Calibration of Eurocode 1: actions on structures – Part 1.2: actions on structures exposed to fire

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This paper has been independently reviewed by BSI and has not gone through the full IStructE peer review process

Synopsis

A calibration study and review has been carried out on the recently published Eurocode 1-1-2 on Fire Actions based upon a major study undertaken led by Corus Fire Engineering. Much of the Code can be supported by both recent and established analyses of experimental data and this is reflected in accepting the Normative and part of the Informative Annexes of the document. For some clauses, additional complementary information has been provided to broaden their scope of application.

Where clauses in the Informative Annexes cannot be supported, alternative guidance is provided and this has been drawn from existing fire engineering design codes in the UK

From this work, the author has drafted a National Annex, which will be published by the British Standards Institution for public consultation during 2004. This paper provides the technical background to the more important decisions made in drafting the National Annex.

Introduction

In November 2002, *Eurocode 1: Actions on Structures Part 1.2: General Actions – Actions on structures exposed to fire*[1] was published. This document is substantially different to the ENV (1991 Part 2.2[2]) that was published in 1996 and reflects the increased understanding on the behaviour of fires in buildings and improved correlations between new and existing test data.

As part of an ODPM PII sponsored programme, during the last 2 years Corus Fire Engineering in collaboration with the University of Edinburgh and the Fire Research Station, Building Research Establishment has carried out a calibration process of validating the various clauses in the new code. As a result of this work, Corus Fire Engineering has prepared a draft National Annex under the auspices of the British Standards Institution (BSI). This will be published for public consultation during 2004.

This paper discusses the background of the important issues that have been studied and how these have been validated against recent data to support the decisions made in drafting the UK National Annex. It also introduces additional information for application in the UK.

Structural fire design

Fig 1 provides an overview of Eurocode 1-1-2 and how it fits in to the overall structural fire design process.

Broadly, there are four steps to the design of structural members in fire. The first two steps of the design process are carried out solely within the confines of the clauses set out in Eurocode1-1-2. Step three, involves a combination of EC1-1-2 with the corresponding fire actions provided in the material codes (Eurocodes 2 to 6 and Eurocode 9). The fourth step is carried out primarily within the confines of the material codes. These are briefly discussed as follows:

Step 1: Selection of relevant design fire scenarios

The first part in the structural fire design process is to define the accidental situation in which the relevant scenarios and design fires should be determined based upon an agreed fire safety design strategy.

Step 2: Determination of the corresponding design fires

For each scenario, a design fire is estimated and unless stipulated, it is considered in one 'fire compartment' at a time.

In selecting the design fire, either a mathematical representation of a real fire can be considered (parametric fire), or, where the fire resistance is specified through the National Code, the heating regime in the Standard furnace test (BS EN 1363[3]) can be used. The parametric fire is discussed later in the paper.

Step 3: Calculation of the temperature rise of the structural member/s

The temperature rise of the structural member may be determined on the basis of exposure to a natural (parametric) fire in which the cooling phase is included, or, a period of heating in a standard furnace test in which there is no cooling phase. In the case of the latter, the period of heating may be specified by national regulatory requirements given in *Approved Document B – England & Wales*[4], *The Building Standards (Scotland) Regulations Part D*[5], *Building Regulations – Northern Ireland*[6].

The location of structural elements in relation to the fire is also considered. For example, members located external to the building façade may be analysed whereby exposure to the fire is due to radiation and flames emerging from openings in the external envelope.

To calculate the temperature rise of the structural members, reference has to also be made to the relevant material Eurocodes to provide thermo-physical properties of the structural material.

Step 4: Calculation of the mechanical response

The mechanical analysis of the structural member is carried out in which verification of the fire resistance is made on the basis of:

- The fire resistance time of the structural element exceeds the fire resistance requirements.
- The strength of the structural element exceeds that necessary for the fire resistance.
- The critical temperature of the structural member exceeds that for the fire resistance.

