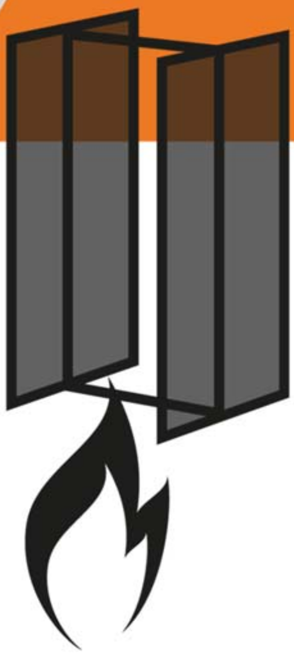
LOCAFI+
Legal Context

Temperature assessment of a vertical steel member subjected to localized fire - Valorization



Fire Engineering: Legal basis and reference documents in the UK

SCI
Steel Knowledge

Foreword

This publication has been prepared as part of the European Union's Research Fund for Coal and Steel Project *Temperature assessment of a vertical steel member subjected to localised fire – Valorisation (LOCAFI-plus)* (contract 754072).

The organisations who participated in the LOCAFI-plus project were:

ArcelorMittal B&D (Coordinator) Luxembourg	**Centre Technique Industriel de la Construction Métallique** France
Universitatea Politehnica Timisoara Romania	**Liège Université** Belgium
Ulster University UK	**Universita Degli Studi Di Trento** Italy
Tallinna Tehnikaulikool Estonia	**Univerza V Ljubljani** Slovenia
Instytut Techniki Budowlanej Poland	**Universitat Politecnica de Valencia** Spain
Technicka Univerzita V Kosiciach Slovakia	**Stichting Bouwen Met Staal** The Netherlands
InfoSteel Belgium	**Ceske Vysoke Uceni Technicke V Praze** Czech Republic
Miskolci Egyetem Hungary	**Tampere University of Technology** Finland
Universidade de Aveiro Portugal	**The Steel Construction Institute** UK
Bauforumstahl ev Germany	**RISE** Sweden

Contents

1. Introduction

Structural fire design addresses the risk associated with the safety of the building occupants, fire fighters, people in the surrounding area and the safety of the building itself. The general requirements of fire safety and the acceptance criteria are defined and outlined prior to the start of the design process. The minimum levels of these requirements are to ensure the protection of human life and are covered by legislation. These minimum requirements are often increased to contain financial loss by minimizing damage to the structure. An increased level of safety in design also protects the environment by minimizing the effects of fire on the surrounding buildings and limiting the release of hazardous material into the environment.

The two common approaches used to ensure fire safety, a prescriptive approach, and a performance-based approach are described in the following sections.

A design process to ensure fire safety is presented in Figure 1.

