Structures in Fire

TEKNISKA
UNIVERSITET

Standard temperature curves (design fires)

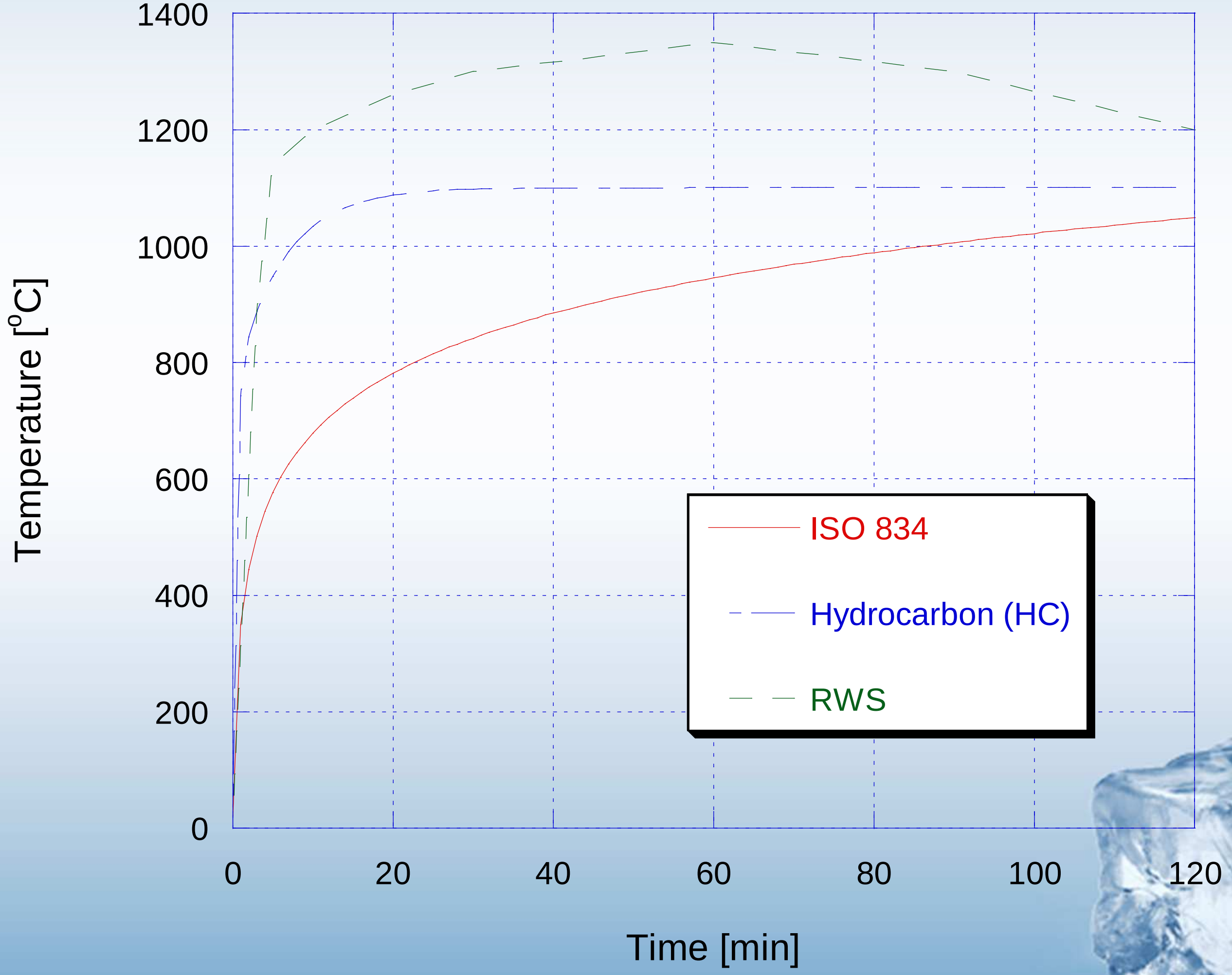


