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Fire resistance tests — Guidance on the application and extension of results

Essais de résistance au feu — Recommandations pour l'application et l'extrapolation des résultats

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standards;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subjected to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 12470, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire resistance*.

The primary objective of this Technical Report is to produce a harmonized approach to the extension of results obtained from fire resistance tests performed according to the time-temperature curve as given in ISO 834-1. Such an approach is usable by writers of fire testing standards to assist with the preparation of harmonized "field of direct application" statements. In addition it is of assistance to fire safety engineers/consultants who either need to establish the extended field of application of a tested construction, to establish whether a similar untested element would be expected to satisfy the test criteria where the variations between the tested and untested constructions are significant, or produce the rules governing the application.

The guidance as to whether the application can be extended is given in three forms. In the simplest form a rule may be used which may be based upon sound scientific facts or even just custom and practice. For quantifiable aspects it identifies where fire engineering calculations may be used. Where judgement needs to be exercised, it identifies the factors that need to be considered. The guidance given also allows a designer or the enforcing authority to assess the fire resistance of an element when it is of a size that cannot be tested due to the physical limitations of testing furnaces. Whether this is a valid use of this guidance document will depend upon the philosophy of a particular country's regulations and the way they use fire resistance tests in their building codes. In a complex building where the behaviour can only be established from first principles, a greater understanding of the limitations applying to a test result is critical.

Structural elements such as beams, girders, columns and floors are generally designed by using calculation methods applicable at room temperature and each element is more or less different from one another. These structural elements also need calculation methods that assess their fire behaviour and it is important that these are correlated by tests.

Annex A forms an integral part of this Technical Report. Annexes B and C are for information only.

Introduction

Fire resistance tests on building components are necessary to establish their behaviour against pre-determined criteria when exposed to a representative fully developed fire and to provide information that may be used in determining the fire safety level of buildings. For several decades people have accepted by means of test results only, the possibility of grading the components. Now, due to the improvement of knowledge and the sophistication of buildings, it is necessary to be able to give a more accurate assessment of the components used in buildings.

Because of the cost of the tests and the size limitations of the testing furnaces, it is not possible for any given building element to be tested at all of its various sizes or designs. As a consequence we need rules or even better mathematical models for predicting, from test results, the behaviour of elements which are changed in size, design and/or application. The performance of these elements is adjudged as a separate consideration and only against standard heating conditions as defined in ISO 834-1.

Even with the knowledge available to assess the behaviour of a given constructional element, whatever its design or its size, we will still be a long way from establishing the real behaviour of a building in a real fire.

The philosophy of only grading elements into different fire resistance categories may not give any indication about how the element behaves when heated. By studying and assessing the data from fire resistance tests, it will be possible, using the guidance within this Technical Report, to obtain a basic understanding of the influence of the main parameters on the element performance during a fire resistance test.

In practice, tests can give much useful information which can be used for interpolation and extrapolation of the results.

In the following, all of these assessments will be based on the one hand on the standard time/temperature conditions and, on the other hand, on isolated elements with no interaction with the adjacent elements.

Also ageing and weathering are not covered here.

This Technical Report is divided in two parts:

— guidance on direct use and extended application of test results for various elements used in buildings; the parameters which would be assessed by rules, calculation or only expert judgements are discussed.

— future evolution:

  - improvement of testing methodologies to give a better prediction of the performance of various sizes and designs of a given element,

- mathematical modelling which can be used by experts to give their judgement,
- expert systems which could take into account the interaction of various factors in an assessment.

In addition annexes A and B give an overview of current practices in various countries as far as application and extension of fire resistance test results are concerned. It is mentioned where agreement could be found and where more efforts have to be made for harmonization.

Annex C gives additional reading.

Fire resistance tests — Guidance on the application and extension of results

1 Scope

Direct and extended applications of test results are the two possible ways to ensure that a modified element will have a good possibility of obtaining the same fire rating as that of the original tested specimen. In both cases these applications refer only to the fire rating that the building element can expect to reach if it were to be tested in a furnace according to the standard fire used for the reference test.

For each type of element of construction, the application of test results will be considered under two sub-headings.

a) Direct application: this section identifies the modifications that can be made to the design of the tested element without reducing its fire rating. These possible modifications are based on obvious knowledge and do not need further evaluation. In every case it is, at least, assumed that the basic materials used for the tested sample will not be changed. The results obtained from tests performed using standard configurations are valid for the field of application derived from that configuration, regardless of any specific advice given in the following chapters.

b) Extended application: this will require in every case an assessment by a fire expert either in developing rules of application or evaluating the results of fire engineering calculations or making a judgement. In every case it will be taken into consideration that extended application may take into account the difference between the result of the original test and the fire resistance required for the untested element.

   A judgement is the result of a qualitative process, normally carried out by experts. Judgements are used to justify a change of design or method of construction which may use, for example, empirical data derived from tests, established physical properties, hot and cold state calculations, a knowledge of fire exposure, fire behaviour and response of the construction, either in isolation or in combination.

   1) Rules of application: these would be applied universally even by persons without expertise in fire as part of the "field of application" of the test result for a given family of products. These rules may require cold state calculation. The quantification of these rules would be agreed universally based upon validated experience related to generic constructions or components. This could cover size changes, number of joints, size of glazing etc.

      Throughout this Technical Report the clauses covering rules frequently express the acceptable change in terms of un-quantified percentages indicated by the letter "X" and an appropriate suffix.

      This allows national code authorities to insert their own acceptable limits which will relate to their established fire safety philosophy.

      Authorities are encouraged to support the necessary research towards internationally harmonized validated value.

   2) Fire engineering calculations: these would be used by an expert in giving advice but will mainly be restricted to the properties indicated below:

- non-loaded elements: this would be restricted to the calculation of temperature rise and deflection of "simple" components and elements;
- loaded element: in addition to the properties permitted for non-loaded elements, calculation at elevated temperature could be permitted for the load-bearing capacity for well-documented materials (steel, concrete, etc.) and for statically determined elements.

In every case the calculation models used by the experts, whatever their source (purchased from software manufacturers or developed in the institution) have to be fully validated by comparison with existing test results and by sensitivity analysis of the various parameters.

3) judgements: for a test result to be extrapolated to cover changes outside those for which calculations or written rules are applicable, the result may still apply subject to some expert judgement being made. The section on judgements highlights the matters that need to be considered and to be explained by the body or person responsible for making such judgements. Generally, components of a construction element could be changed, provided it can be shown that this does not reduce the fire resistance. It must be demonstrated that the interaction of a new component with other components will not affect adversely the performance of the tested construction. When resistance time is higher than required time, it will generally be possible to have a greater change than with only the necessary safety level.

Changes in materials and methods of construction can have significant influences on the fire resistance. Because the advice and recommendations are common to all elements, those aspects are dealt with separately under 2.1.1 "manufacture and materials" to avoid repetition. The user of this Technical Report should consider these aspects in all applications of results whether direct or extended.

2 Common factors

The advice in this clause applies to all subsequent groups of elements.

2.1 Manufacture and materials

2.1.1 General

For certain applications, even small changes in either the materials or the methods of manufacturing may result in large changes in fire resistance (for example glazing, intumescent coatings, primers). The results from a fire resistance test may be used to support an evaluation of the performance of a similar untested element or they may be used to justify an element in use without any further calculations, or the application of rules, if the manufacture of the element complies with the guidance given in 2.1.2. Where the construction is not covered by the direct application then the calculations or application rules need to be applied as indicated.

Additionally there are quality control and certification schemes in some countries. Control procedures ensure that the untested construction is equivalent to the tested construction. Any relaxation of these procedures may only be undertaken if it can be established that they only influence non-critical aspects of the construction (e.g. colour, texture, etc.) Evidence of the effect must be available if the control of the 'critical' processes or materials is involved. Reduced scale fire resistance tests may be used for this purpose subject to the changes not affecting distortion.

The information given for direct and extended applications has to be used for every construction element.

2.1.2 Direct application

a) The quality control procedures are not reduced.

b) The manufacturing/construction procedures remain unchanged.

c) Constituent materials, admixtures, preservatives, flame retardants, adhesives, etc. remain unchanged.

2.1.3 Extended application

2.1.3.1 Rules

As a general rule the quantity of any constituent material may be varied by up to a certain percentage (to be defined for each family of material) from that used in the original specification that was tested without the need for further consideration.

2.1.3.2 Fire engineering calculations

Where, for certain materials, calculation methods have evolved and been documented it may be possible to calculate the influence that changes in material and manufacturing may have on the fire resistance.

2.1.3.3 Judgements

a) Materials

It may be possible to change constituent materials, or add constituents such as preservatives or flame retardants without significantly affecting the fire resistance. Evidence of the effect that this may have should be available or its effect should be able to be calculated to demonstrate that these changes will not reduce the fire resistance. Reduced scale fire resistance tests may be suitable for this purpose. If the additional constituents may be expected to influence distortion patterns, then a full scale test may be required.

b) Manufacturing procedures

The effect of any change in the manufacturing procedure shall be established to show that it does not reduce the fire resistance of the element before such changes are accepted.

2.2 Moisture content

Since it is difficult to measure the moisture content of many elements prior to the test, it is better to try to reach an equilibrium before testing. However when for various reasons this is not possible and if information is available on the assumed moisture content, the following correction can be used.

If the fire resistance with respect to insulation criterion of a specimen is known at one moisture content, then the insulation rating at some other moisture content can be corrected according to the following equation[1]:

$$T_d^2 + T_d \left(4 + \frac{1}{15} b\phi - T_\phi\right) - 4T_\phi = 0$$

where

ϕ is the volumetric moisture content,

T_ϕ is the fire resistance, in minutes, of the element at a moisture content of ϕ,

T_d is the fire resistance, in minutes, of the element in oven-dry condition,

b is a factor, in minutes, which varies with the permeability.

This formula can be used for correcting the insulation criteria relating to a homogeneous structural element such as concrete slabs, brick walls, with some limits of application. It is not applicable to timber and gypsum products.

1) T.Z. HARMATHY, "*Fire Safety Design and Concrete*". Longman Scientific & Technical, 1993.

2.3 Increasing size

A non-loadbearing separating element having obtained a given fire rating could be used for a lower fire rating application at a bigger size than that allowed in an application requiring the obtained fire rating. The reason for this is that to achieve a better performance than that required it is necessary to produce a more stable element to ensure reduced distortion and/or deformation and hence less erosion of any constitutive materials.

3 Loadbearing elements

In practice few structural elements are covered by direct application because there is always a difference in size or strength of material used.

For protected load bearing elements, please refer also to 5.2.

For simple elements, it is normal to use design codes which take fire into account.

3.1 Beams

3.1.1 General

The results from a fire resistance test may be used to support an evaluation of the performance of another beam without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 3.1.2. Where the construction does not comply with the direct application, then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criterion is the loadbearing resistance (loadbearing capacity: determined by maximum deflection and maximum rate of deflection).

