies;
- uninsulating door and shutter assemblies;
- ceiling membranes (horizontal partitions);
- glazed (vertical) elements.

This standard is of value to laboratories and sponsors alike and, as with BS 476-20, an appendix gives detailed background guidance. In the case of fire doors, it explains the importance of various degrees of insulation in the function that the door is to perform.

Equivalent European Standards:

- BS EN 1364-1 (partitions);
- BS EN 1364-2 (ceiling membranes);
- BS EN 1366-2 (fire dampers);
- BS EN 1634-1 (fire doors and shutters).

Equivalent International Standards:

- ISO 834-8 (partitions);
- ISO 834-9 (ceiling membranes);
- ISO 3008 (fire-resisting doors);
- BS ISO 3009 (glazing);
- BS ISO 10294 (fire dampers).

6.6.4 BS 476-23

This standard differs from the others parts of BS 476 as it is a method of testing those elements that do not have inherent fire resistance, but which make a contribution to the fire resistance of other constructions and structural elements. The standard specifies methods (especially where the normal temperature/time/pressure regime differs from that

8) In preparation as ISO/IEC WD 834-10.
9) In preparation as ISO/WD 834-11.

given in BS 476-20), instrumentation, monitoring procedures and specific criteria for evaluating the contribution made by the following elements:

- suspended ceilings used in lieu of cladding to structural beams;
- intumescent seals for use on timber doors.

The suspended ceiling test has a very limited field of application, only demonstrating that normal fire protection can be omitted from a beam if the ceiling is able to keep the temperature of the beam below a ''deemed-to-be'' critical temperature of 400 °C.

Because the ceiling only replaces cladding, uniquely this test is carried out with a neutral pressure differential at the ceiling level as it is not evaluated for its fire separating capability. It does not, therefore, measure the contribution that the ceiling can make to a floor of any kind. If the ceiling is required to protect a floor, it should be tested to BS 476-21 as an integral part of the overall assembly.

The test for the contribution of an intumescent seal to the fire resistance of a timber door assembly is performed on a reduced size, simulated fire door and is used primarily in support of product certification, as a quality control test.

Equivalent European Standards:

- no directly comparable European Standards.

Equivalent International Standards:

- no directly comparable International Standards.

6.6.5 BS 476-24

This standard specifies the methods, instrumentation, monitoring procedures and criteria for evaluating fire-resisting ductwork. It incorporates two different methods: ducts that pass through a compartment without openings (duct A, where only the outside of the duct is exposed to the fire), or terminate in a compartment with openings (duct B, where both the inside and outside of the duct are exposed to fire).

BS 9999 recommends fire-resisting ductwork as one method for the fire protection of heating, ventilation and air-conditioning (HVAC) systems. Some of the most common applications in UK and other countries specifying BS 476-24 include:

- smoke extraction ductwork;
- kitchen extract ductwork;
- staircase and lobby pressurization, lift shaft ventilation, fresh air makeup.

Some of these represent situations where fire-resisting dampers are not recommended. Fire-resisting ductwork might be an appropriate solution.

There are some differences between BS 476-24 and BS EN 1366-1. In particular, BS EN 1366-1 provides for leakage to be measured and more guidance on where to position surface thermocouples in the test is given. (Laboratories testing to BS 476-24 tend to use BS EN 1366-1 for guidance on location of surface thermocouples.) However, no stability requirements are specified in BS EN 1366-1. For the purposes of CE marking, classification of the product should be carried out in accordance with BS EN 13501-3.

In relation to smoke extraction ducts, there is two additional European Standards:

- BS EN 1366-8 (classification of the product should be carried out in accordance with BS EN 13501-4);
- BS EN 1366-9.

The current edition of ISO 6944 is identical to BS 476-24. However, it should be noted that ISO 6944 is currently being revised and might be very similar to BS EN 1366-1. It is anticipated that this will be published as ISO 6944-1 in due course. ISO 6944-2 is under development for kitchen extract ducts. These ducts will be exposed to a higher temperature inside the duct than in the procedure of ISO 6944-1.

Equivalent European Standard:

- BS EN 1366-1 (classification of the product should be carried out in accordance with BS EN 13501-3).

Equivalent International Standard:

- ISO 6944 (current edition identical to BS 476-24).