EC1-1-2 Fire Actions, in combination with the material codes

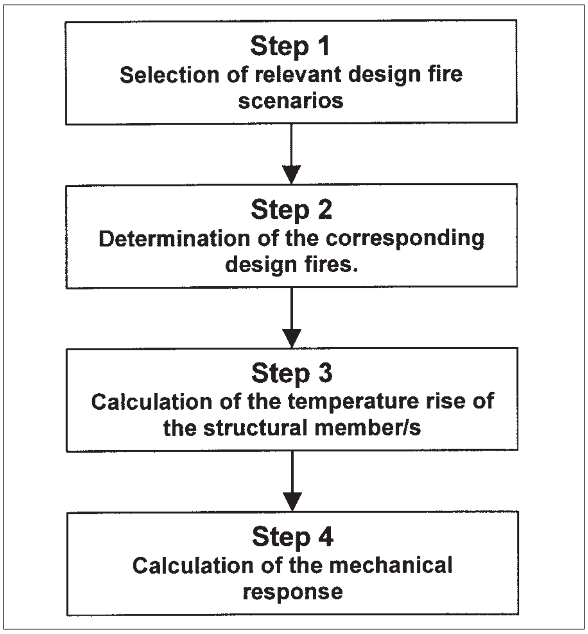


Fig 1. Overview of Euroocode1-1-2 in relation to the structural codes

permit a number of structural fire design strategies to be followed. These broadly fall into one of two categories and are described as either Prescriptive or Performance based ranging in complexity from a simple single member analysis subjected to the Standard furnace heating regime (BS EN 1363), to computational analysis involving advanced fire development models coupled with analysis of entire structural frames.

Thermal actions

The Code is divided into two parts:
Normative Section – in which European member states are obliged to follow.
Informative Section – in which European member states can adopt voluntarily.

In EC1-1-2, the informative part of the Code consists of seven Annexes, A to G.

Annex A – Parametric temperature–time curves
Annex B – Thermal actions for external members
– Simplified calculation method
Annex C – Localised fires
Annex D – Advanced fire models
Annex E – Fire load densities
Annex F – Equivalent time of fire exposure
Annex G – Configuration factor

Within the European rules, an Informative Annex can only be accepted in full, however, where there is additional complementary information that extends the application, or, provides additional supporting data, this can be included. A member state also has the option that if it cannot accept an Annex it can prepare an alternative document for application in that state.

The work carried out by the author recommended to BSI that the UK should not accept Annex C, Annex E nor Annex F and therefore alternative documents have been prepared or, references given, for application in the UK.

Normative clauses

Clause 3.1: Thermal actions for temperature analysis
Equations 3.1 to 3.3 consider the net heat flux $\dot{h}_{net}$ to the surface of the member. This is determined by considering the heat transfer by convection $\dot{h}_{net,c}$ and radiation $\dot{h}_{net,r}$ as follows:

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r} \ (\mathrm{W/m^2}) \qquad ...(3.1)$$

where

$$\dot{h}_{net,c} = \alpha_c \cdot (\theta_g - \theta_m)\ (\mathrm{W/m^2}) \qquad ...(3.2)$$

and

$$\dot{h}_{net,r} = \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \left[(\theta_r + 273)^4 + (\theta_m + 273)^4\right] (\mathrm{W/m^2}) \ ...(3.3)$$

These relationships have altered since the ENV was first published as follows:

In equation 3.1, both the net heat transfer for convection and radiation were previously preceded by a term γ_c or γ_r. Member states were permitted to ascribe their own factors that aligned the heat transfer relationships in accordance with their National data. In the UK National Applications Document (NAD), these were both set at 1.0 for all construction materials with the exception of steel in which the latter was given a value of 0.45.

In equation 3.3 the value of $\varepsilon_m \times \varepsilon_f$ was previously denoted as ε_r which was the product between the emissivity of the material and the emissivity of the fire.

In effect this has stayed the same but the default value for ε_m is now 0.8 rather than 0.7. For structural steel a value of 0.8 has been used in the past. For the fire, ε_f has however changed from 1.0 to 0.8.

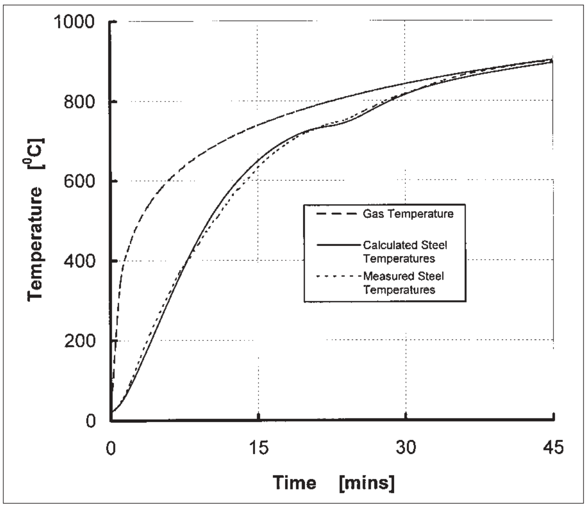


Fig 2. Comparison between the predicted and measured heating curves in the standard furnace test