3.1.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar untested beam provided that all the following are true.

a) The span is not increased.

b) The load is not increased and the location and distribution of the load are unchanged.

c) The rotational and longitudinal restraint are unchanged.

d) The dimensions of the cross-section are not reduced.

e) Characteristic strength and density of any basic materials are unchanged.

f) The number of heated surfaces is unchanged.

g) The length of the unheated part of the construction is not reduced.

h) There is no change in the design of the cross-section (e. g. reinforcing bars within the cross-section).

i) Lining or decorative materials not influencing the fire resistance may be changed or added.

3.1.3 Extended application

3.1.3.1 Rules

Rules can be given for the following.

a) Dimensions and loading (length of span, level and type of load)

The length and load (level and distribution) may be changed as long as it can be calculated that the stresses (bending and shearing) within the section are not increased, and providing that failure mode at room temperature does not change (the span could be increased if the load is reduced and vice versa).

b) Reinforcement for reinforced concrete beams (not relevant for prestressed concrete beams)

A change in the location of reinforcement is possible as long as its temperature is not increased, the total cross-section is not reduced, and the distance between the reinforcement and the centroid of the compressive zone is not reduced.

c) Number of heated surfaces

The number of heated surfaces may be reduced for beams made of materials where this is not detrimental to the performance.

d) Services

Holes for services may be incorporated if they are perpendicular to the span and in the zone of the neutral axis, provided that they are protected at their borders in the same way as the beam itself.

e) Lining materials

Lining or decorative materials not influencing the fire resistance may be changed or added.

3.1.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Temperature profile

Heat transfer through beams may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) Load bearing resistance (load bearing capacity)

The load bearing resistance may be calculated for beams where the physical properties are known as a function of temperature and where the temperature profile over the cross-section of the beam is known. For timber the charring rate and hence the reduction in cross-section also need to be known.

c) Deflection

The deflection may be calculated for beams where the relationships between stress and strain (including, if necessary, creep effect) as a function of temperature are known, in addition to the above properties. It should be noted that the calculated deflections need to take into account deflections due to both the thermal and load induced strains.

3.1.3.3 Judgements

Changes may be made to the following aspects of the beams provided that expert judgement is based on the appropriate considerations mentioned below.

a) Supporting conditions

The supporting conditions may be changed, provided that this will not increase the load effect, reduce the rotational restraint, or increase the longitudinal restraint or the thermal conditions.

b) Protecting materials

When fire protection materials are changed or increased in order to compensate for changes in the load case or cross-sectional area, it must be demonstrated (justified) that the connection between the protective material and the beam will remain effective for a duration sufficient to achieve the fire resistance period.

c) Heated surfaces

The number and area of heated surfaces can be increased, if it can be demonstrated that in increasing the height of the cross-section or decreasing the perimeter/area ratio (for instance) the load bearing resistance is at least the same as the resistance of the tested beam.

d) Components

Components of the beam construction (additional support for floors or the other beams) can be added, provided that it can be shown that this does not reduce the fire resistance.

e) Services

Holes in beams perpendicular to their span may be allowed provided the stresses (bending and shear) at the location of the holes do not exceed the corresponding maximum stresses in the tested beam and the holes are protected at their edges in order to avoid excessive increase of temperature.

f) Protecting holes

Where holes are made in a beam which is protected, it is necessary for the boundary of the hole to be provided with an equivalent level of protection.

3.2 Columns

3.2.1 General

The results from a fire resistance test may be used to support an evaluation of the performance of another column without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 3.2.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criterion is the loadbearing resistance (loadbearing capacity: determined by maximum axial contraction and maximum rate of axial contraction).

3.2.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar untested column provided that all the following are true.

a) The length is not increased.

b) The load is not increased and its eccentricity is not increased.

c) The end conditions are unchanged.

d) The dimensions of the cross-section are not reduced.

e) Characteristic strength and density of any basic materials are unchanged.

f) The number of heated surfaces is unchanged.

g) There is no change in the design of the cross-section (e. g. reinforcing bars within the cross-section).

3.2.3 Extended application

3.2.3.1 Rules

Rules can be given for the following.

a) **Dimensions** (including length), loading and end conditions

The length, slenderness and load may be changed as long as it can be calculated that the load level is not increased, e.g. the length can be increased if the load is reduced or the end conditions result in a lower slenderness ratio and vice versa.

b) **Reinforcement for reinforced concrete columns** (not applicable to prestressed concrete)

A change in the location of reinforcement is possible as long as its temperature is not increased, there is no bending moment and the total cross-section is not reduced.

c) **Services**

Holes with a diameter less than or equal to X_1 for services in concrete columns are allowed where the thickness of the material on both sides of the hole has a minimum of X_2. The hole shall not remove any reinforcement.

d) **Lining materials**

Lining or decorative materials not influencing the fire resistance may be changed or added.

3.2.3.2 Fire engineering calculations

Calculations may be used for the following.

a) **Temperature profile**

Heat transfer through columns may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) **Load bearing resistance**

The load bearing resistance may be calculated for columns where the physical properties are known as a function of temperature and where the temperature profile over the cross-section of the column is known. For timber the charring rate and hence the reduction in cross-section also need to be known.

c) **Deformation**

The deformation (axial and lateral) may be calculated for columns where the relationships between stress and strain (including, if necessary, creep effect) as a function of temperature are known, in addition to the above properties. It should be noted that the calculated deformation needs to take into account deformations due to both thermal and load induced strains.

d) **Services**

Holes for services in concrete columns or holes in columns of material other than concrete, perpendicular to the length, are allowed if it can be calculated that they do not reduce the load bearing resistance at elevated temperature.

3.2.3.3 Judgements

Changes may be made to the following aspects of the columns provided the expert judgement is based on the appropriate considerations mentioned below.

a) Supporting conditions

The supporting conditions may be changed, provided that this will not increase the load effect or reduce the rotational or the thermal conditions.

b) Protecting materials

When fire protection materials are changed or increased in order to compensate for changes in the load case or cross-sectional area, it must be demonstrated (justified) that the connection between the protective material and the column shall remain effective for a duration sufficient to achieve the fire resistance period.

c) Components

Components of the column (brackets etc.) can be added, provided that it can be shown that this does not reduce the fire resistance.

d) Protecting holes

Where holes are made in a column which is protected, it is necessary for the boundary of the hole to be provided with an equivalent level of protection.

3.3 Floors

3.3.1 General

The results from a fire resistance test may be used to support an evaluation of the performance of another floor without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 3.3.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming), insulation (increase of average or maximum temperature) and loadbearing resistance (loadbearing capacity: determined by maximum deflection and maximum rate of deflection).

3.3.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar untested floor, provided that all the following are true.

a) The span is not increased and, in the case of a two-way spanning floor, the span ratio is unchanged.

b) The load is not increased and the location and distribution of the load are unchanged.

c) The rotational and longitudinal restraint are unchanged.

d) The thickness is not reduced.

e) Characteristic strength and density of any basic materials are unchanged.

f) Thermal insulation is not reduced at any point over the whole area.

g) The length of unheated parts of the construction is not reduced.

h) There is no change in the design of the cross section (e. g. the location of reinforcing bars).

3.3.3 Extended application

3.3.3.1 Rules

Rules can be given for the following.

a) **Dimensions**

The width of the floor can be increased provided sufficient space is allowed at the edges to permit the increased thermal expansion without leading to system failure.

b) **Dimensions and loading**

The span can be increased provided the load is reduced or the load can be increased provided the span is reduced. The changes to the loading or the span must not increase stress levels within the section in excess of the design stresses associated with the fire design load case.

Any changes to the loading or the span must not change the mode of failure.

If the thickness of the floor is reduced corresponding to a reduction in the load in order to maintain the same stress levels, the thickness may not be reduced to such an extent that the floor will not provide adequate insulation.

c) **Change in density**

Where light weight concrete is substituted for normal weight concrete, the thickness of the slab may be reduced by X % in respect of the insulation criterion as long as the loadbearing capacity is satisfactory. The temperature of steel beams and the temperature of steel floors in contact with the concrete will increase when light weight concrete replaces normal weight concrete.

d) **Lining materials**

Lining or decorative materials not influencing the fire resistance may be changed or added.

3.3.3.2 Fire engineering calculations

Calculations may be used for the following.

a) **Temperature profile**

Heat transfer through floors may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) **Insulation performance**

Compliance with the insulation criterion may be calculated using appropriate temperature profiles.

c) **Load bearing resistance**

The load bearing resistance may be calculated for floors where the physical properties are known as a function of temperature and where the temperature profile over the cross-section of the floor is known. For timber the charring rate and hence the reduction in cross-section also need to be known.

d) **Deflection**

The deflection may be calculated for floors where the relationships between stress and strain (including, if necessary, creep effect) as a function of temperature are known, in addition to the above properties. It should be noted that the calculated deflection needs to take into account deflections due to both thermal and load induced strains.

3.3.3.3 Judgements

Changes may be made to the following aspects of the floors provided the expert judgement is based on the appropriate considerations mentioned below.

a) Supporting conditions

The supporting conditions may be changed provided that this will not increase the load effect, reduce the rotational restraint or change the thermal conditions.

b) Services

Services may be installed into the floor construction provided that this will not reduce the ability of the construction to satisfy the criteria of loadbearing resistance, insulation, and integrity.

c) Protecting materials

When fire protection materials are changed or increased in order to compensate for changes in the load case or cross-sectional area, it must be demonstrated (justified) that the connection between the protective material and the floor will remain effective for a duration sufficient to achieve the fire resistance period.

d) Components

Components of the floor construction may be changed provided it can be shown that this does not reduce the fire resistance. It must be demonstrated that the interaction of the individual components will not adversely affect the performance of the tested construction.

e) Change of density

The density of timber components may be changed, subject to the section size being altered to compensate for the change in charring rate and any associated change in strength.

Change in the density of concrete, beyond that allowed in the rule 3.3.3.1c) can be made provided the influence of the change in thermal capacity and heat flow is taken into account regarding both the thermal insulation criteria and the temperature of any supporting elements.

3.4 Walls

3.4.1 General

There are two kinds of walls: separating walls which have to fulfil performance criteria of integrity, insulation and loadbearing resistance, and walls which do not perform a separating function. The latter have only to meet performance criteria for loadbearing resistance similar therefore to the clause on columns.

The results from a fire resistance test may be used to support an evaluation of the performance of another separating wall without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 3.4.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming), insulation (increase of average or maximum temperature) and load bearing resistance (load bearing capacity: determined by maximum axial contraction and maximum rate of axial contraction).

3.4.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested separating wall provided that all the following are true.

3.4.2.1 Solid part of the wall

a) The height is not increased.

b) The load is not increased, its eccentricity is not increased and the location of the load is unchanged.

c) The edge conditions are unchanged.

d) The thickness is not reduced.

e) Characteristic strength and density of any materials are unchanged.

f) Thermal insulation is not reduced at any point.

g) There is no change in the design of the cross-section (e. g. location of reinforcing bars).