Plate Thermometer in a furnace

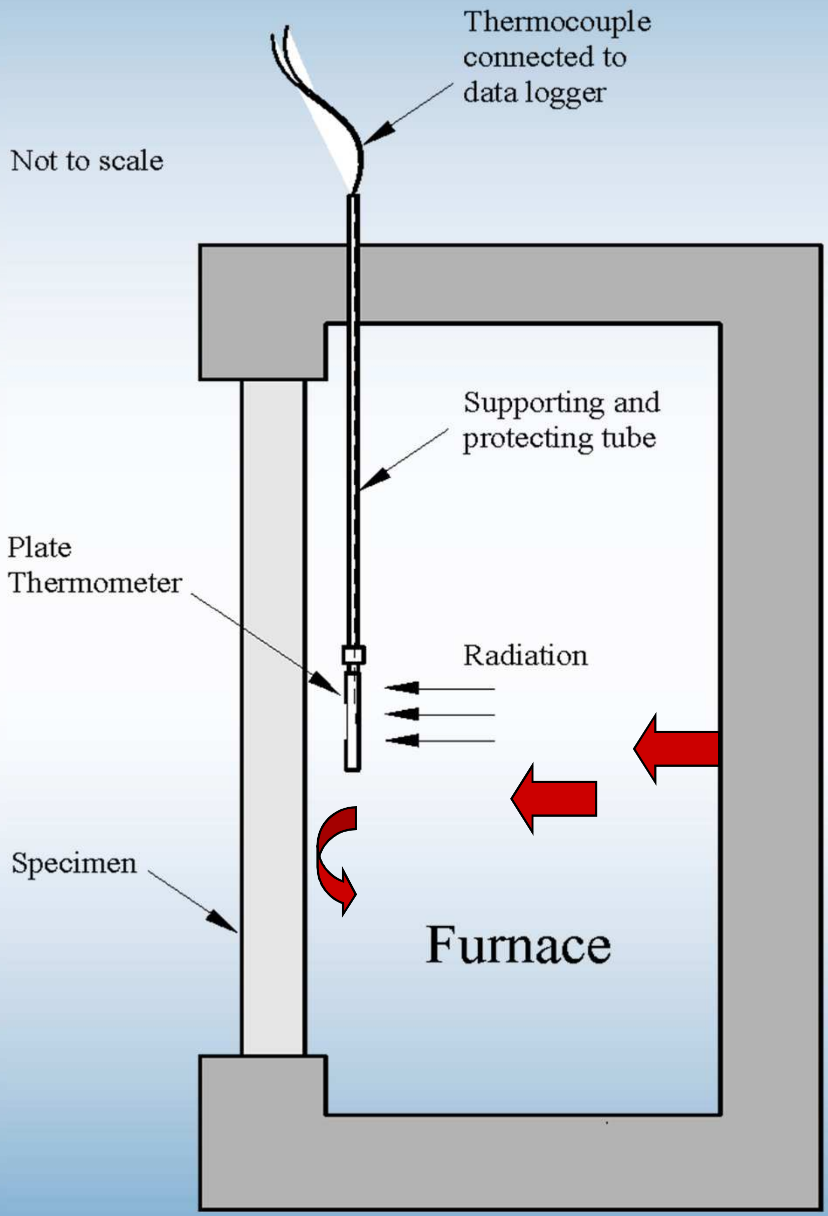
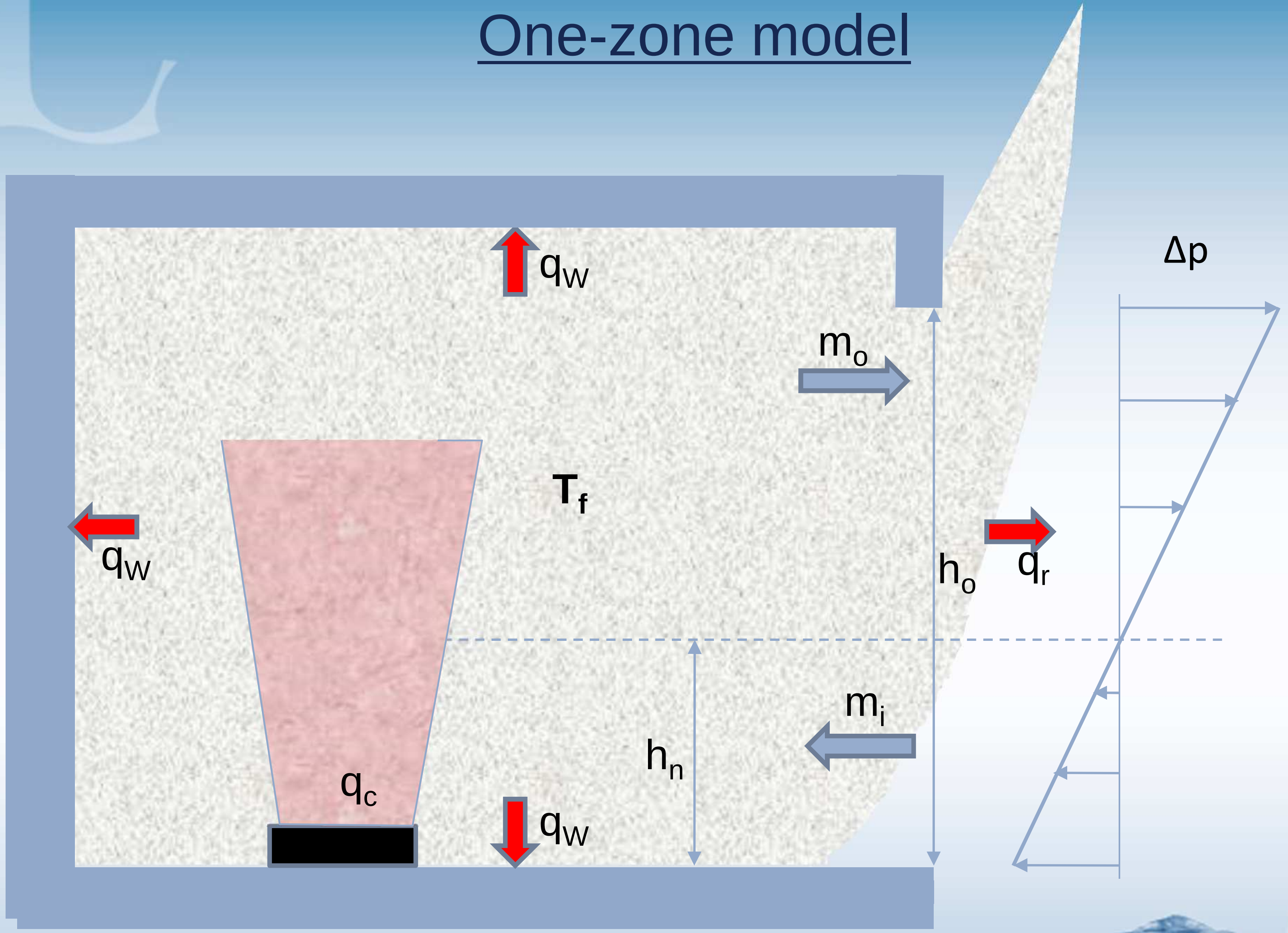
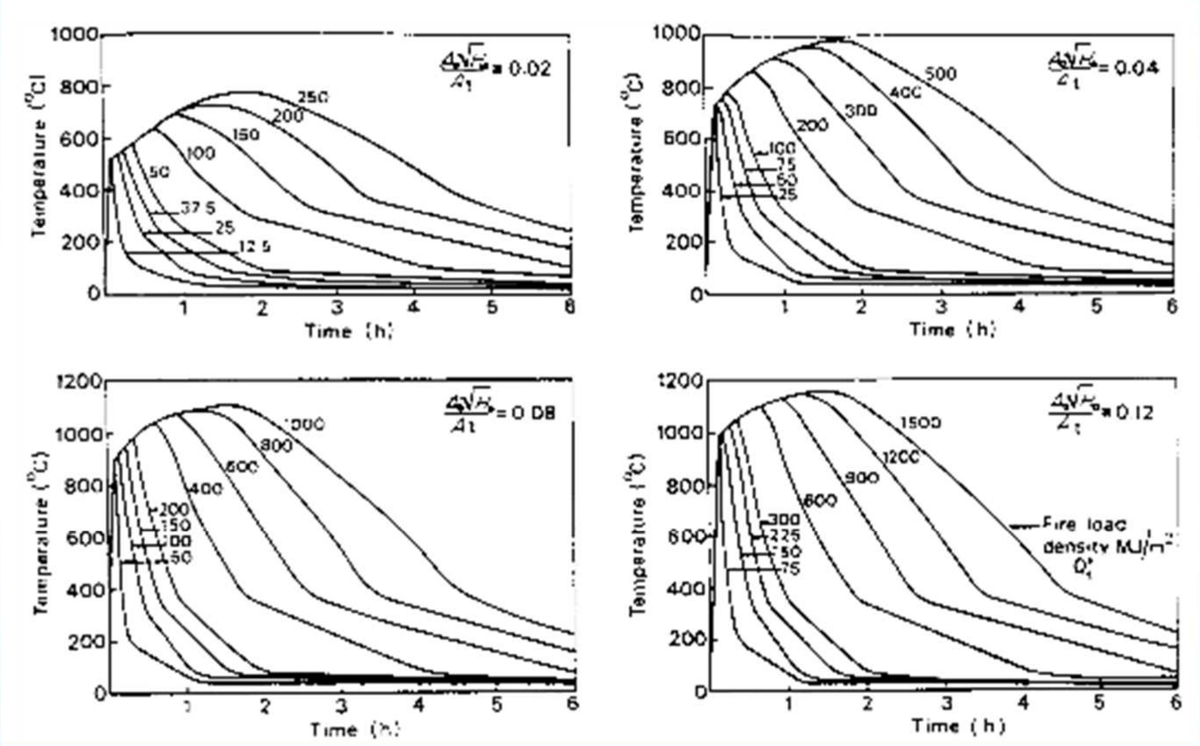


