



DIFHISEK

PART 1
THERMAL & MECHANICAL ACTIONS

Background of the H2020 Project DIFISEK+

ArcelorMittal

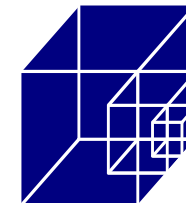
This project is funded by the European Commission in the frame of the “Research Fund for Coal and Steel”

The aim of DIFISEK+ is to promote different projects of the last decades that dealt with fire engineering and, which results have been implemented in the EN 1991-1-2.

This objective will be reached trough seminars held in different European countries.

The partnership of

**University of Hannover
Institute for Steel Construction**



Treated Topics

Part 1: Thermal & Mechanical Actions

Part 2: Thermal Response

Part 3: Mechanical Response of Structures in Fire

Part 4: Software for Fire Design

Part 5a: Worked Examples

Part 5b: Illustration of Completed Projects

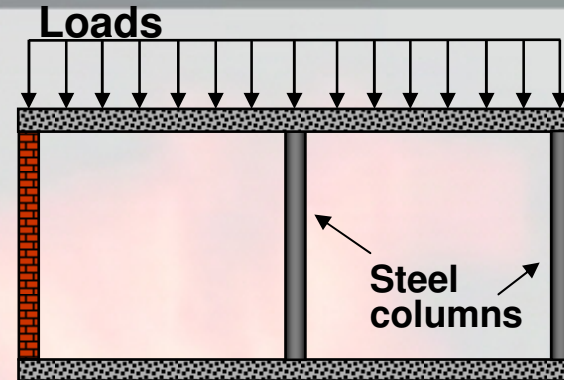
Resistance to Fire - Chain of Events



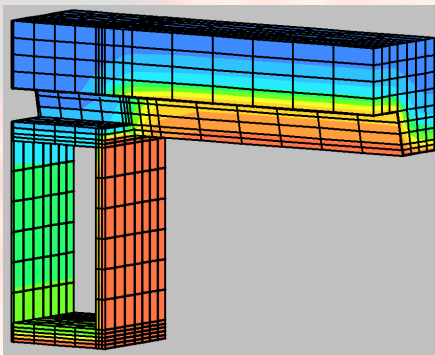
1: Ignition



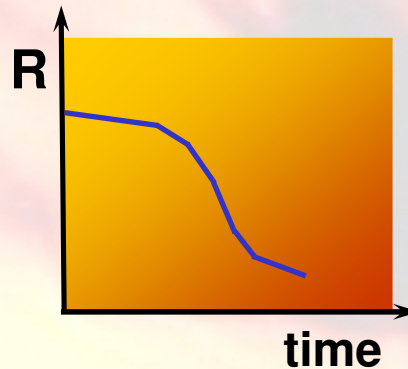
2: Thermal action



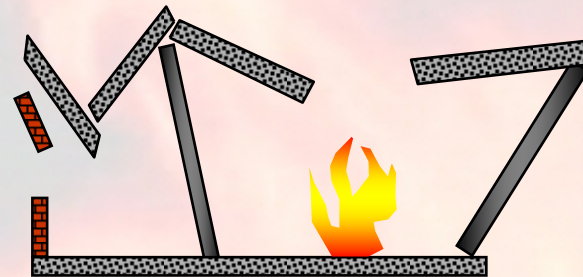
3: Mechanical actions



4: Thermal response

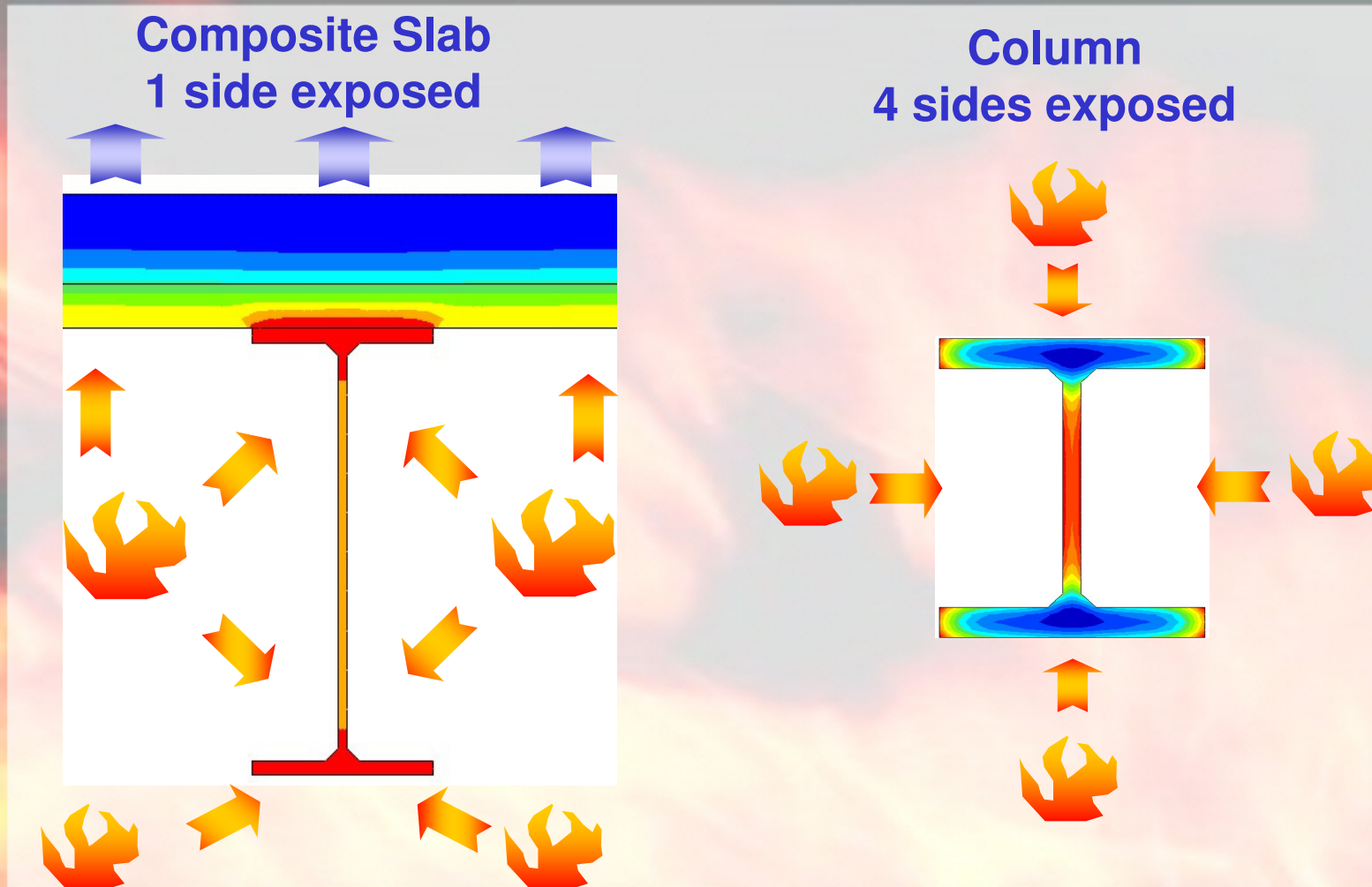


5: Mechanical response



6: Possible collapse

Thermal action on structure



Heat transfer at surface of building elements

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

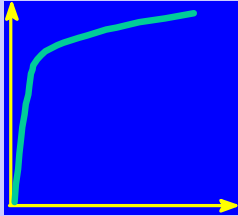
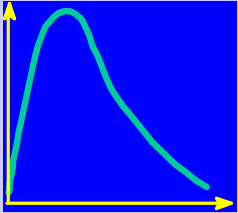

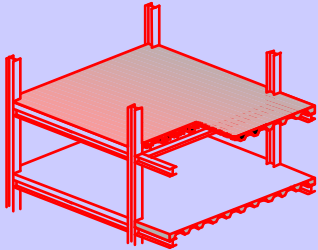
Net Radiative Heat Flux

Net Convective Heat Flux

Total net Heat Flux

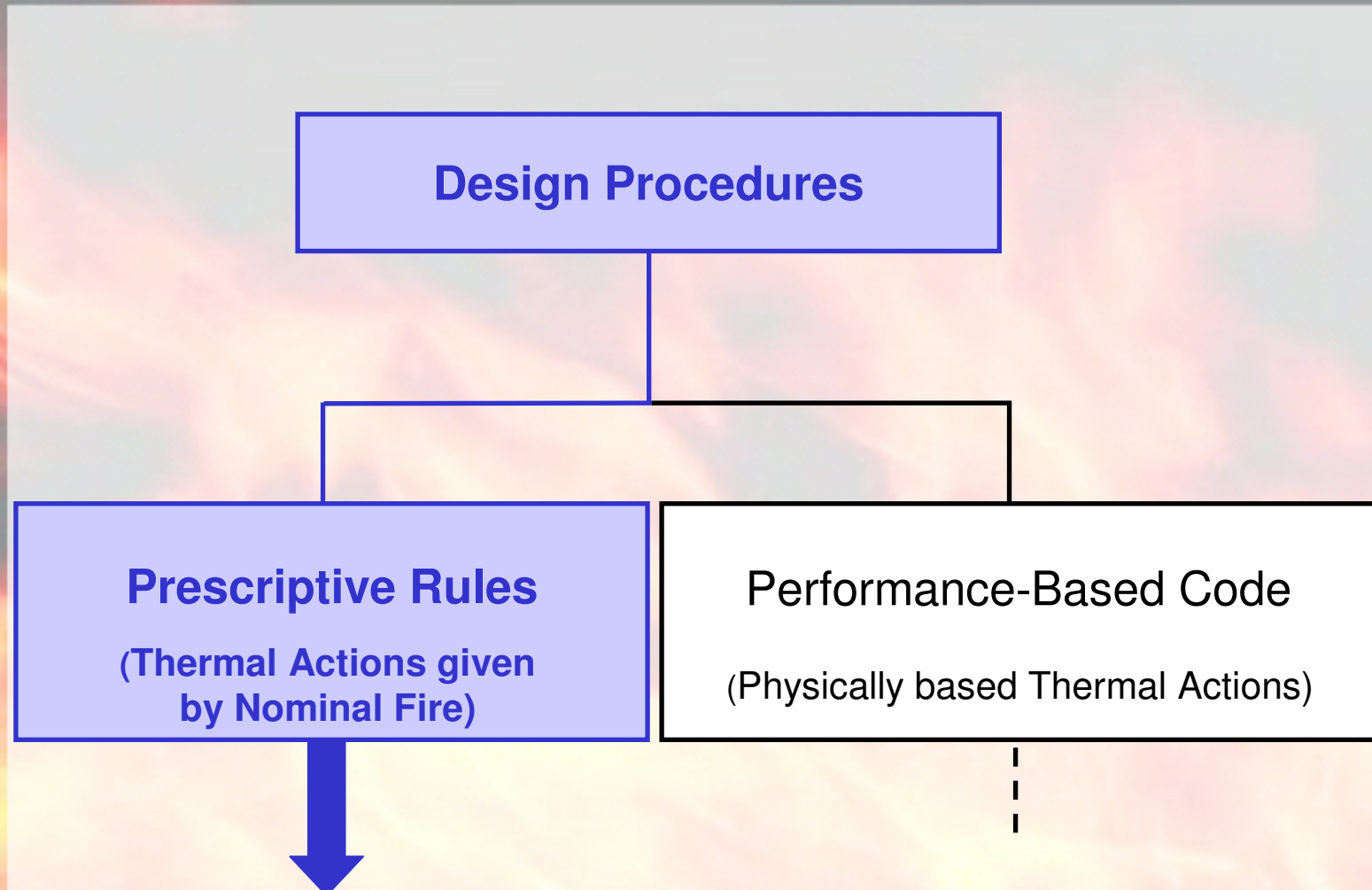
- Exposed side
- Non-exposed side

Structural Fire Safety Engineering vs. Classification

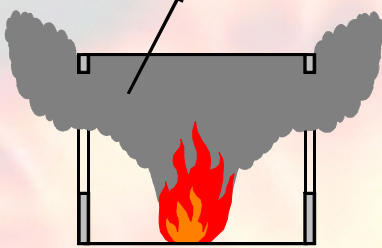
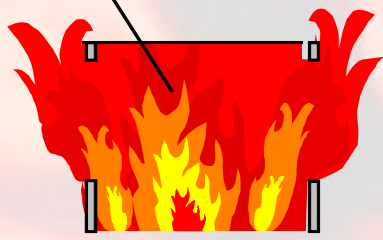
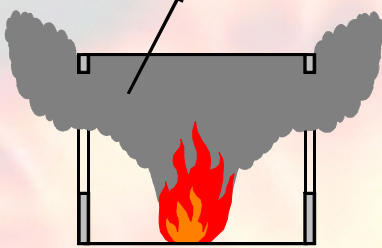
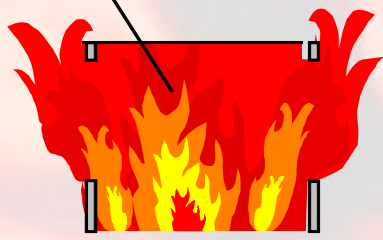
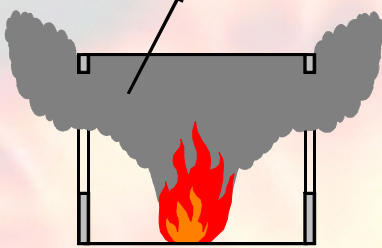
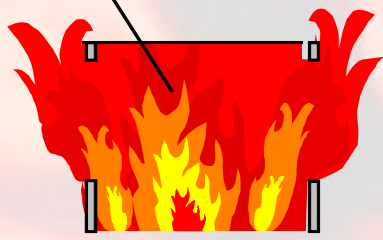
	Prescriptive	Performance based
	standard fire 	natural fire 
	classification	fire safety eng.
	fire safety eng.	fire safety eng.