3.4.2.2 Openings in the wall

a) The size of any openings is not increased.

b) The method of protecting the opening (e.g. glazing, door, sealing systems) is not changed.

c) The partition of any opening is unchanged.

3.4.3 Extended application

3.4.3.1 Rules

Rules can be given for the following.

a) Dimensions and loading

Changing the height and load is possible as long as stresses are adjusted accordingly, e.g. the height can be increased if the load is reduced and vice versa.

b) Slenderness

The slenderness of masonry walls must not exceed X % to prevent buckling failure.

c) Lining materials

Lining or decorative materials not influencing the fire resistance may be changed or added.

3.4.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Temperature profile

Heat transfer through walls may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) Insulation performance

Compliance with the insulation criterion may be calculated using appropriate temperature profiles.

c) Load bearing resistance

The load bearing resistance may be calculated for walls where the physical properties are known as a function of temperature and where the temperature profile over the cross-section of the wall is known.

d) Deformation

The deformation (axial and lateral) may be calculated for walls where the relationships between stress and strain (including, if necessary, creep effect) as a function of temperature are known, in addition to the above properties. It should be noted that the calculated deformations need to take into account deformations due to both thermal and load induced strains.

3.4.3.3 Judgements

Changes may be made to the following aspects of the separating walls provided that expert judgement is based on the appropriate considerations mentioned below.

3.4.3.3.1 Solid part of the wall

a) Boundary conditions

The supporting conditions may be changed provided that this does not increase the load effect, reduce the rotational restraint or change the thermal conditions.

b) Slenderness

Length may be inceased or cross-sectional area may be reduced if it is compensated for by an improvement of the boundary conditions in order to have the same slenderness ratio.

c) Services

Services (doors, ducts, penetrations) may be installed in the wall construction provided that this does not reduce the ability of the construction to satisfy the criteria of loadbearing resistance, insulation and integrity.

d) Protecting materials

When fire protection materials are changed or increased in order to compensate for changes in the load case or cross-sectional area, it must be demonstrated (justified) that the connection between the protective material and the wall will remain effective for a duration sufficient to achieve the fire resistance period.

e) Components

Components of the wall construction may be changed provided it can be shown that this does not reduce the fire resistance. It must be demonstrated that the interaction of the individual components will not adversely affect the performance of the tested construction.

f) Joint materials

Joint materials and systems may be changed provided the changes do not affect insulation or integrity.

3.4.3.3.2 Openings in partition

The size, shape and position of any opening may be varied subject to it being demonstrated that there is no adverse effect on the performance of the partition, e.g. the revised shape does not change the stiffness of the partition and the revised position does not cause different pressure conditions to exist which may influence integrity. The method of protecting the opening shall satisfy the fire requirement at the revised size, shape or position; see the relevant sections of this Technical Report for guidance on the extended application for the appropriate components.

4 Non-loadbearing elements

4.1 Vertical partitions

4.1.1 General

The results from a fire resistance test may be used to support an evaluation of the performance of another vertical partition without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 4.1.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming) and insulation (increase of average and maximum temperature).

4.1.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested vertical partition provided that all the following are true.

4.1.2.1 Solid parts of partition

a) The height is not increased.

b) The edge conditions are unchanged.

c) For a partition fixed at the top and bottom and tested at least with one edge free, wider elements are allowed.

d) Thermal insulation is not reduced at any point.

e) The thickness of component materials (e. g. linings, boards, studs) is not reduced.

f) On a studded system the stud spacing is not increased.

g) The distance between fixing of boards is not increased.

h) The size of any panel or board is not increased.

i) The length of any fixing is not reduced.

j) The type and nature of fixing are unchanged.

4.1.2.2 Openings in partition

a) The size of any openings is not increased.

b) The method of protecting the opening (e. g. glazing, door, sealing systems) is not changed.

c) The position of any opening is unchanged.

4.1.3 Extended application

4.1.3.1 Rules

Rules can be given for the following.

a) Increased height

An increased height of a certain percentage related to the dimensions tested can be accepted if it is based upon an evaluation of the influence on deformation and stability.

b) Changes of materials

Any change of materials must be related to their thermo-mechanical characteristics which may influence the fire resistance.

c) Joints

For system partitions the construction and the number of joints as well as the distance between them must be considered.

For masonry walls changes concerning the width and the reinforcement of the joints must be limited.

d) Linings

Adding linings up to a thickness of X_1 mm will not reduce the fire resistance.
Lining or decorative materials not influencing the fire resistance may be changed or added.

4.1.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Temperature profile

Heat transfer through partitions may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) Insulation performance

Compliance with the insulation criterion may be calculated using appropriate temperature profiles.

c) Deflection due to thermal gradient

Deflections may be calculated for partitions where the physical properties and the relationships between stress and strain (including, if necessary, creep effect) are known as a function of temperature and where the temperature profile over the cross-section of the partition is known.

4.1.3.3 Judgements

Changes may be made to the following aspects of the vertical partitions provided that expert judgement is based on the appropriate considerations mentioned below.

4.1.3.3.1 Solid parts of partition

a) Height

Beyond the percentage given by rule, the height may be increased provided the behaviour of any boards and panels will have no adverse effect on integrity.

b) Thickness

Reductions in thickness of vertical partitions must consider the influence on insulation performance and slenderness (which influences stability).

c) Services

Services may be installed in vertical partitions provided that the ability of the construction to satisfy the insulation and integrity criteria is not reduced.

d) Protecting materials

When fire protection materials are changed or increased in order to compensate for changes in the load case or cross-sectional area, it must be demonstrated (justified) that the connection between the protective material and the vertical partition will remain effective for a duration sufficient to achieve the fire resistance period.

e) Joint materials

Joint materials and systems may be changed, provided the changes do not affect insulation or integrity.

4.1.3.3.2 Openings in partition

The size, shape and position of any opening may be varied subject to it being demonstrated that there is no adverse effect on the performance of the partition, e.g. the revised shape does not change the stiffness of the partition and the revised position does not cause different pressure conditions to exist which may influence integrity. The method of protecting the opening shall satisfy the fire requirement at the revised size, shape or position; see the relevant sections of this Technical Report for guidance on the extended application for the appropriate components.

4.2 Ceiling membranes (Horizontal partitions)

4.2.1 General

The results from a fire resistance test may be used to support an evaluation of the performance of another ceiling membrane without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 4.2.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming) and insulation (increase of average or maximum temperature).

4.2.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested ceiling membrane provided that all the following are true.

a) The distance between hangers for suspended ceiling membranes (or the span of non-suspended ceiling membranes) is not increased.

b) The thermal insulation is unchanged.

c) The size and amount of any services penetrating the membrane are not increased.

d) The characteristic density of the tiles or the ceiling membrane is unchanged.

4.2.3 Extended application

4.2.3.1 Rules

Rules can be given for the following.

a) Dimensions

An increased distance between hangers (or an increased span of non-suspended ceiling membranes) must be based upon an evaluation of the influence on the deformation performance and the fire rating achieved.

b) Changes of materials

Any change of materials must be related to their thermomechanical characteristics which may influence the fire resistance.

4.2.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Temperature profile

Heat transfer through ceiling membranes may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) Insulation performance

Compliance with the insulation criterion may be calculated using appropriate temperature profiles.

c) Deflection

Deflections may be calculated for construction materials with known thermal and mechanical material characteristics.

4.2.3.3 Judgements

Changes may be made to the following aspects of the ceiling membranes provided the expert judgement is based on the appropriate considerations mentioned below.

a) Joint materials

Joint materials and systems may be changed provided the change does not affect integrity and insulation.

b) Services

Services may be installed in a ceiling membrane provided that the ability of the construction to satisfy the insulation and integrity criteria is not reduced.

c) Edge conditions

Edge conditions may be changed provided it can be shown that this will not have an adverse effect on the fire resistance.

4.3 Doors - Hinged and pivoted leaves

4.3.1 General

This clause covers only doors with hinged or pivoted leaves. Other types of doors are not covered due to the lack of knowledge of their fire behaviour.

The results from a fire resistance test may be used to support an evaluation of the performance of another door with hinged or pivoted leaves without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 4.3.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming) and insulation (increase of average or maximum temperature).

4.3.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested door provided that all of the following are true.

4.3.2.1 Leaves

a) The number of leaves is not increased.

b) The mode of operation is unchanged (e.g. single swing/double swing).

c) The height and width of the leaf are not increased.

d) The thickness of the leaf is not reduced.

e) The gaps between leaf and frame are not increased.

f) The restraint on the leaf is not decreased (see ironmongery and intumescent seals).

g) The thickness of any structural facing is not decreased.

h) The stiffness (expressed as the second moment of area) of any structural component in the leaf is not reduced.

i) The number of connectors/spacers per leaf (or per unit area) is not increased.

j) The thermal insulation characteristics of any core, sub-facing or infill material is not decreased in the case of an insulated door or are unchanged for other door types.

k) The number of joints in the core is not increased.

l) For timber doors the quality of the wood as indicated by the density and slope of grain is not reduced.

4.3.2.2 Openings in the leaf

a) The area of any glazed aperture(s) is not increased.

b) The number of glazed apertures is not increased.

c) The proximity of glazed aperture(s) to any leaf edge is not decreased nor is the distance between them.

d) The re-positioning or change of shape of any aperture does not cause the removal of any structural component.

e) The type of glass remains unchanged.

f) The glazing system remains unchanged including the type and number of fixings.

g) Openings made in the leaf for other purposes does not reduce the integrity of the assembly, e.g. air transfer grilles, letter plates.

4.3.2.3 Frames

a) The frame stiffness is not decreased.

b) Any lining or infill to the frame section remains unchanged.

c) Manufacturing/construction procedures and materials remain unchanged.

d) For timber frames the quality of the wood as indicated by its density and screw holding abilities is not reduced.

e) The restraint provided by the method of fixing the frame into the structural opening is not decreased.

4.3.2.4 Ironmongery (door hardware)

a) The ironmongery does not apply less restraint to the door leaf or leaves.

b) The method of attaching the ironmongery to the frame or the leaf remains unchanged.

c) The melting point of any part of the ironmongery that contributes to the restraint is not reduced.

d) The ironmongery does not cause the removal of any additional part of any fire seal.

4.3.2.5 Fire seals

a) The position and type of any fire or smoke seal remains unchanged.

b) The cross-sectional area of any intumescent seal is not decreased. In the jambs of unlatched door assemblies the cross-sectional area of any pressure forming seal is not increased.

4.3.3 Extended application

4.3.3.1 Rules

Rules can be given for the following.

4.3.3.1.1 Leaves

a) The leaf can be increased in height by X_1 %*.

b) The leaf can be increased in width by X_2 %*.

c) The area of glass can be increased by the following:

   i) doors with integrity-only performance: up to Y_1%** but not to exceed X_3%* of leaf area;

   ii) doors with integrity and radiation performance: up to Y_2%** but not to exceed X_4%** of leaf area;

   iii) door with insulation performance: up to Y_3%** but not exceeding more than X_5%* of leaf area.

d) The number of openings may be increased but the combined areas shall not exceed the tested area by more than X_5%** nor exceed the maximum percentages of the leaf areas given in c) above.

e) The mode of operation may be changed to a mode with more restraint (for example from double swing to single swing).