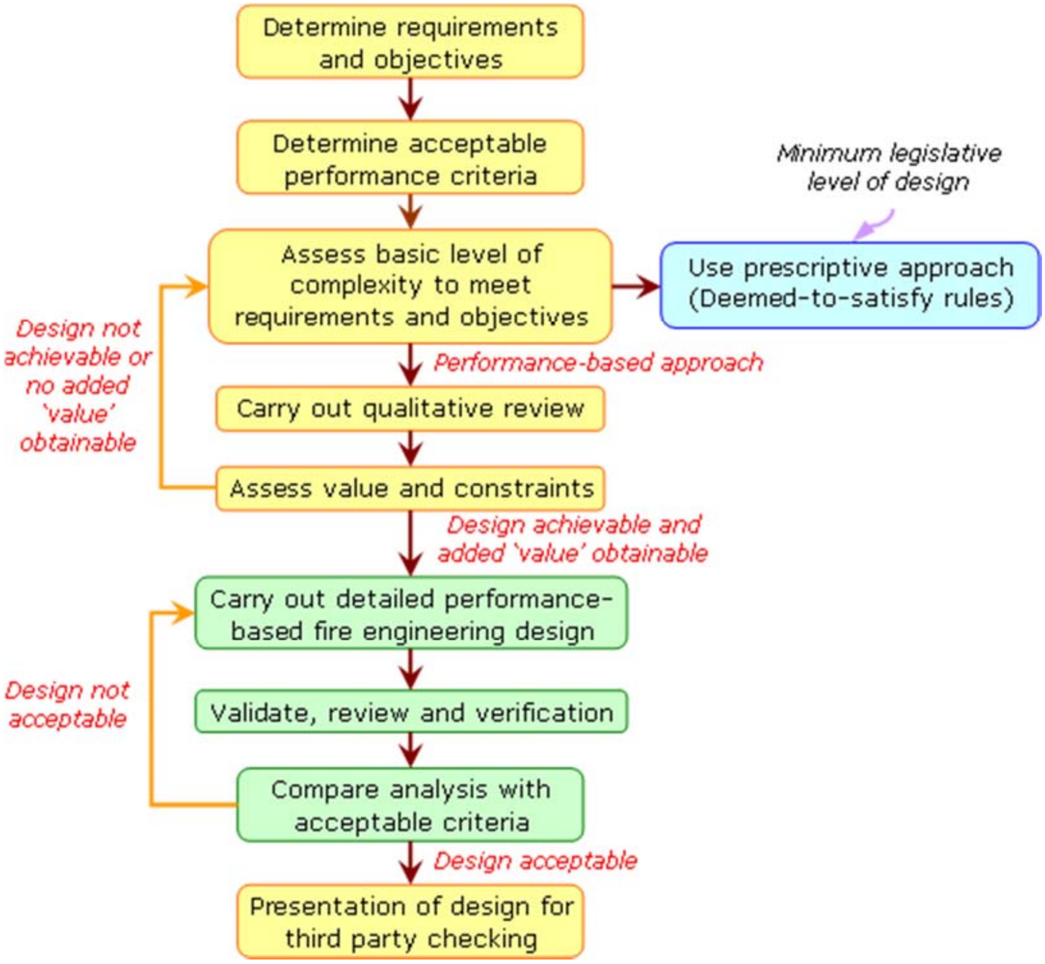


Figure 1: Fire Design Methodology

2. Prescriptive Approach

The prescriptive design approach provides sufficient levels of safety to preserve life. This method is easy to use, however, the designer is unable to estimate the actual levels of safety inherent within the prescriptive rules. A prescriptive method provides structural safety mainly in terms of the material used, geometry of the structural elements and method of construction. The basis of this approach is standard fire tests conducted on similar elements in addition to previous experience. The use of this approach becomes highly limited when the structure includes complex architectural and aesthetic requirements. Current rules for fire design of steel, concrete, masonry and timber members are based solely on the results and observations from standard fire resistance tests. These tests involve subjecting a structural member to a heated furnace environment for a desired duration and the resulting fire resistance rating is expressed as the time in mins. During these tests, standard heating conditions are applied and their response is measured in terms of the specified failure criteria. The structural members are then classified into fire resistance categories, R30, R60, R90, R180, R240, etc., based on the results of these tests. The number of tests necessary for classification varies from country to country. The standard test methods in the UK for determining the fire resistance of beams, columns, roof assemblies etc. are complied with either British Standard BS 476 or European Standards EN 1363 and EN 13381 or the International Standard ISO 834. Relevant British and European standards are given below:

BS 476-20:1987: Fire tests on buildings materials and structures — Part 20: Methods for determination of the fire resistance of elements of construction (general principles)

BS 476-21:1987: Incorporating Corrigendum No. 1: Fire tests on building materials and structures — Part 21: Methods for determination of the fire resistance of loadbearing elements of construction.

BS 476-22:1987: Incorporating Corrigendum No. 1: Fire tests on building materials and structures — Part 22: Methods for determination of the fire resistance of non-loadbearing elements of construction.

BS 476-23:1987: Incorporating Amendment No. 1: 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 EN 1363-1:2012: Fire resistance tests — Part 1: General requirements

BS EN 1363-2:2012: Fire resistance tests — Part 2: Alternative and additional procedures

BS EN 13381-1:2014: Test methods for determining the contribution to the fire resistance of structural members — Part 1: Horizontal protective membranes

BS EN 13381-2:2014: Test methods for determining the contribution to the fire resistance of structural members — Part 2: Vertical protective membranes

BS EN 13381-3:2015: Test methods for determining the contribution to the fire resistance of structural members — Part 3: Applied protection to concrete members

BS EN 13381-4:2013: Test methods for determining the contribution to the fire resistance of structural members — Part 4: Applied passive protection to steel members

BS EN 13381-5:2014: Test methods for determining the contribution to the fire resistance of structural members — Part 5: Applied protection to concrete/profiled sheet composite member

BS EN 13381-6:2012: Test methods for determining the contribution to the fire resistance of structural members — Part 6: Applied protection to concrete filled hollow steel columns

