Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire

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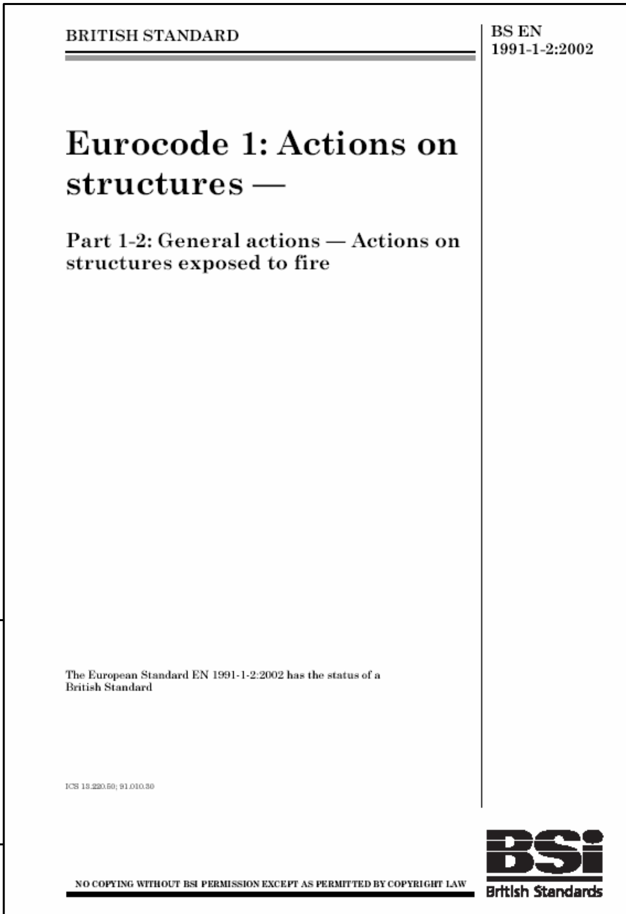
BRITISH STANDARD

BS EN 1991-1-2:2002

Eurocode 1: Actions on structures —

Part 1-2: General actions — Actions on structures exposed to fire

The European Standard EN 1991-1-2:2002 has the status of a British Standard

ICS 13.220.50; 91.010.30

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BSI British Standards

Scope of presentation

Introduction to structural fire engineering design

Section 3 **Thermal actions for temperature analysis**
- 3.2 **Nominal temperature-time curves**
- 3.3 **Natural fire models**

Section 4 **Mechanical actions for structural analysis**
- 4.2 **Simultaneity of actions**
- 4.3 **Combination rules for actions**

Annex A Parametric time-temperature curves
Annex B Thermal actions for external members
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

Worked example – Equivalent time of fire exposure

Why structural fire engineering?

What is structural fire engineering design?

How do we do it?

Structural fire engineering design – Do we need it?

Existing body of data

Tried and tested solutions

Accepted levels of safety and reliability

Tabulated data generally conservative

Structural fire engineering design – Do we need it? – YES!

Levels of safety unknown

Degree of conservatism unknown

No account of interaction between structural elements

No account of alternative load carrying mechanisms

No account of alternative modes of failure

Structural fire engineering design – Do we need it? – YES!

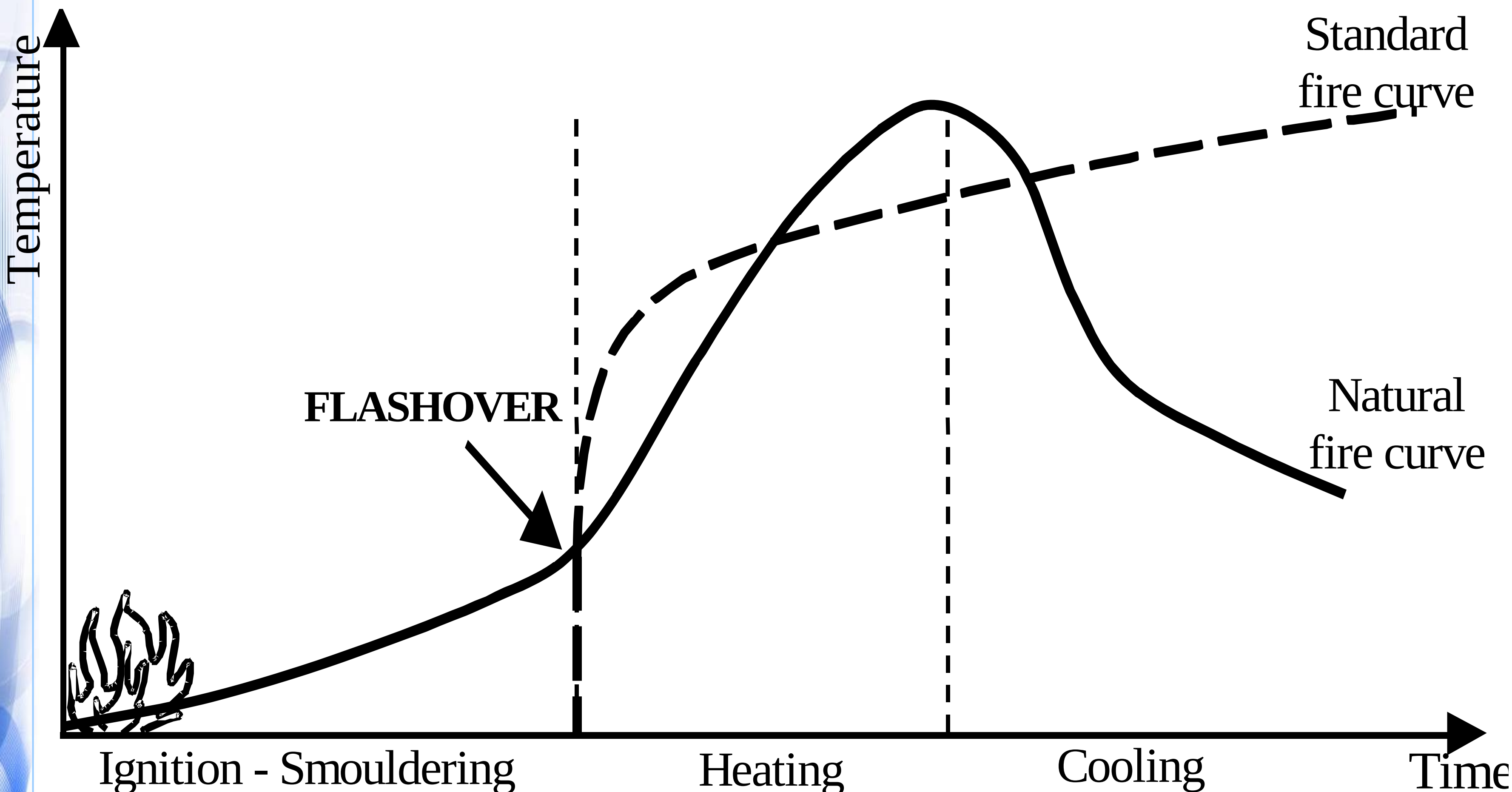
Complex structures not covered by existing regulatory requirement – "fire engineering may be the only suitable approach"