Since the ENV was published, European harmonisation of the furnace test methods has taken place with the result that the British Standard (BS 476) has been replaced by BS EN 1363. This has resulted in a significant change in the furnace heating conditions arising from the introduction of the plate thermometer as means of monitoring and controlling the temperature rise of the gaseous environment. The effect of this change is most pronounced in the early stages of the test and will vary depending upon the material being tested. Those materials that have a low thermal capacity such as structural steel are affected most severely. For protected steel, the effect of the change in furnace conditions is less pronounced and after 60 min of heating the difference is negligible.

For bare structural steel, data derived from the new test standard has been used to determine whether the revised relationships for predicting the heating rates of structural members can be accepted. In the analysis, reference has to be made to EC3: Part 1.2, which describes the heat transfer for structural steel and provides the appropriate material properties. This introduces a shadow factor to take account of structural elements that may not see the full radiation effects of the fire such as an open sided floor beam, and is given by the ratio of the section factors (previously referred to as Hp/A in the UK) for the box and profile for the particular steel section, $[A_m/V]_{box}/[A_m/V]_{contour}$.

Fig 2 compares the actual temperatures monitored during a fire resistance test on an unprotected 406 × 178mm universal beam section against the predicted values calculated using the relationships given in equations 3.1 to 3.3. In general the predicted temperatures were found to be slightly higher (conservative) in the critical range, than those measured.

Clause 3.2: Nominal temperature – time curves
Section: 3.2.1 Standard temperature – time curve: The standard temperature–time curve is given in BS EN 1363: Part 1 by the relationship:

$$\theta_g = 20 + 345 \log_{10}(8t + 1)\ (^\circ\mathrm{C}) \qquad ...(3.4)$$

Where:
θ_g is the gas temperature in the fire compartment (°C)
t is the time (min)

The coefficient of heat transfer by convection is:
$\alpha_c = 25\ \mathrm{W/m^2K}$

This curve is often referred to as the cellulosic heating rate. Although it does not represent an actual fire it forms the basis on which the fire resistance performance of load bearing elements are evaluated and is referred to in the UK building Regulations.

Clause 3.2.2: External fire curve: To characterisecharacterise less severe fires immediately outside enclosures, or, emanating from within the building e.g. the condition of flames issuing from adjacent windows, the temperature/time relationship is given in BS EN 1363:Part 2 and can be calculated from:

$$\theta_g = 660\left(1 - 0.687e^{-0.32t} - 0.313e^{-3.8t}\right) + 20\ \ (^\circ\mathrm{C}) \qquad ...(3.5)$$

Where:

θ_g is the gas temperature in the fire compartment (°C)
t is the time (min)

The coefficient of heat transfer by convection is:
$\alpha_c = 25$ W/m²K

Clause 3.2.3: Hydrocarbon curve: The hydrocarbon temperature–time curve is given by:

$$\theta_g = 1080\left(1 - 0.325e^{-0.167t} - 0.675e^{-2.5t}\right) + 20\ (°\mathrm{C}) \qquad \ldots(3.6)$$

Where:
θ_g is the gas temperature in the fire compartment (°C)
t is the time (mins)

The coefficient of heat transfer by convection is:
$\alpha_c = 50$ W/m²K

This particular curve is representative of the heating rate of hydrocarbon pool fires.

Clause 4: Mechanical actions for structural analysis
The mechanical actions are considered only in so far as providing statements on the importance of expansion, temperature distributions and the impact of additional forces on some certain types of structure.

Clause 4.3: Combination rules for actions: For rules on combination of actions, the Code recommends the representatative value of the variable action Q_1, be the quasi-permament factor $\psi_{2,1}$ Q_1,. The National Annex states that the frequent value $\psi_{1,1}$ Q, should be adopted.

Informative clauses – National Annexes A – G

The National Annexes are Innormative and these are either accepted in full with additional complementary information, or, where they cannot be accepted, then alternative guidance for application in the UK can be provided.