BS EN 13381-7:2002: Test methods for determining the contribution to the fire resistance of structural members — Part 7: Applied protection to timber members

BS EN 13381-8:2013: Test methods for determining the contribution to the fire resistance of structural members — Part 8: Applied reactive protection to steel members

BS EN 13381-9:2015: Test methods for determining the contribution to the fire resistance of structural members — Part 9: Applied fire protection systems to steel beams with openings

Normally, gas burners are used to conduct the standard tests on the specimens. Tests on the structural elements are conducted in approved furnaces. The typical dimensions of the elements used during the test are as follows;

- Walls: 3 m x 3 m
- Beams: 4.5 m span
- Floors: 4 m x 4 m
- Columns: 3 m

The performance criteria are given in terms of their stability, integrity and insulation, based on the type of the structural element. For instance, columns are expected to reach their failure criteria when they fail to support the test loads and undergo collapse or excessive deformation. Performance criteria for different structural members are given in the Table 1.

Table 1: Performance criteria for different element types

Performance or failure criteria	**Element Type**	**Conditions**
Stability – Resistance to collapse or excessive deformation	Beams and Floors	Deflection exceeds Span/20 or the rate of deflection exceeds rate of deflection when deflection is more than Span/30
	Columns	Fail to support the test loads
Integrity – Resistance to penetration of hot gases or flames through cracks and openings	Walls and floors	Ignition of a cotton pad held close to an opening
Insulation – resistance to excessive temperature rise on unexposed face	Walls and floors	Temperature in excess of 180°C at a single point or 140°C on average.

Though the prescriptive approach developed on the basis of the results from standard fire tests is effective, adequate and ensures minimum levels of fire safety for structures, this approach restricts the understanding of the design engineers for the following reasons:

- The prescriptive approach considers the structural elements of a building to be independent, however, these elements in real conditions behave as a whole. This interaction between the structural elements in fire has probable beneficial and harmful effects on the building survival. The beneficial effects include the multiple load transfer paths while the harmful effects include the additional stresses induced by the expansion of the structural elements. In case of vertical elements, especially columns, the additional compressive stresses induced by thermal expansion could induce instability resulting in failure.
- The prescriptive approach considers standard fire curves as the representation of the real fires. The heating conditions in real cases are different to the standard conditions, hence, this approach does not provide accurate replication of the real fire scenarios.
- The prescriptive approach is based on rather old data, some over 70 years old, hence, the rules are somewhat out of date.

Concrete members are supposed to exhibit a better response in fire and are usually unprotected. On the other hand, steel members are protected to achieve the required fire resistance anticipating their poor performance in fire. The prescriptive approach proposes a typical thickness of fire protection required to limit the temperatures to achieve the desired fire resistance. In the UK, the Yellow Book, also known as the Fire Protection for Structural Steel in Buildings (ASFP), is used to determine the required fire resistance for structural steelwork. The Yellow Book provides detailed guidance on selection of thickness of fire protection based on the section factor of a structural member and is available from www.asfp.org.uk .

3 Performance-Based Approach

A performance-based approach is an advanced category of design approach. This approach provides more economical designs in comparison to the prescriptive approach and at the same time maintains the levels of life safety. This approach is suitable both for simple designs and for complex designs where the simple rules cannot be applied. It provides a better understanding of structural response of buildings at elevated temperatures. A performance-based approach provides rigorous designs using advanced design methods and is able to identify the weaker parts of the structure which need strengthening.

A performance-based approach comprises three basic components: the fire behaviour, the heat transfer analysis and the structural response.

3.1 Fire behaviour

Performance-based methods cover various fire types including nominal fires, time equivalent fires, compartment fires, zone models and field modes. The complexity of the design varies with each fire type as shown in Figure 2.