4.3.3.1.2 Frames

a) Dimensions

Increase in the cross-sectional area.

b) Stiffness

Increase in the stiffness.

* This value could be different for each door type.
** This value will vary depending on the period of fire resistance.

4.3.3.2 Fire engineering calculations

Calculations may be used for the following.

4.3.3.2.1 Leaves

a) Temperature profile

Heat transfer through door leaves may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) Insulation performance

Compliance with the insulation criterion may be calculated using appropriate temperature profiles.

c) Heat transfer

This is mainly to determine the unexposed face temperature rise in the centre of the leaf unless the model is specifically designed to take edge effects into account.

d) Deformation

In the case of very simple constructional components it may be possible to predict behaviour due to thermal distortion.

4.3.3.2.2 Frames

a) Heat transfer

Because of edge influences, calculation of temperature rise on the unexposed face can only be done with accurate models and a knowledge of the relevant heat transfer coefficients.

b) Deformation

In the case of simple frames it may be possible to predict distortion but care is needed to correlate this directly with an integrity failure.

4.3.3.3 Judgements

Changes may be made to the following aspects of the assemblies provided that expert judgement is based on the appropriate considerations mentioned below.

4.3.3.3.1 Leaves

a) Thickness

The thickness of the leaf may be reduced but this must not cause an increase in distortion that could result in a reduction in the integrity below the required level. Additional restraint may be used to control the potential increase in distortion.

Any reduction in thickness shall not reduce the ability of the construction to satisfy the insulation requirements of the wall on the exposed face.

b) Restraint

It may be possible to use ironmongery that provides less restraint to the door if the restraint provided by intumescent seals can be increased. Similarly it may be possible to use an intumescent which offers less resistance to distortion if the restraint provided by the ironmongery can be increased.

Both of these measures require a thorough understanding of the mechanisms involved and expert guidance should be sought from the manufacturer or other expert.

c) Change of facing thickness

It may be possible to reduce the thickness of the facing but this must be compensated for by an increase in the core material thickness.

Many facing materials, however, do contribute to the stiffness of the leaf and it must be considered whether the facing is making a significant contribution to stiffness before its thickness is reduced. It may be possible to compensate for any loss of stiffness in the applied facing by stiffening up core components.

In the case of steel doors, the facing material can be reduced in thickness if other compensations are made to maintain the stiffness of the leaf. In the case of insulated steel doors, evidence must be available to show that a reduction in face thickness will not cause an unacceptable rise in temperature.

d) Connections

In the case of steel doors, any increase in the number of connections between the two faces may cause an increase in the temperature rise on the unexposed face. It may be possible to increase the number of connectors but it must be demonstrated that this will not cause an unacceptable rise in the unexposed face temperature.

e) Change of core or infill

It may be possible to use a core or infill material which has a higher thermal conductivity as long as it can be shown that this will not cause the unexposed face temperature of the leaf to increase above the insulation criteria, if this is appropriate, or that the unexposed face temperature will not rise to a level which may cause a deterioration of the unexposed surface. Such deterioration could cause ignition or weaken the external facing to the point that it is not able to provide the required stiffness.

If the thermal conductivity is to be reduced significantly this could increase the temperature differential between the hot and cold faces and with certain door types this may lead to more exaggerated distortion. When considering reductions in the thermal conductivity of these core materials, the effect on distortion shall be considered.

f) Core joints

Joints in the make-up of a door leaf have two distinctly separate influences. Joints often allow stresses to be relieved and therefore they can be used to limit the distortion created by thermal or moisture imbalances. The number of joints should not therefore be decreased without considering whether this will create larger distortions.

The second influence relates to the permeability of the leaf. If the joints are not made tight, or are subject to increase in width due to shrinkage of adjacent components, the number of joints must be severely restricted. It may be possible to increase the number of joints if the quality control or manufacturing processes is improved or if the joints incorporate gap filling materials at the time of manufacture.

4.3.3.3.2 Frames

a) Frame stiffness

It may be possible to reduce the frame stiffness if the method of fixing is increased to reduce the potential increase in distortion.

b) Frame infill

It may be possible to change the infill in a frame if it can be demonstrated that the change in infill will not increase the unexposed face temperature to the critical levels and that it will not lead to an unacceptable increase in distortion.

c) Rebate

The rebate depth may be reduced if it can be demonstrated that it provides no significant restraint or contributes significantly to the performance in other way.

d) Density

It may be possible to use wood of a lower density if its section size is increased to compensate for the likely increase in the rate of erosion due to charring and if the fixings are changed to reflect the greater erosion and reduced screw holding capability.

4.3.3.3.3 Ironmongery (builders' hardware)

It has been demonstrated that the performance of the doorset can be improved if the distortion at the head of the doorset can be controlled. This can also be achieved by mechanical restraint, such as that provided by ironmongery. For those items listed, if a change to these components is proposed the influence that they have, as indicated below, must be taken into account.

a) Overhead closers

When fitted on the fire side of an inward opening door, these devices apply a gradually reducing closing pressure on the door for about 10 min to 20 min. These tend to be known as pending arm closers. When fitted on the non-fire side these devices apply a constant closing force on the door for the duration of the test. When fitted to a door opening into the furnace when considering a change in intumescent seals, the influence of the restraint on the leaf shall be taken into account. These devices tend to be known as parallel arm closers.

b) Floor springs

These devices tend to be located in the threshold of the frame and hence at the coolest part of the furnace and will therefore experience less detrimental effects, thus enabling them to provide a closing function for longer than the parallel arm closer.

c) Latches

These provide a very positive action in restraining the closing edge of the door leaf, thus reducing the amount by which the top closing corner of the door leaf (generally regarded as the most onerous position) distorts relative to the frame.

4.3.3.3.4 Fire seals

One of the factors affecting the performance of insulating doorsets is the level of intumescent used. Without intumescent seals it is unlikely that a performance of 20 min would be achieved on a timber based assembly using a nominal 30 min door leaf construction. With a standard level of intumescent protection, the performance would be increased to over 30 min as a result of the intumescent material sealing the gaps and providing restraint to distortion of the leaf. By further increasing the intumescent to an enhanced level, the performance of the door could be increased to 35 min to 40 min. The correct intumescent detail provides two important functions. Firstly the intumescent will act as a gap filling agent and secondly by selecting pressure generating intumescent material it is possible to provide restraint against the tendency to distort.

4.4 Lift landing doors — Centre opening and two-speed lift landing doors

4.4.1 General

This clause covers only centre opening and two-speed lift landing doors. Other types of lift landing doors are not covered due to the lack of knowledge of their fire behaviour.

Lift landing doors are imperforate doors used to provide access to a lift cab and are installed across openings in the well (lift shaft).

This clause is only applicable to doors tested to the integrity and insulation requirements of ISO 834-1. It is not applicable to tests where evaluation of integrity is by means of leakage measurements (where different rules may need to be developed).

The results from a fire resistance test may be used to support an evaluation of the performance of another lift landing door without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 4.4.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming) and insulation (increase of average or maximum temperature).

4.4.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested lift landing door provided that all of the following are true.

4.4.2.1 Opening

a) The height and width of the opening is not increased.

4.4.2.2 Door leaves

a) The mode of operation is unchanged. (e.g centre opening or two-speed opening).

b) The height and width of each leaf are not increased.

c) The number of door leaves is not changed.

d) The thickness of the metal and the design and position of any stiffeners are not changed.

e) The type of insulation and its thickness are not changed.

f) The suspension system and the materials used for the suspension rollers are not changed.

g) For centre-opening doors:

i the meeting edge detail is not changed;
ii the trailing edge detail is not changed;
iii the detail at the head and sill is not changed.

h) For two-speed lift landing doors:

i the leading edge detail is not changed;
ii the trailing edge detail is not changed;
iii the detail at the head and sill is not changed.

4.4.2.3 Frame

a) The section shape, size and metal thickness of the frame are not changed.

b) The type of fixing used to attach the frame to a wall is not changed.

c) The spacings of the frame fixings are not increased.

d) The design and dimensions of the overlap with the frame and trailing edge of the door leaf(ves) are not changed.

4.4.2.4 Operating mechanism

a) The operating system is not changed.

4.4.2.5 Openings in leaves

a) The area of any glazed aperture(s) is not increased.

b) The number of glazed apertures is not increased.

c) The proximity of glazed aperture(s) to any leaf edge is not decreased nor is the distance between them.

d) The re-positioning or change of shape of any aperture does not cause the removal of any structural component.

e) The type of glass remains unchanged.

f) The glazing system remains unchanged including the type and number of fixings.

g) Openings made in leaves for other purposes do not reduce the integrity of the assembly, e.g. air transfer grilles, letter plates.

4.4.2.6 Surround panels

a) The overall dimensions of head panels or side panels are not increased.

4.4.2.7 Supporting construction

a) With respect to masonry constructions, the density or the thickness of masonry construction is not decreased.

b) With respect to stud partitions, the partition is unchanged.

4.4.3 Extended application

4.4.3.1 Rules

Rules can be given for the following.

a) The leaf can be increased in height by X_1 %.

b) The leaf can be increased in width by X_2 %.

c) Subject to the interlock/overlap detail with the door leaves not being changed, an alternative frame cross-section can be used provided it has, at least, the same stiffness (second moment of area and slenderness ratio).

d) The head leaf height can be increased by X_3 %, subject to the overall height of the complete assembly not exceeding X_4 %.

e) The side leaf width can be increased by X_5 %.

4.4.3.2 Fire engineering calculations

For leaves, calculations may be used for the following.

a) Temperature profile

Heat transfer through door leaves may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation etc.) will occur.

b) Insulation performance

Compliance with the insulation criterion may be calculated using appropriate parts of temperature profiles.

c) Heat transfer

This is mainly to determine the unexposed face temperature rise and is limited to predicting the temperature rise in the centre of the leaf unless the model is specifically designed to take edge effects into account.

d) Deformation

In the case of very simple constructional components it may be possible to predict behaviour due to thermal distortion.

4.4.3.3 Judgements

Changes may be made to the following aspects of the assemblies provided that expert judgement is based on the appropriate considerations mentioned below.

a) Stiffness

The overall stiffness of the leaves may be reduced if it can be demonstrated that the design of the edge detail (trailing edge / frame overlap), interlock (meeting edge detail between leaves) can accommodate more leaf deformation and still satisfy the integrity requirements. A review of the suspension arrangement may also be necessary.

b) Suspension system

An alternative suspension system may be used if it can be demonstrated that the mode of deformation of the door leaves will not change. With respect to combustible rollers, an alternative combustible material may be substituted if it can be shown that the material is less inflammable and/or softening than the original roller.

c) Supporting construction

For stud partitions, an alternative system can be used if it can be demonstrated that the integrity performance of the lift-landing door assembly or the stud partition will not be affected. Test data on the fire resistance of the alternative stud wall system shall be available.