6.7 Field of application

There is now a greater awareness of the need to establish the influence of an element of construction on the fire resistance, resulting from variations in the critical parameters, e.g. size, orientation, design, component materials and construction methods.

It is often impossible to test every possible variation in an element. The field of application of a tested construction is generally subjected to an expert analysis to establish the range of variations to which the result/classification can be applied.

The impact of furnace/specimen sizes on the field of application in respect of the size of the element is obvious, but there are many other factors that need to be considered in the determination of the field of application. Guidance on the subject is given in BS ISO TR/12470 and can also be found in certain national standards such as PD 7974-3.

Direct application is normally applied to all of those variations where the change in the element is obviously beneficial, e.g. the stress in an identical element is lower or the size of the tested member/section is greater.

Project-specific applications are used when the characteristics of the building are considered in a holistic manner in order to establish whether the results of a test can be usd to permit the tested element to be used for an actual application. This holistic approach considers whether the specimen benefits or not from the conditions on site such as better fixings, reduced deflections etc. Project-specific applications should not be used for other projects.

In quantifying the degree to which the result can be applied to non-tested assemblies/products, there are two basic quantifiable techniques that are used.

a) *Interpolation* allows the effect of variations in a component/construction to be established by testing at the extreme ranges of the parameter under investigation and determining the trend between them. This established pattern enables the performance of a component/construction with critical parameters between the two extremes to be assigned a "likely" performance. The trend should not be assumed to be linear because the relationship between the changes in the parameter could be quite complex. The evidence needs to be thoroughly examined. Graphical techniques based upon single curve fitting procedures can be misleading, especially with the lack of repeatability and reproducibility that is inherent in fire resistance testing (see **6.1** and **6.2**). Because the limits of the critical parameter have been tested, interpolation is more appropriate for direct field of application.

b) *Extrapolation* allows the effect of variations in a component/ construction to be established where the change in the parameter extends beyond the range established by previous testing. Extrapolation requires a fire model being developed on the basis of one or more tests and other pertinent data on fire performance. Factors that can be considered are: dimensional, material, or design variations, usually outside the range of variables examined by tests. The reliability of extrapolation depends upon the exactness of the fire model used and this needs to be specified when the procedure is undertaken.

A number of factors affect the ability to make interpolations and extrapolations. Where it is known beforehand that this extension of data will be required, all relevant parameters should be controlled and, if necessary, additional measurements made to facilitate this work. There are three main parameters which need to be considered for this purpose:

1) dimensional variations: length, width, thickness, etc.;
2) material variations: strength, density, insulation, humidity;
3) load or design variations: load, boundary conditions, jointing, fixing methods.

The relevance of these parameters will depend upon the type of specimen and the changes being considered.

It is only possible to indicate some of the factors which might be relevant in a few typical cases. For this purpose, the specimens can be divided into loadbearing and separating categories. In the former case, the main interest is to ensure that the variant will be able to successfully support the loads. In the latter case, the main interest is that it will retain integrity and insulation characteristics. In some cases, both concepts will apply.

The main loadbearing elements for which simple rules are possible are:

- insulated steel systems;
- concrete constructions, depending upon reinforcement protection; and
- wood constructions where the rate of charring is a critical factor.

In the case of steel elements, the effect of varying the size, the load, and the design concept will result in a new critical goal for the insulating material. For concrete elements, a similar approach is possible for simple systems where either the steel or the concrete has to be prevented from reaching the critical state. With more complex arrangements, the redistribution of stresses and strains also has to be taken into account. Most timber structures can be analysed on the basis of considering the ultimate strength of the uncharred section. Guidance on some typical constructional systems in these materials is given in BS 5268-4.2.

Interpolation and extrapolation methods can be divided into the following four groups, each with an increasing degree of sophistication. Precise rules and application limits will need to be agreed upon by the national bodies using the procedures:

- *quantitative design rules based on fire tests and general concepts*. Such rules are only useful for experts in the fields;
- *quantitative design rules (or empirical rules) based on fire tests that attribute a certain value to the fire resistance contribution of materials or products*, with safeguards against unrealistic results;
- *regression techniques*: examination of a number of parameters in a systematic series of tests and the determination of a relationship using regression techniques to obtain the best fit;
- *physical models*: development of a physical model relating fire resistance to material properties either from first principles or by working from the test data. After the model has been validated, fire resistance can be determined by input of the appropriate properties.