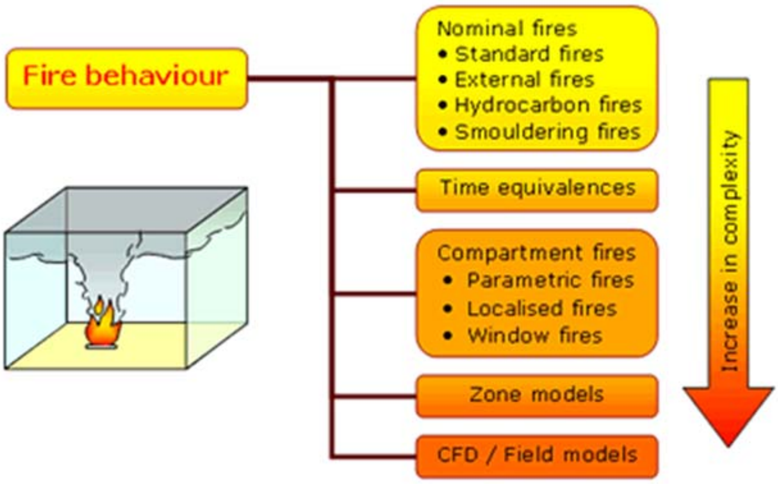


Figure 2: Behaviour of fire and the level of complexity

Nominal fires are the least complex fire models as they do not consider any physical fire parameters. Uniform temperature distribution is considered throughout the compartment and only post-flashover fires are considered. Simple equations are used for fire design and the methods proposed by EN 1991-1-2 *Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire* and PD 7974-1 *Application of fire safety engineering principles to the design of buildings —Part 1: Initiation and development of fire within the enclosure of origin (Sub-system 1are followed.*

The time equivalence models and the compartment models are more complex than the nominal fire models. The models are based on the fire load, ventilation conditions, and the thermal properties, size and height of the compartment. Some of these models involve post-flashover fires and follow the uniform temperature throughout the compartment. The localised fires, on the other hand, consider the pre-flashover fires as well and they consider the exposure conditions to be non-uniform along the plume. Designs are usually performed using spread sheets and simple equations and follow the recommendations of EN 1991-1-2 and PD 7974-1.

The complex fire models include the zone and the field models. The zone models are based on the fire load, ventilation conditions, thermal properties of the boundary, compartment size and consider the detailed heat and mass balance of the system. Single zone models consider post-flashover fires with uniform exposure conditions while the two-zone models consider the re-flashover or the localised fires. The fire exposure conditions are treated as layers of uniform temperatures. The field models consider the complete temperature-time relationships and temperature distributions are considered as time and space dependent. The exposure conditions are calculated based on the detailed input for solving the fundamental equation of the fluid flow. Field models are also known as the Computational fluid dynamics (CFD) models.

3.2 Heat transfer

The evaluation of the transfer of energy that takes place between bodies due to a difference in temperature is known as the heat transfer. Heat transfer takes place through three modes, conduction, convection and radiation. In fire test scenarios, heat is usually transferred from the fire to the structural member through convection and radiation while the heat transfer within the structural members usually takes place through conduction. The process of heat transfer is explained in Figure 3. The thermal analysis of structural members is complex, and this level of complexity increases for members with materials which retain moisture and have low thermal conductivity.

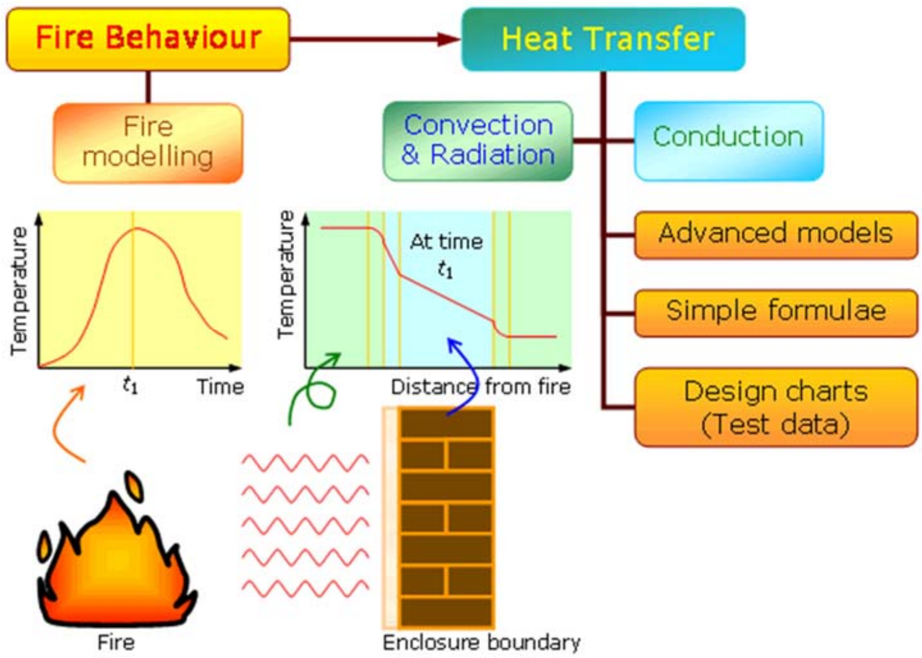


Figure 3: Heat transfer diagram

© One Stop Shop in Structural Fire Engineering, University of Manchester

For bare steel, simple design equations are presented in codes and design guides. These design procedures predict the temperature development by considering both radiative and convective heat transfer. Though these calculations are straightforward, spreadsheets are often needed for calculations. In the case of protected steel, the design philosophy is the same, but the thermal properties of the proposed protection material are required to perform the design.

