EN 1991-1-2

Basic design methods
Worked examples

Prof. VASSART Olivier

Chairman of the CEN/TC250 EC1/ Fire E.G.
ArcelorMittal R&D

email: olivier.vassart@arcelormittal.com

Basic design methods of EN1991-1-2

Fire part of Eurocode 1

Following common layout to provide design rules for fire resistance of various types of structures:

- General
  - Scope, application field, definitions, symbols and units
- Basic principles
  - Performances requirements, design values of material properties and assessment approaches
- Material properties
  - Mechanical and thermal properties at elevated temperatures
- Assessment methods for fire resistance
- Constructional details
- Annexes
  - Additional information: common case - more detailed design rules

Fire resistance - European classes

Fire resistance is defined in terms of time as follows:

- Relevant time of fire exposure during which the corresponding fire resistance function of a structure is maintained despite fire actions

According to European standard, 3 criteria to define the fire resistance:

R – load bearing function

E – integrity separating function

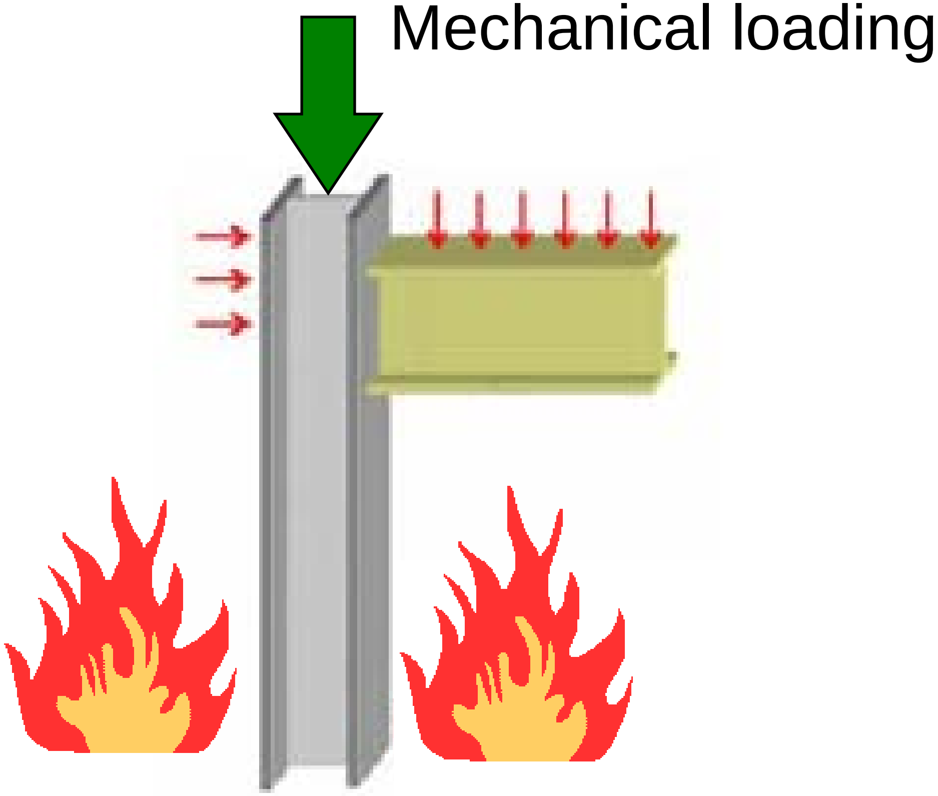
I – thermal insulating separation function

Above criteria may be required individually or in combination:

- separating only: integrity (criterion **E**) and, when requested, insulation (criterion **I**)
- load bearing only: mechanical resistance (criterion **R**)
- separating and load bearing: criteria **R**, **E** and, when requested **I**

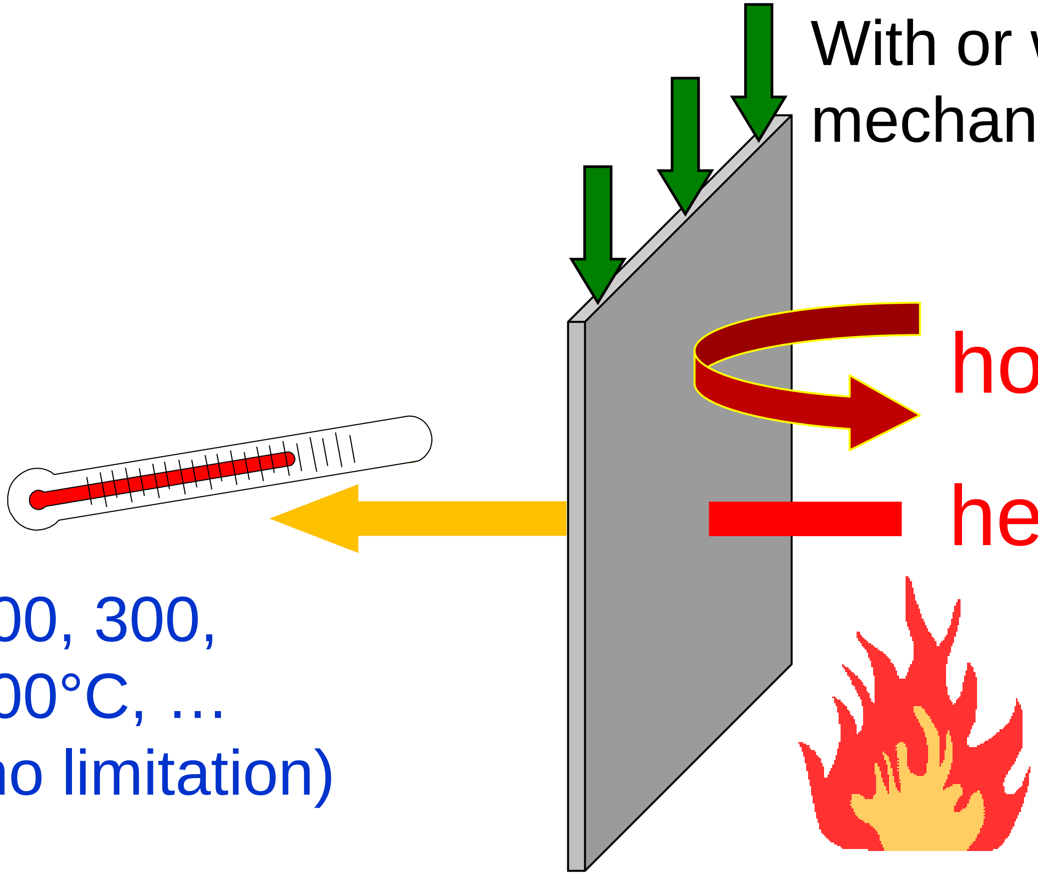
R – load bearing function

Capacity of a structure to maintain its required mechanical resistance in case of fire



E – integrity separating function

Capacity of a structure to maintain its required integrity separating function to hot gases in case of fire

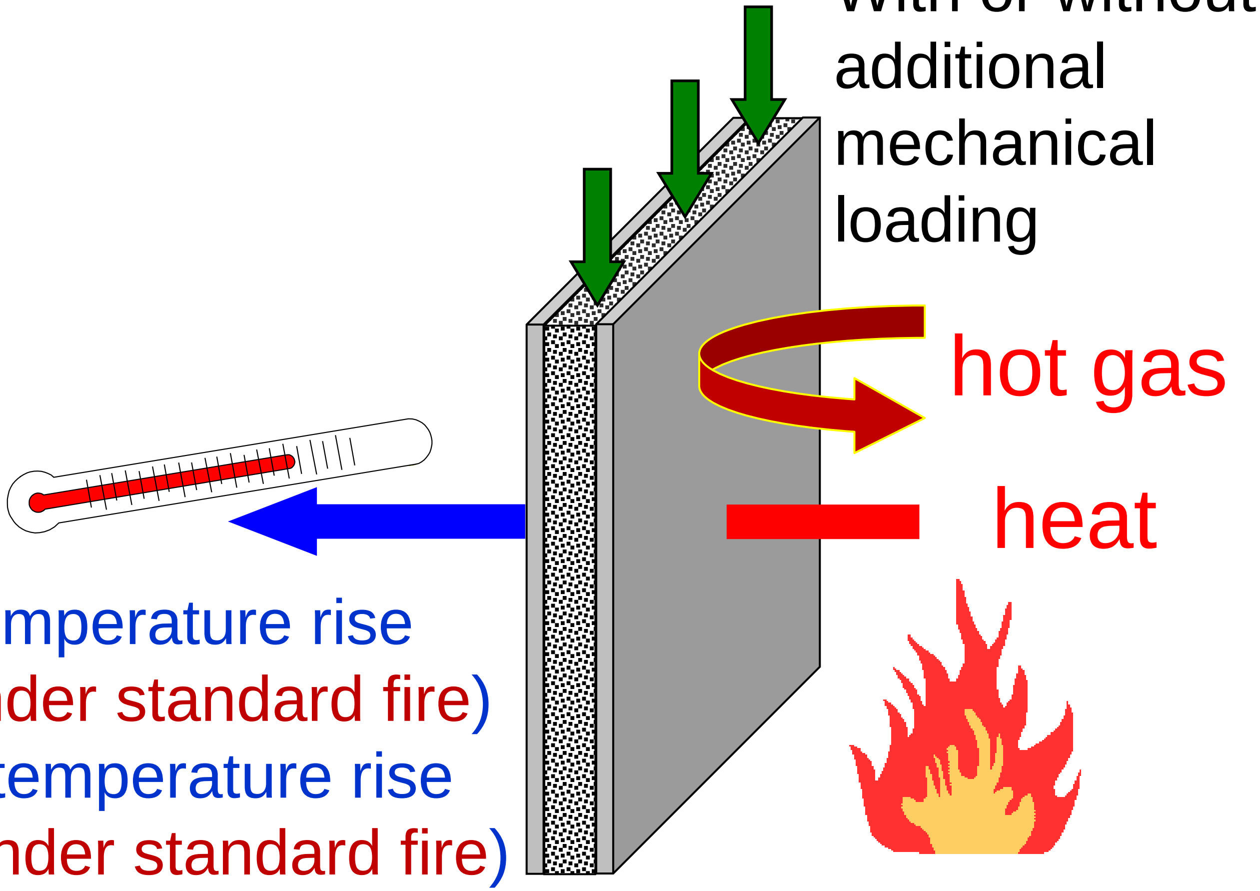


Fire resistance - European classes

European Commission

I – thermal insulation separating function

Capacity of a structure to maintain its required thermal insulation separating function in case of fire

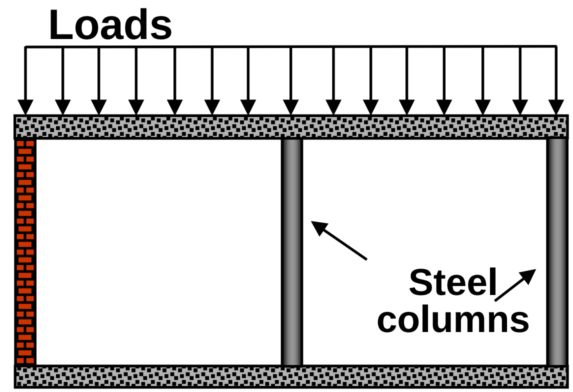


Average temperature rise
≤140 K (under standard fire)
Maximum temperature rise
≤ 180 K (under standard fire)

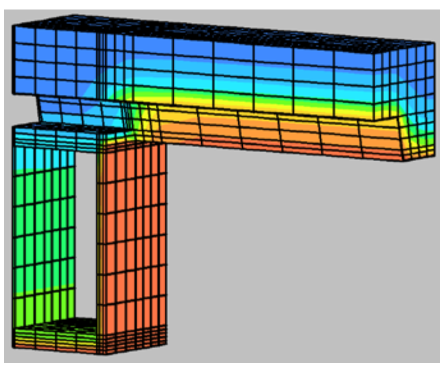
Resistance to Fire - Chain of Events

1: Ignition

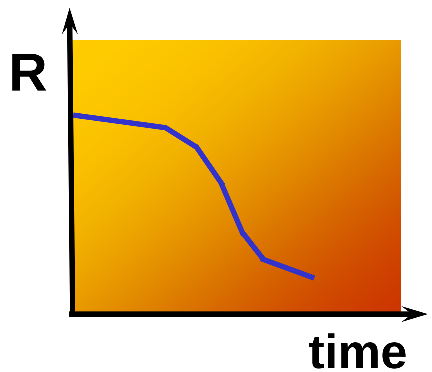
2: Thermal action



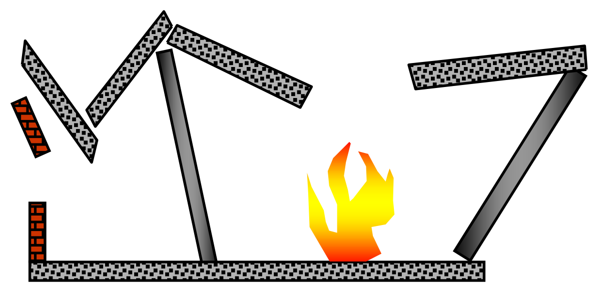
3: Mechanical actions



4: Thermal response

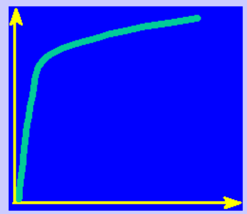
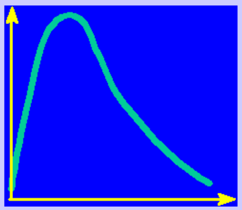
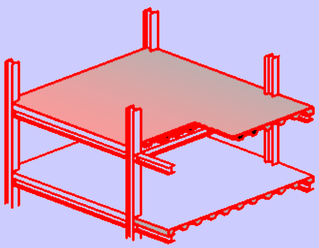


5:Mechanical response



6: Possible collapse

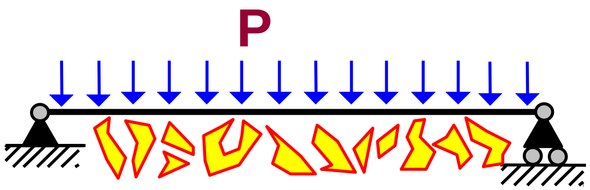
Structural Fire Safety Engineering vs. Classification

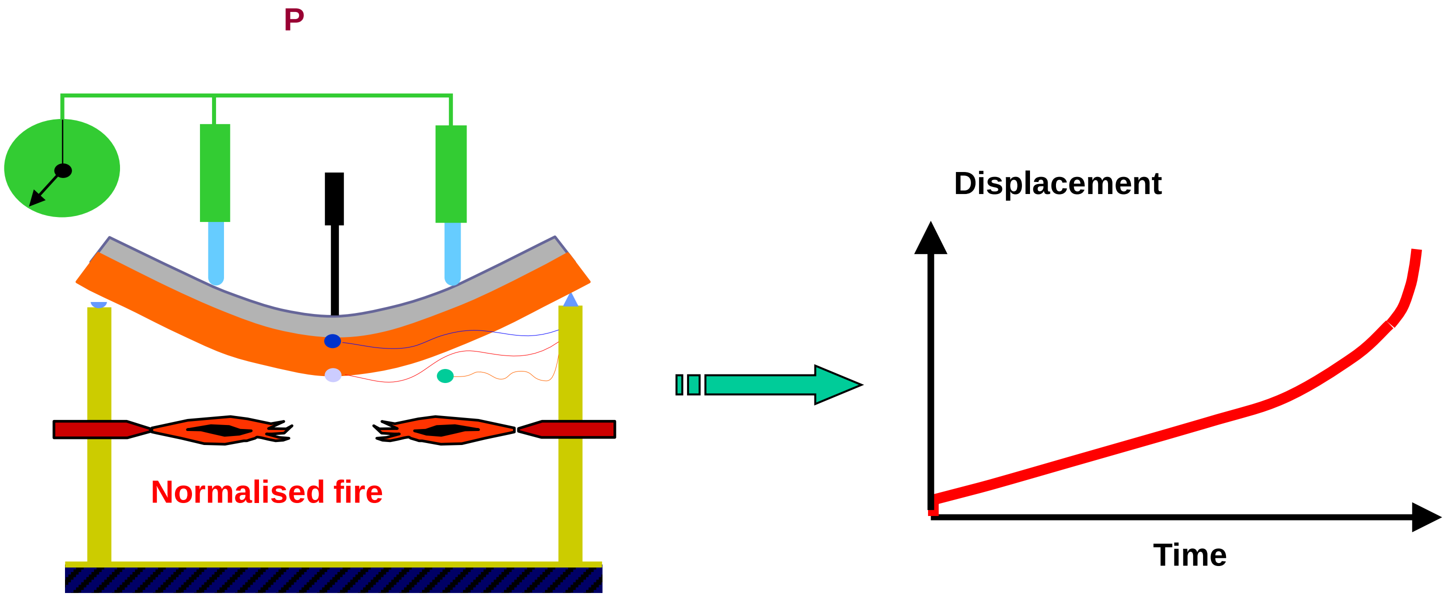
	Prescriptive	Performance based
	standard fire 	natural fire 
	classification	fire safety eng.
	fire safety eng.	fire safety eng.

❑Objective of the classification

- ➢Describe the Thermal and mechanical behaviour of structures subjected to fire

❑Means





Structural Fire Safety Engineering vs. Classification

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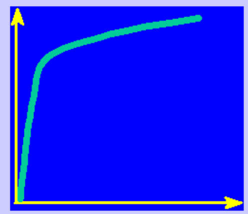
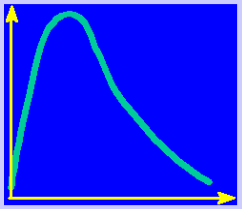
	standard fire 	natural fire 
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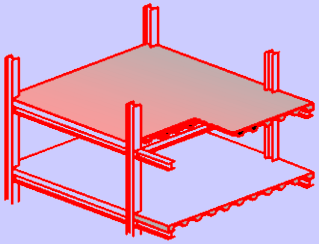
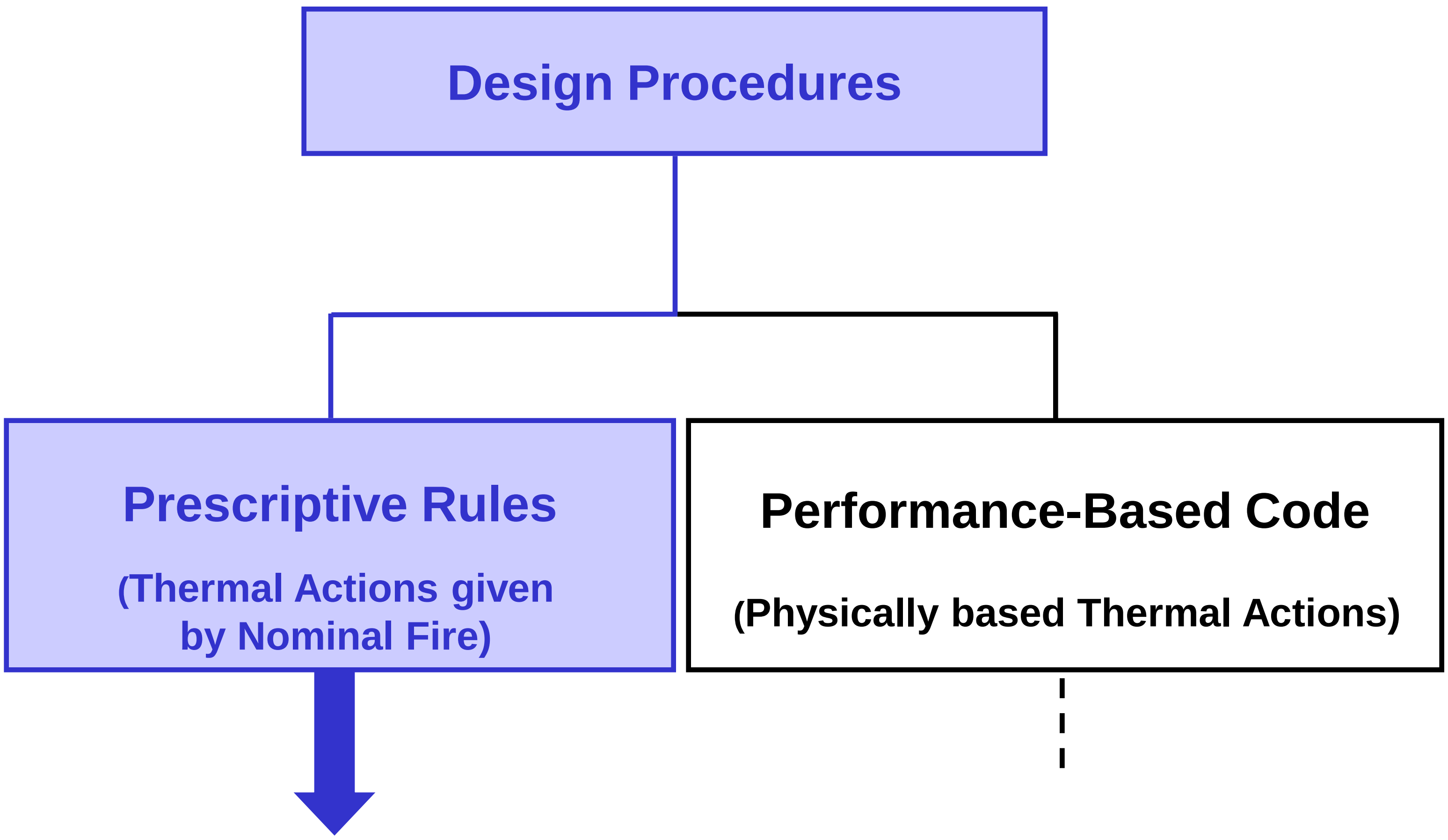
	fire safety eng.	fire safety eng.


Design Procedures
Prescriptive Rules
(Thermal Actions given by Nominal Fire)
Performance-Based Code
(Physically based Thermal Actions)

Nominal Temperature-Time Curve

***) Nominal temperature-time curve**

Standard temperature-, External fire - & Hydrocarbon fire curve

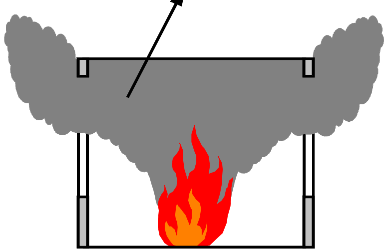
No data needed

***) Simplified Fire Models**

Localised Fire

- HESKESTADT
- HASEMI

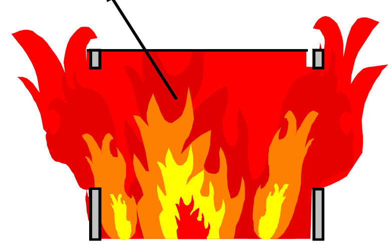
θ (x, y, z, t)



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**

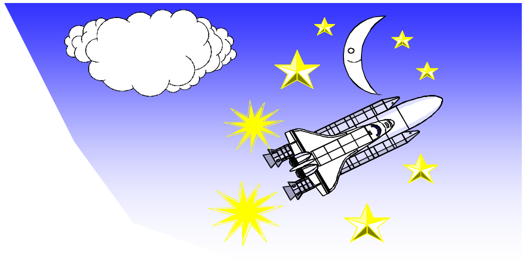
- Two-Zone Model
- One-Zone Model
- Combined Two-Zones and One-Zone fire
- CFD

+

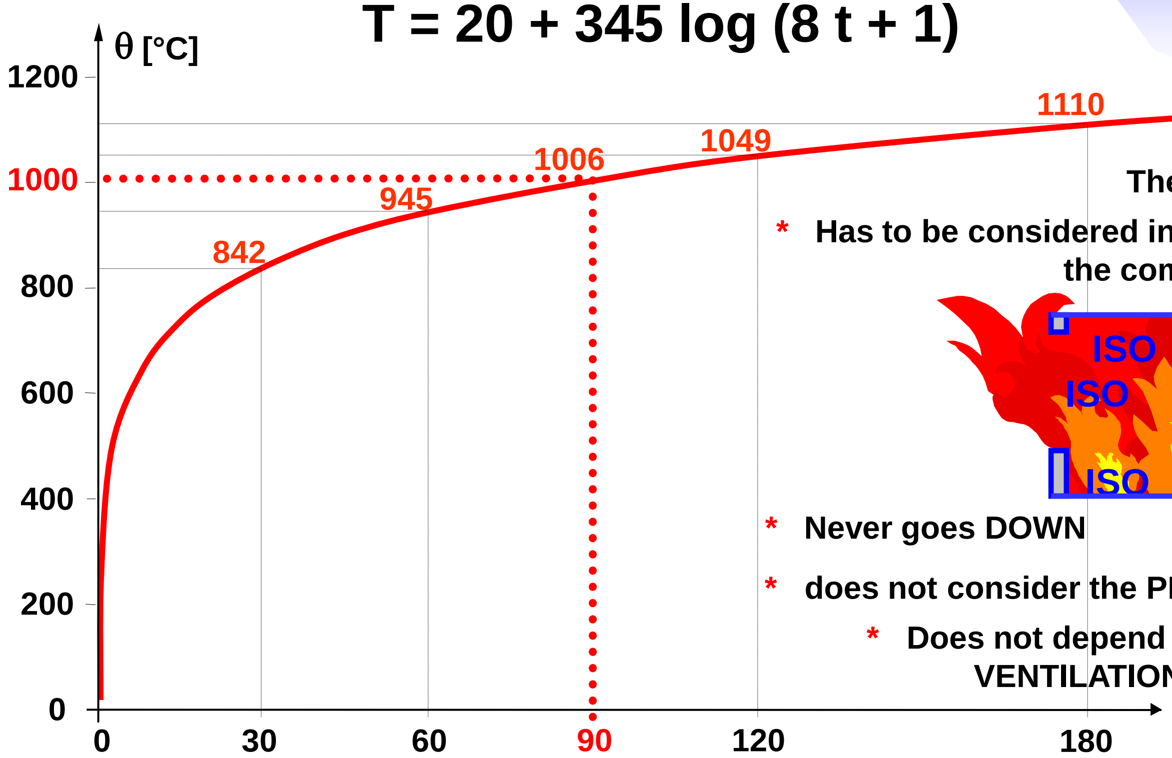
Exact geometry

Prescriptive Fire Regulations Defining ISO Curve Requirements

ISO-834 Curve (EN1364 -1)

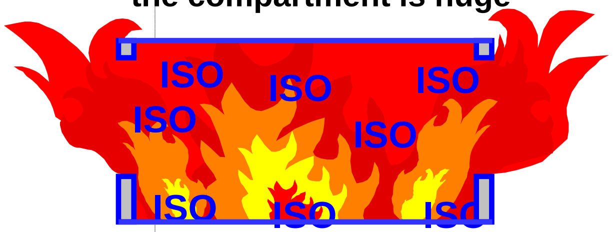


$$T = 20 + 345 \log (8\,t + 1)$$



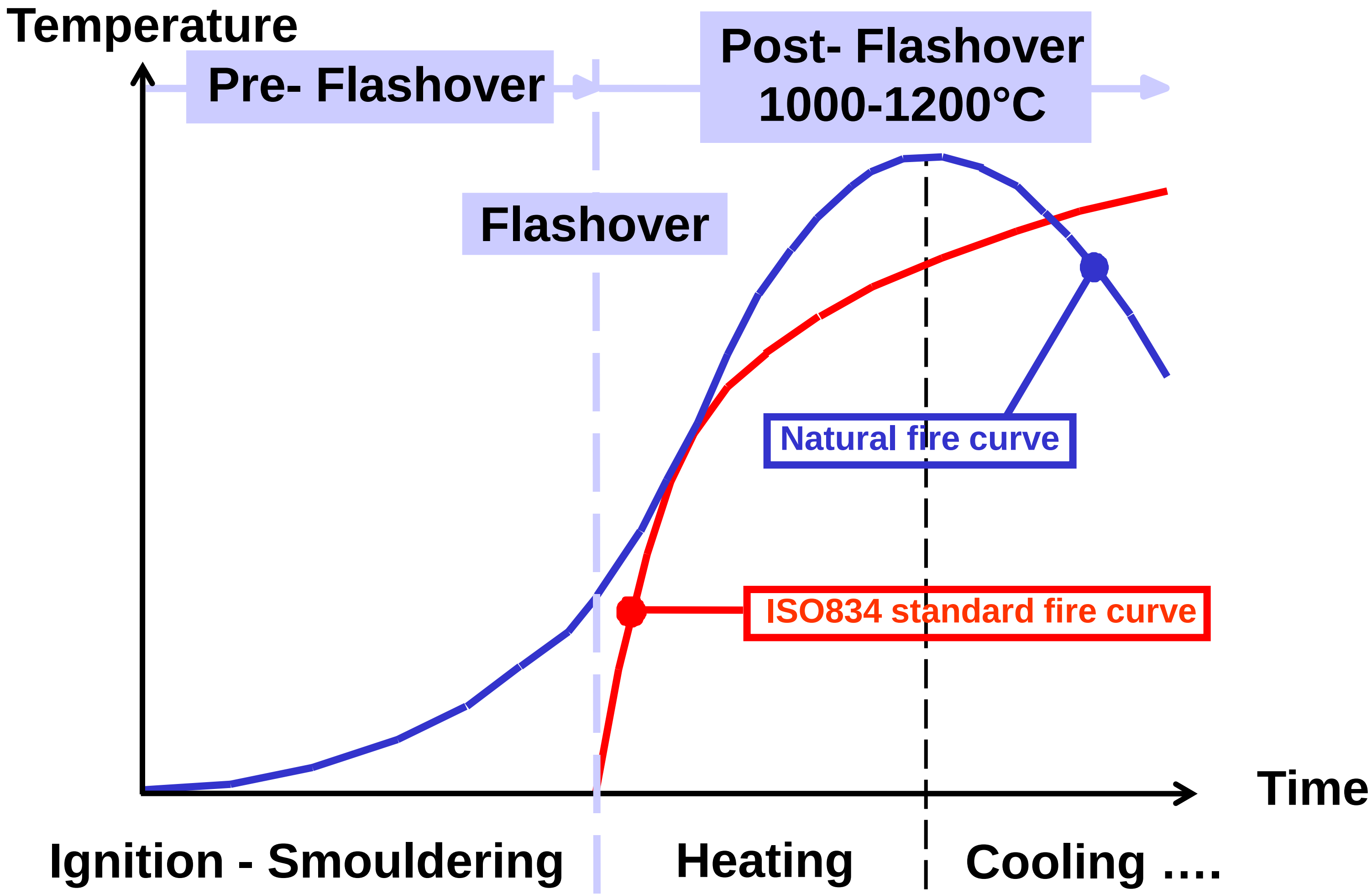
The ISO curve

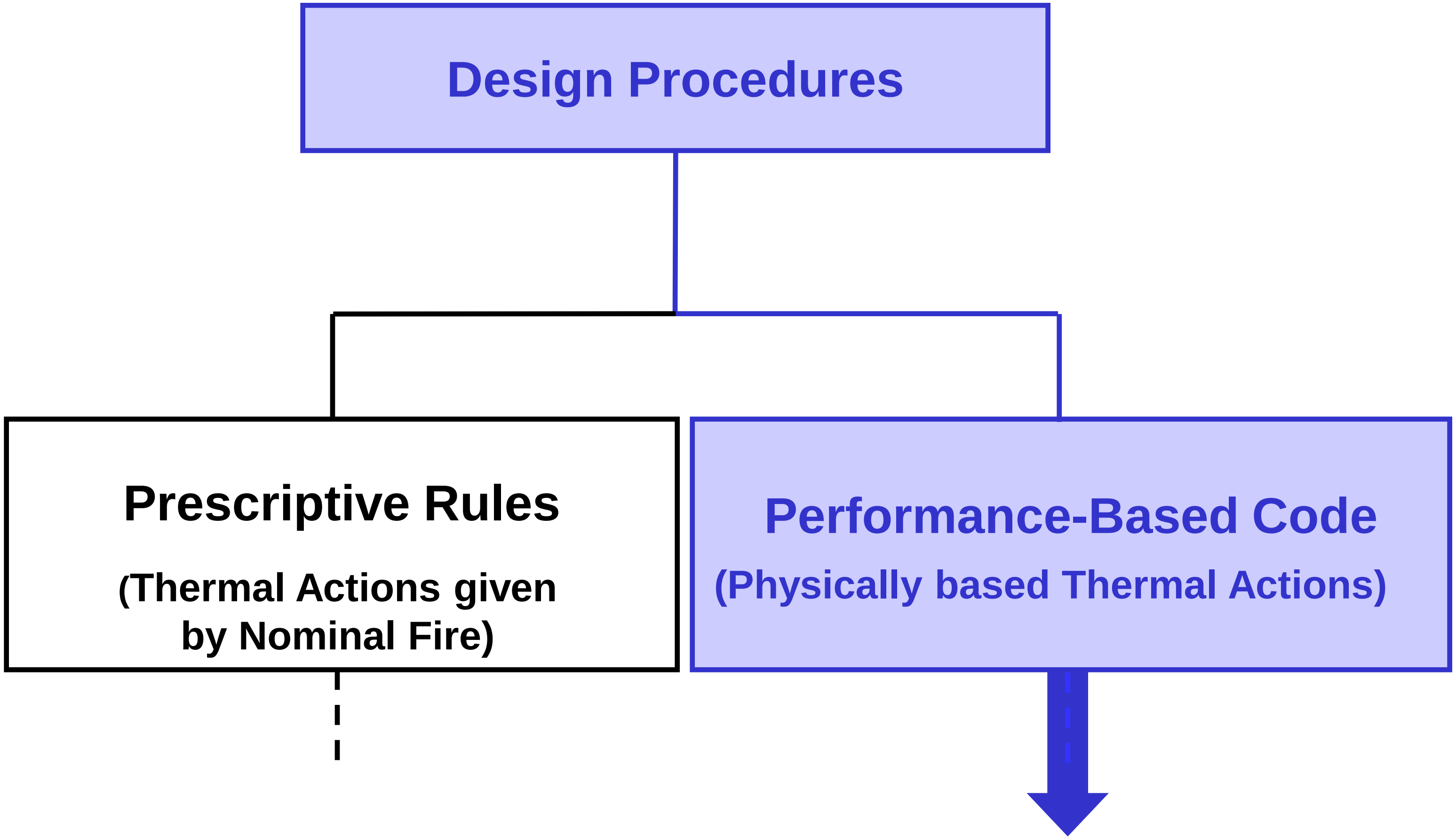
- * Has to be considered in the WHOLE compartment, even if the compartment is huge



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

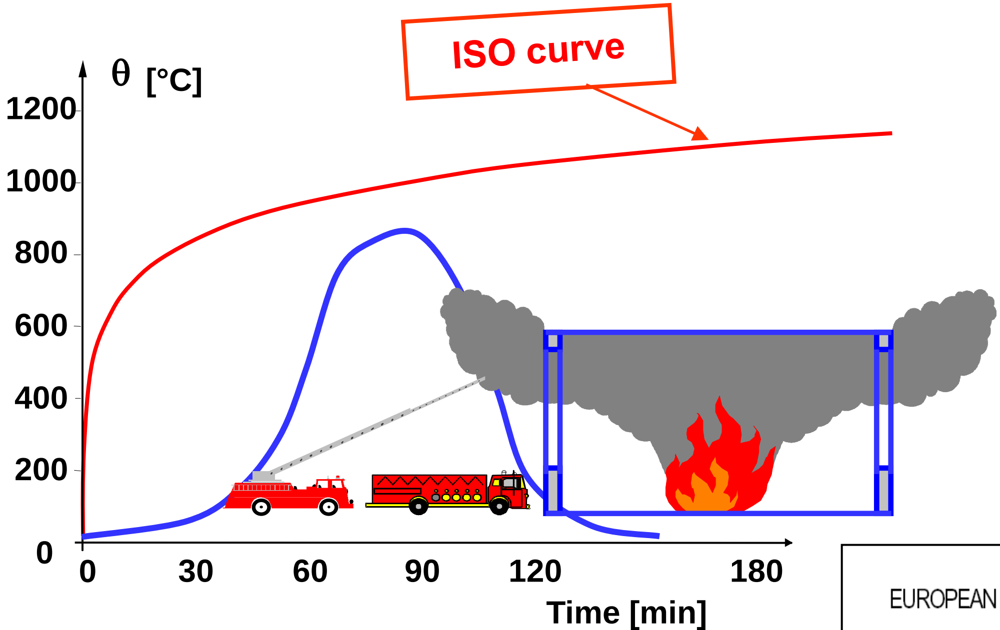
Stages of a Natural Fire and the Standard Fire Curve





