PART 1

THERMAL & MECHANICAL ACTIONS

Background of the RFCS Project DIFISEK+

This project is fund ommission in the frame of the "Research F

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

reached trough sem... 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

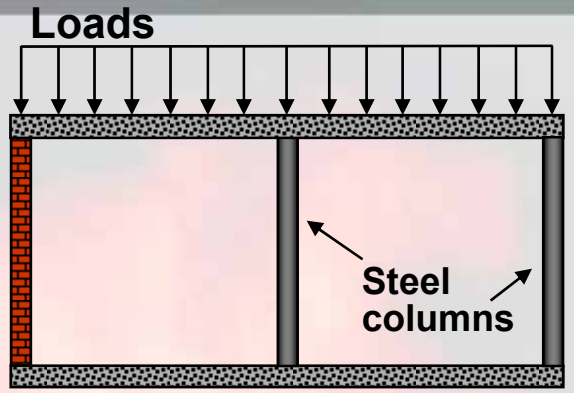
Part 5a: Worked Examples

Part 5b: Illustration of Completed Projects

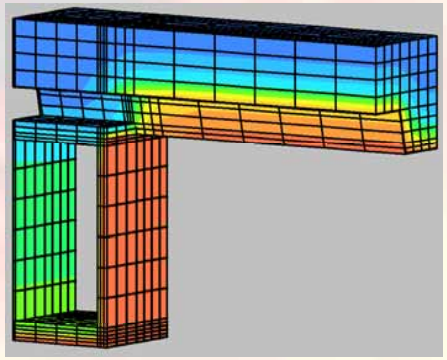
Resistance to Fire - Chain of Events

1: Ignition

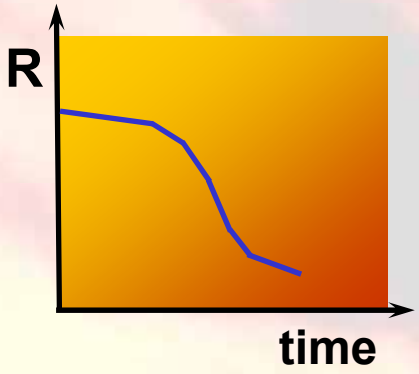
2: Thermal action



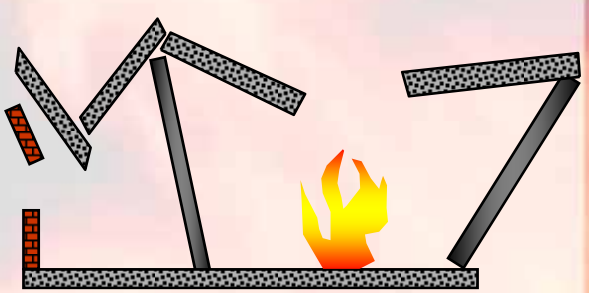
3: Mechanical actions



4: Thermal response



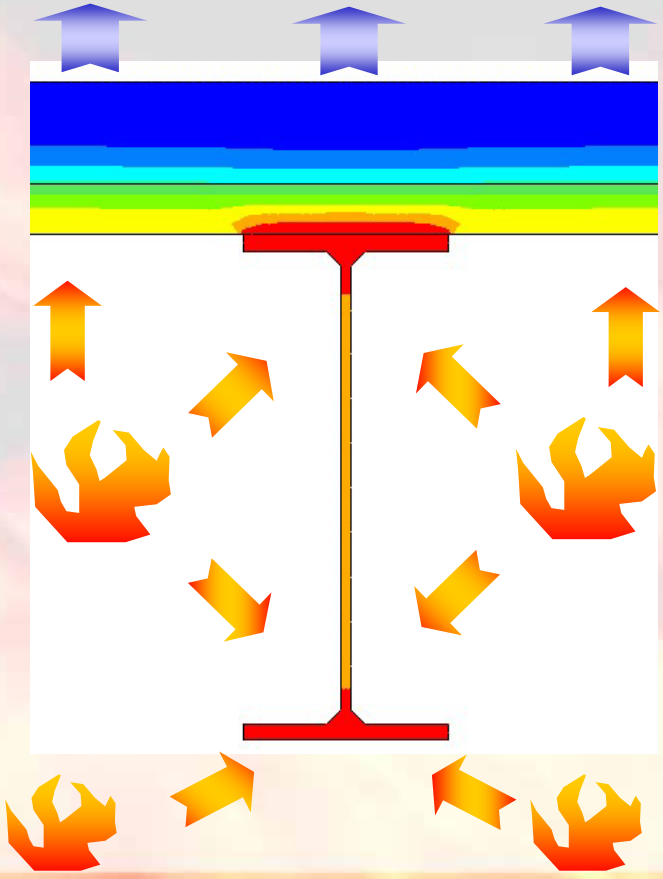
5: Mechanical response



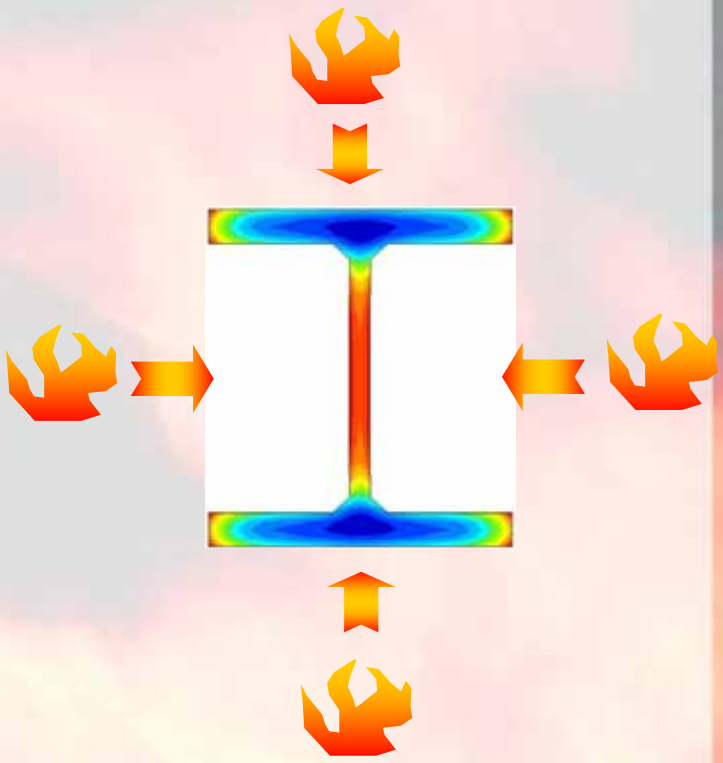
6: Possible collapse

Thermal action on structure

Composite Slab
1 side exposed



Column
4 sides exposed



Heat transfer at surface of building elements

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

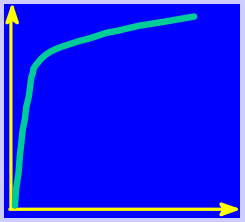
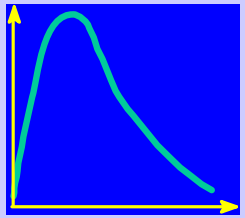
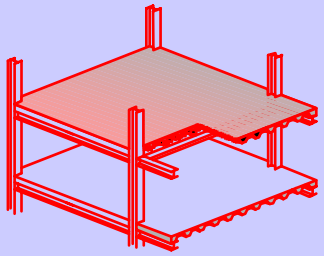
Net Radiative Heat Flux

Net Convective Heat Flux

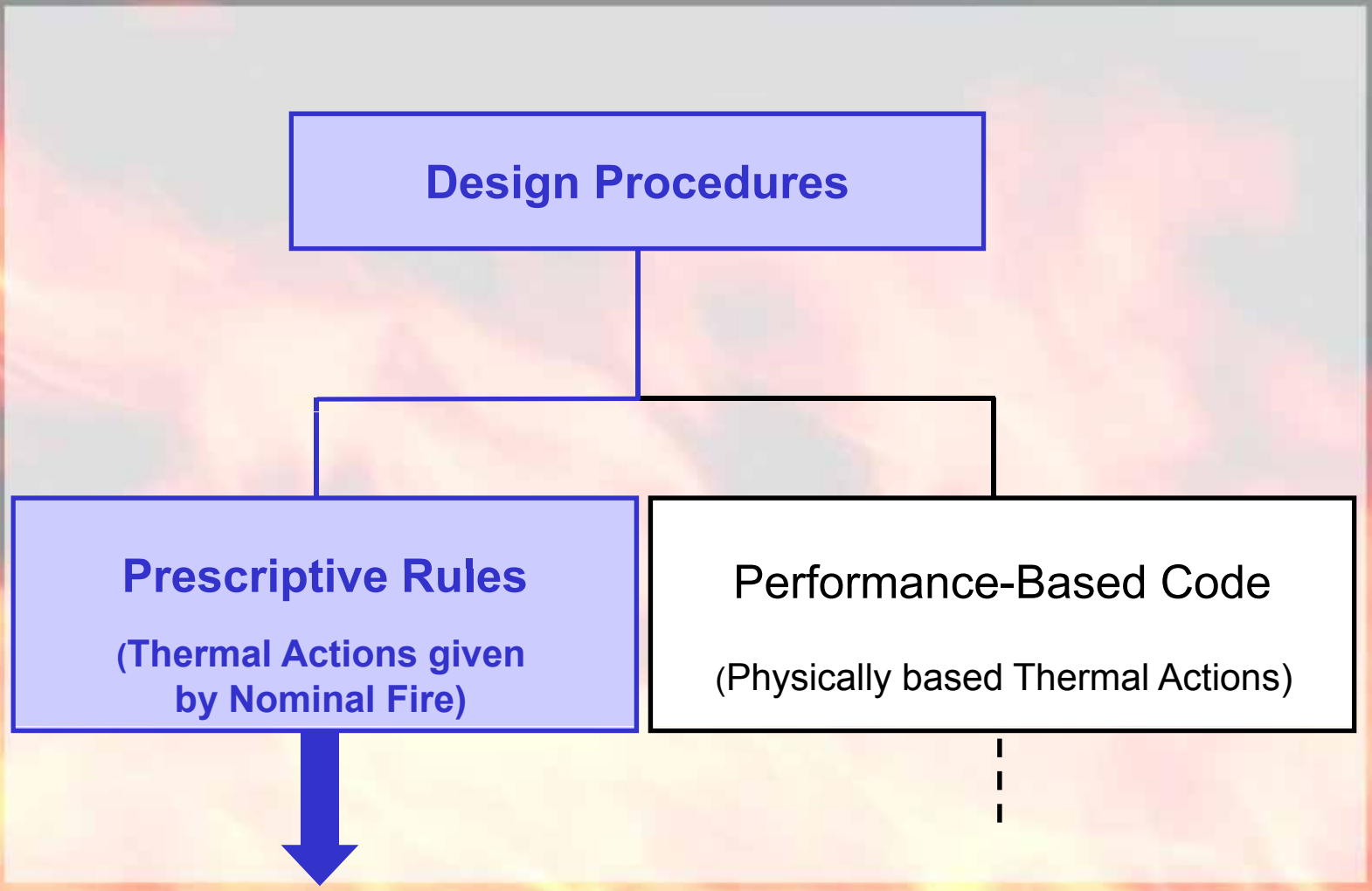
Total net Heat Flux

- 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
ČSN EN 1991-1-2 - Prescriptive Rules



Nominal Temperature-Time Curve

***) Nominal temperature-time curve**

Standard temperature-, External fire - & Hydrocarbon fire curve

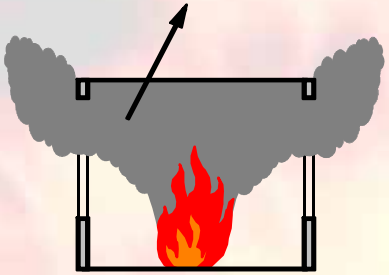
No data needed

***) Simplified Fire Models**

Localised Fire

- HESKESTADT
- HASEMI

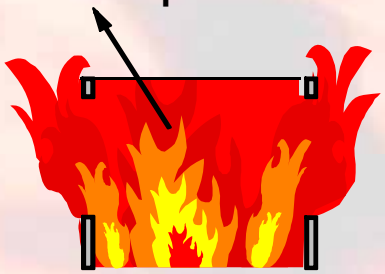
θ (x, y, z, t)



Fully Engulfed Compartment

- Parametric Fire

θ (t) uniform in the compartment



Rate of heat release
Fire surface
Boundary properties
Opening area
Ceiling height