ANNEX A – Parametric temperature – time curves
For compartment fires the temperature – time history of the entire fire process is given by the relationship:

$$\theta_g = 20 + 1325\left(1 - 0.324e^{-0.2t^*} - 0.204e^{-1.7t^*} - 0.472e^{-19t^*}\right) \qquad \ldots(A.1)$$

Where:
θ_g is the gas temperature in the fire compartment (°C)
$t^* = t.\Gamma$ (h) ...(A2a)

With;
t = time (h)
$\Gamma = \left[O/b\right]^2 / \left(0.04/1160\right)^2$
O is the opening factor and is given by:

$A_v h^{1/2} / A_t$ ($m^{1/2}$)

Where:
A_v is the area of vertical openings (m²)
h is the weighted mean height of the vertical openings (m)
A_t is the total area of the enclosure (walls, floor and ceiling including the openings) (m²).

In the Code, the limits of $0.02 \leq O \leq 0.20$ are observed. However, the UK considers that since the parametric fire is based upon a heat balance approach, the minimum value for the opening factor can been extended down to $0.01m^{1/2}$. This is supported by work carried out by Pettersson[7] in the 1970s.

The thermal diffusivity is given by:

$b = \sqrt{(\rho c\lambda)}$ ($J/m^2s^{1/2}K$)

and has now been extended to cover a wider range of compartment types with;

$100 \leq b \leq 2200$

The lower value would be representative of a heavily insulated compartment or, building with a controlled environment, whereas the upper value is representative of a very poorly insulated structure such as bare dense concrete/metal enclosure.

A criticism of the ENV was the treatment of the influence of the thermal properties of the compartment walls, floor and ceiling on the temperature–time curve of the 'natural' fire. This has much improved in terms of the relevant thickness of the structure that influences the fire temperatures as well as the treatment of structures with two or more layers, e.g. a composite wall. It was found that the thermal properties of a wall 1m thick would influence the temperatures in a fire whereas in reality, it is the first few centimetres that are important for most situations.

A limiting value on the thickness of the structure that can affect the fire is now given by:

$$s_{\lim} = \sqrt{\frac{3600 t_{\max} \lambda_1}{c_1 \rho_1}}\ (\mathrm{m}) \qquad \ldots(A.4)$$

To account for different thermal properties of the walls, ceiling and floor, the thermal diffusivity, $b = \sqrt{(\rho c\lambda)}$, is introduced as

$$b = \left(\sum\left(b_j A_j\right)\right) / \left(A_t - A_v\right)$$

Where:
A_j is the area of enclosure surface j, openings not included
b_j is the thermal property of enclosure surface j.

The maximum temperature attained by the fire is now better defined and is given by:
$t^*_{\max} = t_{\max}.\Gamma$ (h) ...(A.6)

With:
$t_{\max} = \max[(0.2.10^{-3}.q_{t,d}/O);t_{\lim}]$ (h) ...(A.7)

Where:
$q_{t,d}$ is the design fire load density and should obey the following limits $50 \leq q_{t,d} \leq 1000 MJ/m^2$
$t_{\lim}$ is given in hours.

The range of fire load density covers the majority of practical situations in buildings. Values less than 50MJ/m² may not develop into post flashover fires.

The maximum temperatures attained in fires are now influenced by the fire growth rate in which $t_{\lim}$ = 25min, 20 min, and 15min is applied for fast, medium and slow growth rates. The growth rates are now determined based upon the building occupancy.

The new parametric expressions have been validated against a background of real fires carried out during the last 20 years by Corus and the FRS(BRE). Fig 3 illustrates one such example.