Actions on Structures Exposed to Fire

EN 1991-1-2 - Prescriptive Rules

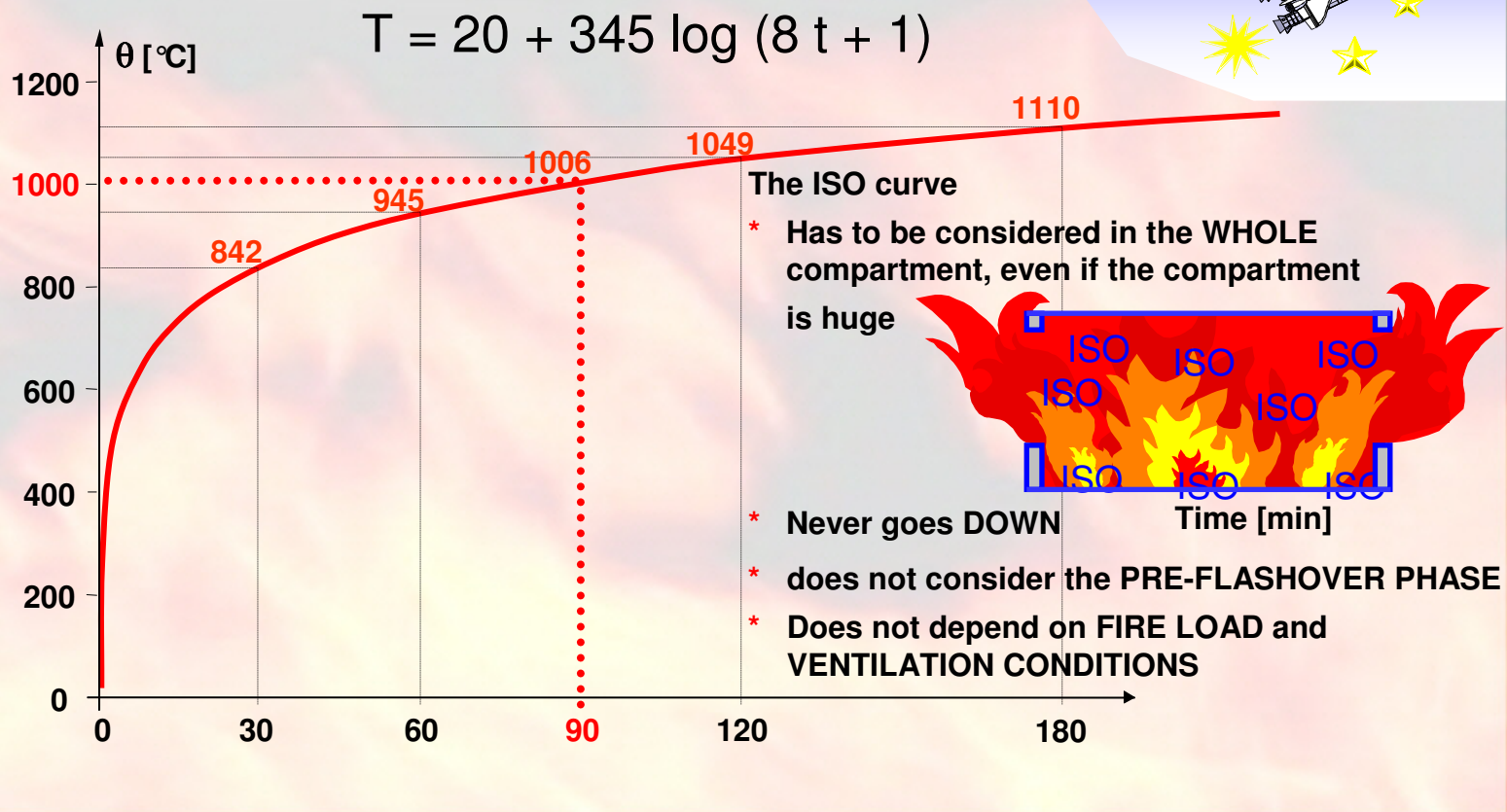


Nominal Temperature-Time Curve

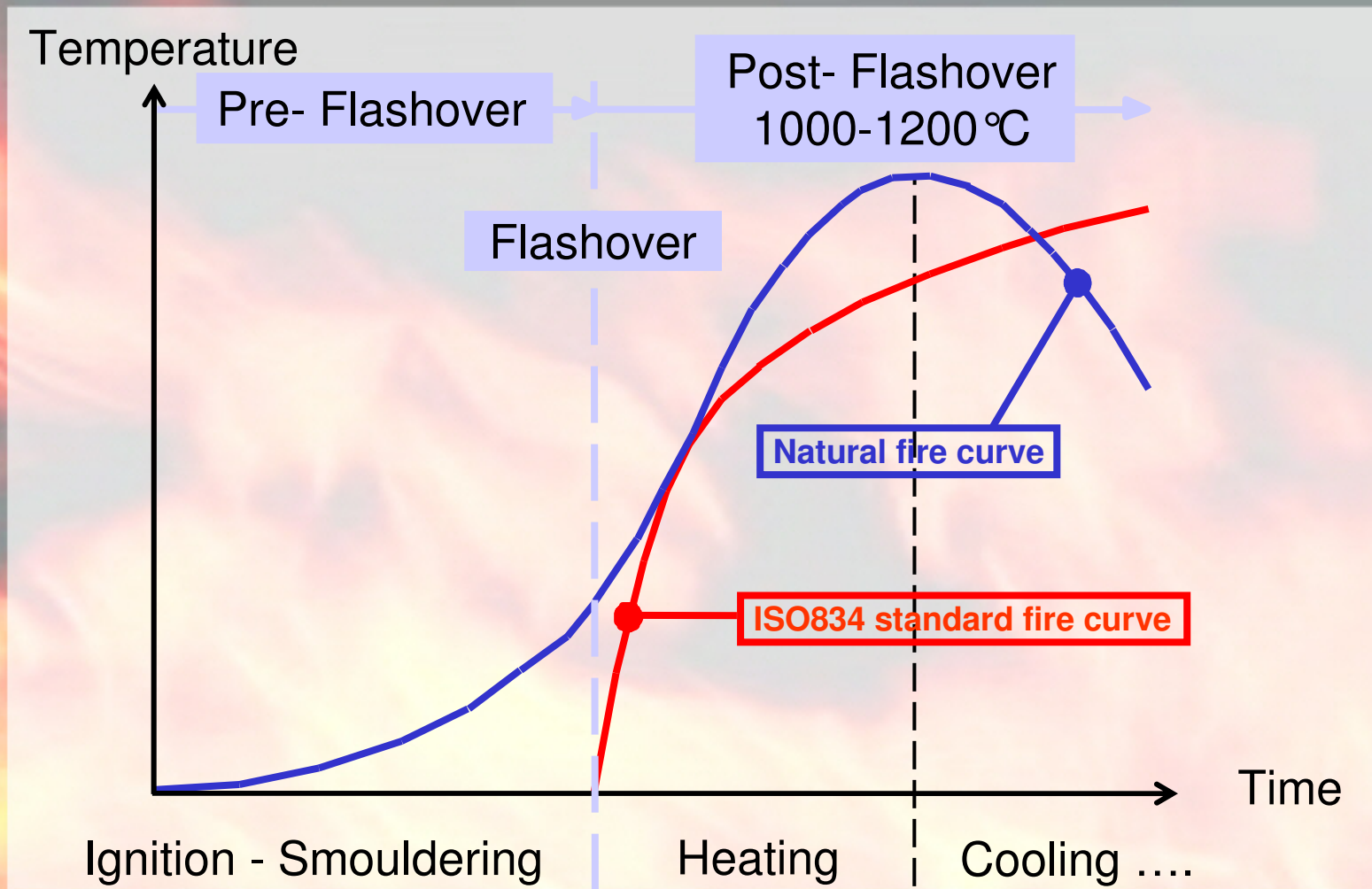
<p>*) Nominal temperature-time curve Standard temperature-, External fire - & Hydrocarbon fire curve</p>		<p>No data needed</p>		
<p>*) Simplified Fire Models</p> <table border="1"> <tr> <td> <p>Localised Fire</p> <ul style="list-style-type: none"> - HESKESTADT - HASEMI <p>$\theta(x, y, z, t)$</p>  </td> <td> <p>Fully Engulfed Compartment</p> <ul style="list-style-type: none"> - Parametric Fire <p>$\theta(t)$ uniform in the compartment</p>  </td> </tr> </table>		<p>Localised Fire</p> <ul style="list-style-type: none"> - HESKESTADT - HASEMI <p>$\theta(x, y, z, t)$</p> 	<p>Fully Engulfed Compartment</p> <ul style="list-style-type: none"> - Parametric Fire <p>$\theta(t)$ uniform in the compartment</p> 	<p>Rate of heat release Fire surface Boundary properties Opening area Ceiling height</p>
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Prescriptive Fire Regulations Defining ISO Curve Requirements

ISO-834 Curve (EN1364 -1)



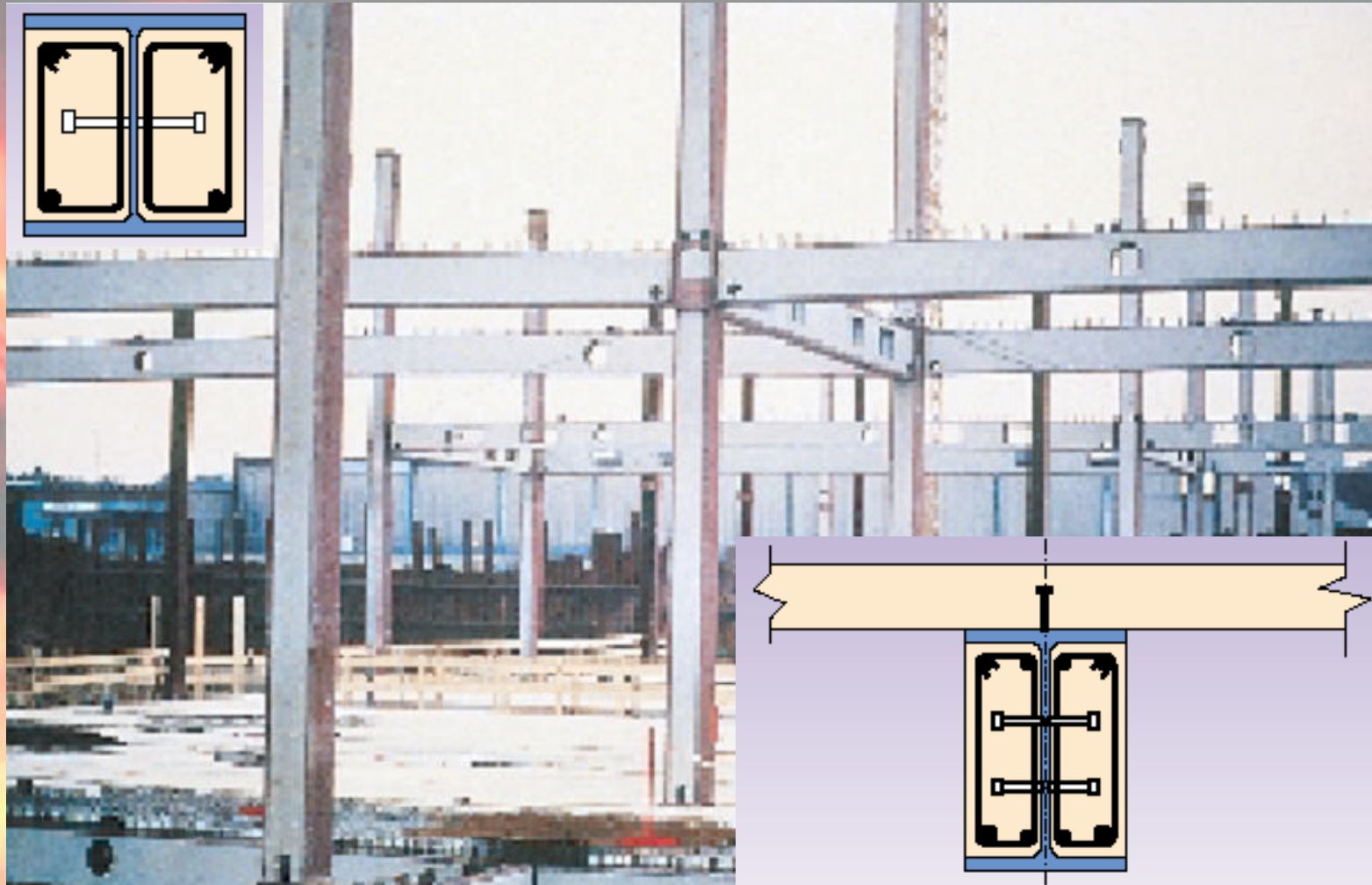
Stages of a Natural Fire and the Standard Fire Curve



