Client Report :

Study on EN 1991-Eurocode 1: Actions on structures, Part 1-2: Actions on structures exposed to fire

Client report number
220824

Prepared for :

Mr Michael McCarthy
Principal Officer
Department of the Environment, Heritage and Local Government

22 April 2005

Prepared on behalf of BRE by

Signature	
Name	Tom Lennon
Position	Principal Consultant

Approved on behalf of BRE by

Signature	
Name	Dr D Smith
Position	Director
Date	

BRE
FRS
Bucknalls Lane
Garston
Watford
WD25 9XX

Tel : 01923 664100
Fax : 01923 664910

Email : frsenquiries@bre.co.uk
Website : www.bre.co.uk

Executive Summary

This report has been prepared at the request of the Department of the Environment, Heritage and Local Government of the Republic of Ireland who wish to investigate the implications of implementation of the fire part of the European standard for Actions (EN1991-1-2) in relation to current structural design practice in Ireland. There is also a requirement to prepare a draft National Annex to allow the European standard to be used for design in Ireland without any adverse effects on current levels of safety and economy.

This report provides a detailed assessment of the implications of implementation of the fire part of the Eurocode for Actions and presents a draft National Annex (in appendix A) according to the rules set out by the European Community.

All of the objectives set out in the project proposal have been completed.

Contents

Introduction

BRE have been commissioned by the Department of the Environment, Heritage and Local Government of the Republic of Ireland to carry out a study of EN1991-1-2, Eurocode 1: Actions on structures, Part 1.2: Actions on structures exposed to fire. The main objectives of the study are:

- To make a technical evaluation of the implications for structural design, in Ireland, of adoption of the Eurocode and
- To produce a draft National Annex to enable the Eurocode to be used in Ireland.

The approach adopted is similar to that used in developing a number of draft National Annexes for the UK government although particular care has been taken to ensure that National concerns are addressed. The detailed methodology adopted for the project is set out elsewhere in this document.

It is recognised that the European standards system differs in many ways from that which is familiar to the Irish structural engineering profession. Much of the terminology will be unfamiliar to designers. A background to the European standards system is given together with an explanation of key terms used in the Eurocodes and relevant to the objectives of the current project. The approach to fire engineering design in the structural Eurocodes is significantly different to that adopted in current National Standards. For this reason a discussion of the inter-relationships between the various European standards is presented along with a description of the fire engineering design process.

The pre-standard ENV1991-2-2, “Actions on structures exposed to fire” was first published in 1996 together with an Irish National Application Document. In the period between the publication of the ENV standard and the full European standard, EN1991-1-2 in 2002 a number of significant changes have been made based on the results of research into the behaviour of buildings subject to fire.

The full European standard contains new and revised relationships for calculating fire exposure to structural members and it is important that these relationships are critically reviewed and assessed. The main output from this project is the preparation of a draft National Annex for consideration by the Irish regulatory authorities and national standards organisation.

Background to the structural Eurocodes

The objectives of the Eurocodes are

- To establish a common set of design rules for buildings and civil engineering works to be used across Europe.
- To remove the barriers to 'free' movement of products and engineering services between European countries, by removing the obstacles caused by different nationally codified practices for the assessment of structural reliability.

Following a period of co-existence the current Irish Standards will be superseded by the Eurocodes. These codes will be denoted as IS EN in Ireland.

The Eurocodes can be considered to be divided into codes that provide fundamental guidance for structural design (Basis of Structural design), guidance that may apply to all designs (loads (including fire), geotechnics and seismic) and detailed guidance for structural materials (steel concrete etc.).

The numbering system used by the structural Eurocodes is EN199#-#-#. The 199# number is not the publication date, but the number of the Eurocode. The year of publication is given after the Eurocode number. The Eurocodes numbering system that will be used in Ireland for the fire part of the eurocode for Actions is, IS EN 1991-1-2:2005. The structural Eurocode system will contain the following codes:

IS EN 1990 – Basis of Structural Design

IS EN 1991 – Actions on Structure

IS EN 1992 – Design of Concrete Structures

IS EN 1993 – Design of Steelwork Structures

IS EN 1994 – Design of Composite Steel and Concrete Structures

IS EN 1995 – Design of Timber Structures

IS EN 1996 – Design of Masonry Structures

IS EN 1997 – Geotechnical Design

IS EN 1998 – Design of Structures for Earthquake Resistance

IS EN 1999 – Design of Aluminium Structures

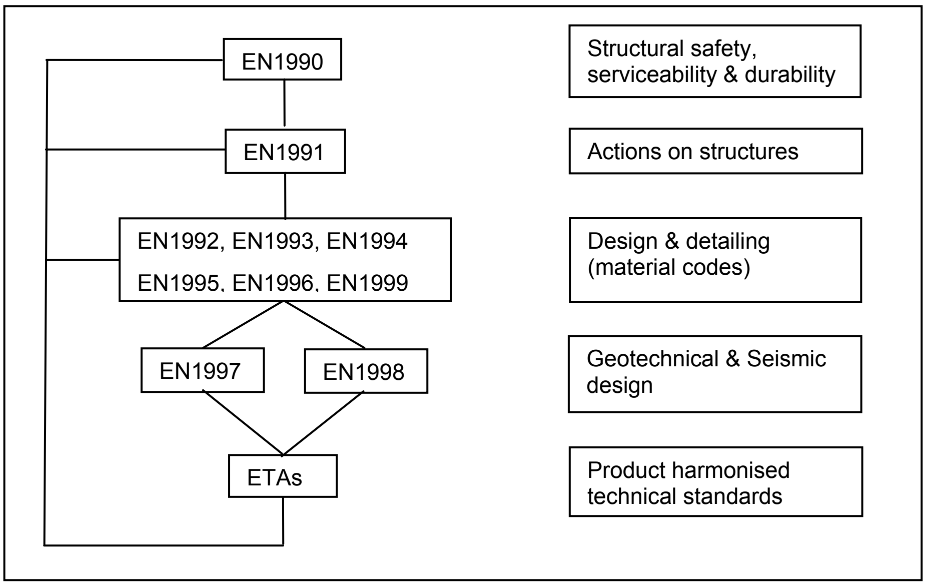
The organisation of design guidance differs from the Eurocode system to the current Irish Standards (IS) system. Safety, serviceability and durability design guidance for different types of structures is presented in Basis of Structural Design, the current IS system presents this design guidance within each material code. Therefore a copy of

Basis of Structural Design is required for all designs performed using the Eurocodes. For both the Eurocodes and current IS systems product standards are used with design codes. The links between the different Eurocodes are shown in Figure 1.

The individual material Eurocodes are divided into parts, the majority contain, Part 1 – General rules and rules for buildings and Part 2 – Rules for Bridges. These 'high level' parts are divided into sub-parts with some material codes adding additional 'high level' parts.

In addition to the 'inter-action' between the materials codes and Basis of Structural Design the parts of each material code may cross-reference each other. This is due to the Eurocodes presenting guidance in only one place and subsequently referring to that clause in other parts of the Eurocode. This may occur where design guidance given in part 1-1 (general rules) of a Eurocode is referred to in a subsequent part instead of repeating the guidance. In some cases parts of different material Eurocodes may be referenced e.g. a part of EN 1994 (Composite Steel and Concrete Structures) may reference a part of EN 1992 (Concrete Structures) or EN 1993 (Steelwork Structures).

Figure 1 Links between the individual Eurocodes



Each part of a Eurocode is divided into distinct sections, these are:

- National title page
- National foreword
- EN title page
- EN main text
- EN Annex(es)

  - *Normative Annexes* contain design rules / methods / values that should be used when designing to the Eurocode.
  - *Informative Annexes* contain design rules / methods or informative values.

- National Annex

The technical content of the EN main text and EN Annex(es) is the same across the whole of Europe. The National Standards Authority is responsible for developing and publishing the National title page, National foreword and National Annex.

Each part of a Eurocode will have an accompanying National Annex. These annexes will contain information that should be referred to when designing a structure to be constructed in that country. Therefore if an Irish designer was designing a building to be constructed in France they would need to refer to the French National Annexes for all the Eurocodes used during design and not the Irish National Annexes.

The National Annex will contain information on the values / methods that should be used, where a national choice is allowed in the main text of the Eurocode. The national choices are collectively referred to as Nationally Determined Parameters (NDPs). NDPs may be given for coefficient values, loads (both applied and self-weight) and where a choice in design approach is given. The EN main text specifies recommended values / approaches, the National Annex can either accept the recommendations given or specify different values / approaches to be used.

The National Annex will state how / if the content of an Informative EN Annex may be used for the design of structures to be constructed in that country. Information given in a Normative EN Annex may only be altered by the National Annex if the EN text allows different rules / values to be given in the National Annex. References to Non-Conflicting Complementary Information (NCCI) may also be included in the National Annex. References may be given to separate documents that give guidance to help with the design of a structure. **However, such design guidance may not be presented in the National Annex itself.**

Eurocodes terminology

The Eurocode system uses different terminology to that used in the current IS system. An important change that will effect every design approach is the change in terminology for loading. In the Eurocodes the term “loads” is replaced by the term “actions”. The Eurocodes also introduce the terms “permanent action”, “variable action” and “accidental action”.

Permanent actions include the self-weight of the structural and non-structural elements. These self-weights are combined to form a single value for consideration during design checks. Loads due to prestressing are also considered as permanent actions.

Variable actions are defined in Basis of Structural Design as ‘actions for which the variation in magnitude with time is neither negligible nor monotonic.’ Loads considered as variable actions include:

- Imposed floor & roof loads
- Snow loads
- Wind loads

Variable actions are sub-divided into two groups:

- *Leading variable actions*

  These are variable actions which when acting on a structure cause the most significant structural effects.

- *Accompanying variable actions*

  These are variable actions that act on a structure at the same time as the leading variable action.

Accidental actions are caused by events that usually have a short duration but have a significant effect. It is considered that such events have a low probability of occurrence during the design working life of a structure. Accidental design situations that should be considered include **fire** and explosion.

Some variable actions may be classed as accidental actions for design checks. These are, impact, snow, wind and seismic. The Eurocodes and National Annexes identify when they may be considered as accidental actions.

Types of clause used in the Eurocodes

The Eurocodes define two types of clause, Principles and Application rules. These terms will be new to Irish designers as the current IS system does not contain these clause types.

Principles are denoted by the letter P following a clause number, e.g. 1.3(2)P. Principles are ‘general statements and definitions for which there is no alternative, as well as; requirements and analytical methods for which no alternative is permitted unless specifically stated.’