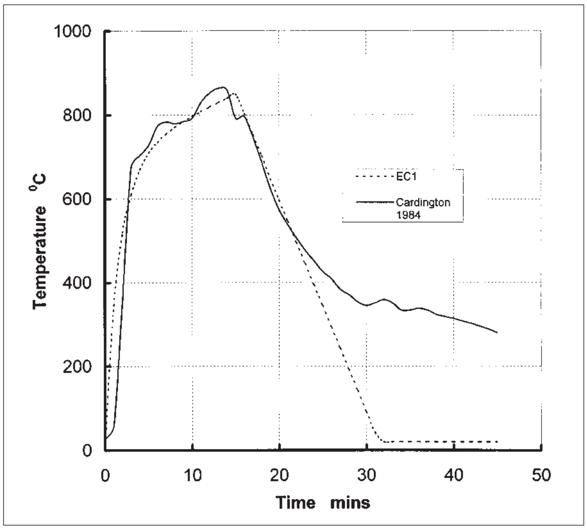
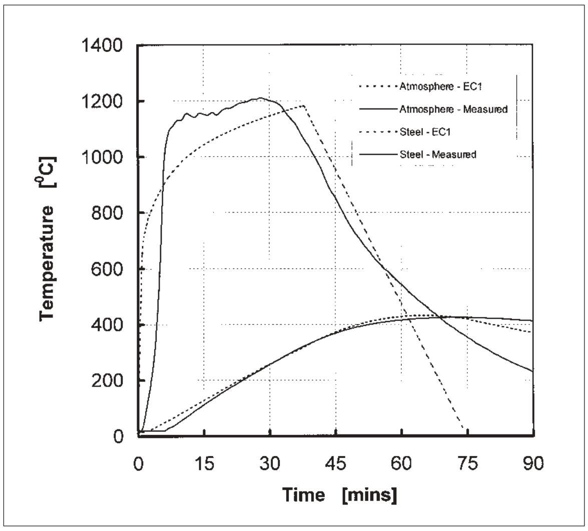
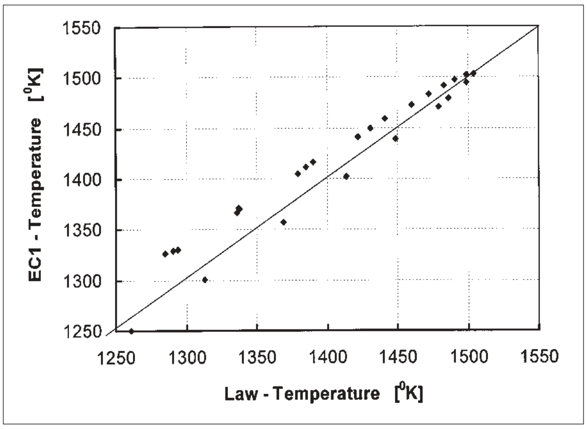


Fig 3. Comparison between the predicted and measured heating curves in the standard furnace test





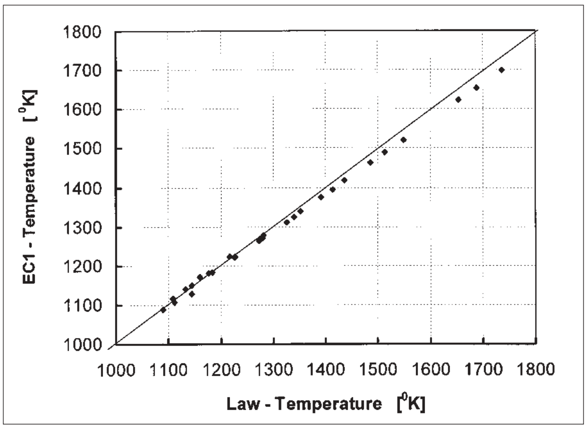


Fig 4. (Left) Comparison of fire temperatures between BRE test data and parametric analysis according to EC1. Fire load = 40kg/m^2, Opening factor = 0.07m$^{1/2}$
Fig 5. (Right) Fire temperatures – Calibration of EC1-1-2 against law
Fig 6. (Below right) Flame Temperatures – Calibration of EC1-1-2 against law

In general, good agreement was obtained between predicted and measured temperatures. However, where the correlation was not good the predicted temperatures were more onerous and therefore provided conservative outputs. In several cases where the correlation was not ideal then this could be evaluated as to whether it would have a significant effect on the structure.

Fig 4 illustrates an example in which variations between the predicted and measured fire curves have been assessed. By carrying out a heat transfer calculations for a protected steel member subjected to both heating cycles, the impact of differences in temperature and time between the two fires was found not to be significant when translated into the thermal response of the structural members.

ANNEX B – Thermal actions for external members – simplified calculation method

Annex B introduces a methodology for calculating the fire and flame temperature as the first part in the fire design of steelwork located external to the building façade.

The outputs from the analysis provides:

- the maximum temperature of a compartment fire
- the size and temperature of the flames emanating from the openings
- radiation and convection parameters

The analysis is similar to the work carried out by Law and has been reported in the Steel Construction Institute publication on External Steelwork[8].