Heat transfer can also be determined using computer programs. For simple cases, one-dimensional heat flow models are employed while for complex designs and/or a higher degree of accuracy, advanced finite element heat transfer models are used. Use of computer programming for such designs requires relevant expertise for the appropriate application of the models.

3.3 Structural analysis

Structural analysis of buildings in the fire condition can be performed using simple element models for predicting the structural response. These methods are given in the codes and design guides and take into account the reduction in strength and stiffness of materials during a fire. Simple design methods, which are based on fundamental engineering principles, can be used irrespective of the fire model used. However, some empirical structural design methods can only be used with the standard time-temperature fire model, which was used in the derivation of the method. These methods deal with individual members and are considered to be conservative.

A finite element (FE) modelling approach is used to predict the behaviour of buildings in fire more accurately. The approach incorporates the stress-strain-temperature relationship of materials and can predict stresses and deformations throughout the whole structure. Though FE modelling methods provide accurate designs, expertise is required to use these advanced models and special care is required in defining the types of elements used, boundary conditions, localised behaviour and interpretation of the results. The FE modelling designs are used to address both single members as well as the whole buildings. The results of a structural analysis will only be accurate when the other two components of design, the fire design and the thermal analysis are performed accurately.

The design of steel members is based on the engineering principles applied in the normal cold design except the effects of reduction in material strength and stiffness are taken into account, together with partial safety factors that relate to the fire limit state.

4 Structural Fire Resistance Requirements

The obligations placed on those who design and construct buildings to ensure that they are both safe and healthy are contained in the Building Regulations. The requirements of the regulations are set out in functional terms, i.e. they outline what has to be done but not how this can be achieved. These requirements help to ensure the integrity of the structure for a reasonable time ensuring life safety of the occupants and fire fighters. They are imposed by relevant regulatory bodies, clients or insurance companies.

Fire safety requirements vary based on factors related to fire commencement as well as the possible damage in case of failure. These factors include the occupancy type and the size of building, usually in terms of the building height. The factors necessary to ensure life safety include the fire resistance of the structural elements and the thermal properties of the internal and external linings in terms of their heat release rate.

The Governments of the various regions of the UK publish documents which provide guidance on the means by which compliance with the Building Regulations in force in that region can be achieved. For fire safety these are: Approved Document B (England); Approved Document B (Wales); Scottish Technical Handbook 2 and Technical Booklet E in Northern Ireland. (It should be noted that the English and Welsh Approved Documents have been separate only since 2014. Differences between them are small but one should be aware that they exist.)

The British Standards Institute has also published BS 9999 *Code of practice for fire safety in the design, management and use of buildings* as an alternative to the Approved Documents. This provides a more transparent and flexible approach to fire safe design through the use of a structured approach to risk.

Some building specific regulations are also in place, for example for schools and healthcare facilities.

Further information on structural fire resistance requirements can be found at: www.steelconstruction.info.

A summary of these regulations is presented in Table 2.

4.1 Approved Document B (England and Wales)

Approved Document B Fire Safety is published in two documents, dealing with residential and non-residential buildings respectively. This section applies to non-residential buildings.

Structural fire resistance requirements in Approved Document B for multi-storey buildings are contained in Table A2 (reproduced here in Table 3). They are a function of the height of the building and the occupancy. (These should not be read in isolation but in conjunction with the accompanying notes and Table A1: Specific provisions of test for fire resistance of elements of structure.)

Single storey buildings do not normally require structural fire resistance (and therefore fire protection) as Section 7.4 of Approved Document B excludes from the definition of elements of structure, that which only supports a roof. Exceptions may occur where an element of structure provides support or stability to elements such as:

- A separating wall
- A compartment wall or the enclosing structure of a protected zone
- An external wall which must retain stability to prevent fire spread to adjacent buildings (i.e. a boundary condition)
- A support to a gallery or a roof which also forms the function of a floor (e.g. a car park or a means of escape).