Sprayed Protection

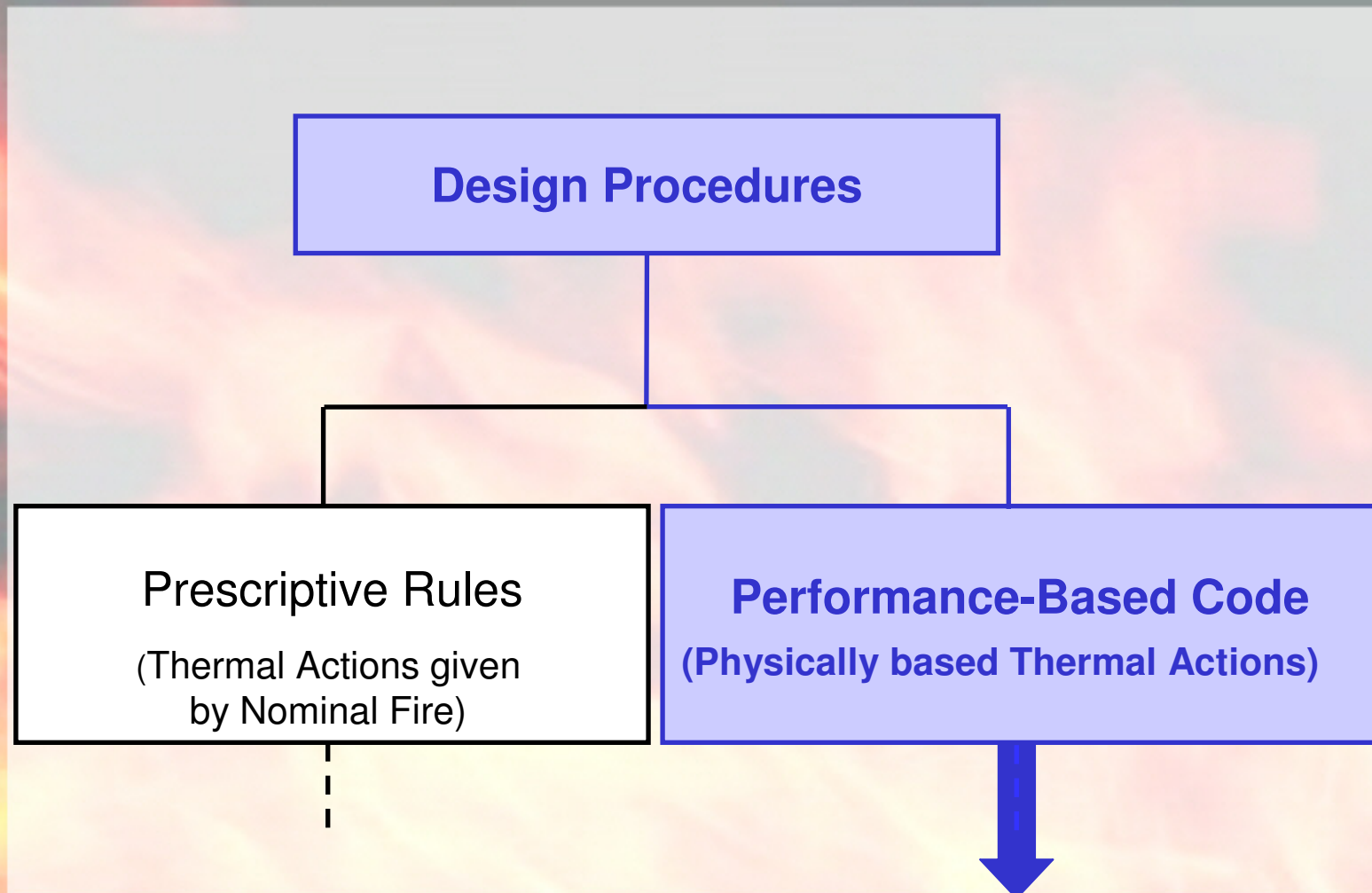


Partially Encased Beams & Columns

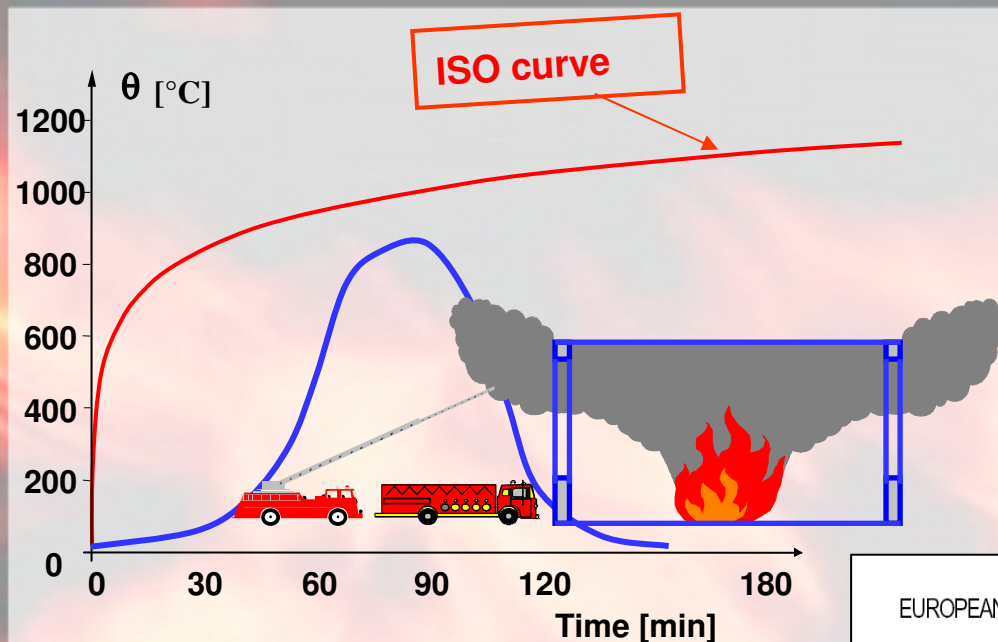


Actions on Structures Exposed to Fire

EN 1991-1-2 - Performance Based Code



Natural Fire Safety Concept



Implemented in:

- EN 1991-1-2
- Some National Fire Regulations include now alternative requirements based on Natural Fire

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1991-1-2



November 2002

ICS 13.220.50; 91.010.30

English version

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

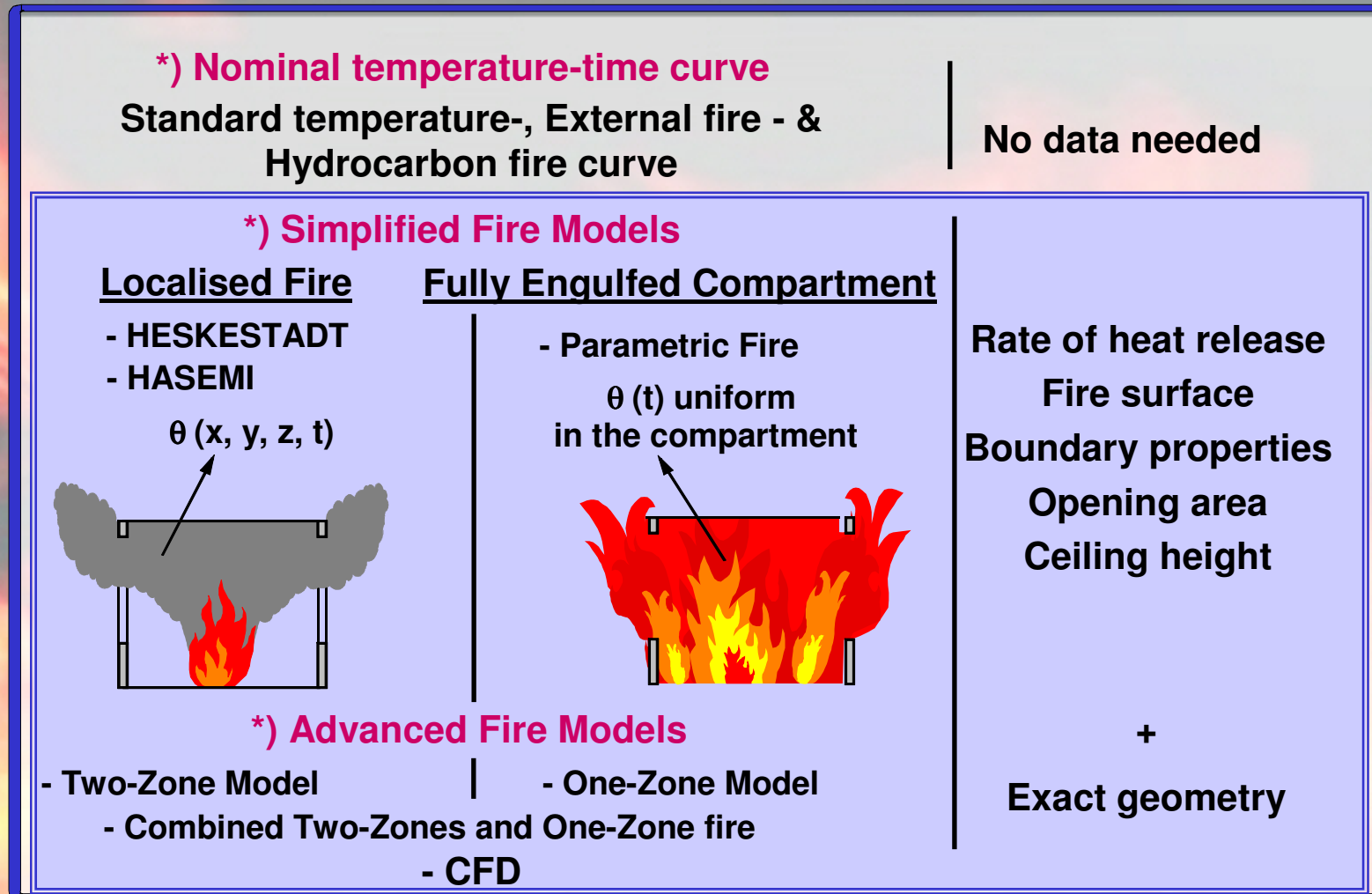
Eurocode 1: Actions sur les structures au feu - Partie 1-2:
Actions générales - Actions sur les structures exposées

Eurocode 1 - Einwirkungen auf Tragwerke - Teil 1-2:
Allgemeine Einwirkungen - Brandeinwirkungen auf
Tragwerke

NFSC Valorisation Project



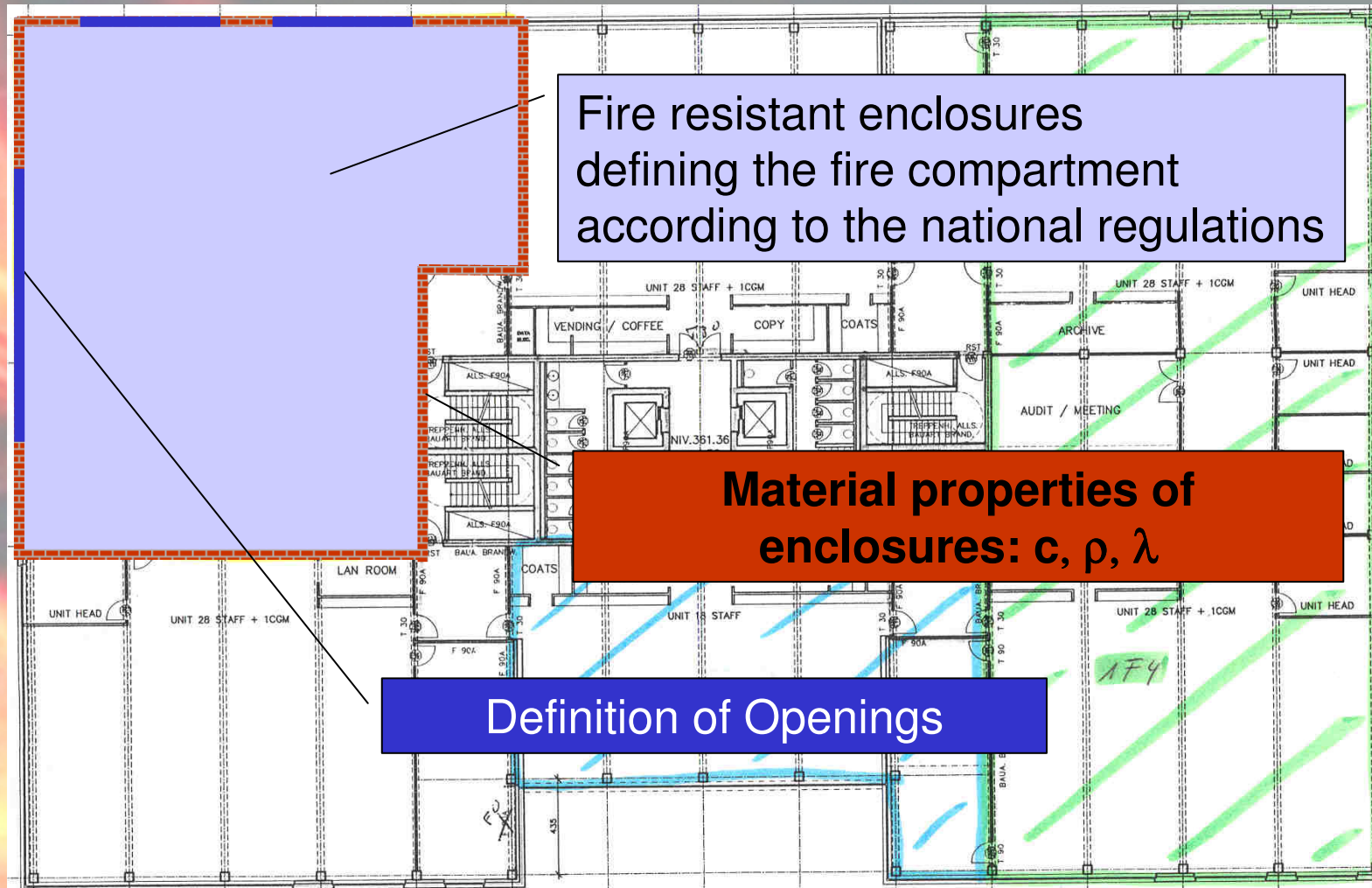
Natural Fire Model



List of needed Physical Parameters for Natural Fire Model

- Boundary properties
 - Ceiling height
 - Opening Area
 - Fire surface
 - Rate of heat release
- } Geometry
- } Fire

Characteristics of the Fire Compartment



Characteristic of the Fire for Different Buildings

Occupancy	Fire Growth Rate	RHR [kW/m ² _f]	Fire Load $q_{80\% \text{ fractile}}^{f,k}$ [MJ/m ²]
Dwelling	Medium	250	948
Hospital (room)	Medium	250	280
Hotel (room)	Medium	250	377
Library	Fast	500	1824
Office	Medium	250	511
School	Medium	250	347
Shopping Centre	Fast	250	730
Theatre (movie/cinema)	Fast	500	365
Transport (public space)	Slow	250	122

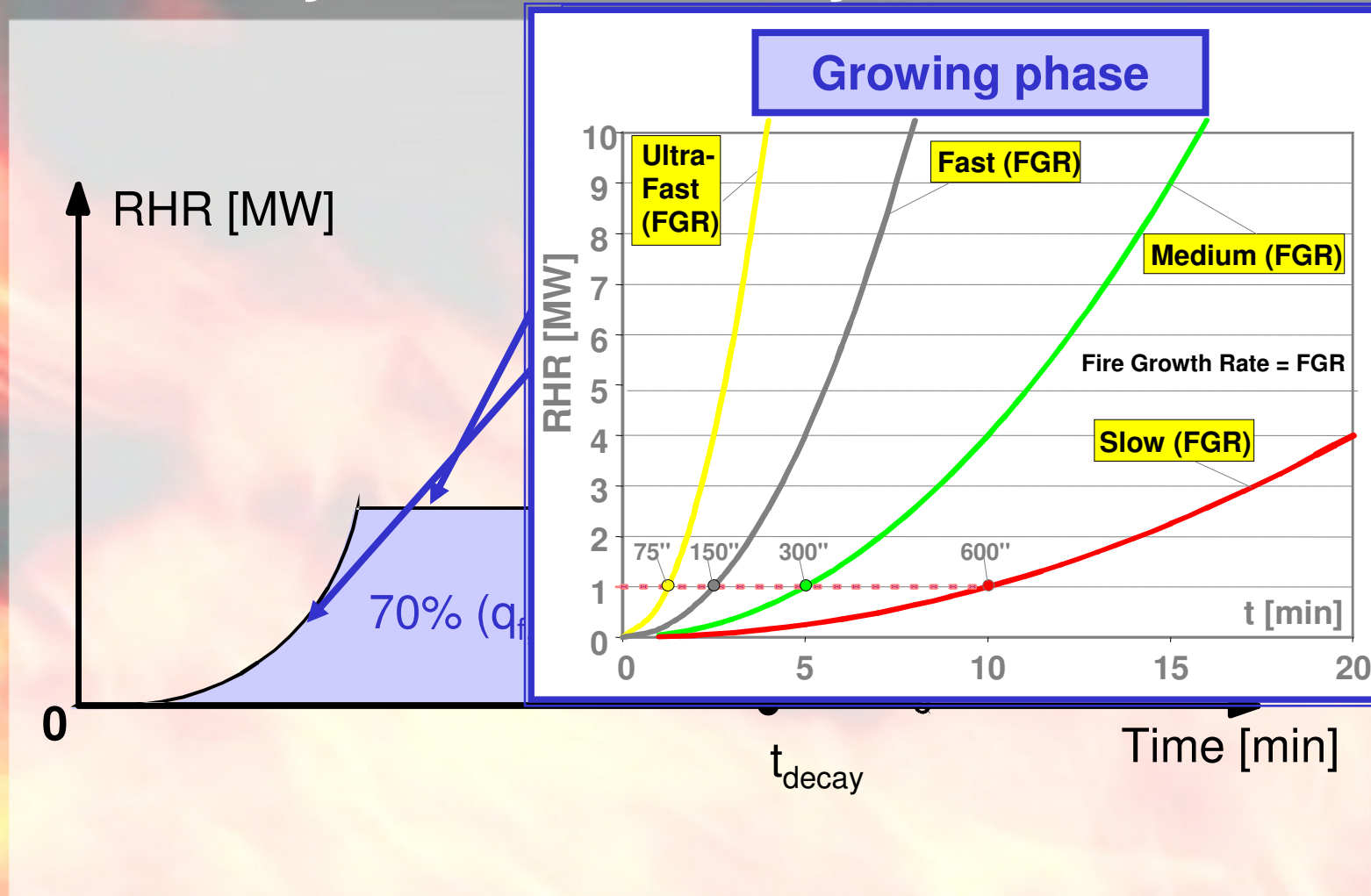
Fire Load Density

Compartment floor area A_f [m ²]	Danger of Fire Activation δ_{q1}	Danger of Fire Activation δ_{q2}	Examples of Occupancies
25	1,10	0,78	Art gallery, museum, swimming pool
250	1,50	1,00	Residence, hotel, office
2500	1,90	1,22	Manufactory for machinery & engines
5000	2,00	1,44	Chemical laboratory, Painting workshop
10000	2,13	1,66	Manufactory of fireworks or paints