***) Advanced Fire Models**

- Two-Zone Model
- One-Zone Model
- Combined Two-Zones and One-Zone fire
- CFD

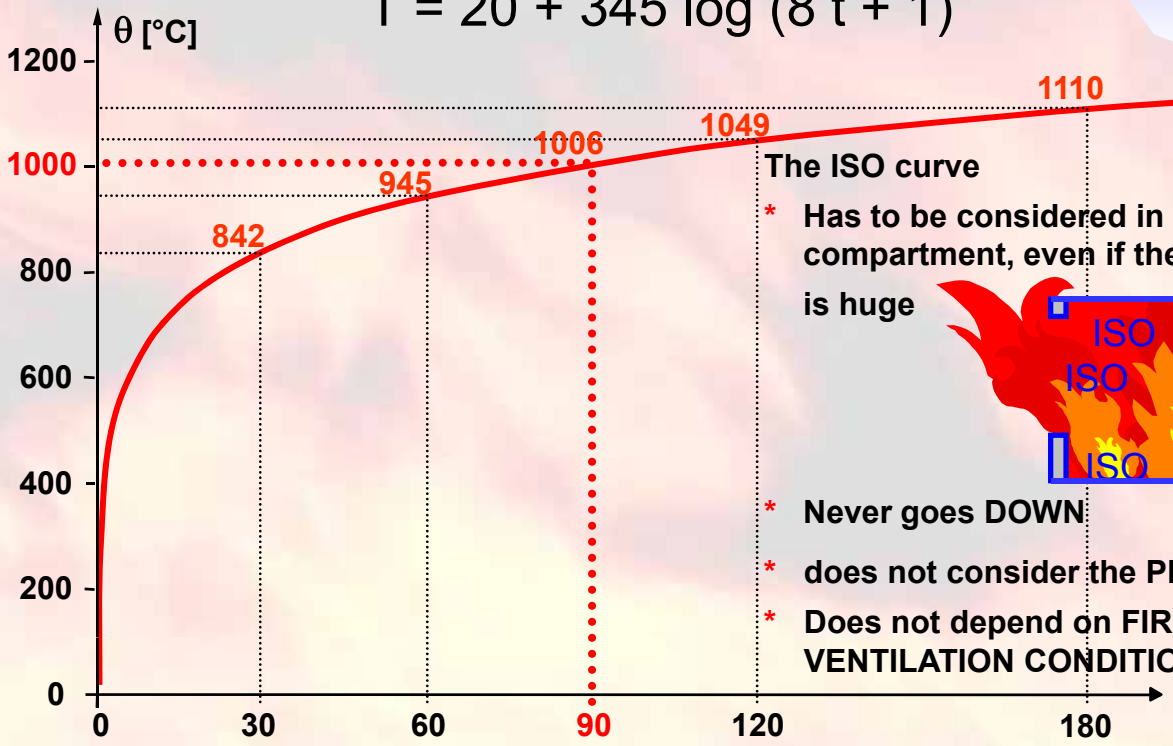
+

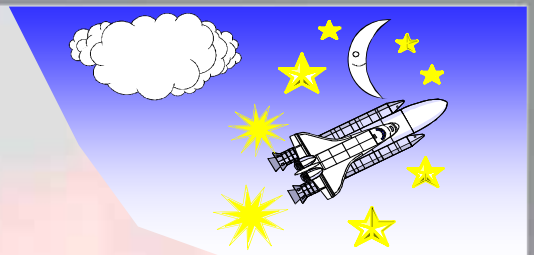
Exact geometry

Prescriptive Fire Regulations Defining ISO Curve Requirements

ISO-834 Curve (EN1364 -1)

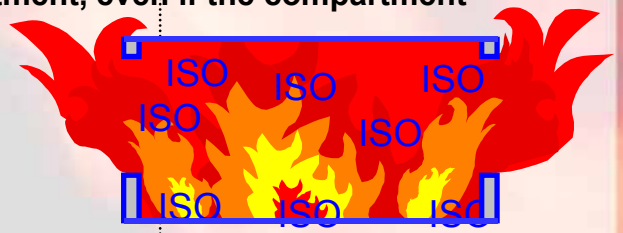
$$T = 20 + 345 \log (8t + 1)$$





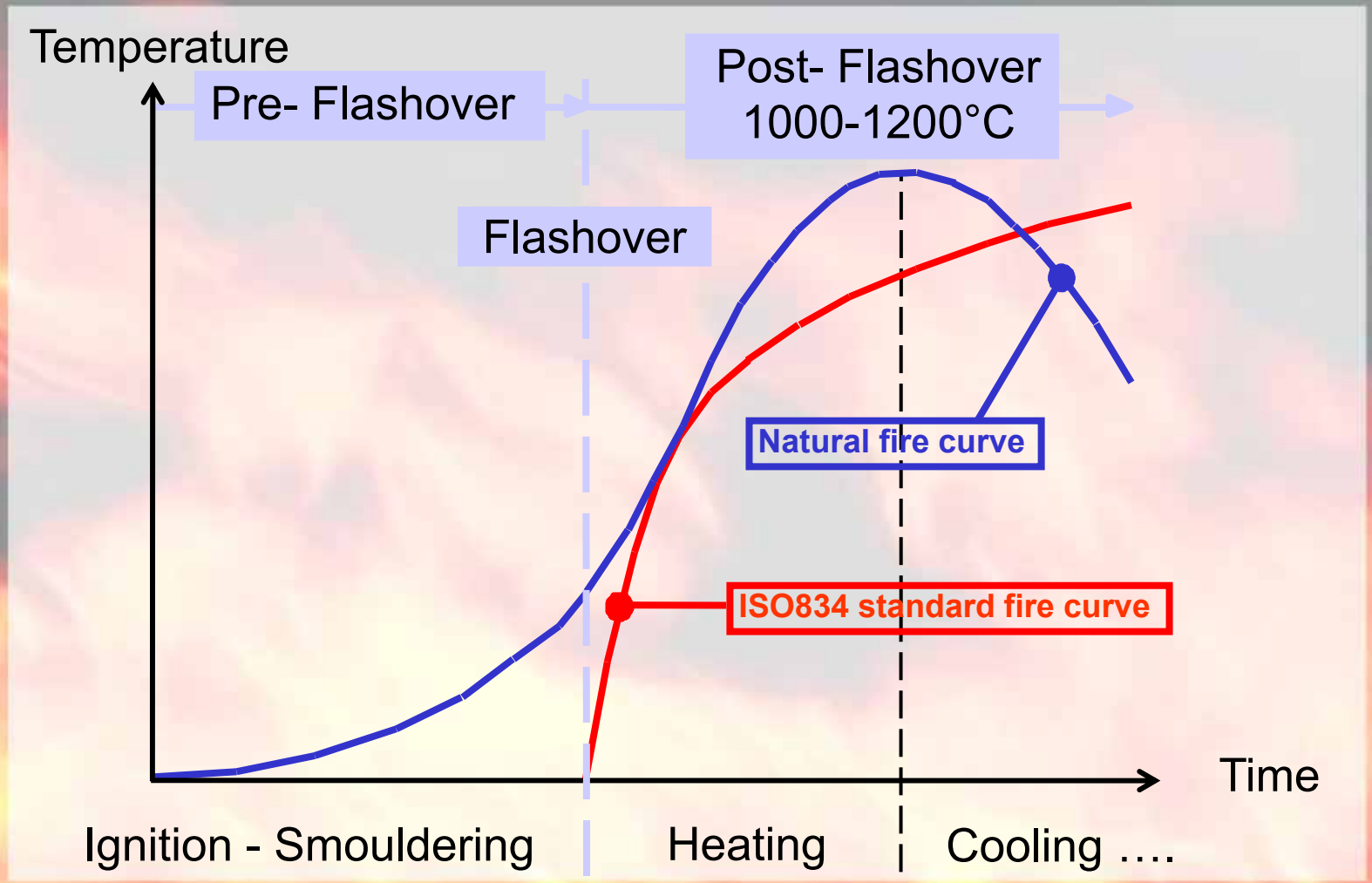
The ISO curve

* Has to be considered in the WHOLE compartment, even if the compartment is huge



* Never goes DOWN
* does not consider the PRE-FLASHOVER PHASE
* Does not depend on FIRE LOAD and VENTILATION CONDITIONS

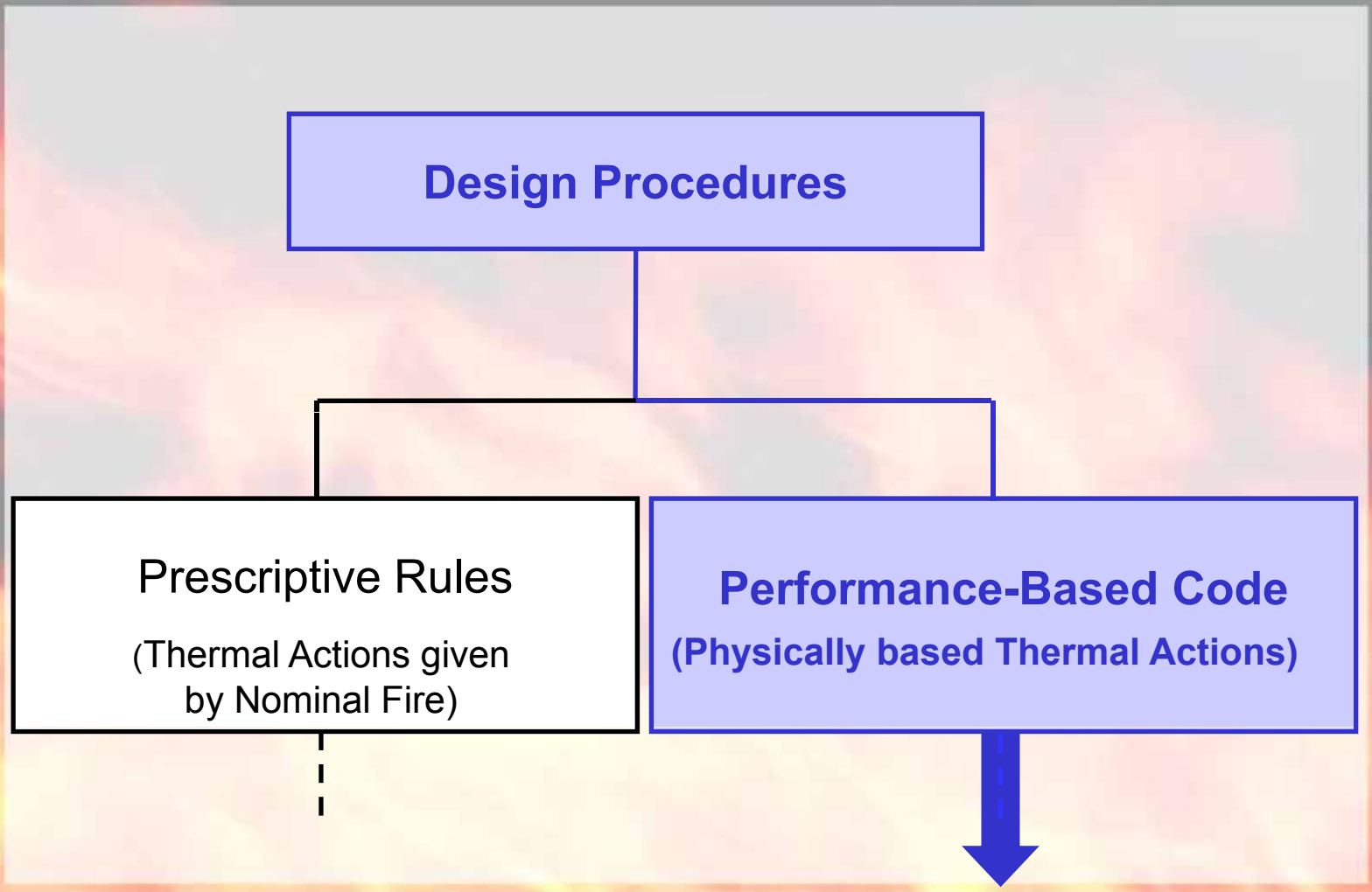
Stages of a Natural Fire and the Standard Fire Curve



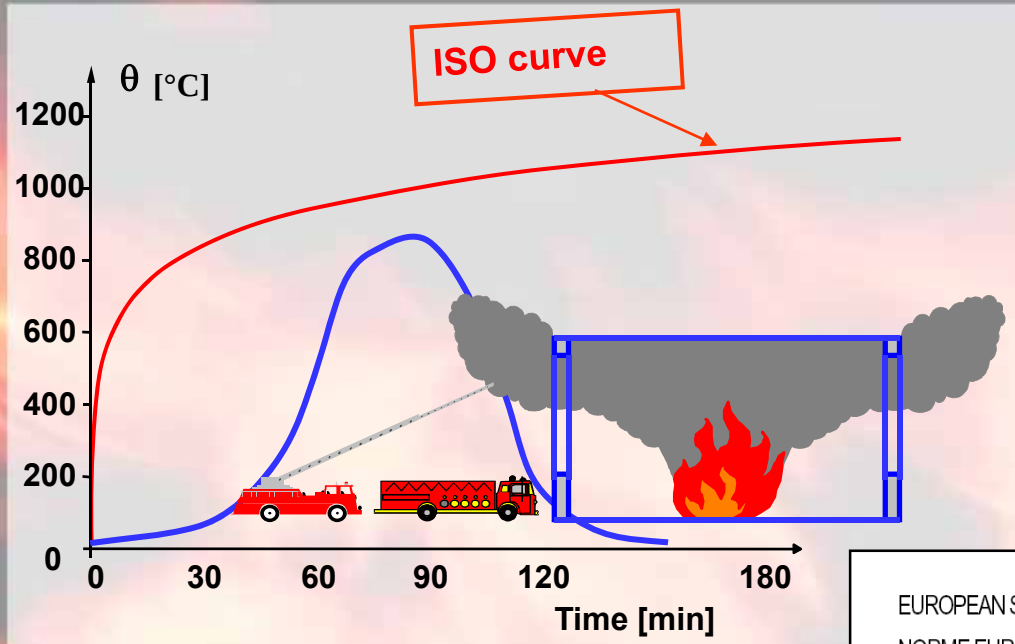
Sprayed Protection

Partially Encased Beams & Columns

Actions on Structures Exposed to Fire
ČSN EN 1991-1-2 - Performance Based Code



Natural Fire Safety Concept



Implemented in:

- ČSN 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

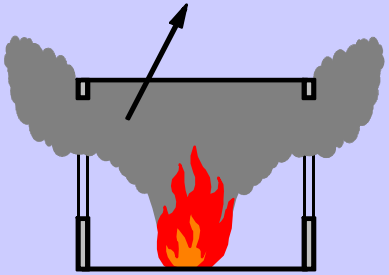
*) Nominal temperature-time curve

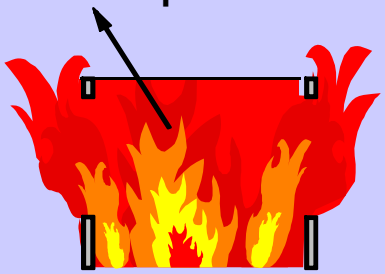
Standard temperature-, External fire - & Hydrocarbon fire curve

No data needed

*) Simplified Fire Models

Localised Fire	Fully Engulfed Compartment	
- HESKESTADT - HASEMI	- Parametric Fire	Rate of heat release Fire surface Boundary properties Opening area Ceiling height
θ (x, y, z, t)	θ (t) uniform in the compartment	





*) Advanced Fire Models

+

- Two-Zone Model
- One-Zone Model
- Combined Two-Zones and One-Zone fire
- CFD

Exact geometry

List of needed Physical Parameters for Natural Fire Model

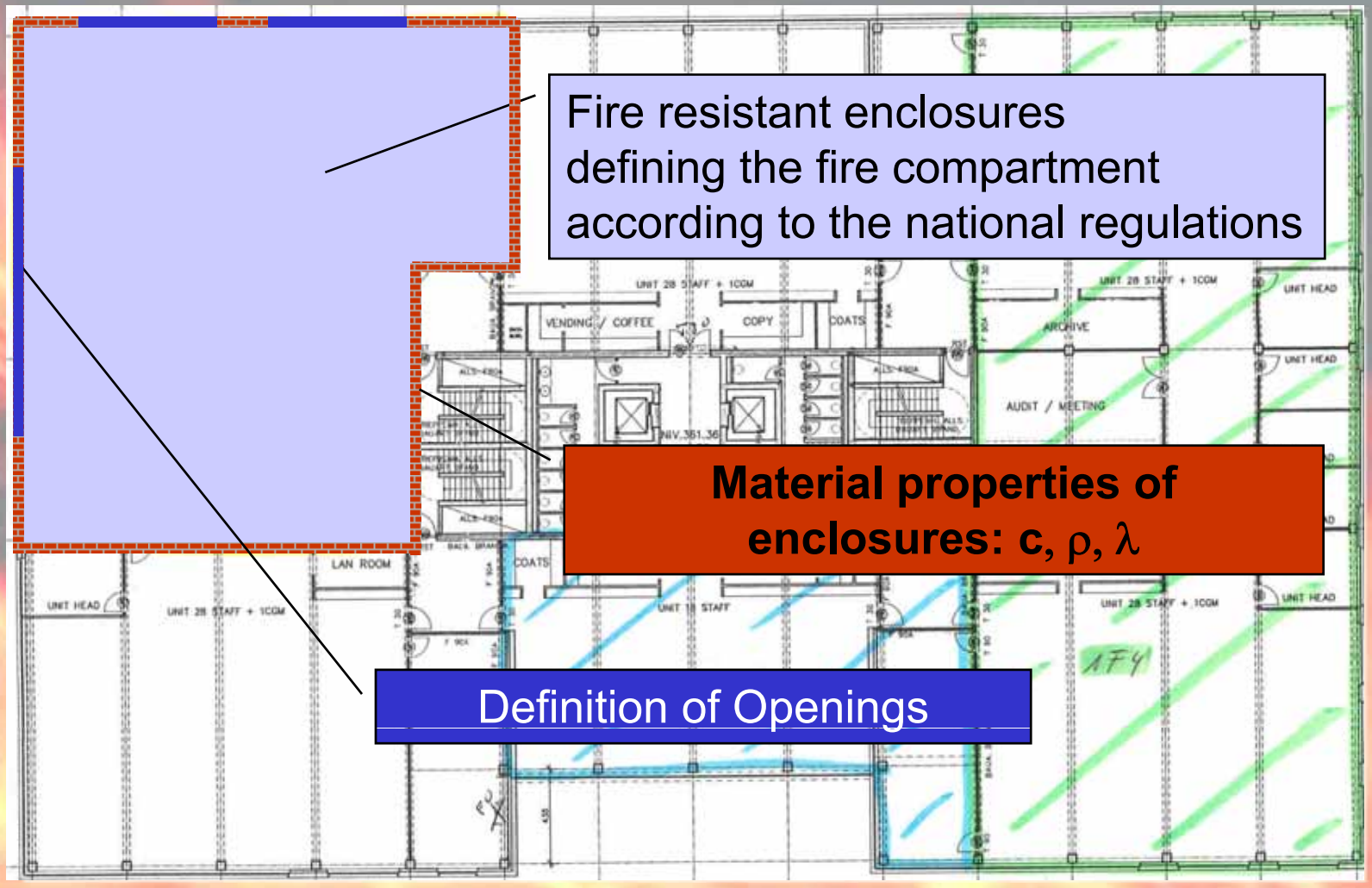
- Boundary properties
- Ceiling height
- Opening Area

} Geometry

- Fire surface
- Rate of heat release

} Fire

Characteristics of the Fire Compartment



Characteristic of the Fire for Different Buildings

Occupancy	Fire Growth Rate	RHR q_f [kW/m²]	Fire Load $q_{f,k}$ 80% fractile [MJ/m²]
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

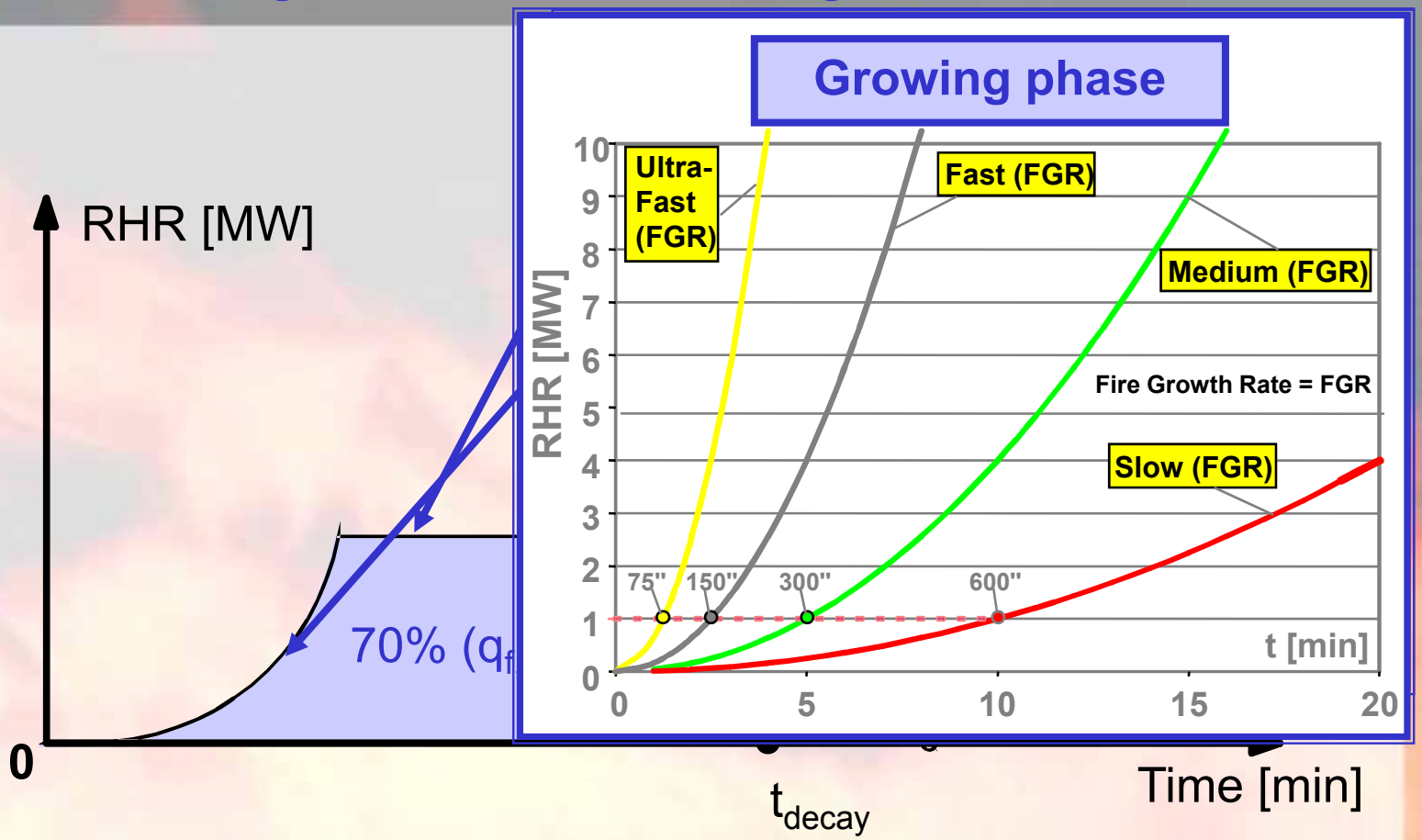
Compartment floor area A_f [m²]	Danger of Fire Activation δ_{q1}	Danger of Fire Activation δ_{q2}	Examples of Occupancies
25	1,10	0,78	Art gallery, museum, swimming pool
250	1,50	1,00	Residence, hotel, office
2500	1,90	1,22	Manufactory for machinery & engines
5000	2,00	1,44	Chemical laboratory, Painting 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

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

*) Nominal temperature-time curve

Standard temperature-, External fire - & Hydrocarbon fire curve

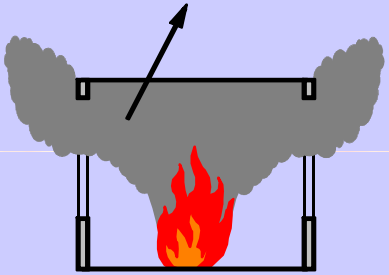
No data needed

*) Simplified Fire Models

Localised Fire

- HESKESTADT
- HASEMI

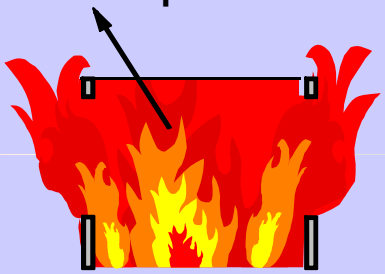
θ (x, y, z, t)



Fully Engulfed Compartment

- Parametric Fire

θ (t) uniform in the compartment



Rate of heat release
Fire surface
Boundary properties
Opening area
Ceiling height