Table 2: Existing Technical Guidance in different parts of the UK on Fire Safety

<table>
<tr><td colspan="6">Regions</td></tr>
<tr><td colspan="2">England and Wales</td><td colspan="2">Scotland</td><td colspan="2">Northern Ireland</td></tr>
<tr><td>Regulatory Documents</td><td>Guidelines Covering</td><td>Regulatory Documents</td><td>Guidelines Covering</td><td>Regulatory Documents</td><td>Guidelines Covering</td></tr>
<tr><td>Approved Document B, Volume 1: dwellinghouses</td><td rowspan="2">• Means of fire alarm and escape
• Inhibiting internal fire spread over linings
• Stability of the buildings
• Limiting fires
• Accessibility to fire service and limiting external fire spread
• Separation</td><td>Technical Handbook Domestic</td><td rowspan="2">• Separation
• Compartmentation
• Structural protection
• Spread on external and internal walls and linings
• Accessibility to fire service
• Fire suppression systems
• Communication
• Fire service water supply
• Fire service facilities
• Escape lighting
• Spread to neighbouring buildings
• Cavities</td><td rowspan="2">The Building Regulations (Northern Ireland) 2012</td><td rowspan="2">• Means of escape
• Internal fire spread: linings
• Internal fire spread: structure
• External fire spread
• Facilities and access for the fire and rescue service</td></tr>
<tr><td>Approved Document B, Volume 2: Buildings other than dwellinghouses</td><td>Technical Handbook Non-domestic</td></tr>
</table>

Single storey buildings are sometimes fire protected however where the insurance company or owner deems that it is necessary.

In determining fire resistance requirements in multi-storey buildings, height is measured from the ground to the upper surface of the top floor. This means that, in most cases, buildings less than 5 m in height are two stories.

Most multi-storey, non-residential buildings in England are 2, 3 and 4 stories in height, i.e. less than 18 m. Also, the majority are classed as offices, shops, commercial and assembly. This means that the dominant period of fire resistance is 60 minutes.

Almost all buildings over 30 m in height must be fitted with a life safety sprinkler system installed in accordance with the appropriate British Standards, the details of which are provided in the Approved Document. The presence of life safety sprinklers can be used to reduce structural fire resistance requirements in most buildings under 30 m in height. Typically, a reduction of 30 minutes can be applied. This reduction also applies to other fire precautions such as fire doors, floors, compartmentation etc. However, this is only rarely invoked as the costs of life safety sprinklers is usually (but not always) greater than the value of the trade-offs which can be utilised by their installation.

Approved Document B makes special provision for two types of structure, open sided car parks and shopping centres.

Open sided car parks are recognised as posing a relatively low risk to life. Therefore they are generally required to have only 15 minutes fire resistance; this is usually achievable using unprotected steel.

With regard to shopping centres, it is acknowledged that the provisions given for single shops in the Approved Document (Section 11.7) may not be suitable for shops that form part of a complex, in particular with respect to compartmentation but also with respect to issues such as fire resistance and boundary distances. The Approved Document therefore states that, *to ensure a satisfactory standard of fire safety in shopping complexes, alternative measures and additional compensatory features to those set out in this document are appropriate. Such features are set out in Sections 5 & 6 of BS 5588 Part 10 and the relevant recommendations of these sections should be followed.* Structural fire resistance requirements for elements of structure in the standard are 120 minutes and provision of a life safety sprinkler system is required. (It should be noted that, although this standard is quoted in the Approved Document, it has been withdrawn and replaced by BS 9999. When a British Standard is withdrawn however, it can still be used. Withdrawn in this context means that it is not being maintained).

Basements in buildings generally require fire resistance periods of 60 minutes where the depth of the basement is less than 10 m. For basements over 10 m in depth, 90 minutes is normal. Exceptions occur in unsprinklered basements in industrial and storage buildings where the requirements are for an additional 30 minutes fire resistance.