Provides for a more rational approach to the design of buildings for fire if undertaken as part of an overall fire safety strategy

Change of use or renovation of existing structure – possible increased fire resistance requirement, removal of existing means of ensuring fire resistance

Uncertainties in existing prescriptive approach

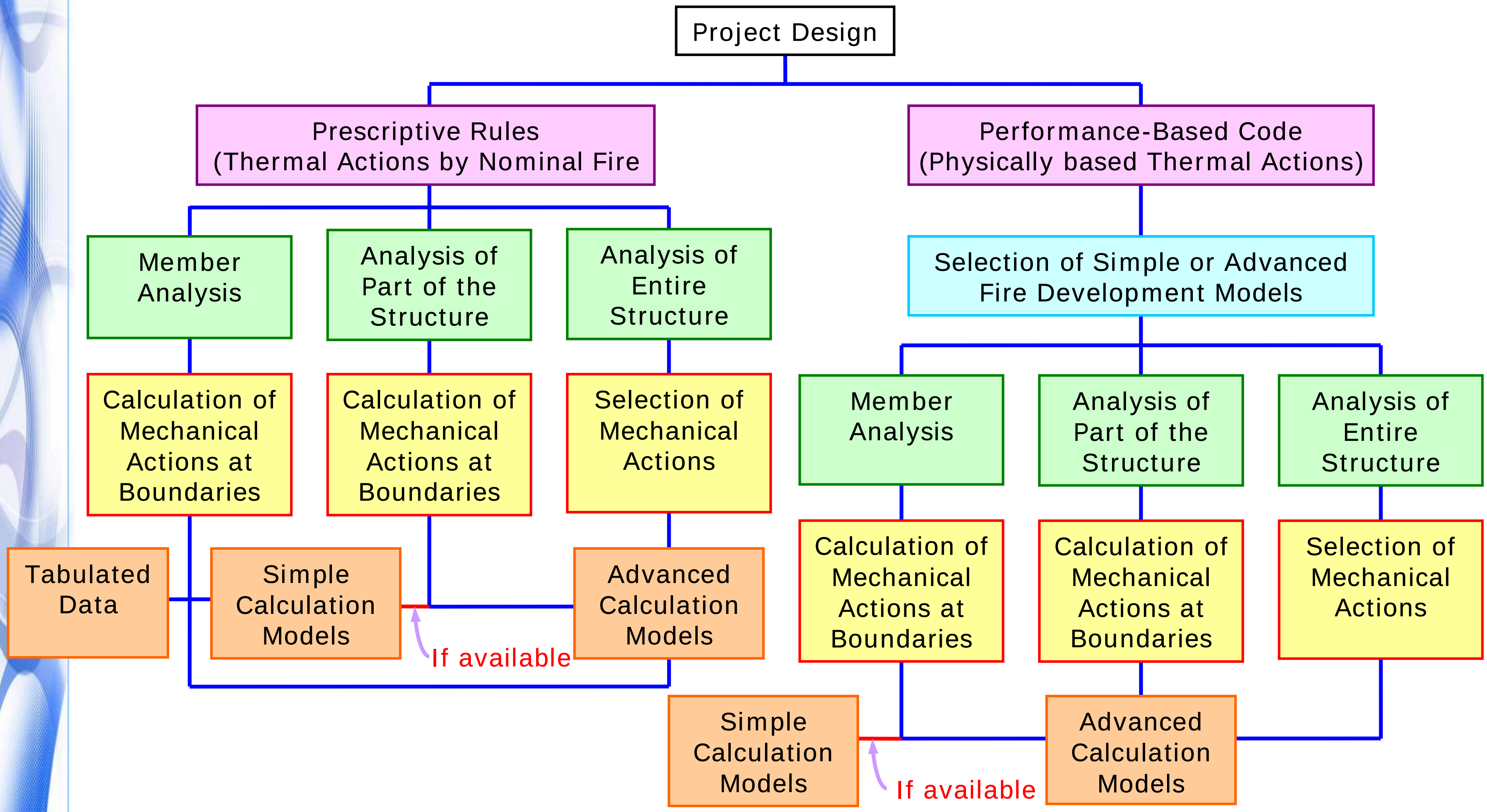
Structural fire engineering design – what is it?



Life safety

Structural damage – risk of collapse – structural fire engineering only concerned with this phase of the fire

General - Design Procedures



Structural fire design procedure

Structural fire design procedure takes into account:

Selection of relevant design fire scenarios

Determination of corresponding design fires

Calculation of temperature within the structural members

Calculation of mechanical behaviour of the structure exposed to fire

EN1991-1-2 is principally concerned with the first two above. Fire parts of the material codes cover the remaining two.

Consider relevant design fire scenario

Building fire **/ tunnel fire / petrochemical fire**

Localised fire / fully developed fire

Identification of suitable compartment size/occupancy/ventilation condition for subsequent analysis – representative of “reasonable worst case scenario”

The choice of the design fire scenario will dictate the choice of the design fire to be used in subsequent analysis.

The choice of a particular fire design scenario should be based on a risk assessment taking into account the likely ignition sources and any fire detection/suppression systems available.