Design Procedures
Prescriptive Rules
(Thermal Actions given
by Nominal Fire)
Performance-Based Code
(Physically based Thermal Actions)

Natural Fire Safety Concept



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

Implemented in:

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

NFSC Valorisation Project

European Commission

Natural Fire Model

European Commission

***) Nominal temperature-time curve**

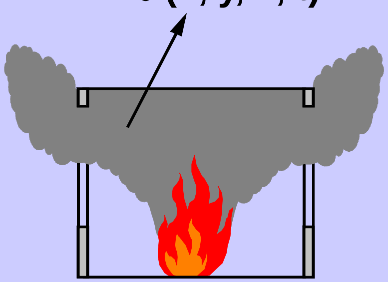
Standard temperature-, External fire - & Hydrocarbon fire curve | **No data needed**

***) Simplified Fire Models**

Localised Fire

- HESKESTADT
- HASEMI

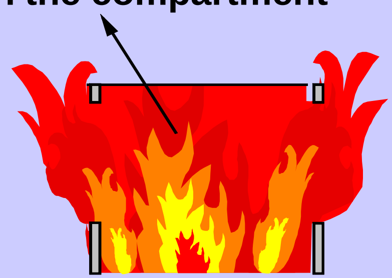
θ (x, y, z, t)



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

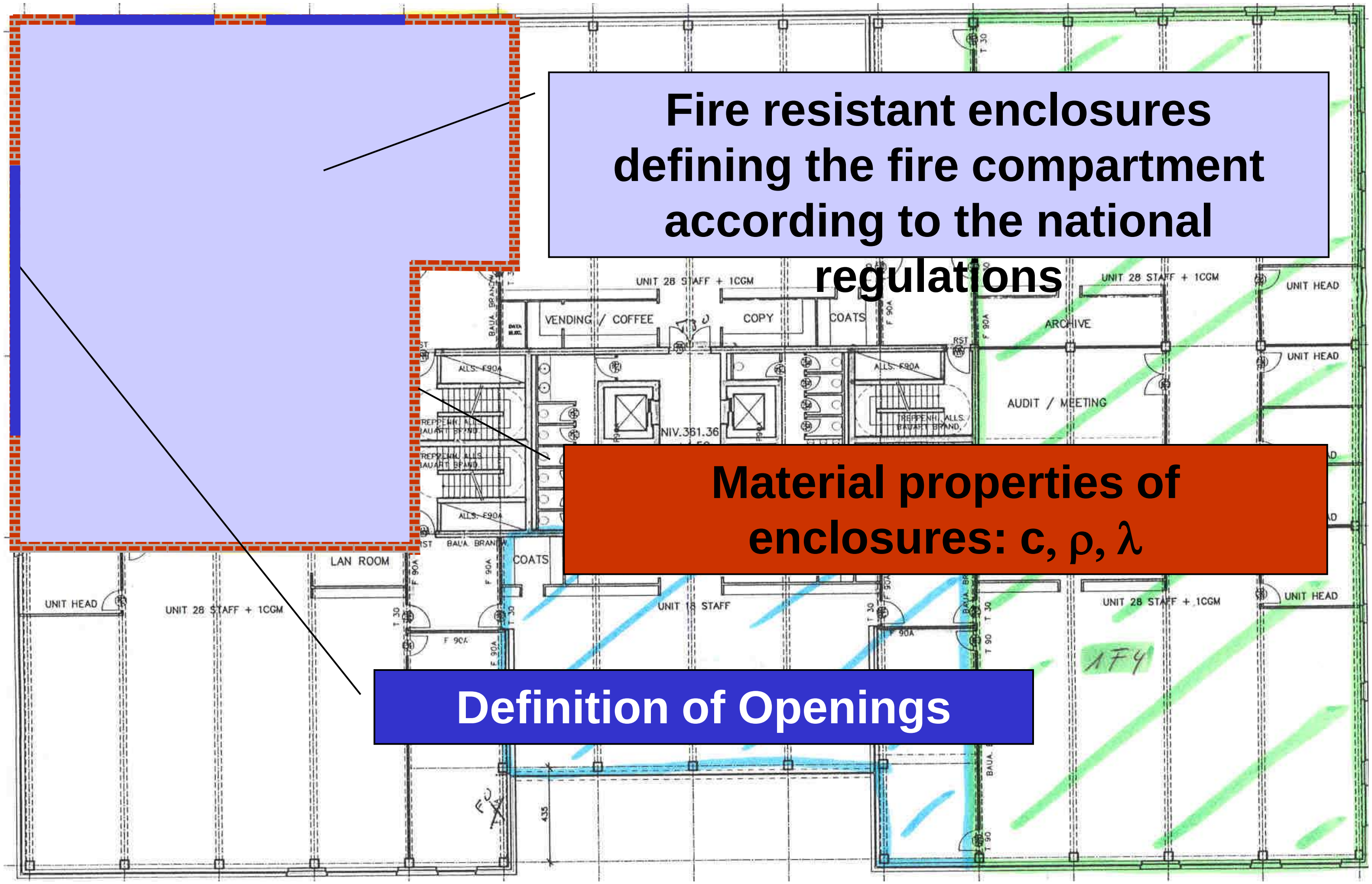
+

Exact geometry

List of needed Physical Parameters for Natural Fire Model

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

Characteristics of the Fire Compartment



Characteristic of the Fire for Different Buildings

Occupancy	Fire Growth Rate	RHR_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

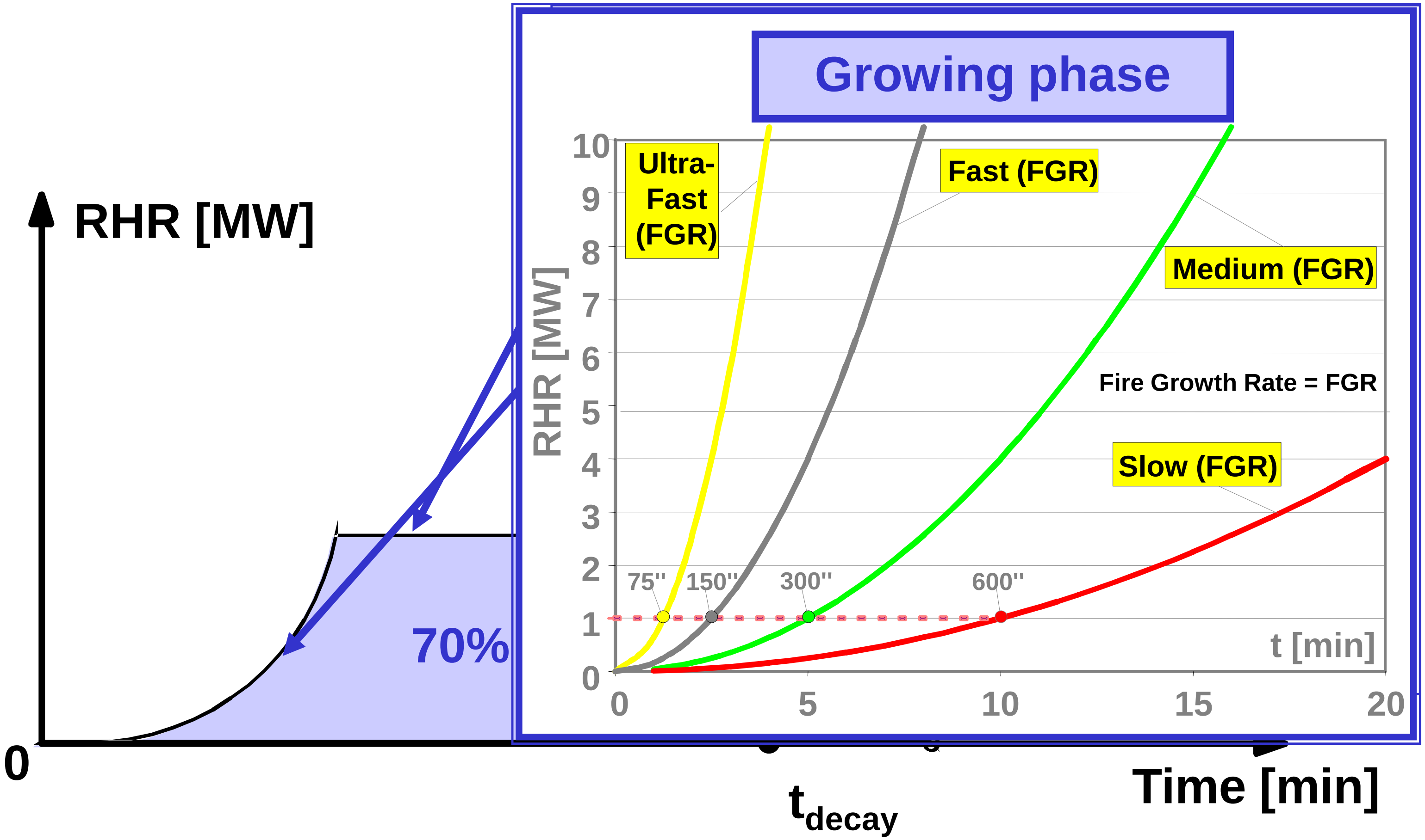
Compartment floor area A_f [m²]	Danger of Fire Activation δ_{q1}
25	1,10
250	1,50
2500	1,90
5000	2,00
10000	2,13

Danger of Fire Activation δ_{q2}	Examples of Occupancies
0,78	Art gallery, museum, swimming pool
1,00	Residence, hotel, office
1,22	Manufactory for machinery & engines
1,44	Chemical laboratory, Painting workshop
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 0 | 1 | 2 δ_{n2}			Automatic fire Detection & Alarm by Heat δ_{n3}	Automatic fire Detection & Alarm by Smoke δ_{n4}	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}
0,61	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

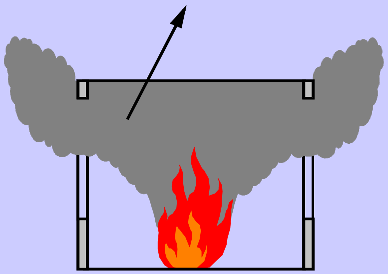
No data needed

***) Simplified Fire Models**

Localised Fire

- **HESKESTADT**
- **HASEMI**

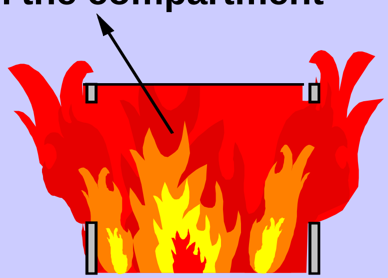
θ (x, y, z, t)



Fully Engulfed Compartment

- **Parametric Fire**

θ (t) uniform in the compartment



Rate of heat release

Fire surface

Boundary properties

Opening area

Ceiling height

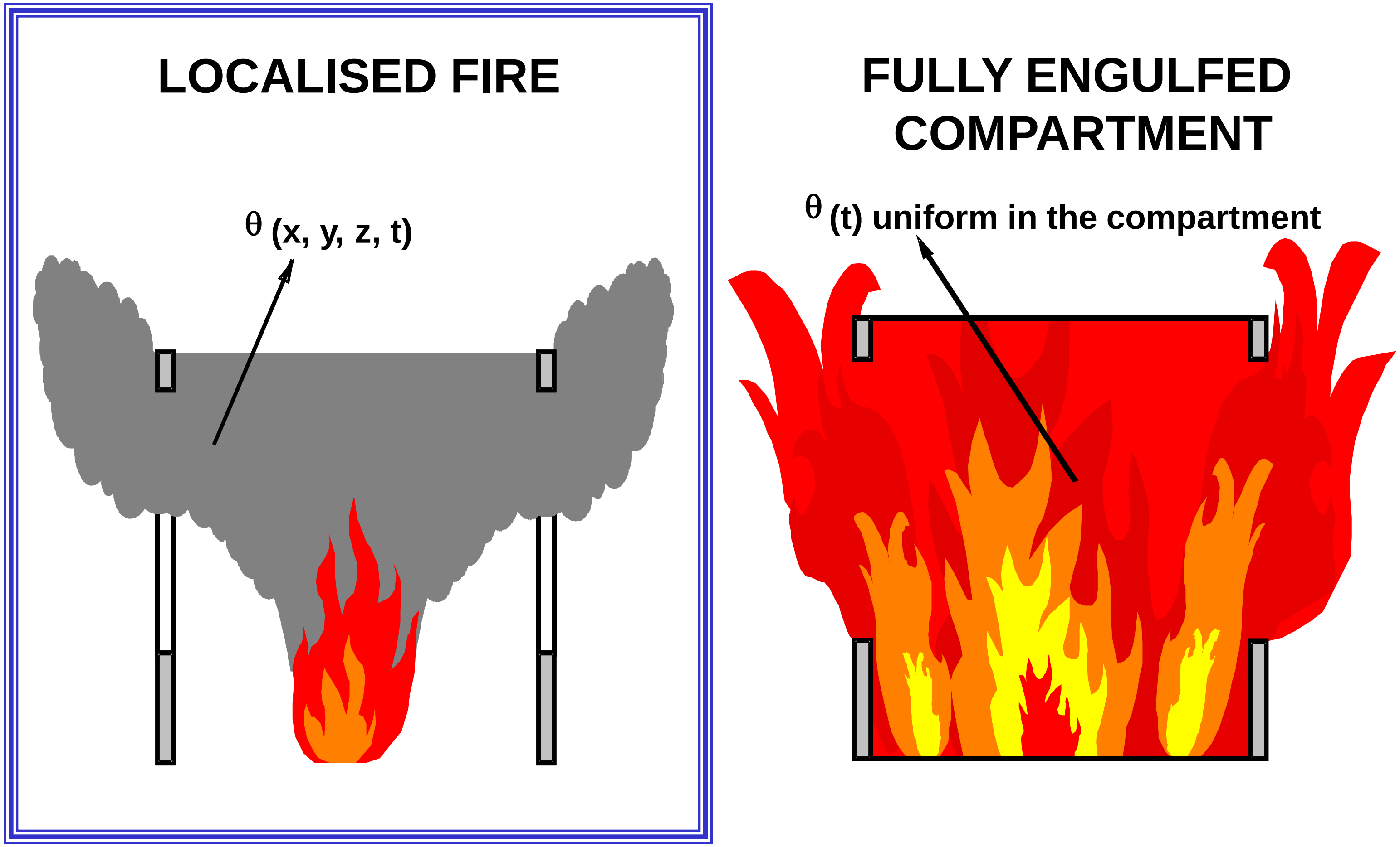
***) Advanced Fire Models**

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

+

Exact geometry

Simplified Fire Models Localised Fire

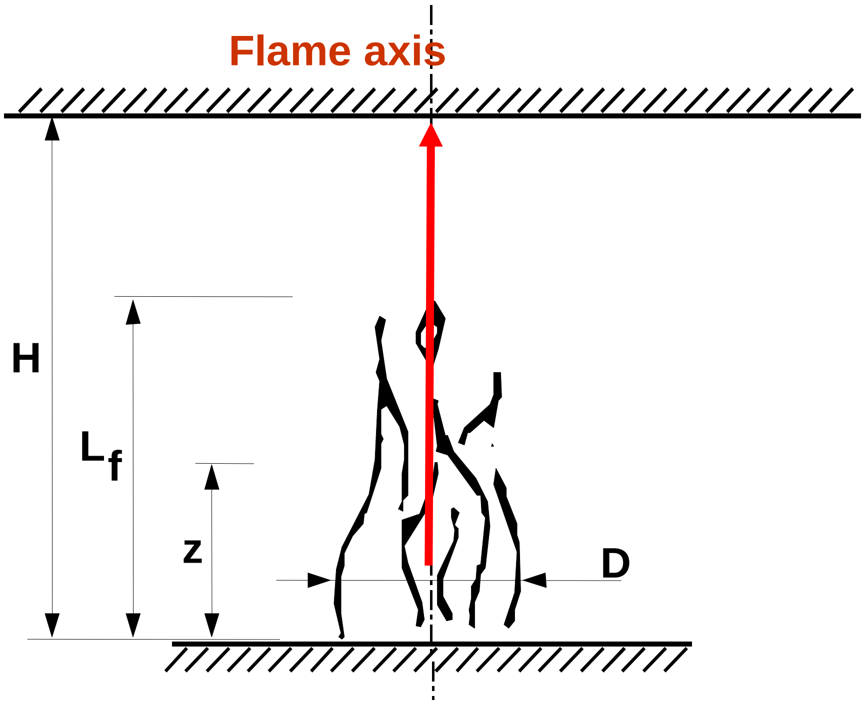


Real Localised Fire Test

Annex C of EN 1991-1-2:

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

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

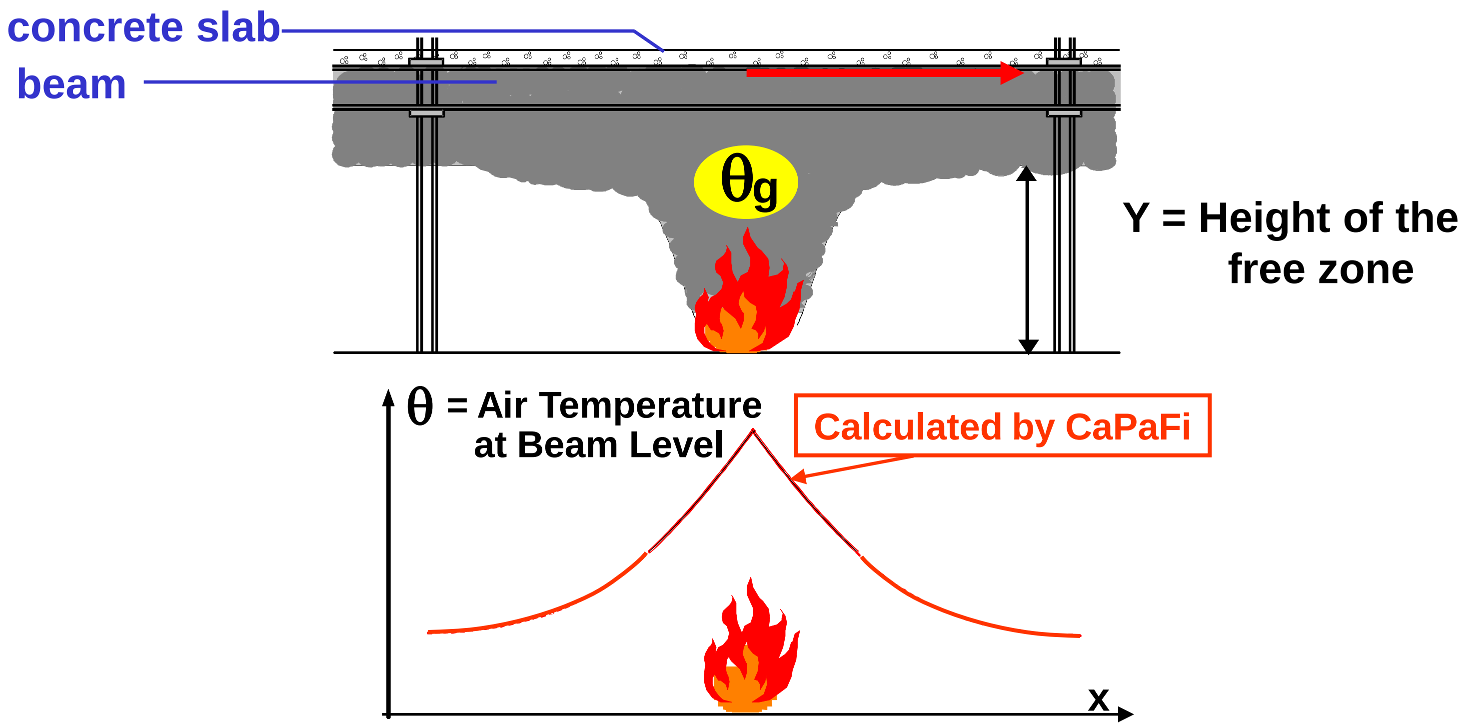


The flame length L_f of a localised fire is given by :

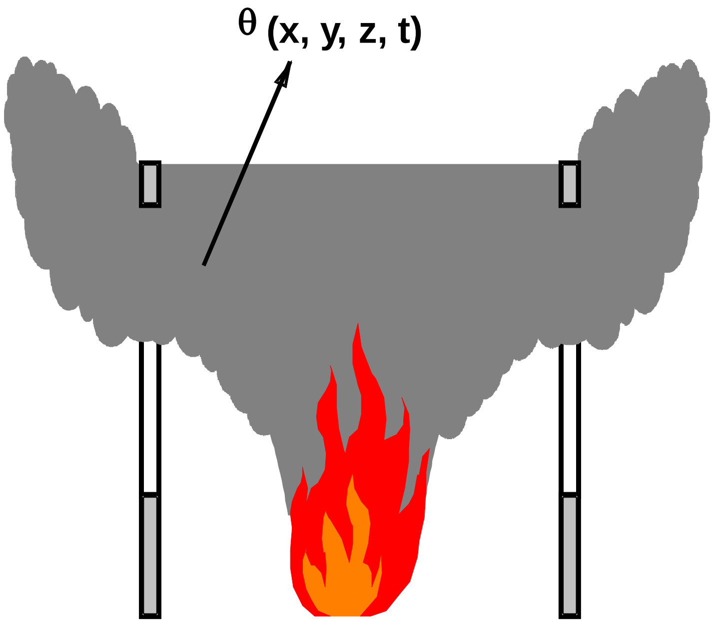
$$L_f = -1{,}02\ D + 0{,}0148\ Q^{2/5}$$

Annex C of EN 1991-1-2:

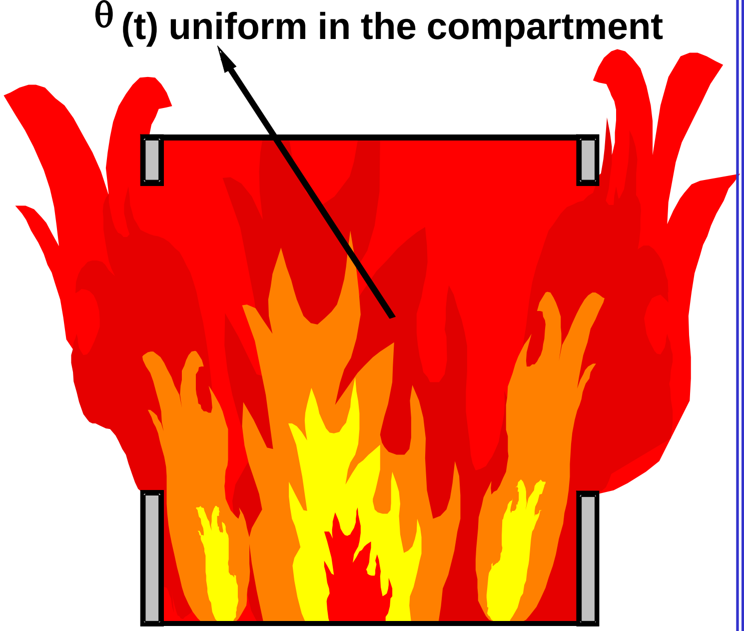
- **Flame is impacting the ceiling (L_f > H)**



LOCALISED FIRE



FULLY ENGULFED COMPARTMENT



Real Fire Test Simulating an Office Building

Fully engulfed fire

Real Fire Test Simulating an Office Building

Demonstration test : set-up

Openings with normal glazed windows

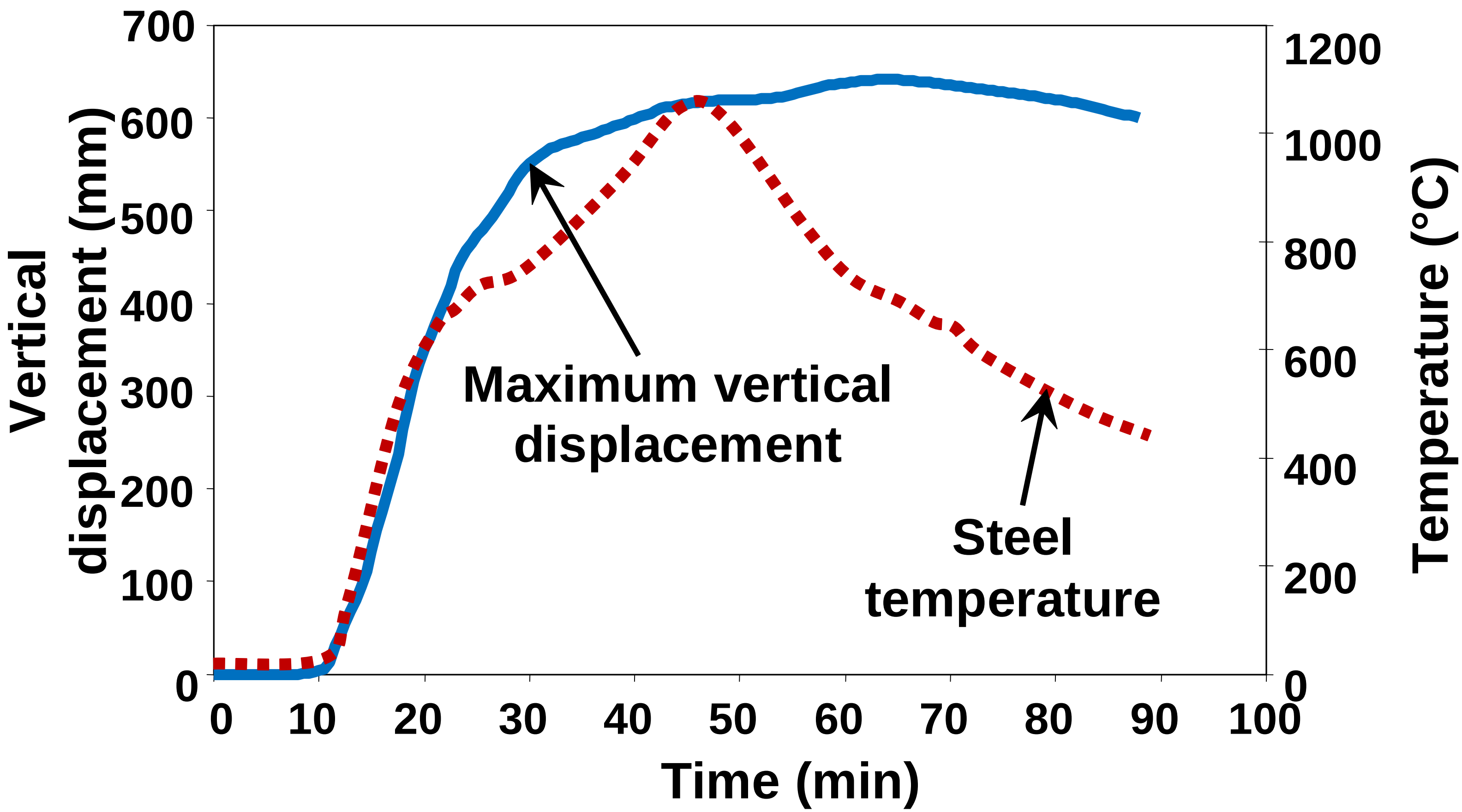
Fire load with real office furniture

Real Fire Test Simulating an Office Building

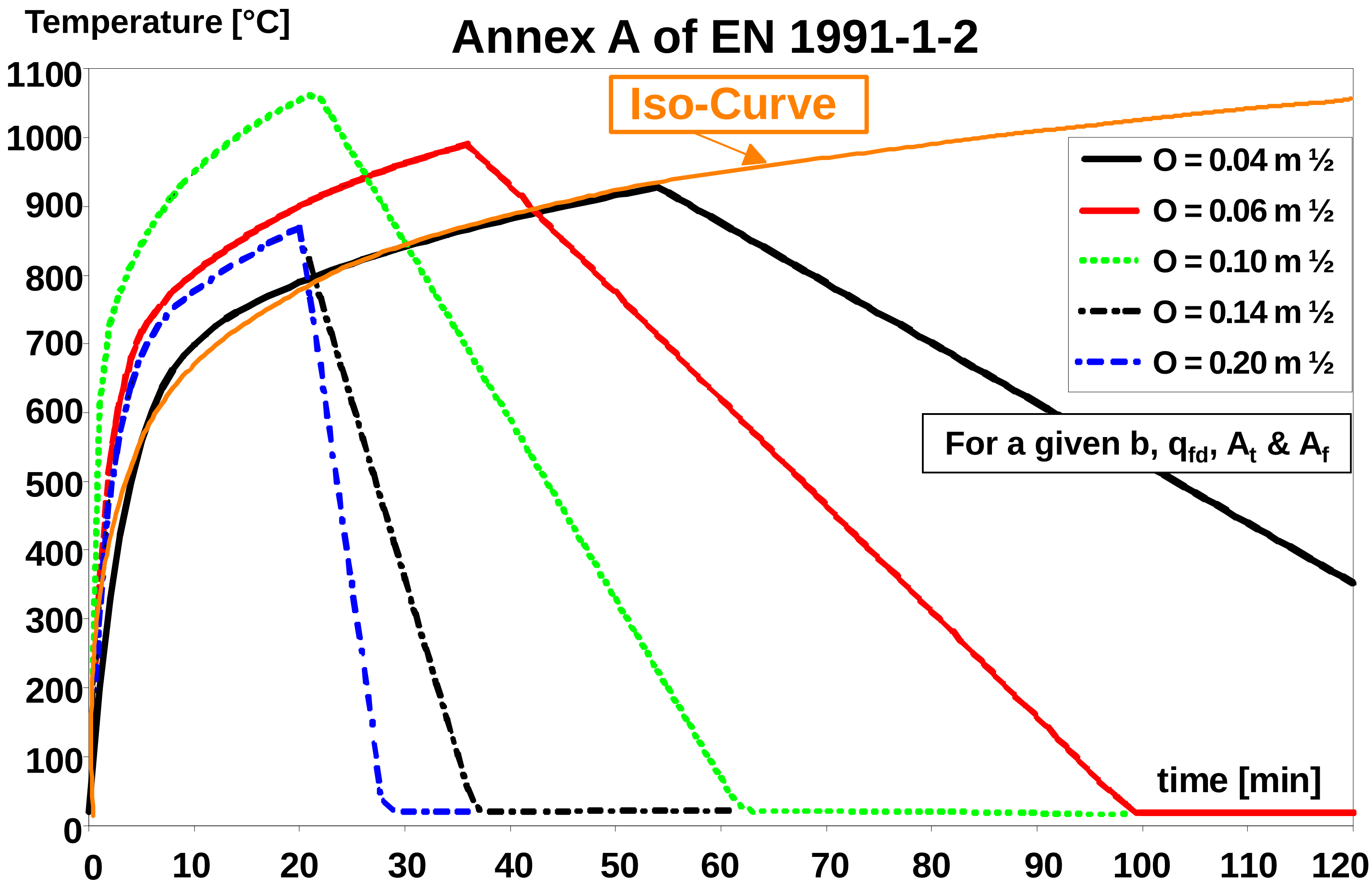
Early stage of fire

Fully developed fire

Real Fire Test Simulating an Office Building



Fully Engulfed Compartment
Annex A: Parametric Fire



Natural Advanced Fire Model

***) Nominal temperature-time curve**

Standard temperature-, External fire - & Hydrocarbon fire curve

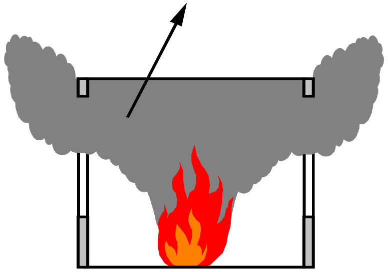
No data needed

***) Simplified Fire Models**

Localised Fire

- HESKESTADT
- HASEMI

θ (x, y, z, t)



Fully Engulfed Compartment

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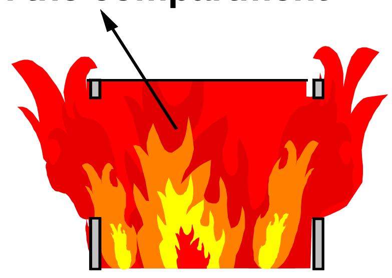
θ (t) uniform in the compartment



Rate of heat release
Fire surface
Boundary properties
Opening area
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***) Advanced Fire Models**

- Two-Zone Model
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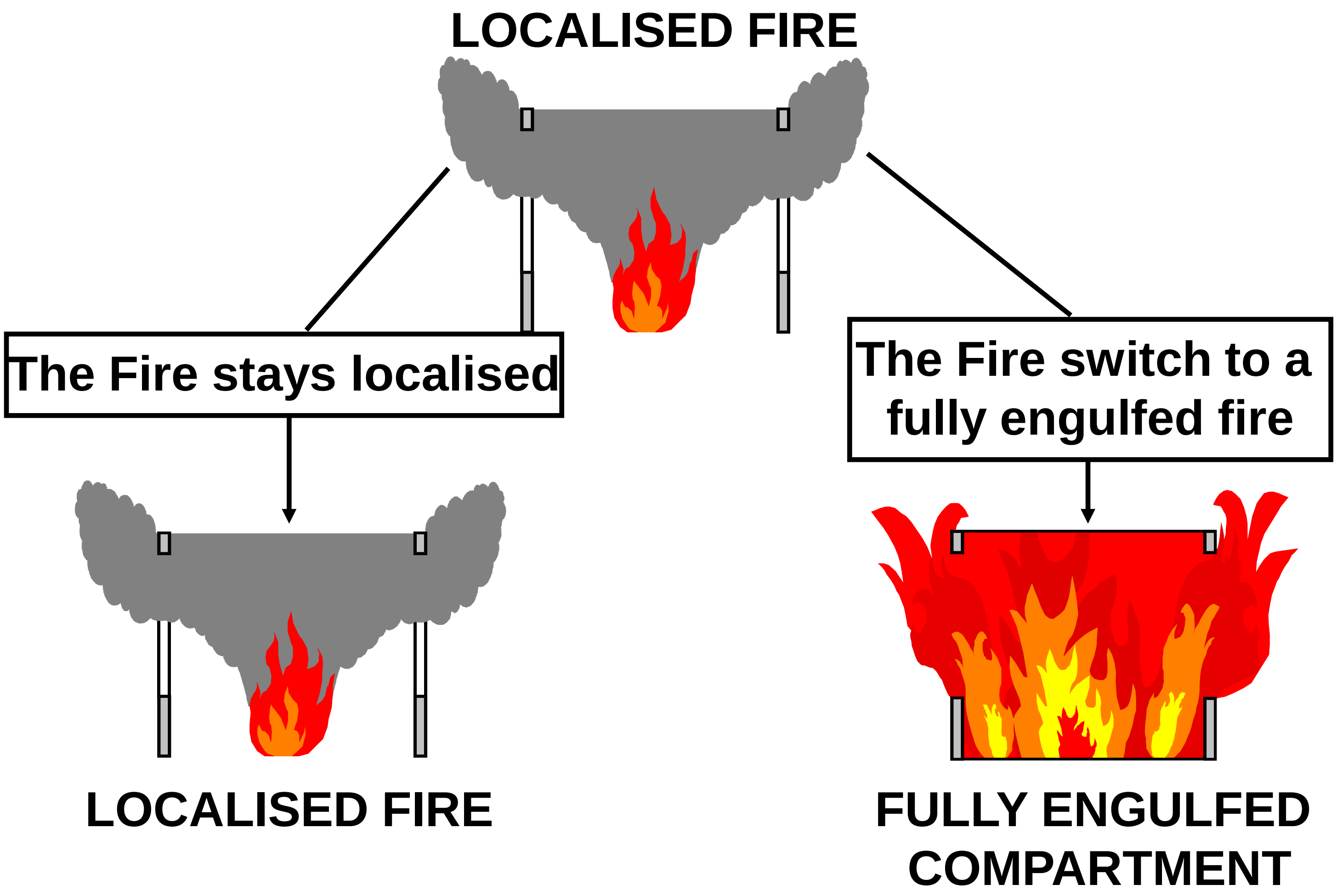
- CFD