For masonry walls, the thickness of the wall may be reduced by X_6 %, subject to test evidence that the fire resistance of the wall will be, at least, X_7 % above that required for the door.

d) Insulated leaves

An increase in thickness of an insulated leave may change its mode of deformation and, consequently, may increase the size of openings at the meeting edges, leading edge and trailing edges. Where an increase is possible then a change of design at these locations may be necessary as well as a review of the suspension arrangement.

4.5 Rolling shutters

4.5.1 General

Shutters are mechanical items which include mechanisms for the raising and lowering of semi-flexible steel curtains. This Technical Report does not cover extensions to the performance with respect to any changes in the drive mechanism or gears. If any change in these items is contemplated the influence that this may have on the measured fire resistance must be considered. In particular any change in the operating mechanism shall not impair the ability of the shutter to close.

This Technical Report only considers the performance of the passive elements of the shutter which play a function in the ability of the shutter to provide an adequate fire barrier. These items include, for example, guides, laths, barrel, barrel casing, end plates/barrel supports, etc.

The relevant performance criterion is normally integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming).

4.5.2 Direct application

The results of the fire resistance are deemed to be applicable to similar type of untested rolling shutter provided that all of the following are true.

4.5.2.1 General

The width and height of the shutter shall not be changed if this entails a change in the barrel dimensions. Any change in the span (width) or height of a shutter which requires a change in the barrel dimensions can only be considered under extended application due to the interdependency of all components.

4.5.2.2 Laths (slats)

a) The thickness of the lath is not reduced.

b) The cross-sectional geometry of the lath remains unchanged.

4.5.2.3 Guides

a) The thickness of material used for the guide shall not be decreased.

b) The depth of the guide shall not be reduced.

c) The width of the guide remains unchanged.

d) The rotational restraint provided by the guide is not decreased.

4.5.2.4 Barrel

The length and diameter of the barrel remain unchanged.

4.5.3 Extended application

4.5.3.1 Rules

Rules can be given for the following.

a) Shutter width

The width of the shutter can be increased by X_1 % or decreased by X_2 % subject to the barrel diameter not needing to be changed. All gaps shall remain proportional to those in the tested construction.

b) Shutter height

The height of the shutter can be increased by X_1 % or decreased by X_2 % subject to the barrel diameter not needing to be changed. All gaps shall remain proportional to the tested construction.

4.5.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Changes to the barrel dimensions

The new barrel dimensions may be able to be calculated subject to a valid model being available.

4.5.3.3 Judgements

Changes may be made to the following aspects of the rolling shutters provided that expert judgement is based upon the appropriate considerations mentioned below.

a) Changes to the width of the shutter

The width of the shutter may be increased or decreased beyond that permitted by the "rules" of extended application providing that any changes in the design necessitated by the change in size consider the following aspects.

i) The thickness of the laths may need to be increased when increasing the width of the curtain to ensure that they have adequate strength and stiffness. In some cases, the profile may also need to be changed. Any reduction in thickness of the lath that may be contemplated when reducing the width of the curtain must consider the influence of the increased rate of heating and possibly higher temperatures that the laths may experience.

ii) The clearance gaps between laths and guides shall be revised to take into account change in thermal expansion and to maintain the same proportional relationship between lath length and guide depth.

iii) The barrel diameter may need to be changed to reflect the different load and hence stress levels acting on it. All such changes shall be quantified as in 4.5.3.3 c).

iv) The support for the barrel will need to be reviewed in the light of any changes made in the barrel design.

v) The stiffness of the housing around the barrel may need to be increased.

b) Changes to the height of the curtain

The height of the curtain may be changed beyond that permitted by the "rules" of extended application provided that any changes in the design necessitated by the change in size consider the following points.

i) Any change to the length of the guides needs to consider the increase or decrease in thermal expansion. The guides shall be fixed to reflect this so they do not deflect away from the wall and cause an integrity loss.

ii) The barrel diameter may need to be changed to reflect the different load and hence stress levels acting on it. All such changes shall be quantified as in 4.5.3.3 c).

iii) The support for the barrel and curtain will need to be reviewed in the light of any changes to the mass of the curtain and/or barrel.

c) Changes to the barrel dimensions

The barrel is a key component and any proposed changes to its size should only be contemplated when necessary (e.g. to accommodate increased width or mass of curtain). The change to a different barrel shall only be undertaken with the full understanding of the mechanical and thermal behaviour, taking into account stresses and deflections. An increase in the barrel stiffness can be achieved by an increase in the diameter or the wall thickness or both. These will have different influences on the rate of heating of this component and hence the deflection and expansion of it. This shall be taken into account when choosing the new dimensions.

d) **Supporting construction**

Because the roller shutters are attached to the face of supporting construction, possibly on the side exposed to the fire, the supporting construction will be vital to the performance. The supporting construction may be changed but its ability to take fixings and withstand the stresses of the eccentric load must be fully analysed.

Similarly, if the shutter is increased in size or mass the ability of the tested construction to take any increased load/stress must be considered.

4.6 Glazed elements

4.6.1 General

Glazed elements are separating elements containing or consisting of translucent elements with an area large enough to influence the fire performance. It is the total behaviour of the whole element which must be considered.

The results from a fire resistance test may be used to support an evaluation of the performance of another form of construction without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 4.6.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity (measured by gap gauge, ignition of cotton pad, or sustained flaming) and, when requested, insulation (increase of average or maximum temperature) or radiation.

The following information comes from experimental knowledge on glass elements. It seems possible to extend it to the behaviour of ceramic glazed elements.

4.6.2 Direct application

The results of the fire resistance test are deemed to be applicable to a similar type of untested glazed element provided that all of the following are true.

a) The dimension of the largest panel is not increased.

b) The height of the whole element is not increased.

c) The perimeter/area ratio of any framing components is not increased.

d) The permeability of the non-glazed areas of the construction is not increased (e.g. the size of, or the number of joints/unit area is not increased).

e) The rotational restraint provided by the method of fixing is not decreased.

f) The overall thickness of the wall cross-section of framing members (if used) is unchanged.

g) Characteristic strength and characteristic density of the components remain unchanged.

h) The width of any framing members between panes is not reduced.

i) The edge cover and the method of retaining the glass remains unchanged.

j) The composition of the glass remains unchanged.

k) The thickness of the glass is not reduced.

l) Additional layers of glass of any type are not mounted into the same opening as the fire resisting glass.

m) In the case of glass not mounted vertically, the angle of the glass away from the vertical is not increased.

If any of the above are not complied with, then an assessment for extended applicability following the rules given below will be required.

4.6.3 Extended application

This can include both insulating and non-insulating glass types.

The performance and failure mechanisms of these two glass types are very different.

4.6.3.1 Rules

Rules can be given for the following.

a) Size of the element

The separating element or the framework into which the glass is fitted is allowed to be extended by the rules given in 4.1.3.1. Where this entails the glass sizes being increased beyond the sizes permitted in b) and c) below, then additional mullions and transoms must be introduced to restrict the glass accordingly.

b) Size of panes (non-insulating glass)

For non-insulating glass where the failure of the glazed element was not the result of glass slumping due to its average temperature being greater than the thermal softening temperature of the product at the required duration then:

i) the pane height may be increased by X_1%;

ii) the pane width may be increased by X_2%;

iii) the pane area can be increased by X_3%.

c) Size of panes (insulating glass)

For insulating glass where the unexposed face remains below the mean temperature rise criterion of 140°C above ambient, below the maximum temperature rise criterion of 180°C above ambient and the outer pane of glass remains substantially intact then:

i) the pane height may be increased by X_4%;

ii) the pane width may be increased by X_5%;

iii) the pane area can be increased by X_6%.

4.6.3.2 Fire engineering calculations

Calculation methods to predict the performance of glass at elevated temperatures are not readily available.

Calculations may used for the following.

a) Deformation

Calculations to predict temperature gradients and thermal bowing of steel frame sections can be made using agreed material properties and heat transfer mechanisms. The resulting curvature predicted by the calculation method should be no greater than that measured during the test because increased curvature will cause increased edge stresses on the glass.

4.6.3.3 Judgements

Changes may be made to the following aspects of the glazed elements provided that expert judgement is based on the appropriate considerations mentioned below.

a) Pane sizes

The pane size may be increased if the failure of the glass over the required duration was shown to not be related to any plasticity in the glass.

Clearances between the glass and the surrounding structure have to be made proportional to the pane mass or width.

Compensatory measures may be required to the glass system in order to accommodate the increased mass of a larger pane. Such measures must not be introduced without considering the influence they may have on the thermal behaviour of the glass.

Larger pane sizes may be used if, when tested, the glass gave a sufficient margin of safety concerning the relevant criteria. The manufacturer shall be contacted for guidance. Expert guidance will be needed. The pane size may be increased with certain glasses by increasing the thickness of the glass.

b) Distance between glazed apertures

Reducing the width of mullions between adjacent panes can have the effect of increasing the average temperature of this component. The reduction in width will inevitably reduce its thermal inertia and the temperature will increase.

Increases in mullion temperature may well lead to increased deflections which may, in turn, cause premature loss of integrity between the glass and the surrounding structure.

It may be possible to reduce the width of components between glass, if it can be demonstrated that the temperature rise will not cause increased temperatures in the mullion or that compensatory measures such as increasing the insulation to the separating member will keep its temperature below the point at which increased deflection will occur.

c) The glass system

Conventional fire resisting glass achieves ratings by means of a well-balanced combination of edge cover and glass materials. Some glass can fail if the edge cover is too large whilst others will fail if the edge cover is too small. Some glass requires high thermal insulation within the glass system to achieve their potential performance whilst others do not require any insulation from the glass system. The method of glazing a pane shall not be varied without consultation with the manufacturer or a fire safety engineer knowledgeable about the product.

d) Additional layers of glass

The plasticity of conventional glass is related to its temperature which is, in turn, a function of the average temperature between the cold face and the hot face.

When additional panes are fitted in the same aperture, they can change this balance significantly. Fire rated glass shall not be incorporated in a double glazed system, for thermal energy reasons, or laminated to another glass for strength or vandal resistance without assessing the influence that this may have on its fire performance.

e) Height of framing

The height can be increased provided that self-induced loads due to restrained expansion are not increased. However, the changes to the height must not produce a failure in the proposed glazed element different from that observed during the test of the systems. Expansion allowances must be increased in metal systems if the height is to be extended.

f) End restraint

Any additional rotational restraint to a glazed element will improve fire resistance, whilst additional restraint in the plane of the element will reduce fire resistance.

g) Width of framing

The width of the glazed element can be increased provided sufficient space (infilled to prevent movement of smoke and hot gases) at the edges or within the width is provided to accommodate any increase in thermal expansion.

h) Orientation

Conventional glass is a super cooled liquid and once it reaches a particular temperature, related to its composition, it will start to revert to its liquid state and begin to flow. This makes its mode of failure different from many other building materials. Because this rate of flow is dependent upon the way gravity acts on the glass, the orientation is critical. A change from vertical to horizontal must not be contemplated without compensating for this influence.