Plate Thermometers mounted in a furnace

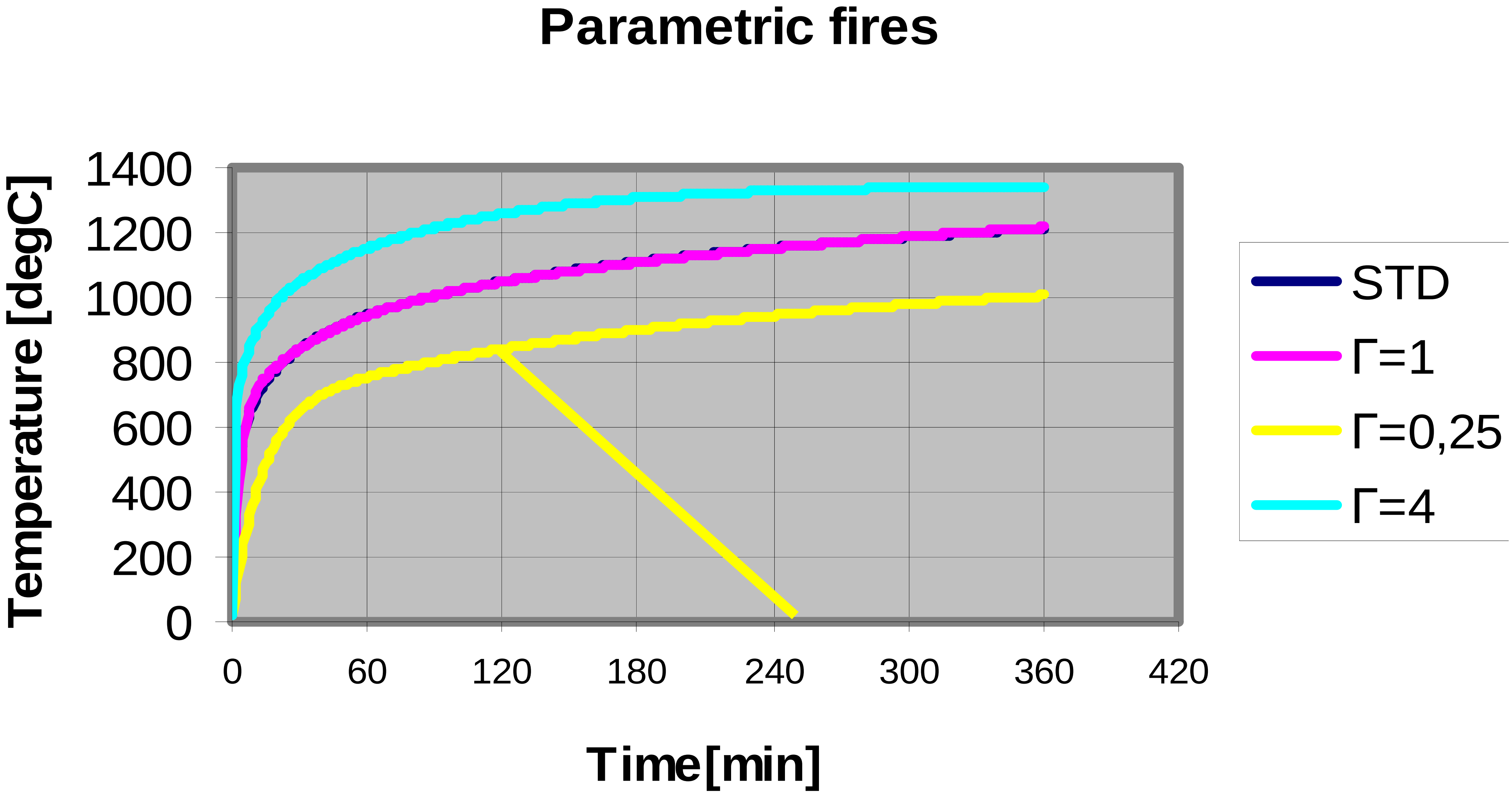
One-zone model



From the 1960-70’s



From 1980-90’s

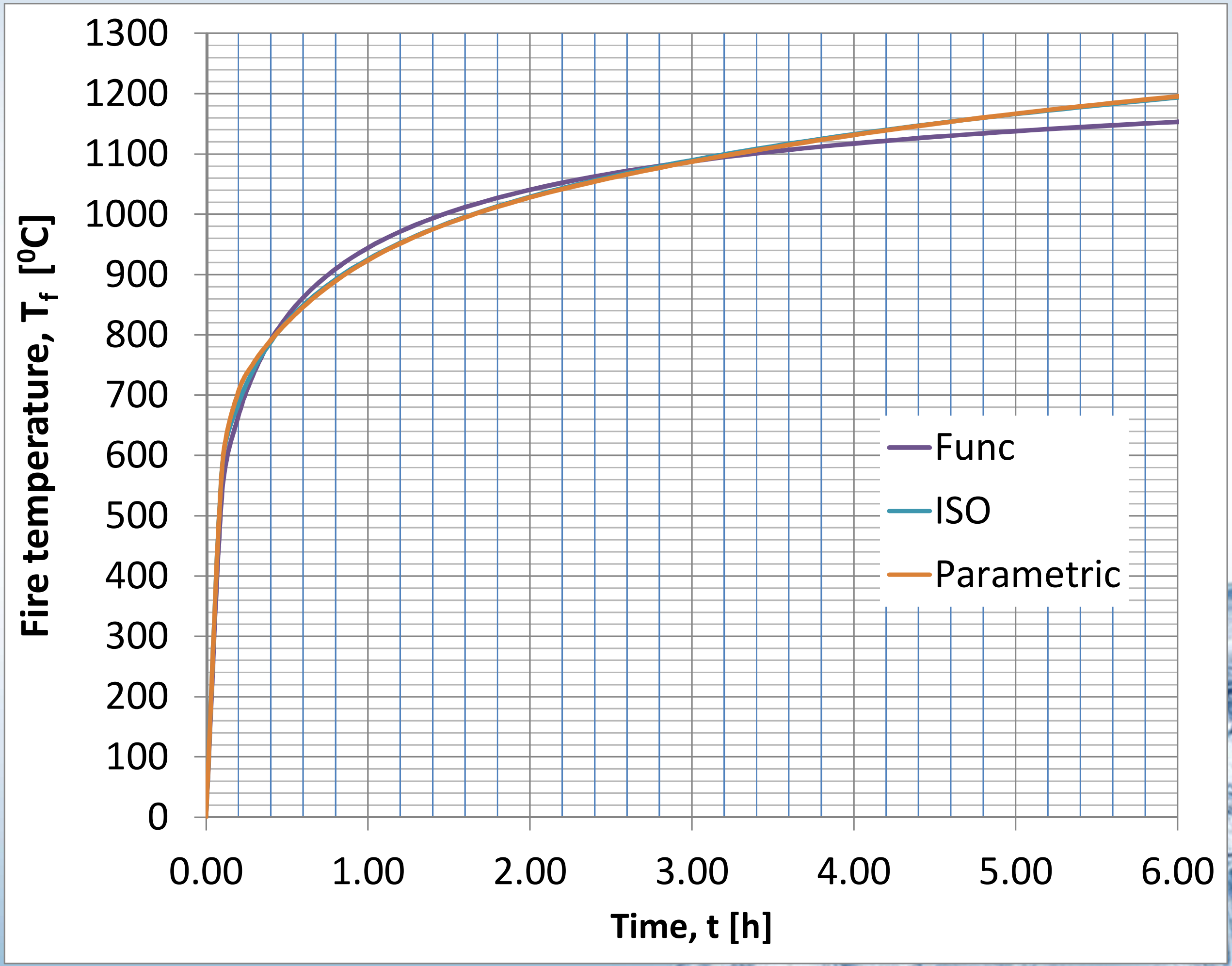


Semi-infinite surrounding structures

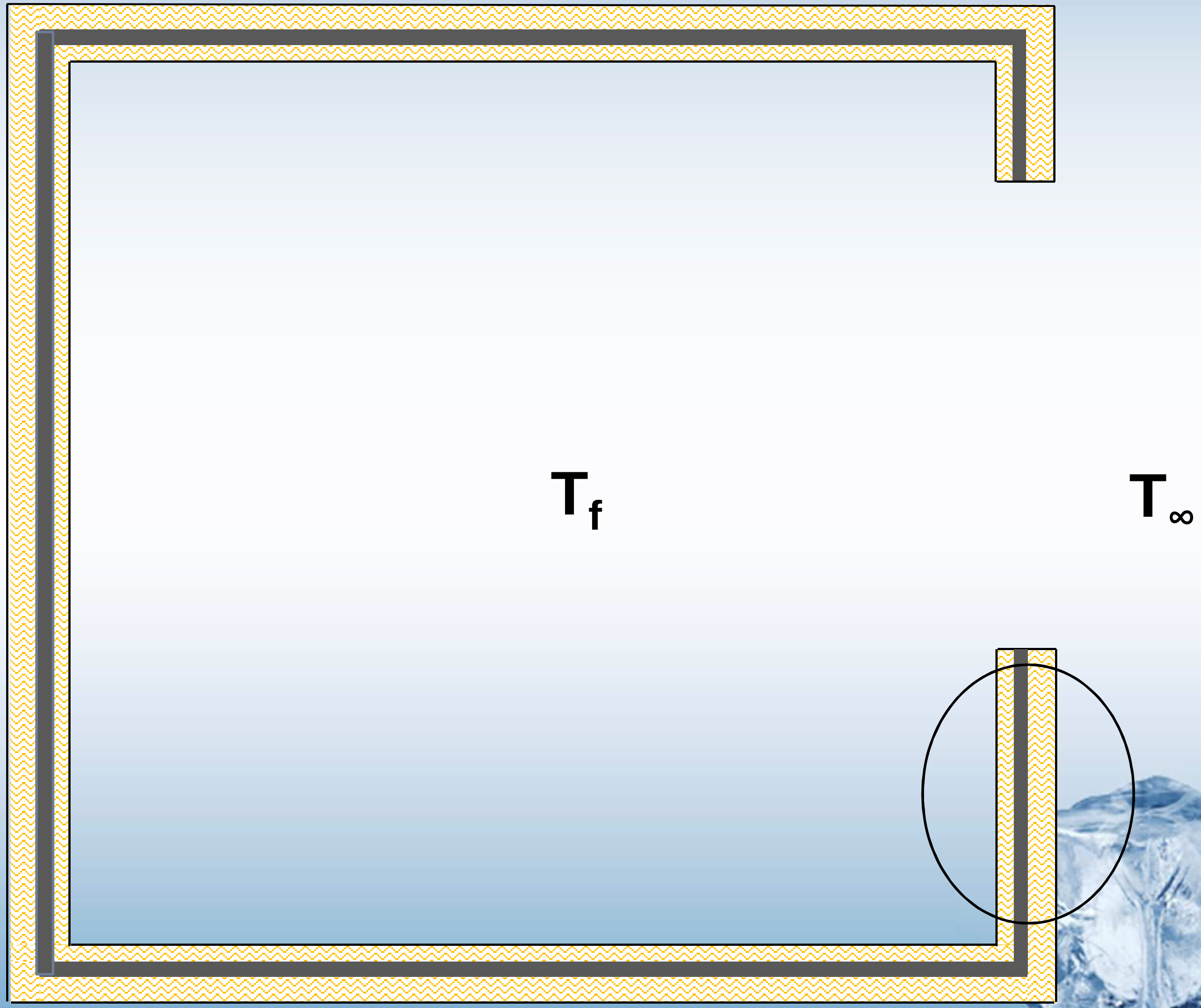
$$\theta_f = \theta_{ult}\left[1 - e^{\frac{t}{\tau_f}} erfc(\sqrt{\frac{t}{\tau_f}})\right]$$