Application rules are denoted by a clause number without the letter P, e.g. 1.3(2). Application rules are ‘generally recognised rules which comply with the Principles and satisfy their requirements.’ It is permitted to use alternative design rules in place of those given in Application rules. However, it must be shown that the alternative design rules meet the requirements of any relevant Principles. It must also be shown that the alternative rules provide equivalent structural safety, serviceability and durability to that expected from the guidance given in the Application rules. If an alternative design rule is substituted for an application rule, the resulting design cannot be claimed to be wholly in accordance with the Eurocode although the design will remain in accordance with Principles of the Eurocode.

Eurocode notation

A unified system of notation is adopted across the Eurocodes where the main parameter is followed by a series of subscripts separated by commas. Common notation and subscripts related to fire design are illustrated in table 1 below.

Common Notation		Common Subscripts	
G	Permanent action	A	Accidental situation
Q	Variable action	cr	Critical
E	Effect of an action	fi	Fire
R	Resistance	d	Design
t	Time	θ	At temperature
θ	Temperature	k	Characteristic
γ	Partial safety factor	t	Time of exposure in fire
Ψ	Combination factor	1,2	Ranking order

Table 1 Commonly used notation for fire design

As an example $R_{fi,d,t}$ is the design Resistance to fire at time t.

Structural Fire Engineering Design

Alternative design procedures

In Ireland the traditional means of meeting the requirements of the Building Regulations in terms of fire resistance has been to rely on tabulated data published in guidance to the Building Regulations[1]. The Eurocode presents a range of options for the designer ranging from prescriptive rules based on standard fire resistance periods and the use of tabulated data to calculation procedures based on a natural fire exposure and whole building behaviour. The table below summarises the alternative methods available in the Eurocode for the verification of fire resistance. Traditional Irish practice generally only considers the first row in the table. Advanced calculation methods typically involve the use of complex finite element models and would not in general be available to designers.

Thermal model	Structural model	Method of analysis
Nominal (standard) fire curves	Single element	Tabulated data
Calculation based on standard curve (time equivalent)	Sub-assembly	Simple calculation models
Simple calculation based on compartment characteristics (parametric approach)	Entire structure	Advanced calculation models (non-linear finite elements)
Advanced calculation model (CFD)		

Table 2 Range of options available to the designer

The hierarchy in terms of complexity is tabulated data followed by simple calculation methods followed by advanced calculation methods. For the designer the tabulated approach should be the first port of call and should be suitable for the vast majority of structures. Calculation methods can be used to demonstrate performance under specific conditions and may provide substantial savings in certain circumstances. Advanced calculation methods (typically non-linear finite element models) may be used where the structure is very complex and where the provisions of the National regulations are not applicable. Examples of such structures would include sports stadia, exhibition halls or airport terminals.

The Eurocode approach to structural design will be unfamiliar to many Irish engineers. However, there are a number of similarities between the approach adopted. The standard design route will remain the use of tabulated data with reference to specified periods of fire resistance related to the standard fire test. The most significant difference in approach is one which is not restricted to the use of the fire parts of the material codes but is perhaps more pronounced in this area. The information required to carry out structural fire engineering design has traditionally been located within one material code (albeit in different parts). The structural Eurocodes are an integrated suite of design standards and are meant to be used as such. To carry out a design for concrete structures using tabulated values from the National standards the designer needs only refer to the relevant National material codes. For a similar design to the Eurocode it is necessary to obtain partial factors from EN1990, information on loads from EN1991-1, information on the thermal and mechanical response from **EN1991-1-2** and finally obtain the required dimensions from EN1992-1-2. Although the fire design methodology adopted in the Eurocodes is radically different from the procedures generally used in Ireland, the end result, in terms of member sizes and cover to reinforcement is, in many cases, similar.

In the fire parts of the various material codes (EN1992-1-2, EN1993-1-2, EN1994-1-2, EN1995-1-2, EN1996-1-2) fire resistance may be determined either by:

- Simple calculation models,
- Advanced calculation models or
- Tabulated data.

The current Irish Standard is based on tabulated periods of fire resistance derived from standard fire tests and fire resistance derived from calculations in certain specific cases.

The regulatory requirement is generally specified in National regulations based on the type of occupancy (office, domestic, retail etc.) and the height of the structure. The design procedure from the Eurocodes indicating the relationship between the various standards required for design is as follows:

- Selection of relevant design fire scenario (**EN1991-1-2**)
- Determination of corresponding design fire (**EN1991-1-2**)
- Calculation of the temperature rise of the structural members (EN1992-1-2, EN1993-1-2, EN1994-1-2, EN1995-1-2, EN1996-1-2)
- Calculation of the mechanical response (EN1992-1-2, EN1993-1-2, EN1994-1-2, EN1995-1-2, EN1996-1-2)

The situation is illustrated schematically in figure 2 below.

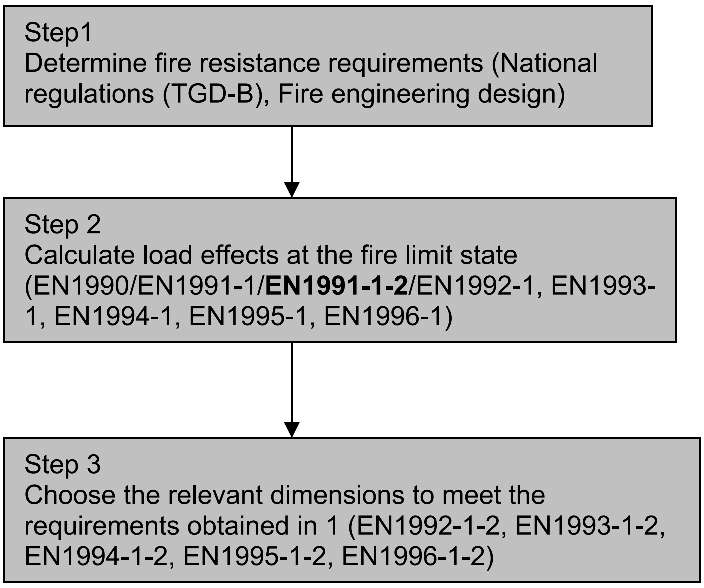


Figure 2 Simplified fire design procedure

The most significant difference in approach is that load effects both in relation to dead and imposed loading and the time-temperature regime to be used for assessment are not contained within the material code but in the relevant codes for actions on structures.

Partial load factors for the fire limit state

The calculation of the load effects at the fire limit state is different to the procedure adopted in the Irish material codes. The designer must be familiar with both EN1990 (basis of design) which provides the required load combinations (as for ambient temperature design) and with **EN1991-1-2** (the fire part of the Actions code) which in addition to specifying the available options for thermal actions for temperature analysis (see above) also specifies the mechanical actions for structural analysis. In particular **EN1991-1-2** specifies the partial factor for imposed (assuming leading variable action) loading for the fire limit state. Fire loading is an ultimate limit state accidental design situation (see EN1990) of the form:

$$E_d = E(G_{k,j};\ P;\ A_d;\ (\Psi_{1,1} \text{ or } \Psi_{2,1})Q_{k,1};\ \Psi_{2,i}Q_{k,i}) \text{ for } j \geq 1;\ i > 1$$

here:

E	the effect of actions (E_d is the design value of the effect of actions)
G	permanent action (dead load)
P	relevant representative value of a prestressing action (where present)
A_d	design value of an accidental action
Ψ_1	factor for frequent value of a variable action
Ψ_2	factor for quasi-permanent value of a variable action
Q_k	characteristic value of a single variable action ($Q_{k,1}$ is the characteristic value of the leading variable action – often the imposed load)

In the fire situation A_d is the effect of the fire itself on the structure i.e. the effects of restrained thermal expansion, thermal gradients etc. However, **EN1991-1-2** states that

"*Indirect actions from adjacent members need not be considered when fire safety requirements refer to members under standard fire conditions*" and "*Imposed and constrained expansions and deformations caused by temperature changes due to fire exposure results in effects of actions e.g forces and moments which shall be considered with the exception of those where they:*

- *May be recognised a priori to be negligible or favourable*
- *Are accounted for by conservatively chosen support models and boundary conditions and/or implicitly considered by conservatively specified fire safety requirements*."

EN 1990 allows the use of either Ψ_1 (frequent value) or Ψ_2 (quasi-permanent value) with the main variable action (generally the imposed load). **EN1991-1-2** recommends the use of Ψ_2, however this is a Nationally Determined Parameter and the Irish National Annex will specify the appropriate choice for use in Ireland. The recommended values of ψ_1 and Ψ_2 taken from EN1990 are detailed in table 2 below.

Action	Ψ_1	Ψ_2
Imposed loads in buildings,		
Category A: domestic, residential	0.5	0.3
Category B: office areas	0.5	0.3
Category C: congregation areas	0.7	0.6
Category D: shopping areas	0.7	0.6
Category E: storage areas	0.9	0.8
Category F: traffic area, ≤ 30 kN	0.7	0.6
Category G: traffic area, 30-160 kN	0.5	0.3
Category H: roofs	0	0
Snow load: H ≤ 1000m a.s.l		0
Wind loads on buildings	0.2	0

Table 2 Recommended values for Ψ factors for buildings

The effect of the choice of Ψ factors will be dependent on the ratio of the imposed to dead loads for a given structure. The relationship between the reduction factor and the ratio of the dead and imposed loads is illustrated in figure 3 below.

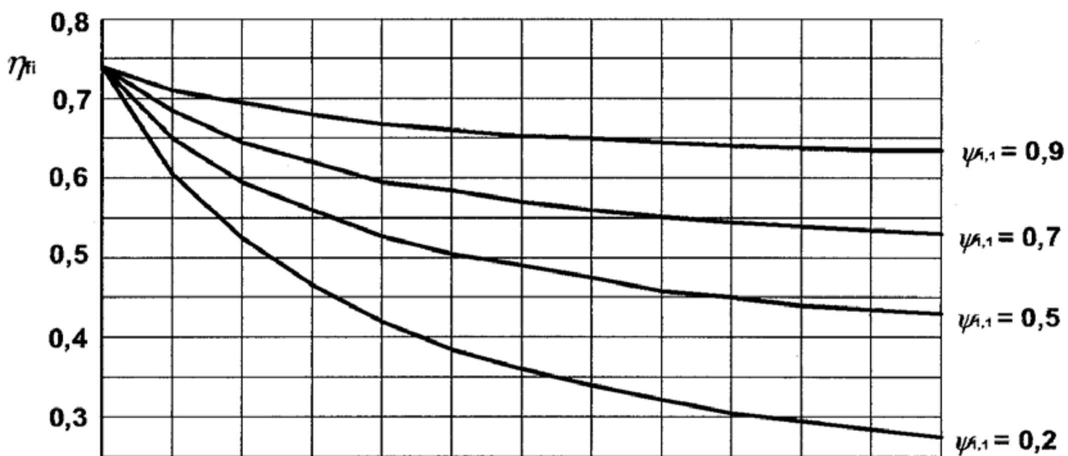


Figure 3 Relationship between reduction factor η_{fi} and ratio of dead and imposed load for values of ψ_{fi}

Methodology

The work carried out for this project is based on extensive experience of the development of the Eurocode. The starting point for the investigation has been the ENV version of the Eurocode and the Irish National Application Document. The assessment and review is based largely on work carried out for the development of the National Annex for the United Kingdom. The detailed methodology adopted is summarised in the flowchart below.