Choose appropriate design fire

For fully developed post-flashover building (compartment) fires the usual choice is between nominal and natural fire exposures

Nominal fires are representative fires for the purposes of classification and comparison but bear no relationship to the specific characteristics (fire load, thermal properties of compartment linings, ventilation condition) of the building considered

Natural fires are calculation techniques based on a consideration of the physical parameters specific to a particular building.

Modelling compartment fires

In compartment fires it is often assumed that the whole compartment is fully involved in the fire at the same time and the same temperature applies throughout. Such a scenario is the basis of a one zone model.

Two zone models exist in which the height of the compartment is separated into two gaseous layers each with their own thermal environment

Three zone models exist in which there is a mixed gas layer separating the upper and lower gas levels

Computational Fluid Dynamics (CFD) may be used to analyse fires in which there are no definite boundaries to the gaseous state. This type of analysis would be suitable for very large compartments such as airport terminals, atria and sports stadia. It is often used to model smoke movement.

Post-Flashover Fire Models

In a compartment flashover occurs when sustained flaming from combustibles reach the ceiling and the temperature of the hot gas layer is between 550°C and 600°C.

After flashover the rate of heat release will increase rapidly until it reaches a maximum value for the enclosure. To simplify design, the growth period between the onset of flashover and the maximum heat release rate is usually ignored and it may be assumed that when flashover occurs the rate of heat release instantaneously increases to the maximum value set by the available air.

Thermal actions are given by the net heat flux:

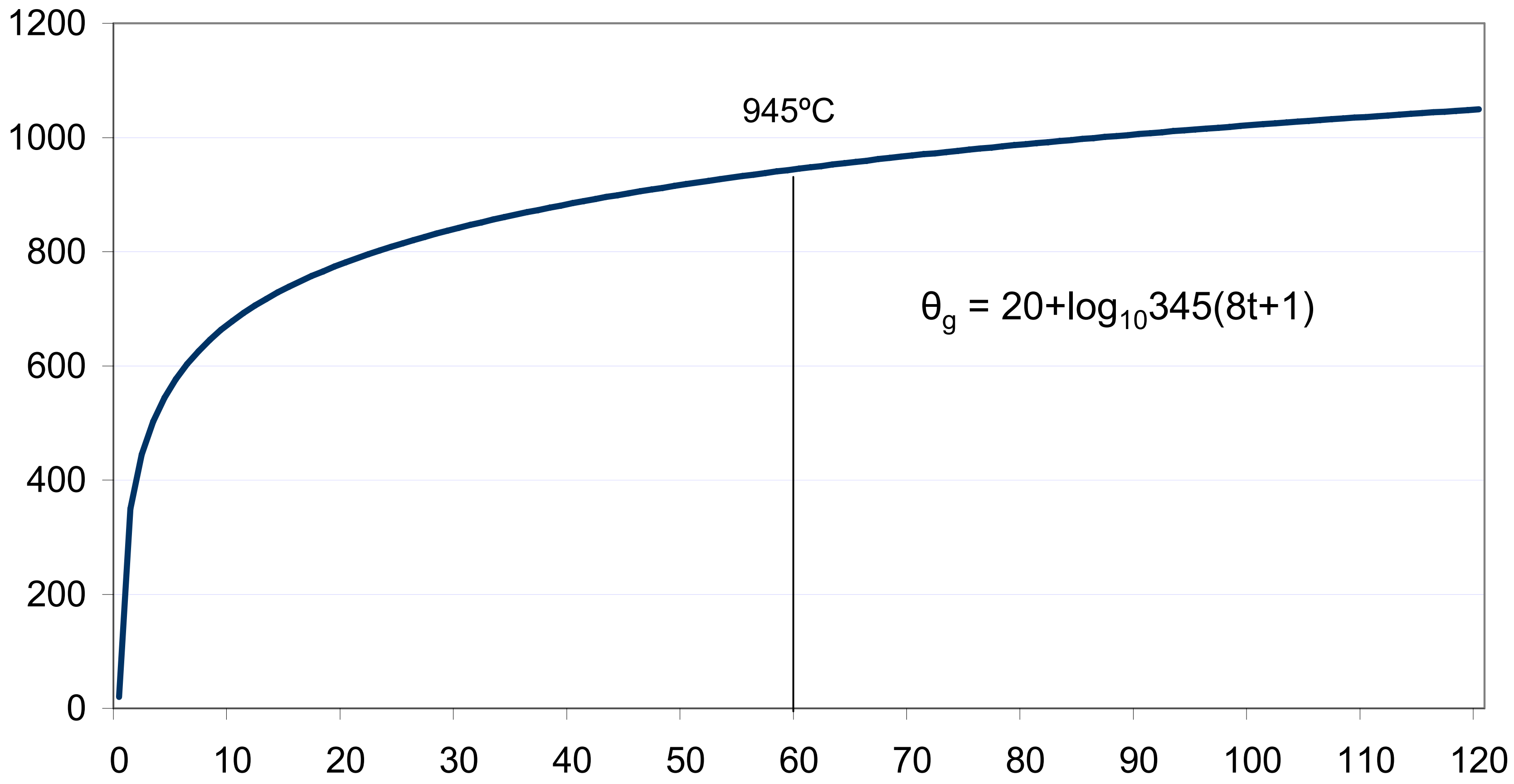
$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r}$$