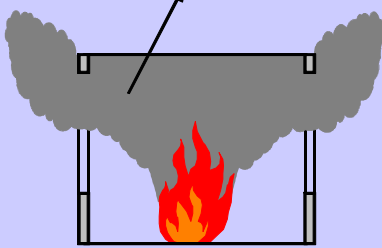
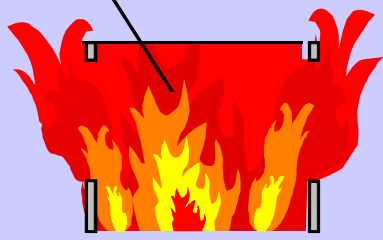
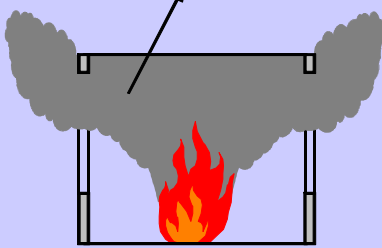
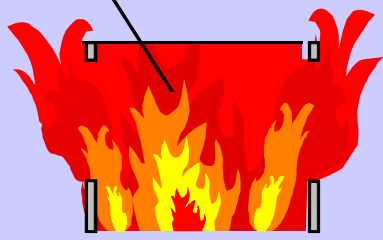
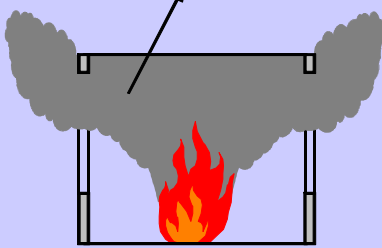
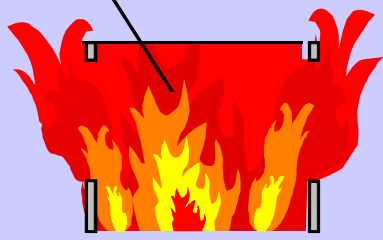
$$q_{f,d} = \delta_{q1} \cdot \delta_{q2} \cdot \prod \delta_{ni} \cdot m \cdot q_{f,k}$$

Automatic Water Extinguishing System		Independent Water Supplies			Automatic fire Detection & Alarm		Automatic Alarm Transmission to Fire Brigade	Work Fire Brigade	Off Site Fire Brigade	Safe Access Routes	Fire Fighting Devices	Smoke Exhaust System
δ_{n1}	0 1 2	δ_{n2}		by Heat δ_{n3}	by Smoke δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}	
0,61	1,0 0,87 0,7	0,87 or 0,73		0,87		0,61 or 0,78	0,61 or 0,78	0,9 or 1 1,5	1,0 1,5	1,0 1,5		

Rate of Heat Release Curve Stationary State and Decay Phase

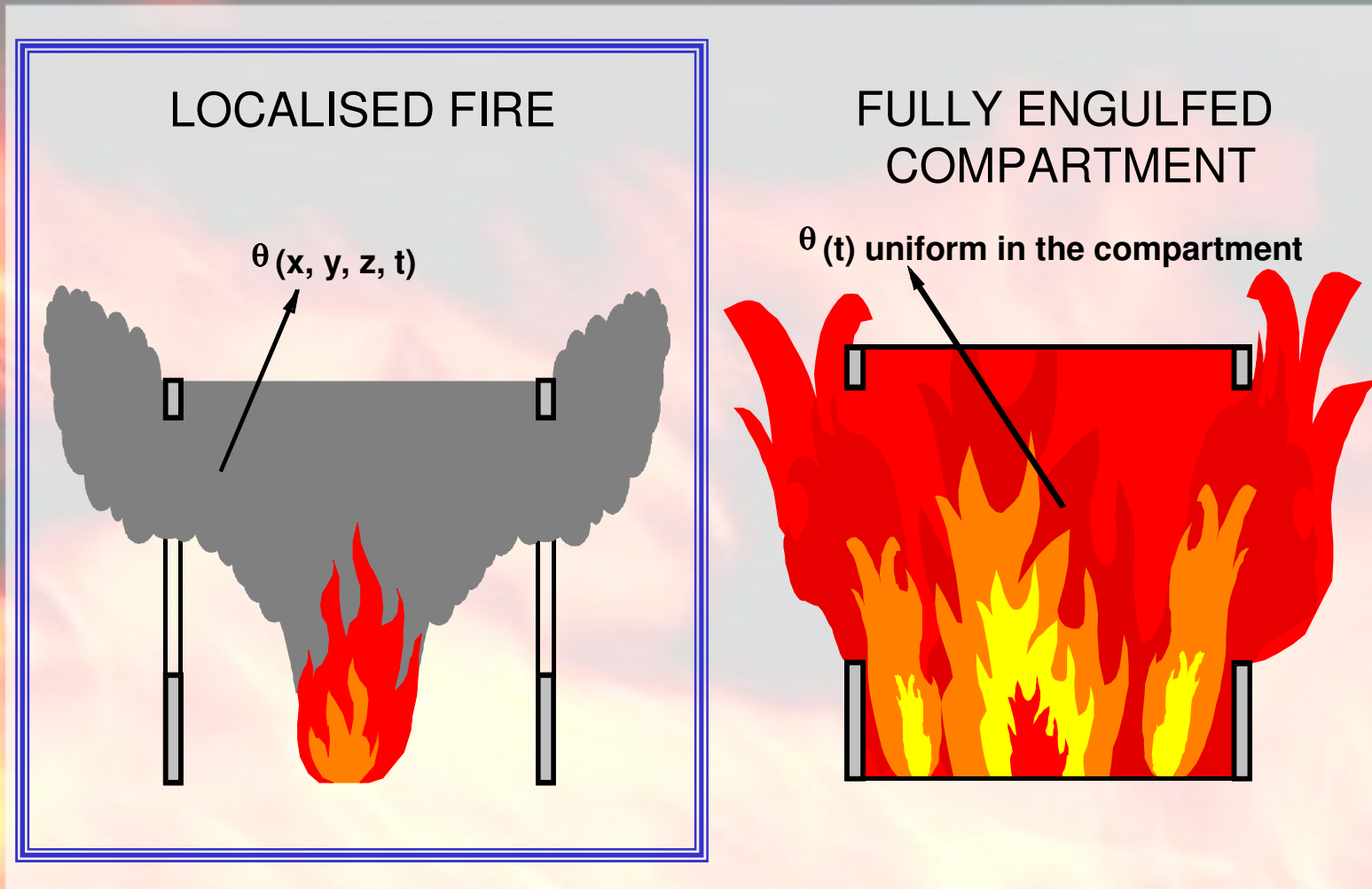


Natural Simplified Fire Model

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Simplified Fire Models

Localised Fire



Real Localised Fire Test

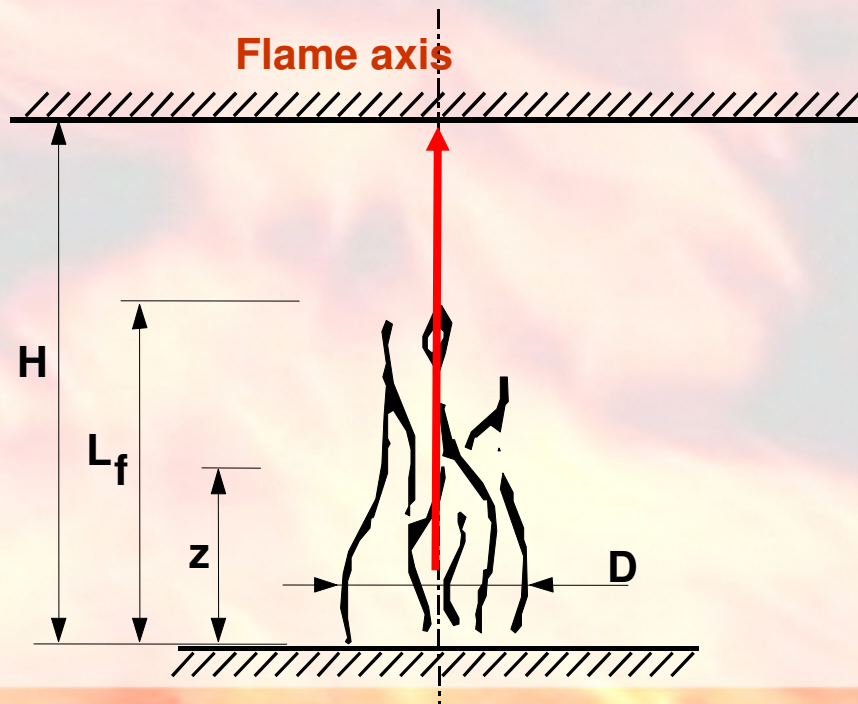


Localised Fire: HESKESTAD Method

Annex C of EN 1991-1-2:

- Flame is not impacting the ceiling of a compartment ($L_f < H$)
- Fires in open air

$$\Theta_{(z)} = 20 + 0,25 (0,8 Q_c)^{2/3} (z-z_0)^{-5/3} \leq 900 \text{ }^\circ\text{C}$$



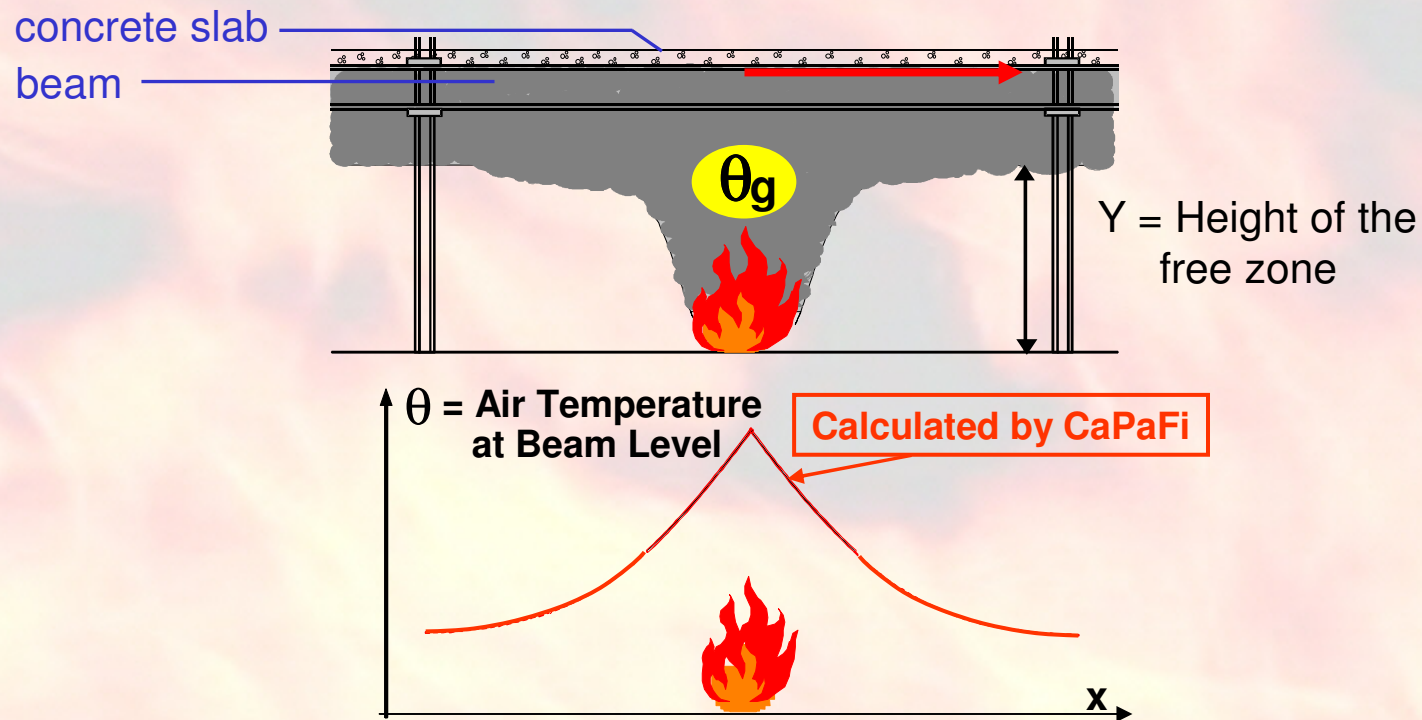
The flame length L_f of a localised fire is given by :

$$L_f = -1,02 D + 0,0148 Q^{2/5}$$

Localised Fire: HASEMI Method

Annex C of EN 1991-1-2:

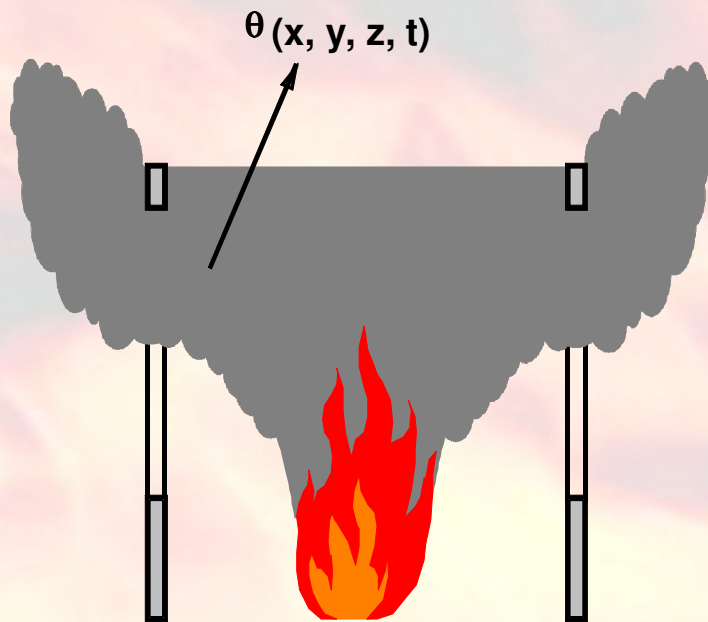
- Flame is impacting the ceiling ($L_f > H$)