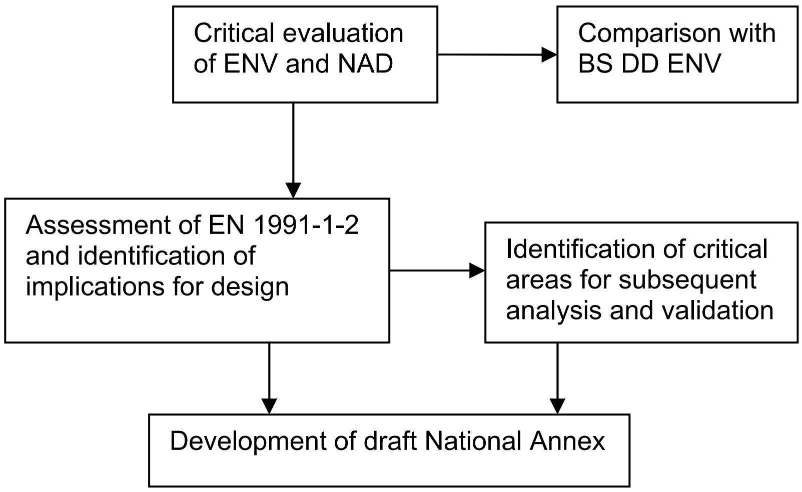


Figure 4 Project Methodology

As mentioned previously the study will concentrate on those areas where National choice is allowed – NDPs and Informative Annexes. These are the areas of greatest significance for design and construction in Ireland.

Implications of implementation and development of draft National Annex

This section considers the impact of various clauses and relationships within the Eurocode on design practice in Ireland. It provides an assessment of the accuracy of some of the key relationships for determining time-temperature response and provides a commentary on the decisions taken with respect to the draft National Annex. The National Annex itself is included in the format required by the European Commission in Annex A of this report.

Because the degree to which National choice is allowed is restricted to those clauses identified as Nationally Determined Parameters and decisions concerning the informative technical annexes **the report is only concerned with these issues**. In providing a positive vote to the main part of the Eurocode **it is assumed that decisions for which National choice is not allowed are accepted by the National authorities**.

Nationally Determined Parameters

The Nationally determined parameters in EN1991-1-2 are summarised in table 3 below. This section is concerned with the impact of each NDP in terms of design and construction in Ireland. The recommended values and decisions related to each of the informative annexes are included in the draft National Annex provided as an appendix to this report.

EN Clause number	Description

2.4(4)	Specification of periods of time related to fire resistance (reference to informative annex F)
3.1(10)	Use of nominal temperature-time curves and natural fire models
3.3.1.1(1)	Calculation of design fire load density (reference to informative annex E)
3.3.1.2(1)	Specification of procedure for calculating the heating conditions within compartments (reference to informative annex A)
3.3.1.2(2)	Specification of procedure for calculating the heating conditions for external members (reference to informative annex B)
3.3.1.3(3)	Specification for procedure for calculating the heating conditions from localised fires (reference to informative annex C)
3.3.2(1)	Specification for procedure for calculating the heating conditions using advanced fire models (reference to informative annex E)
3.3.2(2)	Specification for procedure for calculating the heating conditions using advanced fire models (reference to informative annex D)
4.2.2(2)	Choice of additional actions to be considered
4.3.1(2)	Combination rules to be adopted for Actions

Table 3 Summary of NDPs and relationship with informative annexes

Clause 2.4(4) Temperature Analysis

This clause identifies the specified periods of time to be used for fire engineering design. Adoption of this clause as defined in the draft National Annex (NA 2.1) will have no impact on design procedures in Ireland. There is effectively no change from the previous situation with regard to the ENV version of the Eurocode used with the Irish National Application Document. Periods of fire resistance will still be specified by the relevant Irish Building Regulation in accordance with the recommendations of Technical Guidance Document B. An alternative fire engineering approach using the concept of time equivalence as defined in the replacement Irish guidance in the draft National Annex (NA 5.3) may also be used. Although time equivalence was included in the National Application Document for the ENV version of the Eurocode the proposed replacement guidance is substantially different. For this reason a validation exercise has been undertaken to assess the impact of the proposed guidance on construction in Ireland.

It should be emphasised that the two areas where replacement guidance has been produced (Informative Annexes E and F) are inextricably linked. There are two main reasons why the Annexes are not acceptable in their current form.

1. The inclusion of partial factors for active measures (other than approved sprinklers) is not justified. Automatic detection or fire service attendance do not reduce the fire load. The partial factors to take account of risk of initiation do not

take into account consequences of failure and no allowance is made for the height of the structure. Implicit allowance for occupant mobility and awareness and consequence of failure are included in the prescriptive approach and they should be included in any alternative fire engineering approach. For this reason the semi-probabilistic approach to the calculation of design fire load density has been removed from the alternative guidance which retains the general principles for sourcing data on fire loads either from a classification system or on the basis of a survey. The fire load density derived from the alternative guidance therefore becomes a raw input to subsequent calculations and the effects of risk of initiation and consequence of failure can be included explicitly.

2. The input data required for the time equivalent calculation is derived from the alternative guidance discussed above. Therefore the output from the calculation does not include any allowance for risk or consequence. The formulation in the Eurocode would provide the same period of fire resistance for a ground floor office as for a similar office on the 50th floor of a high rise building. This approach cannot be justified. The factor in the original Informative Annex for unprotected steel cannot be justified.

Validation for Time Equivalent Approach

Table 5 below summarises the results of the application of the time equivalent method to a selective number of design scenarios. The Irish and UK ENV results are included for comparison. The detailed calculations are included in Appendix B of this report. Within the scope of the current project it is not possible to include all possible cases. Three different occupancies have been chosen – offices, dwellings and retail premises and three different heights of structure corresponding to 2 storey and 6 storey buildings in each case. A description of each case is given in table 4.

Case	Occupancy	No of stories	Sprinklers Y/N	Floor area A_f (m²)	Ventilation area A_v (m²)	Height of compartment (m)

1	Dwelling	2	N	28.8	5.42	2.443
2	Dwelling	2	Y	28.8	5.42	2.443
3	Dwelling	6	N	28.8	5.42	2.443
4	Dwelling	6	Y	28.8	5.42	2.443
5	Office	2	N	54	18	3.7
6	Office	2	Y	54	18	3.7
7	Office	6	N	54	18	3.7
8	Office	6	Y	54	18	3.7
9	Retail	2	N	378	50.4	3.7
10	Retail	2	Y	378	50.4	3.7
11	Retail	6	N	378	50.4	3.7
12	Retail	6	Y	378	50.4	3.7

Table 4 Parameters for comparative study on time equivalence

Case	TGD – B	ENV 1991-2-2 (with Irish NAD)	ENV 1991-2-2 (with UK NAD)	EN1991-1-2	EN1991-1-2 (with draft NA)

1	30*	71	45	48	82
2	30*	53	27	29	50
3	60	106	62	48	82
4	60	64	37	29	50
5	60	32	31	17	57
6	30*	19	19	11	28/56
7	90	73	62	17	85
8	60	44	46	11	56
9	60	127	54	44	100
10	60	51	32	26	99
11	90	169	74	44	151
12	60	127	44	26	99

Table 5 Results of Time Equivalent Analysis (* increased to 60 minutes for separating walls)

Specific points raised in the analysis are as follows:

- The differences in the results between the different versions of the standard are a function of the calculation of design fire load density. This is a function both of the tabulated characteristic values and the choice of partial factors adopted in each case in relation to risk and consequence.
- In general the analysis indicates that the prescribed (TGD-B) values are too low in relation to residential buildings and too high in relation to office buildings. This confirms results of previous studies in particular the work carried out to develop tables of fire resistance for DD9999[2]. This aspect of the analysis is not immediately apparent when comparing the TGD-B values with EN1991-1-2 & draft NA, for occupancies other than residential dwellings. This is because the risk factor (see table 5.3.2 of draft NA) has been used to bring those values below currently acceptable fire resistance periods in line with the TGD-B values.
- The characteristic fire load density adopted in the ENV version of the Eurocode in relation to dwellings is not consistent with any other commonly used reference value. This was addressed to some extent in the Irish NAD which accounts for the consistently higher values compared to the equivalent UK document.
- Using reasonable figures for characteristic fire load density for domestic dwellings together with typical ventilation factors means that the time

equivalent approach will not yield any benefit (in terms of reduced periods of fire resistance) in relation to residential buildings.

- The impact therefore of using time equivalent as the basis for specifying fire resistance periods for buildings is likely to be restricted to office buildings. It is important that each design is considered on its merits and that due account has been taken of risk and consequence of failure and that sensitivity studies have been undertaken in accordance with the guidance produced as part of the draft NA.

Clause 3.1(10) Thermal actions for temperature analysis

This clause allows the use of nominal time-temperature relationships and natural fire models. Reference is made to Annex A, Annex B and Annex E where Annex E is the method for determining design fire load density and Annex A and Annex B are calculation methods for determining internal and external compartment temperatures respectively. The derivation of design fire load densities has been discussed in relation to the concept of time equivalence. The adoption of the method in Annex E would have significant implications for the Irish construction industry as the use of the method as it stands could allow significant reductions in characteristic design fire load densities to the extent that a fully developed fire would not be a design scenario and buildings could be constructed on the basis of localised fire behaviour. This could have a significant effect on overall structural stability particularly for key elements such as columns.