$$\theta_{ult} = \theta_f^{max} = \frac{\alpha_2}{c_p}$$

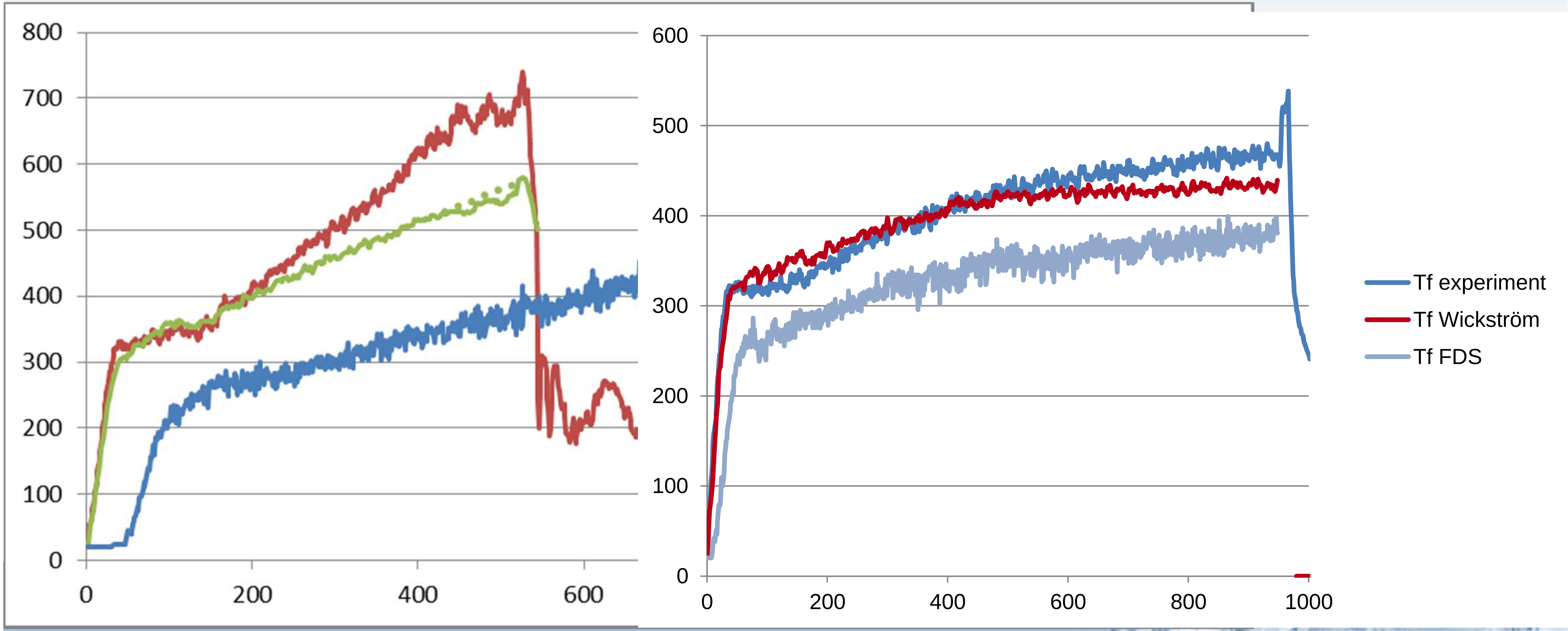
$$\tau_f = \frac{k\rho c}{\left(c_p\ \alpha_1 O\right)^2}$$



Thin surrounding structures

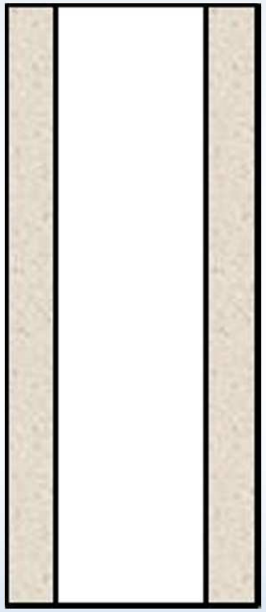


Comparison of the actual and estimated fire temperature in insulated and non-insulated enclosure.