Convective heat flux

Radiative heat flux

2.2 Nominal temperature-time curves

Standard temperature-time curve



Nominal fire curves

Other nominal curves include:
Smouldering fire curve

"Semi-Natural" fire curve

External fire exposure curve*

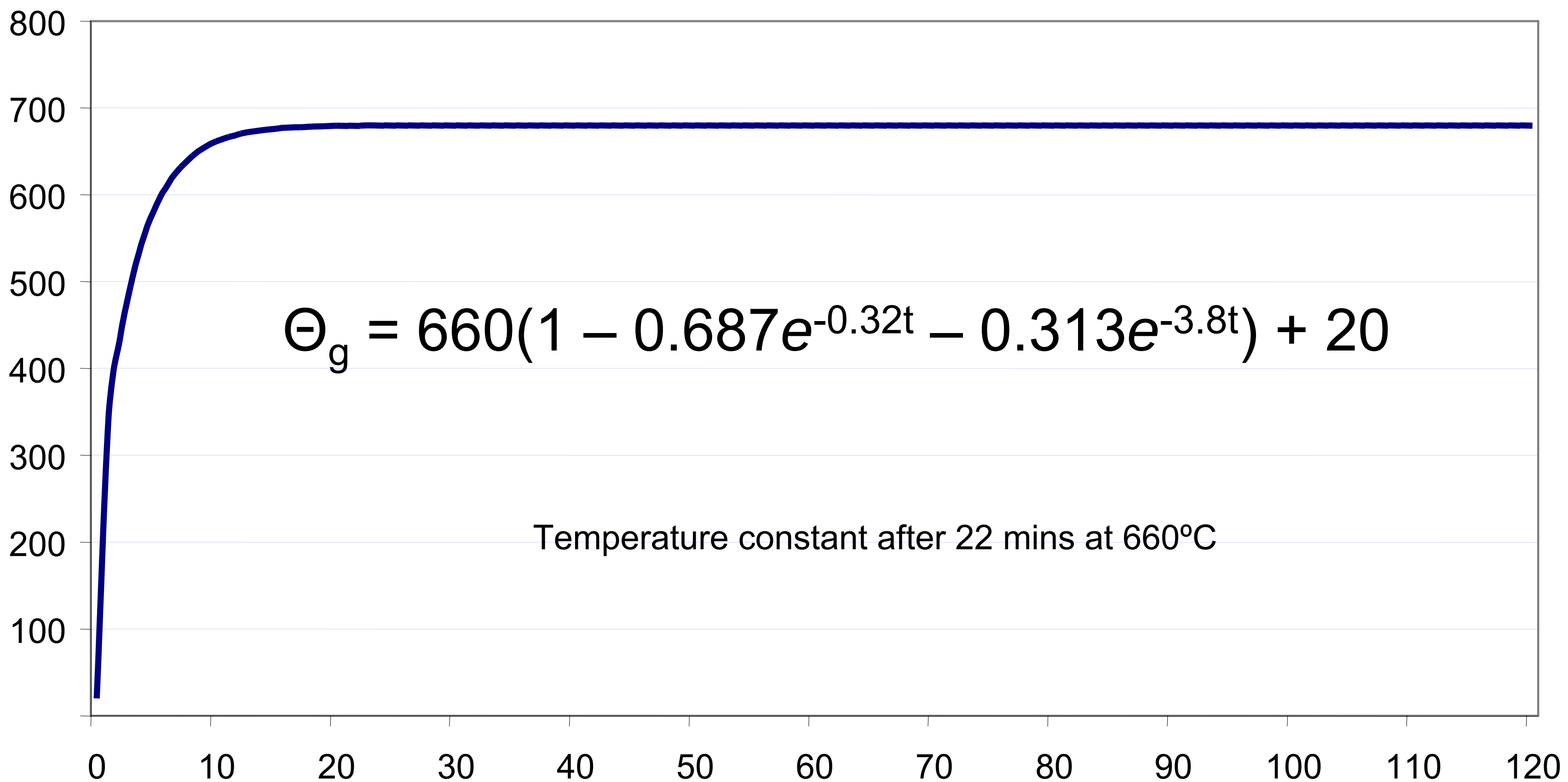
Hydrocarbon curve*

Modified hydrocarbon curve

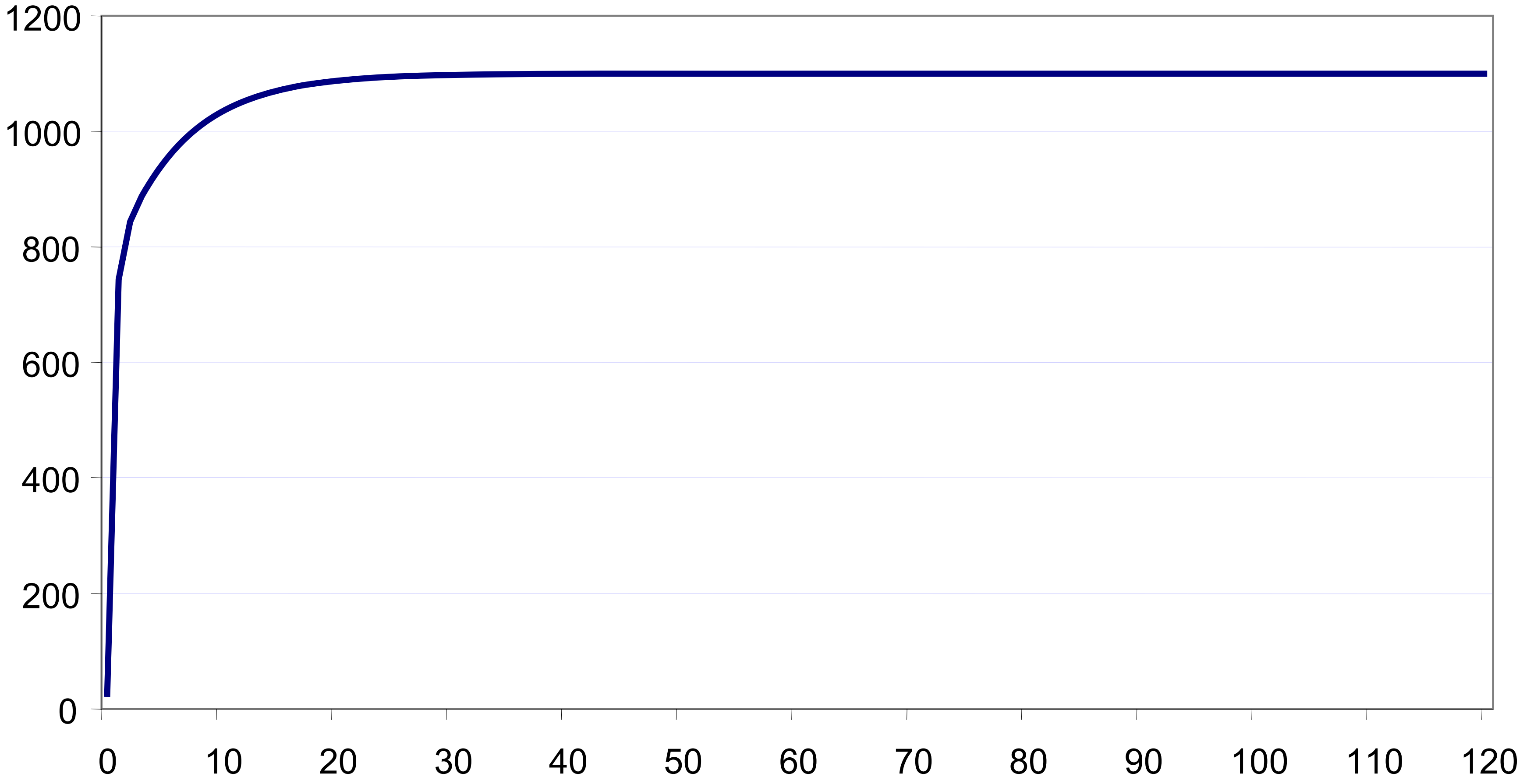
Tunnel lining curves – RWS/RABT

*** Included in the Eurocode**

External fire temperature-time curve



Hydrocarbon temperature-time curve



2.3 Natural fire models

Natural fire models are based on specific physical parameters with a limited field of application

For compartment fires a uniform temperature distribution as a function of time is generally assumed

For localised fires a non-uniform temperature distribution as a function of time is assumed

Natural fire models

Simplified fire models – compartment fires

Any appropriate fire model may be used considering at least the fire load density and the ventilation conditions

The parametric approach in Annex A of the code is one example of a simplified natural fire model

Simplified fire models – external members

For external members the radiative heat flux should be calculated from the sum of the radiation from the compartment and from the flames emerging from the opening

An example of a simplified calculation method for external members is given in Annex B of the Code

Simplified fire models – localised fires

In many cases flashover is unlikely to occur. In such cases a localised fire should be considered.

Annex C presents an example of a procedure for calculating temperatures in the event of a localised fire

If they are likely to occur during a fire the same actions assumed for normal design should be considered.

Indirect actions can occur due to constrained expansion and deformation caused by temperature changes within the structure caused by the fire.

INDIRECT thermal actions should be considered. EXCEPT where the resulting actions are:

recognized *a priori* to be negligible or favourable.

accounted for by conservatively chosen models and boundary conditions or implicitly considered by conservatively specified fire safety requirements.

The indirect actions should be determined using the thermal and mechanical properties given in the fire parts of EN1992 to EN1996 and EN1999.

For member design subjected to the standard fire only indirect actions arising from the thermal distribution through the cross-section needs to be considered.

Section 4 Mechanical actions for structural analysis

Actions considered for ‘normal’ design should also be considered for fire design if they are likely to act at the time of a possible fire.