It is therefore recommended (see draft NA) that design fire load densities are calculated on the basis of the alternative National guidance produced. This allows for a reduction in the design fire load density based on the presence of sprinklers designed for life safety but not for other active measures. For the parametric approach the input parameter would then be the design fire load density without any factors to account for risk or consequence of failure. The parametric approach is a scientific method for determining compartment temperatures given certain input parameters. In the Irish NAD the use of the parametric approach was restricted due to uncertainties concerning validation and scope of the method. These concerns are addressed below and it is recommended that the parametric approach together with the non-conflicting complementary information presented in the draft National Annex is adopted for use in Ireland.

Validation of parametric approach

Since publication of the ENV version of the Eurocode the parametric approach has been considerably extended in scope and has been validated against a large number of fire tests.

The ENV version was restricted to compartment floor areas less than $100m^2$, floor to ceiling heights below 4m, ventilation opening factors between $0.02m^{½}$ and $0.2^{½}$, and thermal properties of the compartment lining materials between 1000 and 2000 $J/m^2s^{½}K$. Even if the parametric calculation were allowed in the ENV such restrictions means that it would be very difficult to imagine a realistic building for which the method could be used. The restrictions on the use of the method in the final EN version of the Eurocode have been largely removed. The changes have been based on the results from a number of large scale experiments. The scope of the equation in EN1991-1-2 is summarised in Table 6 below. The recommended values from the draft NA are included in brackets.

Parameter	Height of compartment (m)	Opening factor ($m^{½}$)	Floor area (m^2)	Thermal properties b ($J/m^2s^{½}K$)
Scope	≤ 4m (no limit)	0.02 ≤ O ≤ 0.2 (0.01 ≤ O ≤ 0.2)	≤ 500 (no limit)	100 ≤ b ≤ 2200

Table 6 Scope of parametric approach (Draft NA values in brackets)

The recommended relaxation in compartment floor area and height of the compartment are based on the fact that if these conditions are exceeded the parametric approach can be used but is likely to produce more onerous results (i.e. predicted temperature in excess of those experienced). Therefore for large compartments or large floor to ceiling heights the designer may wish to consider alternative approaches such as multi-zone or CFD models.

The range of insulation (b) factors adopted is felt to be reasonable. However, the designer should be free to use elevated temperature material properties if available. There is experimental evidence to suggest that the range of opening factors can be extended below the Eurocode provisions to cover compartments with opening factors as low as $0.01m^{½}$.

Other changes to the parametric approach since the publication of the NAD include:

- Changes to calculation of time to maximum temperature to more closely reflect observed behaviour in terms of natural fire duration.
- Changes to the method for calculating the influence of the thermal properties of the compartment boundaries (the previous version in the ENV was inaccurate and illogical).

The resulting changes means that predicted behaviour now more closely follows that observed from real fire tests. Figure 5 is a comparison between predicted and measured values for a small office fire compartment constructed from precast hollow core slabs and masonry walls lined with fire resisting plasterboard. Figure 6 shows a similar relationship for an office fire within a steel framed building with composite floors. Figures 7 and 8 show the predicted time-temperature response for two domestic dwellings with similar forms of construction and small differences in ventilation openings and compartment geometry.

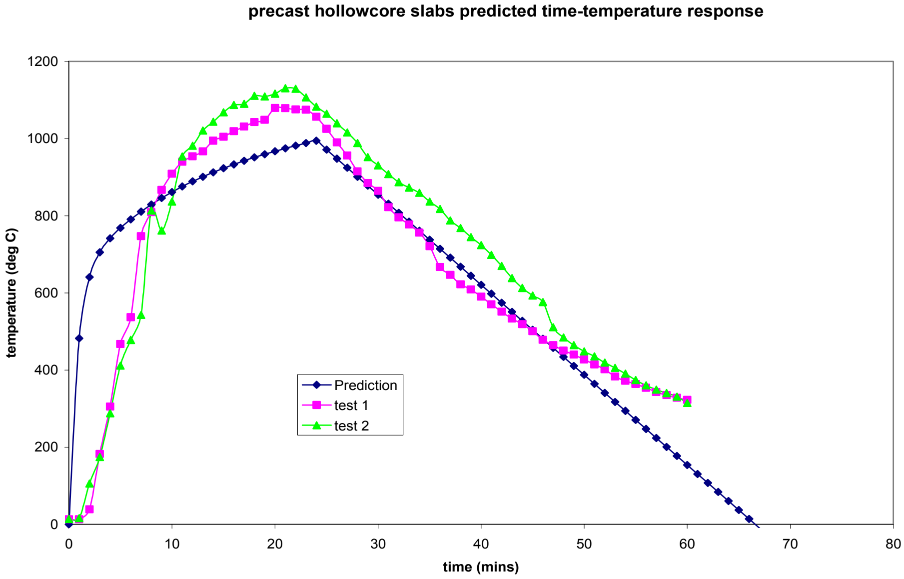


Figure 5 Parametric validation – hollow core fire test

Although the prediction slightly underestimates the peak temperatures in the compartment the overall heat release (area under the curve) is very similar for both the measured and predicted fires. Work by Kirby[3] has shown that such differences are not significant when translated into the thermal response (through heat transfer calculations for protected steel members) of the structure.

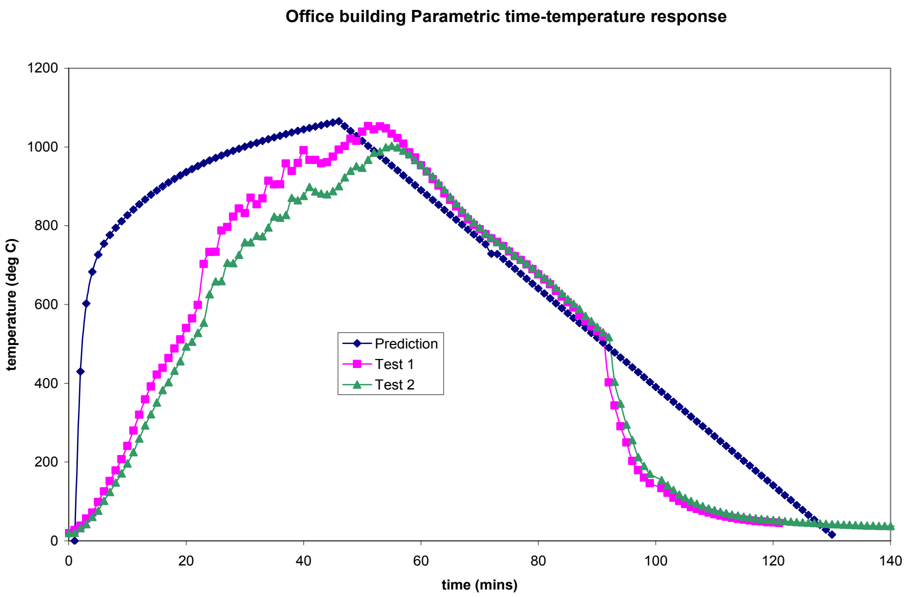


Figure 6 Parametric validation – composite steel framed building

In this case both the peak temperature and overall duration of the fire are accurately modelled using the parametric approach in the Eurocode.

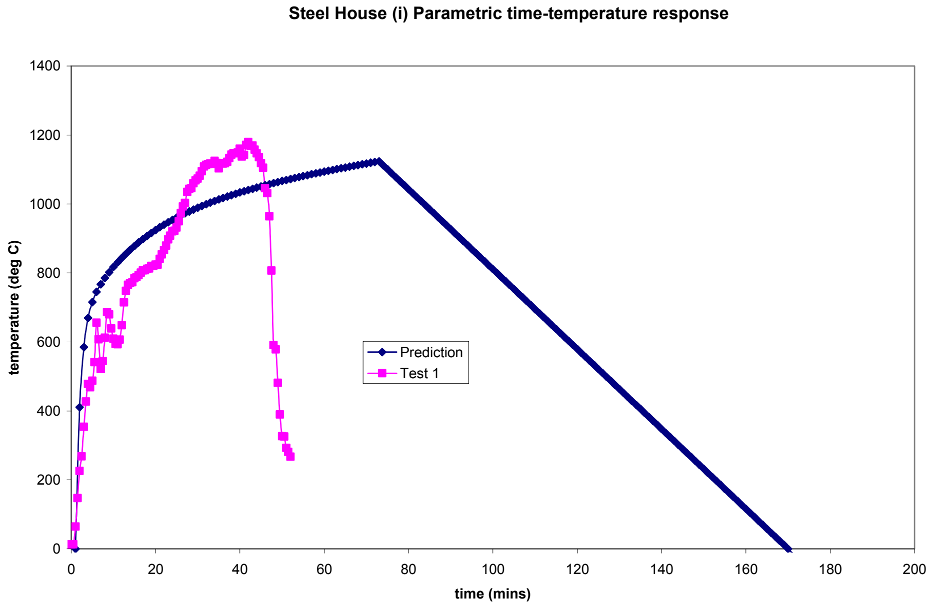


Figure 7 Parametric validation – Domestic dwelling

The particular circumstances of the test meant that a full measured time-temperature history is not available in this instance. However, the thermal exposure in the growing phase is correctly modelled and the estimate of peak temperature within the compartment is close to the measured peak value.

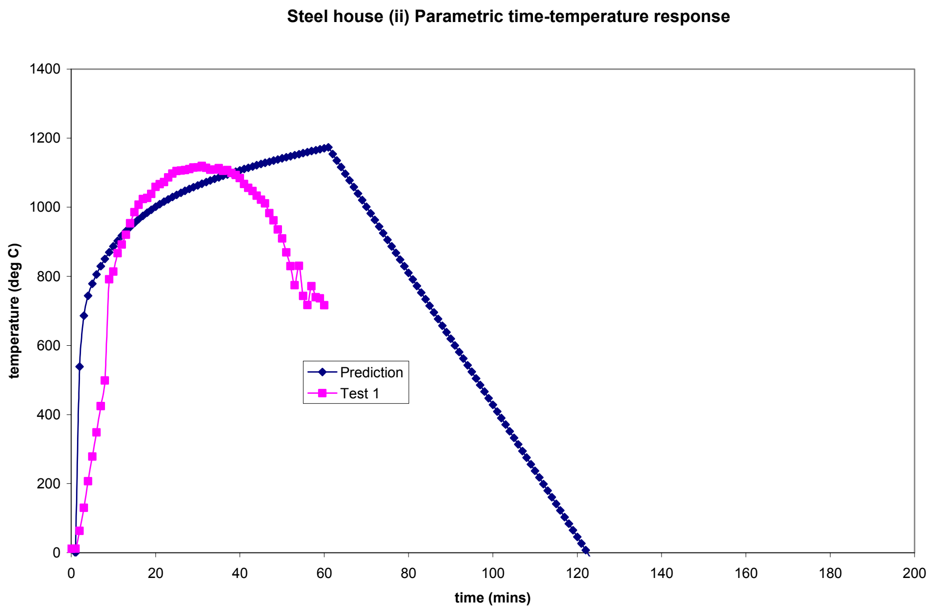


Figure 8 Parametric validation – Domestic dwelling

Again a full measured time-temperature history is not available from this test. However, in this case the peak temperature has been reached and the fire has commenced the decay phase. The parametric approach provides a reasonable if slightly conservative estimate of both peak temperature and overall duration.