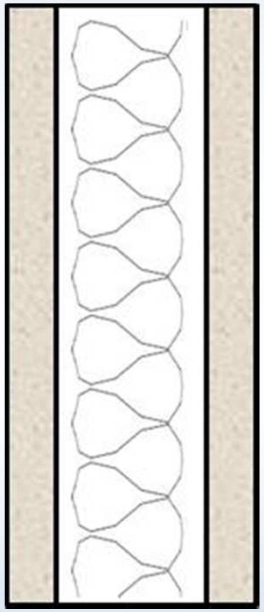


Effect of compartment boundaries on T_f

Type 1:
Gypsum

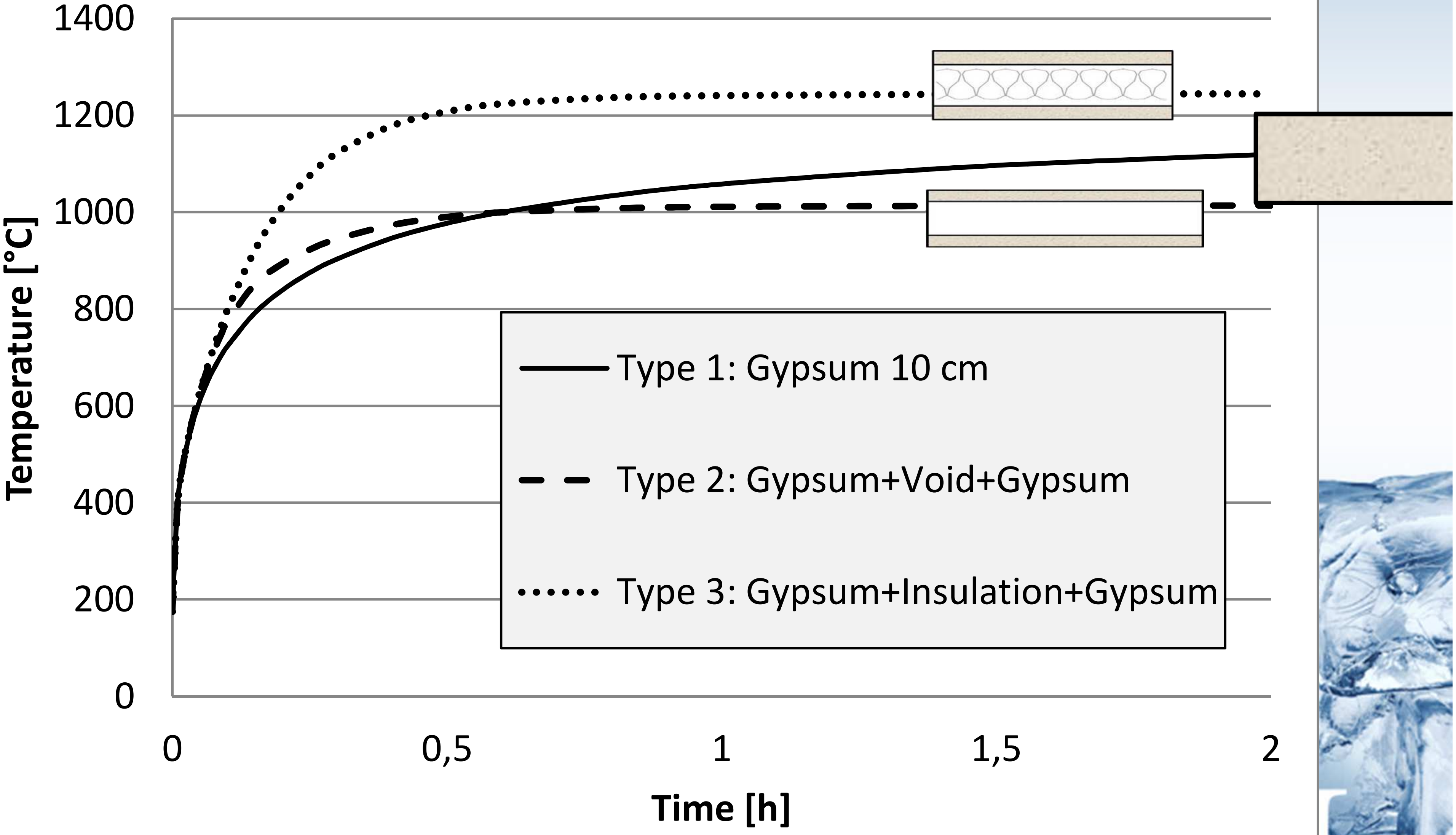


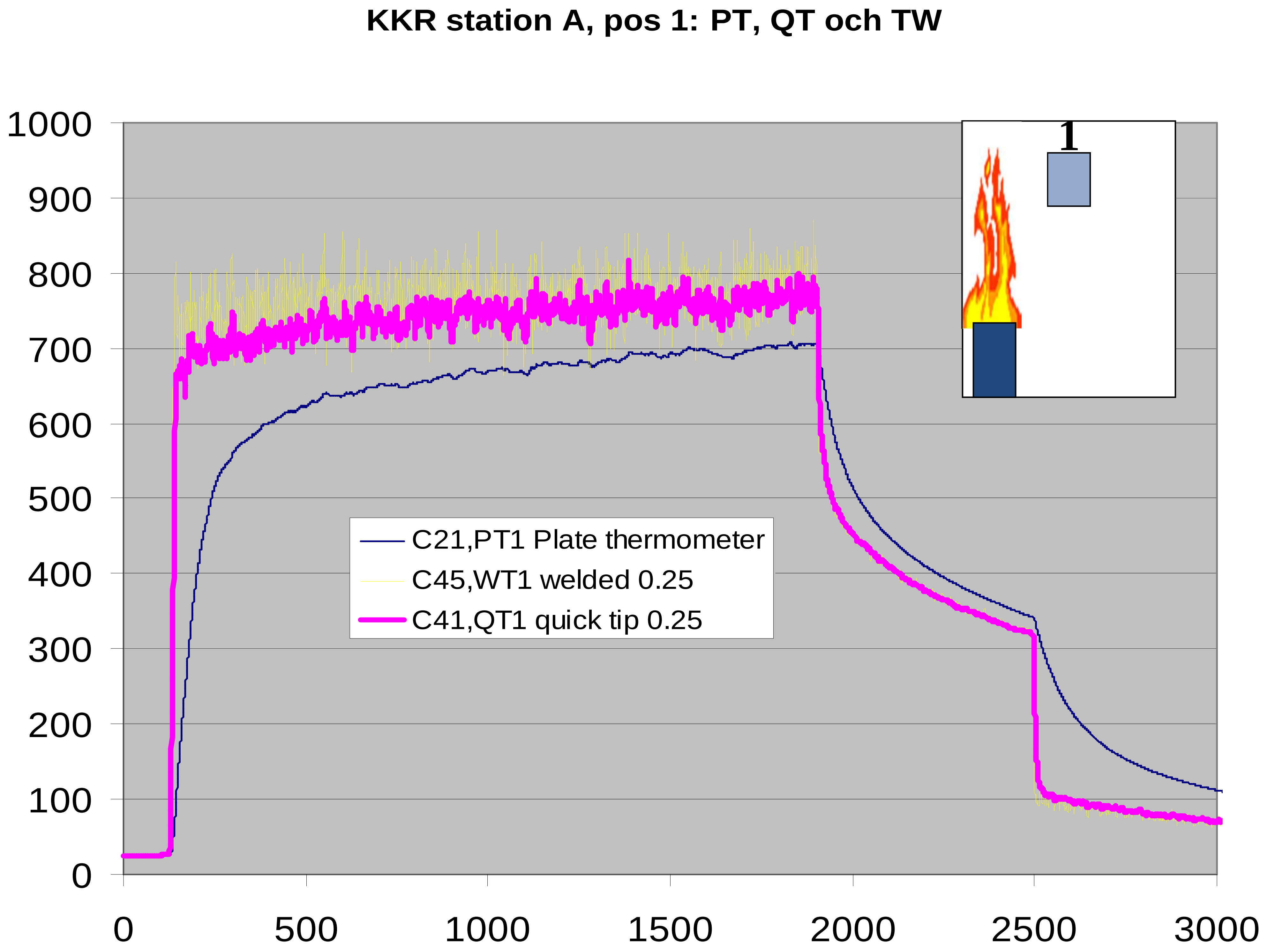
Type 2:
Gypsum + Void +
Gypsum



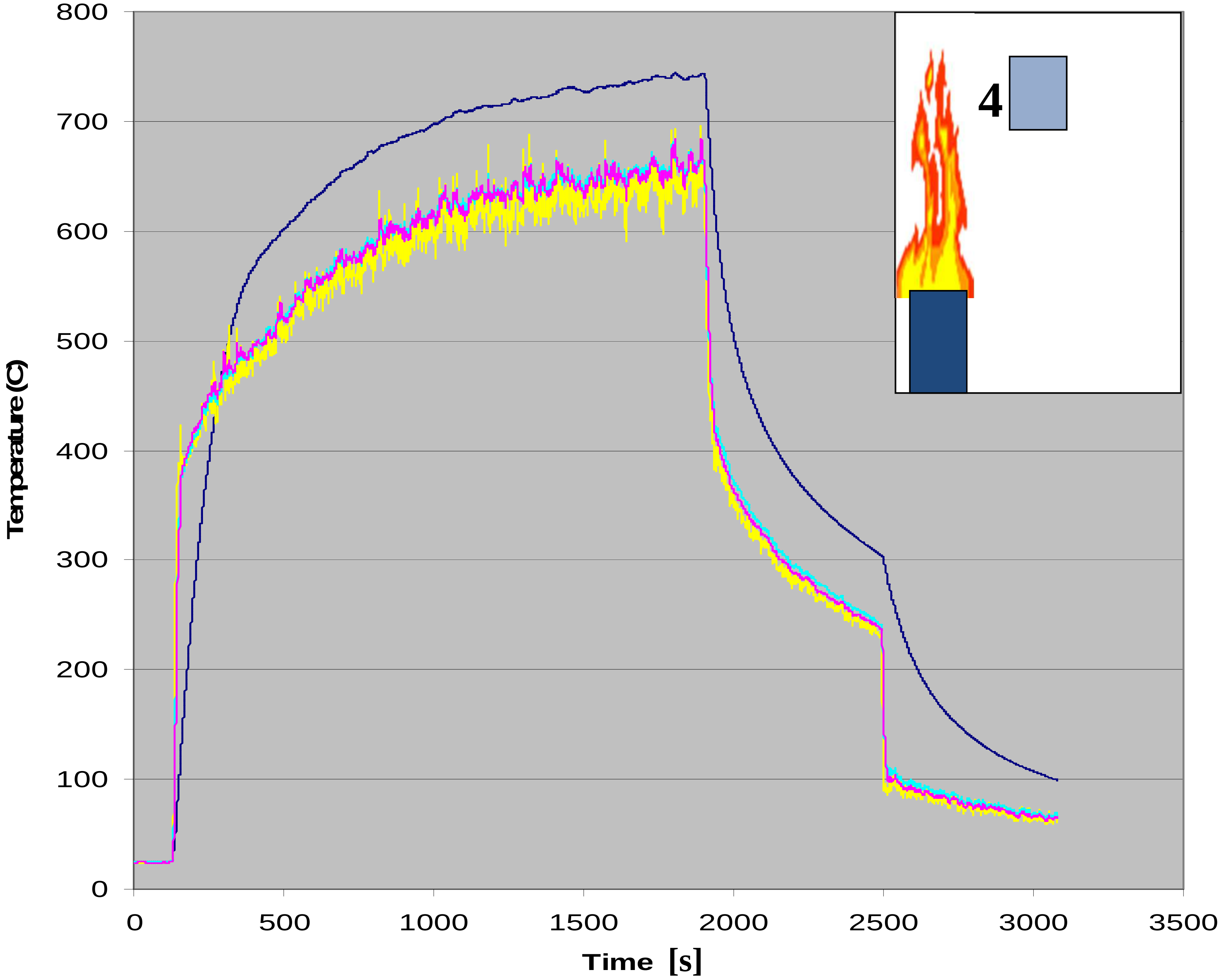
Type 3:
Gypsum + Insulation+
Gypsum