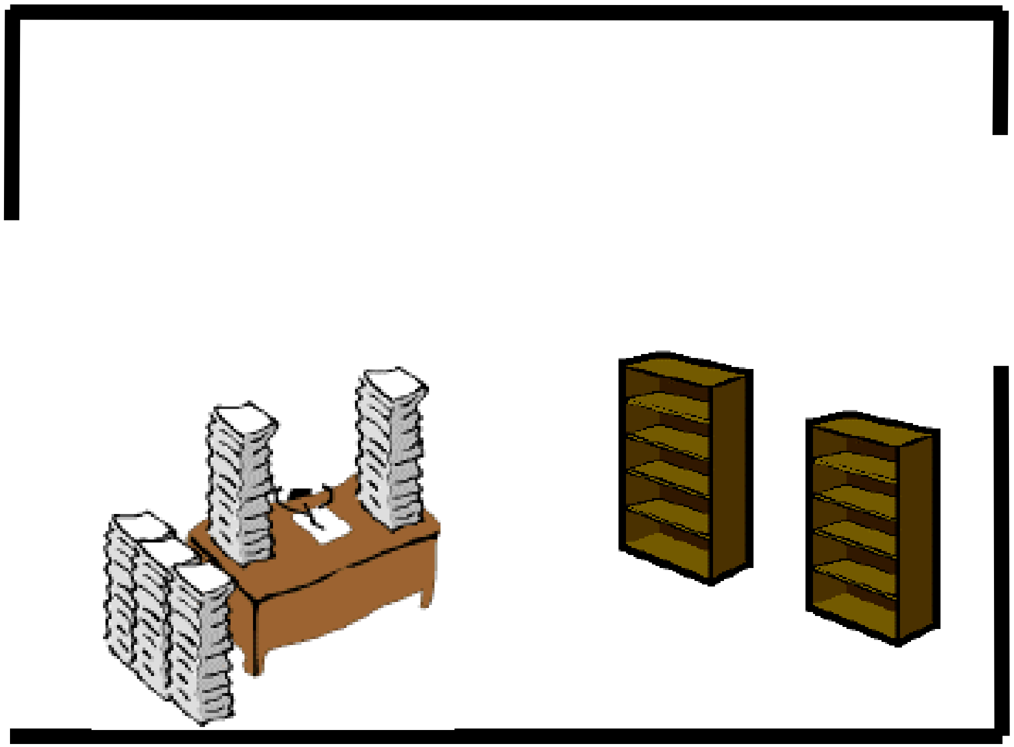
+

Exact geometry

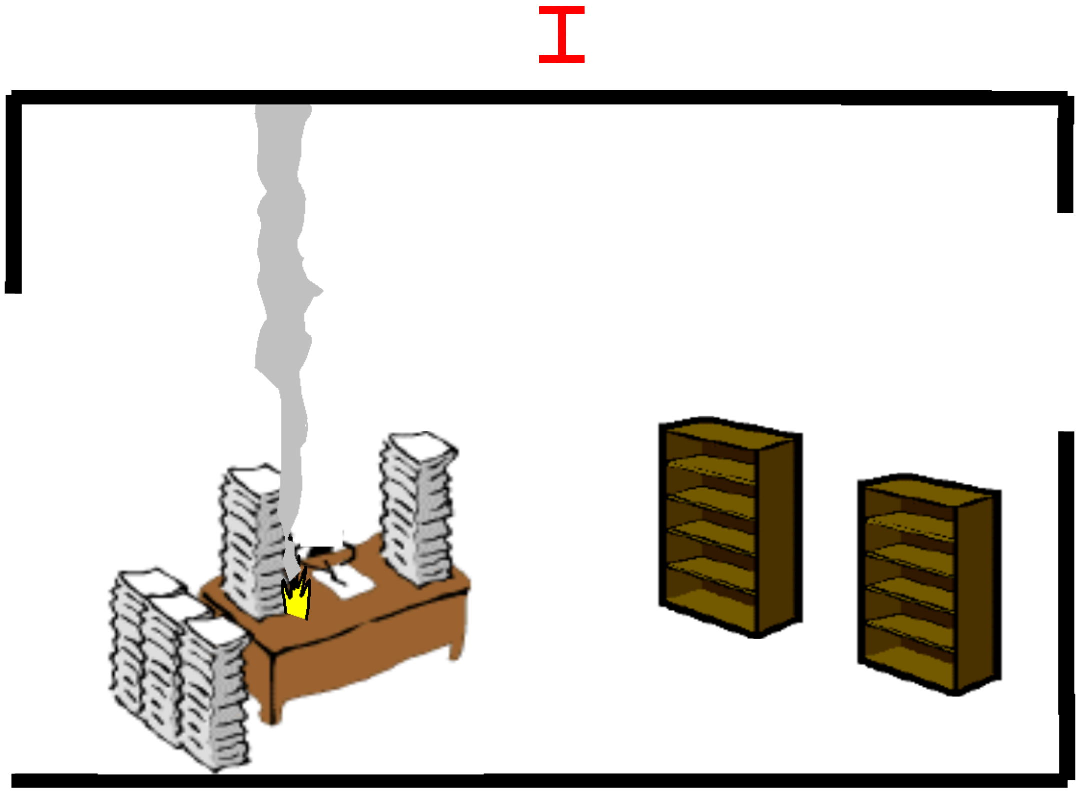
Advanced fire Models



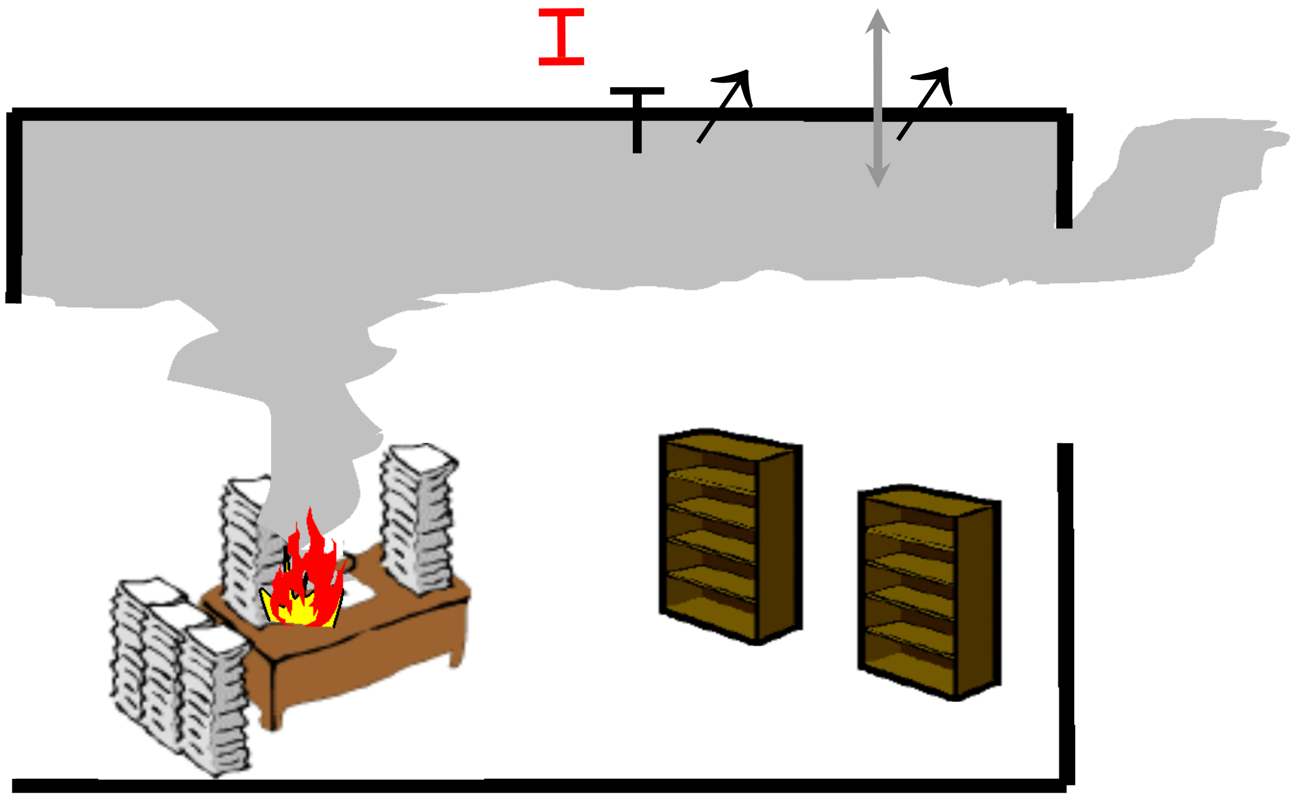
Advanced fire Models



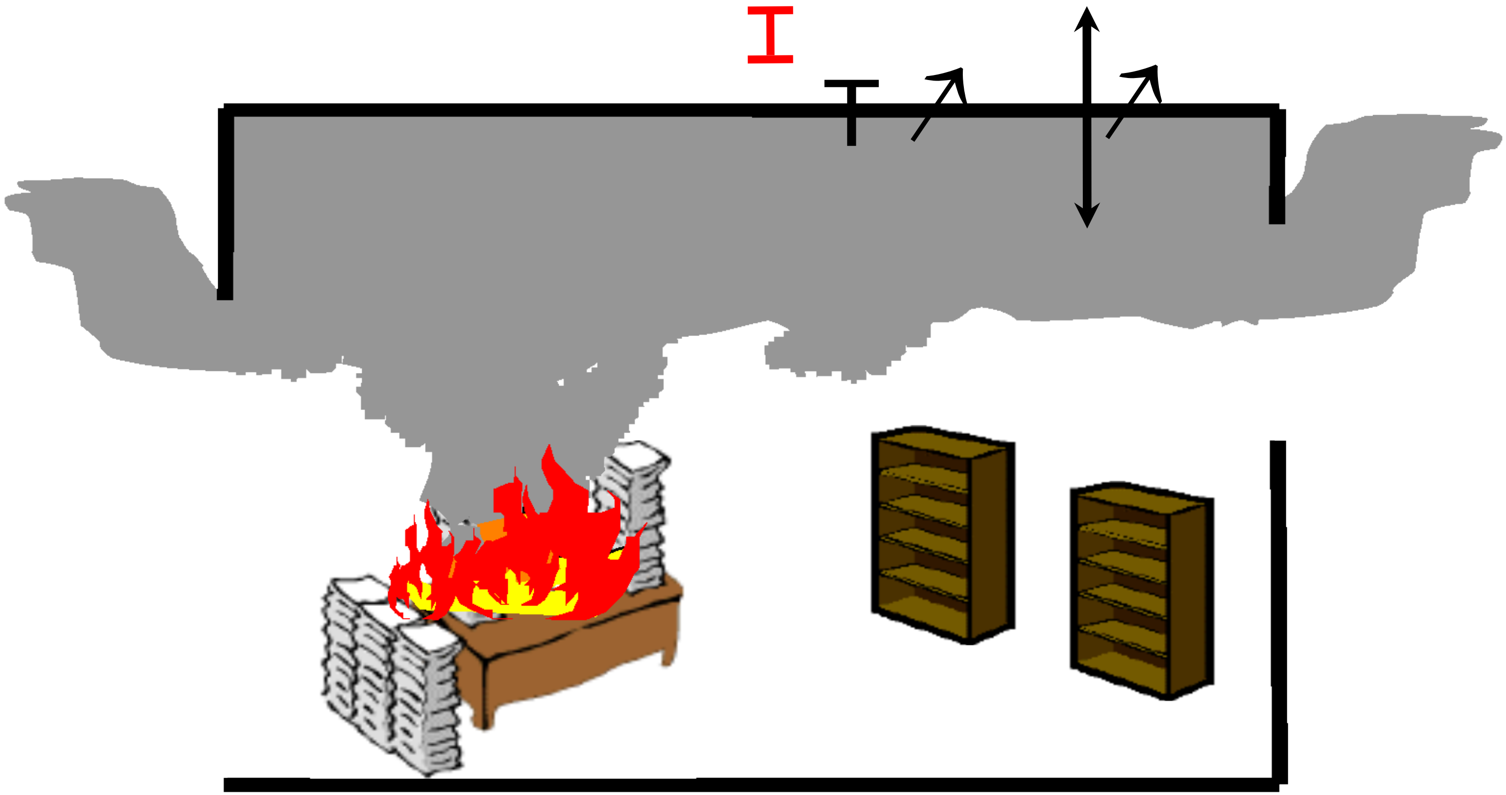
Ignition



Localised Fire



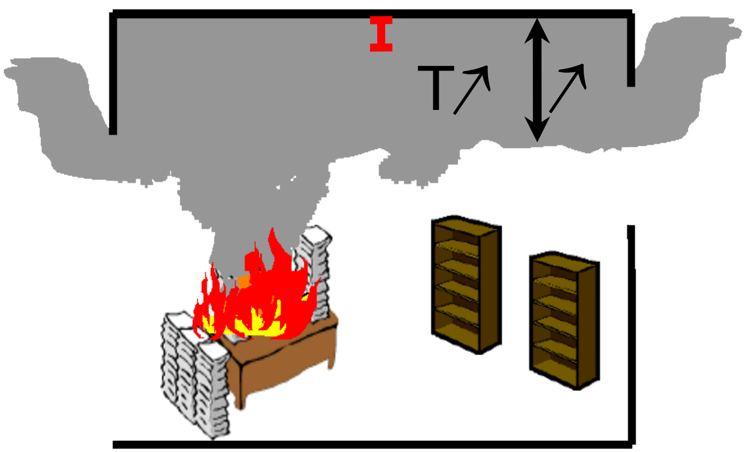
Growing of Localised Fire



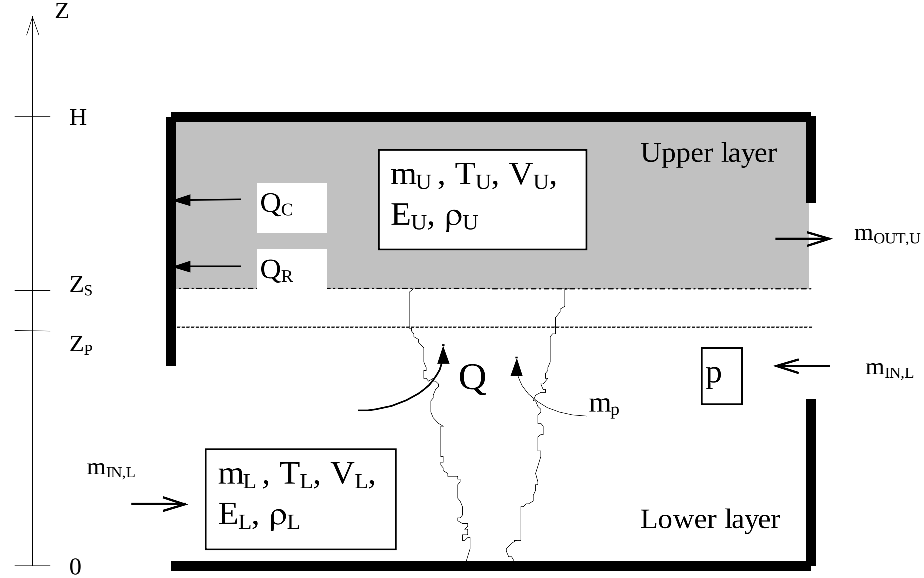
Theory of two zones models

→

Localised Fire



Ozone Software Model



Theory of two zones models

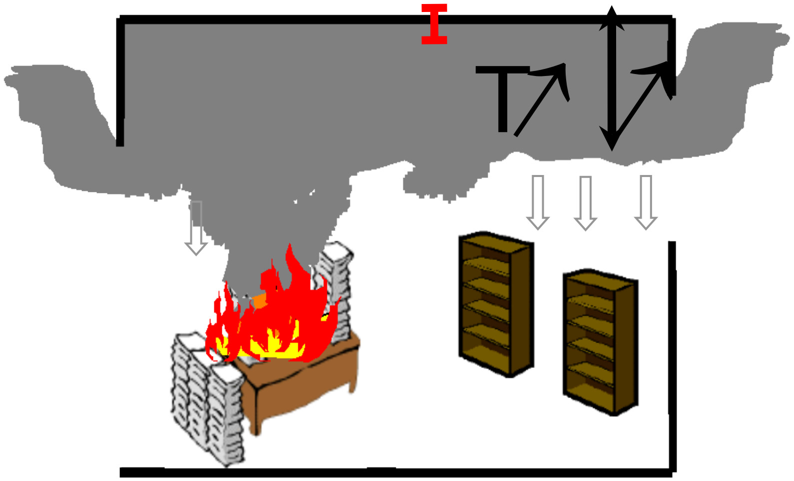
2 ➔ 1 zone: if one of the following criteria is reached

$T_{hot\ gases}$> 500 ºC

Combustible material in the smoke and T_{smoke}> 300 ºC

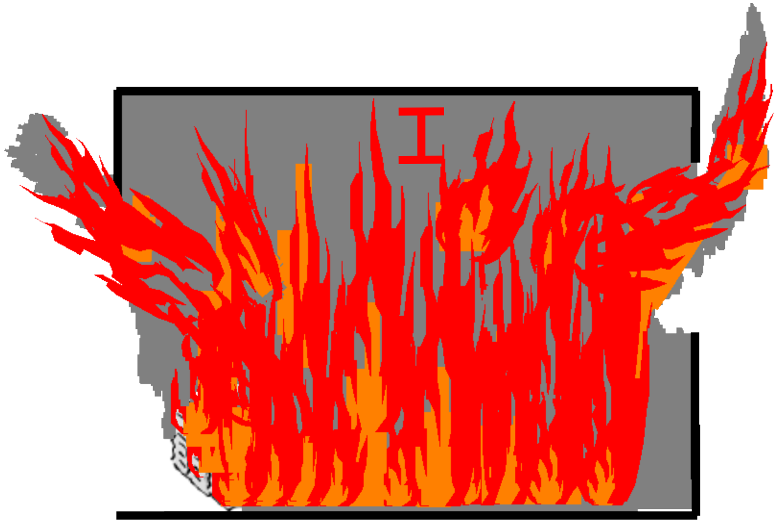
Localised fire> 25 % of the compartment's surface

Smoke height > 80 % of the total height of the compartment

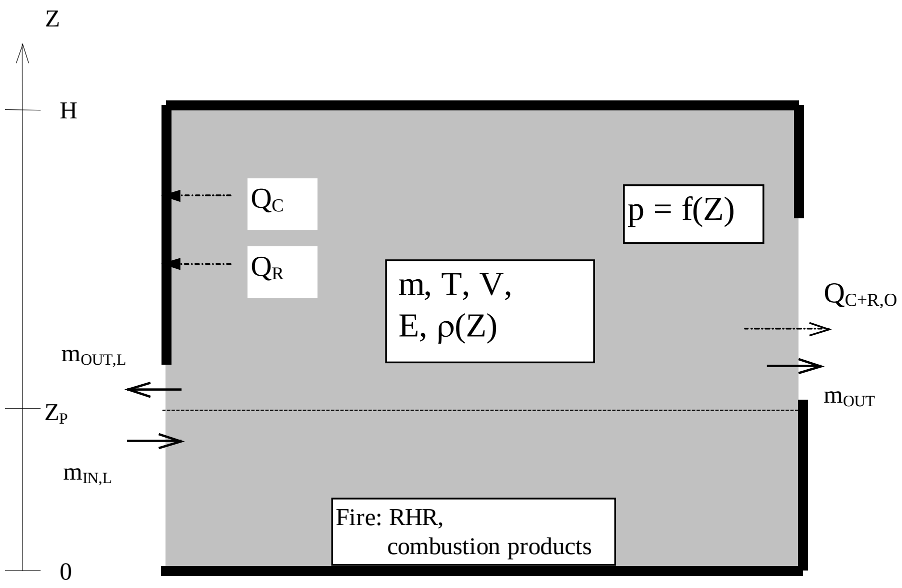


Theory of two zones models

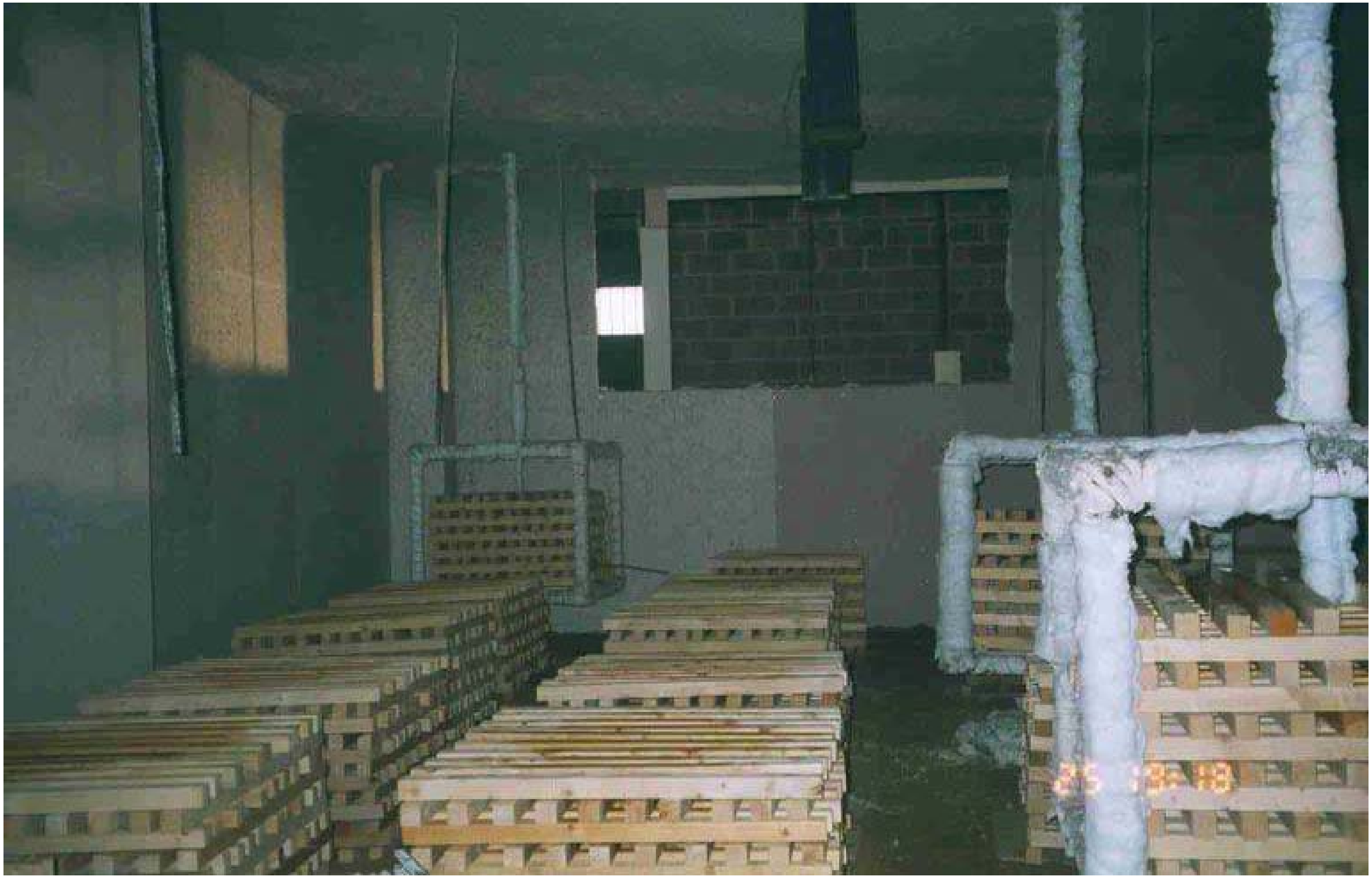
Generalised Fire



Ozone Software Model



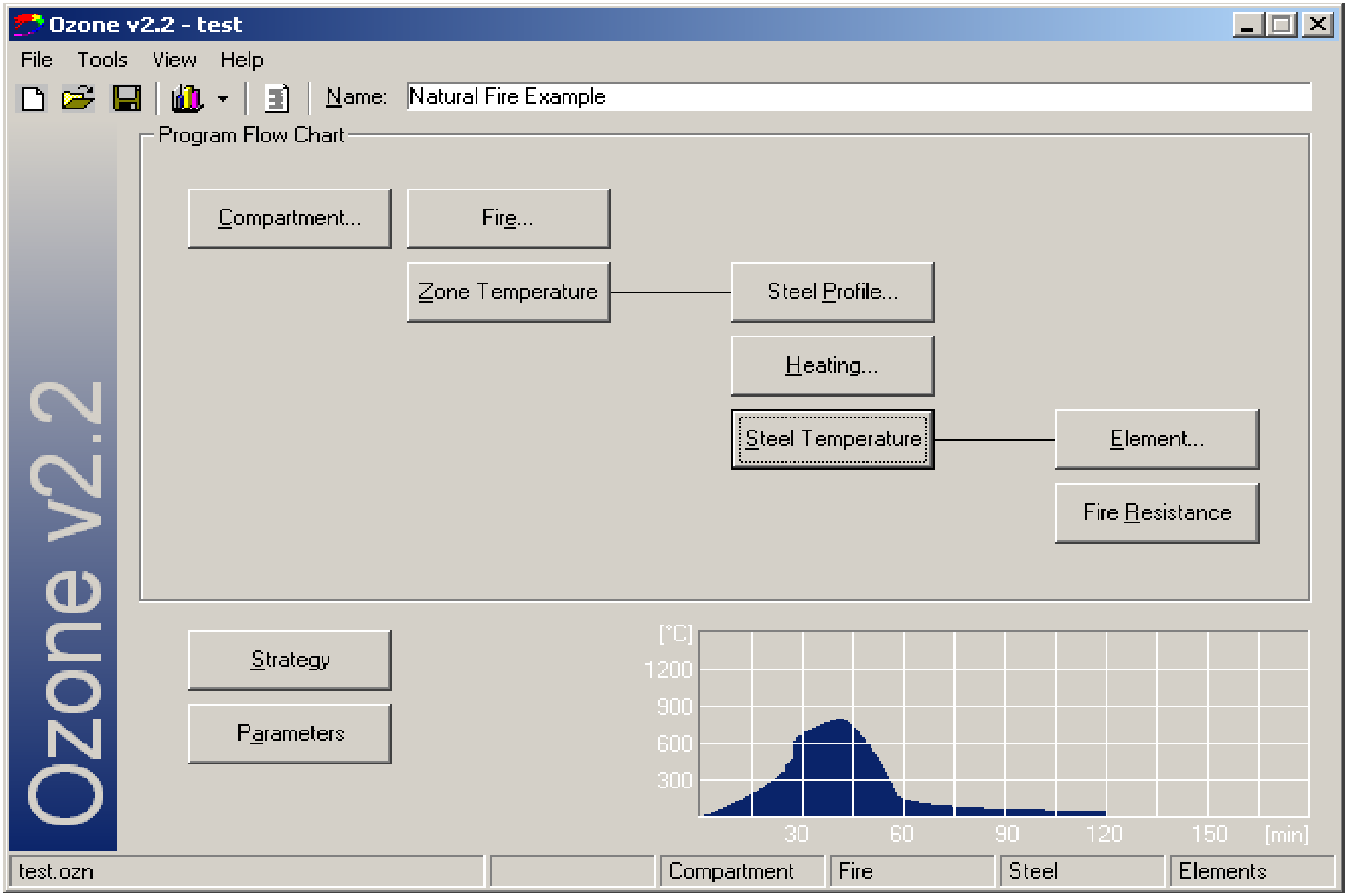
Large Compartment Test
Fire Load



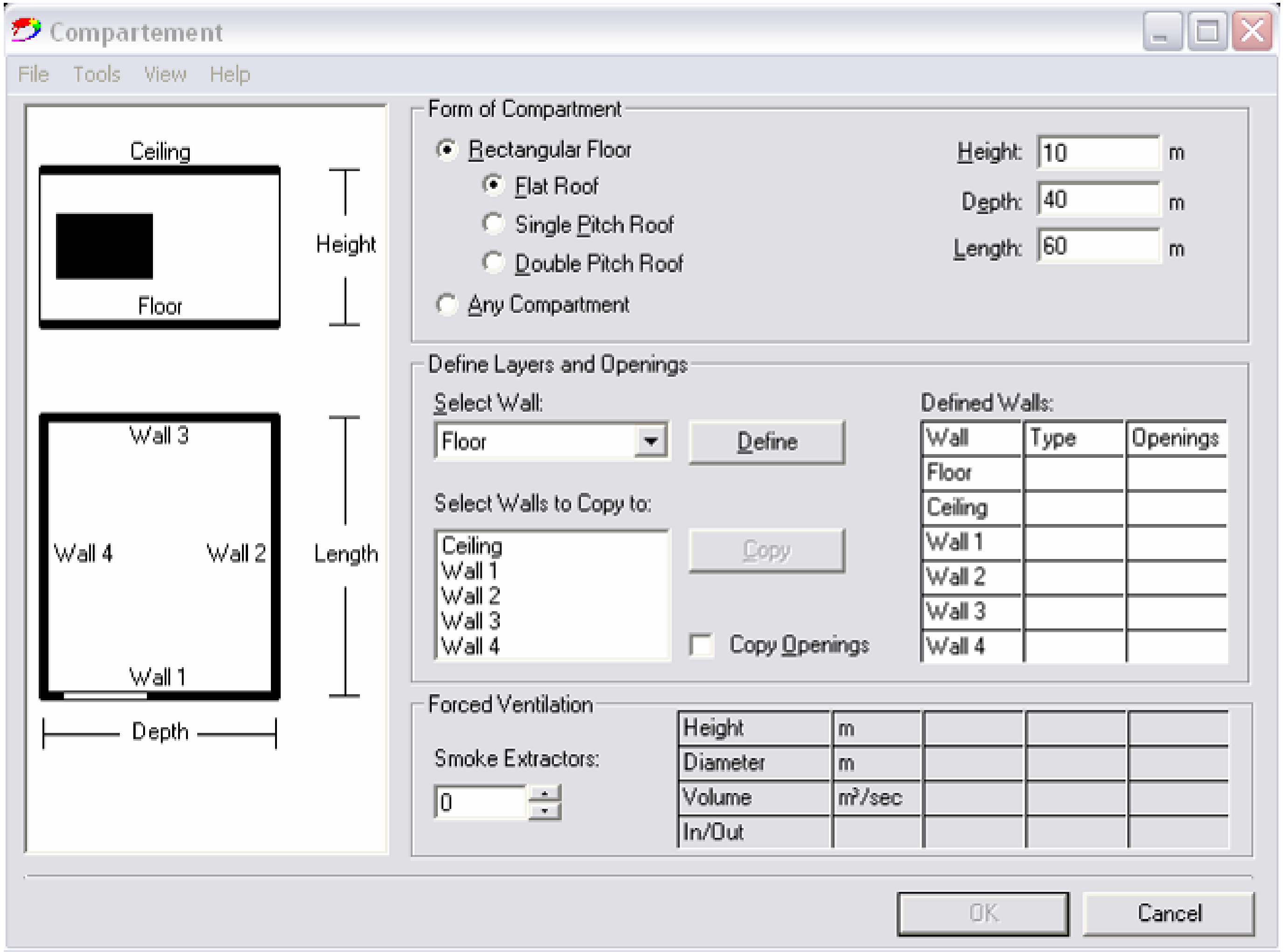
Large Compartment Test
External Flaming During the Test

Large Compartment Test After the Test

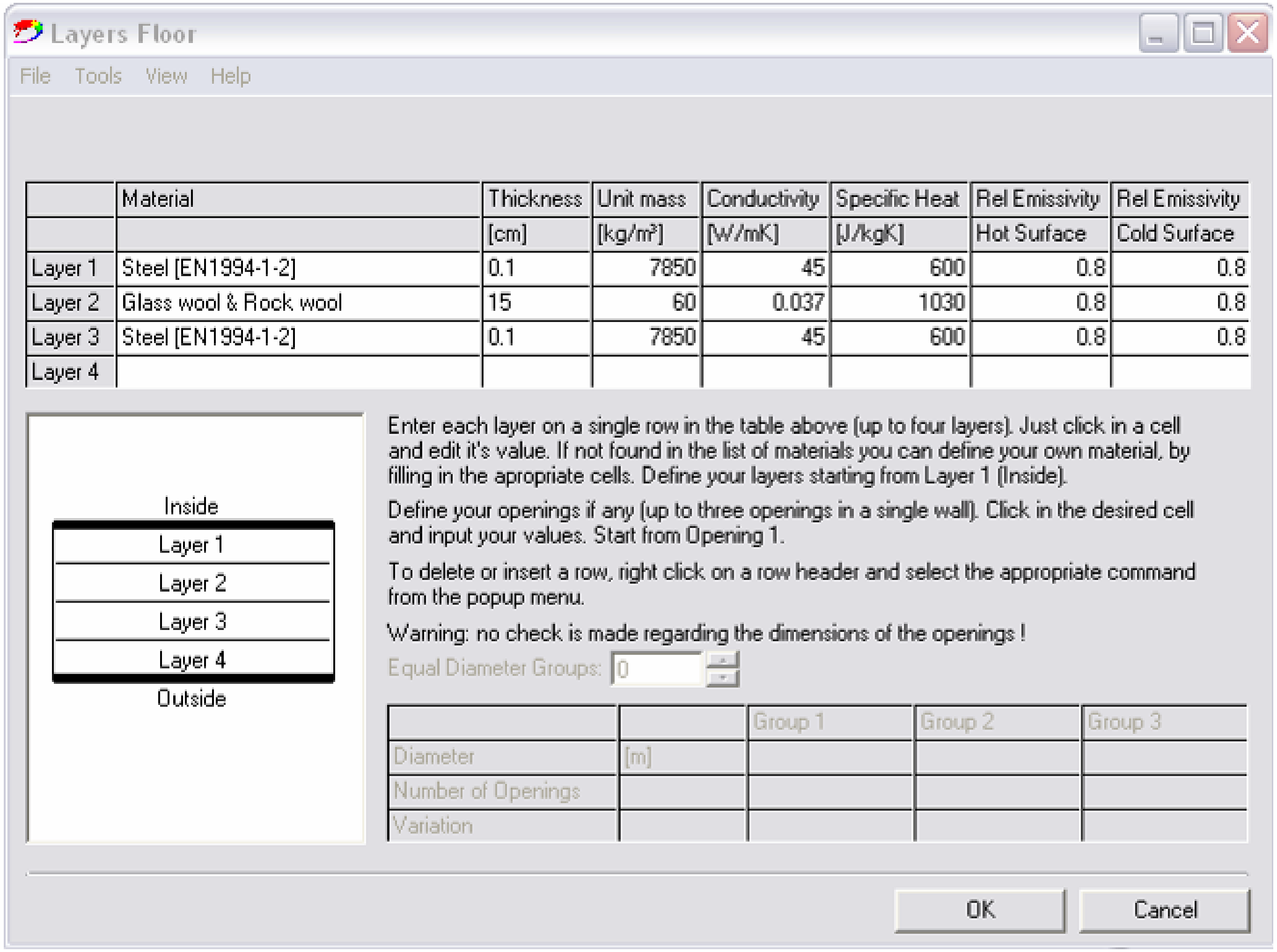
Two Zone Calculation Software "OZone V2.2"