Additional data for validation is available from a series of tests undertaken in support of the European Natural Fire Safety Concept[4]. Figures 9 to 11 below show the correlation with the test results.

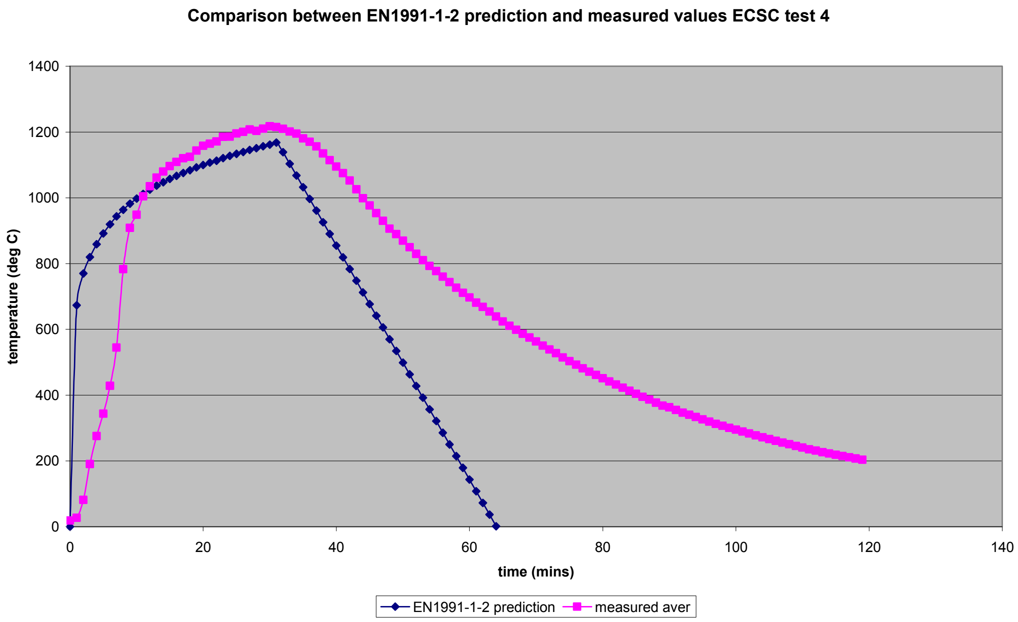


Figure 9 Parametric validation – comparison with ECSC test 4

Comparison between EN1991-1-2 prediction and measured values ECSC test 5

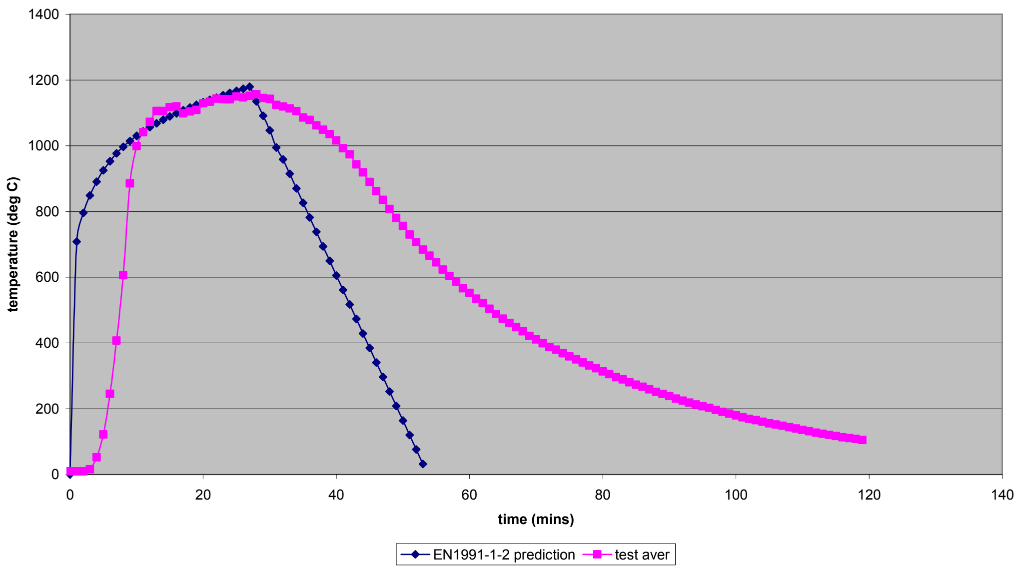


Figure 10 Parametric validation – comparison with ECSC test 5

comparison between EN1991-1-2 prediction and measured data ECSC test 7

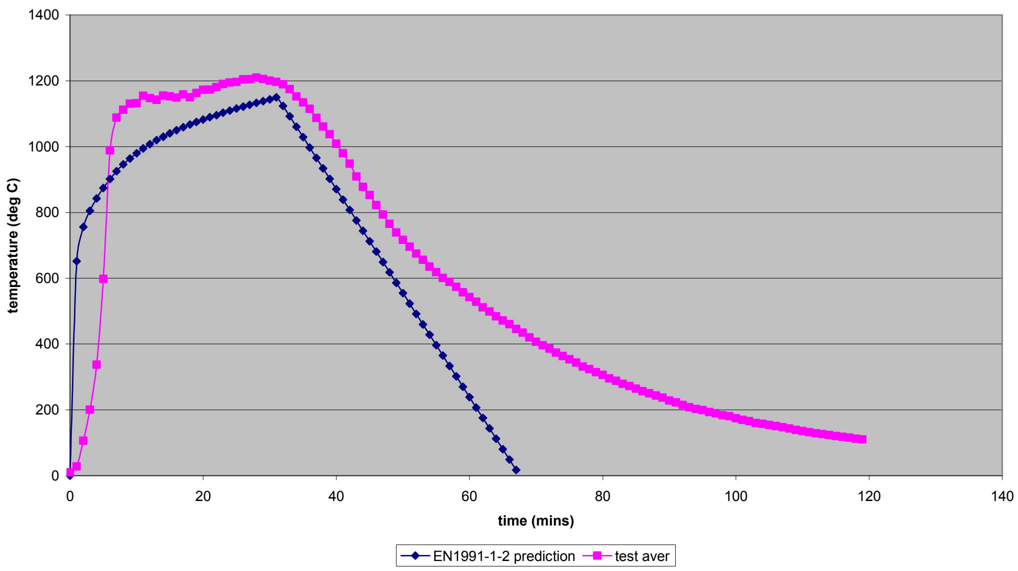


Figure 11 Parametric validation – ECSC test 7

It can be seen that there is close correlation between the maximum temperature predicted and that achieved during the test. Although the parametric approach tends to under predict the overall duration of the fire this can be explained by the choice of a design value for fire load density in the Eurocode prediction (570MJ/m²) while the test value used a fire load density of 720MJ/m².

The validation exercise has shown that the parametric approach is suitable for design purposes and provides a reasonable prediction of both peak temperatures and overall fire duration. The design calculations for the comparison are detailed in Appendix B.

The procedures for evaluating the temperature regime to be used for external members subjected to heating from flames emerging from window openings is based on design guidance which has been in the public domain for some time[5] and was accepted for use in the ENV. However, recent calibration exercises in support of the development of the UK NA[3] have shown that for certain input values the calculation of the fire and flame temperatures and the trajectory of the flames do not provide sensible results. Therefore it is recommended that Annex B is used together with the non-contradictory complementary information set out in the draft NA. Implementation of this part of the code will have no significant impact on Irish construction practice.

Clause 3.3.1.1 (1) Simplified fire models

See above in relation to Informative Annex A and Informative Annex B.

Clause 3.3.1.2 (1) Simplified models, compartment fires

See above in relation to Informative Annex A.

Clause 3.3.1.2 (2) Simplified models, external members

See above in relation to Informative Annex B.

Clause 3.3.1.3 (1) Simplified models, localised fires

Informative Annex C does not represent the most up to date technical information and therefore should not be used. The heating conditions should be calculated according to the alternative Irish guidance provided. As the reference is to existing information already in the public domain through BS 7974 PD1 there is no significant impact for Irish construction.

Clause 3.3.2 (2) Advanced fire models

Annex D covers a basic description of the various approaches to be used. There is no detailed guidance on carrying out the analysis. Consequently the Annex is acceptable for use in Ireland but the impact of its incorporation will be minimal. All the information is well known to practising fire engineers and, as with all advanced numerical methods, there are procedures for ensuring competency and validity of the output from computer models.

Clause 4.2.2 (2) Additional actions

This clause has been included to enable those countries (such as Germany) whose National regulations call for additional actions to be considered during the fire test regime. An example would be the use of impact testing on compartment walls. As the Irish regulations do not call for any additional actions this clause will have no influence on current practice.

Clause 4.3.1 (2) Mechanical actions

The influence of imposed load in relation to the combination rules for actions is explained briefly elsewhere in this report. The European system allows for a reduction in the value of the design imposed load at the fire limit state in recognition of the small probability that the full design load will be present at the same time that a fire occurs. The value of $\Psi_{1,1}$ has been adopted. This corresponds to a reduction in the imposed load for offices and dwellings of 50% at the fire limit state (see table 2). This is the most conservative of the choices allowed.

There will be an impact on design in terms of passive fire protection thicknesses if designers choose to go down the calculation route. There may also be a reduction in minimum sizes of reinforced concrete members or reduced covers. However, the additional costs and complexity of undertaking a fire engineering calculation that takes into account load effects means that overall impact will be minimal.