Fire temperature in compartment with different boundaries, duration 2 hours

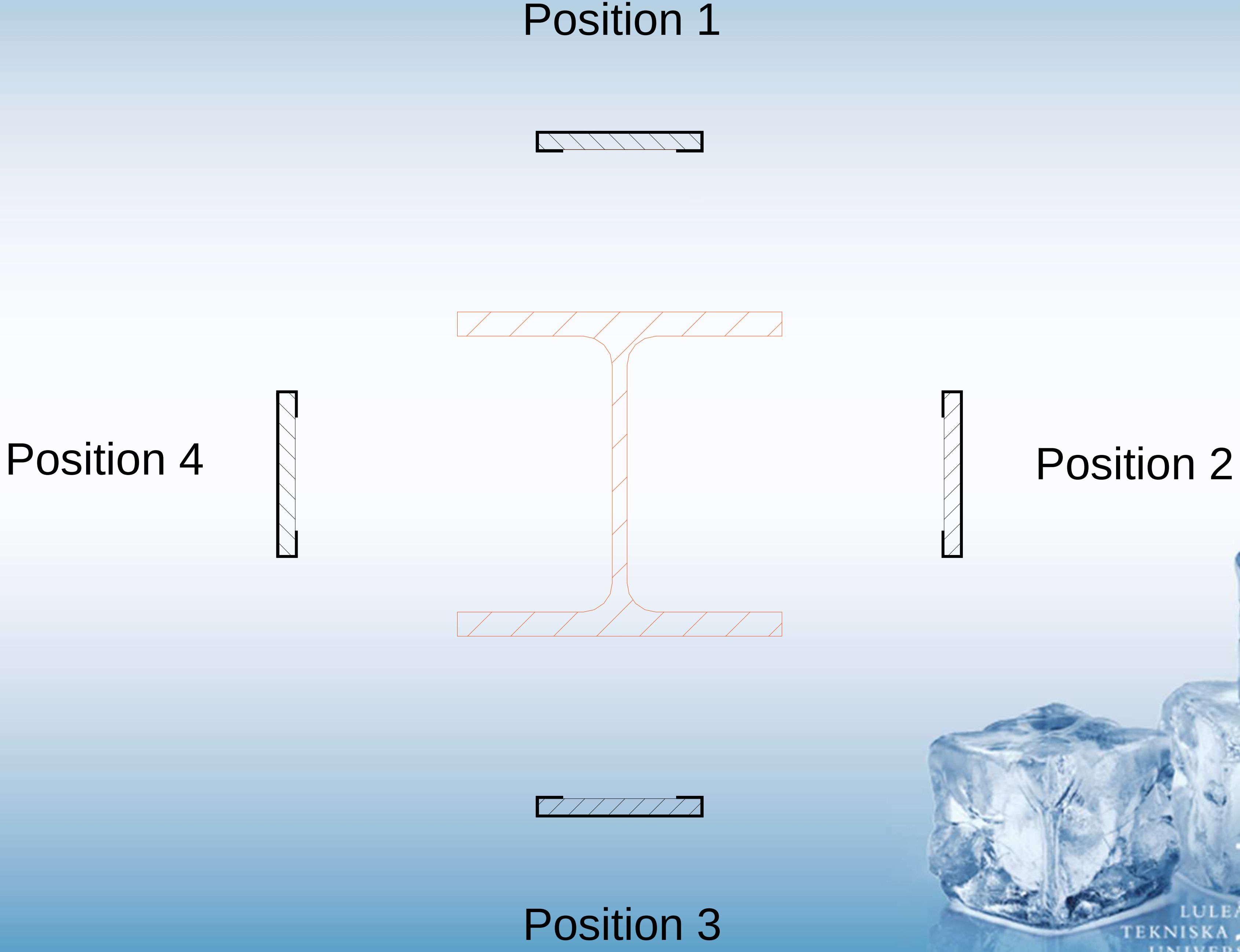



KKR station A, pos 1: PT, QT och TW
1000
900
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
C21,PT1 Plate thermometer
C45,WT1 welded 0.25
C41,QT1 quick tip 0.25
1