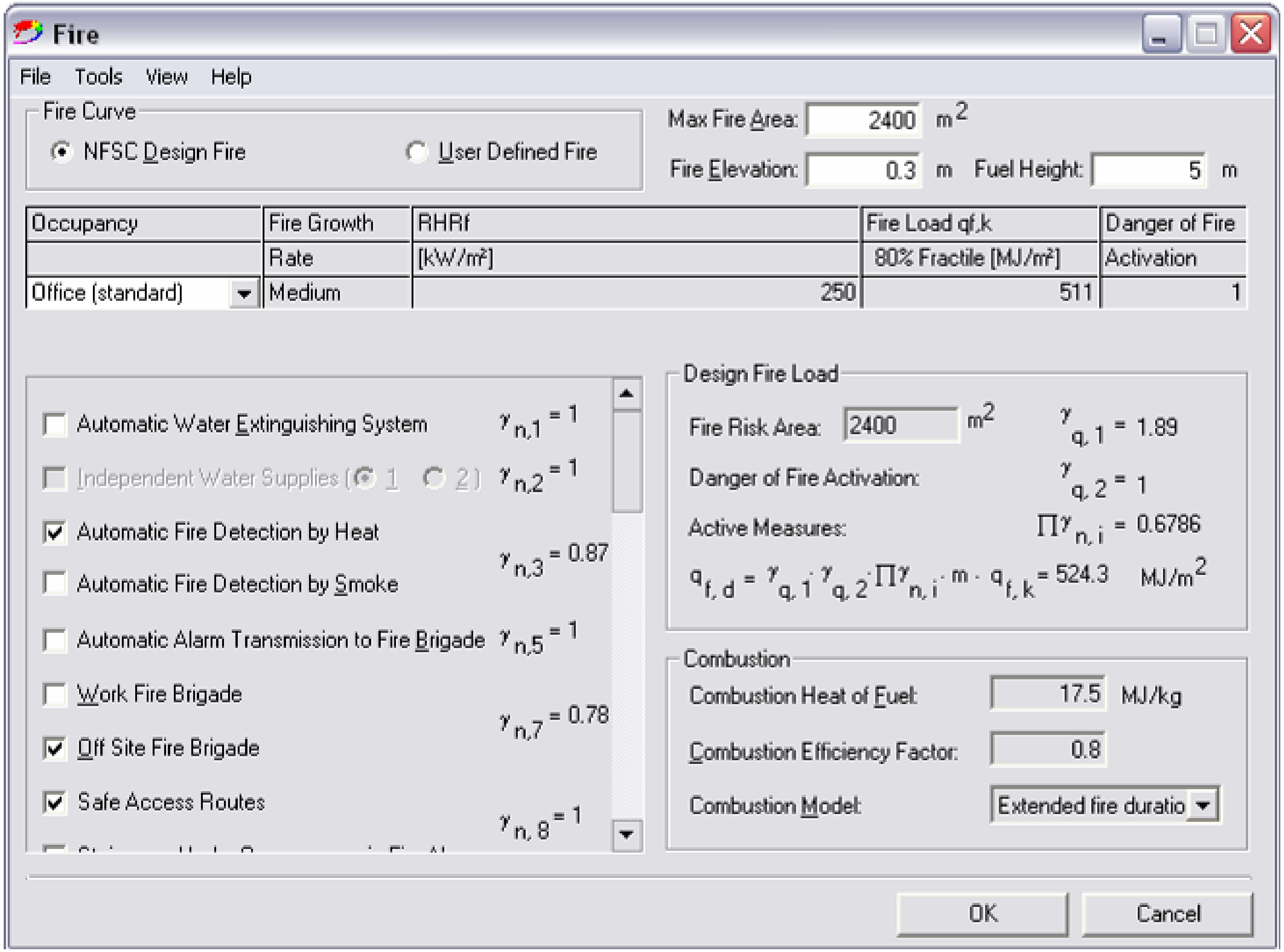
Software "OZone V2.2"
Definition of the Compartment



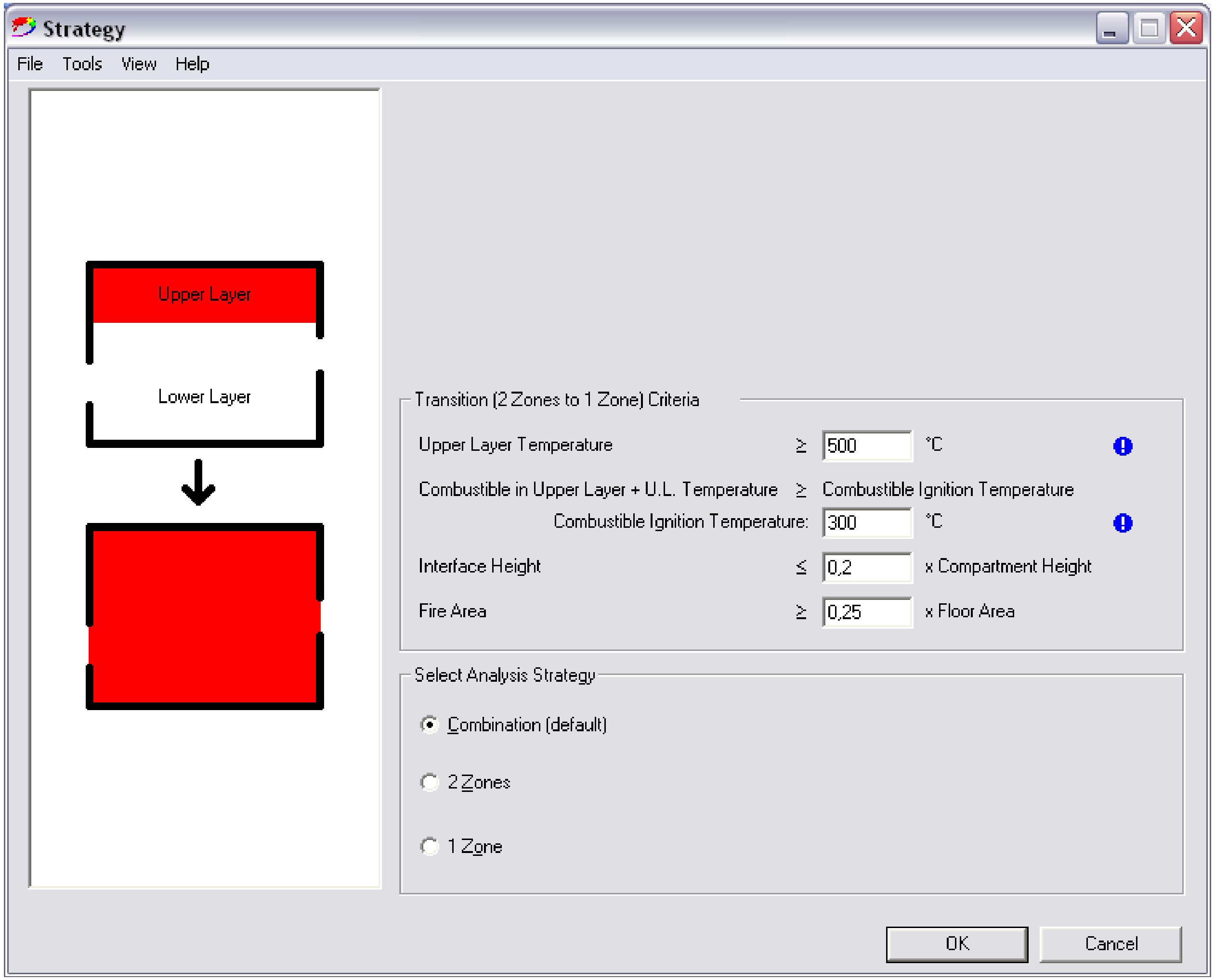
Software "OZone V2.2" Definition of the boundaries



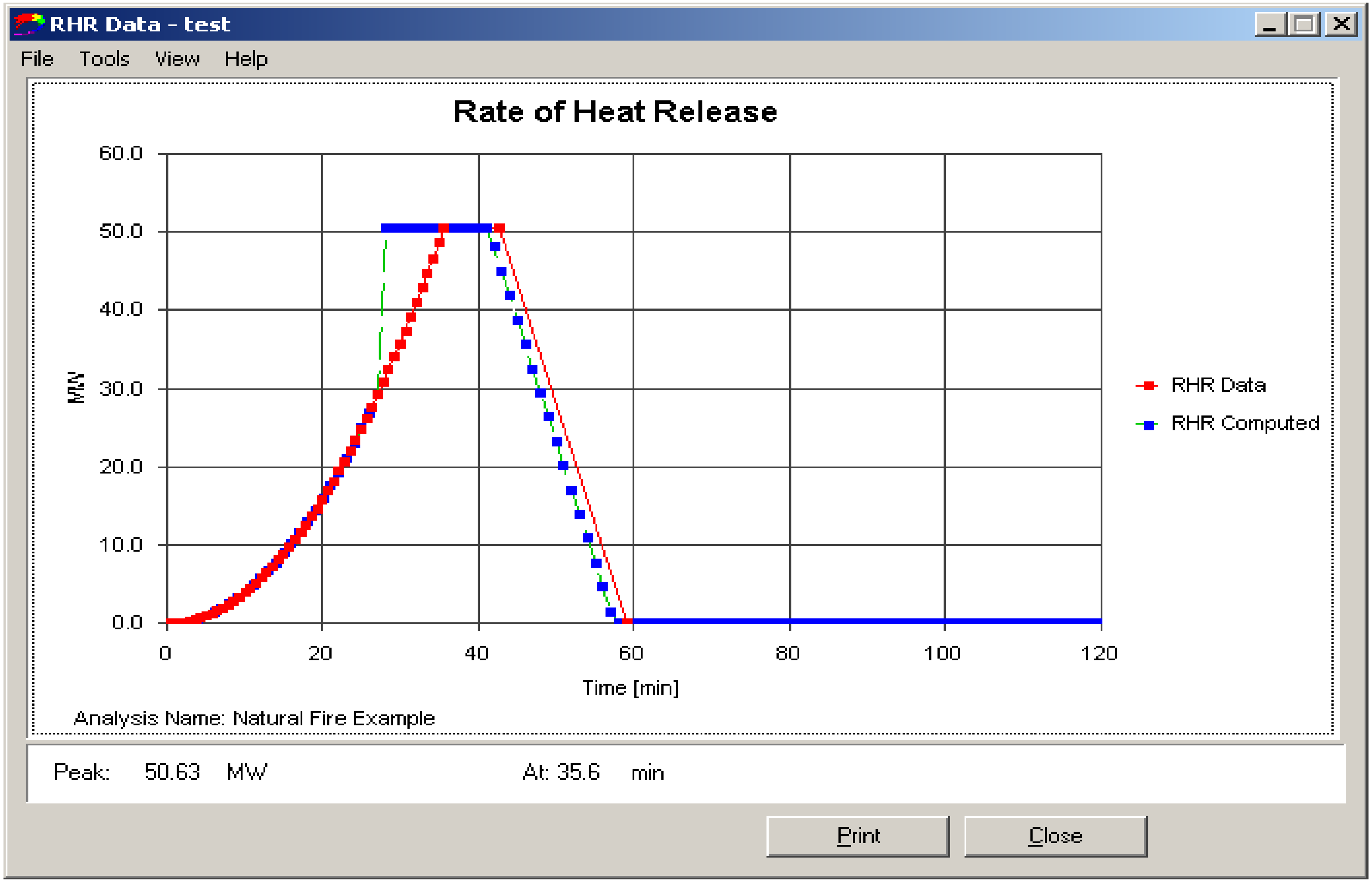
Software “OZone V2.2” Definition of the fire



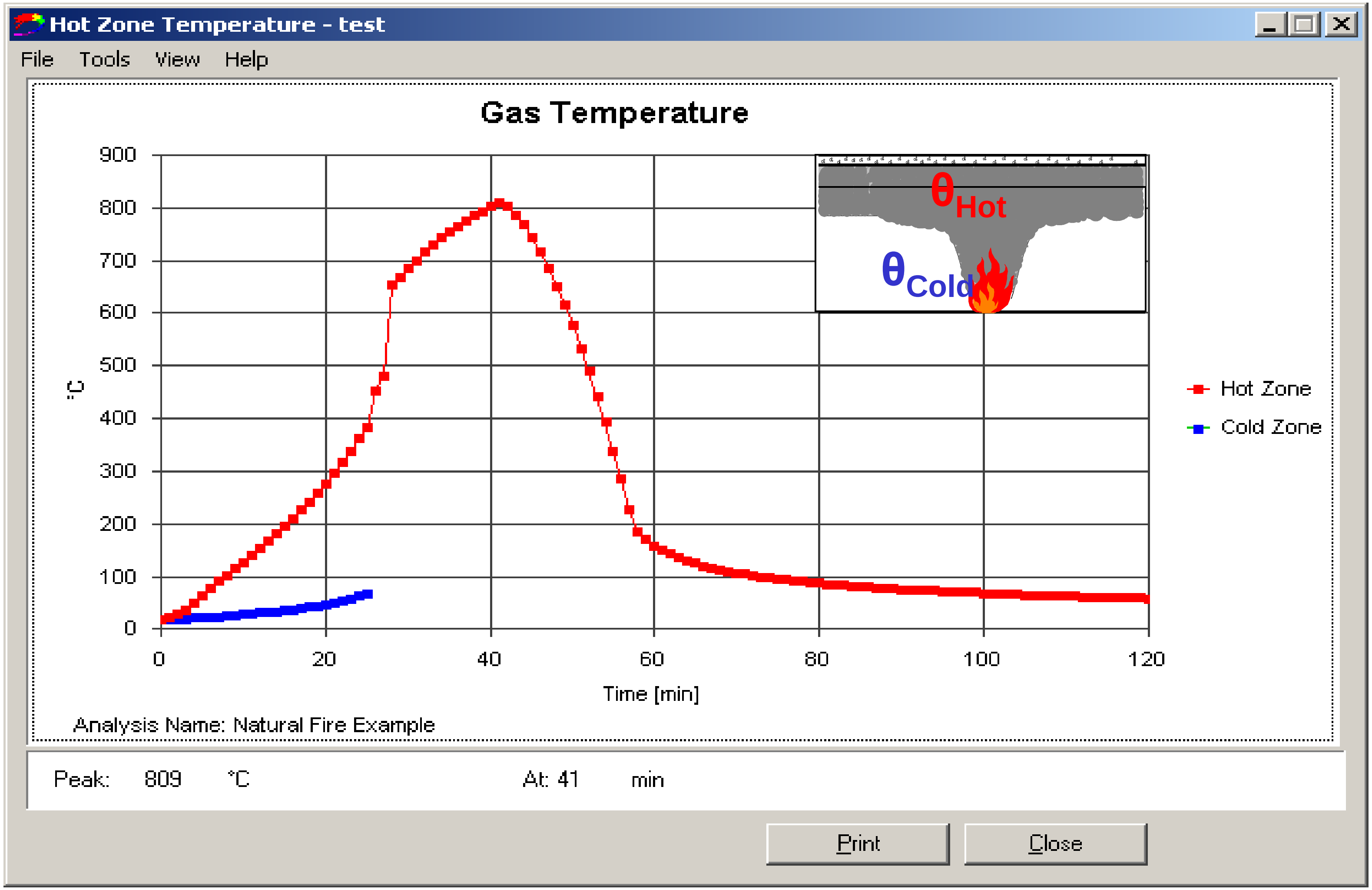
Software "OZone V2.2"
Criteria 2 zones – 1 zone



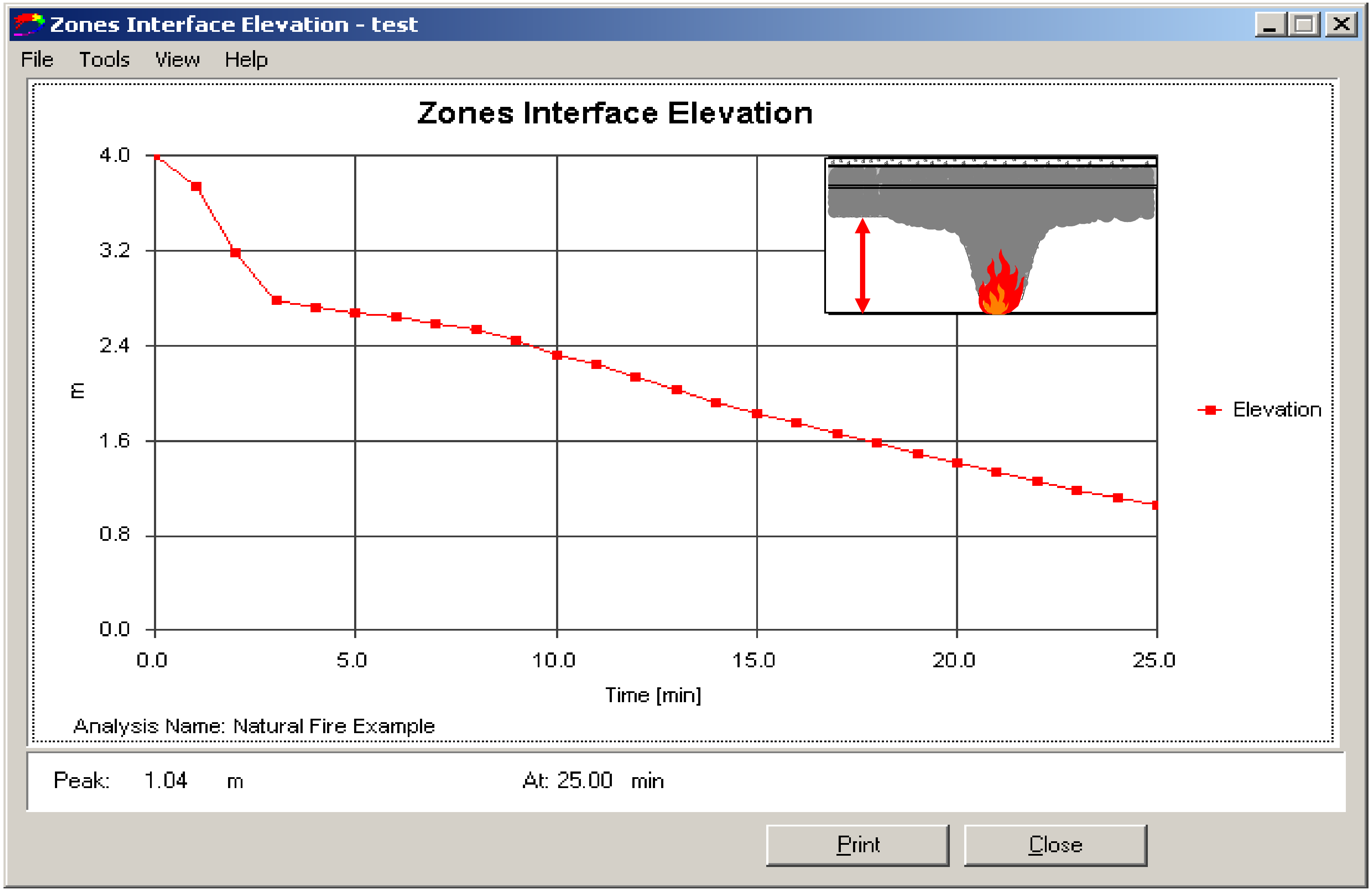
OZone results : Input and Computed RHR



OZone results : Gas Temperatures



OZone results : Smoke Layer Thickness

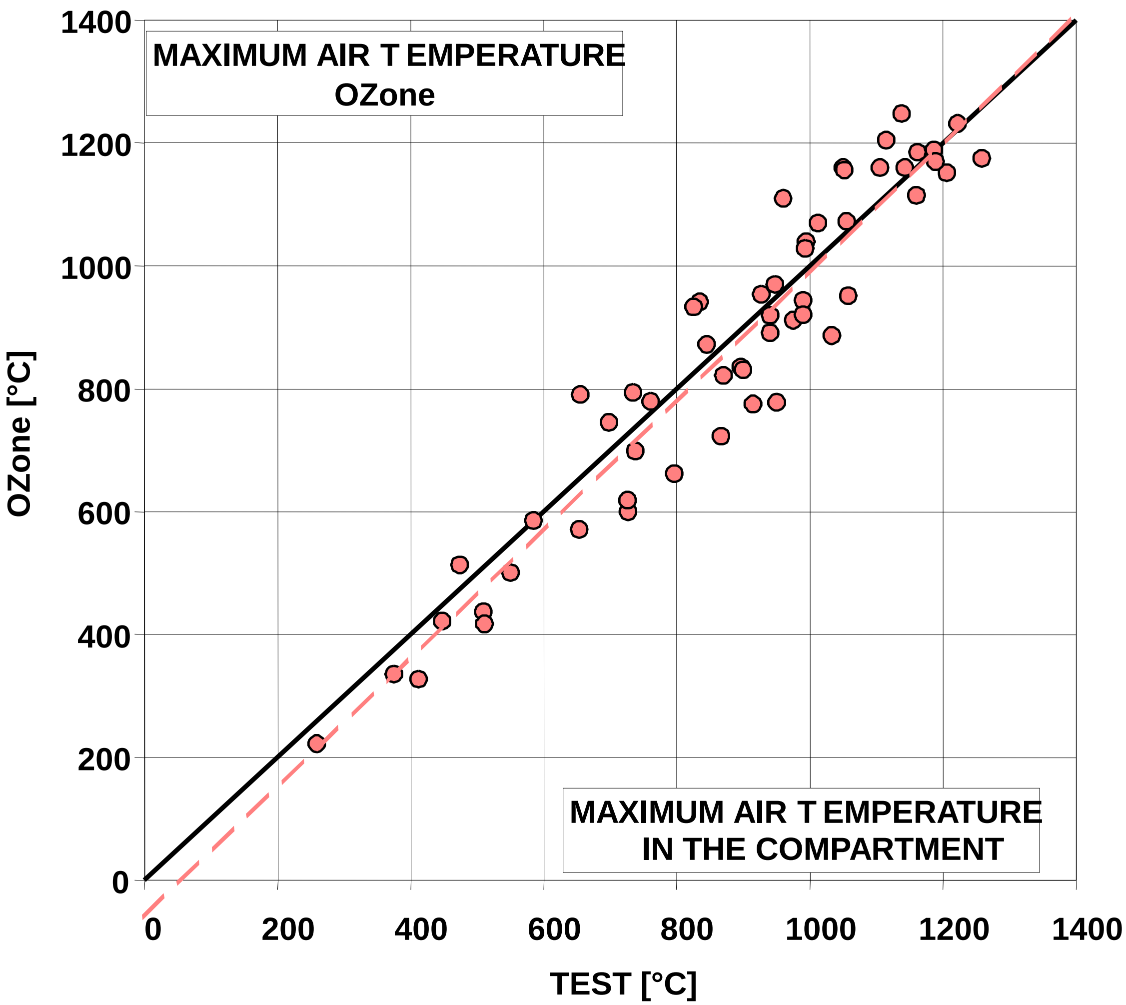



0

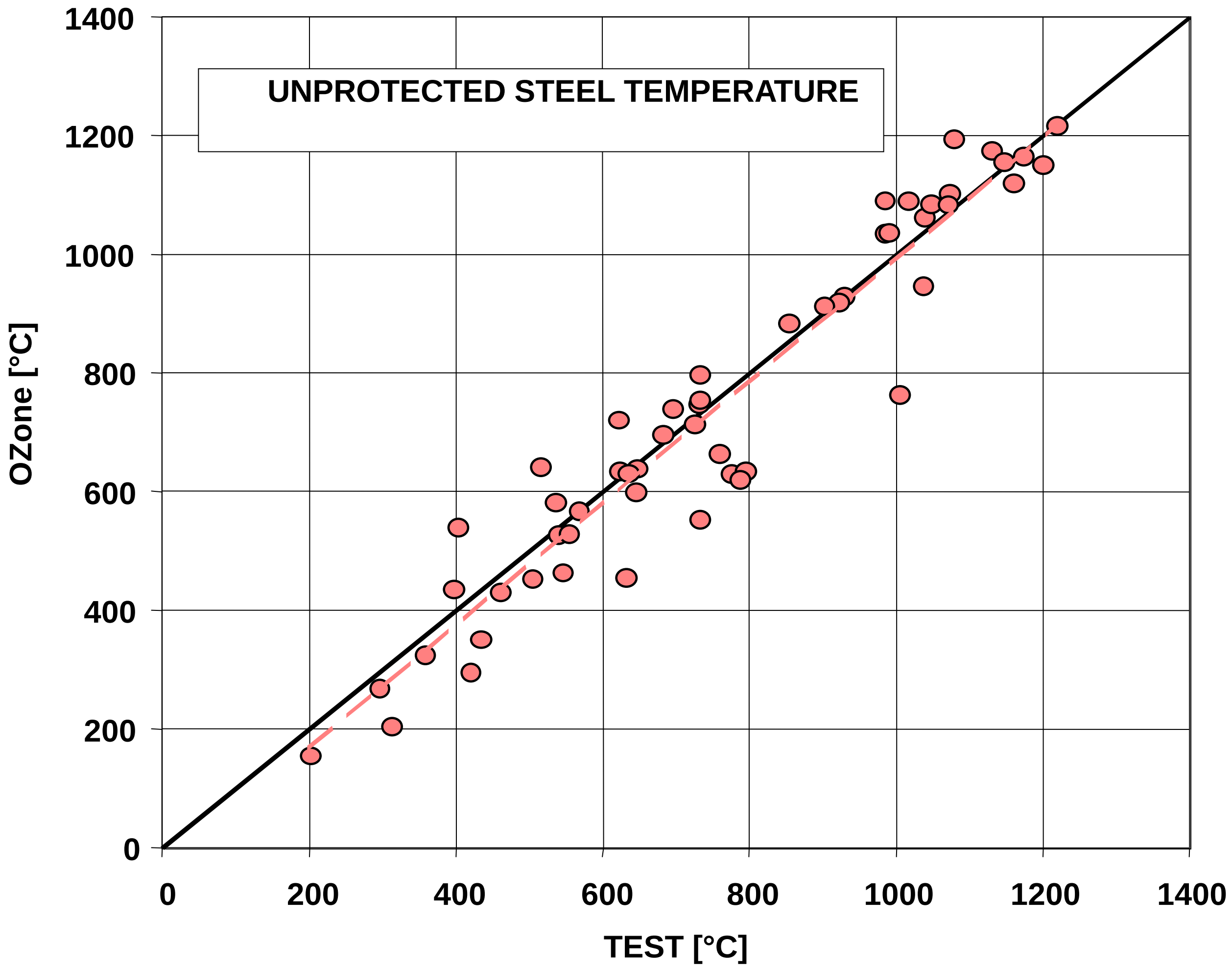

22
0

Compartment Fire test

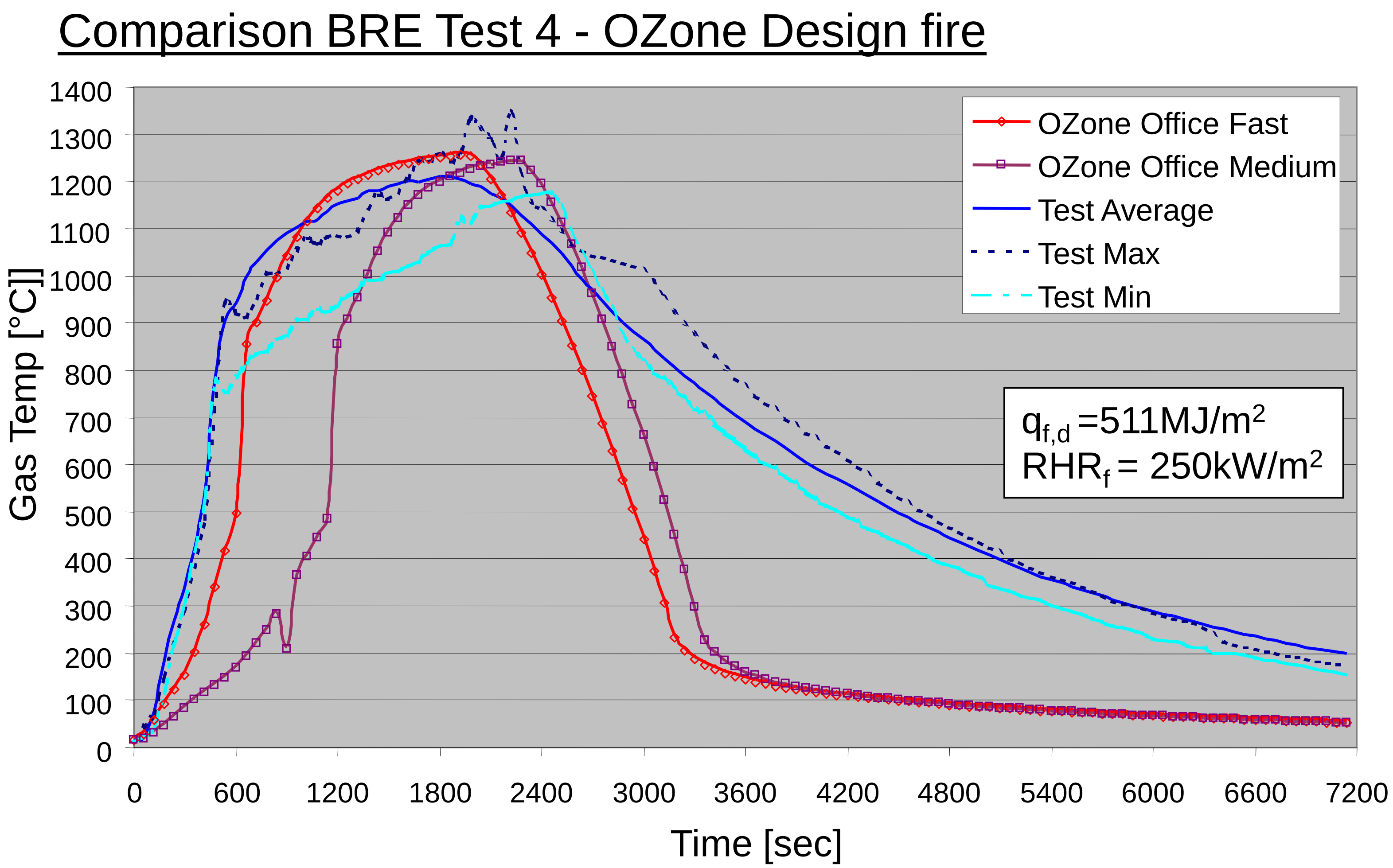
Calibration of Software OZone: Gas Temp



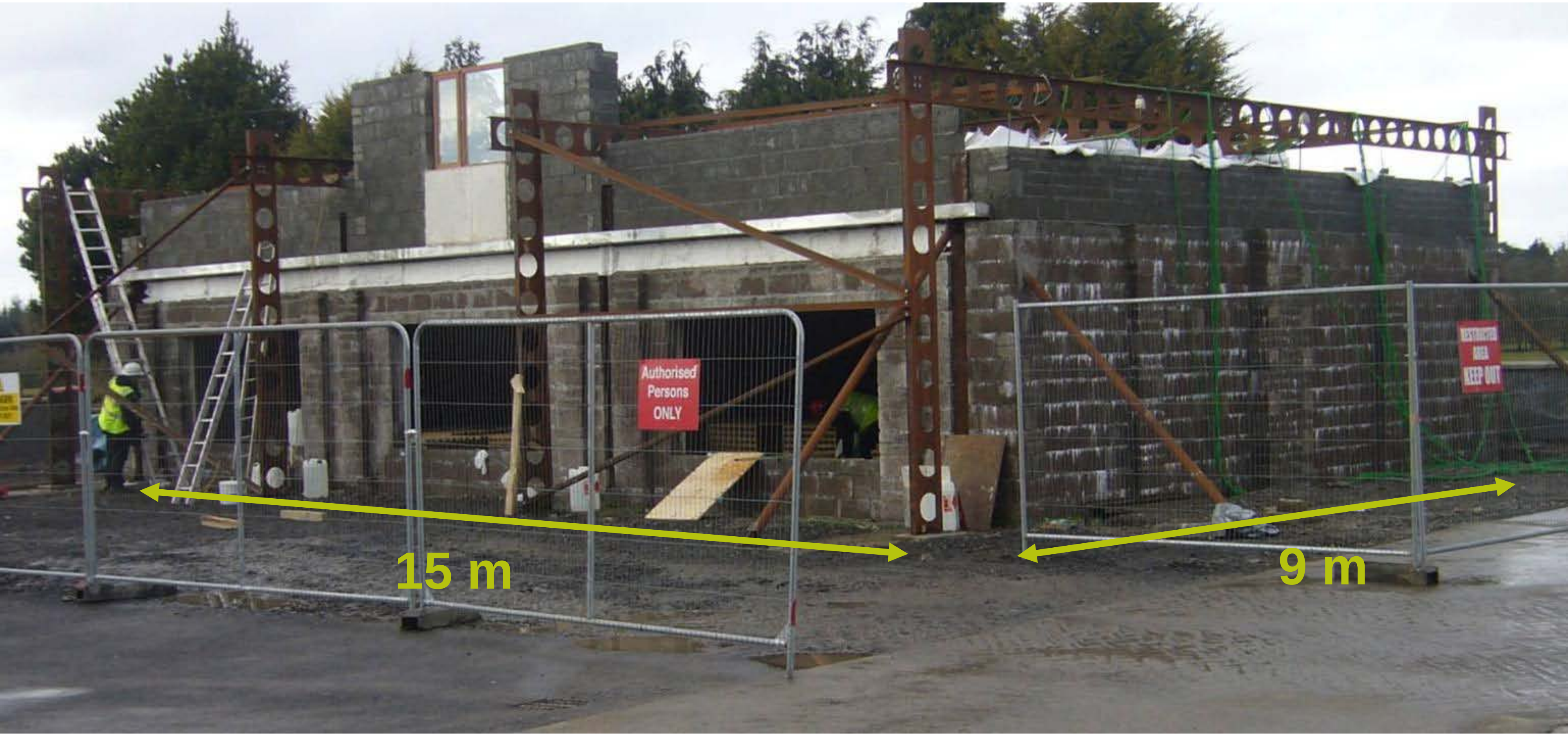
Calibration of Software OZone: Steel Temp



Calibration of Software OZone: OZone Vs Test

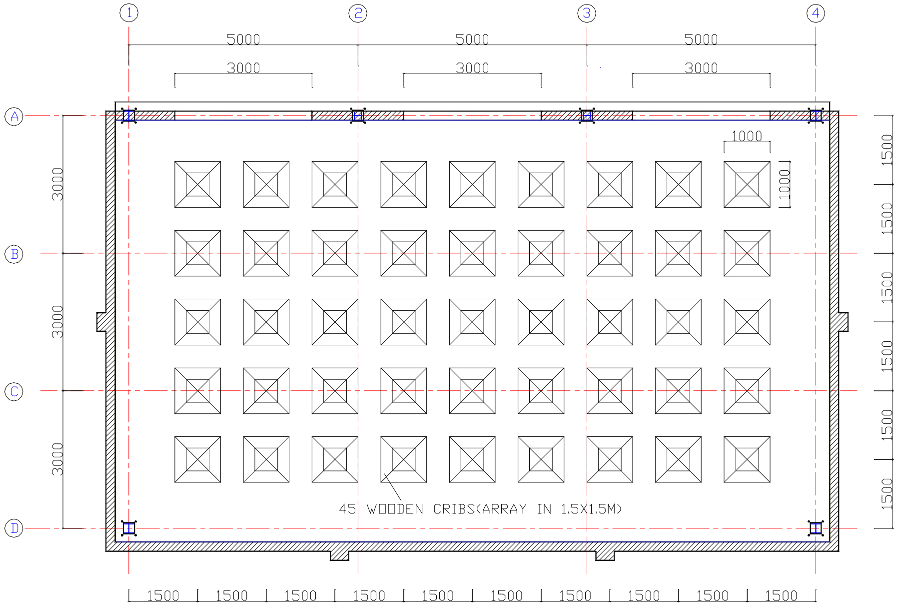


Calibration of Software OZone: OZone Vs Ulster Test



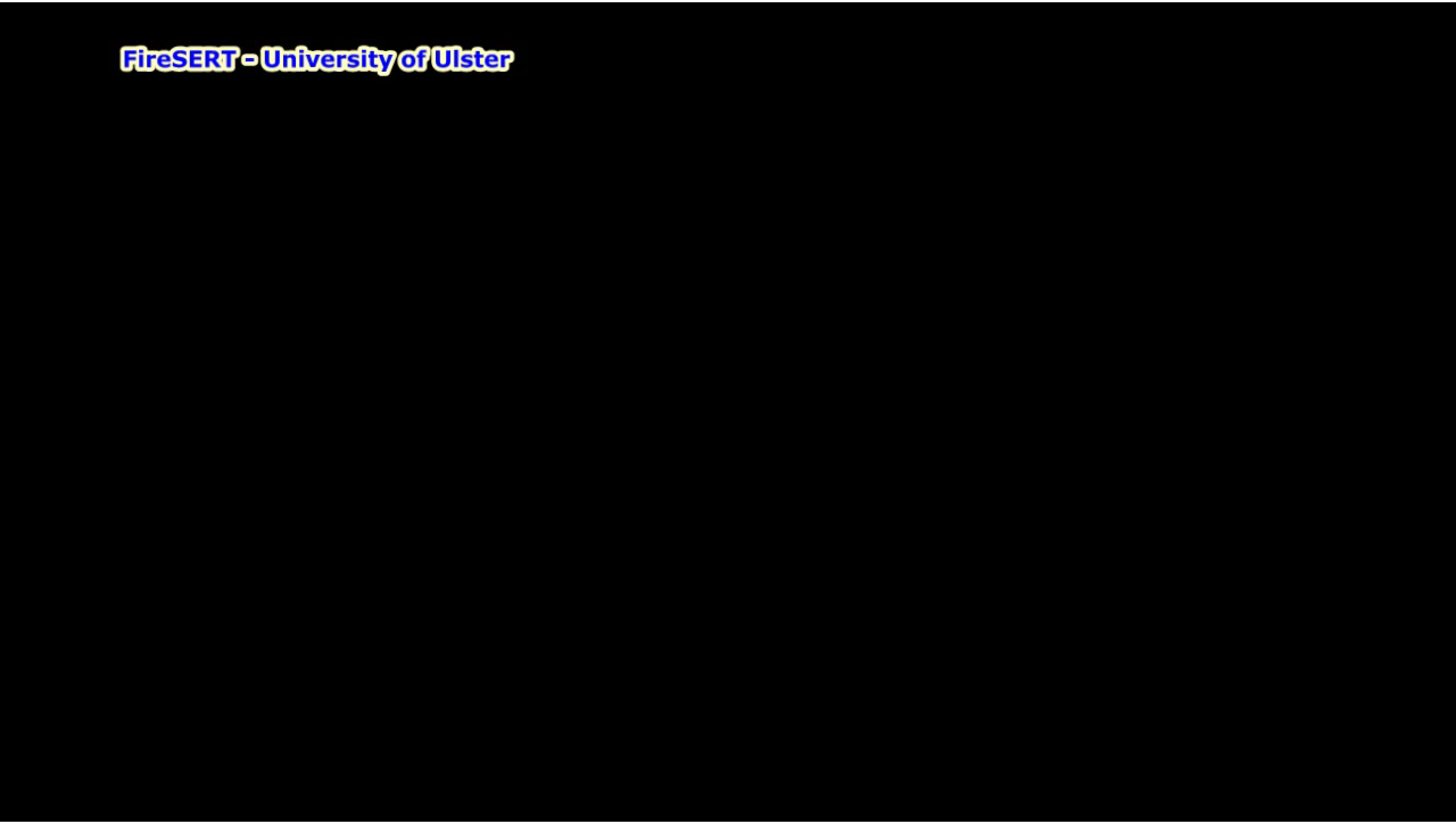
Calibration of Software OZone: OZone Vs Ulster Test

Fire load energy density was700MJ/m²
The fire load can be achieved using 45 standard wooden cribs(1m x 1m x 0.5 m high), positioned evenly around the compartment(9.0m x 15.0m).