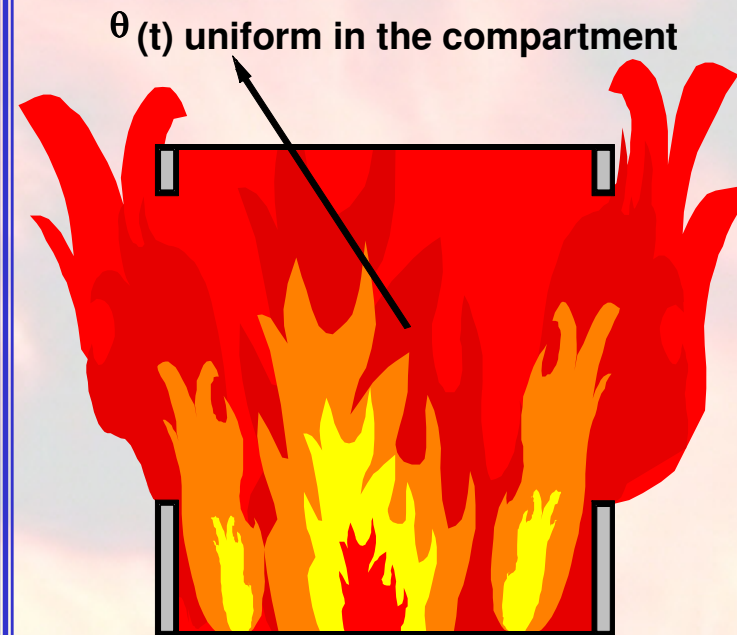
Simplified Fire Models

Fully Engulfed Compartment

LOCALISED FIRE



FULLY ENGULFED COMPARTMENT

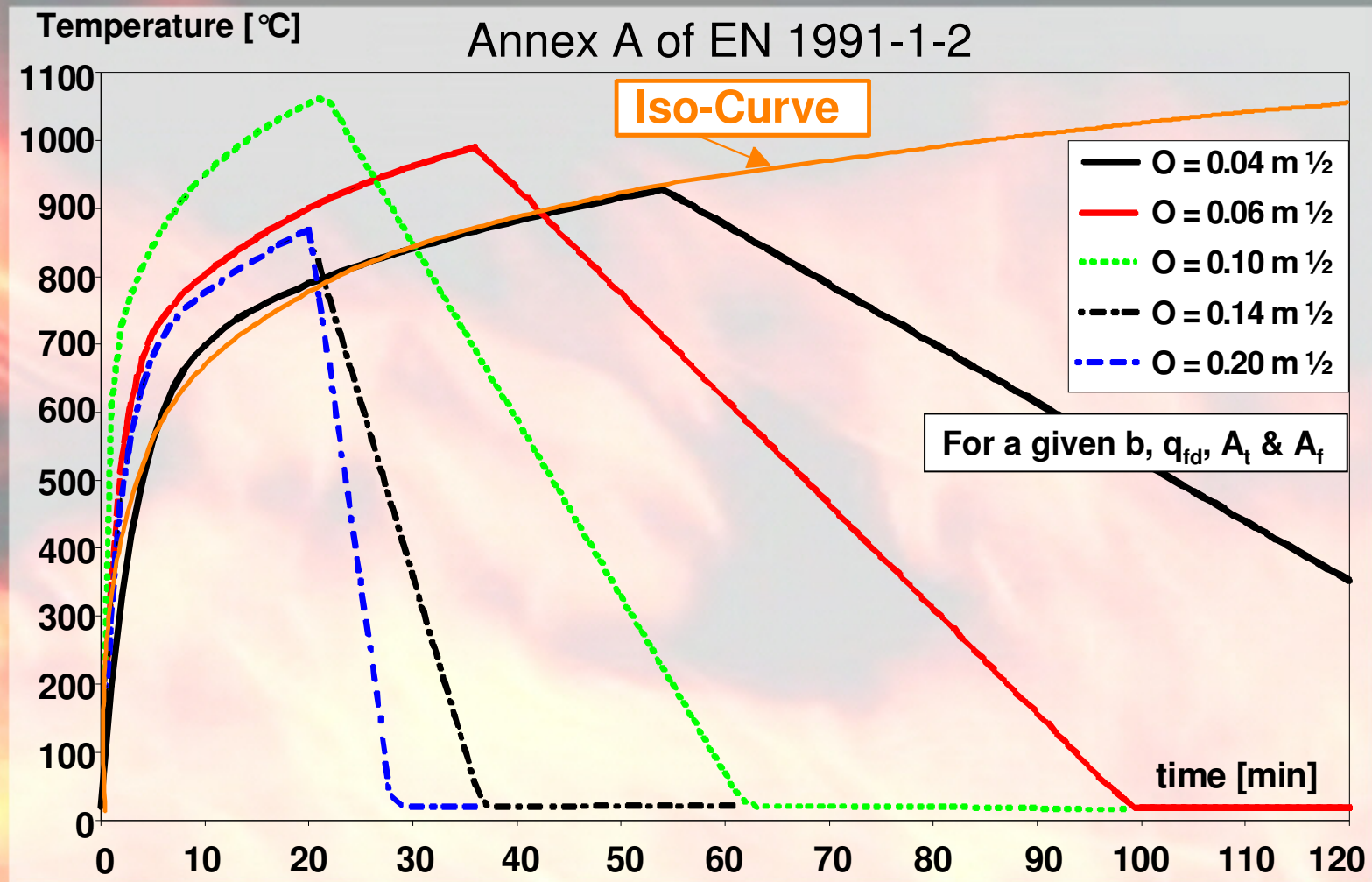


Real Fire Test Simulating an Office Building

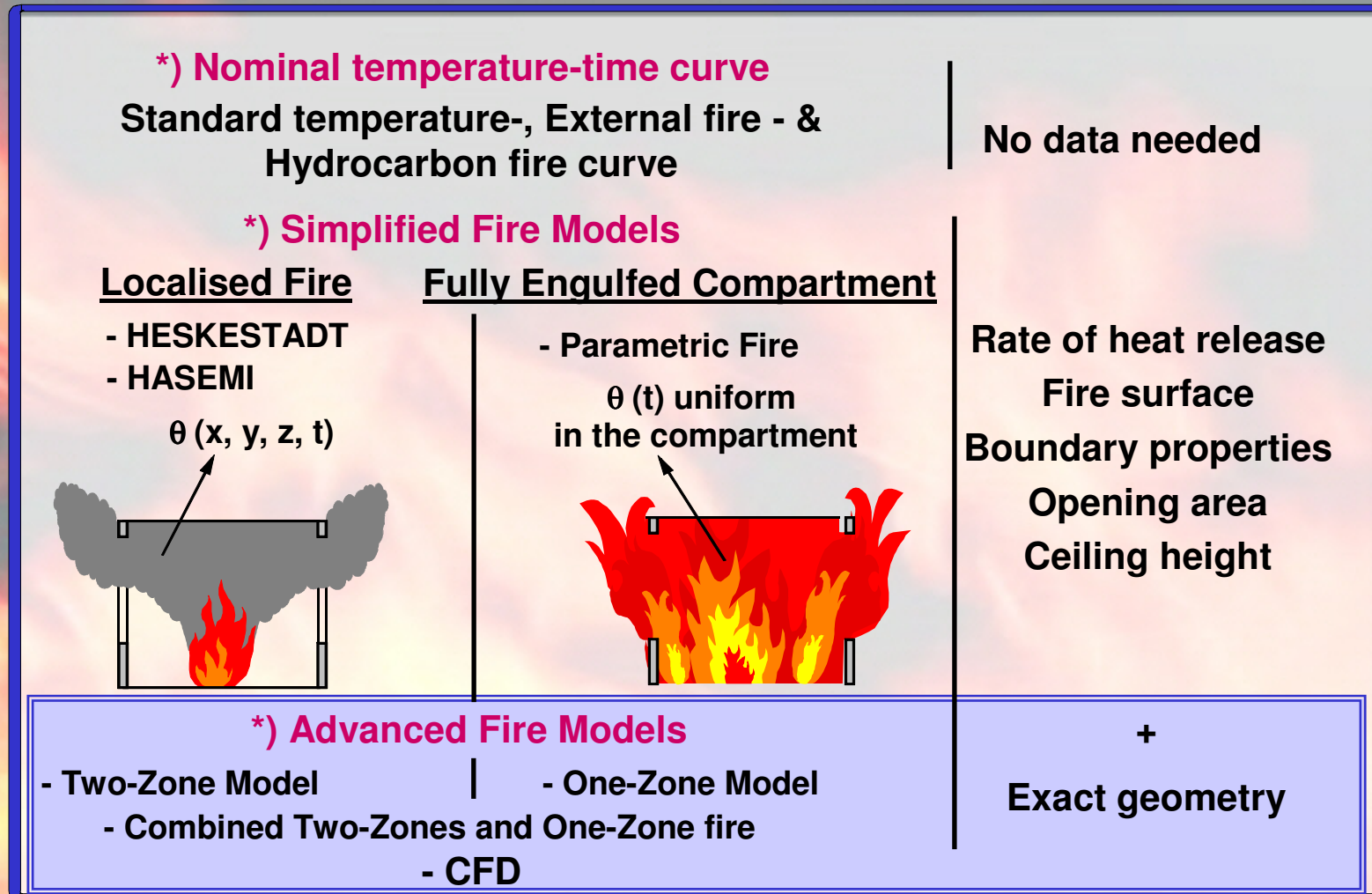
Fully engulfed fire



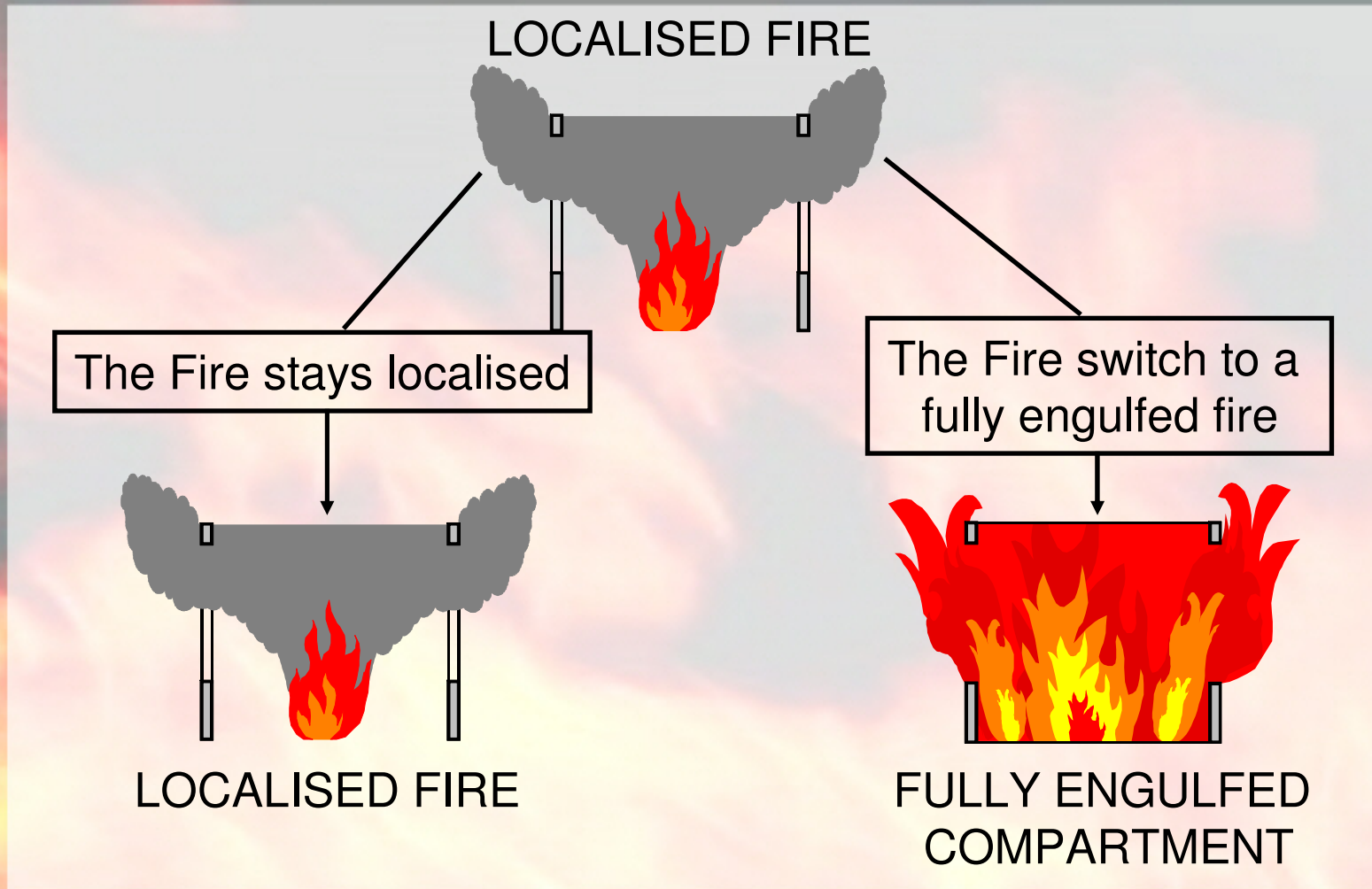
Fully Engulfed Compartment Parametric Fire