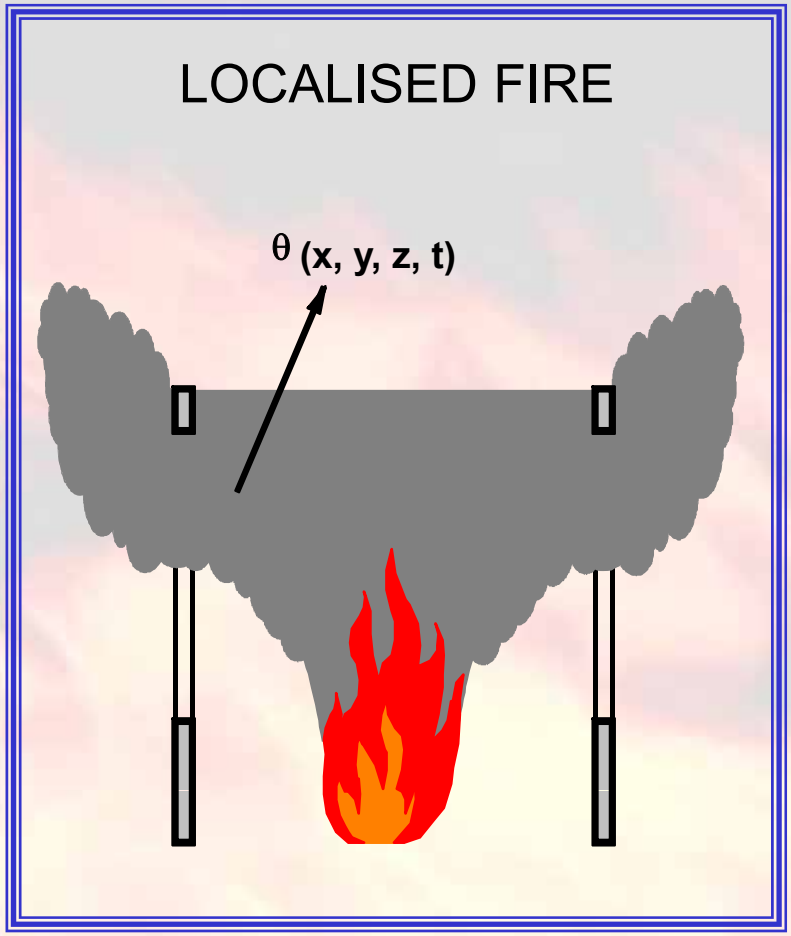
*) Advanced Fire Models

- Two-Zone Model
- One-Zone Model
- Combined Two-Zones and One-Zone fire
- CFD

\+

Exact geometry

Simplified Fire Models
Localised Fire



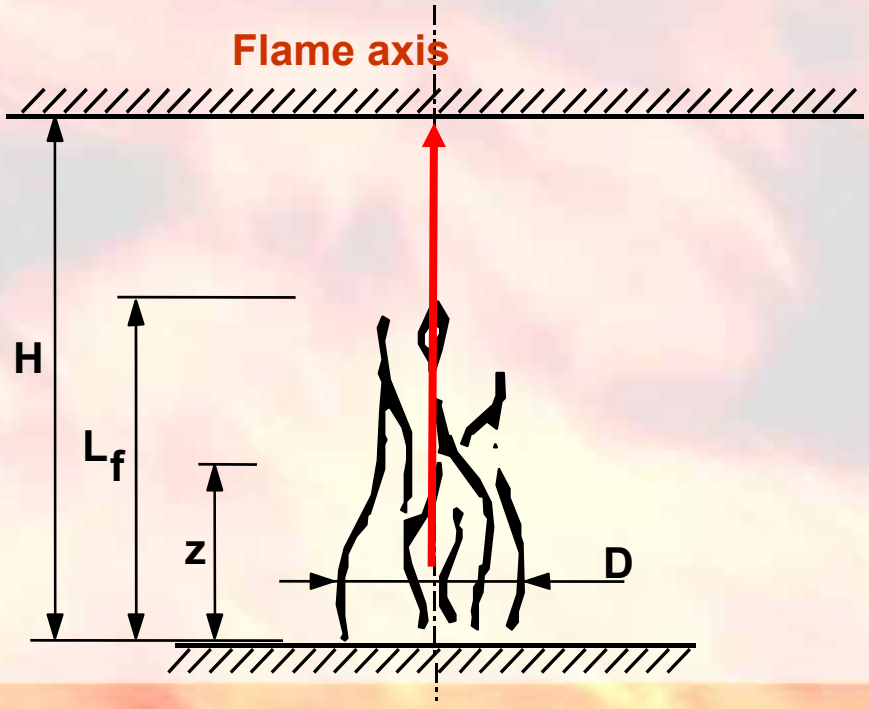
Localised fire test

Localised Fire: HESKESTAD Method

Annex C of ČSN EN 1991-1-2:

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

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



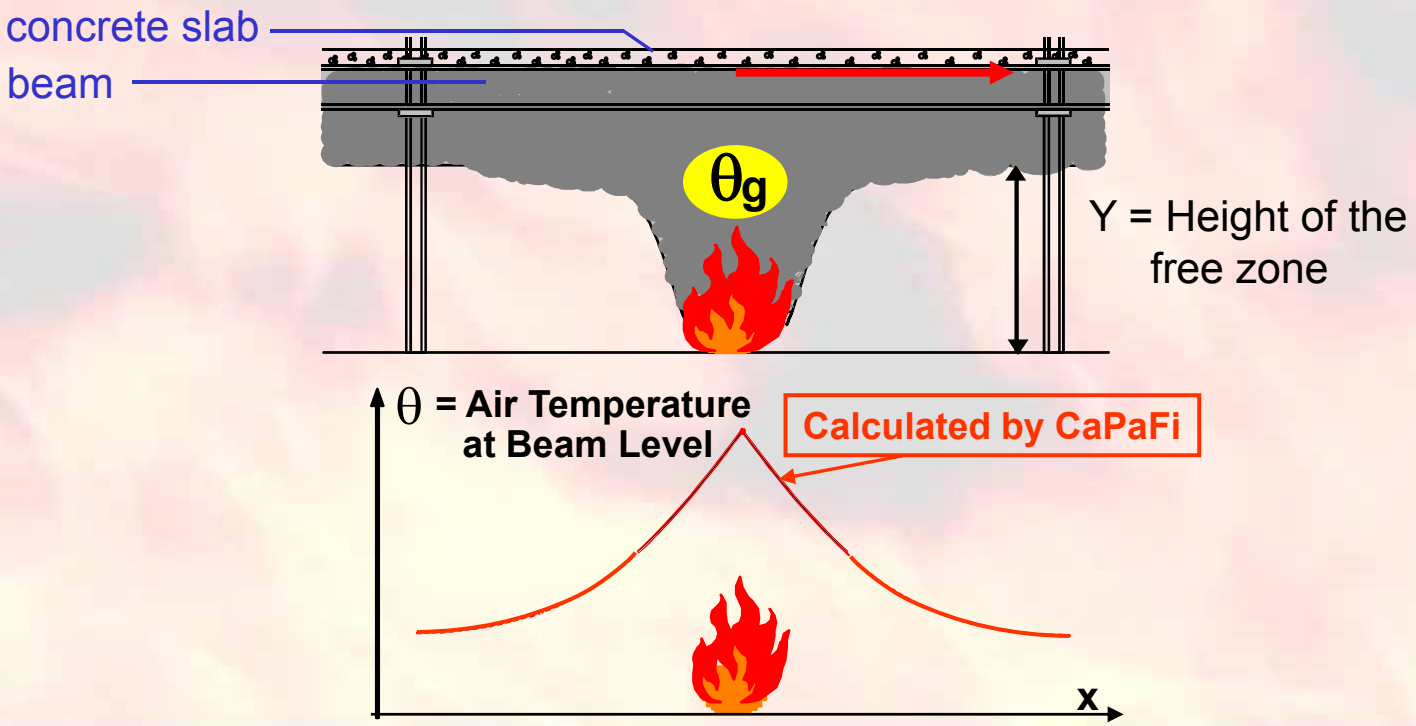
The flame length L_f of a localised fire is given by :

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

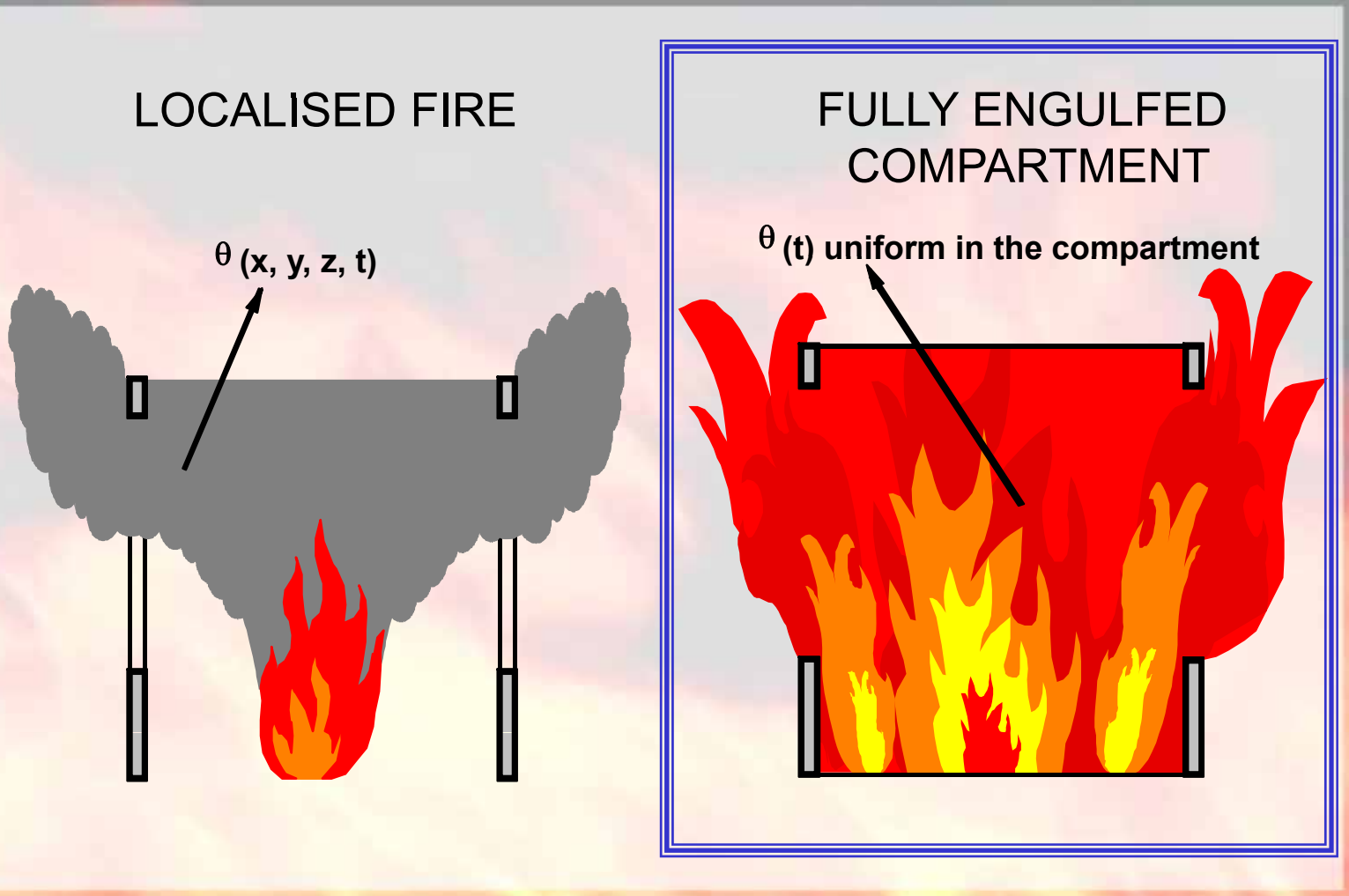
Localised Fire: HASEMI Method

Annex C of ČSN EN 1991-1-2:

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



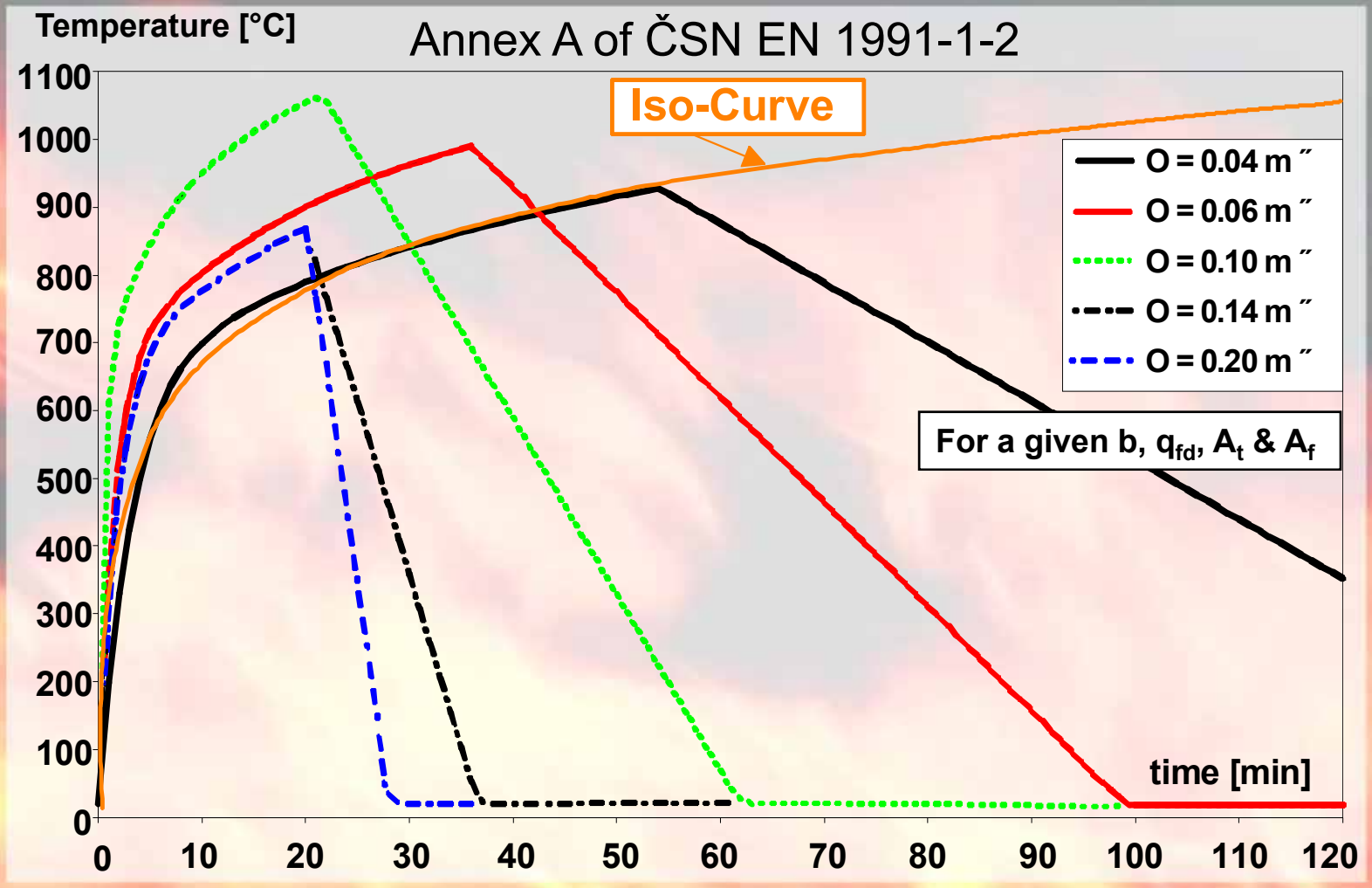
Simplified Fire Models
Fully Engulfed Compartment