KKR station A, pos 4: PT, QT, TW och PS



Gas phase measuring positions around I-section steel beam



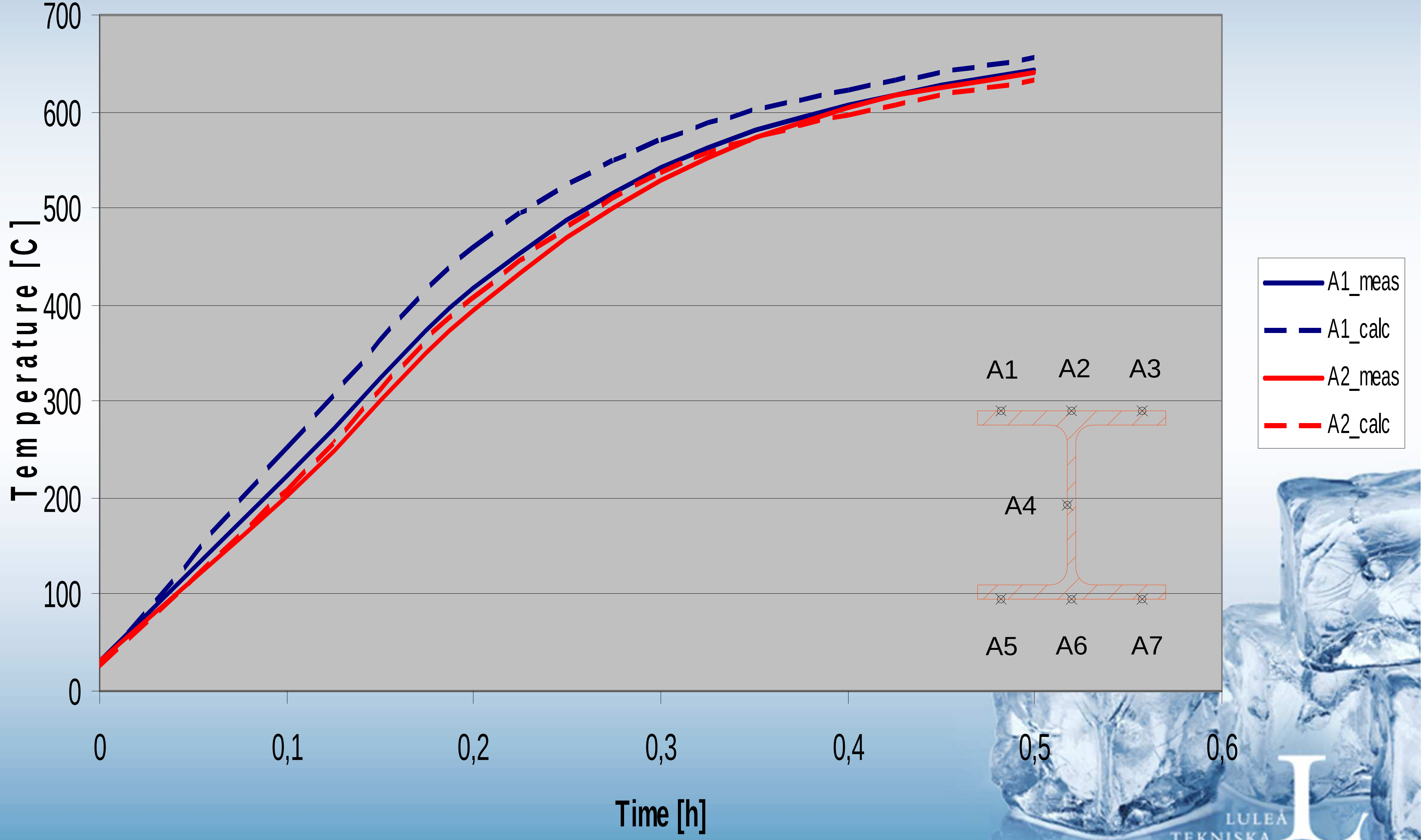
Position 1

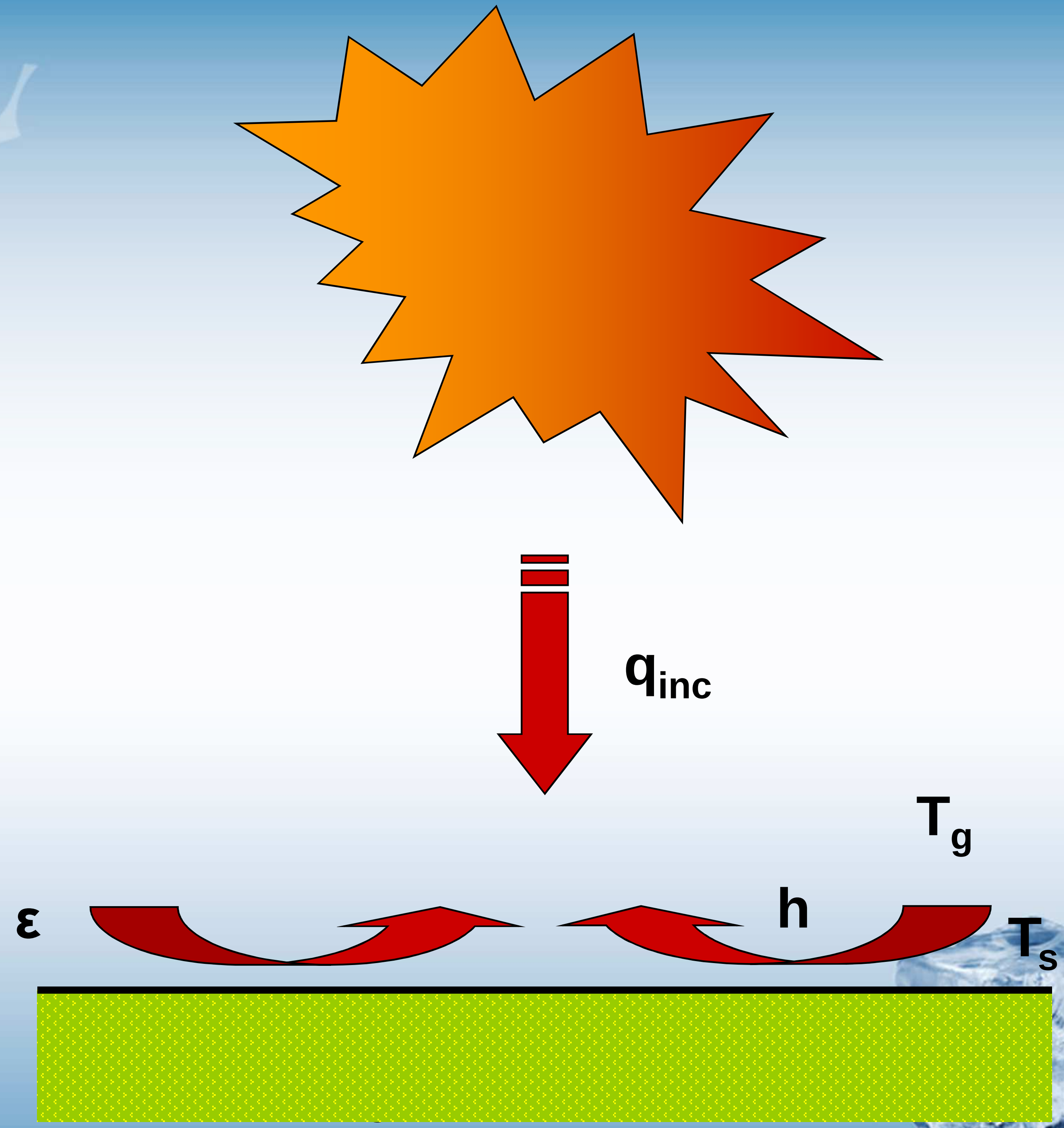
Position 4

Position 2

Position 3

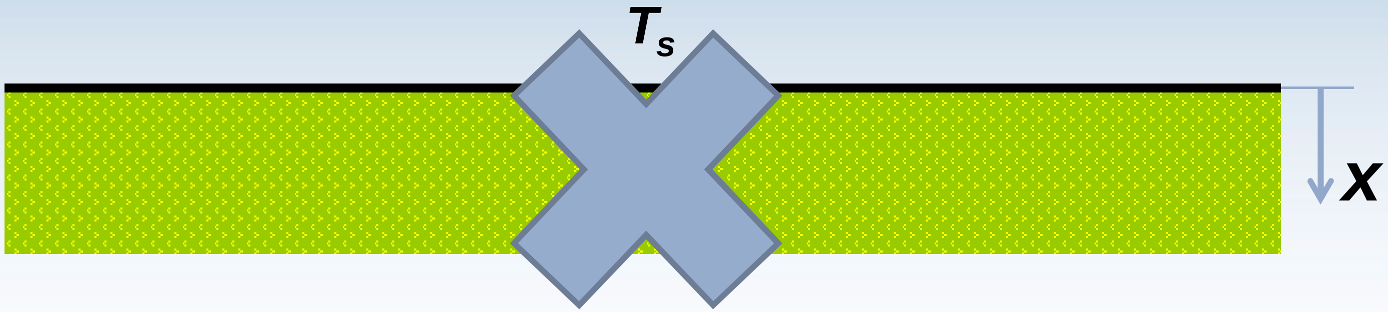