Natural Advanced Fire Model



Advanced fire Models



Large Compartment Test Fire Load



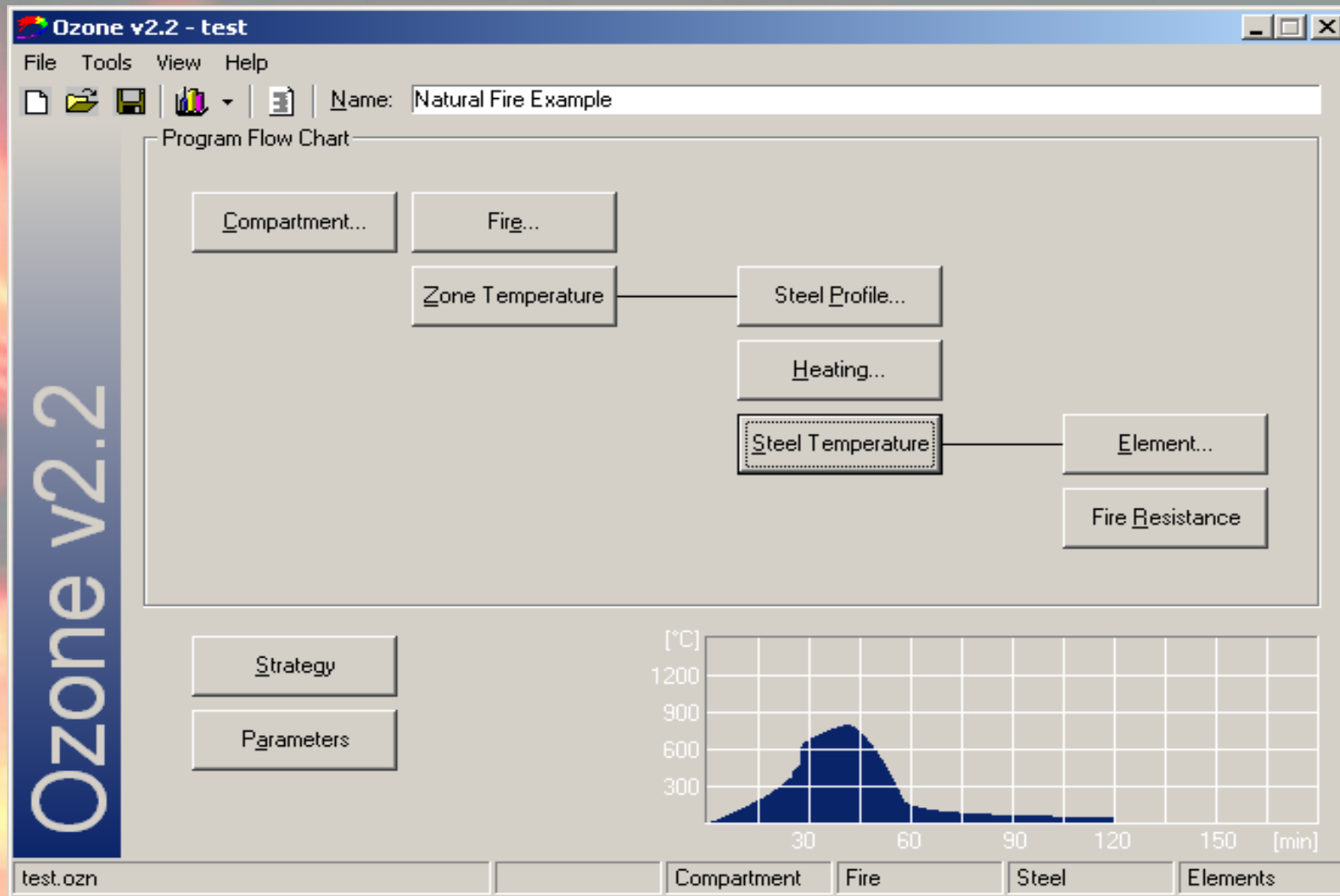
Large Compartment Test External Flaming During the Test



Large Compartment Test After the Test

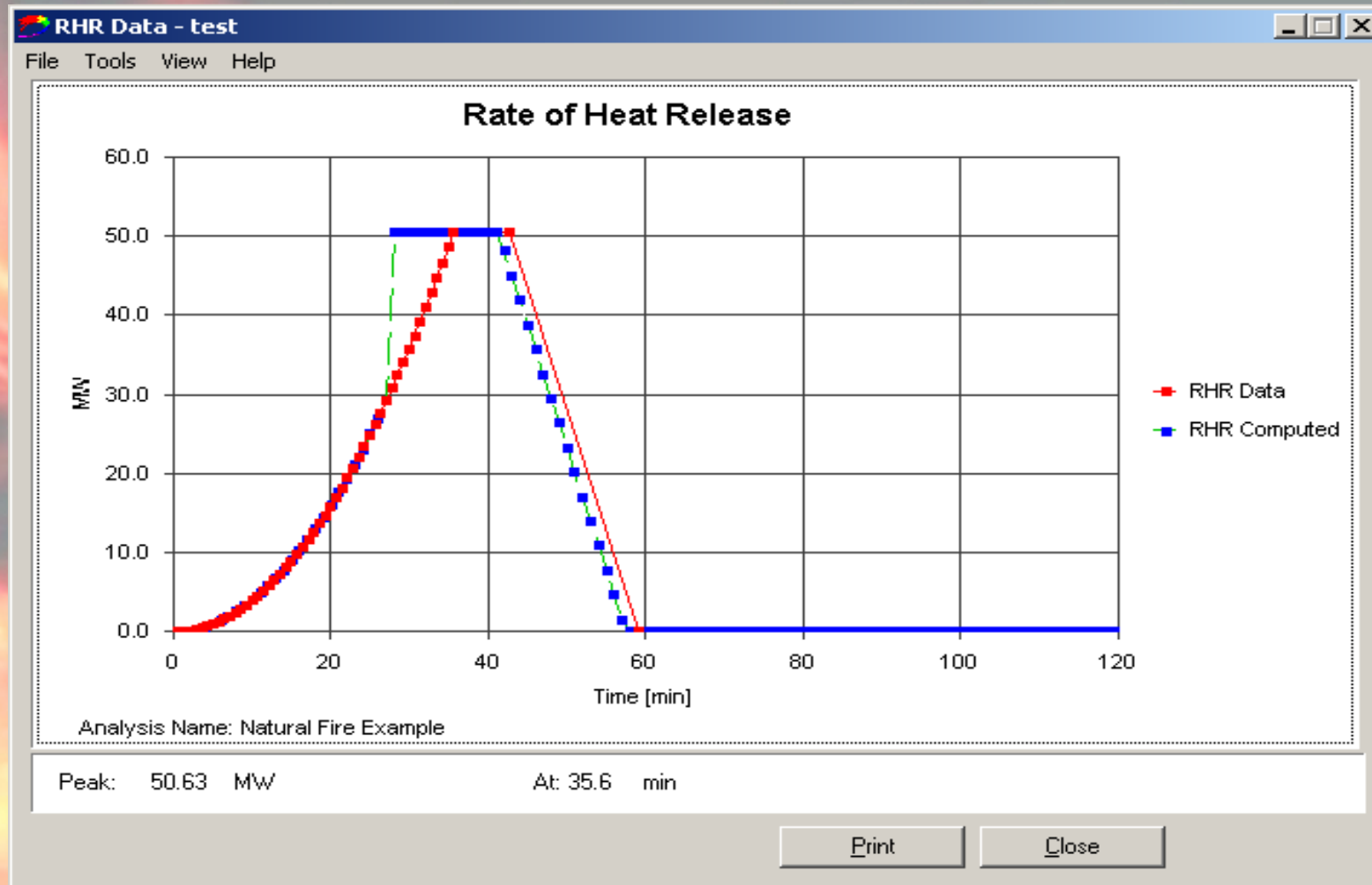


Two Zone Calculation Software “OZone V2.2”