Caution should be exercised in regard to the use of interpolation or extrapolation techniques for the derivation of fire resistance classifications in cases where there is insufficient data or where the construction under consideration is significantly unrepresentative of the fire tested construction.

See also ISO/TR 10158.

6.8 Relationship between fire resistance and building fires

In considering this relationship, it is necessary to understand that determination of fire resistance is by complete test procedure. When making comparisons with building fires, attention is usually focussed on the time–temperature curve and its relation to the temperatures and growth rates achievable in ‘‘real’’ compartment fires under various fire scenarios.

A standard test is used to qualify products or elements of construction for classification according to defined fire resistance performance criteria as a way of providing a basic level of fire safety in buildings. This is achieved by applying a fire resistance test result through some code or prescriptive document that will determine the performance needed in a given situation. Adequacy of the approach is monitored by practical feedback, which generally means avoidance of an unacceptable failure rate.

The result of the test is stated in terms of a fire resistance classification or rating, expressed as a period of time for which certain criteria are satisfied.

This period of time represents a relative ranking of performance and cannot be related directly to a particular building situation. It is important to recognize this transformation from an arbitrary time base to the engineering performance of buildings in fire, made through the building codes.

The actual performance achieved in a fire resistance test is intimately connected with the test conditions, the extent to which the test models the building, and the criteria applied to determine failure. A small change in conditions for failure, particularly with respect to integrity and thermal insulation, could have a significant effect on the rating obtained.

In particular, the time recorded in the fire resistance test in respect of these criteria bears no direct relationship to the failure times in real fires. This has been recognized in principle from the inception of the test.

The verification of performance by carrying out fire tests can be traced back about 100 years. These early tests used gas, oil and wood for fuel, or even a combination of these. With such a wide variety of test conditions, it was difficult to compare and evaluate the findings.

The first moves towards a more uniform approach were in the USA when, in 1918, an ASTM committee introduced a time–temperature relationship close to current ISO standards. The natural time constants of the original furnaces probably had much to do with the originally established time–temperature curve. It is well established over a variety of furnaces, even in different countries, that a furnace once ''on'' the standard tends to ''run itself'', i.e. follow the curve with little operator interference.

A classification system was evolved in which elements lasting for a longer time in the furnace test with respect to chosen criteria were assumed to have the potential for better performance in actual building fires. Ingberg [8], using an equal area concept, was the first to try to express the standard test in real fire terms, deriving an equivalence relationship between a notional fire loading and the measured fire resistance period.

Many later attempts have been, and still are being, made to strengthen the link between the test method and actual building fires. These have been extended to include factors such as ventilation, compartment size, fire loading and the compartment thermal properties. The aim is to be able to quantify the likely fire severity in a building, and hence, through empirically derived relationships, to be able to assign a prescribed fire resistance period to be achieved in the test that will provide sufficient safety. Much of this work has been reviewed by Ödeen [9].

The fire test should be regarded as a way of measuring the comparative response of building elements to fire scenarios that involve an approximation in both the fire and the physical model.

The growth in the application of fire safety engineering in the design and construction of buildings means that there needs to be clarity between the application of the results of a fire resistance test within a prescriptive legislative framework, and the use of the results for providing calculated periods of fire resistance based upon parametric curves.

Materials that are temperature-sensitive rather than time-sensitive may be graded very optimistically by the standard temperature–time conditions described in ISO 834-1. Therefore, whilst the introduction of modifications to the test procedure to make it more realistic should be viewed with caution in the context of prescriptive legislation, it might be sensible to improve the test, or a separate version of the standard, to make it more realistic, to obtain a true comparison of materials in the context of real-fire performance.

7 Semi-natural tests

7.1 Principles of the tests

Furnace-based tests carried out to evaluate the fire containment capability of constructional elements are limited in their scope and application by:

- the size of the furnaces; and
- the lack of interaction between adjacent elements (i.e. the three-dimensional aspects).

As a consequence, an increasing number of fire tests are being performed in order to explore the relationship between elements, and also to test assemblies much larger than furnaces can accommodate. These tests can be used to establish the fire containment capability of constructions that consider the three-dimensional behaviour, which might be beneficial or detrimental to the performance depending upon the restraint and fixity that one element can provide to the other.