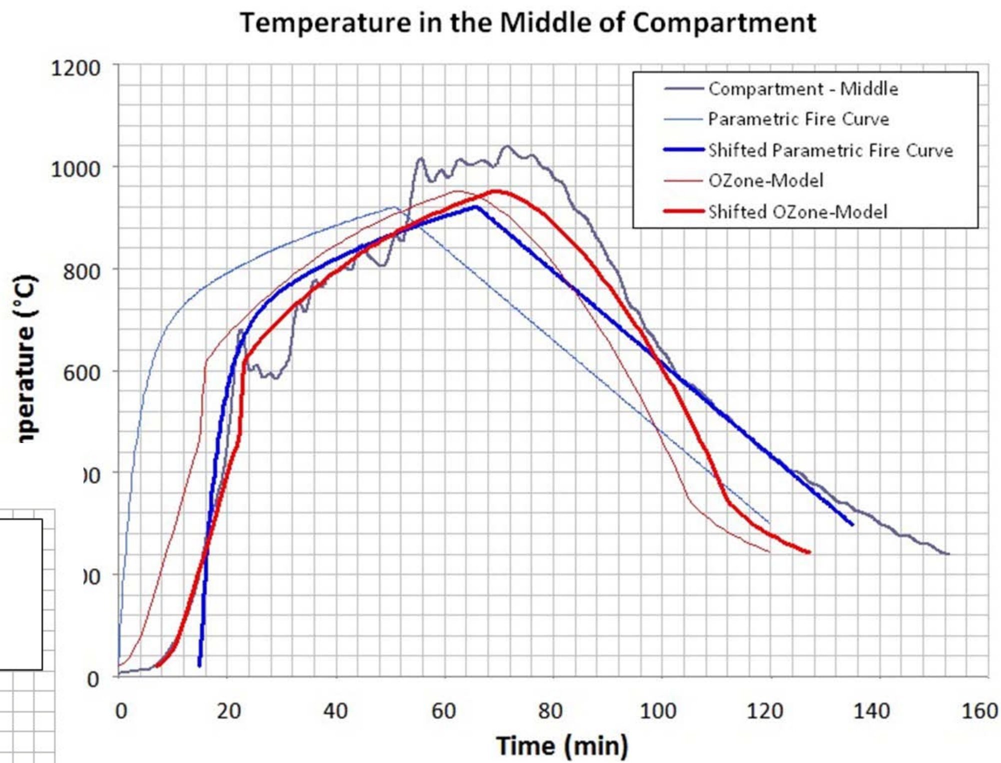


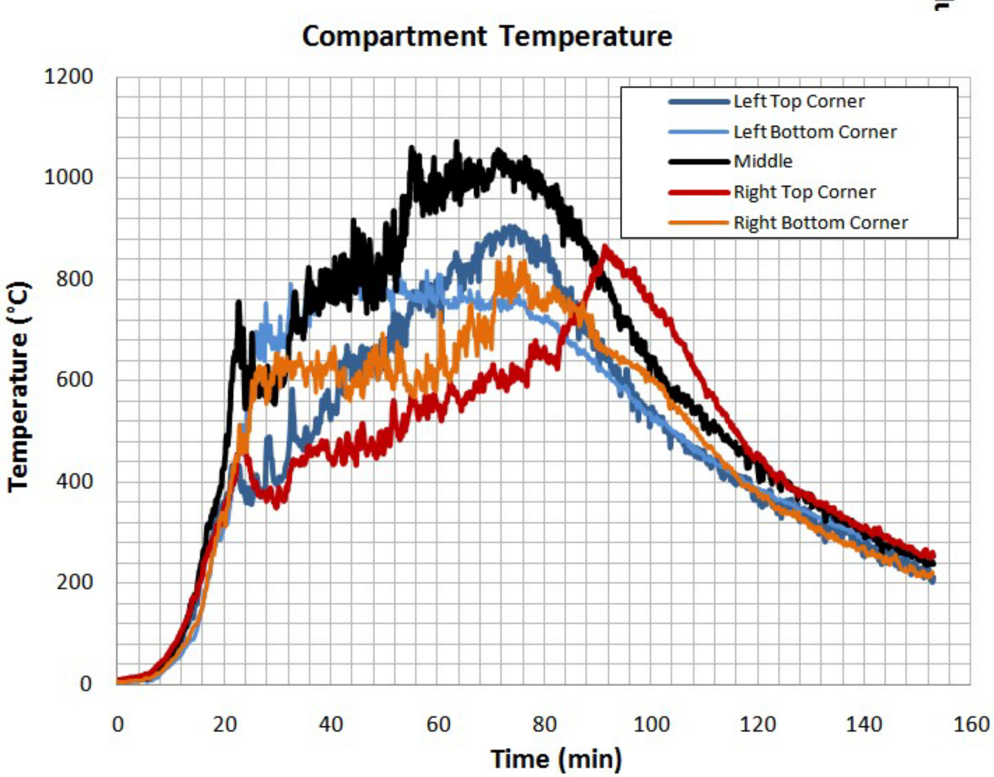
WOODEN CRIBS LOCATION

Calibration of Software OZone: OZone Vs Ulster Test



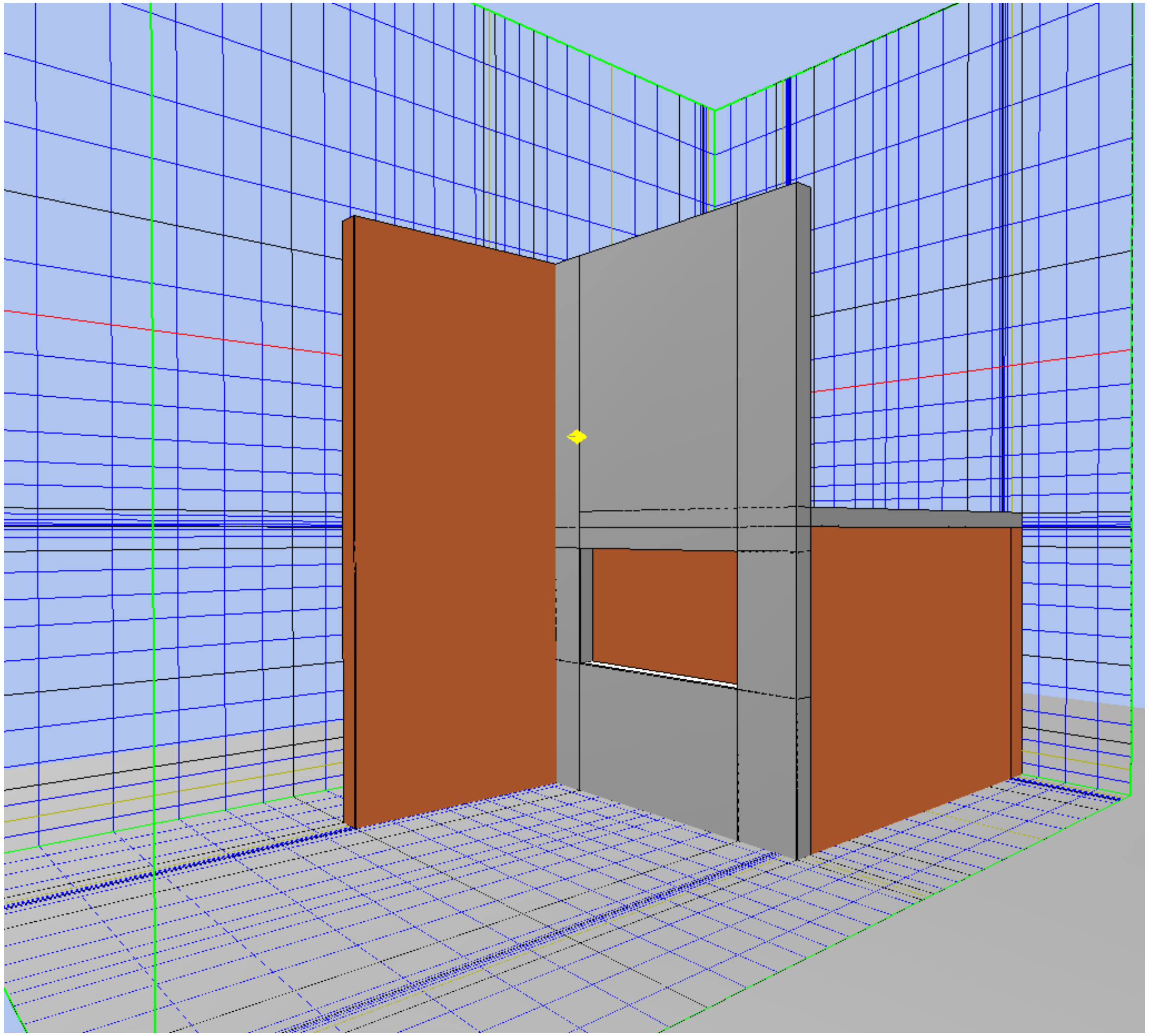
Calibration of Software OZone: OZone Vs Ulster Test



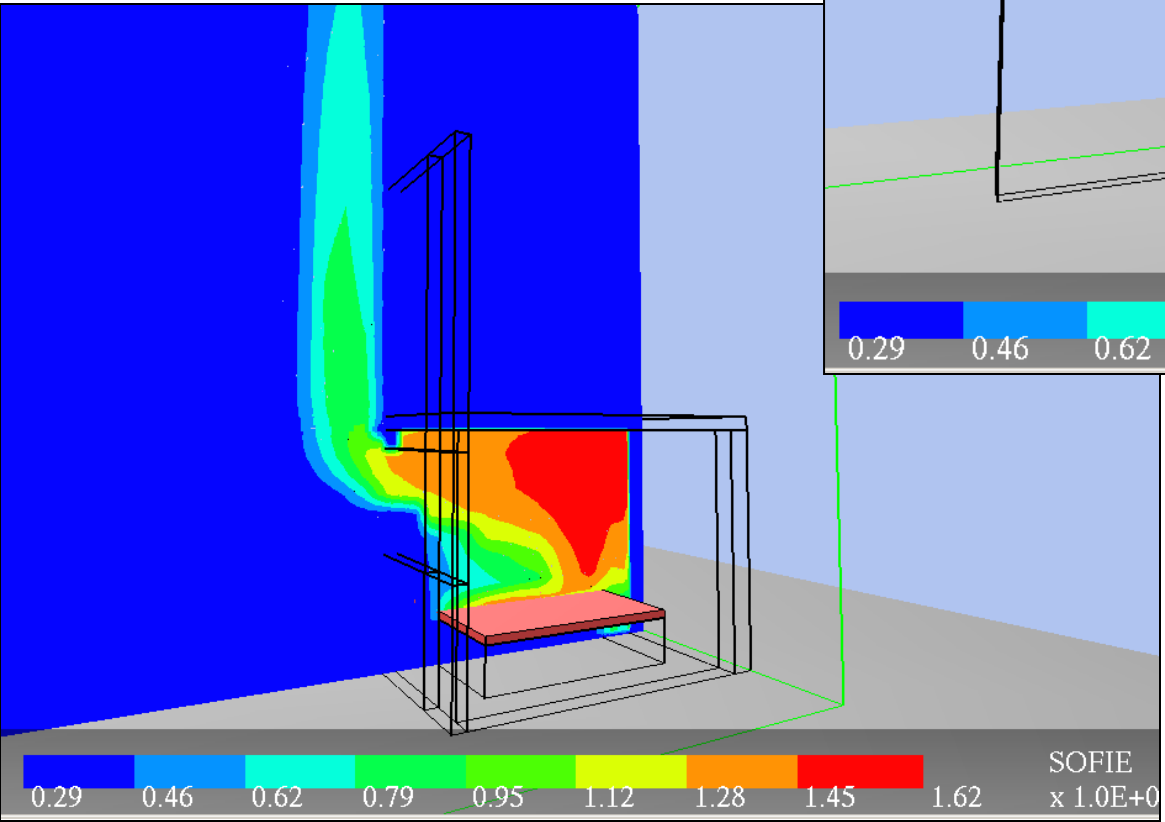


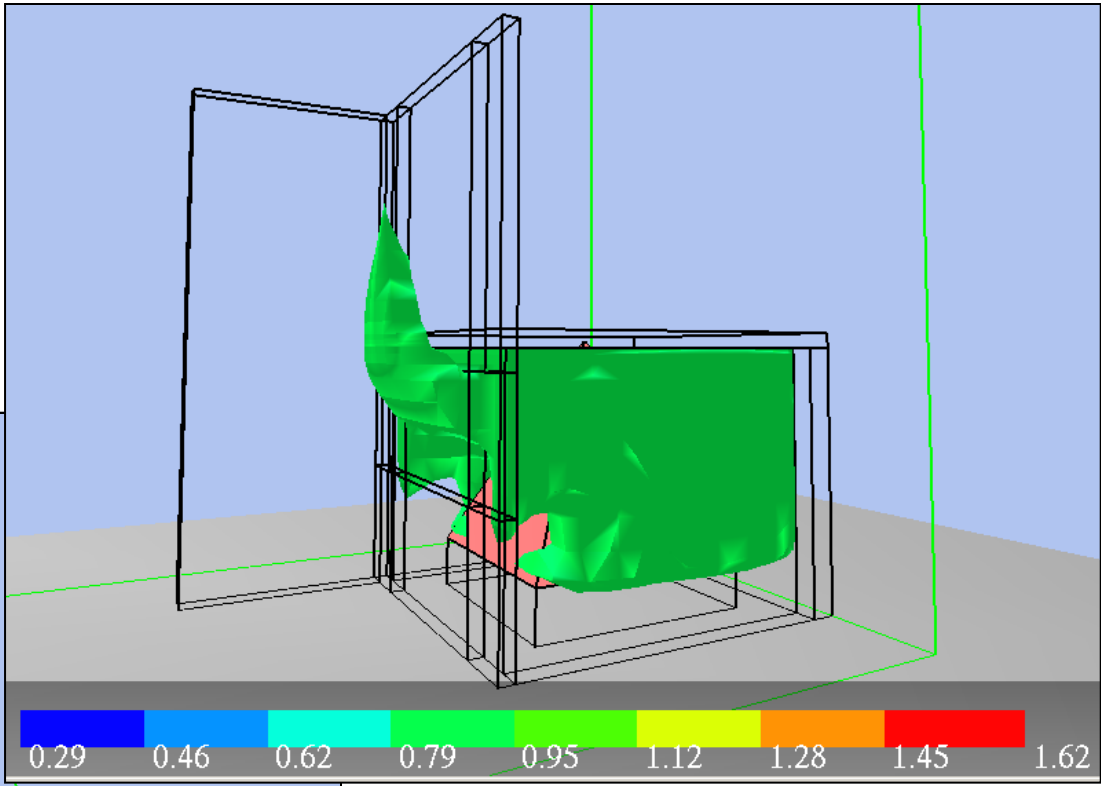
Computer Fluid Dynamics: Software Sofie

Grid definition

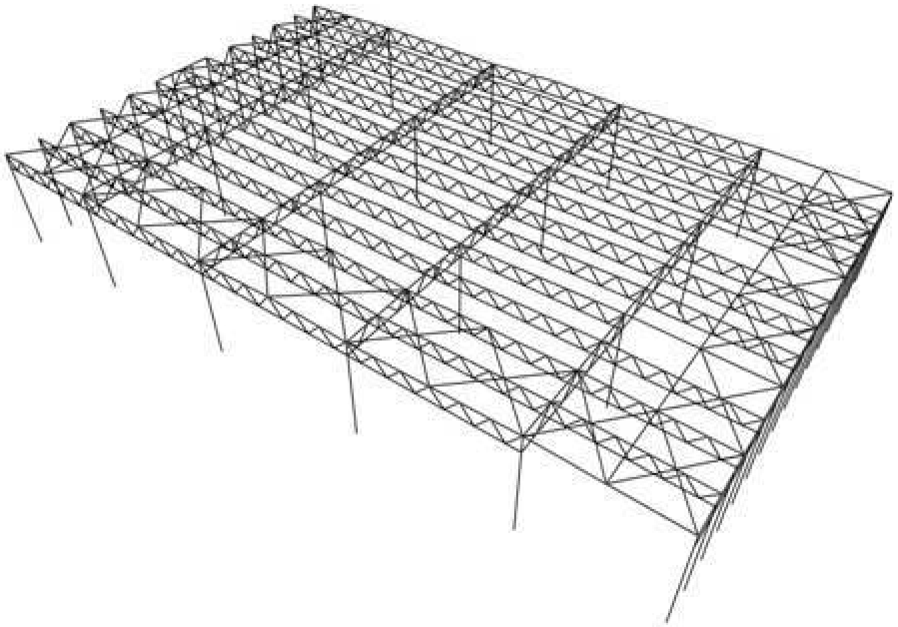


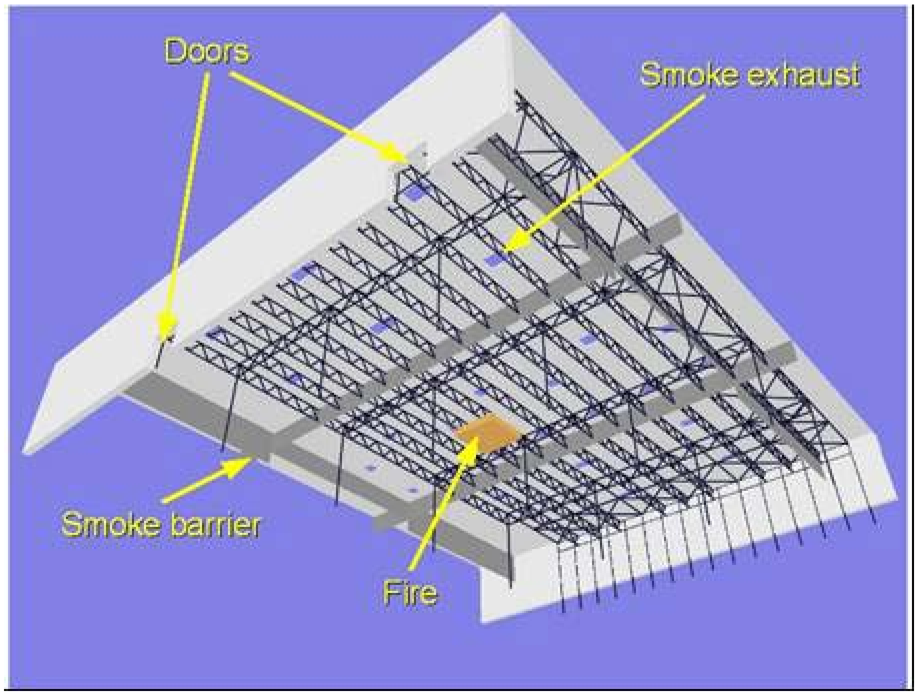
Sofie Results: Gas Temperatures



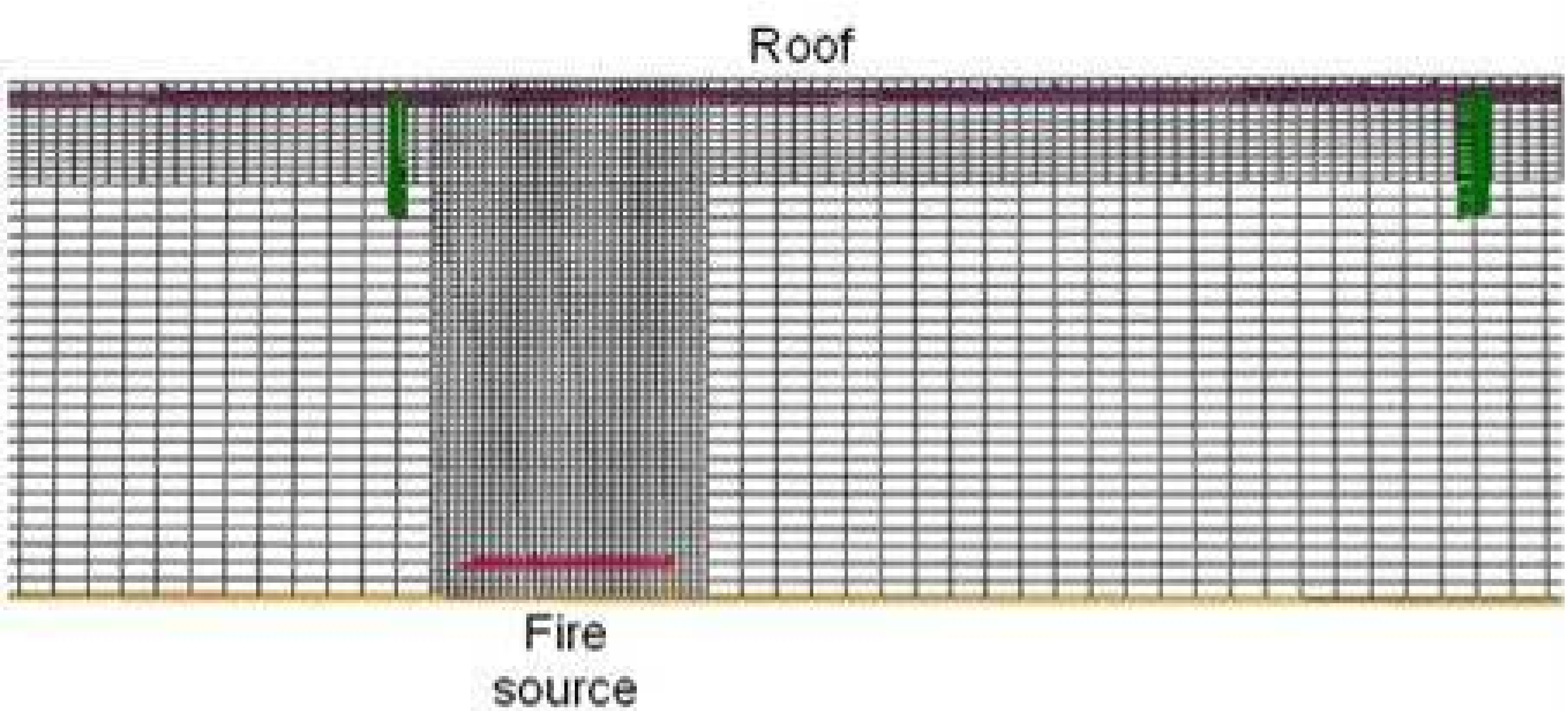


Computer Fluid Dynamics: Free Software FDS

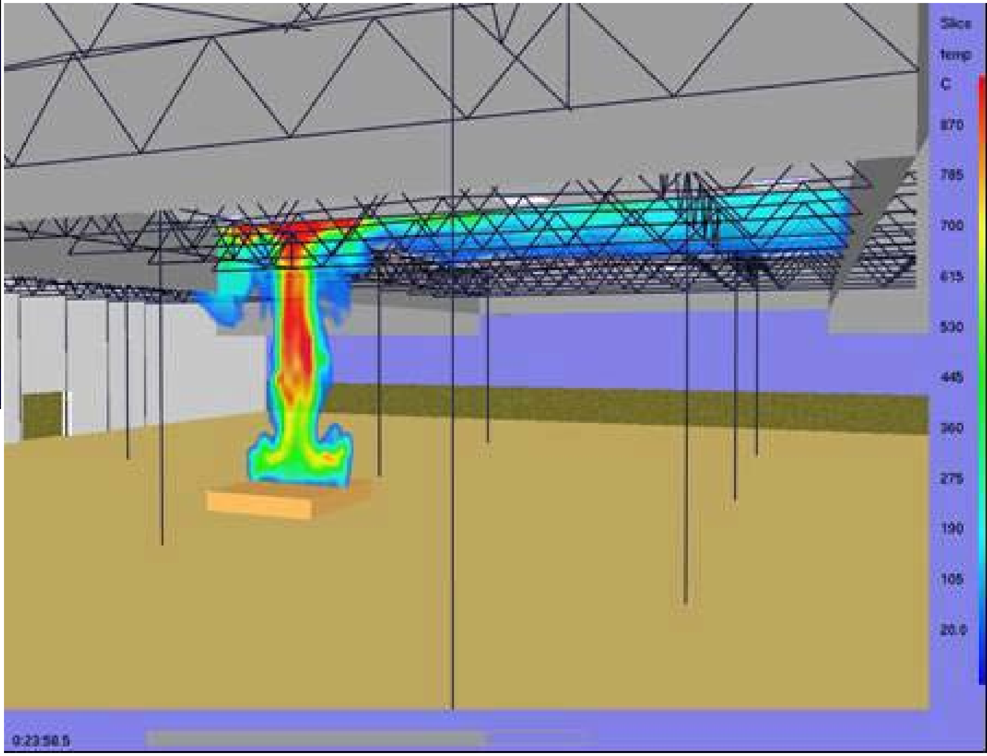




Definition of the mesh



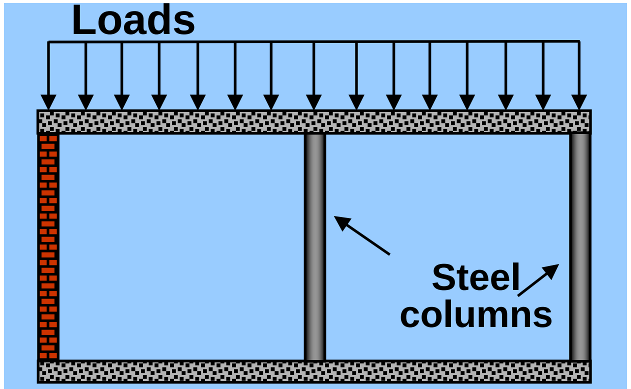
Computer Fluid Dynamics: Free Software FDS



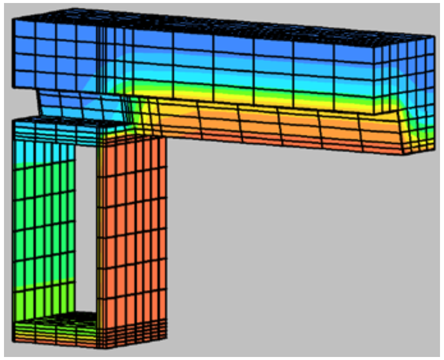
Resistance to Fire - Chain of Events

1: Ignition

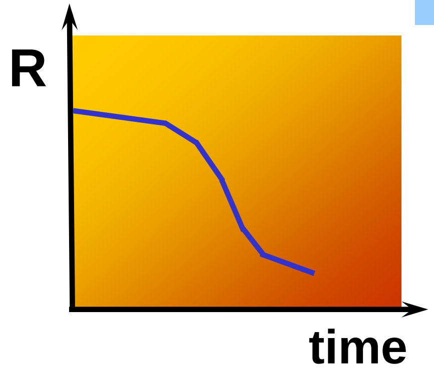
2: Thermal action



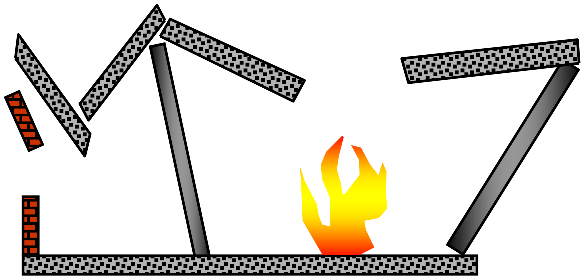
3: Mechanical actions



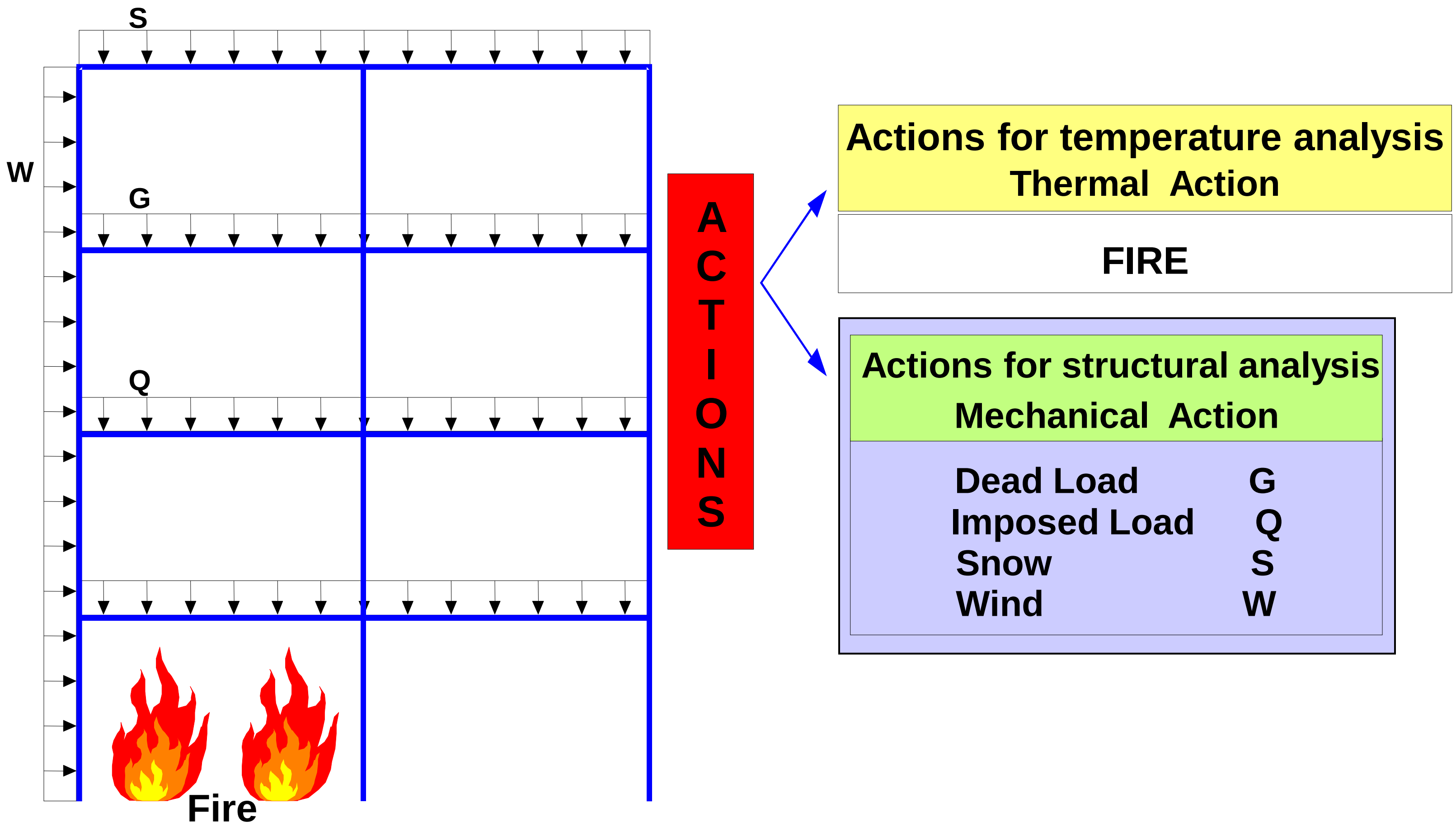
4: Thermal response



5:Mechanical response



6: Possible collapse


S
W
G
Q
Fire
ACTIONS
Actions for temperature analysis
Thermal Action
FIRE
Actions for structural analysis
Mechanical Action
Dead Load G
Imposed Load Q
Snow S
Wind W

Room temperature

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

<u>f.i.</u> : Offices area with the imposed load Q, the leading variable action

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

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

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

Offices area with the wind W, the leading variable action

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

Values of ψ factors for buildings

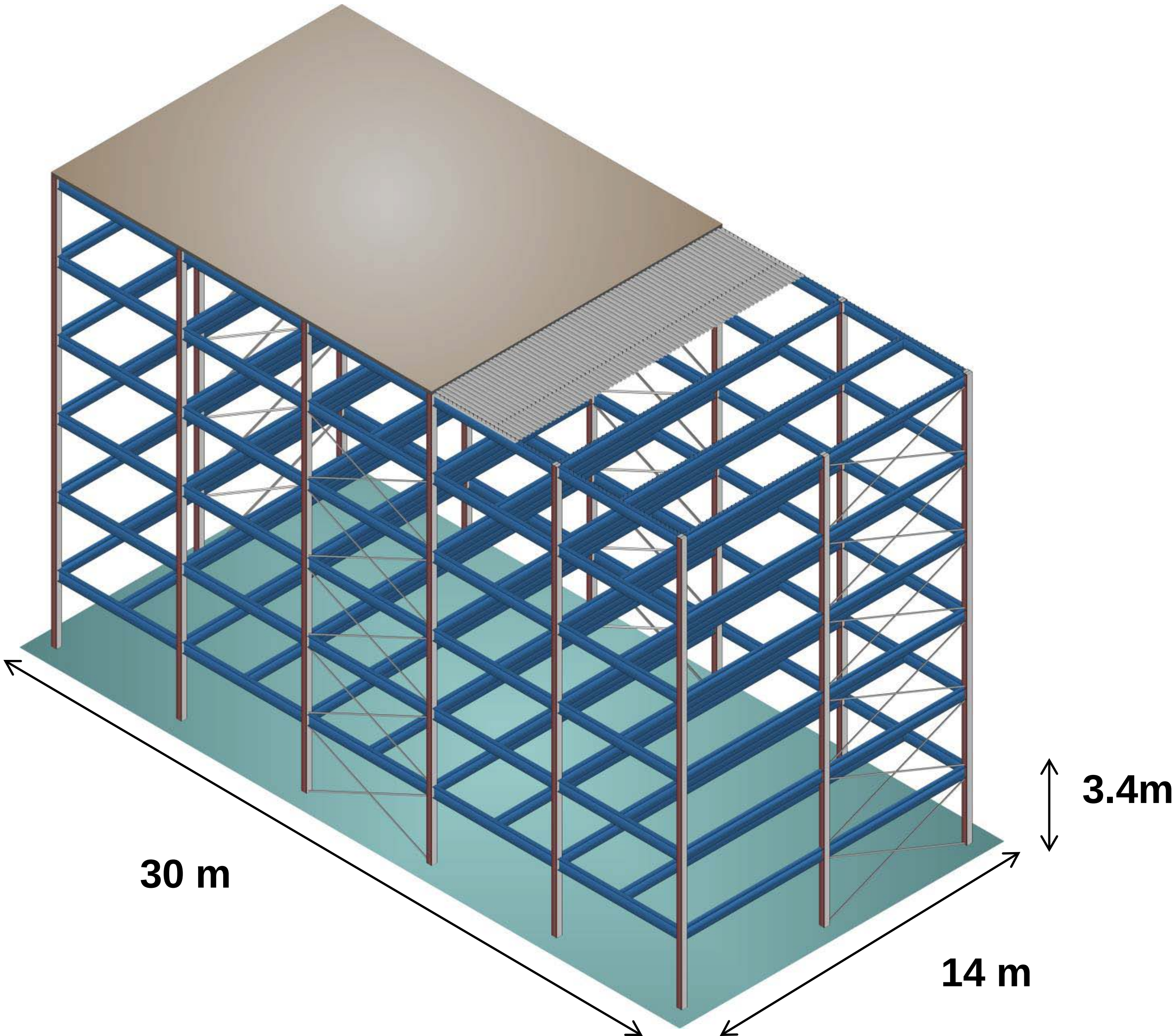
Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1.1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category F : traffic area vehicle weight ≤ 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 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 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 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)

Worked examples of EN1991-1-2

Fire part of Eurocode 1

The Building (R+5)



What do we need for the calculation ?