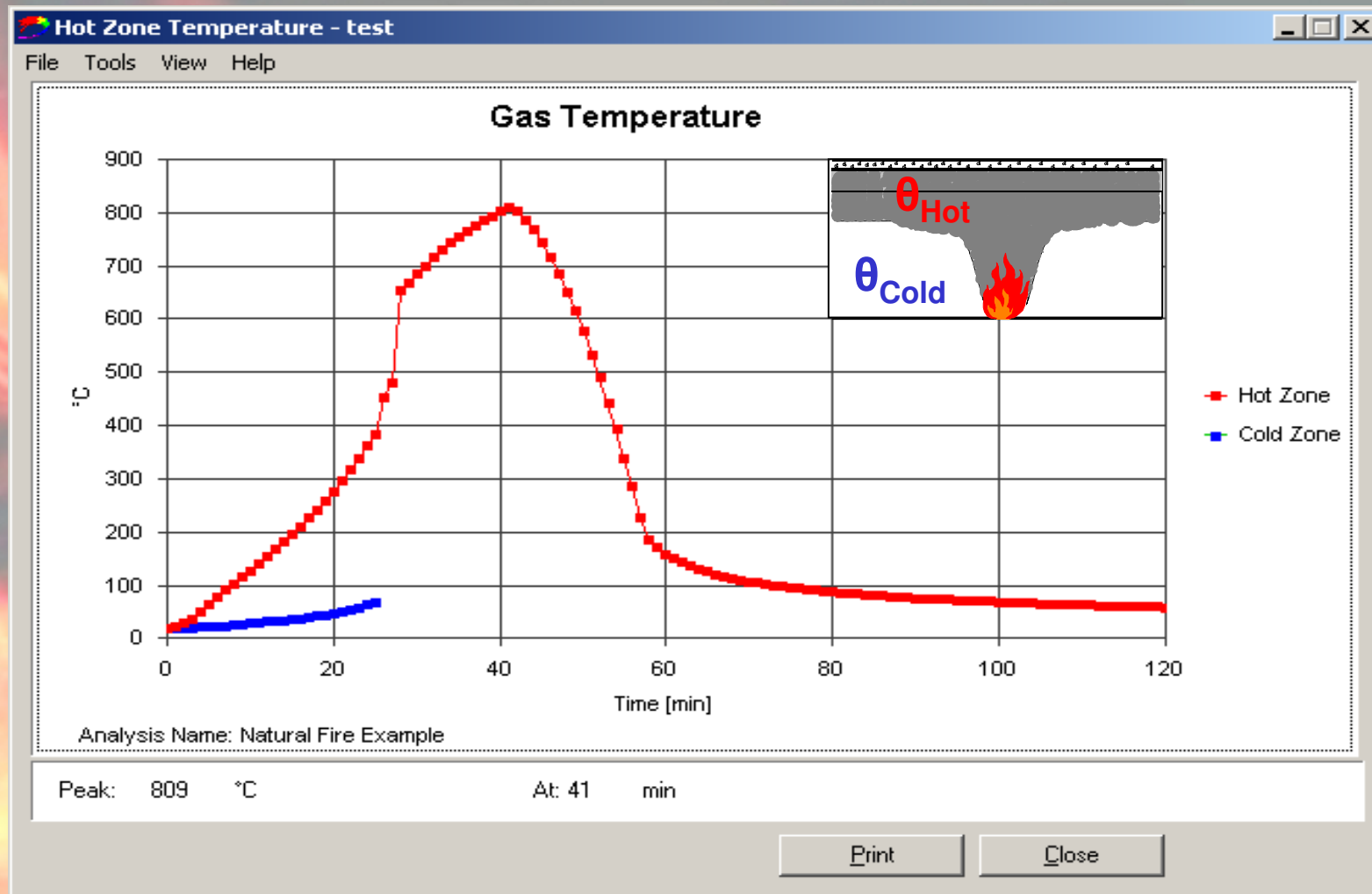


Ozone v2.2

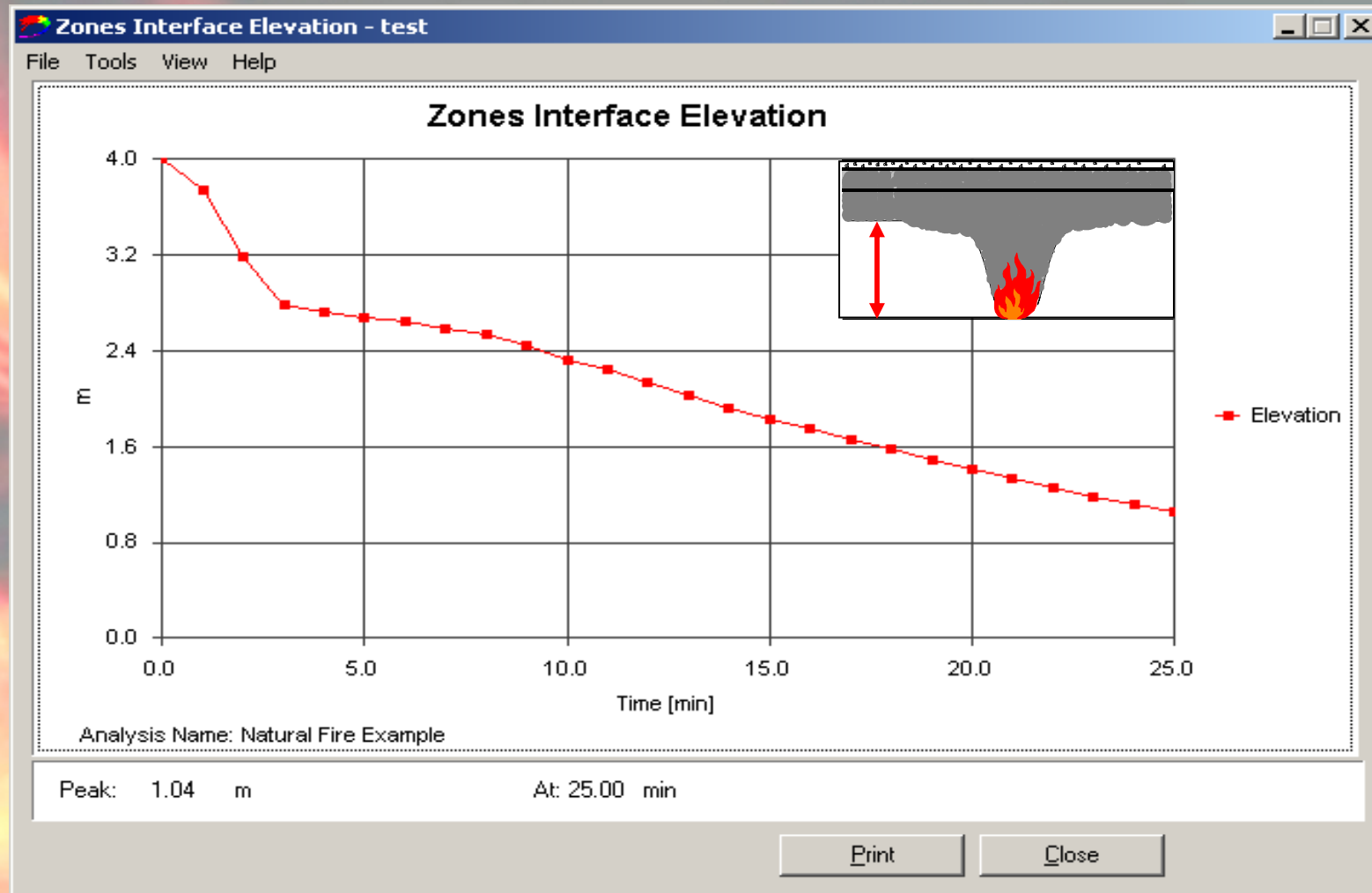
OZone results: Input and Computed RHR



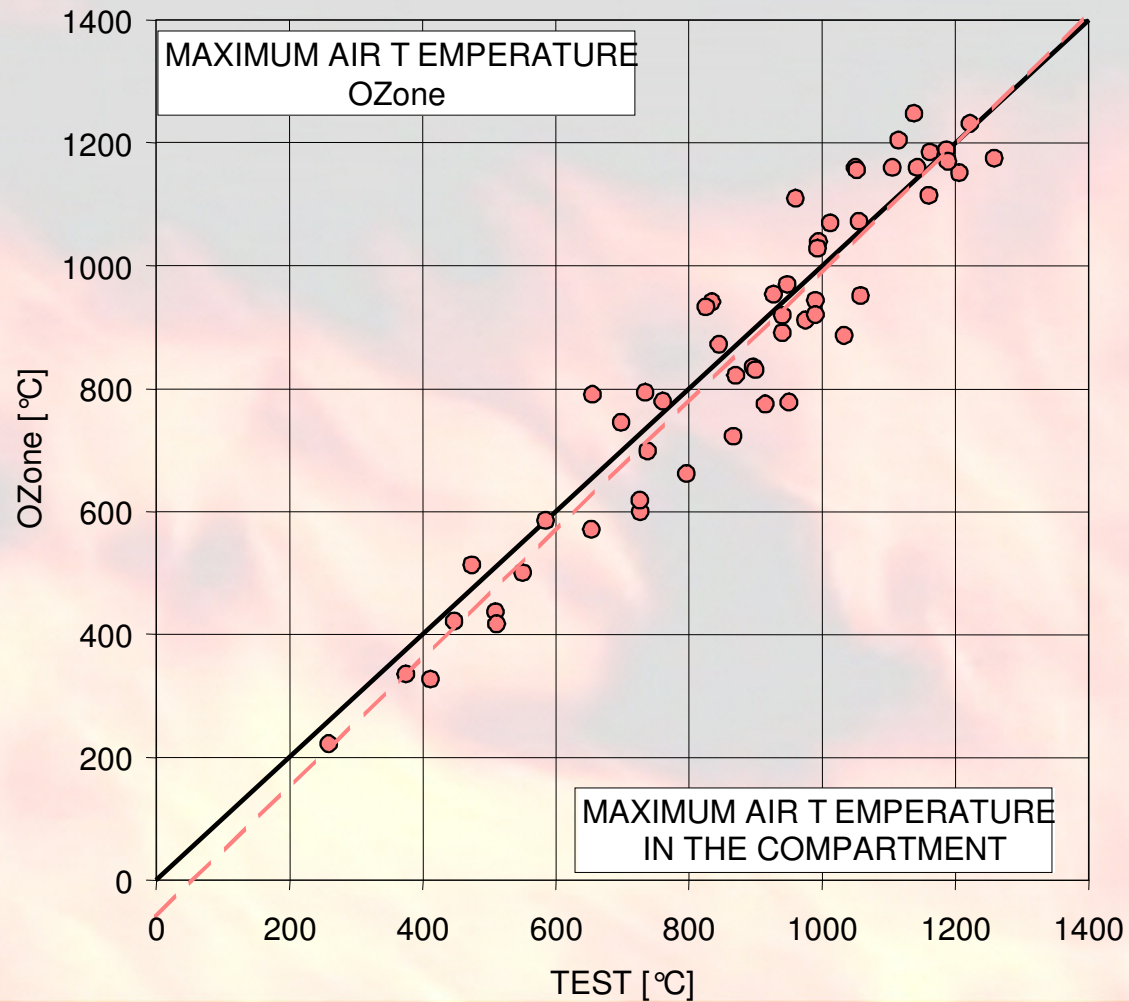
OZone results: Gas Temperatures



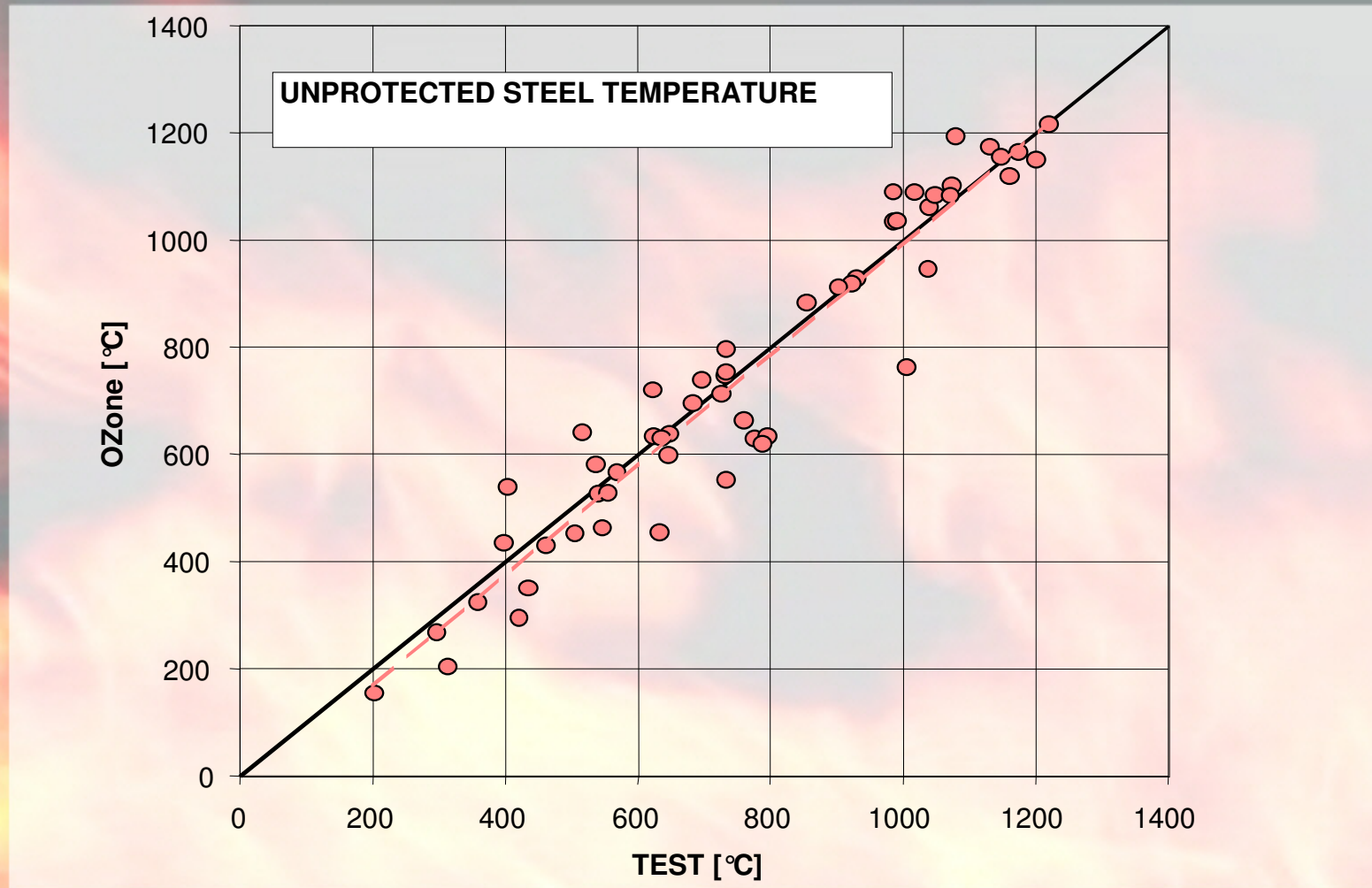
OZone results: Smoke Layer Thickness



Calibration of Software OZone: Gas Temp

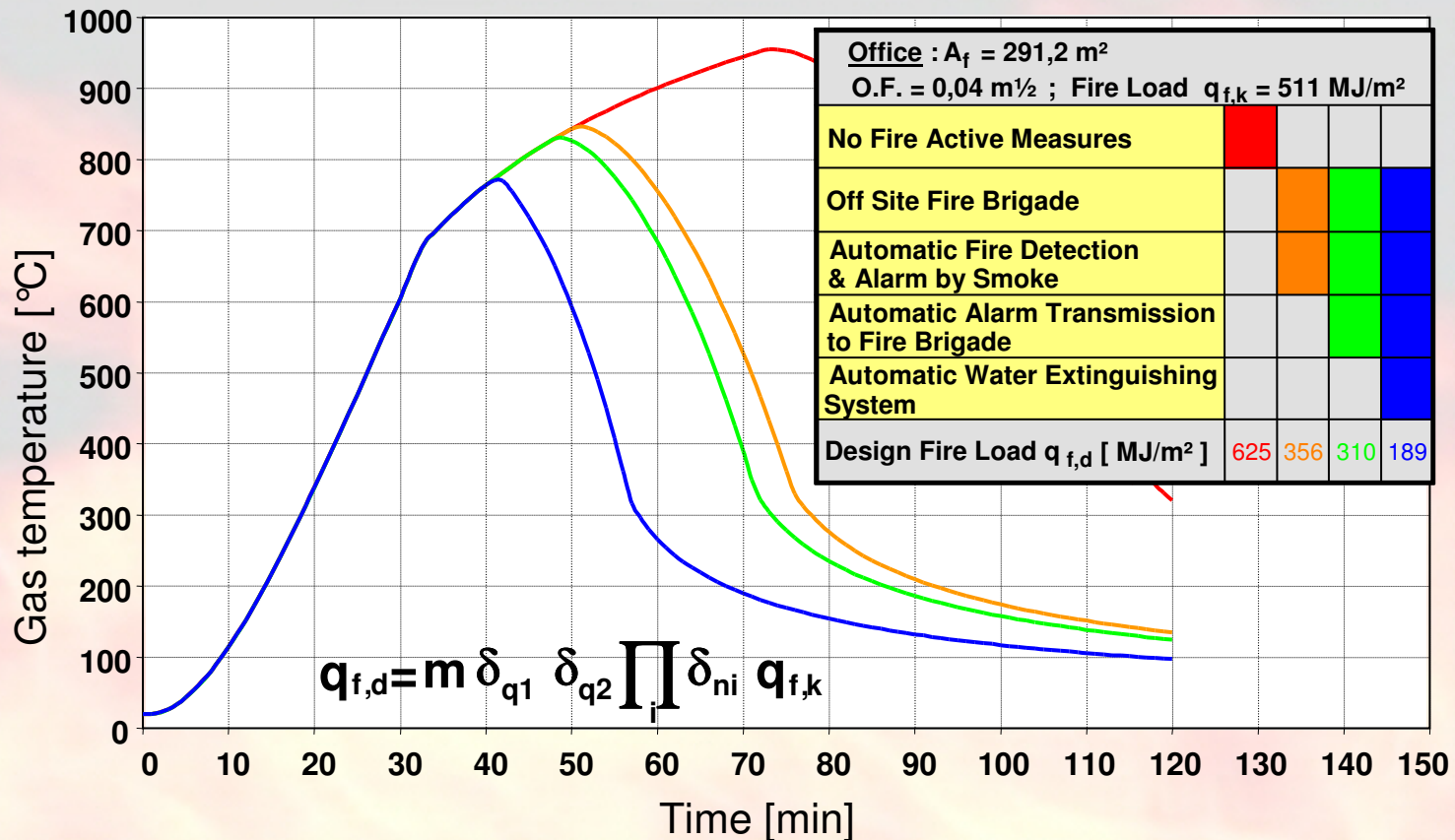


Calibration of Software OZone: Steel Temp



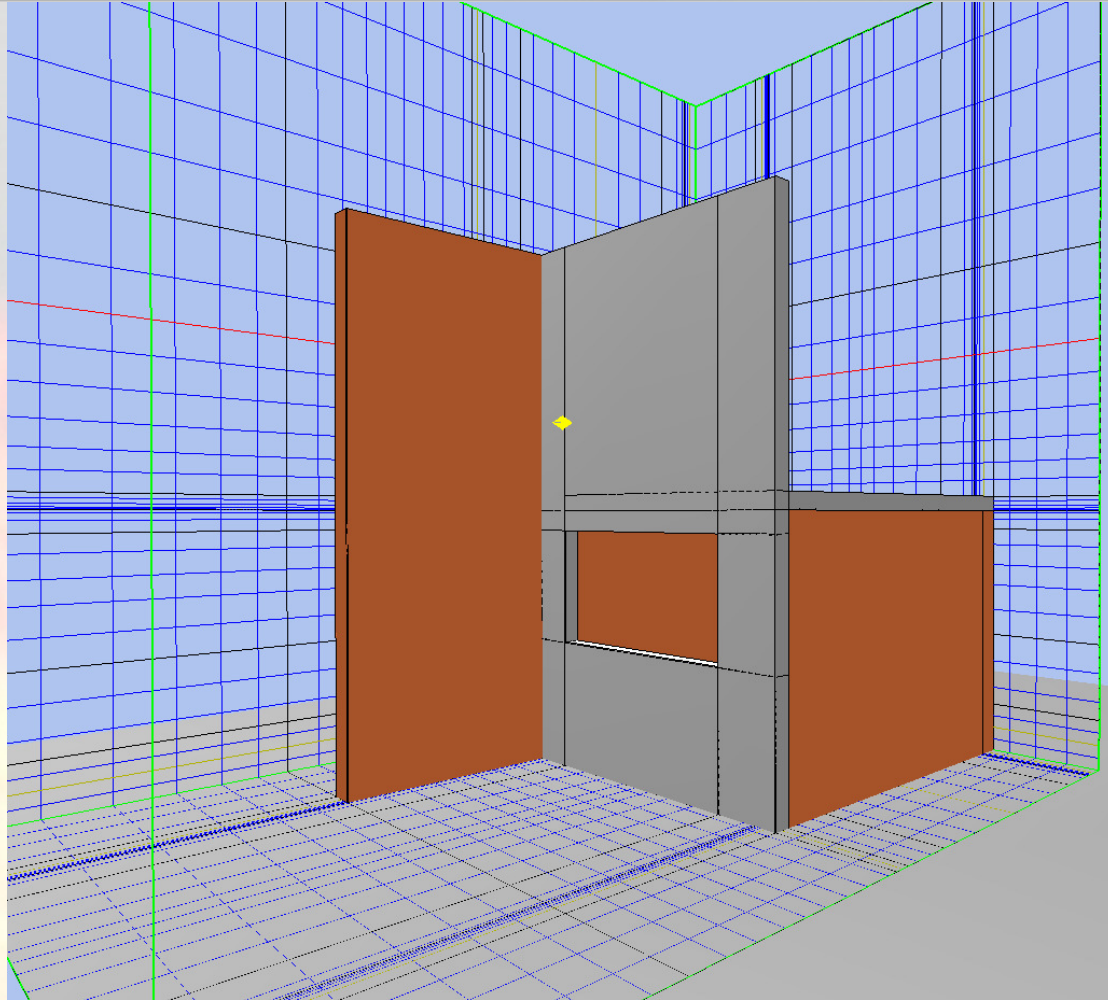
OZone: Case Study

Influence of the Actives Fire Safety Measures

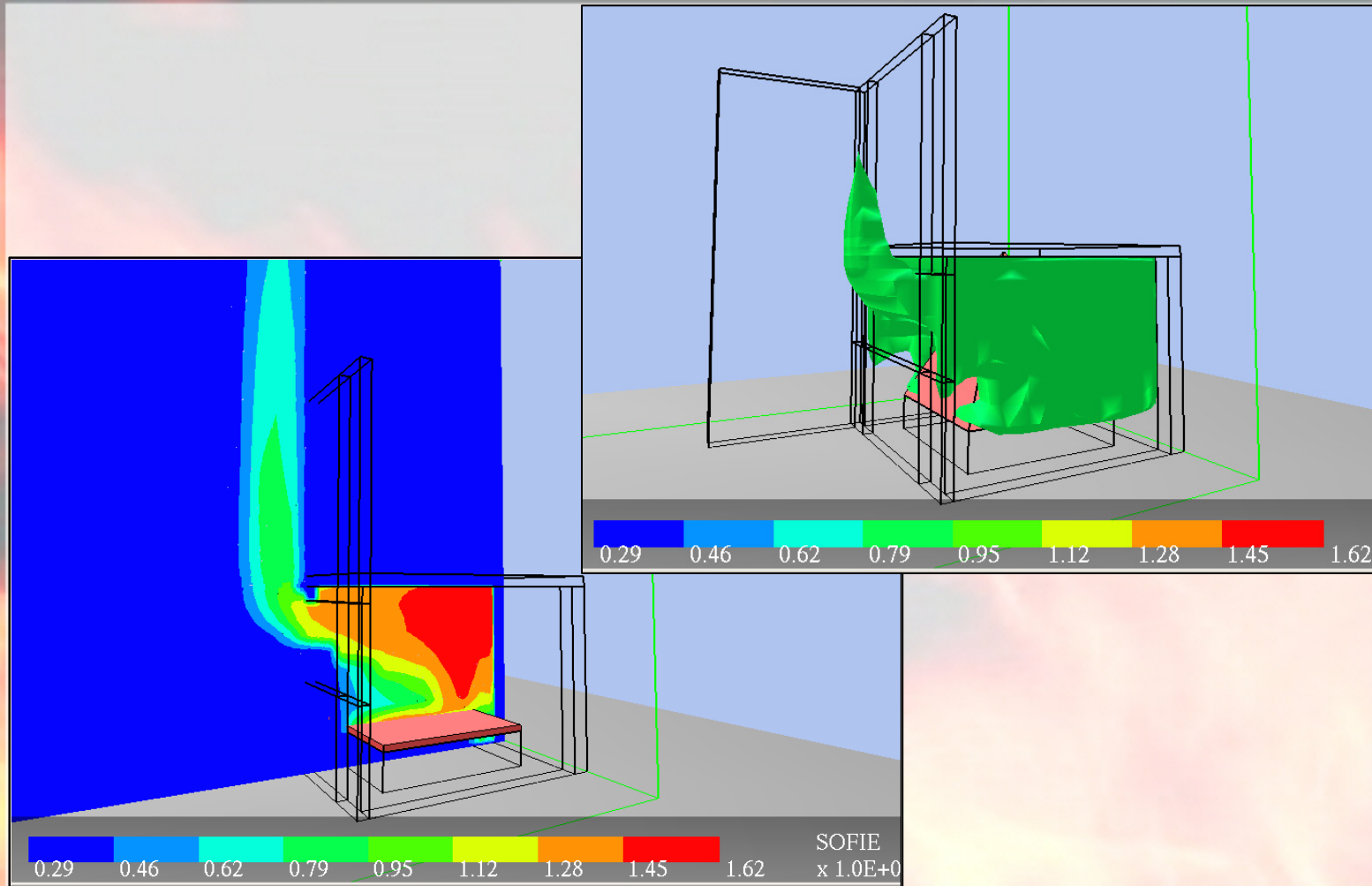


Computer Fluid Dynamics: Software Sofie

**Grid
definition**



Sofie Results: Gas Temperatures



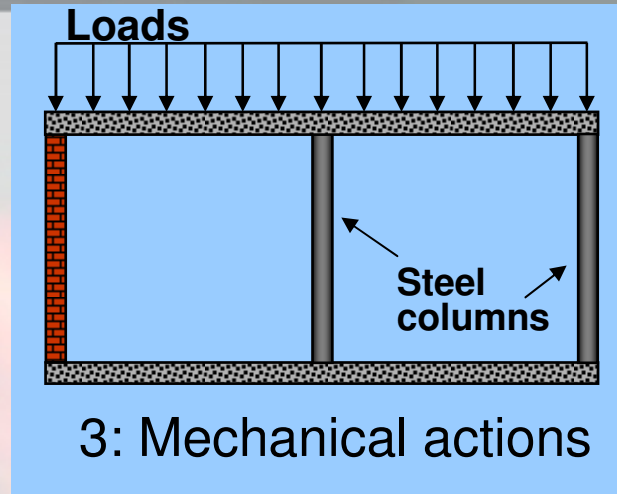
Resistance to Fire - Chain of Events



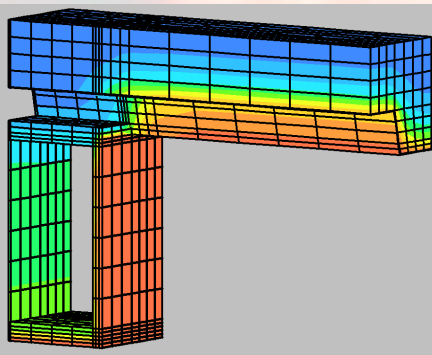
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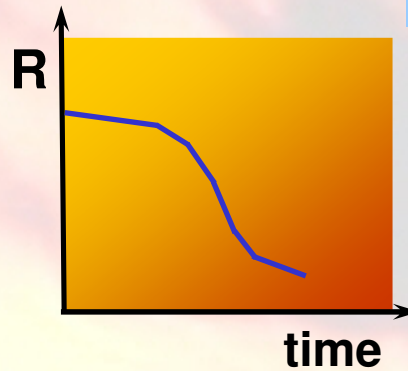
2: Thermal action



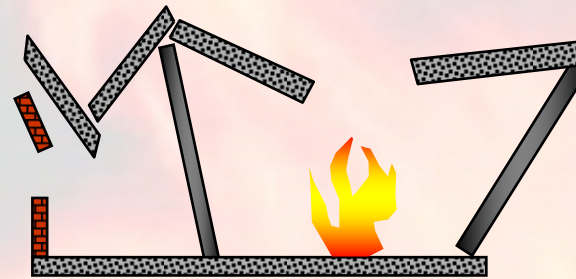
3: Mechanical actions



4: Thermal response

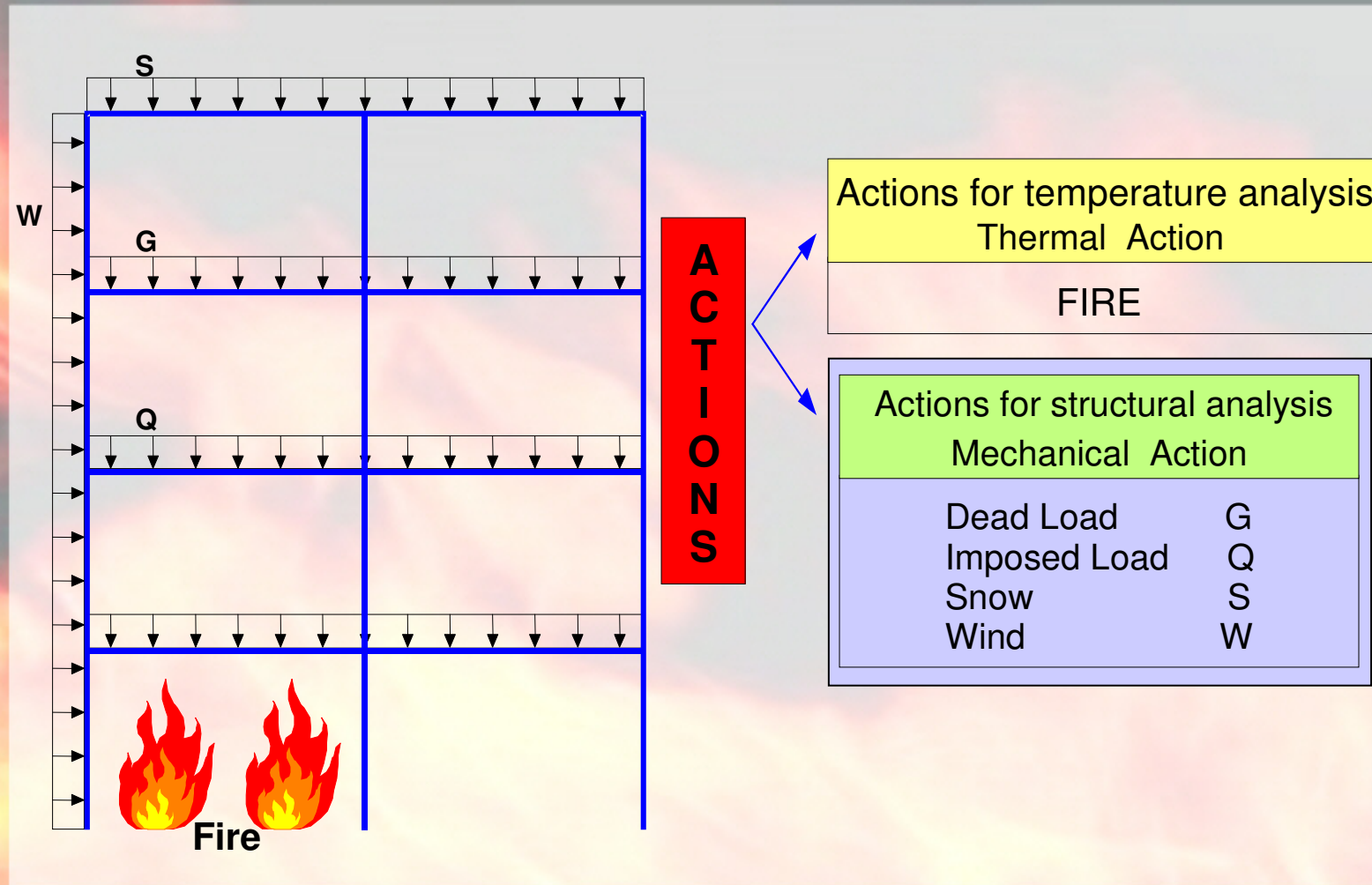


5: Mechanical response



6: Possible collapse

Basis of Design and Actions on Structures



Combination Rules for Mechanical Actions

EN 1990: Basis of Structural Design

Room temperature

$$E_d = \gamma_G G + \gamma_{Q,1} Q_1 + \sum_{i>1} \psi_{0,i} \gamma_{Q,i} Q_i$$

f.i. : Offices area with the imposed load Q,
the leading variable action