5 Components contributing to the fire resistance of elements

5.1 Suspended ceilings

5.1.1 General

This clause only considers fire rated suspended ceilings, as defined in ISO/TR 6167, which have demonstrated by test, their ability to provide a contribution to the fire resistance of a horizontal loadbearing element. The suspended ceiling does not have to comply by itself with the actual criteria for integrity and insulation given in ISO 834-1. Direct and extended applications of tests performed on a specific ceiling to comply by itself with the actual criteria for integrity and insulation are identified in 4.2.

The results from a fire resistance test may be used to support an evaluation of the performance of another suspended ceiling without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 5.1.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

5.1.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested construction protected by a suspended ceiling providing that all of the following are true.

5.1.2.1 Regarding the horizontal loadbearing element

a) The type of construction (beams and slab) is unchanged.

b) The perimeter/area ratio of the beams is not increased.

c) The thermal inertia (expressed by $\sqrt{k\rho c}$) of the cover slab floor is not increased.

d) The conductivity of any bedding material between the beam and slab is not increased.

5.1.2.2 Regarding the suspended ceiling

e) Permeability of the cover slab is not increased.

f) The thickness of any tile is not reduced.

g) The design and material used for tiles are unchanged.

h) The area of tiles is not increased and the aspect ratio of the tiles is unchanged.

i) The method of fixing to the support structure is unchanged.

j) The depth of the cavity is not reduced.

k) The length of the hangers is not increased by more than X %.

l) The expansion allowance of the suspension system and of the support structure is not reduced.

m) The distance between hangers is not increased.

n) The cross-sectional area and thermal capacity of the hangers are not reduced.

o) The ceiling is not penetrated by more services or by services of greater size than tested.

p) No additional insulation is put in the cavity.

5.1.3 Extended application

There is a need to differentiate between the construction to be protected and the suspended ceiling.

5.1.3.1 Rules

Rules can be given for the following.

5.1.3.1.1 Construction to be protected

a) Load bearing resistance

Fire resistance of loadbearing structure may be demonstrated by applying, for instance, criteria of a maximum temperature in the cavity ([320]°C for timber, [400] °C for composite steel deck, [550] °C for steel and [600] °C for reinforced concrete).

b) Dimensions and loading

Dimensions and/or loading of beams and floors may be changed by applying rules given in 3.1.3.1 a) and 3.3.3.1 b) respectively.

c) Service penetration

Ceilings not tested with service penetrations may be penetrated by not more than a single cable with a maximum diameter of X mm.

5.1.3.1.2 Suspended ceiling

a) Area of tiles

Any increase of the area of the tiles (leading to an increase of their spans between the supporting frame)should consider:

— the aspect ratio of the tile (unchanged),

— stress level from selfweight (not increased),

— fixing details due to application of changes in thermal expansion of the tile at the support points,

— expansion allowance of the framework.

b) Length of hangers

Any increase of the length of the hangers should consider:

— the maximum deformation allowed for the ceiling,

— the possibility of decreasing thermal elongation of hangers by decreasing their temperature,

— stress levels from selfweight (not increased).

5.1.3.2 Fire engineering calculations

Calculations may be used for the following.

5.1.3.2.1 Construction to be protected

a) Temperature profile

Heat transfer through the assembly including the suspended ceiling may be calculated by using an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the assembly and relevant calculation model to deal with convection and radiation within the cavity. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element (i.e. boards, insulation, etc.) will occur.

b) Raising temperature of the protected structure

From the characteristic time-temperature curve recorded in the cavity during the fire test, calculation can be made to determine:

— the temperature of steel beams by taking into account the perimeter/area ratio and the relevant radiation and convection factors;

— the temperature profile within a concrete element by taking into account its thickness and the relevant thermal characteristics.

c) Load bearing resistance and deformation

Knowing the temperatures of elements it is possible, by referring to 3.1.3.2 and 3.3.3.2, to calculate load bearing resistance and deformation.

5.1.3.2.2 Suspended ceiling

a) Temperature of the tile

Calculations can be made to determine the interior and the unexposed face temperature rise in the centre of the tiles.

b) Temperature within the cavity

Calculations can be made only with an accurate model, taking into account convection and radiation heat transfer within the internal cavity, as well as conduction within the tiles, framing and construction to be protected.

5.1.3.3 Judgements

Changes may be made to the following aspects of the construction to be protected, provided that expert judgement is based on the appropriate considerations mentioned below.

5.1.3.3.1 Construction to be protected

Changes in the construction may be made, provided:

— the temperature reached in the cavity will not be increased;

— the deformation of the supporting construction, for a given temperature in the cavity, will not be higher that the one recorded during the test.

5.1.3.3.2 Suspended ceiling

Changes may be made to the following aspects of a suspended ceiling, provided that expert judgement is based on the appropriate considerations mentioned below.

a) Span

The distance between hangers may be increased provided it can be shown that the grid supporting the ceiling tiles does not produce deflections more than those observed during the test (deflections more than those observed during the test may promote an increase in the permeability of the ceiling).

b) Penetrations and openings

Any opening in the suspended ceiling for access or lighting purposes shall be closed off so that it does not decrease the integrity or insulation of the ceiling nor increase the dead weight on the suspension grid unless compensatory measures are introduced. The penetration of suspended ceiling by services may affect the fire resistance performance.

c) Edge sealing

Therefore, any cut-out at the perimeter of the ceiling, caused by columns, ducts, etc. shall be sealed and if large cut-outs are present then additional support to the tiles will be required. (The performance under fire exposure of a suspended ceiling is dependent upon retaining a suitable edge seal between the suspended ceiling and the walls, columns, etc.)

d) Tile fixing details

Alternative fixing details may be incorporated in the construction provided that they have been shown to provide adequate fixing for similar components during a fire resistance test on an otherwise similar construction.

e) Hanger fixing details

Any changes to the detail for securing the hangers to the protected structure must take into consideration any changes to the material used in the substrates.

f) Depth of cavity

Decreasing the depth of the cavity may be allowed by considering the safety margin for temperature and/or resistance time.

5.2 Insulating systems

5.2.1 General

This clause only considers insulating systems which have demonstrated by test their ability to provide a contribution to the fire resistance of standard elements and which have been tested to evaluate protection given to standard elements with various insulation thicknesses and element sizes.

Direct and extended applications of tests performed on specific insulated beams, columns or floors to establish the fire resistance of the complete element are identified in 3.1 to 3.3.

The testing methodology used should provide information on stickability of the insulating system to its support and on heat transfer conditions through the structural element according to an established assessment method.

The results from a fire resistance test may be used to support an evaluation of the performance of another structural element without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 5.2.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are related to the increase of temperature within the structural element by comparison with its limiting temperature.

5.2.2 Direct application

The results from a set of fire resistance tests are deemed to be applicable to an insulated untested structural element as far as temperature of this element is concerned, providing that all of the following are true.

a) The kind of structural element (e.g. beam, column, floor) is unchanged.

b) The kind of material of the structural element (e.g. steel, concrete, wood, composite) is unchanged.

c) The cross-sectional size of the structural element is within the limits of the tested range.

d) The insulating materials are unchanged.

e) The insulating system is unchanged.

f) The thickness of the insulation is within the limits of the tested range.

5.2.3 Extended application

5.2.3.1 Rules

Rules can be given for the following.

a) Size of cross-section

The size of the cross-section of structural elements can be extended outside the limits of direct application of the results. The significance of the possible extension has to be a function of the accuracy of the assessment method used, as far as physical laws on heat transfer are concerned.

b) Thickness of insulation

The thickness of insulation system can be extended outside the limits of direct application of the results for the same conditions as tested and provided it is proven that the material and its method of attachment will remain coherent and cohesive.

c) Density of insulation

The density of the insulation material can be allowed to vary by $\pm X$ %.

d) Orientation of the load bearing element

A test performed on a loaded beam may be accepted as far as stickability is concerned as also valid for columns, as long as the design of the insulating system is not changed.

5.2.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Heat transfer

Change in the size of the structural element cross-section and of the thickness of insulating system, outside the limits of direct application and rules for extended application may be assessed by heat transfer calculation providing thermal characteristics of the insulating system (thermal conductivity, specific heat, density — at the relevant temperature) are known or can be derived from test data.

b) Material of protected element

If the thermal characteristics of the insulating system and the thermal characteristics of the kind of material of the structural element are known (and checked with existing fire test data), it is possible, by heat transfer calculation, to calculate the field of temperature in the structural element providing the stickability of the insulating system is proved.

5.2.3.3 Judgements

Changes may be made to the following aspects, provided the expert judgement is based on the appropriate considerations mentioned below.

a) Components of the insulating system

Changes to a component of a mechanically fixed insulating system or in its relative ratio may be made if such a new insulating system has already been tested on another support.

b) Fixing conditions

For a given insulating material, its way of fixing to its support can be changed providing it can be proved that the new way is not more onerous.

c) Size of cross-section (stickability)

Increasing the size of a cross-section (height or width of the structural element) may be made if it is demonstrated that the insulating system will adhere to its support and that more adverse conditions are addressed through compensatory measures.

d) Surface conditions of the support

Adhesion of sprayed materials is a function of the substrate. In these regards, it is only possible to accept the use of the protecting material on a rougher surface than tested.

Changes in primer can influence the adhesion of sprayed or glued materials.

e) Rigidity of the support

Adhesion of the protecting system to its substrate is a function for a given temperature level of the deformation of that support. It is necessary to check that the deformation will not be higher than experimental results.

6 Service installations

6.1 Ducts

6.1.1 General

This clause applies to fire-tested ducts that resist the ingress and egress of fire and are able to pass between compartments without having dampers.

The results from a fire resistance test may be used to support an evaluation of the performance of another duct without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 6.1.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

Two kinds of extrapolation of test results have been differentiated according to tests performed: according to ISO 6944 (i.e. without air flow) or according to national testing methods using air flow. When different applications are possible for the duct with fresh air flow they are identified.

The relevant performance criteria are integrity (defined by a specified amount of leakage, ignition of cotton pad, or sustained flaming) and insulation (increase of average or maximum temperature).

6.1.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested duct provided all of the following are true.

a) The width of the duct is not increased.

b) The cross-sectional area of the duct remains the same.

c) The shape of the cross-sectional area of the duct remains the same.

d) Regarding ducts with air flow, the length of the duct through a fire compartment is not increased.

e) Characteristic strength and density of the components remain unchanged.

f) The distance between the hangers or other suspension devices is not increased.

g) The length of the hanger or suspension devices is not increased.

h) The fire protection for the hangers/suspension devices is not reduced.

i) The ratio between the exposed perimeter and cross-sectional area of the hanger/suspension device is not increased (perimeter/area ratio).

j) The thickness of any steel used in the construction of the duct is not decreased.

k) The mass of the protection system per unit length remains the same.

l) The fire sealing (stopping) system around the duct in the area where the duct passes out of the heated zone remains the same.

m) The number of joints between panels of the fire protection material(s) is not increased per unit length (unit length should be taken as the exposed length of the duct when in the furnace).

n) The orientation, either horizontal or vertical, of the duct remains the same.

o) The density of the wall penetrated by the duct is not reduced.

p) The thickness of the wall penetrated by the duct is not reduced.

q) The duct will not be subjected to an underpressure greater than that used during the test.