Two situations are considered for calculating the temperatures of the internal fire and flames that may emerge from any openings:

- No through draft
- Through draft

Through draft conditions will prevail where openings on two or more walls exist and it can be assumed there will be a preference for flames to emerge from one set of openings. Through draft conditions will influence the:

- rate of heat release
- temperature of the fire within the compartment
- flame height
- horizontal projection of the flame
- flame width
- flame length along its axis
- flame temperature emerging from the window

Once the temperatures of the fire and flames emerging from openings have been established, the heat transfer to the external structure is calculated. This is achieved by considering the configuration (or view) factor, which is determined using a set of geometric calculations. These are given in this particular Annex but are described more fully in Annex G.

The calculations given in Eurocode 1-1-2 have been compared with the outputs determined using the existing publication.

In general, good agreement is achieved between the two slightly different methods as illustrated in Fig 5 and Fig 6.

In the analysis, it is possible to select certain conditions that provide unrealistic temperatures and therefore the National Annex places upper limits of 1650K and 1750K respectively for the fire and flame temperatures respectively.

It is also possible to obtain negative flame heights when certain compartment and window geometries are selected. This indicates that the tip of the flame is below the top of the window.

Annex C – Localised fires

The UK BSI committee considered Annex C was unacceptable.

Annex C was found to be technically inaccurate and only superficially covered a complex area of fire safety engineering with the result that there would be a lack of confidence in the outputs generated from such an analysis. It was agreed that the guidance provided in BS 7974 PD1[9] was more appropriate and the relevant sections 8.2.1.1 to 8.2.1.14 given in this document was recommended. The reference covers the following areas:

- Flame length for axi-symmetric fire
- Source flame length for line sources
- Flame lengths for corner room and wall fires
- Flame emissivity
- Flame radiation

Annex D – Advanced fire models

Annex D covers a basic description of the different approaches that can be adopted in fire analysis.

The concept of heat balance in compartment fires is introduced and a very brief description is given of the fundamentals and complexities behind each of the types of fire models from single zone models up to CFD analyses. However, apart from statements on principles, there is little in terms of calculations that would enable the engineer to carry out any detailed analysis.

Reference would need to be made to available software

Table 1: Fire load densities for various occupancies

Occupancy	Fire load density			
	Average MJ/m²	Fractile[1] MJ/m²		
		80%	90%	95%
Dwelling	780	870	920	970
Hospital	230	350	440	520
Hospital storage	2000	3000	3700	4400
Hotel bedroom	310	400	460	510
Offices	420	570	670	760
Shops	600	900	1100	1300
Manufacturing	300	470	590	720
Manufacturing and storage[2]	1180	1800	2240	2690
Libraries	1500	2250	2550	–
Schools	285	360	410	450

[1]The 80% fractile is the value that is not exceeded in 80% of the rooms or occupancy of the survey data. Typically this value may be used in design

[2]Storage of combustible materials at less than 150kg/m².

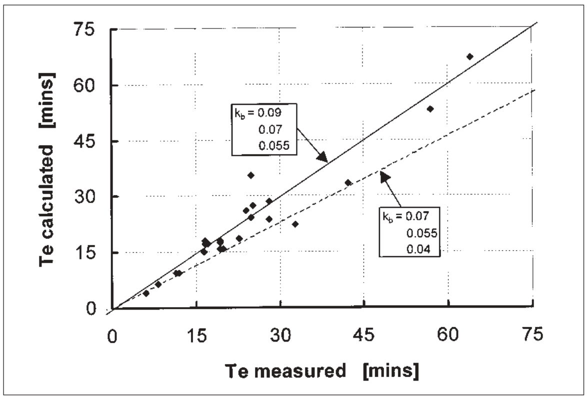


Fig 7. Comparison of the values for k_b for Te measured vs Te calculated

Table 2: Conversion factor k_b depending on the thermal properties of the enclosure

$b = \sqrt{\rho c \lambda}$ (J/m²s$^{1/2}$K)	k_b (min. m²/MJ)
b > 2500	0.055
720 ≤ b ≤2500	0.07
b < 720	0.09

packages. However, with the use of any model the practitioner must be competent in its use and be able to interrogate the accuracy of the outputs.

Annex E – Fire load densities

The UK was unable to accept Annex E as currently presented. In particular, there was a fundamental disagreement on the use of factors that multiply the design fire load density to provide fires of much lower severity.