Real Fire Test Simulating an Office Building

Fully engulfed fire

Fully Engulfed Compartment
Parametric Fire



Natural Advanced Fire Model

*) Nominal temperature-time curve

Standard temperature-, External fire - & Hydrocarbon fire curve

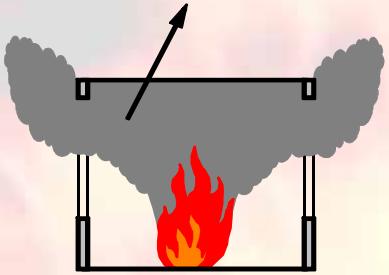
No data needed

*) Simplified Fire Models

Localised Fire

- HESKESTADT
- HASEMI

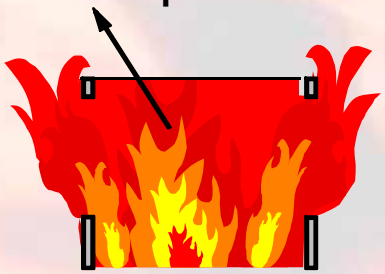
θ (x, y, z, t)



Fully Engulfed Compartment

- Parametric Fire

θ (t) uniform in the compartment



Rate of heat release
Fire surface
Boundary properties
Opening area
Ceiling height

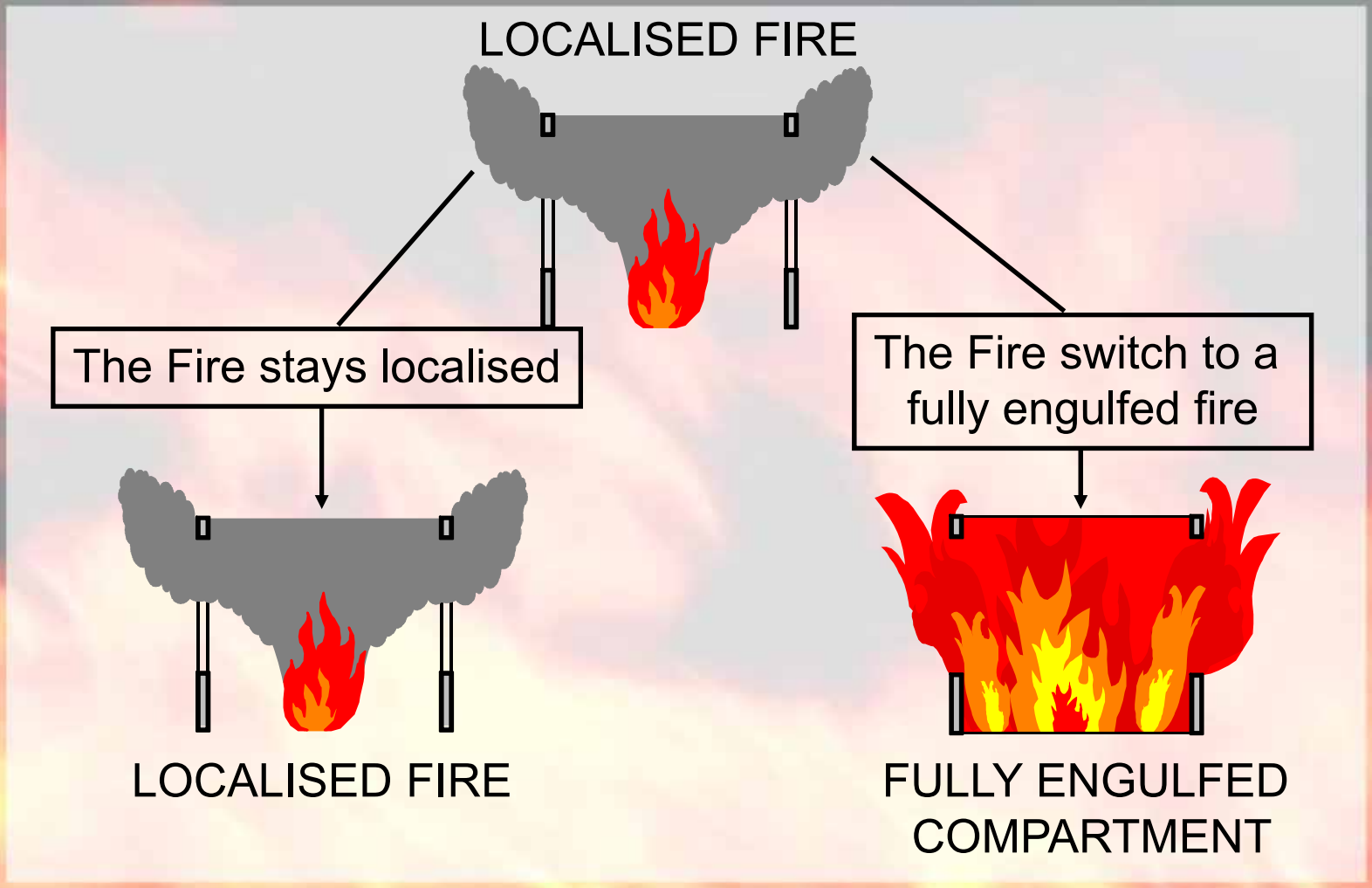
*) Advanced Fire Models

- Two-Zone Model
- One-Zone Model
- Combined Two-Zones and One-Zone fire
- CFD

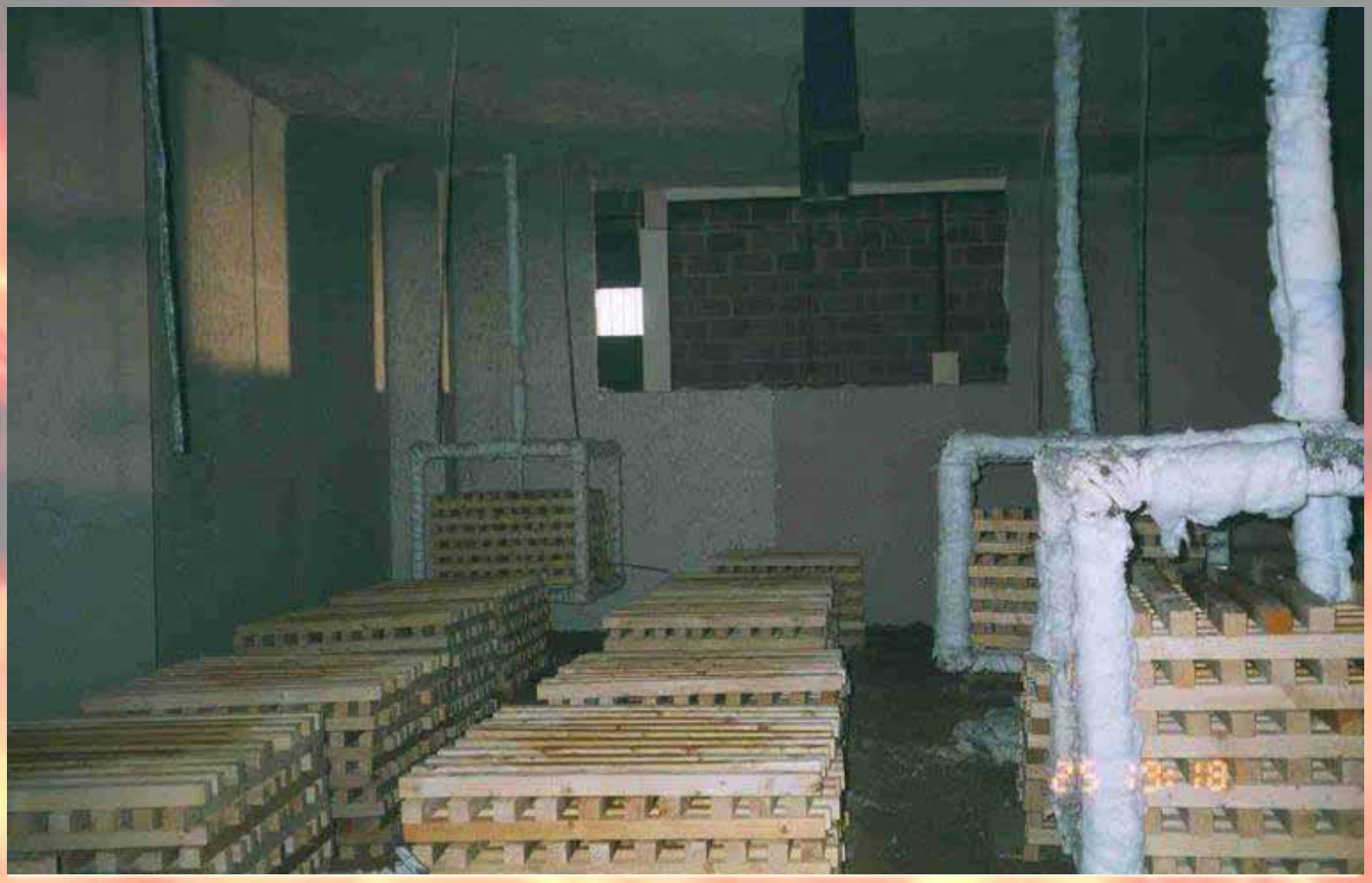
\+

Exact geometry

Advanced fire Models



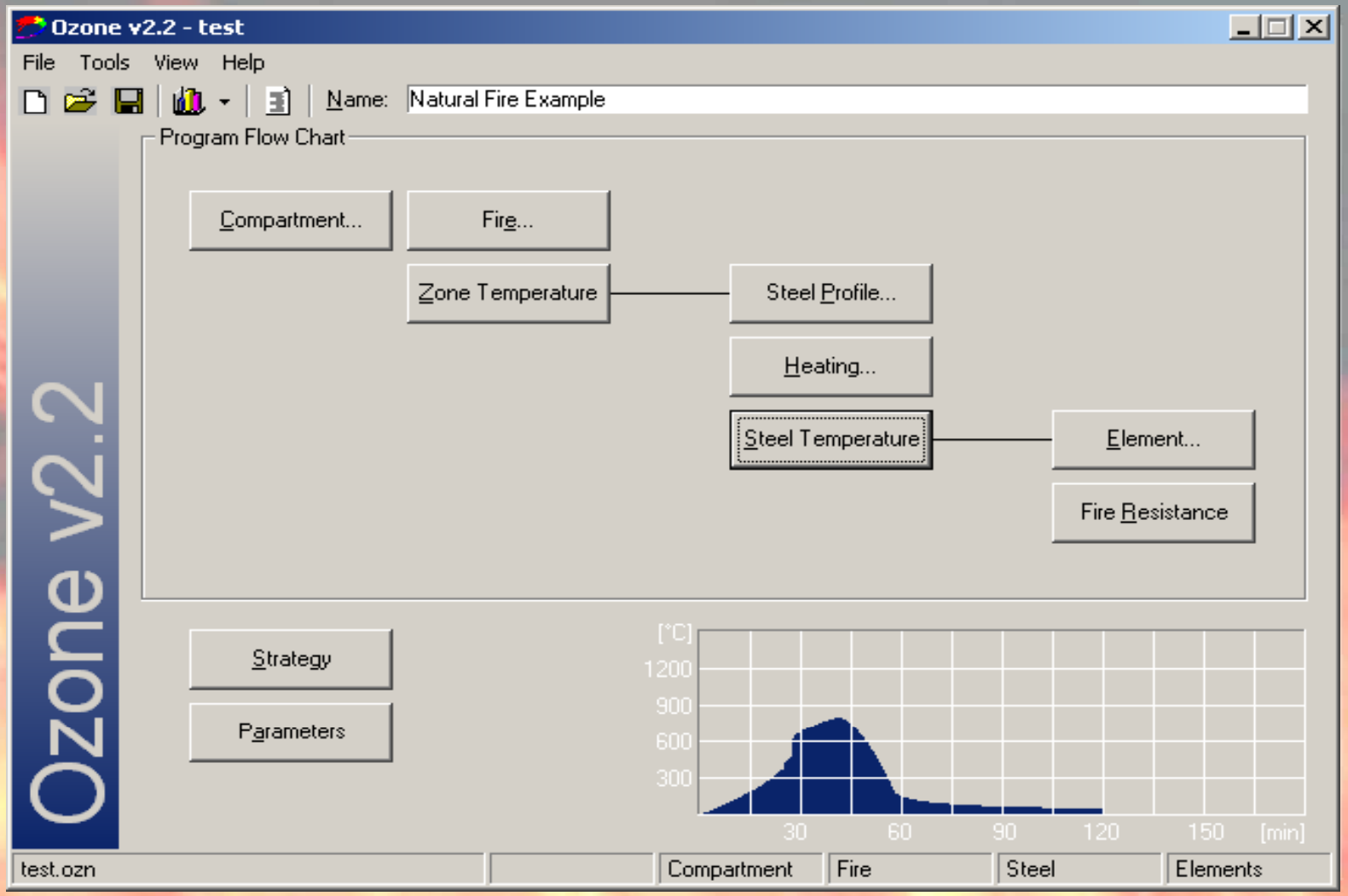
Large Compartment Test
Fire Load



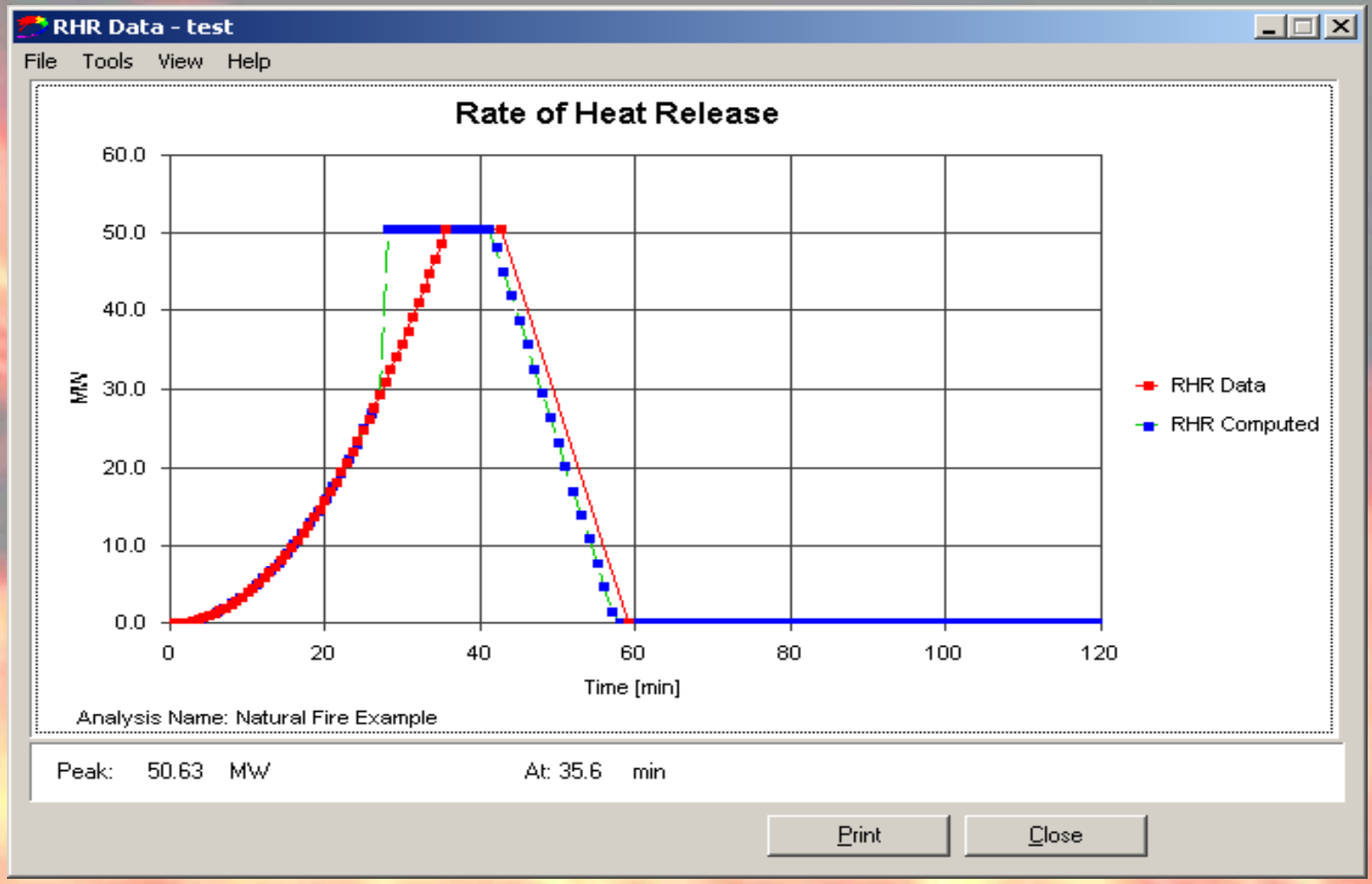
Large Compartment Test
External Flaming During the Test

Large Compartment Test
After the Test

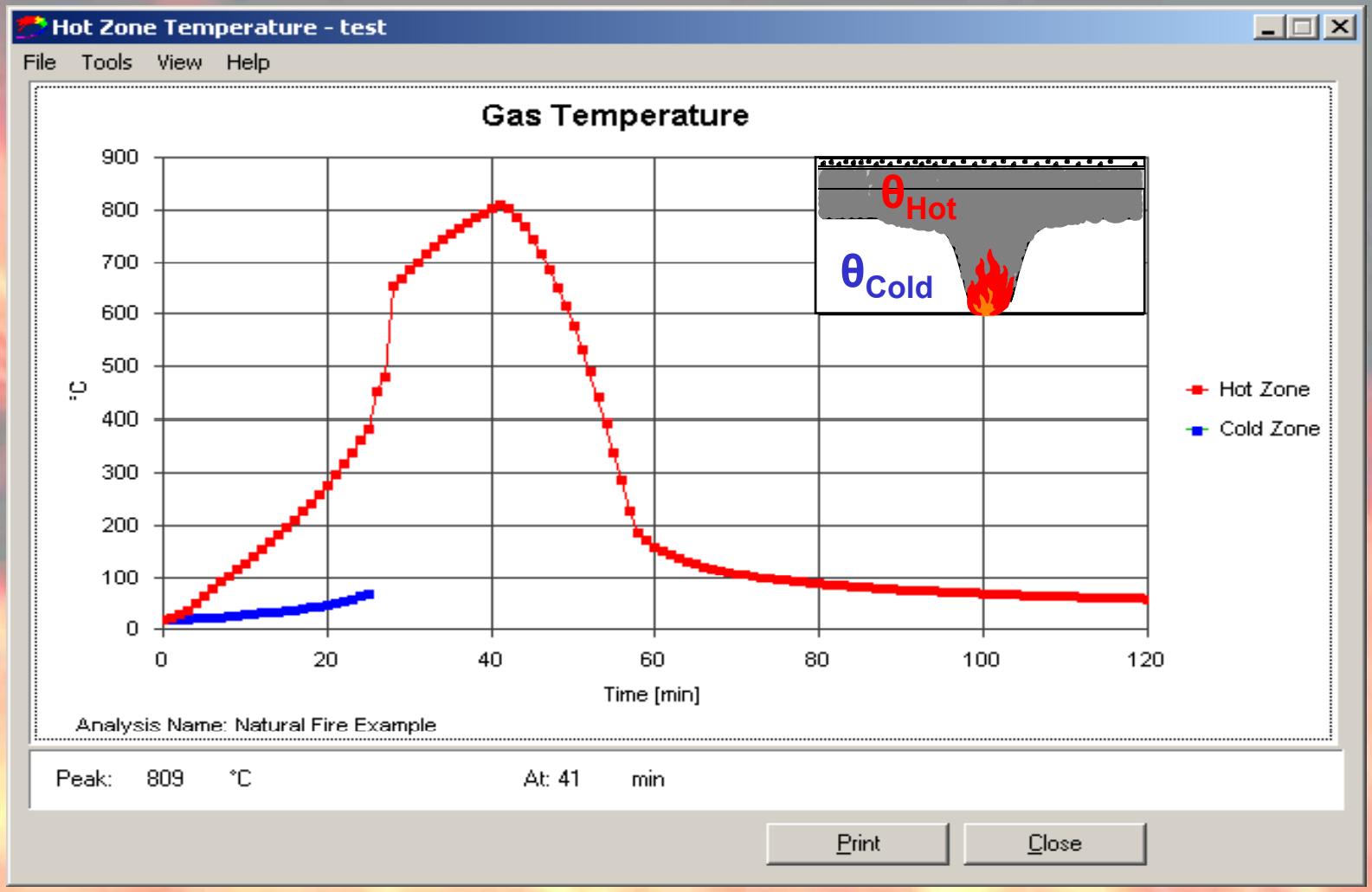
Two Zone Calculation Software “OZone V2.2”