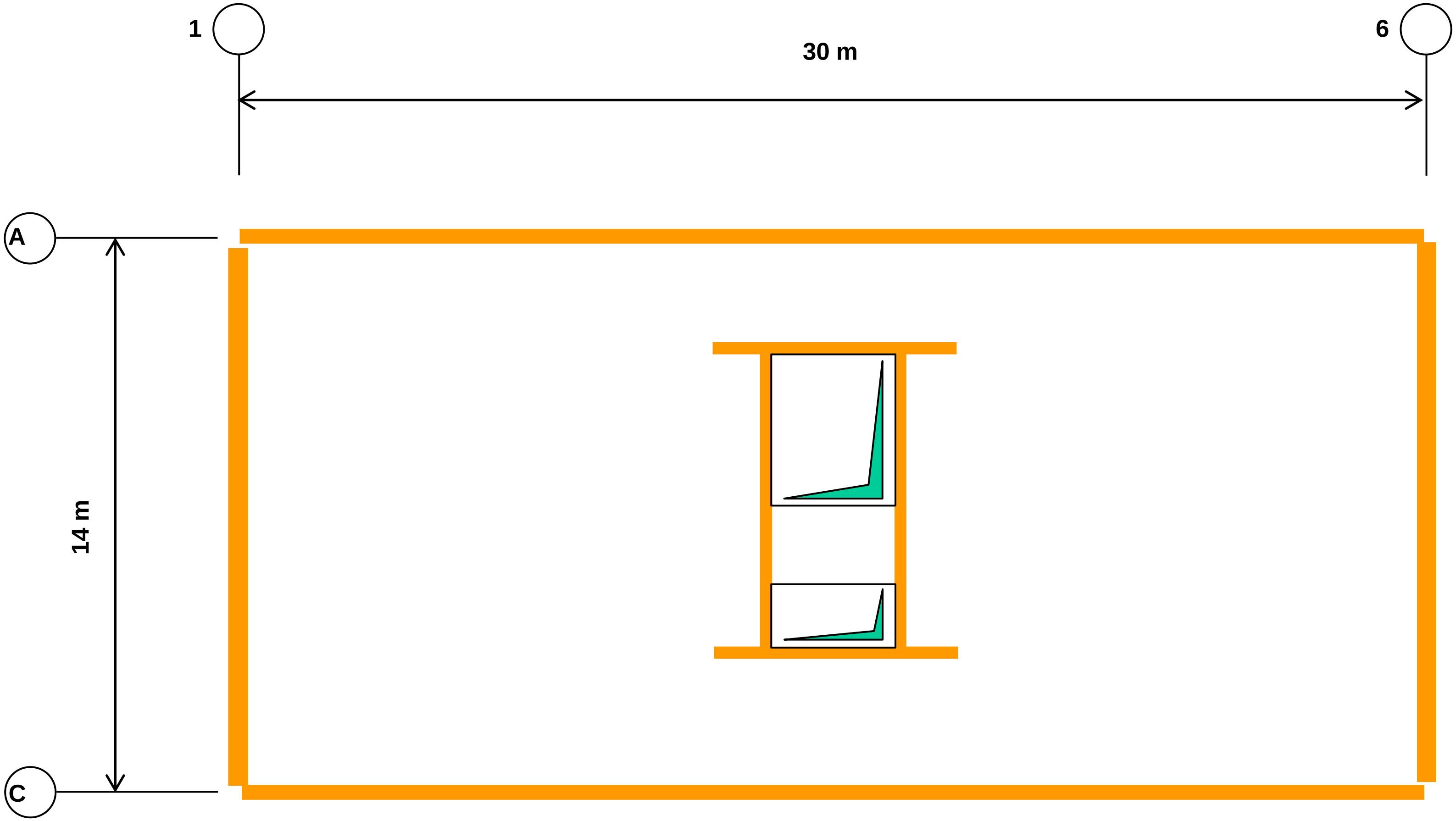
Size of the compartment
Boundary properties
Ceiling height
Opening Area

} **Geometry**

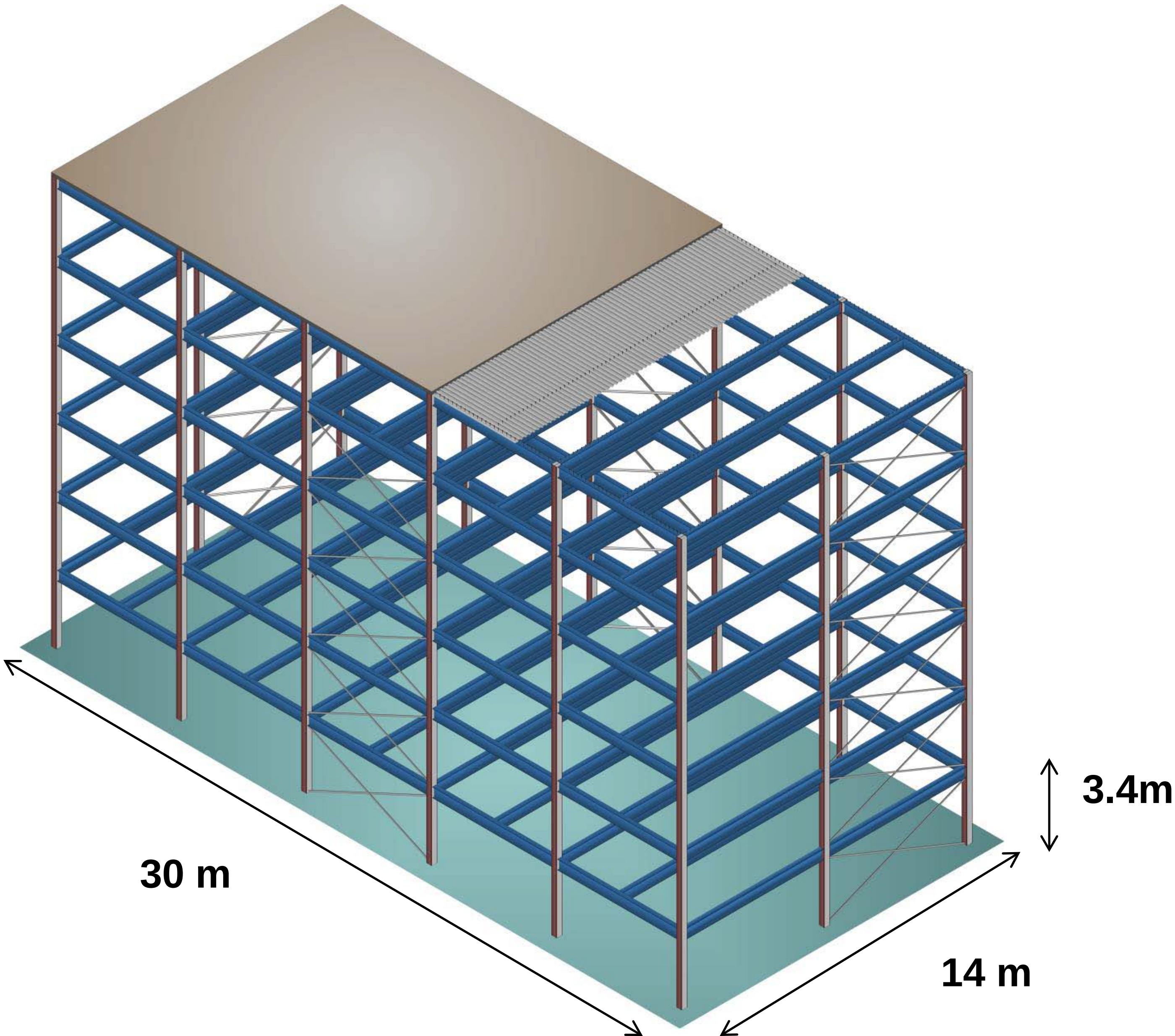
Fire surface
Rate of heat release

} **Fire**

Size of the compartment



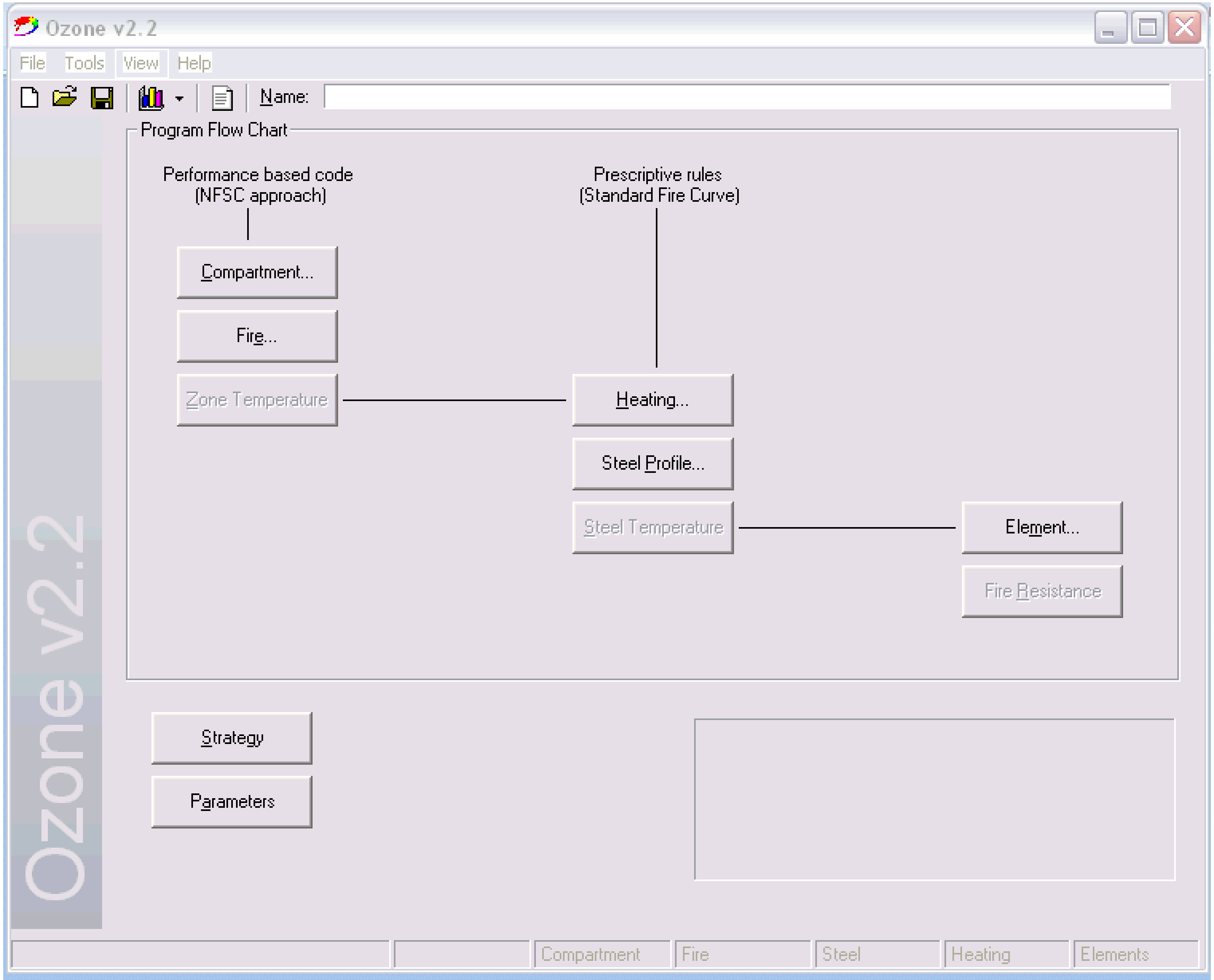
Ceiling height : 3.05 m



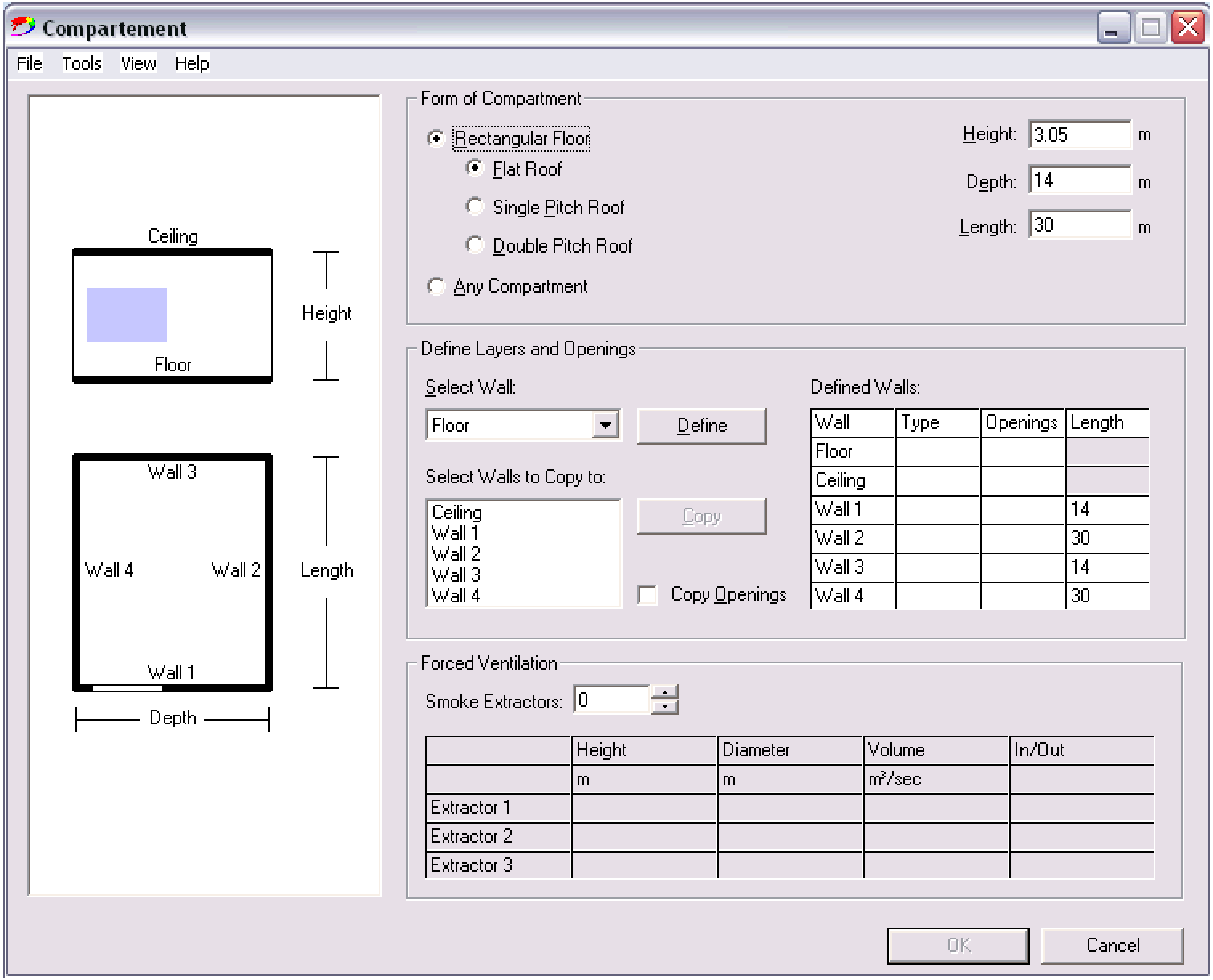
OZone Software

The Software Package that will be used to perform this calculation is OZone.
This Software package has been developed by the University of Liège (Cadorin-Franssen) and is available for free download on:
http://www.argenco.ulg.ac.be/logiciel.php
http://www.arcelormittal.com/sections

OZone Software



OZone Software



Boundaries

Typical floor will be chosen:

- Exterior walls : 20 cm of normal concrete

- Slab : 15 cm of Normal concrete

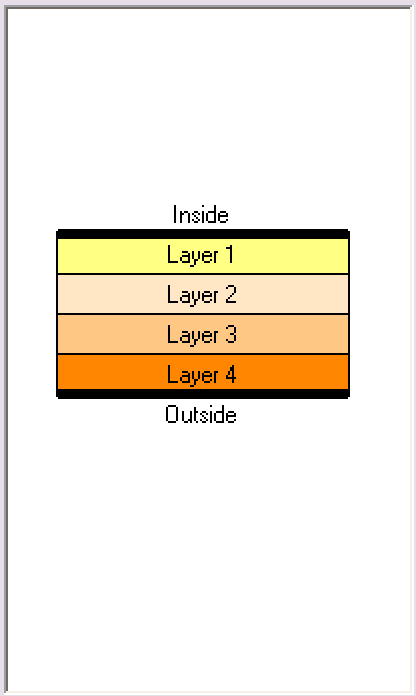
- Ceiling : 15 cm of normal concrete

Boundaries

Layers Floor

File Tools View Help

	Material	Thickness	Unit mass	Conductivity	Specific Heat	Rel Emissivity	Rel Emissivity
		[cm]	[kg/m³]	[W/mK]	[J/kgK]	Hot Surface	Cold Surface
Layer 1	Normal weight Concrete [EN1994-1-2]	15	2300	1.6	1000	0.8	0.8
Layer 2							
Layer 3							
Layer 4							



Enter each layer on a single row in the table above (up to four layers). Just click in a cell and edit it's value. If not found in the list of materials you can define your own material, by filling in the apropriate cells. Define your layers starting from Layer 1 (Inside).

Define your openings if any (up to three openings in a single wall). Click in the desired cell and input your values. Start from Opening 1.

To delete or insert a row, right click on a row header and select the appropriate command from the popup menu.

Equal Diameter Groups: 0

	Diameter	Number of Openings	Variation
	[m]		
Group 1			
Group 2			
Group 3			

OK Cancel

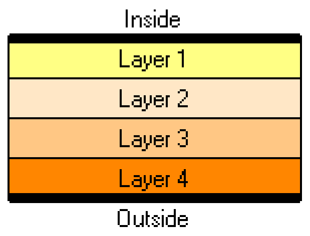
Boundaries

Layers and Openings Wall 1

File Tools View Help

Wall Length: m

	Material	Thickness	Unit mass	Conductivity	Specific Heat	Rel Emissivity	Rel Emissivity
		[cm]	[kg/m³]	[W/mK]	[J/kgK]	Hot Surface	Cold Surface
Layer 1	Normal weight Concrete [EN1994-1-2]	20	2300	1.6	1000	0.8	0.8
Layer 2							
Layer 3							
Layer 4							



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Define your openings if any (up to three openings in a single wall). Click in the desired cell and input your values. Start from Opening 1.

To delete or insert a row, right click on a row header and select the appropriate command from the popup menu.

	Sill Height Hi	Soffit Height Hs	Width	Variation	Adiabatic
	[m]	[m]	[m]		
Opening 1					
Opening 2					
Opening 3					

OK Cancel

Opening Factors

This point is one critical point.

The Eurocode is not providing the scenario that must be chosen to take into account the openings.

Openings can be doors, windows and general « porosity » of the building.

If no opening is taken into account from the beginning of the fire, the amount of oxygen in the compartment will be too small and the fire will not develop.

Opening Factors

Here are some information to help for definition of the scenario for the breaking of the windows:

In the literature, it can be found that:

-Normal glazing will start to break with a ΔT of 40°C on the glass

-Tempered glazing will start to break with a ΔT of 120°C on the glass

-Tempered glazing with reinforcement will start to break with a ΔT of 120°C on the glass (The reinforcement will melt at 300°C)

Opening Factors

Luxembourgish authorities have realized a guide that needs to be followed when FSE is used. This guide will become official soon. But here is some extract for the non fire resistant glazing:

-Scenario 1 : 90% of the glazing is open since the beginning

-Scenario 2:

- -Simple glazing : 100°C : 50% and 250°C: 90%
- -Double glazing: 200°C : 50% and 400°C: 90%
- -Triple glazing: 300°C : 50% and 500°C: 90%

Opening Factors

Assumptions for the façade:

-Ex. 1: 0.8m open all around the building

-Ex. 2: 1.5m open all around the building

-Ex. 3: full glazing Façade

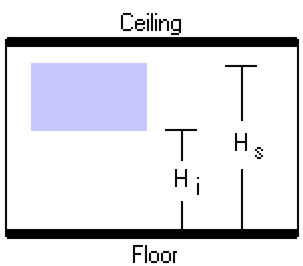
Opening Factors Ex.1

Layers and Openings Wall 1 - ECW_Ex1

File Tools View Help

Wall Length: 14 m

	Material	Thickness	Unit mass	Conductivity	Specific Heat	Rel Emissivity	Rel Emissivity
		[cm]	[kg/m³]	[W/mK]	[J/kgK]	Hot Surface	Cold Surface
Layer 1	Normal weight Concrete [EN1994-1-2]	20	2300	1.6	1000	0.8	0.8
Layer 2							
Layer 3							
Layer 4							



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Define your openings if any (up to three openings in a single wall). Click in the desired cell and input your values. Start from Opening 1.

To delete or insert a row, right click on a row header and select the appropriate command from the popup menu.

	Sill Height Hi	Soffit Height Hs	Width	Variation	Adiabatic
	[m]	[m]	[m]		
Opening 1	1.2	2	14	Stepwise	no
Opening 2					
Opening 3					

OK Cancel

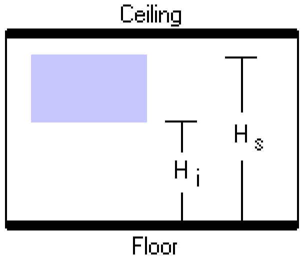
Opening Factors

Layers and Openings Wall 1 - ECW_Ex1

File Tools View Help

Wall Length: 14 m

	Material	Thickness	Unit mass	Conductivity	Specific Heat	Rel Emissivity	Rel Emissivity
		[cm]	[kg/m³]	[W/mK]	[J/kgK]	Hot Surface	Cold Surface
Layer 1	Normal weight Concrete [EN1994-1-2]	20	2300	1.6	1000	0.8	0.8
Layer 2							
Layer 3							
Layer 4							



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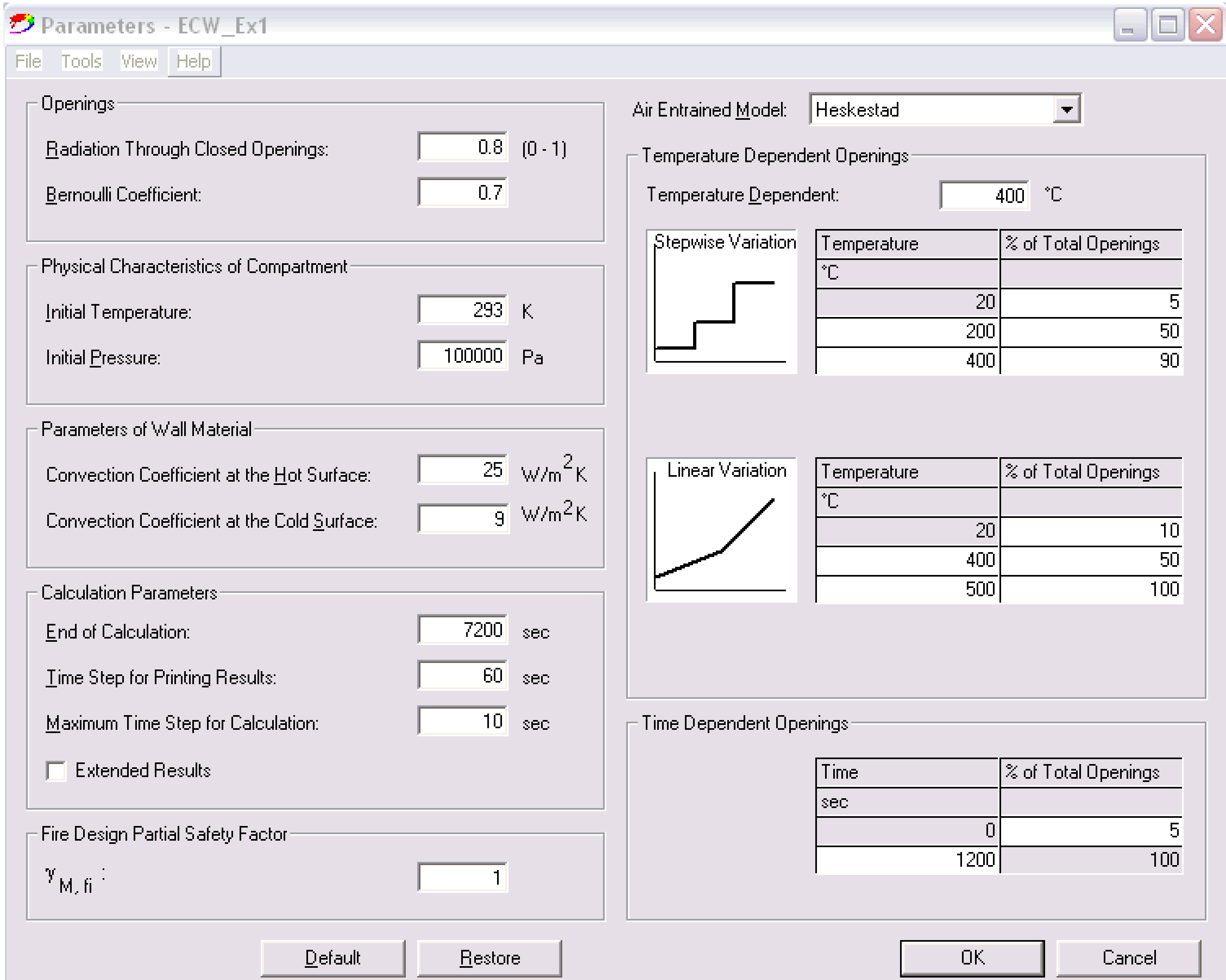
	Sill Height Hi	Soffit Height Hs	Width	Variation	Adiabatic
	[m]	[m]	[m]		
Opening 1	1.2	2	14	Stepwise	no
Opening 2					
Opening 3					

OK Cancel

Opening Factors



Definition of the fire

European Commission

Occupancy	Fire Growth Rate	RHR_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

Definition of the fire

European Commission

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Shopping Centre	Fast	250	730
Theatre (movie/cinema)	Fast	500	365
Transport (public space)	Slow	250	122

Definition of the fire

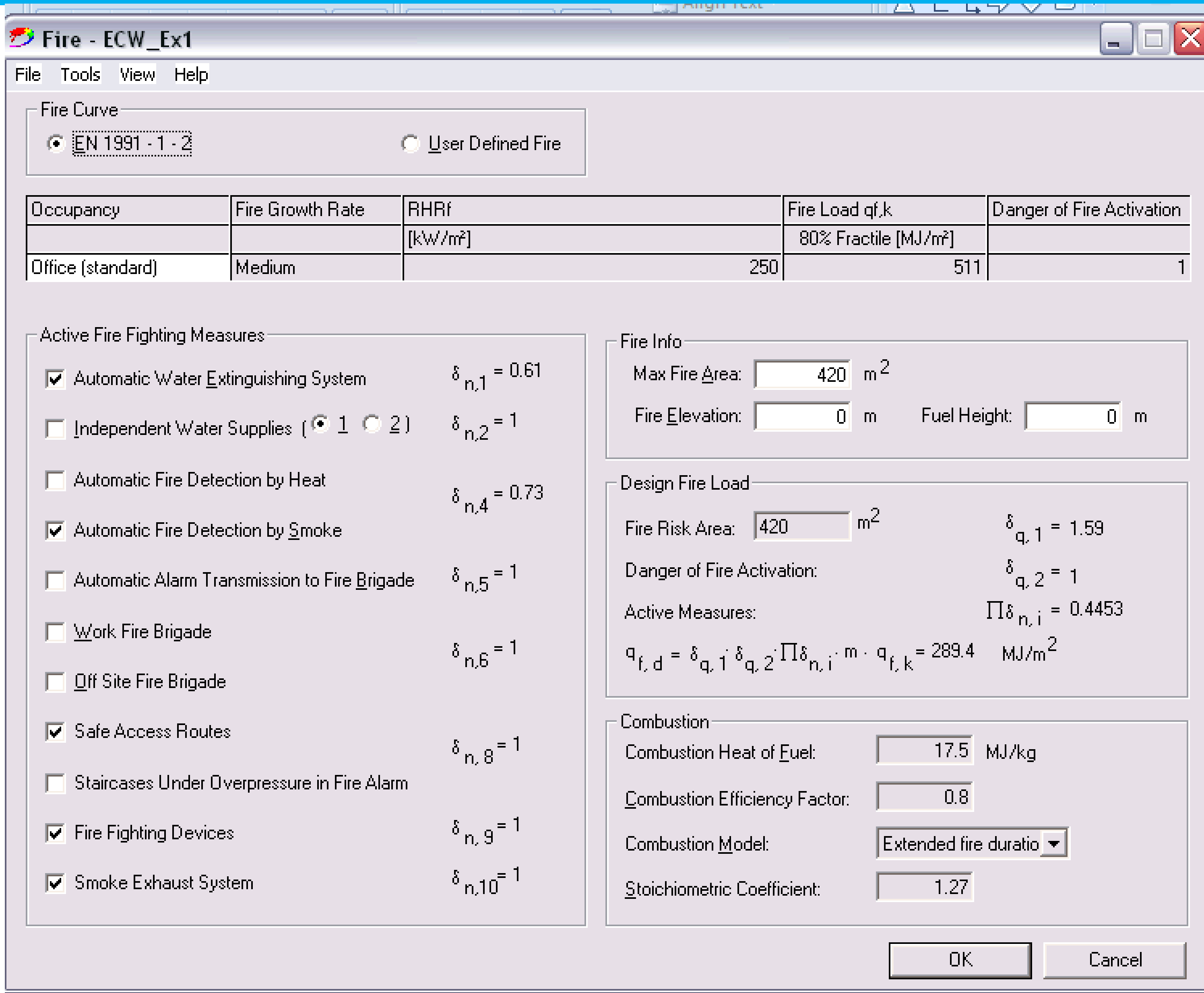
Compartment floor area A_f [m²]	Danger of Fire Activation δ_{q1}
25	1,10
250	1,50
2500	1,90
5000	2,00
10000	2,13

Danger of Fire Activation δ_{q2}	Examples of Occupancies
0,78	Art gallery, museum, swimming pool
1,00	Residence, hotel, office
1,22	Manufactory for machinery & engines
1,44	Chemical laboratory, Painting workshop
1,66	Manufactory of fireworks or paints