The Code attempts to apply a risk base approach by influencing the fire load density. The UK considered the consequences of fire should not be addressed in the engineering calculations but should form part of a separate analysis after the fire related outputs have been obtained.

Alternative guidance for application in the UK has been prepared. This will enable the fire load densities to be determined for use in calculating fire scenarios e.g. parametric temperature time relationships, or time equivalent assessments for estimating the period of heating in the Standard furnace test (BS EN 1363: Part 1).

The main differences to the Code are as follows:

General

The fire load density used in calculations should be a design value, either, based on measurements, or, in special cases, based on fire resistance requirements given in UK Building Regulations.

The design value may be determined:

- from a national fire load classification of occupancies and/or,
- specific for an individual project by performing a fire load survey

The design value of the fire load q_{fd} is defined as:

$$q_{f,d} = q_{f,k} \cdot m \cdot \delta_1 \text{ (MJ/m}^2\text{)} \qquad \text{...(E1)}$$

Where:

$q_{f,k}$ is the characteristic fire load density per unit floor area (MJ/m²)

m is the combustion factor

δ_1 a factor of 0.61 can be applied to take into account sprinklers which should be installed for life safety purposes.

Additional safety measures such as automatic fire detection and alarm, smoke exhaust, means of escape (simultaneous, phased, pressurised stair cases) and fire fighting devices, should be considered as part of the fire safety design strategy for the building and guidance is given in UK Building Regulations, BS 5588[10] and BS DD 9999: Part 2[11].

Annex E suggested that a combustion factor of 0.8 of the fire load density could be applied. Based upon real fire experiments carried out in the UK, at the present time this cannot be supported. However, further analysis of compartment fires may demonstrate that some allowances may be acceptable.

The danger of fire activation may be linked to the occupancy risk profile and the size of the building. Guidance is given in BS 7974: PDs 1[1] and 7[5], and BS 9999.

Determination of fire load densities

The fire load should consist of all combustible contents and the relevant parts of the building construction, including linings and finishes. Combustible parts of the fire load, which do not char during the fire need not be taken into account.

The fire load densities can be determined:

- specific for an individual project and/or
- from a fire load classification of occupancies

Where fire load densities are determined from a fire load classification of occupancies, fire loads are distinguished as:

- fire loads from the occupancy, given by the classification;
- fire loads from the building fabric, (construction elements, linings and finishes, furnishings) which are generally not included in the classification.

Net calorific values

The net calorific values should be used.

For materials which, retain some moisture (kiln dried wood has 10% moisture) can be taken into account as follows:

$$H_u = H_{u0}(1 - 0.01u) - 0.025u \text{ (MJ/kg)} \qquad \text{...(E2)}$$

Where:

u is the moisture content expressed as percentage of dry weight.

H_{u0} is the net calorific value of dry materials.

The net calorific value of some solids and liquids are given in BS 7974: PD1. Additional information is also provided in the *SFPE Handbook of Fire Protection Engineering*[12].

Fire load classification of occupancies

The fire load densities can be classified according to occupancy, be related to floor area, and be used as characteristic fire load densities $q_{f,k}$ (MJ/m²). Although data is available in the Code, information given in BBS 7974: PD1 is more comprehensive as presented in Table 1.

The fire load densities given in Table 1 assumes perfect combustion, but in real fires, the heat of combustion is usually considerably less than 100%. They are valid for ordinary compartments in connection with the relevant occupancy. Special rooms are considered separately

Table 1 does not necessarily include fire loads contributed from the building (construction elements, fabric, linings and finishes) and therefore should be added to the characteristic values.

For additional information on occupancy related fire growth rates, combustion rates and heat release rates, reference is made to BS 7974: PD1.

Annex F – Equivalent time of fire exposure

The UK was unable to accept the contents of Annex E in their entirety and therefore alternative guidance has been prepared for application in the UK.

In recent years, various forms of equations have been developed on Time Equivalent and these have mostly originated from individual research programmes. Some are limited in their application to within the range of variables studied while others have a more fundamental justification.