References

1. Department of the Environment, Heritage and Local Government, (Draft) Technical Guidance Document B, Fire Safety, 2003 Edition
2. Kirby B R, Newman G M, Butterworth N, Pagan J and English C, A new approach to specifying fire resistance periods, The Structural Engineer, 5 October 2004, pp. 34-37
3. Kirby B R, Calibration of Eurocode 1: actions on structures – Part 1.2: actions on structures exposed to fire, The Structural Engineer, 5 October 2004 pp 38-43
4. Lennon T and Moore D B, Natural Fire Safety Concept, Fire Safety Journal
5. Law M and O'Brien T, Fire safety of bare external steel, Constrado, 1979

Appendix B – Structural Fire Engineering Design Calculations

B1 – Time Equivalence calculations

TGD-B All values taken from table A2. 2 storey domestic dwelling assumed to be owner occupied house. 6 storey domestic dwelling assumed to be multi-tenancy block of flats.

ENV 1991-2-2 with Irish NAD

$t_{ed} = q_{fd}. K_b . w_f$

where $q_{fd} = Y_q . Y_{n.} q_{f,k}$

Y_q – is a partial safety factor, dependent on the occupancy and height of top storey (from table 3 of Irish NAD).

Y_n – is a factor depending on if approved sprinkler system is used or not.

$q_{f,k}$ – is the characteristic fire load density (taken from the Irish NAD p.6).

k_b – is a conversion factor (0.09 in all cases).

w_f – is a ventilation factor

where $w_f = (6/H)^{0.3}[0.62+90(0.4-\alpha_v)^4 / (1+b_v \alpha_h)] \geq 0.5 (m^{½})$

where α_v is the ratio of the area of the vertical openings to the area of the floor and should lie between the values of 0.025 and 0.25. α_h is the ratio of the horizontal openings in the roof to the floor area of the compartment and $b_v = 12.5(1+10 \alpha_v - \alpha_v^2)$ and should be greater than or equal to 10. H is the height of the compartment.

ENV with UK NAD

$t_{ed} = q_{fd}. K_b . w_f$

where $q_{fd} = Y_q . Y_{n.} q_{f,k}$

$Y_q = Y_{q1} . Y_{q2}$

Y_q – is a partial safety factor,

Y_{q1} – partial safety factor to account for consequences of failure

Y_{q2} – partial factor to account for risk of failure factor to be used in equation

$q_{f,k}$ – is the characteristic fire load density (taken from the UK NAD Table 7)

k_b and w_f as above

EN 1991-1-2

$t_{ed} = (q_{fd} . k_b . w_f) k_c$

$q_{fd} = q_{f,k} . m. \delta_{q1} . \delta_{q2} . \delta_n$

$q_{f,k}$ - is the characteristic fire load density.(80% fractile from table E4)

m – is a combustion factor (0.8 is used in this case)

δ_{q1} – is a factor to account for the danger of fire activation.

δ_{q2} – is a factor taking into account fire activation risk due to the type of occupancy (note no guidance for retail premises)

where

δ_n – is a factor to account for active fire fighting measures. (no sprinklers 0.73 (fire detection by smoke) x 0.78 9off site fire service) = 0.57, with sprinkler 0.73x0.78x0.61 = 0.35

$k_{c =}$ is a correction factor to account for different materials
= 1.0 for protected steel and concrete
Note: no account is taken of the height of the building

EN 1991-1-2 with proposed draft NA

$t_{ed} = (q_{fd} . k_b . w_f) \beta$

$q_{fd} = q_{f,k} . m. \Upsilon_1$

β is a factor to account for risk and consequence of failure from table 5.3.2

$q_{f,k}$ is taken from table 5.2.2 fire load density

m - is a combustion factor (1.0 is used in this case)

Υ_1 – is a factor to account for the effect of sprinklers installed for life safety purposes.

k_b - is a conversion factor (0.09 in all of the cases).