Variable actions should be defined for the accidental design situation, with associated partial load factors, as given in EN1990.

Simultaneous action with other independent accidental actions does not need to be considered

Additional actions (i.e partial collapse) may need to be considered during the fire exposure

Fire walls may be required to resist horizontal impact loading according to EN1363-2

When indirect actions do not need to be considered, and there is no prestressing force, the total design action (load) considering permanent and the leading variable action is given by;

$$\sum_{j\geq 1} G_{k,j} \text{ "+" } \left(\psi_{1,1}\, or\, \psi_{2,1}\right) Q_{k,1}$$

The use of $\psi 1,1$ or $\psi 2,1$ is defined in the National Annex

The values of $\psi 1,1$ and $\psi 2,1$ are given in Annex A of EN1990:2002

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1-1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category F : traffic area, vehicle weight ≤ 30kN	0,7	0,7	0,6
Category G : traffic area, 30kN < vehicle weight ≤ 160kN	0,7	0,5	0,3
Category H : roofs	0	0	0
Snow loads on buildings (see EN 1991-1-3)*			
Finland, Iceland, Norway, Sweden	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H > 1000 m a.s.l.	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H ≤ 1000 m a.s.l.	0,50	0,20	0
Wind loads on buildings (see EN 1991-1-4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0
NOTE The ψ values may be set by the National annex. * For countries not mentioned below, see relevant local conditions.			

Mechanical actions for structural analysis

As a simplification, the effect of actions in the fire condition can be determined from those used in normal temperature design

$$E_{fi,d,t} = E_{fi,d} = \eta_{fi} E_d$$

Where

$$\eta_{fi} = \frac{E_{fi,d,t}}{R_d}$$

EN 1991-1-2 Annex A- Parametric Equation

$$\theta_g = 1325(1-0.324e^{-0.2t^*}-0.204e^{-1.7t^*}-0.472e^{-19t^*})$$

where $t^* = t.\Gamma$

and $\Gamma = (O/b)^2/(0.04/1160)^2$

O is the opening factor

and b relates to the thermal inertia $\sqrt{(\rho c \lambda)}$

Where ρ = density (kg/m^3)

c = specific heat (J/kgK)

Λ = thermal conductivity (W/mK)

Parametric equation (contd)

O = opening factor $A_v\sqrt{h}/A_t$ ($m^{1/2}$)

A_v = area of vertical openings (m^2)

h = height of vertical openings (m)

A_t = total area of enclosure – walls, ceiling and floor including openings (m^2)

Parametric Equation

Scope of Equation

- $0.02 \leq O \leq 0.2$ ($m^{½}$) (lower limit of 0.01 in UK NA)
- $100 \leq b \leq 2000$ ($J/m^2 s^{½}$ °K)
- $A_f \leq 500m^2$ (No restriction in UK NA)

- mainly cellulosic fire loads
- maximum compartment height = 4m (No restriction in UK NA)
- concept of limiting duration (20 minutes for offices)