Similarly, most reaction to fire material tests are performed on bench scale specimens that exhibit even less of a relationship to the real fire behaviour than fire containment tests. Semi-natural testing may be performed on materials in order ascertain scale effects, dynamic fire behaviour and the influence that this might have on the bench scale results, and characteristics such as the total rate of heat release.

Semi-natural tests are influenced by more ambient/environmental factors than laboratory performed tests and therefore the design, setting-up and monitoring of such tests is critical if the tests are to have any reproducibility, repeatability or broad validity. Both BS 476-32 and BS 476-33 tests need to be performed as part of a well managed, preferably quality controlled, testing regime.

7.2 BS 476-32

This standard specifies procedures for monitoring instrumentation and parameters for carrying out an evaluation of the ability of elements of buildings to resist a fully developed fire exposure. It cannot be used as a direct basis of classification of a building element, but can be used to demonstrate the capabilities of elements of construction to resist a simulated fire as part of a functional or fire safety engineered approach. It does not set out to identify the behaviour of linings.

Equivalent European Standards:

- no equivalent tests.

Equivalent International Standards:

- no equivalent tests.

7.3 BS 476-33

This is a semi-natural test method for evaluating the fire growth provided by a surface product using a specified ignition source. Whilst a specified ignition source is given, the methodology does not preclude other sources.

The test is identical to ISO 9705. The test does not evaluate the fire containment capabilities of the structure.

Equivalent European Standards:

- no equivalent tests.

Equivalent International Standards:

- ISO 9705.

8 External fire performance

8.1 External fire exposure scenarios for roofs and façades

8.1.1 General

The fire scenario supporting BS 476-3 is designed to give information concerning the hazard that exists from fires spreading to the roof of a building from a nearby fire outside the building itself. This test method is not concerned with the behaviour of the roof when subjected to a fire from within the structure attacking the internal surface (underside) of the roof build up. (In the same way, BS 8414-1 and BS 8414-2 are concerned with the effect of fire spread on the external surface of the structure from a fire source, either originating outside the structure or from fire break-out from a compartment within the primary structure, on to the external face.)

In the cases of both roof and façade fires, it is the fire performance of the external envelope that is of concern and the response of these elements to fire sources which, in themselves, are at the post-flashover stage.

Some of the routes of spread are illustrated in Figure 4. For each case, the test methods that are available for characterizing the fire performance have been listed.

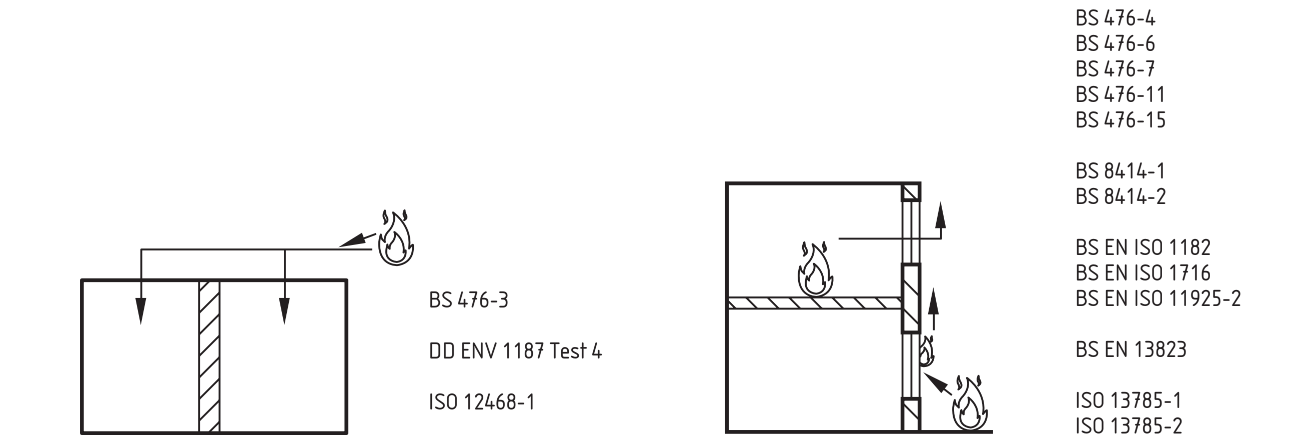
A key area of concern is that these types of fires have the potential to extend over large surfaces of multi-compartmented structures. They therefore have the potential to bypass any compartmentation controls within the structure, allowing fire re-entry to the structure via the external surface. Documents such as BR 135 [10] discuss these issues in detail in relation to external fire spread concerns on façade structures.