Figure B1, Case 1 – 2 storey residential building

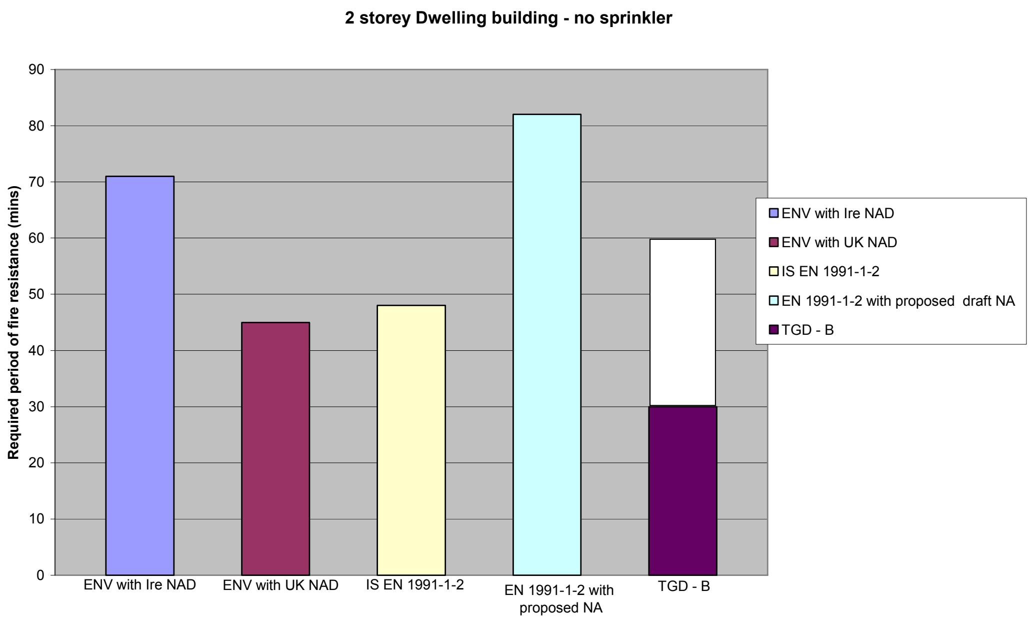


Figure B2, Case 2 – 2 storey residential building with sprinklers

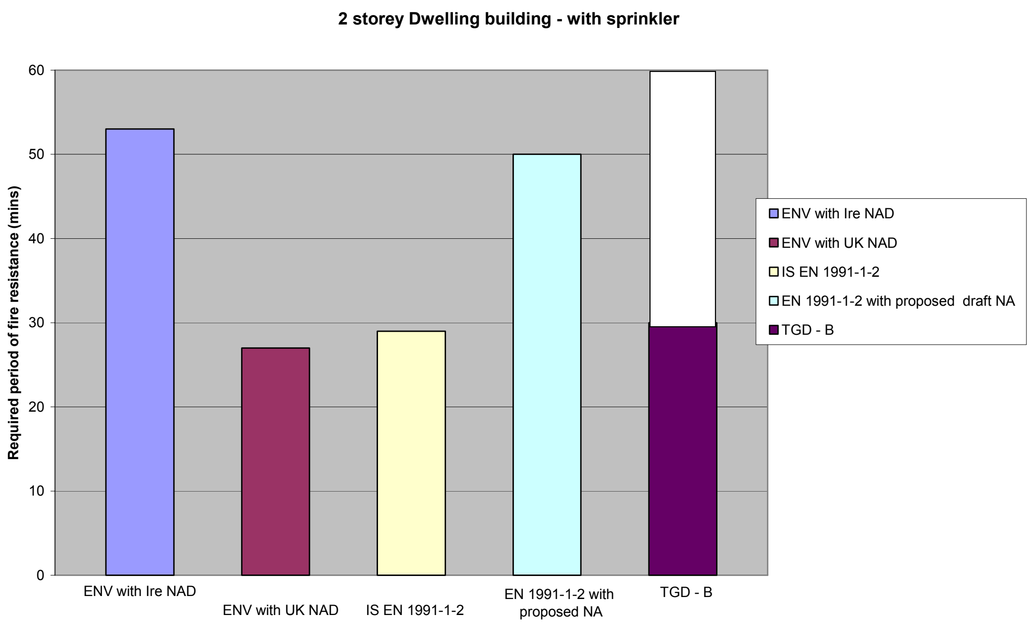


Figure B3, Case 3 - 6 storey residential building

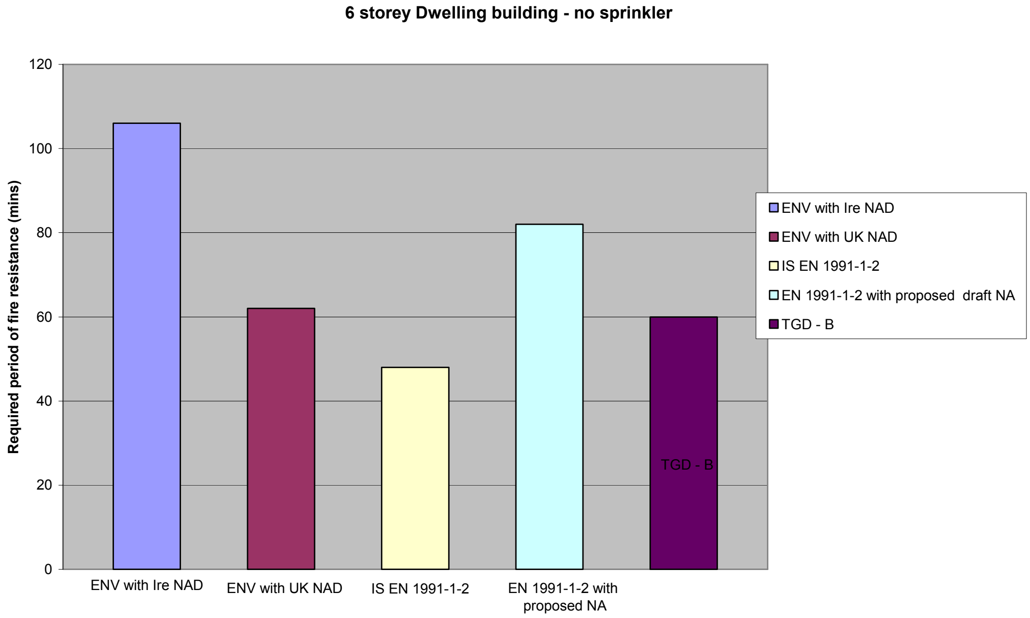


Figure B4, Case 4 - 6 storey residential building with sprinklers

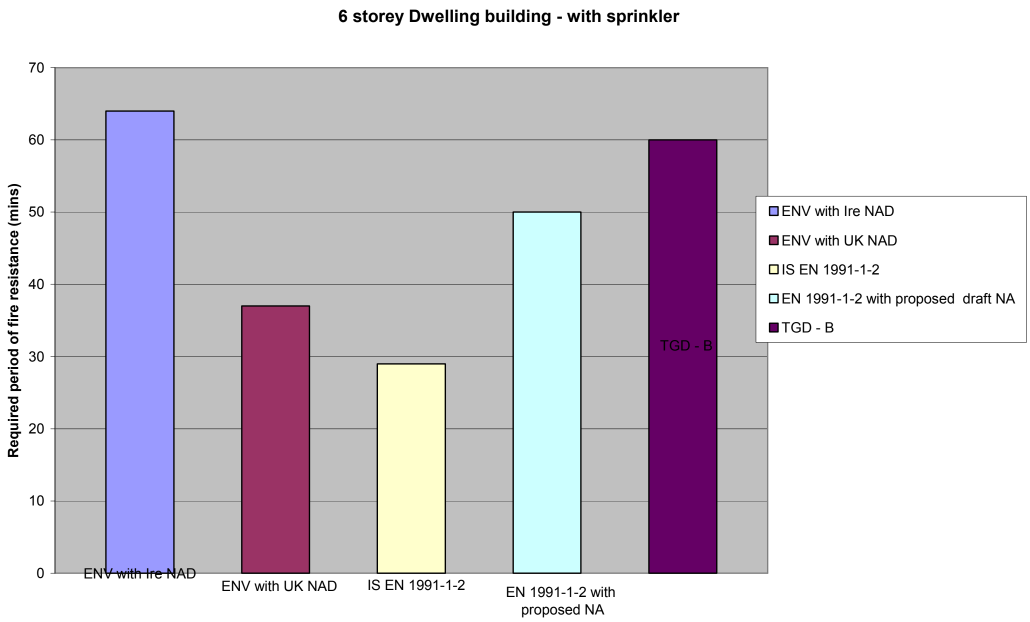


Figure B5,Case 5 - 2 storey office building

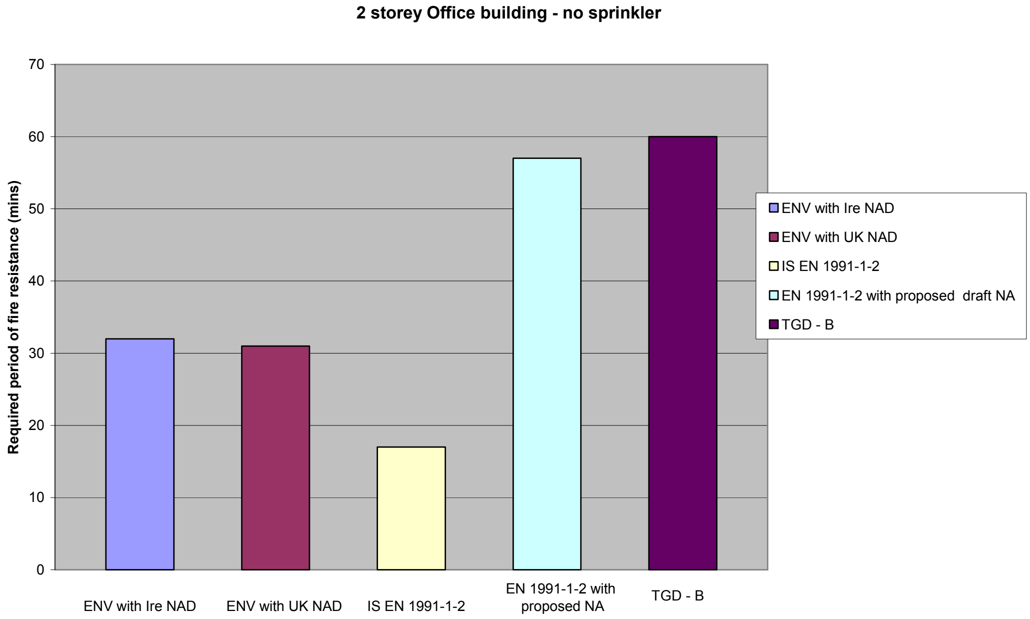


Figure B6,Case 6 - 2 storey office building with sprinklers

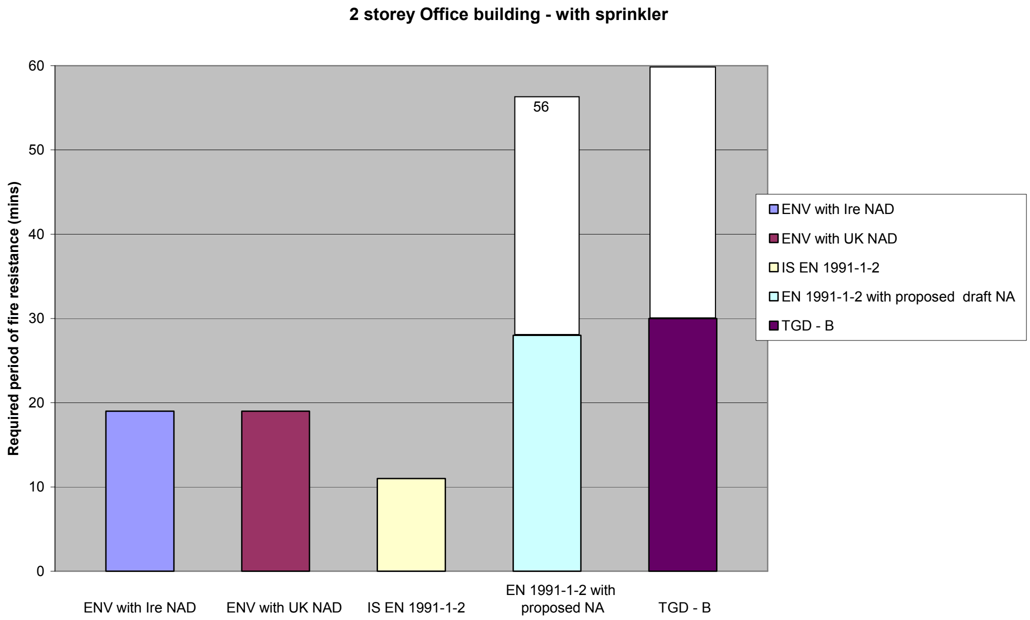


Figure B7, Case 7 - 6 storey office building

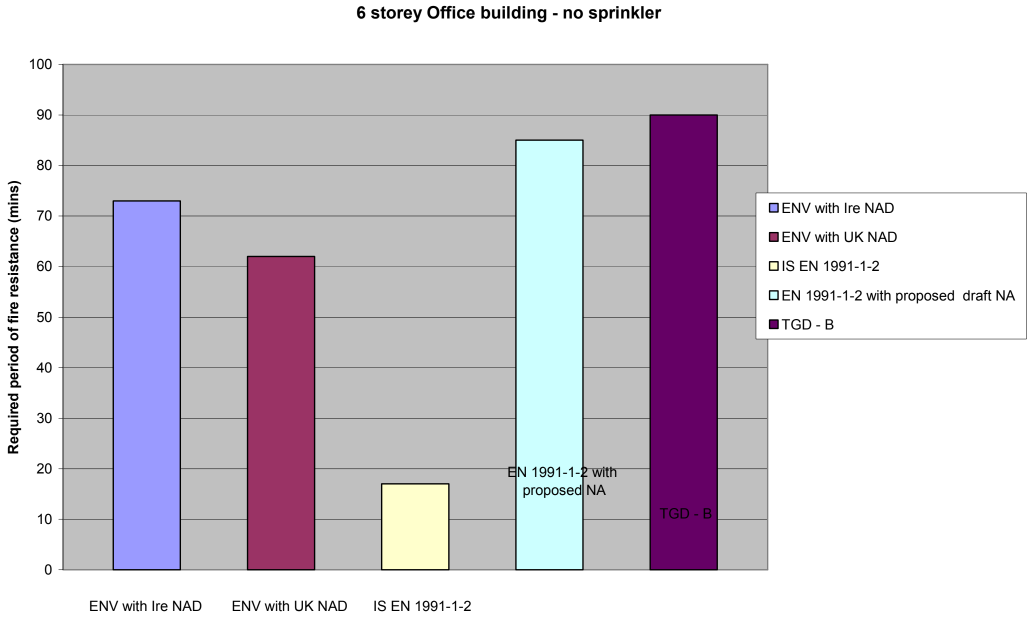


Figure B8, Case 8 - 6 storey office building with sprinklers

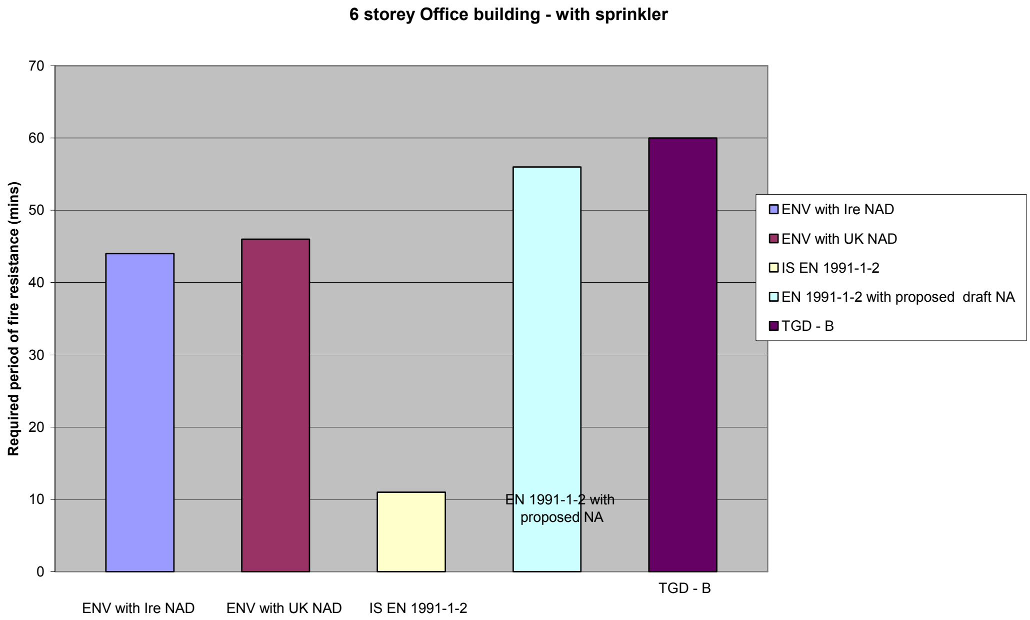


Figure B9,Case 9 - 2 storey retail building

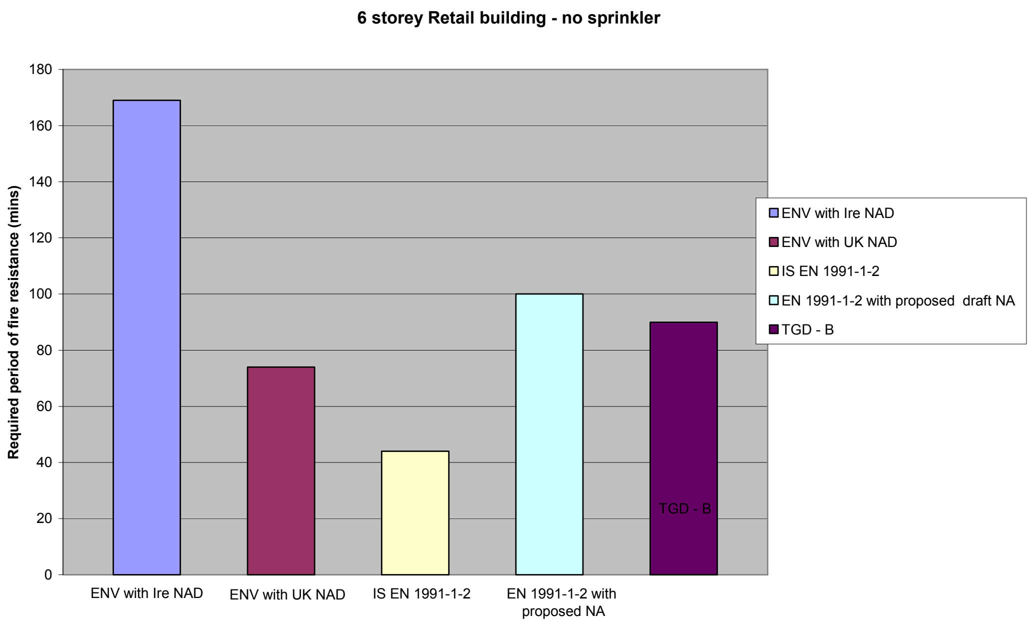


Figure B10, Case 10 - 2 storey retail building with sprinklers

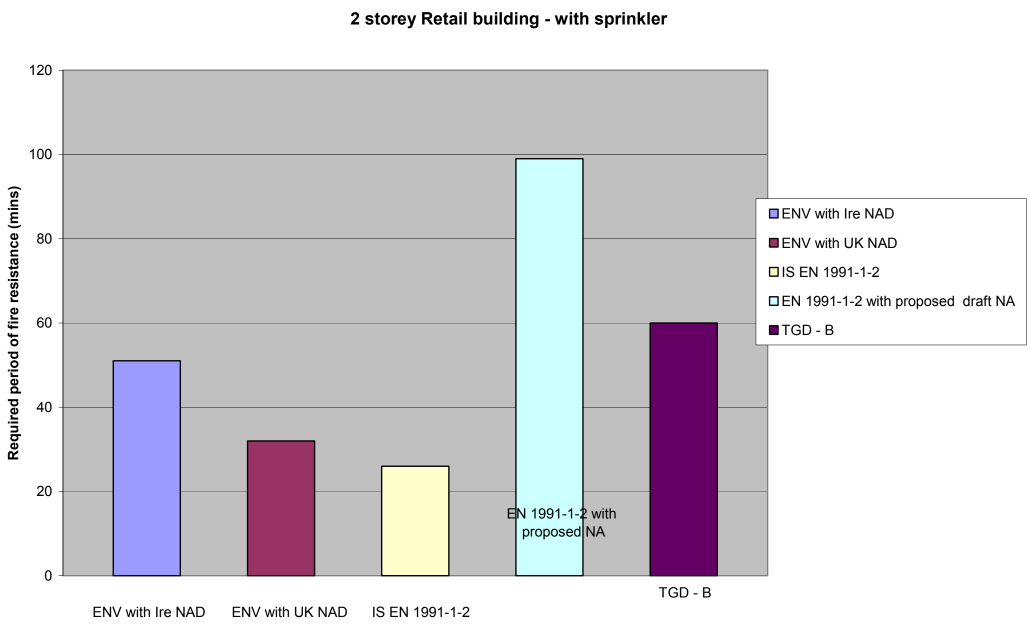


Figure B11,Case 11 - 6 storey retail building

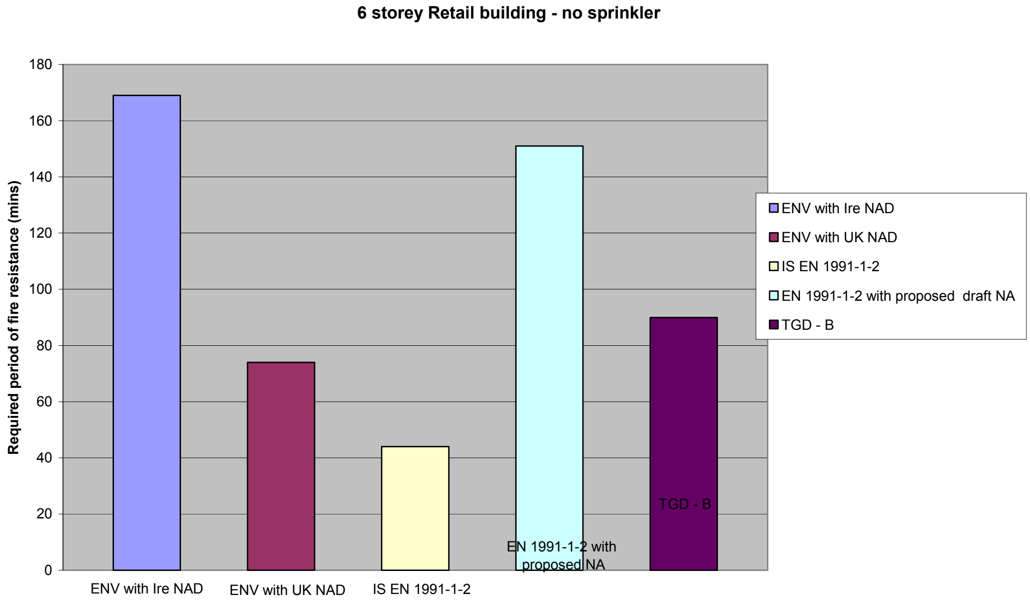
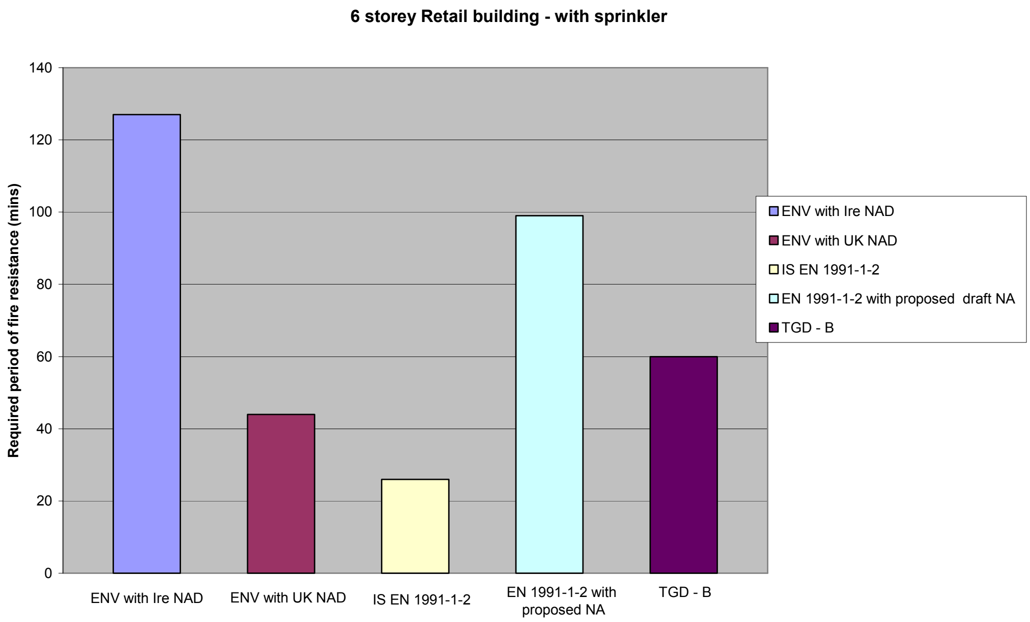


Figure B12,Case 12 - 6 storey retail building with sprinklers



Design values for the parametric calculations.

Office building 1 (2 tests)

Parameter	Value
Design fire load density related to floor area q_{fd} (MJ/m²)	570
Design fire load density related to total surface area q_{td} (MJ/m²)	131.5
Floor area A_f (m²)	36
Area of ventilation openings A_v (m²)	7.2
Total surface area A_t (m²)	156