EC1 Parametric exposure

Cooling phase

$\Theta_g = \theta_{max} - 625(t^* - t^*_{max}.x)$ for $t^*_{max} \leq 0.5$

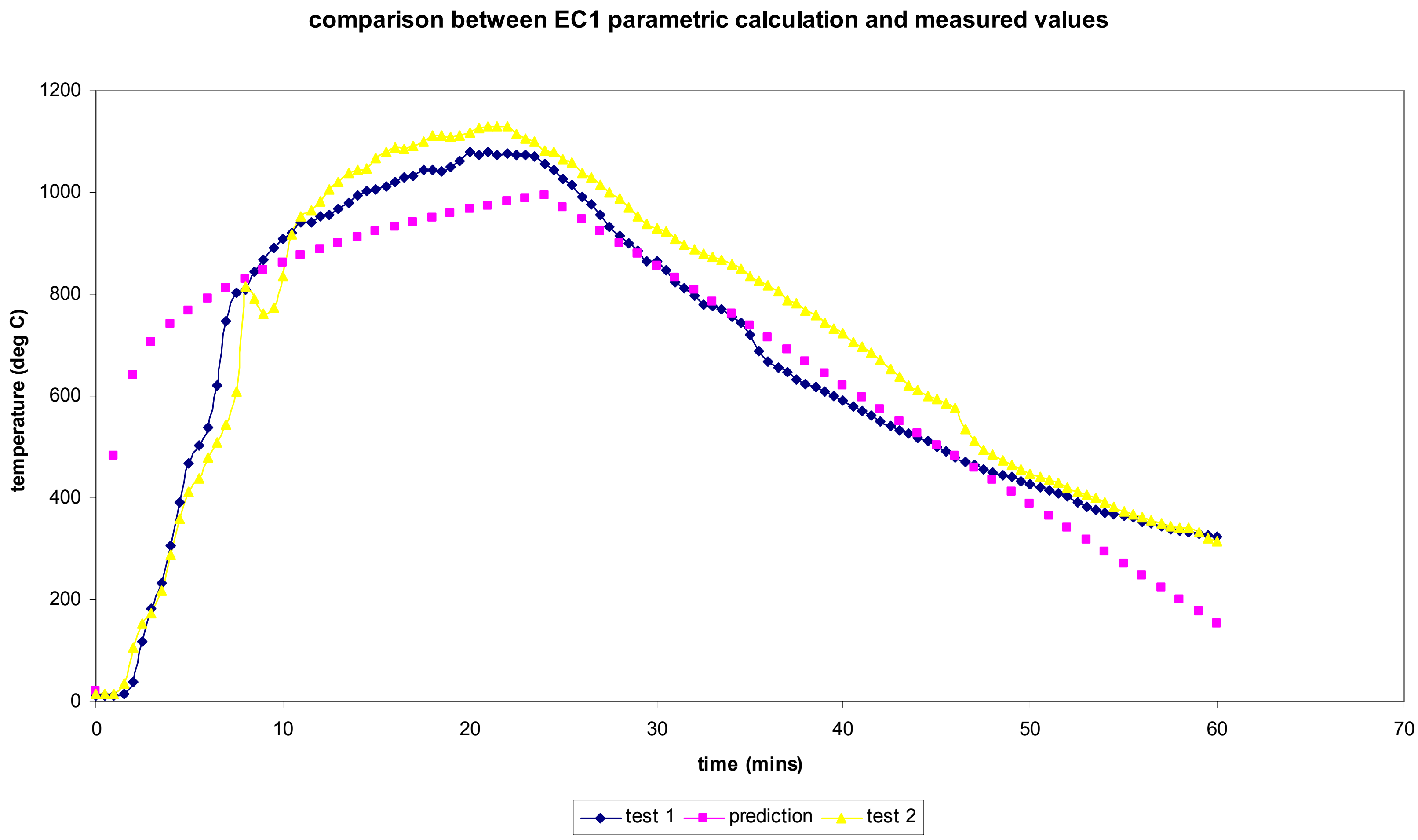
$\Theta_g = \theta_{max} - 250(3 - t^*_{max})(t^* - t^*_{max}.x)$ for $t^*_{max} < 2$

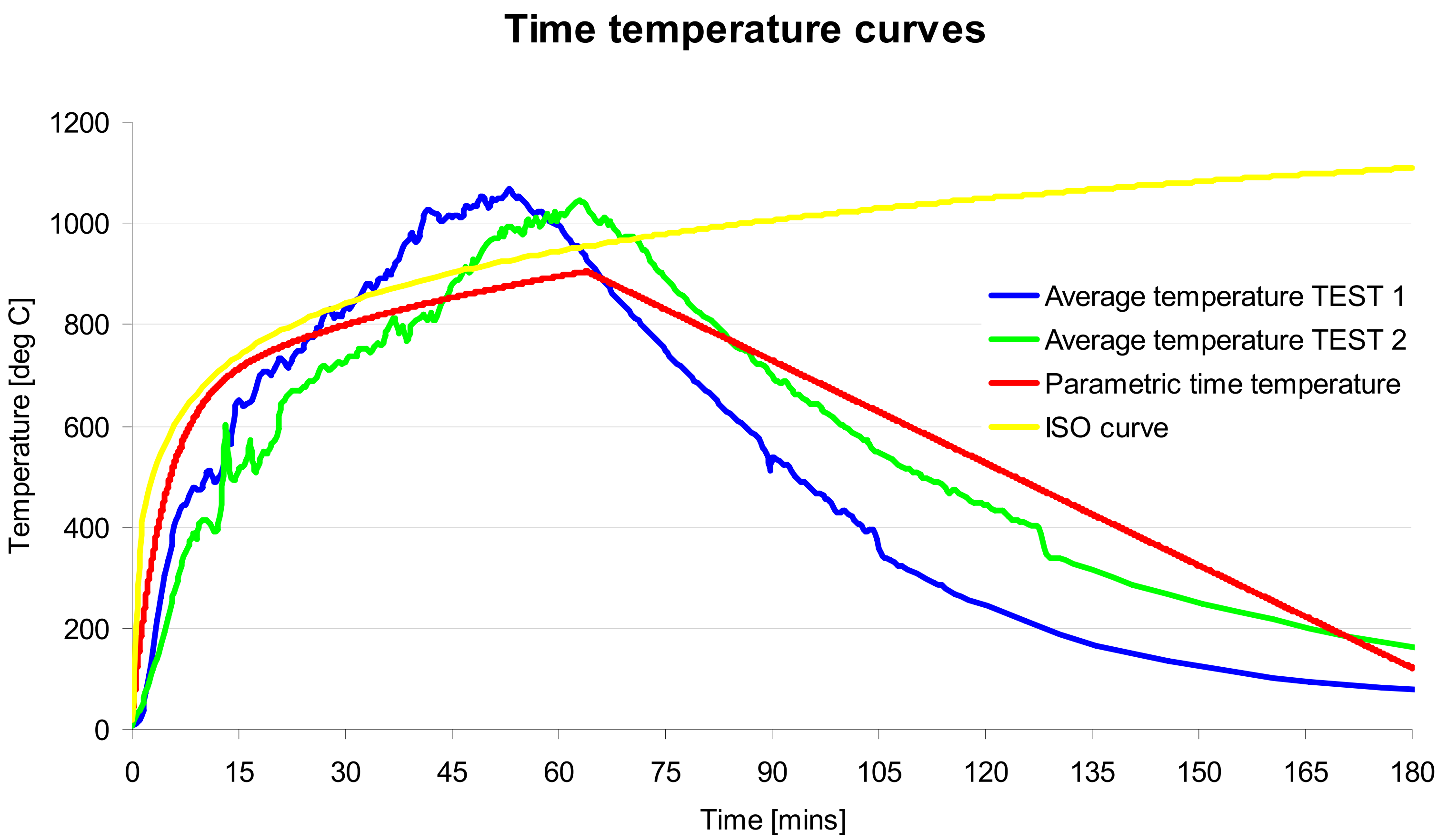
$\Theta_g = \theta_{max} - 250(t^* - t^*_{max}.x)$ for $t^*_{max} \geq 2$