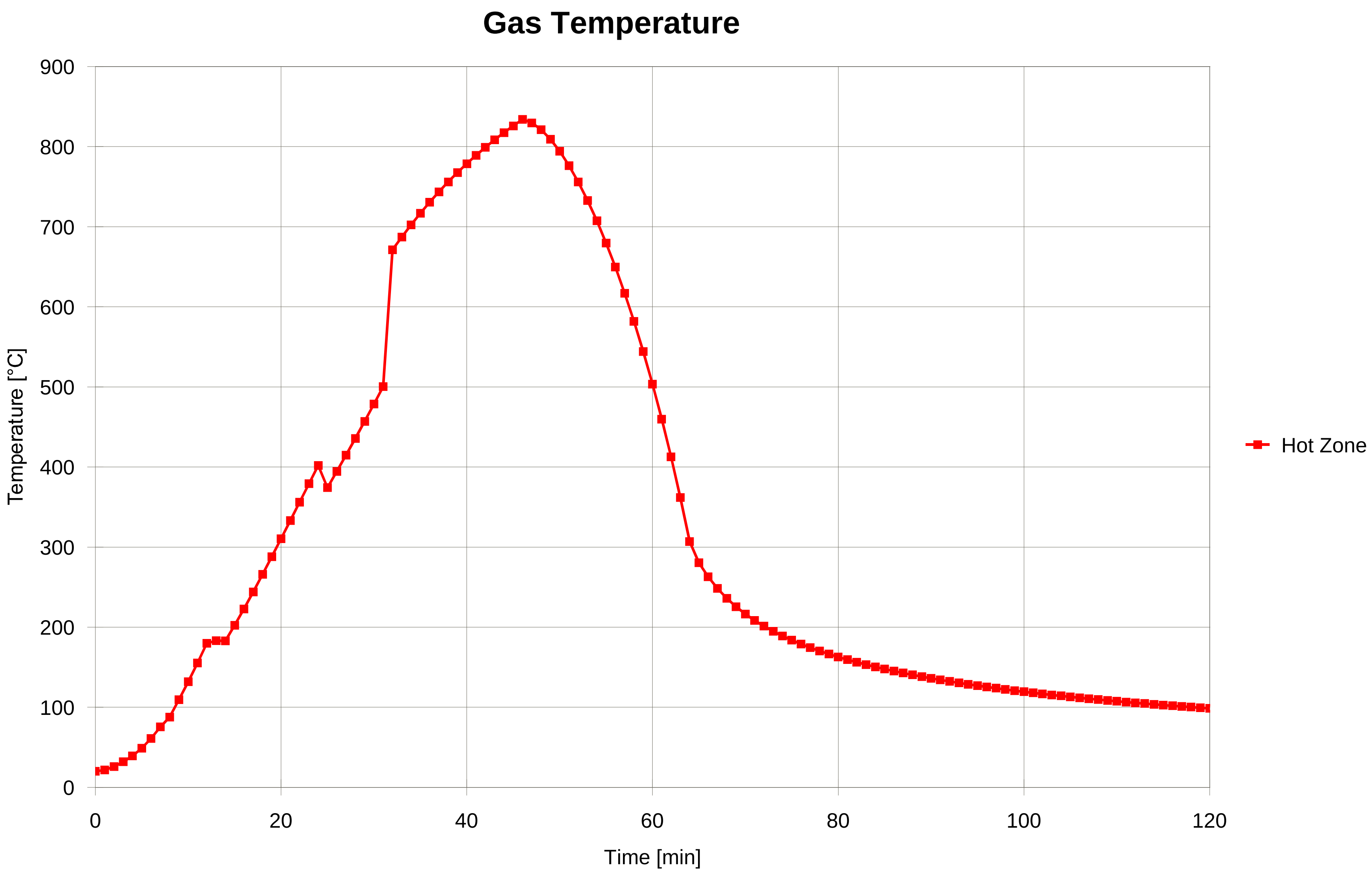
$$q_{f,d} = \delta_{q1} \cdot \delta_{q2} \cdot \prod \delta_{ni} \cdot m \cdot q_{f,k}$$

Automatic ...										
Automatic Water Extinguishing System δ_{n1}	Independent Water Supplies 0 | 1 | 2 δ_{n2}	Automatic fire Detection & Alarm by Heat δ_{n3}	Automatic fire Detection & Alarm by Smoke δ_{n4}	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}
0,61	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

Definition of the fire

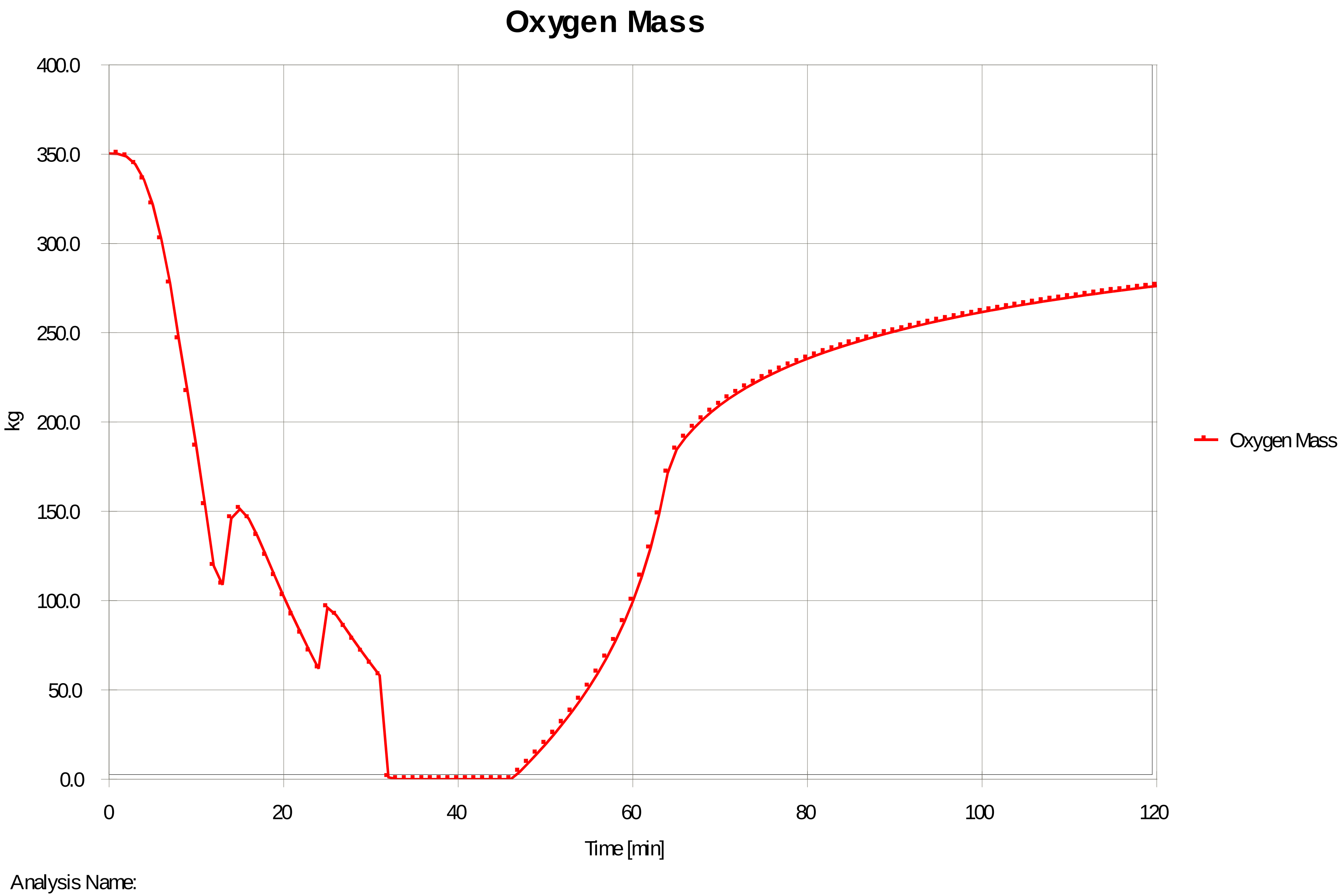


Results for 0.8m windows

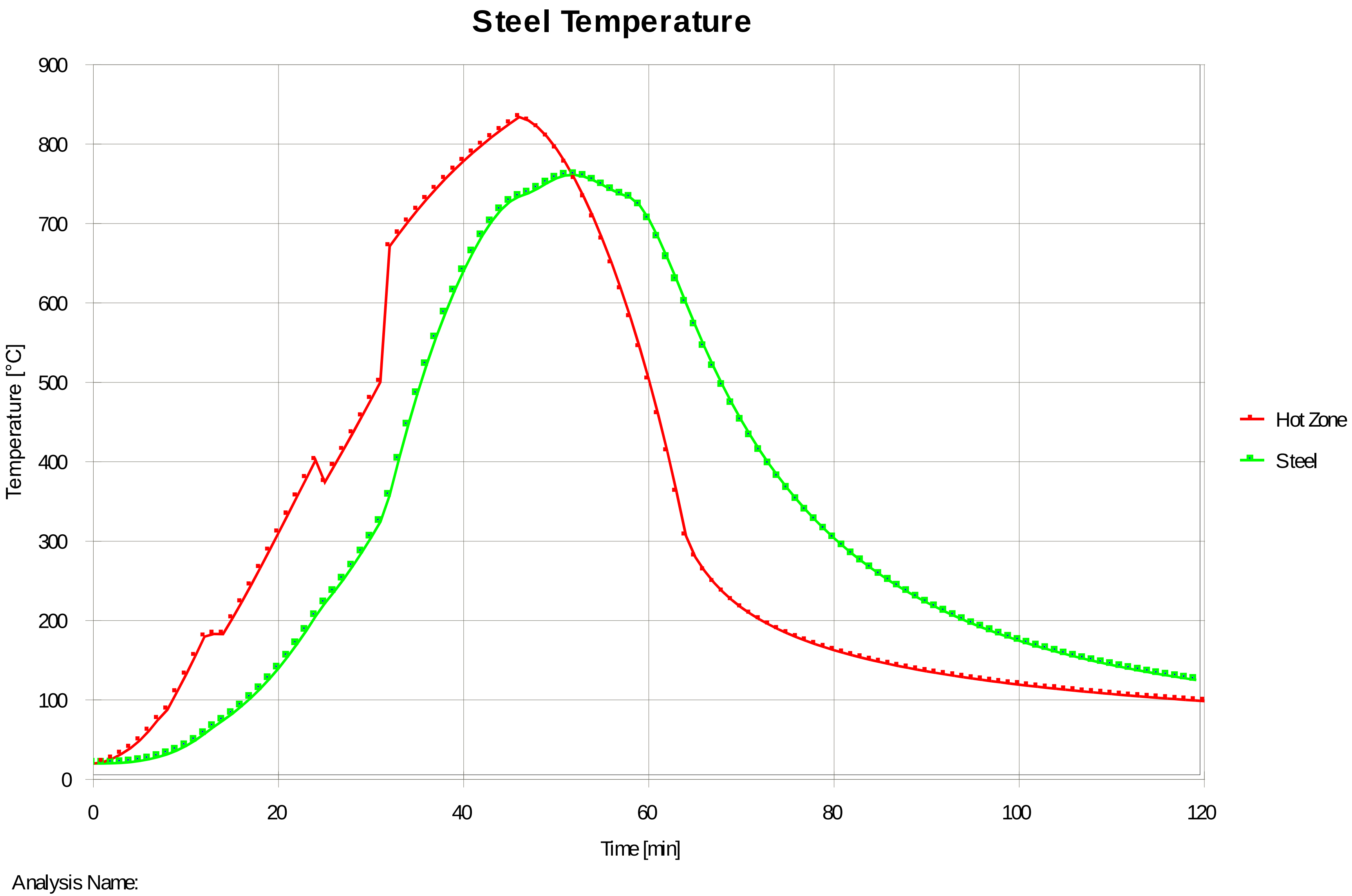


Analysis Name:

Results for 0.8m windows



Results for IPE450



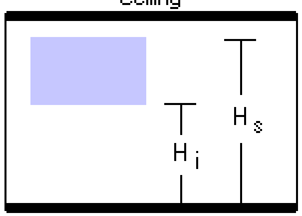
Opening Factors Ex. 2

Layers and Openings Wall 1 - ECW_Ex2

File Tools View Help

Wall Length: 14 m

	Material	Thickness	Unit mass	Conductivity	Specific Heat	Rel Emissivity	Rel Emissivity
		[cm]	[kg/m³]	[W/mK]	[J/kgK]	Hot Surface	Cold Surface
Layer 1	Normal weight Concrete [EN1994-1-2]	20	2300	1.6	1000	0.8	0.8
Layer 2							
Layer 3							
Layer 4							



Enter each layer on a single row in the table above (up to four layers). Just click in a cell and edit it's value. If not found in the list of materials you can define your own material, by filling in the apropriate cells. Define your layers starting from Layer 1 (Inside).

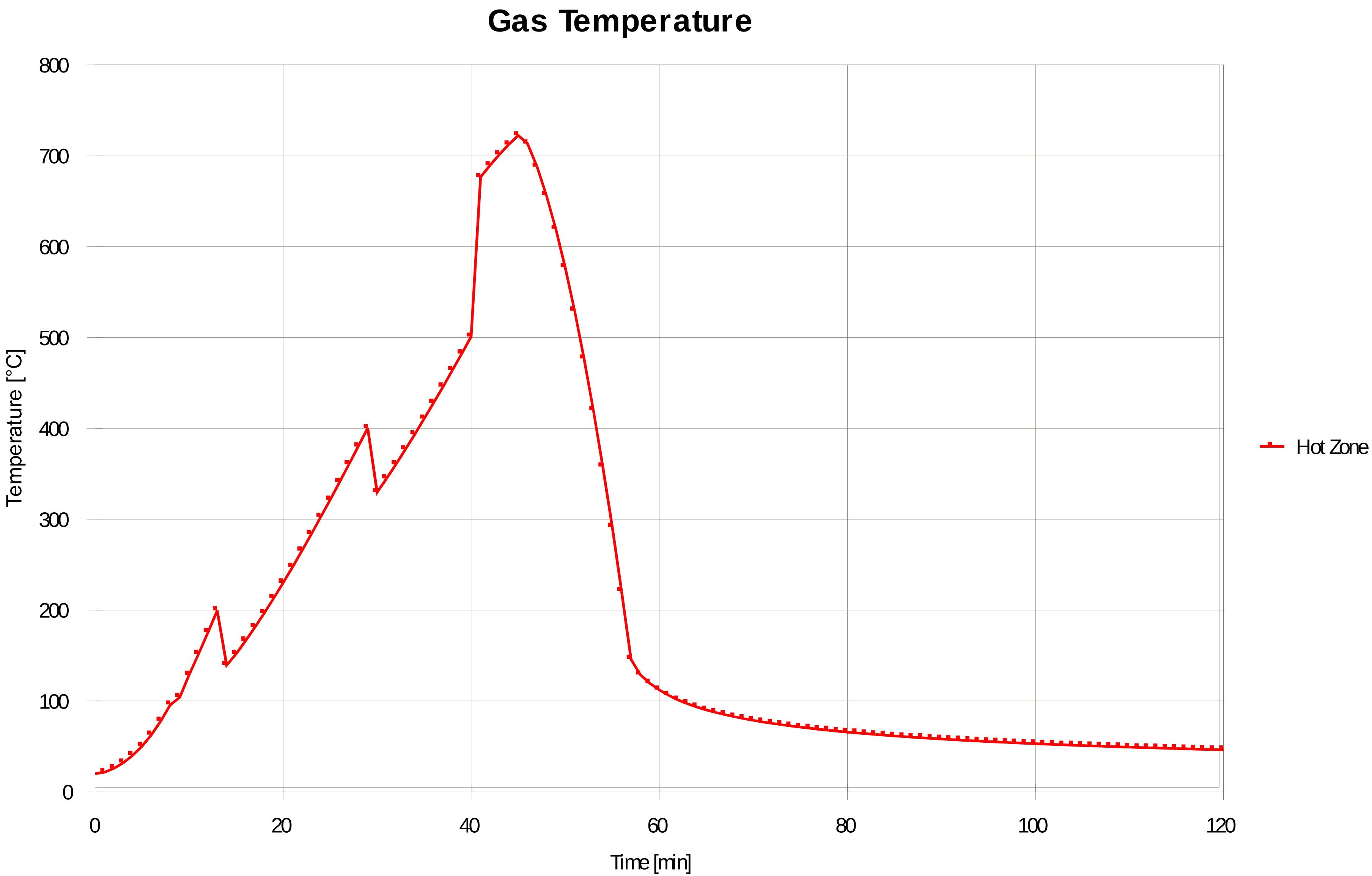
Define your openings if any (up to three openings in a single wall). Click in the desired cell and input your values. Start from Opening 1.

To delete or insert a row, right click on a row header and select the appropriate command from the popup menu.

	Sill Height Hi	Soffit Height Hs	Width	Variation	Adiabatic
	[m]	[m]	[m]		
Opening 1	1	2.5	14	Stepwise	no
Opening 2					
Opening 3					

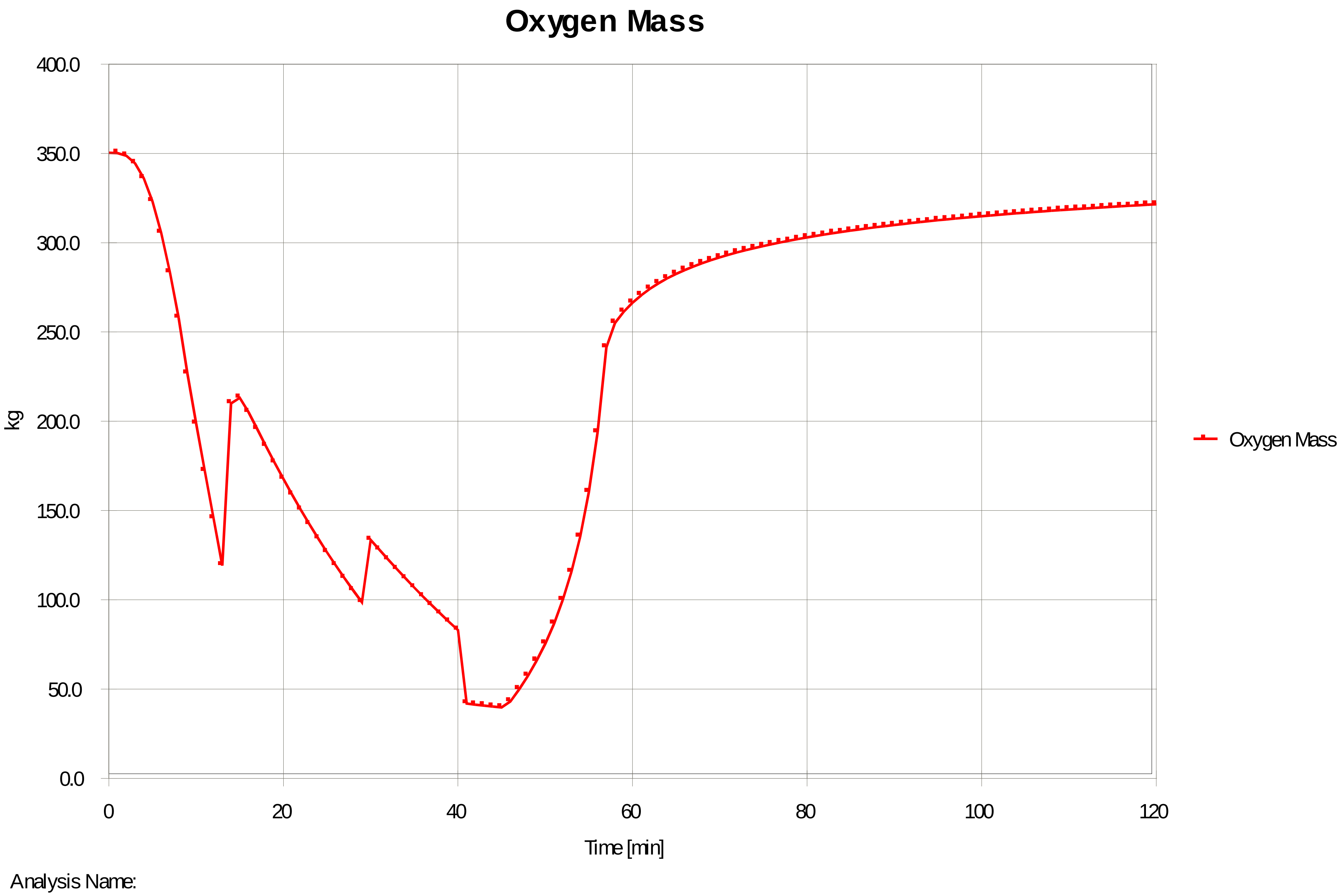
OK Cancel

Results for 1.5m windows

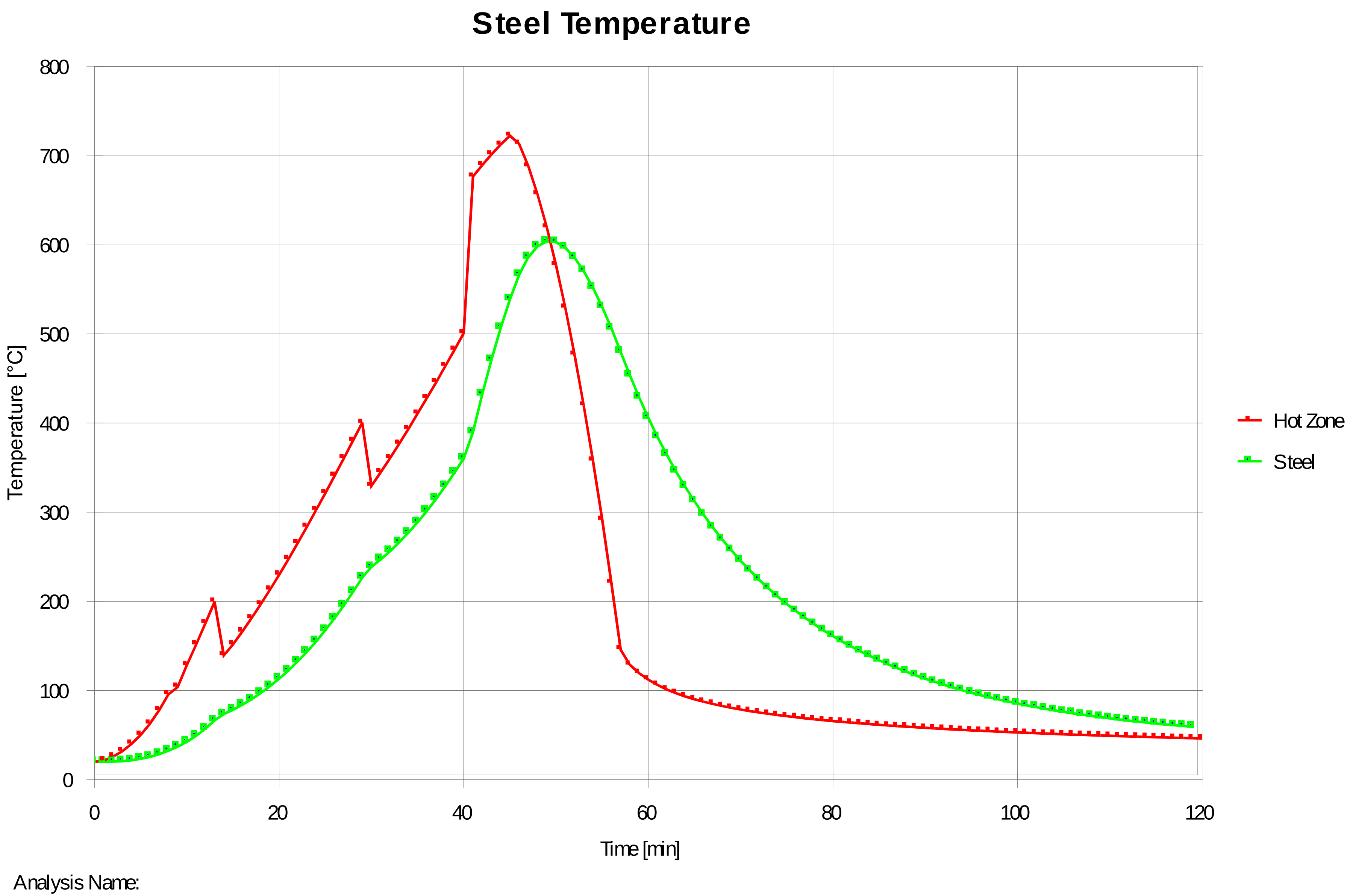


Analysis Name:

Results for 1.5m windows



Results for IPE450



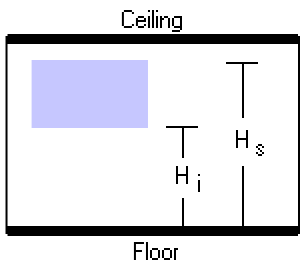
Opening Factors Ex. 3

Layers and Openings Wall 1 - ECW_Ex3

File Tools View Help

Wall Length: 14 m

	Material	Thickness	Unit mass	Conductivity	Specific Heat	Rel Emissivity	Rel Emissivity
		[cm]	[kg/m³]	[W/mK]	[J/kgK]	Hot Surface	Cold Surface
Layer 1	Normal weight Concrete [EN1994-1-2]	20	2300	1.6	1000	0.8	0.8
Layer 2							
Layer 3							
Layer 4							



Enter each layer on a single row in the table above (up to four layers). Just click in a cell and edit it's value. If not found in the list of materials you can define your own material, by filling in the apropriate cells. Define your layers starting from Layer 1 (Inside).

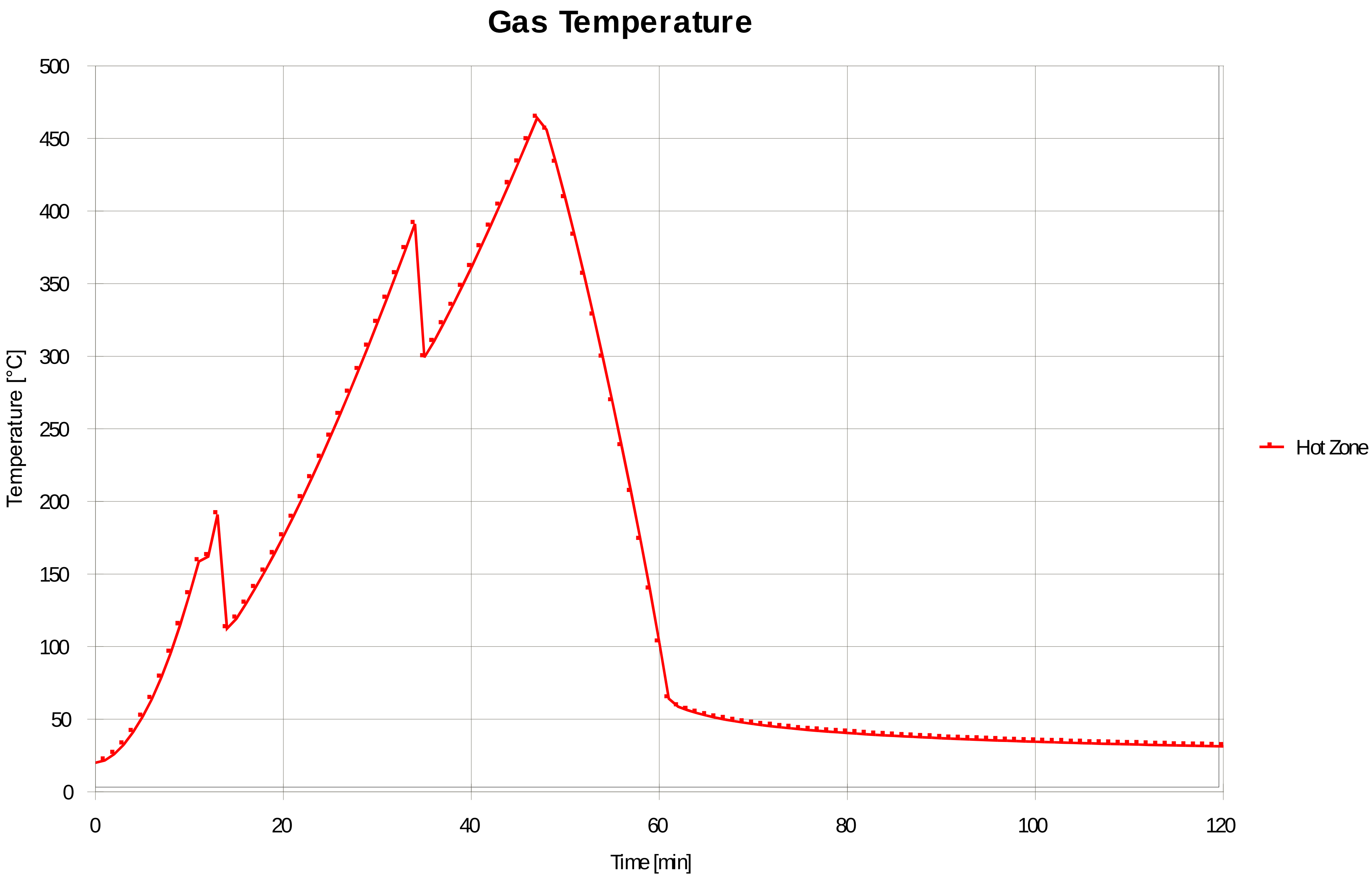
Define your openings if any (up to three openings in a single wall). Click in the desired cell and input your values. Start from Opening 1.

To delete or insert a row, right click on a row header and select the appropriate command from the popup menu.

	Sill Height Hi	Soffit Height Hs	Width	Variation	Adiabatic
	[m]	[m]	[m]		
Opening 1	0.65	2.85	14	Stepwise	no
Opening 2					
Opening 3					

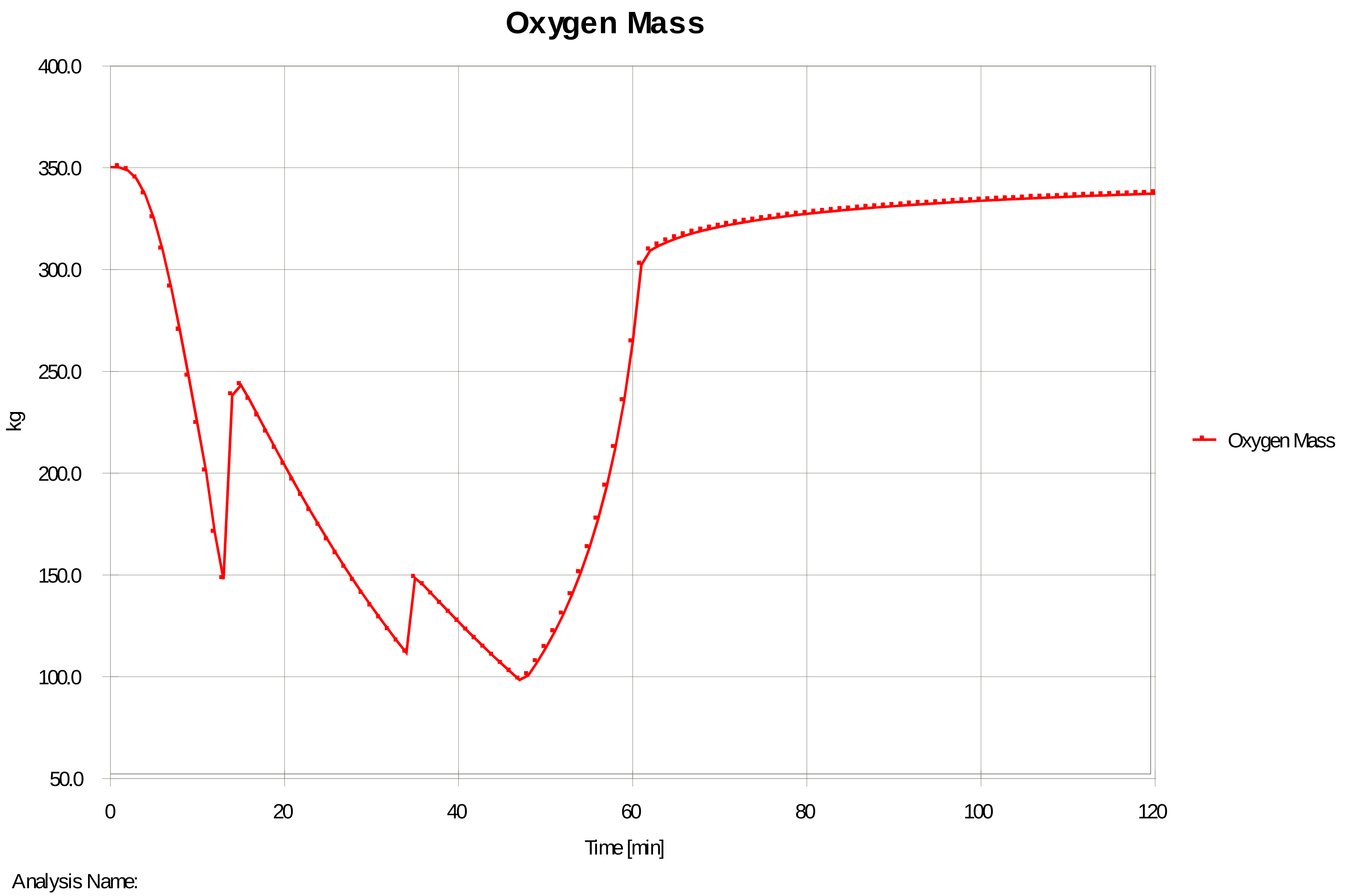
OK Cancel

Results for full windows

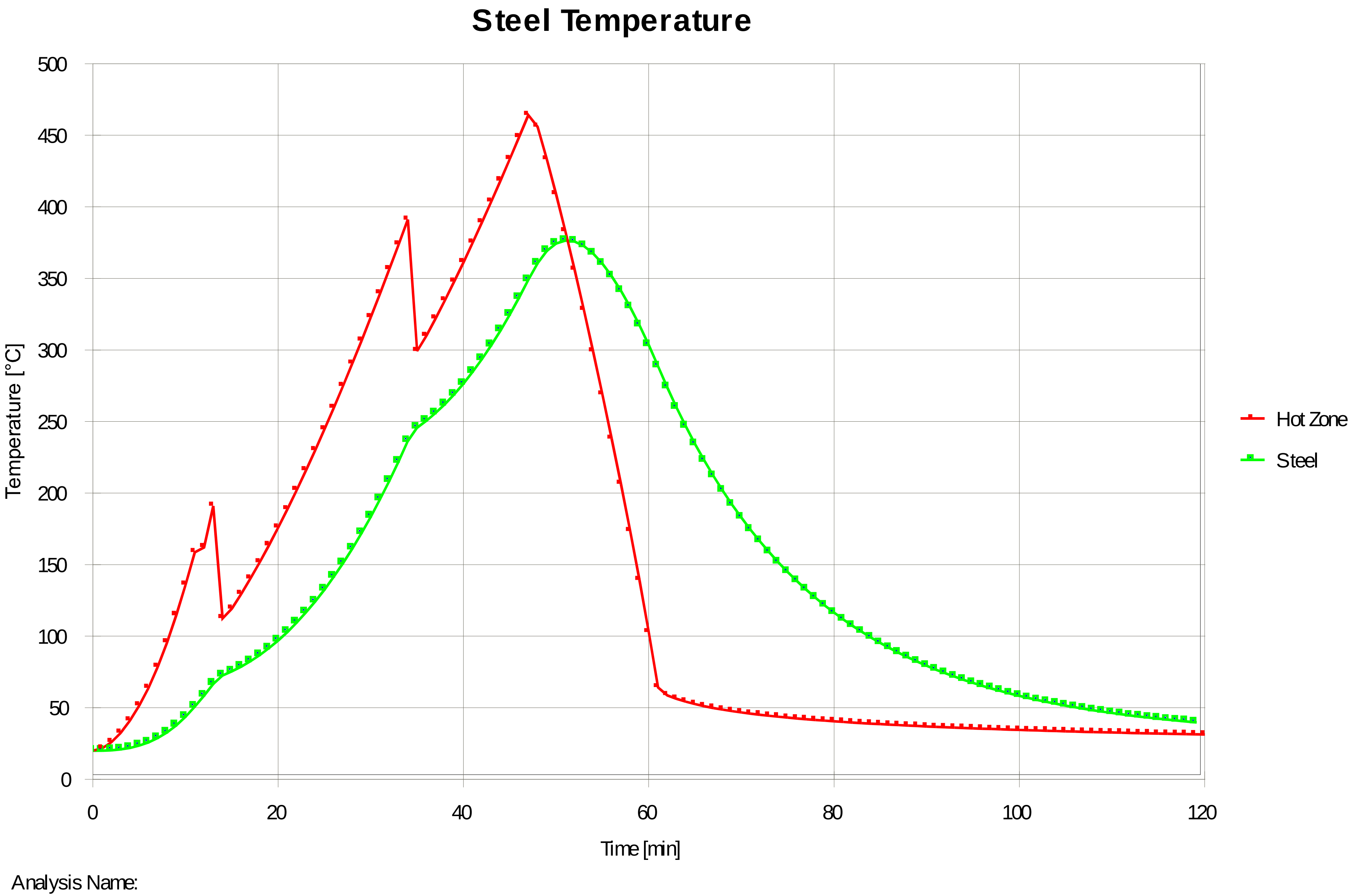


Analysis Name:

Results for full windows



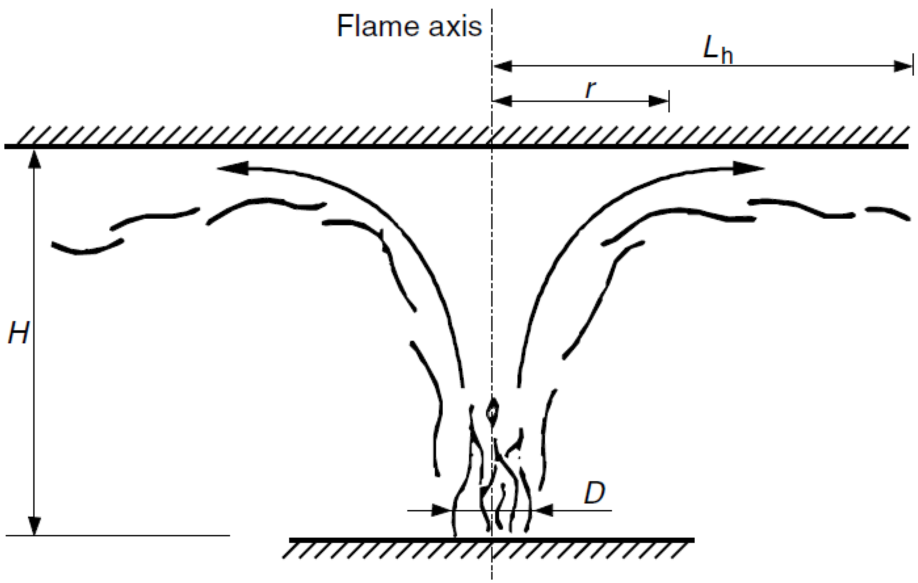
Results for IPE450



Worked examples of EN1991-1-2

Fire part of Eurocode 1 : Localised Fire

Hasemi method for localised fires



EN 1991-1-2 : 2002; Annex C

Non-dimensional parameters:

$$Q_H^* = Q / (1{,}11 \cdot 10^6 \cdot H^{2{,}5})$$

$$Q_D^* = Q / (1{,}11 \cdot 10^6 \cdot D^{2{,}5})$$

$$y = \frac{r + H + z'}{L_h + H + z'}$$

Horizontal length on the ceiling:

$$L_h = \left(2{,}9\ H\ (Q_H^*)^{0{,}33}\right) - H$$

Virtual vertical coordinate:

$$z' = 2{,}4\, D\, (Q_D^{*\,2/5} - Q_D^{*\,2/3}) \quad \text{when} \quad Q_D^* < 1{,}0$$

$$z' = 2{,}4\, D\, (1{,}0 - Q_D^{*\,2/5}) \quad \text{when} \quad Q_D^* \geq 1{,}0$$

Heat flux:

$\dot{h} = 100\ 000$ if $y \leq 0{,}30$

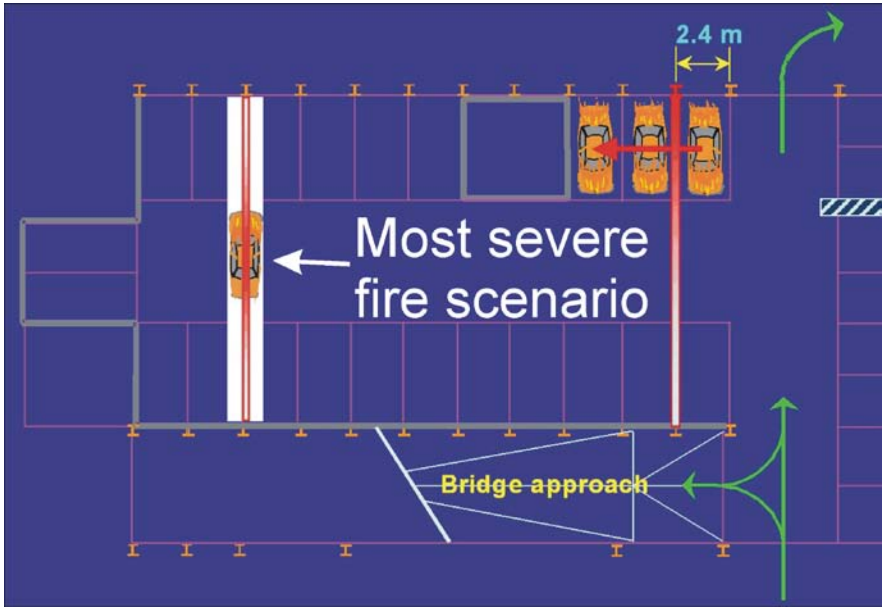
$\dot{h} = 136\ 300$ to $121\ 000\ y$ if $0{,}30 < y < 1{,}0$

$\dot{h} = 15\ 000\ y^{-3{,}7}$ if $y \geq 1{,}0$

Net Heat flux:

$$\dot{h}_{net} = \dot{h} - \alpha_c \cdot (\Theta_m - 20) - \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot [\,(\Theta_m + 273)^4 - (293)^4\,]$$

Localised fire Parameters



Building: Car park Auchan, Luxembourg

Type: Underground car park

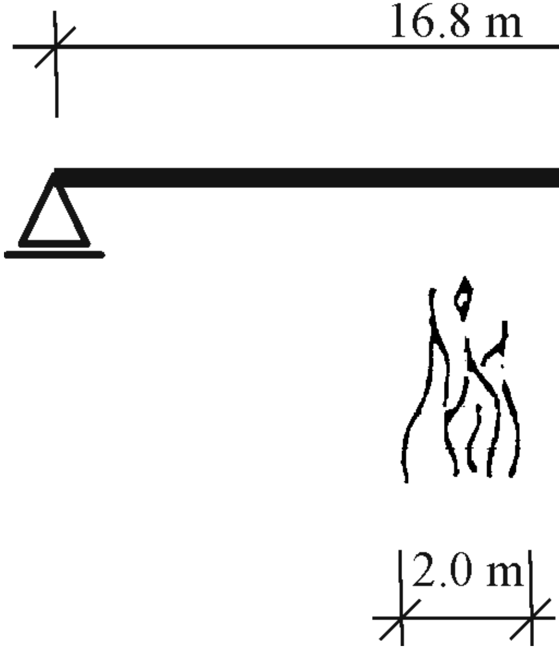
Height: H = 2.7 m

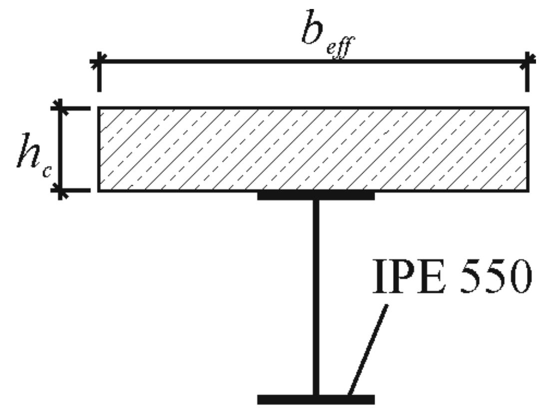
Horizontal distance from flame axis to beam: r = 0.0 m

Diameter of flame: D = 2.0 m

Steel Beam: IPE 550

Localised fire
Static system and section of the beam





Localised fire Hypothesis

Diameter of the fire: D = 2.0 m

Vertical distance between fire source and ceiling:
H = 2.7 m

Horizontal distance between beam and flame axis:
r = 0.0 m

Emissivity of the fire: ε_f = 1.0

Configuration factor: Φ = 1.0

Stephan Boltzmann constant: σ = 5.67 · 10-8 W/m2K4

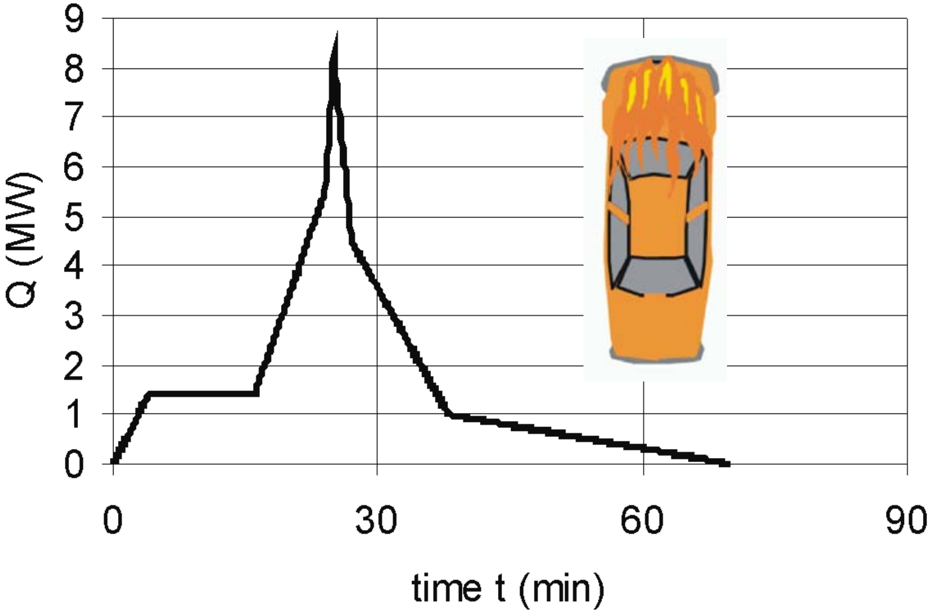
Coefficient of the heat transfer: α_c = 25.0 W/m²

Steel profile: IPE 550

- Section factor: Am/V = 140.1/m
- Unit mass: ρ_a = 7850 kg/m³
- Surface emissivity: ε_m = 0.7

Localised fire
Rate of Heat Release

Curve of the rate of heat release of one car



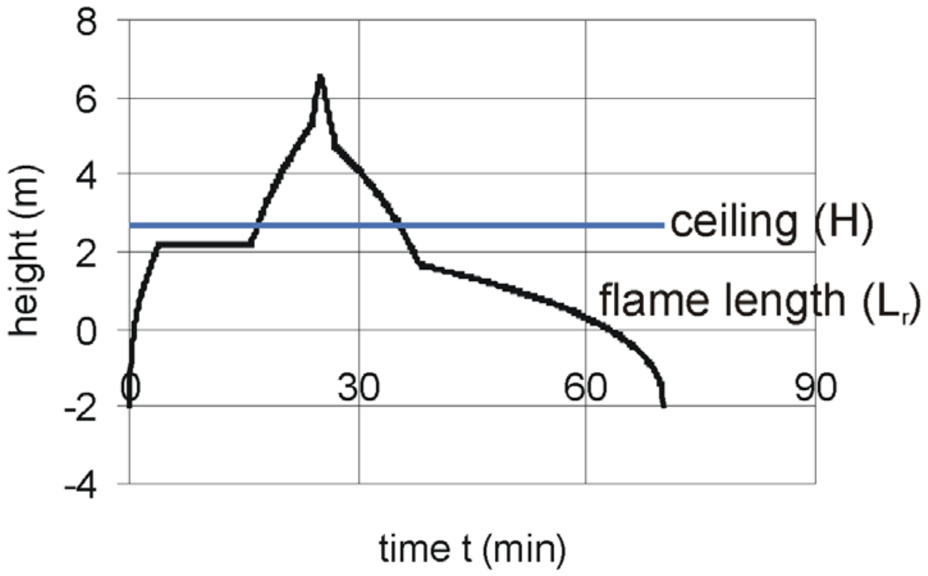
From ECSC project: Development of design rules for steel structures subjected to natural fires in closed car parks.

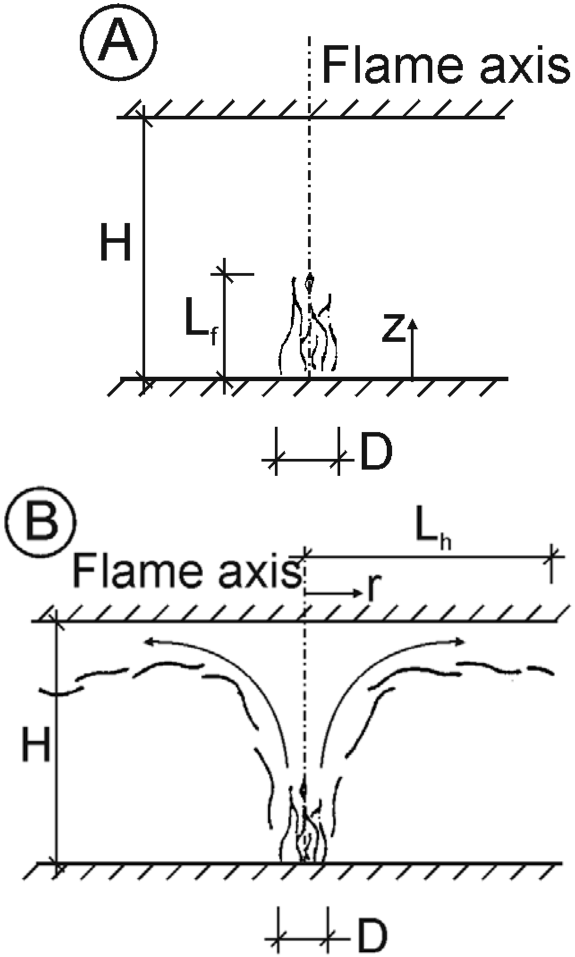
Localised fire
Flame Length

$$L_f = -1.02 \cdot D + 0.0148 \cdot Q^{2/5} = -2.04 + 0.0148 \cdot Q^{2/5}$$

if $L_r \geq H$ ⇒ Model A has to be used

if $L_r < H$ ⇒ Model B has to be used





1st case: The flame is not impacting the ceiling

The net heat flux is calculated according to Section 3.1 of EN 1991-1-2.

$$\dot{h}_{net} = \alpha_c \cdot \left(\theta_{(z)} - \theta_m\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left(\left(\theta_{(z)} + 273\right)^4 - \left(\theta_m + 273\right)^4\right)$$

$$= 25.0 \cdot \left(\theta_{(z)} - \theta_m\right) + 3.969 \cdot 10^{-8} \cdot \left(\left(\theta_{(z)} + 273\right)^4 - \left(\theta_m + 273\right)^4\right)$$

1st case: The flame is not impacting the ceiling

The gas temperature is calculated to:

$$\theta_{(z)} = 20 + 0.25 \cdot (0.8 \cdot Q)^{2/3} \cdot (z - z_0)^{-5/3} \leq 900 \text{ °C}$$

$$= 20 + 0.25 \cdot (0.8 \cdot Q)^{2/3} \cdot \left(4.74 - 0.0052 \cdot Q^{2/5}\right)^{-5/3} \leq 900 \text{ °C}$$

where:

z is the height along the flame axis (2.7 m)

z_0 is the virtual origin of the axis [m]

$$z_0 = -1.02 \cdot D + 0.0052 \cdot Q^{2/5} = -2.04 + 0.0052 \cdot Q^{2/5}$$

2nd case: The flame is impacting the ceiling

Net heat flux, if the flame is impacting the ceiling, is given by:

$$\dot{h}_{net} = \dot{h} - \alpha_c \cdot (\theta_m - 20) - \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left((\theta_m + 273)^4 - (293)^4 \right)$$

$$= \dot{h} - 25.0 \cdot (\theta_m - 20) - 3.969 \cdot 10^{-8} \cdot \left((\theta_m + 273)^4 - (293)^4 \right)$$

2nd case:
The flame is impacting the ceiling

The heat flux depends on the parameter y. For different dimensions of y, different equations for determination of the heat flux have to be used.

if $y \leq 0.30$: $$\dot{h} = 100{,}000$$

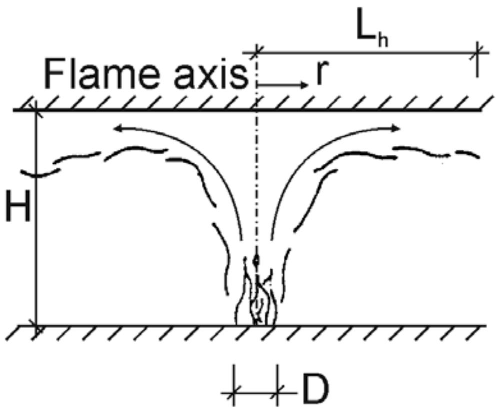
if $0.30 < y < 1.0$: $$\dot{h} = 136{,}300 - 121{,}000 \cdot y$$

if $y \geq 1.0$: $$\dot{h} = 15{,}000 \cdot y^{-3.7}$$

where: $$y = \frac{r + H + z'}{L_h + H + z'} = \frac{2.7 + z'}{L_h + 2.7 + z'}$$

2nd case:
The flame is impacting the ceiling

$$y = \frac{r + H + z'}{L_h + H + z'} = \frac{2.7 + z'}{L_h + 2.7 + z'}$$



The horizontal flame length is calculated by:

$$L_h = \left(2.9 \cdot H \cdot \left(Q_H^{\ *}\right)^{0.33}\right) - H = \left(7.83 \cdot \left(Q_H^{\ *}\right)^{0.33}\right) - 2.7$$

where:

$$Q_H^{\ *} = Q \Big/ \left(1.11 \cdot 10^6 \cdot H^{2.5}\right) = Q \Big/ \left(1.11 \cdot 10^6 \cdot 2.7^{2.5}\right)$$

The vertical position of the virtual heat source is determined by:

if ***QD* < 1.0:*** $z' = 2.4 \cdot D \cdot \left(\left(Q_D^{\ *}\right)^{2/5} - \left(Q_D^{\ *}\right)^{2/3}\right) = 4.8 \cdot \left(\left(Q_D^{\ *}\right)^{2/5} - \left(Q_D^{\ *}\right)^{2/3}\right)$

if ***QD* ≥ 1.0:*** $z' = 2.4 \cdot D \cdot \left(1.0 - \left(Q_D^{\ *}\right)^{2/5}\right) = 4.8 \cdot \left(1.0 - \left(Q_D^{\ *}\right)^{2/5}\right)$

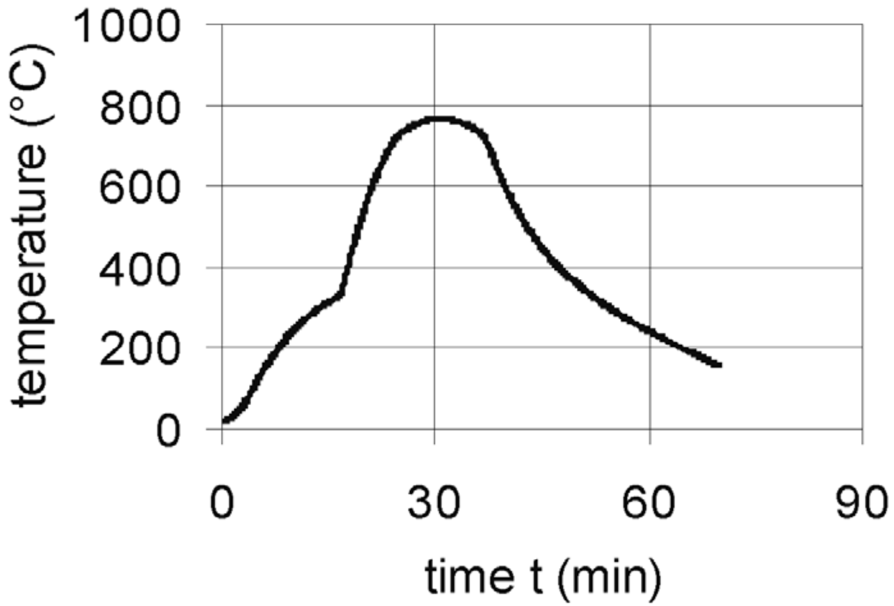
where: $Q_D^{\ *} = Q \Big/ \left(1.11 \cdot 10^6 \cdot D^{2.5}\right) = Q \Big/ \left(1.11 \cdot 10^6 \cdot 2.0^{2.5}\right)$

Temperature-time curve for the unprotected steel beam:

$$\theta_{a,t} = \theta_m + k_{sh} \cdot \frac{A_m/V}{c_a \cdot \rho_a} \cdot \dot{h}_{net} \cdot \Delta t = \theta_m + \frac{1.78 \cdot 10^{-2}}{c_a} \cdot \dot{h}_{net}$$

$\theta_{a,max} = 770$ °C

at $t_{\theta,max} = 31.07$ min

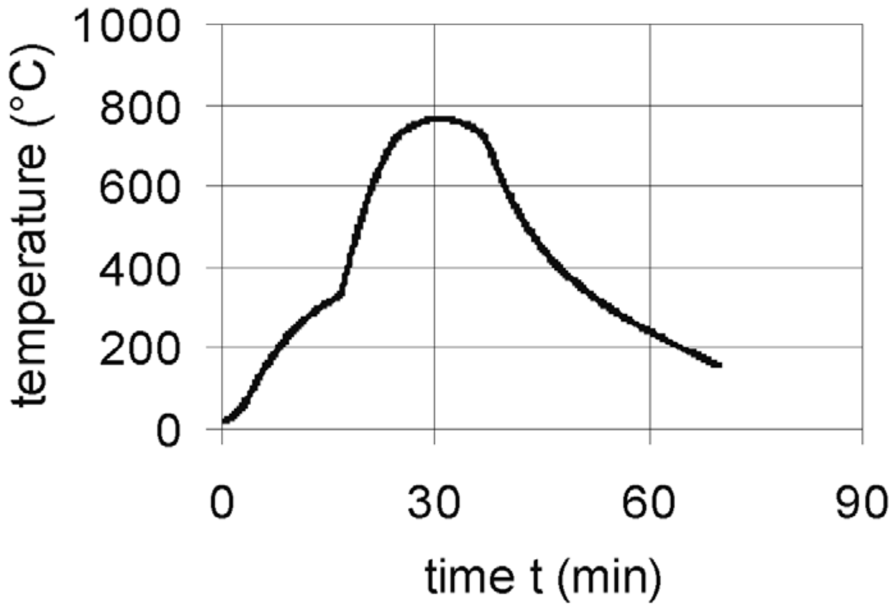


Temperature-time curve for the unprotected steel beam:

$$\theta_{a,t} = \theta_m + k_{sh} \cdot \frac{A_m/V}{c_a \cdot \rho_a} \cdot \dot{h}_{net} \cdot \Delta t = \theta_m + \frac{1.78 \cdot 10^{-2}}{c_a} \cdot \dot{h}_{net}$$

$\theta_{a,max} = 770$ °C

at $t_{\theta,max} = 31.07$ min



Excel Spreadsheet Capafi

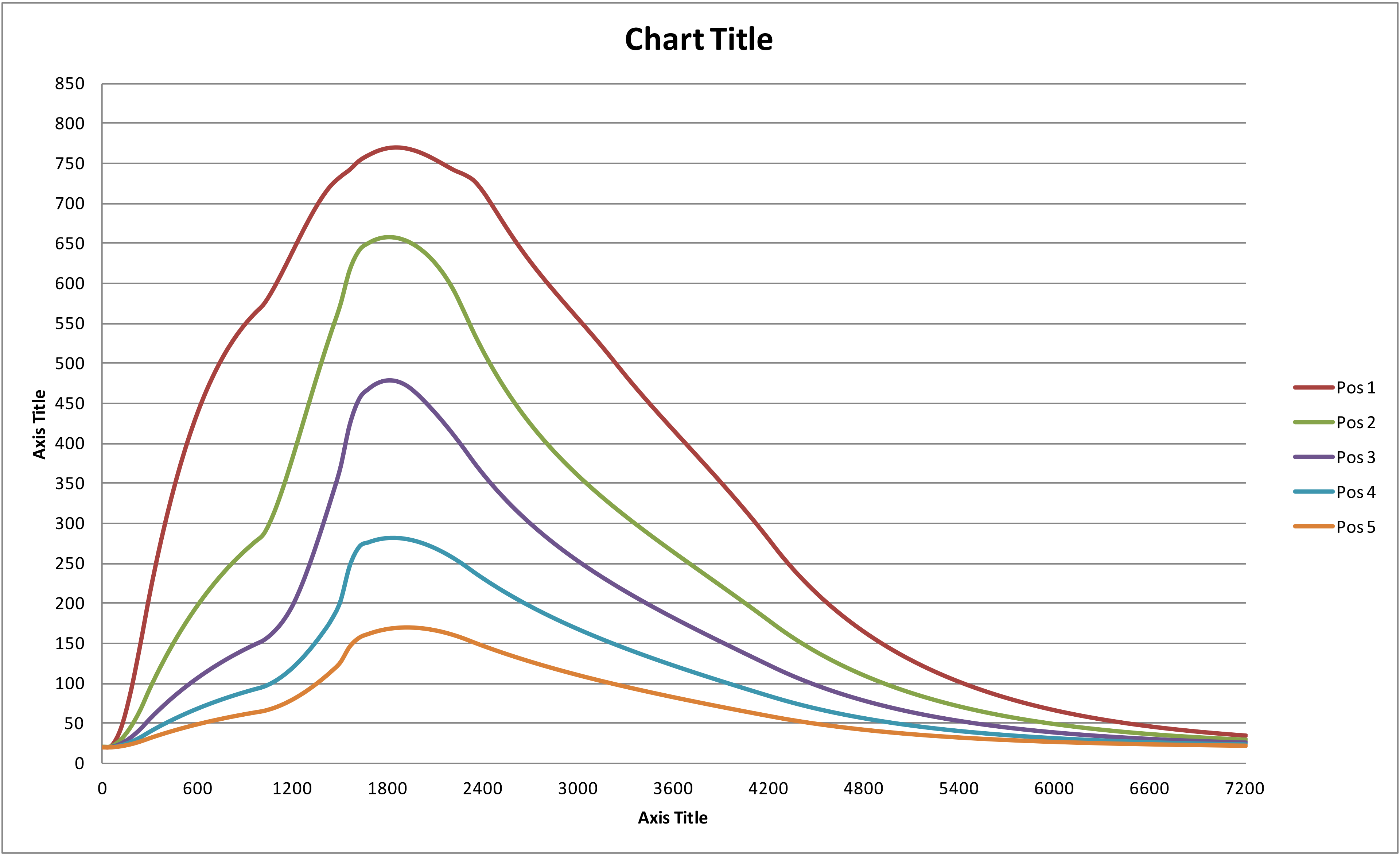
Position of the calculated point(s) X [m]	Y [m]	
0	0	Pos. 1
1	0	Pos. 2
2	0	Pos. 3
3	0	Pos. 4
4	0	Pos. 5
		Pos. 6
		Pos. 7
		Pos. 8
		Pos. 9
		Pos. 10
		Pos. 11
		Pos. 12
		Pos. 13
		Pos. 14
		Pos. 15
		Pos. 16
		Pos. 17

Y X	Position of the car(s) X [m]	Y [m]
CAR 1	0	0
CAR 2		
CAR 3		
CAR 4		
CAR 5		

H_f =	3.000	m
H_b =	0.001	m
H_s =	0.300	m
Coeff beam =	1.000	
Fire diam D =	2.000	m
A_m/V =	140.1	m^{-1}
A_m/V (box) =	130	m^{-1}
ρ_s =	7850	kg/m^3
α =	25	W/m^2K
ε =	0.7	

CAR 1 Time [min]	RHR [MW]	CAR 2 Time [min]	RHR [MW]	CAR 3 Time [min]	RHR [MW]	CAR 4 Time [min]	RHR [MW]	CAR 5 Time [min]	RHR [MW]
0	0								
4	1.4								
16	1.4								
24	5.5								
25	8.3								
27	4.5								
38	1								
70	0								

Excel Spreadsheet Capafi



Worked examples of EN1991-1-2

Example of Application of buildings calculated with Natural Fire Safety Concept

Switzerland

Braun Building in Crissier
Production of Medical Material

INGENIEURS CONSEILS SA

Switzerland

BOBST Building in Lausanne
Offices + Production

INGENIEURS
CONSEILS SA

Switzerland

Congress centre of EPFL in Lausanne
Crédit Suisse / HRS / Richter-Dahl&Rocha

INGENI
INGENIERIE
STRUCTURALE

France

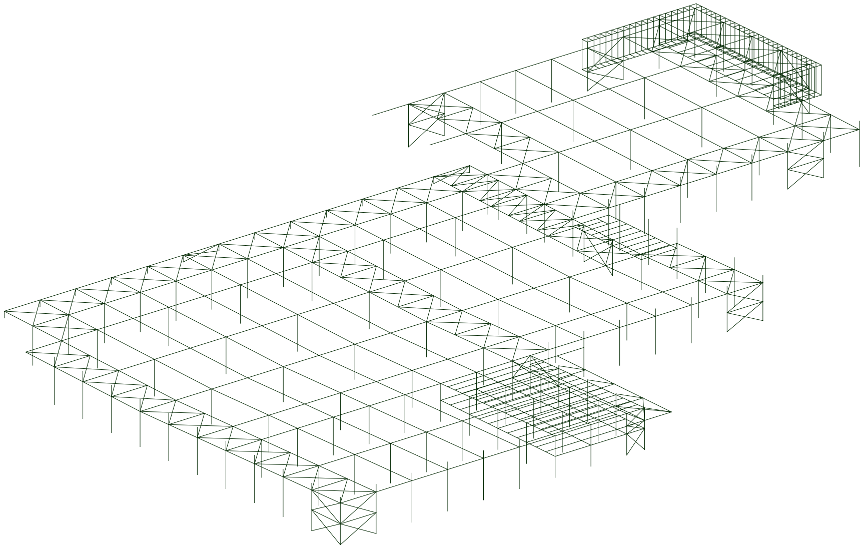
© EADS Airbus

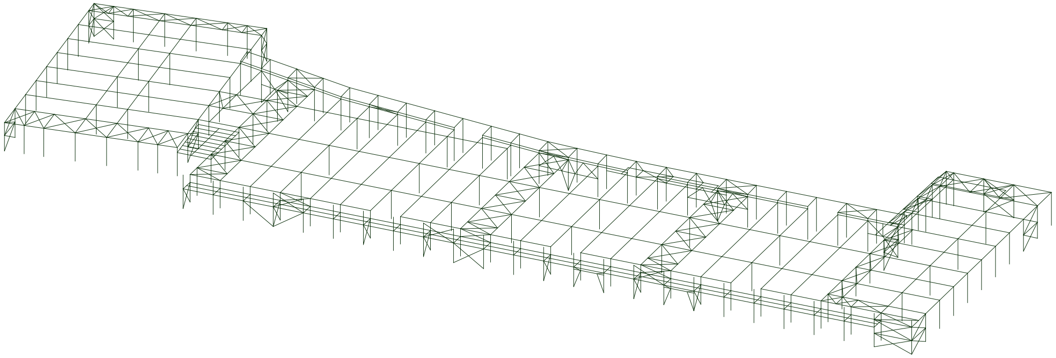
France

Car park of Toulouse Blagnac Airport

Belgium

Greich Office Building in Liège





BARREIRO RETAIL PARK

Portugal

Exhibition Center

universidade de aveiro

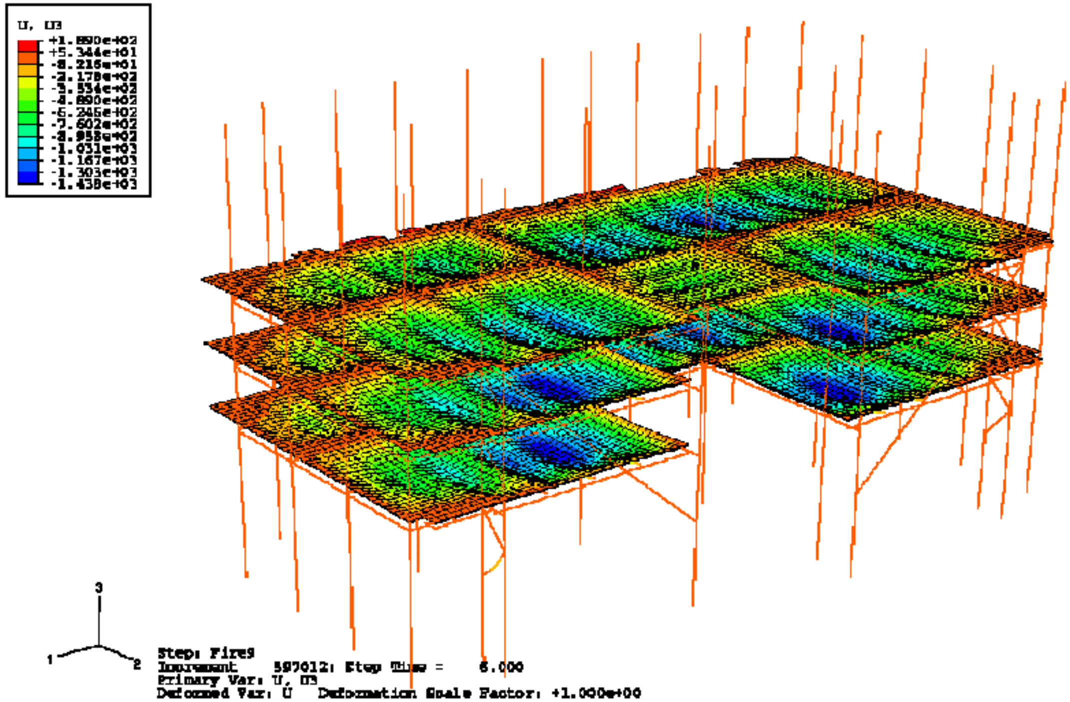
Cyprus

European Commission

IKEA shopping center in Lefkosia

Redesco Progetti srl

Milano, Italy gc-giuliani@redesco.it



Heron Tower – Arup Fire London

ARUP

Luxembourg

Fonds du Logement, 17 rue de Hollerich à Luxembourg Ville
Shopping centre
Residential

Luxembourg

Chambre de Commerce Luxembourg
Office Building

Luxembourg

European Commission

Dexia-Bil in Esch sur Alzette
Office Building

Simon-Christiansen & Associés
Ingénieurs-Conseils S.A.

Luxembourg

ArcelorMittal Office Building in Esch sur Alzette

Luxembourg

ArcelorMittal Office Building in Esch sur Alzette


Thank you for your attention
... QUESTIONS?