8.1.2 Thermal exposure conditions and separation distances

8.1.2.1 Roofs

Scenarios identified as being of concern regarding the external fire performance of roofs result from the exposure of the roof systems to post-flashover fires that arise from other nearby structures or compartments within the existing structures. Therefore, small-scale single point ignition sources are only considered in the preliminary test in BS 476-3 where no imposed radiant is used.

Figure 4 **Routes of fire spread on roofs and external face of buildings**



a) External fire spread over roofs

b) Fire spread up external face of buildings

The thermal exposure condition used in the BS 476-3 test assumes a radiant heat load of 12.5 kW/m^2 over a 60 min period, the penetration part of the test, and this is regarded as the intensity incident on a roof 7.6 m above ground level from a fire 13.7 m away in a building with a façade of 15.2 m × 15.2 m and 50% window openings.

In the spread of flame test, however, the intensity of radiation varies over the exposed surface of the specimen. The distance to which the fire spreads downwards over the specimen gives a measure of the minimum intensity required to ignite the surface when a small ignition source such as a brand is present. The standard notes that the intensity can be interpreted as being equivalent to the distances given in Table 1, between an exposed roof 7.6 m above ground level and a burning building with a façade 15.2 m × 15.2 m and 50% window openings.

Table 1 **Intensity of radiated heat (based on BS 476-3:2004, Table B.1)**

Radiated intensity of specimen	**Equivalent distance from a 15.2 m × 15.2 m façade with 50% window openings to an adjacent roof**
kW/m^2	m
9.2	18.3
7.9	21.3
5.9	24.4
4.2	27.4
2.5	36.6

The thermal exposure conditions found in DD ENV 1187 and ISO 12468-1 differ significantly both between themselves and those found in BS 467-3.

DD ENV 1187:

- *Method 1* imposes no additional radiant heat to the test specimen other than that generated by a single 300 mm × 300 mm × 200 mm deep mesh basket containing 600 g of wood wool.

- *Method 2* also uses a single wooden brand, consisting of eight pieces of 10 mm × 10 mm × 100 mm pine without any additional radiant heat on the specimen.
- *Method 3* uses two brands 55 mm × 55 mm × 32 mm deep located on the surface of the specimen, together with an imposed radiant heat source of 12.5 kW/m² at the centre of the 600 mm × 600 mm radiant panel zone.

ISO 12468-1 uses two thermal exposure scenarios, depending upon the required classification.

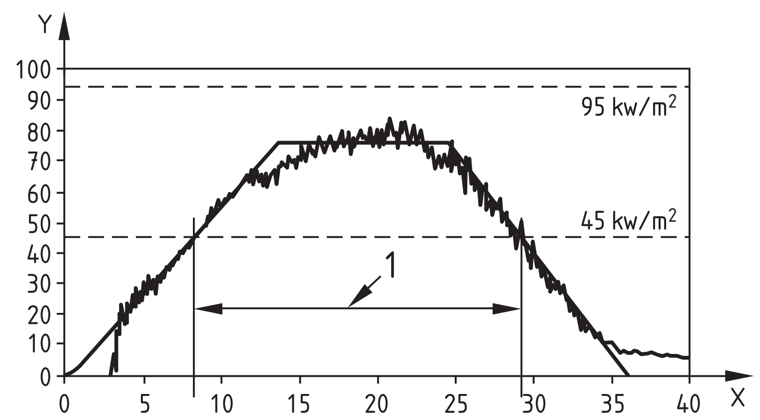
- *Level A*: A large burning brand (18 pieces of beech timber, 19 mm × 19 mm ×150 mm, giving a brand 150 mm × 150 mm × 57 mm) coming from a nearby building and falling onto the roof. Level A considers the effects of wind and additional radiant heat (12.5 kW/m² at the centre of the heating zone).
- *Level B*: A small burning brand (piece of lumber 40 mm × 40 mm × 40 mm with a saw cut 3 mm wide, half the thickness of the brand across the centre of the top and bottom faces, with the saw cuts on the opposite face at right angles to each other) transported by the wind from a remote fire and falling onto the roof. Level B considers the effect of wind but without additional radiant heat.