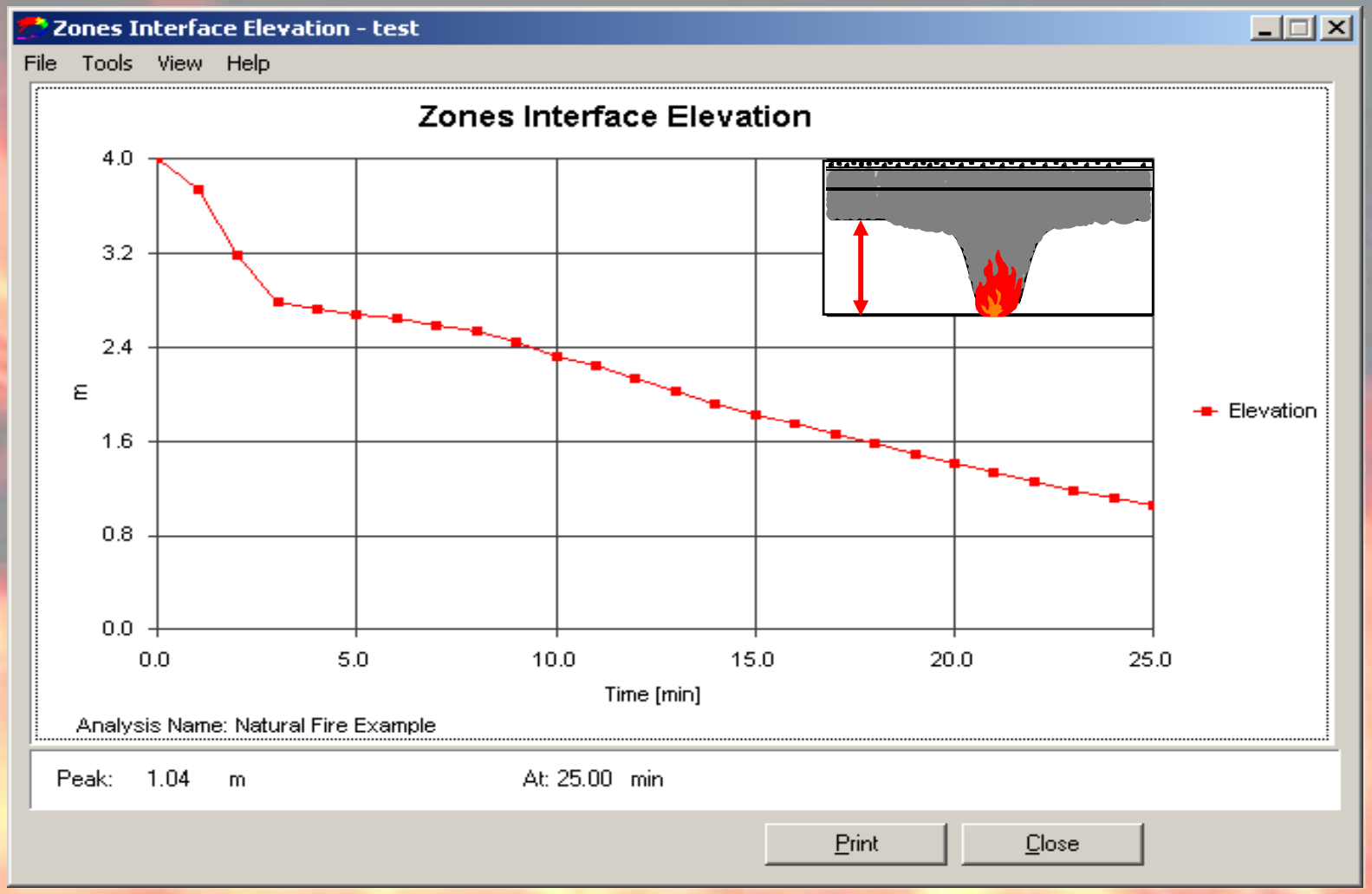
OZone results: Input and Computed RHR



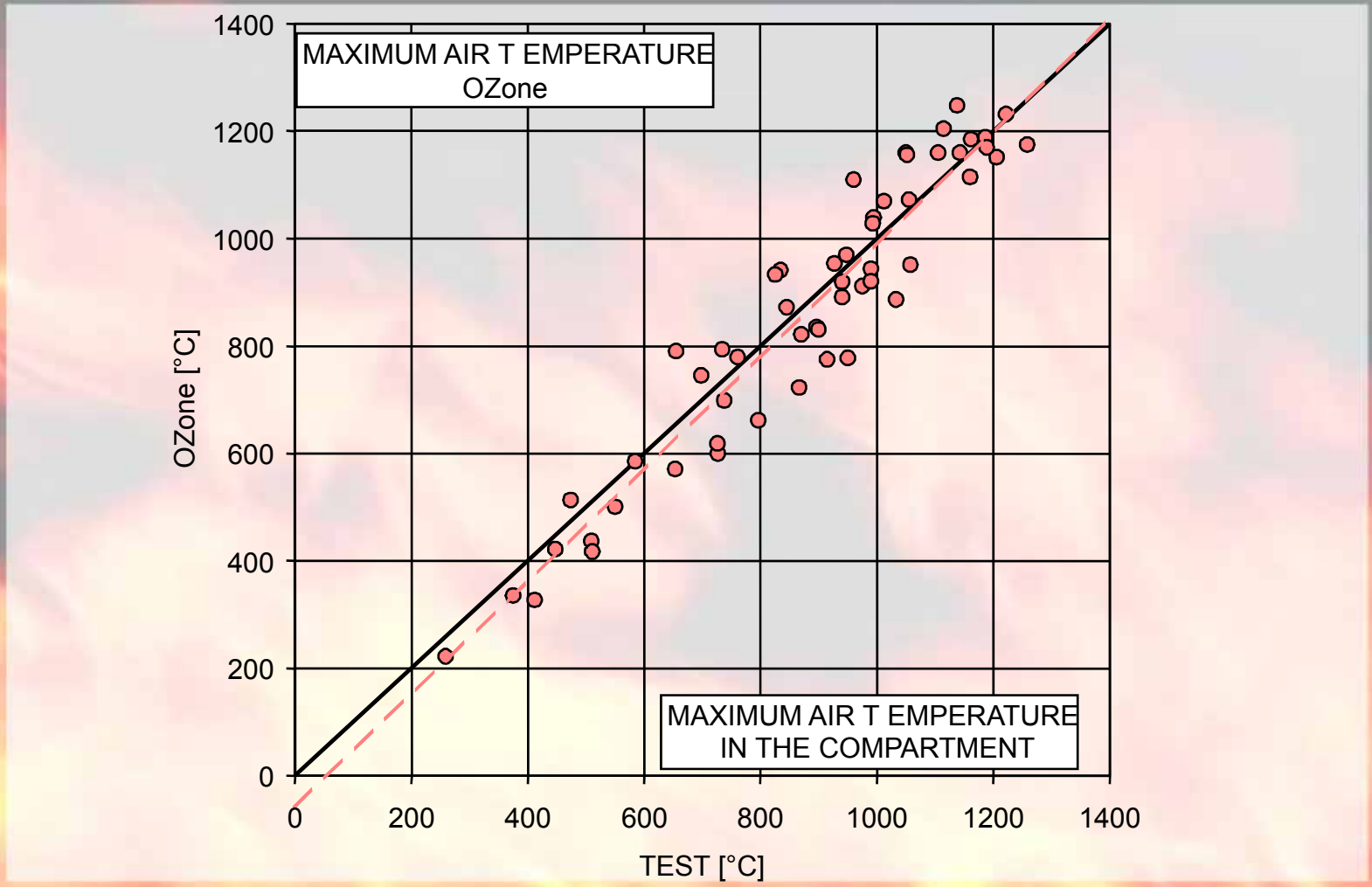
OZone results: Gas Temperatures



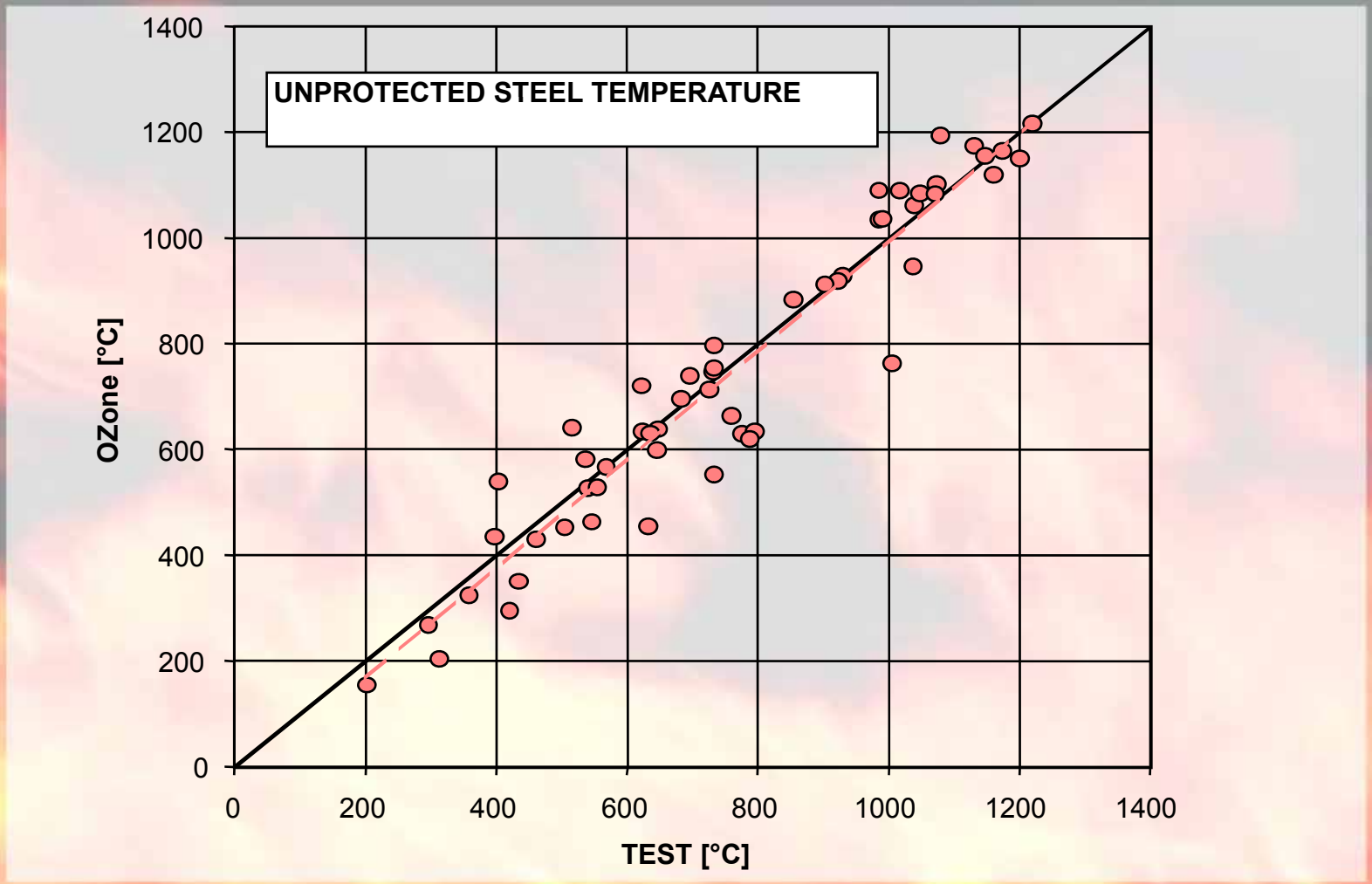
OZone results: Smoke Layer Thickness



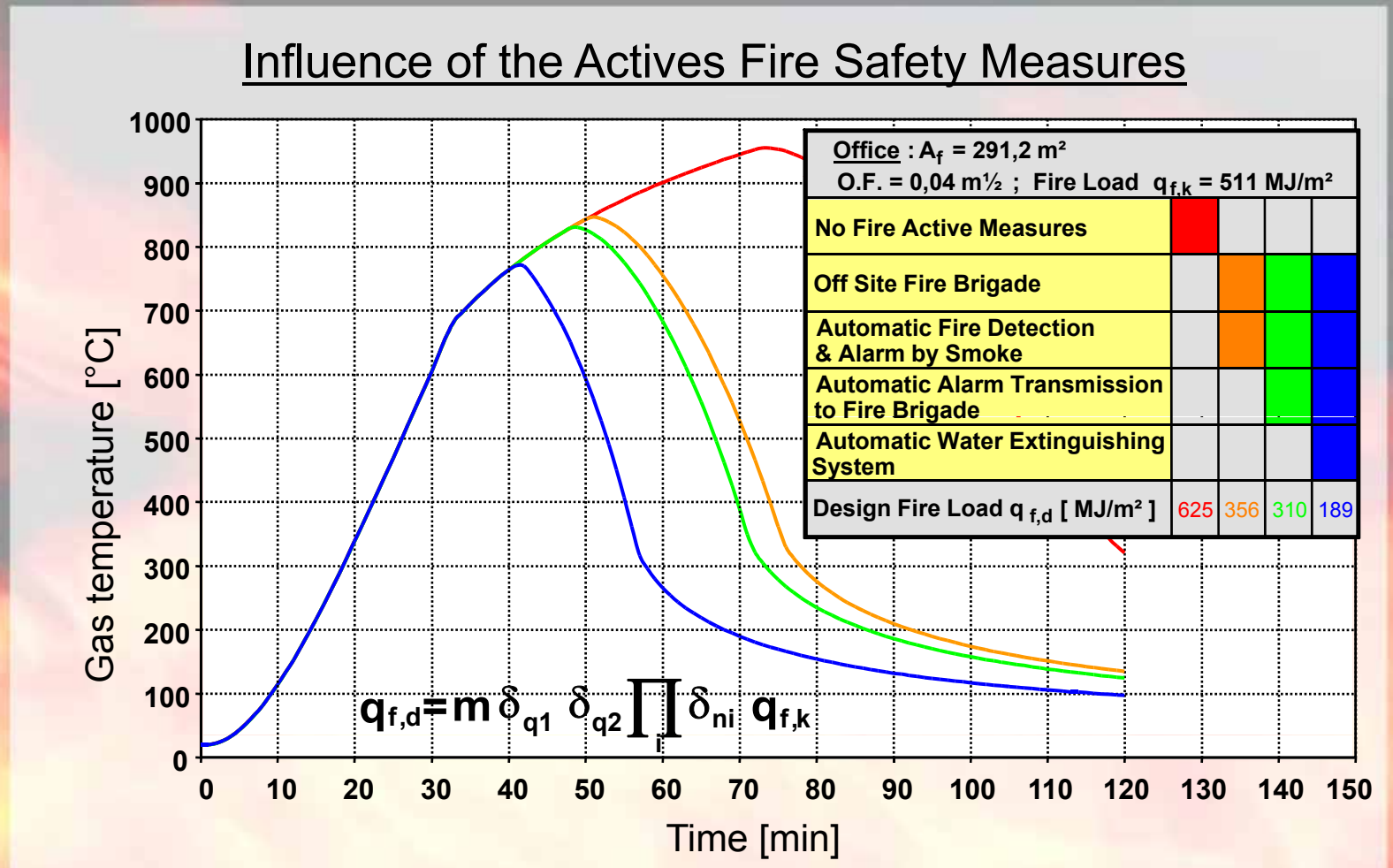
Calibration of Software OZone: Gas Temp



Calibration of Software OZone: Steel Temp

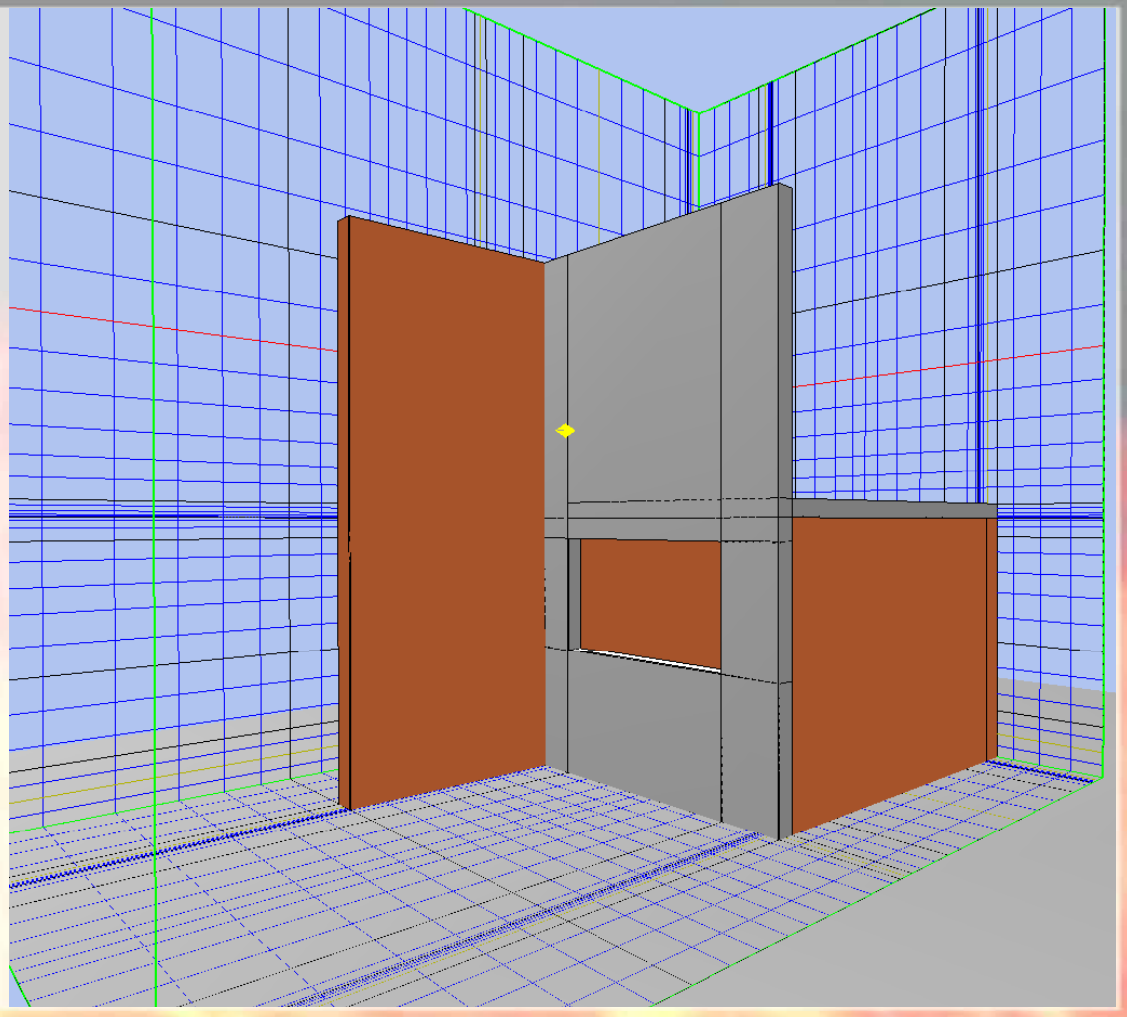


OZone: Case Study

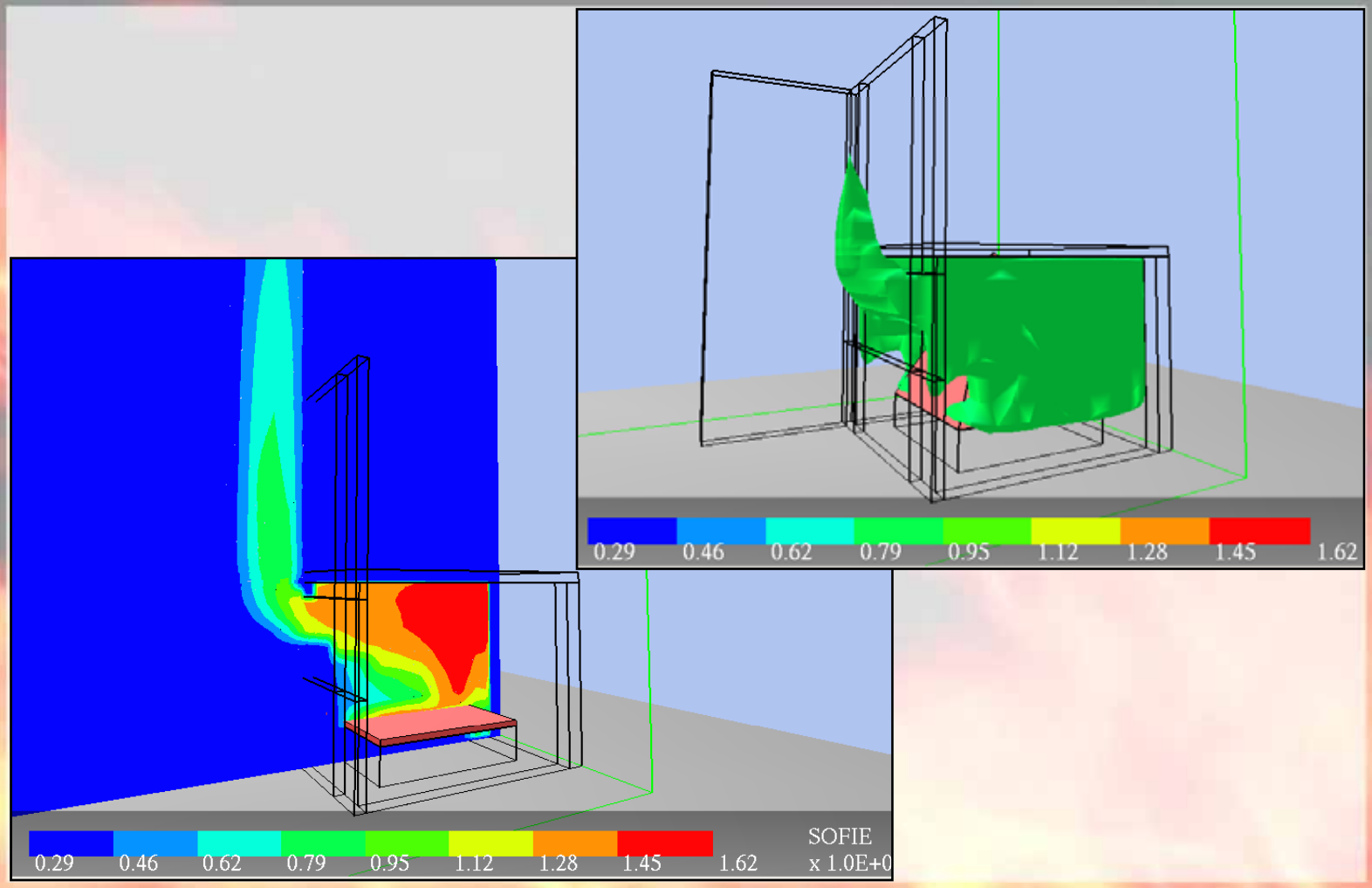


Computer Fluid Dynamics: Software Sofie

Grid definition



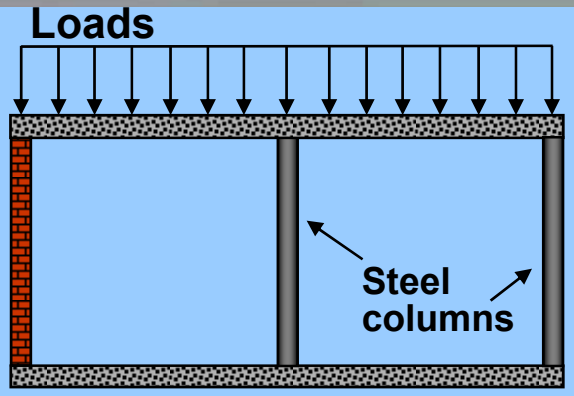
Sofie Results: Gas Temperatures



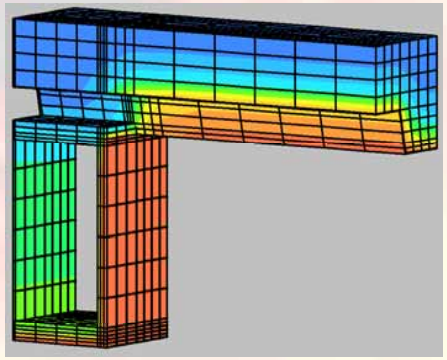
Resistance to Fire - Chain of Events

1: Ignition

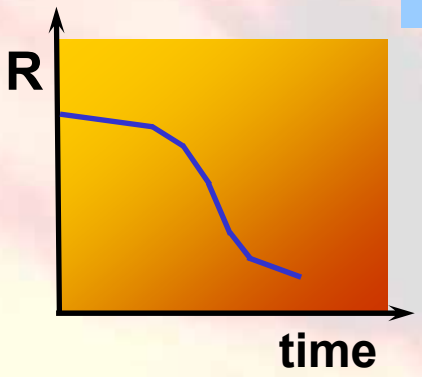
2: Thermal action



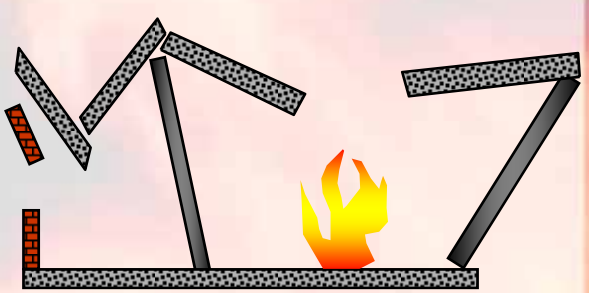
3: Mechanical actions



4: Thermal response

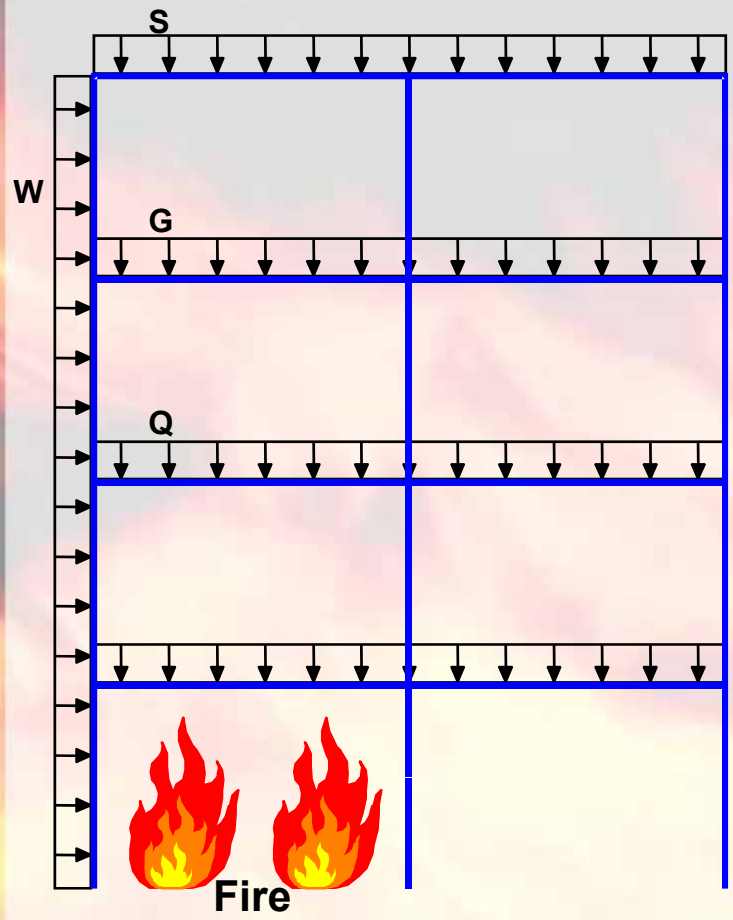


5: Mechanical response



6: Possible collapse

Basis of Design and Actions on Structures



ACTIONS

Actions for temperature analysis
Thermal Action

FIRE

Actions for structural analysis
Mechanical Action

Dead Load	G
Imposed Load	Q
Snow	S
Wind	W

Combination Rules for Mechanical Actions ČSN 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