The time equivalent relationship given in EC1-1-2, was first developed in DIN 18230, was later adopted in CIB W14 and then ENV1-2-2. It now is given by the following:

$$t_{e,d} = q_{f,d} \,.\, k_b \,.\, w_f \text{ or}$$

$$t_{e,d} = q_{t,d} \,.\, k_b \,.\, w_t \text{ (min)} \qquad \text{...(F1)}$$

Where:
$q_{f,d}$ is the design fire load density according to the UK guidance
k_b is the conversion factor according to (F2)
w_f is the ventilation factor according to (F4),
whereby $w_t = w_f \,.\, A_t/A_f$

In the Code a factor $K_c = 13.7 \times O$ (the opening factor), was introduced for unprotected steel. Analysis carried out based upon tests in the UK found a lack of correlation in this formulation and is therefore not accepted. However, from the analysis it was also clear that the use of unprotected steel in Time Equivalent calculations could only be acceptable for periods of fire resistance up to 60min.

The time equivalent method recognises the influence of the thermal properties of the walls, floor and ceiling materials on the temperatures attained during the fire, through the factor k_b.

In the Code, three values are given for k_b (0.04, 0.055, 0.07) as a function of thermal diffusivity $b = \sqrt{(\rho c \lambda)}$ which correspond to $b > 2500$, $720 \leq b \leq 2500$, $b < 720$ (min.m²/MJ). The Code also recommends default value of:

$$k_b = 0.07 \text{ (min.m}^2\text{/MJ) when } q_d \text{ is given in (MJ/m}^2\text{)} \qquad \text{...(F2)}$$

Analysis of UK data found that this could lead to unsafe results and could not be supported. Fig 7 illustrates the correlation between measured and calculated values of time equivalent based upon the National Annex to EC1-2-2 that was published in the 1990s (k_b = 0.055, 0.07, 0.09) and those currently recommended in EC1-1-2 (k_b = 0.04, 0.055, 0.07).

On a 1:1 correlation values given in Table 2 provide the most realistic and safe outputs in which a default value of 0.09 should be adopted where there is no further calculation.

Where multiple materials are used in the construction of the compartment, a law of mixtures approach may be adopted.

The ventilation factor w_f may be calculated as:

$$w_f = (6.0/H)^{0.3}[0.62+90(0.4-\alpha_v)^4/(1+b_v\alpha_h)] \geq 0.5 \qquad \text{...(F3)}$$

Where:
$\alpha_v = A_v/A_f$ is the area of vertical openings in the façade (A_v) related to the floor area of the compartment (A_t) where the limit $0.025 \leq a_v \leq 0.25$ should be observed.
$\alpha_h = A_h/A_f$ is the area of the horizontal openings in the roof (A_h) related to the floor area of the compartment (A_f).
$b_v = 12.5(1+10\alpha_v-\alpha_v^2) \geq 10.0$

Where:
H is the height of the compartment (m)

For small fire compartments ($A_f < 100\text{m}^2$) without openings in the roof, the factor w_f may also be calculated as:

$$w_f = O^{-1/2} A_f/A_t \qquad \text{...(F4)}$$

Where:
O is the opening factor according to Annex A

In any time equivalent analysis, due consideration should be given to the changes in ventilation during the fire, which can have a major influence on both the temperatures attained and the duration of heating. A sensitivity analysis should be conducted, or, a Monte Carlo statistical analysis carried out to identify the range of fire conditions that may exist.

It is stressed that the numerical outputs from the Time Equivalent calculations should not be used in isolation and should be considered only as part of an overall fire strategy for the building or structure in which the following should be addressed:

- The awareness of fire and the ability of the occupants to reach a place of safety.
- The influence of the size and height of the building or structure on the consequences of failure to life safety and neighbouring property.

Without any further consideration the BSI committee developed a set of factors that should be applied for each occupancy group and building height in situations where no further analysis is carried out.

ANNEX G – Configuration factor

Annex G provides a set of geometric relationships for determination of the heat transfer (radiation) from the fire to the structural element.

The information provided is standard textbook geometry. Although it was intended to primarily deal with the radiation from a fire within a building to externally placed structural members, the relationships can be used to quantify the heat transfer to members within a fire compartment where part of a members' profile creates a shadow effect and therefore receives a lower level of thermal radiation.

Conclusions

Eurocode 1-1-2 and the accompanying UK National Annex provides a significant advance in the application of fire safety engineering to the design of structural members in buildings. However, while it offers consistency in the design process throughout the EU it has to be recognised that through the development on the National Annexes for each member state, differences in the design outputs from one country to another will still exist in some aspects.

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