8.1.2.2 Façades

The BS 8414 test series assumes a fire load from a post-flashover room exiting a window opening and generating a heat load on the surface of the test specimen as shown in Figure 5.

This heat load in the test can be supplied by a specified timber crib without the need for additional calibration of the system, and is based on heat loads typically encountered above the opening of a post-flashover room in a domestic scenario. Other heat sources may be used if designed to follow the profile given in Figure 5. This heat output profile is similar to that used in ISO 12468-1, although it specifies a gas burner to generate the fire load.

Figure 5 **Mean heat flux versus time profile used in BS 8414**



Key

1 Continuous 20 min period

X Time (min)

Y Heat flux (kW/m²)

In both cases, this type of fire source will give rise to flame heights on the surface of the specimen in excess of 1.5 m, typically peaking at around 2 m above the fire chamber opening. The geometry and size of the test specimen will also influence the performance of the system under consideration, hence the move to full-scale tests for these systems away from small-scale elemental studies of component parts.

8.1.3 Wind effects

8.1.3.1 Roofs

Physical factors such as geometry, ventilation and wind effects have the potential to influence the course of a fire event. Since the scenario considered here is that of external fire exposure, the influence of factors such as wind has to be taken into account. BS 476-3 considers the potential effect of wind on the performance of the roof by assuming a wind loading of 6.7 m/s across the surface of the roof covering. In order to simulate the physical effect of this wind on the roof structure under test, a pressure drop of 1.5 Pa is maintained across the test specimen. It should be noted that this effect is also considered in DD ENV 1187 Methods 2, 3 and 4.

Each takes a different wind speed scenario:

- *Method 2* uses both 2 m/s and 4 m/s, where the air is blown across the surface of the specimens;
- *Method 3* uses 3 m/s blown over the surface of the specimen;
- *Method 4* uses 6.7 m/s obtained by maintaining a pressure drop of 1.5 Pa across the specimen.

ISO 12468-1 also considers wind effects at 3 m/s across the surface of the specimen.

8.1.3.2 Façades

In the case of full-scale façade tests, both the BS 8414 series and ISO 13785-2 are operated under nominally still air conditions. This might be due to the scale of the tests involved (at over 8 m in height in both cases) where it would prove difficult to determine and achieve a representative wind load scenario. When assessing the data from these events, the location of the structure might suggest that consideration of this factor should be taken.

8.1.4 Performance classification for external fire performance tests

8.1.4.1 Roofs

The different roof test methods rank performance based on two main elements:

- flame spread: rate and area;
- penetration of the roof system: time and area.

BS 467-3 uses both time to penetration and flame spread to classify the performance of the roof system as follows:

- fire penetration (first letter):

  A – those specimens that have not been penetrated within 1 h;

  B – those specimens that are penetrated in not less than 30 min;

C – those specimens that are penetrated in less than 30 min;

D – those specimens that are penetrated in the preliminary flame test.;

- spread of flame (second letter);

  A – those specimens on which there is no spread of flame;

  B – those specimens on which there is not more than 533 mm spread of flame;

  C – those specimens on which there is more than 533 mm spread of flame;

  D – those specimens that continue to burn for 5 min after the withdrawal of the test flame or spread more than 381 mm across the region of burning in the preliminary test.

Roof systems are designated by the letters EXT. F. or EXT. S., indicating whether the results apply to a flat (horizontal) or an inclined roof system, respectively.

DD ENV 1187 results are classified using the protocol provided in BS EN 13501-5, and the standard offers no method of comparing or ranking the performance of a given roof system under the four different test methods. In fact, since the DD ENV 1187 Method 4 does not utilize the flame spread measurement available in BS 476-3, the classification under DD ENV 1187 Method 4 can only be compared on the basis of penetration with BS 476-3.

Classification under the ISO system is via ISO 12468-2. This again provides no means of directly comparing performance with any of the other test methods discussed. In all cases, the classification systems provide a means of ranking performance based on key performance indicators such as flame spread and penetration, but only within each test method and not over the range of test methods available.

8.1.4.2 Façades

The façade test methods (BS 8414-1, BS 8414-2 and ISO 13785-2) provide information on the overall performance of complete systems at a scale close to that of full scalespecific scenario needs. The performance drivers for the regulatory needs behind the BS 8414 series can be found in BR 135 [10]. The performance criteria are based on the time for fire to spread through across the external surface of the system, through any part (material or cavity) in the system, and to report on any mechanical failure of the system.