Table 3: Minimum periods of fire resistance (minutes) from Approved Document B (England and Wales)

Building Group	Basement Storey		Storey above ground			
	Depth of lowest basement (m)		Height of top floor above ground in a building or a separated part of a building (m)			
	Not more than 10	More than 10	Not more than 5	Not more than 18	Not more than 30	More than 30
Residential						
Flats, not sprinklered	60	90	30*	60**	90**	Not permitted
Flats, sprinklered	60	90	30*	60**	90**	120**
Institutional	60	90	30*	60	90	120#
Other residential	60	90	30*	60	90	120#
Office						
Not Sprinklered	60	90	30*	60	90	Not permitted
Sprinklered	60	60	30*	30*	60	120#
Shop and Commercial						
Not Sprinklered	60	90	60	60	90	Not permitted
Sprinklered	60	60	30*	60	60	120#
Assembly and recreation						
Not Sprinklered	60	90	60	60	90	Not permitted
Sprinklered	60	60	30*	60	60	120#
Industrial						
Not Sprinklered	90	120	60	90	90	Not permitted
Sprinklered	60	90	30*	60	60	120#
Storage and other non-residential (any building or part not described elsewhere)						
Not Sprinklered	90	120	60	90	120	Not permitted
Sprinklered	60	90	30*	60	90	120#
Car parks for light vehicles						
Open sided	NA	NA	15*Γ	15*Γ	15*Γ	60
Any other	60	90	30*	60	90	120#

* increased to a minimum of 60 mins for compartment walls separating buildings
** reduced to 30 mins for any floor area within a floor with more than one storey, but not if the floor contributes to the support of the building
\# reduced to 90 mins for elements not forming part of the structure
Γ increased to 30 mins for elements protecting means of escape

4.2 Technical Handbook 2 (Scotland)

Structural fire resistance requirements in Scottish Technical Handbook 2 for multi-storey buildings are contained in Section 2.1.1. They are a function of the height of the building (measured in the same way as described for Approved Document B), the occupancy and the floor area of the compartment. Fire resistance requirements are either short (30 minutes), medium (60 minutes) or long (120 minutes). Unlike England & Wales, where periods of fire resistance of 120 minutes usually occur in buildings over 30 m in height, in Scotland this can occur at any height, if the compartment floor area is large enough. The most significant trade-off for life safety sprinklers allowed in Technical Handbook 2 is that allowable floor areas may be doubled when an automatic fire suppression system is installed in the building.

Structural fire resistance requirements in basements are either 60 or 120 minutes. They are also a function of the floor area of the compartment and are not influenced by the depth.

Single storey buildings do not normally require structural fire protection. The common exceptions to this are where the building is in a boundary condition (i.e. where there is a danger of fire spread to adjoining buildings should a wall collapse in a fire) or where the insurance company or owner deems that it is necessary.

Scottish Technical Handbook 2 makes special provision for open sided car parks. These are recognised as posing a relatively low risk to life and unprotected steel can usually be used.

The guidance contained in the Technical Handbooks, if followed, can be relied upon to demonstrate compliance with the functional standards, however, because the guidance is NOT mandatory, there is no obligation to adopt any particular solution contained in the Handbooks. If the guidance is not followed, the onus is on the designer to demonstrate compliance with the standards.

4.3 Technical Handbook E (Northern Ireland)

A new format for Technical Booklet E (Northern Ireland) came into force in October 2012. Structural fire resistance requirements in Technical Booklet E for multi-storey buildings are contained in Table 4.2. (Table 4.2 should not be read in isolation but in conjunction with the accompanying notes and Table 4.1: *Specific provisions of test for fire resistance of elements of structure and other components of a building*). They are broadly the same as those in Approved Document B and are a function of the height of the building (measured in the same was as described for Approved Document B) and the occupancy. The main exception is that the requirement to install sprinklers in blocks of flats over 30 m in height, a relatively recent addition in England & Wales, has not yet been implemented in Northern Ireland.

Single storey buildings do not normally require structural fire protection. The common exceptions to this are where the building is in a boundary condition (i.e. where there is a danger of fire spread to adjoining buildings should a wall collapse in a fire) or where the insurance company or owner deems that it is necessary.

Technical Booklet E makes special provision for open sided car parks. These are recognised as posing a relatively low risk to life. Therefore they are generally required to have only 15 minutes fire resistance. This is usually achievable using unprotected steel sections.

Trade-offs for sprinkler installation are also available.

4.4 BS 9999

Recent decades have seen a significant commitment to research in the UK and Europe which has resulted in improvements in knowledge and understanding of fire behaviour and how risk is created in fire. As a consequence, it is now recognised that the provisions of Approved Document B, Scottish Technical Handbook 2 (Scotland) and Technical Booklet E (Northern Ireland) may not provide the most efficient solution for fire in many buildings; this has led to the increased use of performance-based fire safety approaches, especially for large and complex structures.