Where $t^*_{max} = (0.2x10^{-3}.\ q_{t,d}/O).\Gamma$

And t_{max} = maximum of $(0.2x10^{-3}.\ q_{t,d}/O)$ and t_{lim}

With t_{lim} = 25 minutes for slow fire growth rate,
20 minutes for medium fire growth rate and
15 minutes for fast fire growth rate


comparison between EC1 parametric calculation and measured values
temperature (deg C)
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
time (mins)
test 1
prediction
test 2


Time temperature curves
1200
1000
800
600
400
200
0
Temperature [deg C]
0
15
30
45
60
75
90
105
120
135
150
165
180
Time [mins]
Average temperature TEST 1
Average temperature TEST 2
Parametric time temperature
ISO curve

Annex B Thermal actions for external members – Simplified calculation method

Allows for the determination of:

Maximum temperatures of a compartment fire

The size and temperatures of the flames emerging from the openings

Radiation and convection parameters

Takes into account effect of wind through inclusion of forced draught and no forced draught calculations

Annex C Localised fires

Where a fully developed fire is not possible the thermal input from a localised fire source to the structural member should be considered.

Annex C provides one possible method – The UK NA specifies an alternative methodology based on existing National information

Annex D Advanced Fire Models

Annex D sets out general principles associated with advanced fire models (One zone, two zone or CFD)

There is no detailed guidance and such methods should only be used by experts

Annex E Fire load densities

Annex E presents a method for calculating design fire load densities based on characteristic values from survey data for different occupancies

The characteristic values are modified according to the risk of fire initiation and the consequence of failure related to occupancy and compartment floor area

Active fire safety measures are taken into account through a reduction in the design fire load density

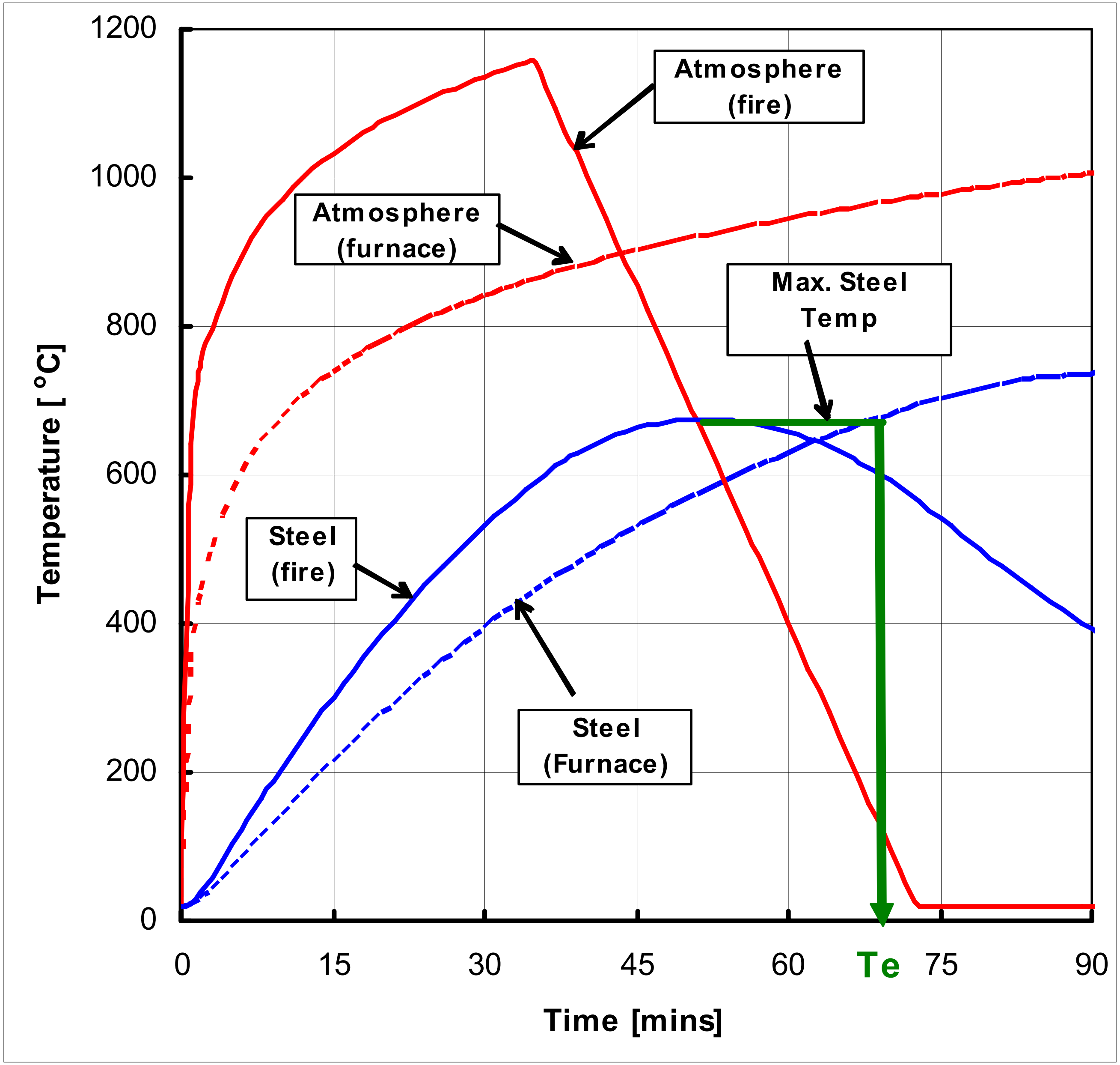
This approach is not accepted in the UK NA