6.1.3 Extended application

6.1.3.1 Rules

Rules can be given for the following.

a) Shape

The cross-sectional area of the duct, as far as heat transfer is concerned, may be changed by $\pm X_1$%.

b) Steel sheet

For insulated steel ducts, the thickness of the steel sheet may be decreased by X_2 %.

c) Thickness of protection material

The thickness of the protection material may be increased provided the stresses in hangers are not increased.

6.1.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Protection material

Heat transfer through the duct walls may be calculated by using an accepted temperature analysis model in order to change the thickness or density of the protection material.

Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element.

b) Hangers

Maximum elongation related to stress and temperature (perimeter/area ratio and insulation) of hangers may be calculated with known thermal and mechanical material characteristics to change the hanger or the suspension devices.

Regarding duct with supplied air flow:

c) Length

The temperature of air flow inside the duct can be calculated with an appropriate numerical model to allow change in the fire exposed length of the duct.

d) Supplied air velocity

The temperature of air flow inside the duct can be calculated with an appropriate numerical model to allow change in the velocity of the supplied air flow in the duct.

6.1.3.3 Judgements

Changes may be made to the following aspects of the duct assemblies provided the expert judgement is based on the appropriate considerations mentioned below.

a) Span

If a shorter length of duct does occur in practice, it is recommended that the number of hangers/suspension devices are not less than the number exposed in the furnace. For applications where the span is greater, a check shall be made to ensure that the stress in the hanger/suspension device is not increased and the torsion resistance of the system is not reduced.

b) Length of the duct

When increasing the exposed length of the duct, the thermal elongation has to be considered.

c) Shape of the duct

As far as integrity is concerned, any modification of shape (mainly with board material) has to consider the joints and angles. Any change in shape will require joining any protection in a different way and this must be considered when making the judgement.

d) Physical properties of the protection material(s)

The material is likely to be subject to a combination of forces (not present in other types of fire resistance tests) and the retention of the insulation system has to be assessed if any change is contemplated.

e) Fire stopping material/system

An evaluation will need to be undertaken to investigate the effect of the forces applied to the fire stop (during the test the movement of the duct will subject the fire stopping to forces).

f) Orientation

When making an extended application of a horizontal duct to vertical applications, the effect of the change in orientation on the protection and the support shall be taken into account. In general terms the test on a horizontal duct can represent the worse case. In most cases a result for a vertically oriented duct cannot be applied to a horizontal situation.

g) Specification of wall

The density and thickness of the wall penetrated by the duct may be increased. If either the density or thickness is to be reduced, then the influence of this on the thermal flow and physical support and restraint shall be taken into account in the assessment or else an additional test shall be performed.

6.2 Dampers

6.2.1 General

This clause applies to dampers that are installed in non-fire resisting ducts at (or nearby) the point they penetrate fire separating walls or floors.

The results from a fire resistance test may be used to support an evaluation of the performance of another damper without any further calculations or the application of rules or judgements if the construction complies with the guidance given in 6.2.2. Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The test procedure taken into account is given in ISO 10294-1. Some countries use door testing methodology to test dampers without underpressure on the unexposed side. In this case, 4.3 has to be used for application and extension of the test results.

The relevant performance criteria are leakage rate (maximum value), integrity (measured by a specified amount of leakage, gap gauge, ignition of cotton pad, or sustained flaming) and, when requested, insulation (increase of average or maximum temperature).

6.2.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested damper providing that all of the following are true.

a) The damper is being used in the same orientation.

b) The size of the damper is not changed.

c) For blade type dampers, the number of blades is not increased.

d) The axis of the blade(s) is in the same horizontal or vertical position.

e) The overlap at the blade edges is not decreased.

f) The underpressure within the duct (absolute value) is not increased.

g) The wall or floor has, at least, the same fire resistance as the damper.

h) The density and thickness of the wall or floor construction are not decreased.

i) The sealing system between the damper and the supporting construction is not varied.

j) The restraint provided by the supports around the damper is not decreased.

k) The mechanism for operating the damper is unchanged and located on the same fire exposure side.

l) If tested only on one side, asymmetrical elements are only approved for the same side of fire exposure.

m) Its position regarding the supporting construction (either the blade is in the plane of the supporting construction, or outside towards the fire, or outside opposite the fire) is unchanged.

6.2.3 Extended application

6.2.3.1 Rules

Rules can be given for the following.

a) The area or the size of the damper can be modified by up to $\pm X_1$ %.

6.2.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Temperature profile

Heat transfer through damper blades may be calculated by an accepted temperature analysis model. Input data must be based on values for specific heat capacity and thermal conductivity as a function of temperature for all materials included in the element. For composite elements it is necessary to estimate, using relevant test results, the time of exposure at which destruction or detachment of parts of the element will occur.

b) Leakage rate

To obtain an estimate of the leakage rate when the absolute value of the underpressure is decreased, assume the size and shape of gaps will remain unchanged.

6.2.3.3 Judgements

Changes may be made to the following aspects of a damper, provided that expert judgement is based on the appropriate considerations mentioned below.

a) Number of blades

The number of blades may be increased where the tested leakage rate and temperature in the connecting duct are sufficiently below the applicable limits.

b) Sealing system inside duct

The sealing system between the blade and the surrounding duct may be changed, provided that the new sealing system has passed fire tests on a similar design of damper with equal or greater pressure.

c) Sealing system outside duct

The sealing system between the damper and the supporting construction may be changed, provided that the new sealing system has passed fire tests in similar conditions.

d) Mechanism for operating

The mechanism for operating the damper may be changed, provided that the new one has been tested and demonstrated that it will work.

e) Position

The position of the damper, regarding the blade and the plan of the supporting construction, may be changed, considering that the better position is when the blade is at mid-thickness of the supporting construction.

6.3 Penetration seals

6.3.1 General

This clause applies to fire tested penetration seals that resist the ingress of fire through floor and wall penetrations.

The application guidance assumes that it exists standard configurations for penetration seals.

The results from a fire resistance test may be used to support an evaluation of the performance of another penetration seal without any further calculation or the application of rules or judgements if the construction complies with the guidance given in 6.3.2.

Where the construction does not comply with the direct application then the calculations or application rules or judgements need to be applied as indicated.

The relevant performance criteria are integrity(measured by gap gauge, ignition of cotton pad, or sustained flaming) and insulation (increase of average or maximum temperature).

6.3.2 Direct application

The results of a fire resistance test are deemed to be applicable to a similar type of untested penetrating seal provided that all the following are true.

a) The size of individual cables or pipes is not increased.

b) The size of cable bundles is not increased.

c) The size of the opening is not increased.

d) The sealing material is unchanged and the thickness is not reduced.

e) No changing of penetration service (e.g. cables and pipes) is allowed.

f) The separation between services and edges of the penetration is not reduced.

g) The thickness of separating elements (wall/floor) can be increased as well as the density of the separating element.

h) No change in the orientation of the separating element.

i) Continuous support passing through the seals is used in the same situations or without continuity of the support (but not vice versa).

j) Results obtained with light-weight partitions are used in the same kind of partitions or in concrete or masonry walls with larger thickness.

k) Results obtained from tests with both ends uncapped are used for all other pipe end situations.

l) Results obtained with copper pipes are used with copper, steel or cast iron pipes.

6.3.3 Extended application

6.3.3.1 Rules

Rules can be given for the following.

6.3.3.1.1 Sealing material

The density of the seal material can be allowed to vary by $\pm X$ %.

6.3.3.1.2 Cable penetration

a) Area of seal

The area of the seal around the penetration can be modified up to $+ X_1$ %, $-Y_1$ %.

b) Diameters of cables

Diameters of cable cores can be increased depending on the temperature reached at the requested fire rating.

6.3.3.1.3 Pipe penetration

a) Area of seal

The area of the seal around the penetration can be modified up to $+ X_2$ %, $-Y_2$ %.

b) Diameters of pipes

Diameters of pipes can be increased depending on the temperature reached at the requested fire rating.

6.3.3.2 Fire engineering calculations

Calculations may be used for the following.

a) Calculations can be used in order to calculate the heat transfer along non-combustible pipes providing that heat transfer within the pipe is taken into account.

6.3.3.3 Judgements

Changes may be made to the following aspects of penetration seals, provided that expert judgement is based on the appropriate considerations mentioned below.

a) Increase in services

Increase in the number of services and/or of their size can be allowed by considering the ratio of services to the opening area and the influence of these changes on the temperature on the unexposed side.

b) Combination of pipes and cables

Combined services (e.g. cables and pipes) can be accepted, provided that expert judgement is based on test experience with each of the systems and it can be demonstrated that there is no interaction between the different services.

c) Orientation

Results obtained from tests conducted in the horizontal configuration could generally be considered as the worst case and thus may qualify for application in either wall or floor/ceiling configuration provided the seal design is symmetrical.

d) Specification of supporting construction

If either the density or the thickness of the wall or floor is reduced, then the influence of this on the thermal flow, the robustness of the support and the restraint conditions must be taken into account.

e) Cable loading

Cable loading obtained from a fire test (total cross-sectional area of cables divided by the inside cross-sectional area of a cable tray or pipe) can be utilized to qualify a configuration with the same or smaller cable loading.

f) Pipe diameter

Results obtained from tests of mechanical penetrations will qualify pipes of the same material and thickness that are of lesser diameters.

7 Future evolution

For a long time, it was sufficient to have a rating system based on the fire resistance of construction products exposed to heat according to ISO 834 and to have confidence in the fire safety level of buildings using construction products of the same design.

Over the last decade the improvement in knowledge about modelling of fire actions and fire behaviour has made feasible a focus upon the actual behaviour of construction and construction products in real fire situations.

As explained in the introduction, it is not yet possible to obtain easily this kind of information. However, as stated in the previous clause, it will be possible to have a larger extension of test results by using existing knowledge in conjunction with modelling or statistics.

On the other hand, it is possible from standard fire tests to obtain more information on the behaviour of the product than done up to now.

Proposals on how to obtain this extra information are given in the following subclauses regarding:

— improvement of testing methodologies to get additional experimental data;

— possible mathematical modelling for calculation;

— expert system to provide more consistency in expert judgements.

7.1 Improvement of testing methodologies

To a large degree, testing standards were only developed in order to obtain the necessary information to meet the three main criteria in fire resistance:

— maximum deflection / deformation or rate of deflection for loadbearing resistance;

— cotton pad test and use of gap gauges for integrity purpose;

— maximum rise of temperature of 140 K to 180 K for insulation.