Height of ventilation opening h (m)	2
Height of compartment H (m)	3.5
Thermal properties of compartment linings b ($J/m^2s^{1/2}K$)	863
Opening factor O ($m^{1/2}$)	0.065

Office building 2

Parameter	Value
Design fire load density related to floor area q_{fd} (MJ/m²)	570
Design fire load density related to total surface area q_{td} (MJ/m²)	162.55
Floor area A_f (m²)	77
Area of ventilation openings A_v (m²)	7.2
Total surface area A_t (m²)	270
Height of ventilation opening h (m)	2
Height of compartment H (m)	3.5
Thermal properties of compartment linings b ($J/m^2s^{1/2}K$)	720
Opening factor O ($m^{1/2}$)	0.043

Domestic dwelling 1

Parameter	Value
Design fire load density related to floor area q_{fd} (MJ/m²)	870
Design fire load density related to total surface area q_{td} (MJ/m²)	224.27
Floor area A_f (m²)	29.645
Area of ventilation openings A_v (m²)	7.2
Total surface area A_t (m²)	115
Height of ventilation opening h (m)	2
Height of compartment H (m)	3.5
Thermal properties of compartment linings b ($J/m^2s^{½}K$)	650
Opening factor O ($m^{½}$)	0.0374

Domestic dwelling 2

Parameter	Value
Design fire load density related to floor area q_{fd} (MJ/m²)	870
Design fire load density related to total surface area q_{td} (MJ/m²)	241
Floor area A_f (m²)	28.8
Area of ventilation openings A_v (m²)	7.2
Total surface area A_t (m²)	104
Height of ventilation opening h (m)	2
Height of compartment H (m)	3.5
Thermal properties of compartment linings b ($J/m^2s^{½}K$)	650
Opening factor O ($m^{½}$)	0.048

Office building 3 (8 tests)