$$E_d = 1,35 G + 1,5 Q + 0,6 \cdot 1,5 W + 0,5 \cdot 1,5 S$$

Combination Rules for Mechanical Actions

EN 1990: Basis of Structural Design

Fire conditions \equiv Accidental situation

$$E_{fi,d} = G + \psi_{1or2,1} Q + \sum_{i>1} \psi_{1or2,i} Q_i$$

f.i. : Offices area with the imposed load Q ,
the leading variable action

$$E_{fi,d} = G + 0,5 Q$$

Offices area with the wind W , the leading variable action

$$E_{fi,d} = G + 0,2 W + 0,3 Q$$

Values of ψ factors for buildings

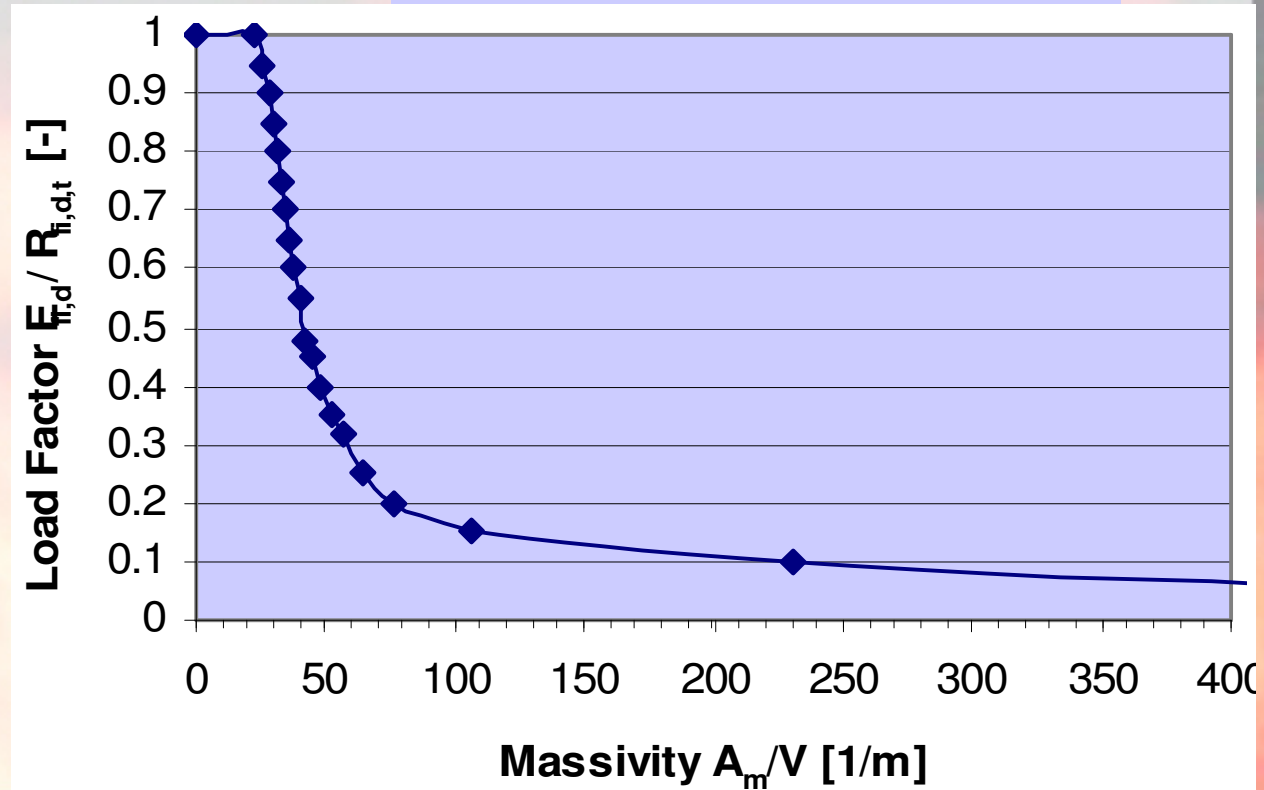
Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1.1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category F : traffic area vehicle weight $\leq 30\text{kN}$	0,7	0,7	0,6
Category G : traffic area, $30\text{kN} < \text{vehicle weight} \leq 160\text{kN}$	0,7	0,5	0,3
Category H : roofs	0	0	0
Snow loads on buildings (see EN1991-1.3)			
Finland, Iceland, Norway, Sweden	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude $H > 1000 \text{ m a.s.l.}$	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude $H \leq 1000 \text{ m a.s.l.}$	0,50	0,20	0
Wind loads on buildings (see EN1991-1.4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN1991-1.5)	0,6	0,5	0

(Reference : EN1990 - February 2002)

Load Factor

$$\eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,l}}{\gamma_G G_k + \gamma_{Q,l} Q_{k,l}}$$

Maximal Load level after R30



Thank you for your attention