Accordingly, measurements performed during tests are often limited to the parameters required to demonstrate conformity with the relevant criteria.

In addition, the initial purpose of many fire testing standards was to give a fire rating for an individual construction product, assuming that it was sufficiently representative of what was used in practice. In reality, it is well known that for each tested specimen there are many possibilities for changing size, components and design.

Of course by considering extended application of results, it is possible to give some guidelines on the possible changes in the design of the tested specimen but it must be admitted that test standards are not, in their majority, written with the aim of having a wider range of application of results.

For the purpose of producing a wider field of application of the results for a tested construction product which may have a variety of applications, it is possible to distinguish three types of action that can be taken:

— improvement of existing test methods;

— additional small-scale tests to be performed;

— selection of the best representative specimen(s) of the construction products to be tested.

7.1.1 Existing test methods

Improvement can be made in order to have more and better knowledge of the fire behaviour of a specimen and the necessary data for using numerical model for simulation of physical phenomena.

For instance it could be very valuable to have:

— better understanding of heat flux to the specimen over the whole fire exposure in the furnace.

— recorded temperatures within the specimen (between layers of different materials, in voids, in the various parts of loadbearing element, etc.) and in structural elements;

— recorded heat flux from a separating element;

— measured deformation of separating elements at various locations.

Better accuracy in the knowledge of material used in the specimen and their thermophysical characteristics at elevated temperature should also be of great interest for numerical simulation and when a component is changed.

Regarding loadbearing elements, the actual end conditions of the specimen are often difficult to know accurately. In this respect, it is useful to quantify the restraint with load cells. The recording of plastic deformation of the specimen, after the fire test, could also provide interesting data.

It is recommended to continue fire tests until all three failure criteria are fulfilled and even, if possible, up to the real collapse of the specimen. It is only when the exact behaviour is known that extrapolation of results can be made with accuracy.

Additionally for loadbearing elements, after reaching the failure criteria, if there is no danger to the staff of the laboratory, the loading can be reduced to continue the test and to record additional data on temperature in the element.

7.1.2 Test using reduced size specimen (reduced-scale test)

A reduced-size specimen (reduced-scale test) means tests on specimens of about 1 m × 1 m in size.

When, for a given design of a specimen, a test was performed at its full size, it can be possible to perform only small-scale tests to investigate the influence in the change of some parameters of this specimen.

These small-scale tests are generally useful for assessing the effect of parameters on the heat transfer by taking into account the side effects which can be due to different boundary conditions as far as heat loss is concerned. This is mainly the case for assessing the effect of protective coatings on structural elements such as steel, concrete, timber or composite sections.

They are less appropriate for assessing mechanical behaviour since with such small samples it is impossible to obtain realistic loading conditions for both flexural effect and shear effect. Additionally the boundary conditions in terms of rotational capacity and restraint to elongation are of greater importance. Nevertheless such small-scale tests can be used in some cases when results are not directly used but are taken as data for checking the ability of numerical models to predict, with enough accuracy, the tested phenomena.

7.1.3 Selection of the specimen

When it is intended to cover, as far as fire resistance performance is concerned, the full range of use of a construction product, it is necessary to have, before testing, a clear view of the possible changes in the size, components and design of this construction product.

Being aware of the possible variations in the product design, it is easier to choose the right specimens to be tested. In this respect several options can be selected: either to test the specimen leading to the most onerous conditions when it is possible to define it, or to test two or more specimens of various designs to cover the full range of use.

Of course this way is only possible if the changes in the design are not too many. Current examples are:

— tests on the smaller and the larger sizes of a door, a damper or the cross-section of a duct when the design of these element is exactly the same;

— tests on various sizes of steel sections insulated by various thicknesses of a given coating material.

Because the fire resistance ratings may differ from one specimen to another, the assessment of results generally requires the use of agreed methods to derive the rating for intermediate specimens.

7.2 Mathematical modelling of thermal and mechanical response

There is a growing interest in mathematical modelling. This modelling may be used for assessing, from test results, what would be the fire resistance of differently designed elements. In the near future, modeling may be used for assessing the real fire behaviour of elements within a building.

Most modelling of structural behaviour under fire conditions currently tends to be deterministic in nature. This form of modelling is based on assumed specific relationships and formulae which can be used to predict in an unambiguous way the outcome for a given fire scenario. Design is based on physical, chemical and thermodynamic properties which are well known or derived from science or empiricism.

A probabilistic, also known as a stochastic, approach to modelling is less developed but more suited to the randomness of the available fire scenarios. There is a need to have knowledge of the probability distributions associated with the events that affect the fire development, involving factors such as growth rate, duration and temperatures achieved. The response of the structure, sometimes in terms of a notional fire resistance, also can be assigned a probability distribution, particularly in the case of complex structures or works. The outcome is not a precise definition of failure time but a likelihood that failure will occur, usually matched against a degree of acceptability for the outcome.

In the following, the structure of the related deterministic models is described with reference to four levels with varying degrees of complexity.

7.2.1 Level 1 — Numerical regression analysis

This is a curve-fitting methodology for interpolation between measured values. It usually has no direct relation to the physical phenomena. It can be used when only a few parameters change from one tested specimen to another.

This technique cannot provide data outside the range of tested assemblies or for temperature-time curves other than the one used. It is mainly used for interpolation between test results.

7.2.2 Level 2 — Physical equation analysis

The physical phenomena (mainly in terms of heat transfer and load bearing resistance) are expressed by analytical formulae, the validity of which are established by analysis of experimental results.

Since these analytical formulae are based on the physical parameters influencing the fire behaviour of the components, it is possible to use them outside the range of experimental evidence. Sometimes reference to other fire curves is possible.

Regarding heat transfer, such formulae are currently used for unprotected steel sections, for assessing the fire protection of steel sections, and for determining the temperature within concrete or composite elements.

Regarding load bearing resistance, simple plastic theory is used, taking into account the effect of temperature on the strength of materials, which leads to the possibility of determining the ultimate loadbearing capacity of sections subjected to fire.

Some other examples can be found concerning, for instance, thermal bowing and charring rate.

7.2.3 Level 3 — Finite element methods

Such methods can simulate in a realistic manner the evolution of physical phenomena in a given element during fire exposure and generally also for the complete structure.

As for level 2, it is necessary to differentiate between temperature analysis and mechanical response analysis It may be possible in the near future to model also such phenomena as cracks, spalling, bond and anchorage.

a) Temperature analysis

Depending upon their complexity, it is possible to use computer programs based on the finite element method (or on the finite difference method) handling one-, two- or three-dimensional heat flow. Cross-sections of elements may consist of different materials and the thermal properties (thermal conductivity, specific heat) can be expressed in terms of a non-linear relationship versus temperature.

Both heat transfer (by convection and radiation) to the element and heat transfer (by conduction) within the element are taken into account. Cavities in the member can also be considered.

The heat exposure is modelled either as a gas temperature-time curve or as a prescribed time-heat flux-time relationship.

In some computer programs, mass transfer is taken into account which allows more accurate results for elements containing moisture.

The limits of application of such computer programs are mainly due to the lack of knowledge about the effective thermal properties of the materials and their behaviour in real fires.

b) Mechanical response analysis

By using finite element method, it is possible to simulate the deformations of members during a fire exposure. The field of temperature needs to be known as well as the mechanical properties at the relevant temperatures of the materials. Numerical models for two- or three-dimensional behaviour currently exist. They are able to simulate the evolution of stresses and deformations within members due to interaction between them and redistribution of external actions.

Some of them are based on shell and plate theory, but the majority are based on beam/column members.

This can be illustrated by the following example using a three-dimensional steel frame consisting of four legs, stiffened with braces in horizontal and vertical planes. At the top it is fitted with a lattice girder. On the top of one leg a vertical load is applied. Fire is applied at the floor level near the loaded leg. The asymmetry in load and heating yields significant load distribution capability. The response history anticipated is as follows.

i) The leg and adjacent diagonals are subjected to a rapid temperature rise. Due to thermal expansion of the brace, the leg below the joint is subjected to additional compression forces, initially. Above the joint the leg compression force decreases. Thus, the effect of thermal expansion is intermediately to cause transfer of a fraction of the vertical load to the lattice girder and the brace.

ii) After a while the leg starts to fail due to reduction in yield stress and elastic modulus. As a consequence, part of the leg compressive force has to be taken up by tension in the diagonal brace, thus counteracting the effect of thermal expansion. This cause a transfer of leg load from heated leg to other legs of the structure.

iii) As the temperature increases further, the load bearing resistance of both the diagonal and the leg is reduced so much that some of the vertical load has to be transferred to adjacent legs by mobilisation of the lattice girders at the top. Eventually the compression brace in the lattice girder close to the top of the heated leg fails by buckling, resulting in a global collapse.

7.2.4 Level 4 — Integrated interactive analysis

This level deals with the full package of mathematical models to simulate the behaviour of a whole building on fire. The following models need to be available:

— model for thermal actions, to simulate fire development, taking into account type and size of fire load, ventilation conditions, surrounding separating elements, etc., and to simulate propagation of fire through different compartments, either due to failure of separating elements or due to failure of penetrating services such as ducts, dampers, sealed penetrations, pipes, etc.;

— model for heat transfer to structural and surrounding elements (using mainly the analysis approach mentioned in level 3);

— model for mechanical response of the structural elements within the building with respect to such phenomena as redistribution of forces and moments, progressive collapse (use mainly of numerical computer programs mentioned in level 3);

— model for effectiveness of fire separation.

Such integrated analysis requires an interaction between the different models, in order to estimate when failure of surrounding separating elements can occur, leading to a propagation of fire and consequently to redefine the actions on the structural load bearing elements.

Additionaly, integrated analysis can take into account interaction between fire exposure and fire extinguishment and even between fire and explosion.

Different codes specify fire as an accidental event which is to be designed for in the limit state of progressive collapse. In contrast to the traditional ultimate state criterion allows for local failures in the form of buckling, yielding etc. provided that the structural integrity is not put in jeopardy.

7.3 Expert system based upon the use of performance coefficients

7.3.1 Concept

There are many situations where mathematical modelling is not appropriate for predicting performance. Modelling works best when there are only two or three variables and where only one of these changes at a time. Typically, in a steel protection system when the duration of fire resistance needs to be increased or where the duration is constant but where the beam or column cross-section is changed, then the new levels of protection can be calculated by modelling techniques.

Where there are a large number of variables and particularly when several of these change simultaneously, the mathematical model becomes very complex. Typical of these situations are fire resisting door assemblies, solid and glazed partitions, penetration sealing systems, etc. In addition to the complexity of the model, there is a serious shortage of the data needed for such modelling, e.g. heat exchange coefficients, specific heat, etc. Connections and adhesives play a large role in the performance and the influence of these is hard to predict numerically.

It is possible, however, to set up experiments to evaluate the influence that various changes may have on the performance. By controlling the design and construction of a test specimen such that only one variable is changed at a time, it is possible to establish a coefficient of performance related to that variable. By planning a test program