8.2 External fire performance tests

8.2.1 BS 476-3

The classification and fire performance standard for roof systems was originally produced in 1958 and was initially revised in 1974 and again in 2004. The 1974 version was not widely used, with documents such as Approved Document B (ADB) [5] continuing to reference the 1958 version of the standard until the 2004 revision was produced. It is the 2004 version of the standard which is now referenced in ADB.
The 2004 version of the standard reverted to the original 1958 test methodology but was updated to reflect the use of SI units and changes in heat flux measurement technology. The standard is in three parts: the preliminary, fire spread and penetration tests.

DD ENV 1187 is the European fire performance test method for external fire exposure to roofs under the Construction Products Directive (CPD) [1]. Although only a draft for development, ongoing activities within CEN are actively seeking to upgrade the status of this standard to a full European Standard as soon as possible. The original standard contains three different test methods, each closely relating to other roof test methods used in other member states:

- Test 1, with burning brands: similar to the DIN roof test standard;
- Test 2, with burning brands and wind: similar to the NORD roof test standard;
- Test 3, with burning brands, wind and radiation: similar to the AFNOR roof test standard.

A fourth test method based on the UK regulatory guidance was published as Amendment 1 to DD ENV 1187. This amendment utilizes the preliminary flame and flame penetration test procedures from the standard but does not undertake the flame spread measurements. Whilst this position meets the regulatory guidance needs, BS 476-3 is still widely used by the industry and specifiers for differentiating products in the market outside the needs of the building regulations.

No direct comparison or ranking is possible under these test methods (BS, ENV or ISO) and each should be assessed against the local regulatory needs to show conformity as required, directly or via a fire engineering approach.

8.2.2 BS 8414-1 and BS 8414-2

BS 8414-1 is a test method to determine the fire performance of a façade system when installed on to a masonry substrate. This test was developed due to a series of fires involving these types of system when installed on multi-storey high-rise tower blocks. It became apparent that a system test at a scale that could consider the interaction of the elements of construction was required when an elemental small-scale approach could not be used. The ISO test method ISO 13785-2 is similar but the test methodologies are slightly different and the data from the two tests are not directly comparable.

BS 8414-2 is designed to consider the fire performance of façades not installed on to a masonry substrate and, as such, there are no other test methods available against which to assess systems.

8.3 Field of application

8.3.1 Roofs

As with all fields of application, the data falls into the three main areas. In the case of BS 476-3, the guidance is limited to the selection of the roof test pitch available. All other fields of application are undertaken as extended applications.

DD ENV 1187 offers some limited direct application rules for each of the test methods within the test standard, and a new standard for direct application and extended application rules relating to the ENV is currently being drafted to increase the guidance available. The key areas of concern involve changes in the make-up of the roof system by substitution of materials or additions and/or changes in fixing details.

Where no direct application or extended application rules exist, the field of application will be restricted to the specific application tested unless an engineering approach based on agreed direct or extended application rules can be applied.

8.3.2 Façades

For façades, no direct application rules have been published. The data is used either on a project-specific basis or as part of an extended application assessment of individual systems.

8.4 Relationship between test methods and building fires

8.4.1 Roofs

The BS 476 roof tests provide data from clearly defined fire scenarios that provide a route for assessing and ranking the performance of different products under these conditions, as would be the case with any fire test. When looking at the relationship of this scenario to real fire events, the points discussed in **6.8** are valid with regard to use of the data beyond a ranking methodology against regulatory compliance.

Each of the other test methods identified provide a different background scenario and, as has already been discussed, are not directly comparable, reinforcing the view that, when using test data to assess real building performance, careful consideration of the key performance parameters for this type of building element is essential.

8.4.2 Façades

Work by Oleszkiewicz [11] and Ondrus [12] identified scale as a key element to understanding the fire performance of façade systems. Even beyond the scale of the fire resistance tests, these systems are reliant upon the interaction of each element in the system to ensure their overall fire performance. There is therefore a need for a full-scale test beyond the typical element analysis of fire properties for each part of the system build-up.

The data from these tests is currently limited and so little direct or extended application information is available. The relationship between these systems and typical building fires is heavily based on individual system scenario analysis, although a sound knowledge of the interaction of these elements is possible in a way that has not typically been available form small-scale elemental testing.

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