$$E_d = 1{,}35\ G + 1{,}5\ Q + 0{,}6 \bullet 1{,}5\ W + 0{,}5 \bullet 1{,}5\ S$$

Combination Rules for Mechanical Actions ČSN EN 1990: Basis of Structural Design

Fire conditions ≡ Accidental situation

$$E_{fi,d} = G + \psi_{1or2,1} Q_1 + \sum_{i>1} \psi_{1or2,i} Q_i$$

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

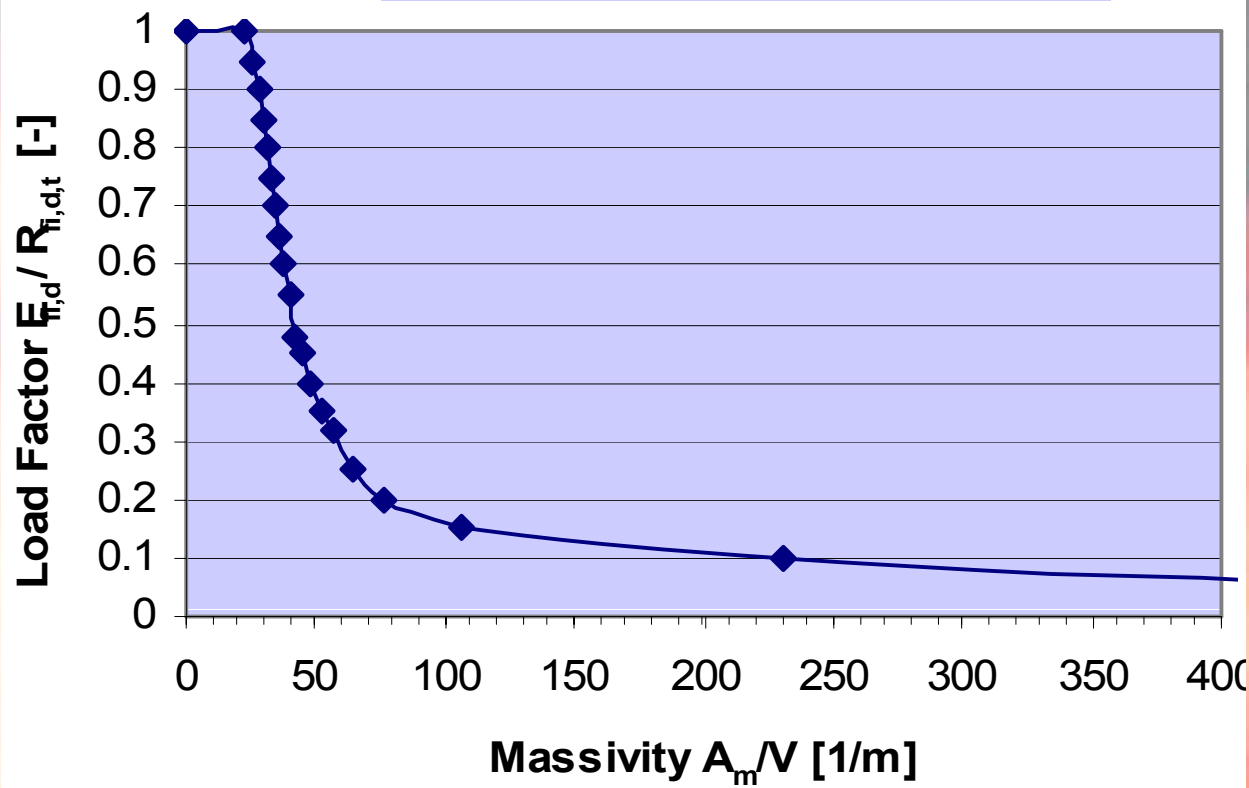
Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see ČSN EN 1991-1.1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category 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 ČSN 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 ČSN EN 1991-1.4)	0,6	0,2	0
Temperature (non-fire) in buildings (see ČSN EN 1991-1.5)	0,6	0,5	0

(Reference : ČSN EN 1990 - 2004)

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



National Annex to ČSN EN 1991-1-2

- Annex **normative** for buildings located in the Czech Republic

- Allows to change 10 parameters
  - In 9 cases the values from EN 1993-1-2 are used without any changes
  - In paragraph NA 2.10 is recommended,
    especially by halls for snow and wind load,
    during fire attack to apply the **frequent value** of live load
    $\psi_{1,1} \cdot Q_1$

Thank you for your attention