Annex F Equivalent time of fire exposure

Provides a quick and easy method of relating a real fire exposure to an equivalent period in a standard fire resistance furnace

Mainly based on work on protected steel specimens

Recent analysis extended the use of the concept to unprotected steel for low fire resistance periods


Atmosphere
(fire)
Atmosphere
(furnace)
Max. Steel
Temp
Steel
(fire)
Steel
(Furnace)
Temperature [°C]
Time [mins]
Te
1200
1000
800
600
400
200
0
0
15
30
45
60
75
90

Time equivalent – calculation methods

CIB W14: $t_e = q_f\ c\ w$

Law: $t_e = kL/\sqrt{(A_v A_t)}$

Pettersson: $t_e = 0.067 q_f (A_v \sqrt{h}/A_t)^{-½}$

EC1: $t_{e,d} = q_{f,d}\ k_b\ w_f$

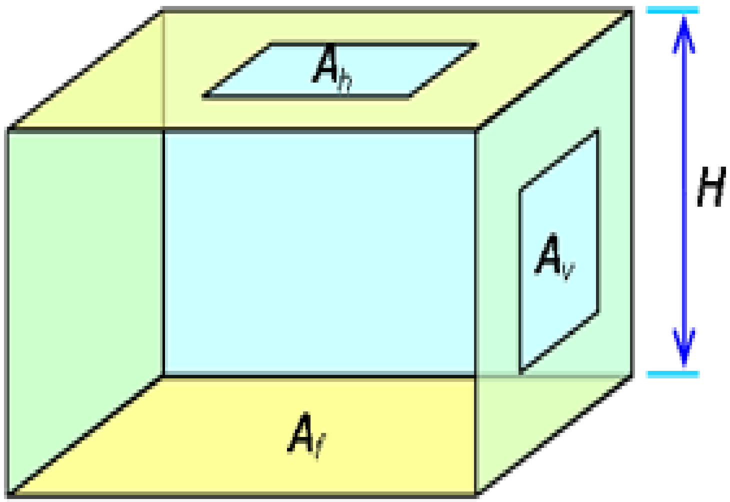
Where $q_{f,d}$ = design fire load density

k_b = factor to take into account the thermal properties of the enclosure

w_f = ventilation factor to take into account vertical and horizontal openings

Time equivalent – what is it? How does it work? How do you do it?

Worked example – fire compartment within an office building Geometric data



Floor area (m²)	36 (6m x 6m)
Ventilation area A_v (m²)	7.2 (3.6m wide by 2m high)
Height of ventilation opening h (m)	2
Height of compartment H (m)	3.6
Area of horizontal opening (roof light) A_h	0

Time equivalent – thermal properties

Element	Material	Thermal inertia (b value – $J/m^2s^{1/2}K$)	Area (m^2)
Roof	Concrete	2280	36
Floor	Plasterboard	520	36
Walls	Plasterboard	520	76.8

Time equivalent worked example

$te,d = (q_{f,d}.k_b.w_f)k_c$

Where $q_{f,d}$ = design fire load density (MJ/m²)

k_b is a factor dependent on thermal properties of the lining materials
And w_f is a ventilation factor given by:

$w_f = (6/H)^{0.3} [0.62 + 90(0.4-\alpha_v)^4]$ in the absence of vertical openings
Where H is the height of the compartment (m) and
$\alpha_v = A_v/A_f$

k_c = factor dependent on material = 1.0 for protected steel

Time equivalent worked example

$b = (\rho c \lambda)^{1/2}$ ($J/m^2 s^{1/2} K$)	k_b ($min.m^2/MJ$)
$b > 2500$	0.04 (0.055)
$720 \leq b \leq 2500$	0.055 (0.07)
$b < 720$	0.07 (0.09)

Time equivalent worked example

Occupancy	Characteristic fire load density (MJ/m²) 80% fractile
Dwelling	948 (400)
Hospital	280 (350)
Hotel	377 (400)
Office	511 (570)
School classroom	347 (360)

Time equivalent worked example

$q_{f,d}$ = 570 MJ/m²

w_f = 0.863 (α_v = 0.2)

k_b = 0.07 (b = 945 ($\Sigma(b_j A_j / A_j)$))

k_c = 1.0 (protected steel beam)

$t_{e,d}$ = 570 x 0.863 x 0.07 = 34 minutes therefore 60 minutes fire protection would be appropriate

Time equivalent – important questions to ask

Have sensitivity studies been carried out on % glazing removed during the fire. Breaking of glass during a fire is very difficult to predict. In reality the ventilation area will vary with time during the fire process.

What value has been used for the fire load density

What confidence is there in the final configuration of the compartment linings? In the absence of definite data then a figure of $k_b = 0.09$ should be used (UK National Annex)

Annex G Configuration Factor

Text book information on general principles for radiative heat transfer

Specific guidance for external members

Thank you for your attention!