This led, in 2001, to the publication of BS 7974 *Application of fire safety engineering principles to the design of buildings*. This is a high level document which sets out the processes and procedures to be applied when adopting these solutions in a building. It is intended for the use of specialists in this area.

It then became clear that there was scope for another approach which would sit between these two. The result has been the creation of BS 9999, published in October 2008. Whilst prescriptive, this standard allows the user to vary the solutions required to meet the provisions of the Building Regulations according to the particular circumstances of the building. On publication, the British Standards Institute said: *The standard builds on government guidance to legislative requirements, providing an advanced approach to fire safety in the design, management and use of buildings. It promotes a more flexible approach to fire safety design through use of structured risk-based design where designers can take account of varying human factors.*

One of the most obvious changes in BS 9999 involves structural fire resistance requirements. Approved Document B, for example, requires 60 minutes fire resistance for most buildings up to 18 m in height; 90 minutes for most buildings between 18 and 30 m and 120 minutes plus a life safety sprinkler system for buildings over 30 m in height. Some trade-offs are allowed in these ratings for buildings under 30 m where life safety sprinklers are installed but these are not usually cost effective and are rarely invoked.

The option of reduced fire ratings when sprinklers are installed is still available in BS 9999 and it is complemented by an alternative approach which classifies buildings according to a risk profile based on occupancy, fire growth rate, ventilation conditions and height. There are limitations on the buildings on which this approach can be used, mainly based on ventilation area, but it is expected that relatively few buildings will be excluded. The risk profile of the building, and therefore the fire resistance requirement, can be reduced if a life safety sprinkler system is installed. Sprinklers are not mandatory in any building although two separate statements are made to the effect that, for heights over 30 m or for heights over 30 m in buildings using phased evacuation, sprinklers should be installed.

Fire resistance requirements for a number of common building types are compared in Table 4.

Table 4: Comparison of structural fire resistance requirements in selected buildings in Approved Document B and BS 9999

Building Description[a]	Approved Document B (mins)	BS 9999 without sprinklers (mins)	BS 9999 with sprinklers (mins)
Open plan office building, 2 storey, less than 1000 m^2 ground floor area	30	15[b]	15[b]
Open plan office building over 30 m but less than 60 m in height	120 plus sprinklers	90[c]	60
3 storey Department store	60	45	30
Department store between 11 and 18 m in height	60	75	60
Medium risk, 4 storey storage	90	90	60
Leisure centre, 2 storey	60	30	30
Notes: [a] Height is measured from ground to the height of the floor on the top storey [b] Most steel members can achieve 15 minutes fire resistance without added protection [c] It is unlikely that planning permission would be given without sprinklers			

It is important to note that the recommendations of BS 9999 must be applied as an entire package; favourable aspects of the guidance cannot be cherry picked.

4.5 UK National Annex to EN 1991-1-2 and PD 6688-1-2

Performance-based fire engineering using localised fires is covered by Annex C of EN 1991-1-2, which has Informative status. This Annex gives a method for calculating the flame length and temperatures in the plume of a localised fire. It is based on work by Heskestad and Hasemi, which provides a correlation between fire size (defined by the rate of heat release and diameter) and other parameters, including the flame height and the internal temperature of the fire.

The UK National Annex to EN 1991-1-2 does not adopt Annex C and instead refers to PD 6688-1-2 *Background paper to the UK National Annex to BS EN 1991-1-2 for actions in localised fires*; this in turn refers to PD 7974-1, 8.2.1.1 to 8.2.1.14, which provides a range of fire models. For example, PD 7974-1 gives three models for calculating the flame height (Thomas, Heskestad, Zukoski) whereas EN 1991-1-2 Annex C gives simply gives the Heskestad model.

The method for calculating the temperature rise in a column in the SCI publication P423 *Design of columns subject to localized fire* can be used in the UK as an alternative to the approach in PD 7974-1 and will also be included in a revision to Annex C in the next edition of EN 1991-1-2 (expected to be issued in about 2023). The UK National Annex to the next edition of EN 1991-1-2 may then adopt the new Annex C.

Additionally, the UK National Annex does not adopt Annex E, which gives rules for determining fire load densities. This is because the experts responsible for the UK NA do not agree with the use of factors applied to the design fire load density to provide fires of much lower severity. Instead, the UK NA refers to Annex A of PD 6688-1-2.