Station A (1-2)
Test 2 - HE200B




q_{inc}
T_g
ε
h
T_s

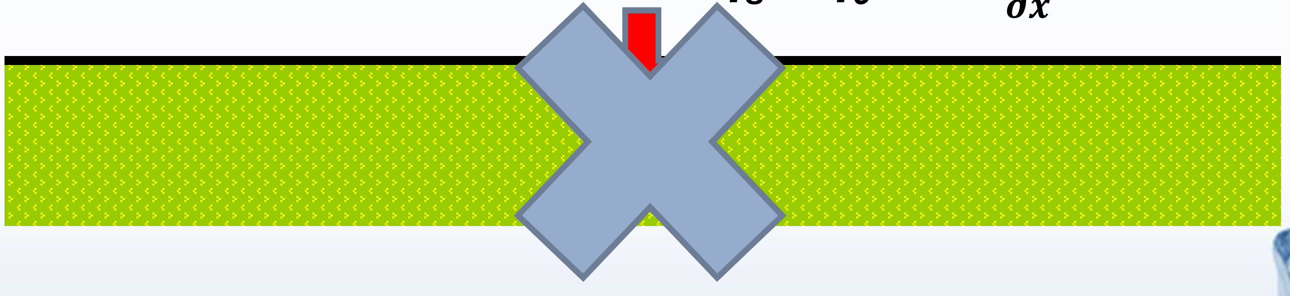
Kind of boundary conditions

1st kind
Prescribed temperature



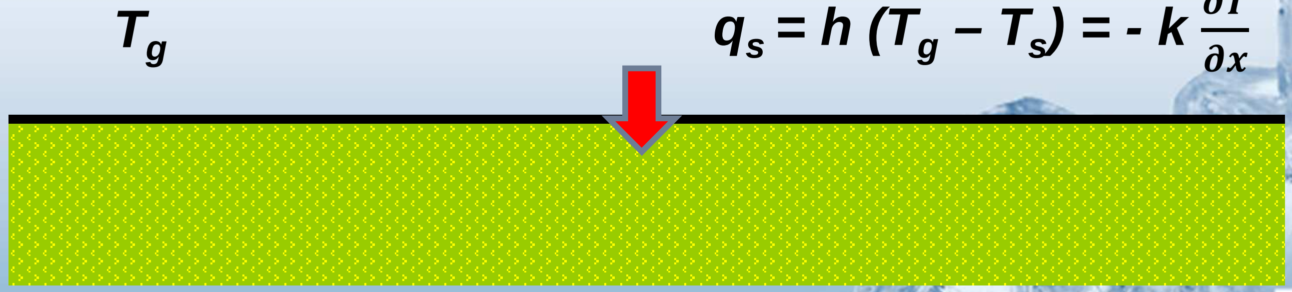
2nd kind
Prescribed heat flux

$$q_s = q_0 = -k\,\frac{\partial T}{\partial x}$$



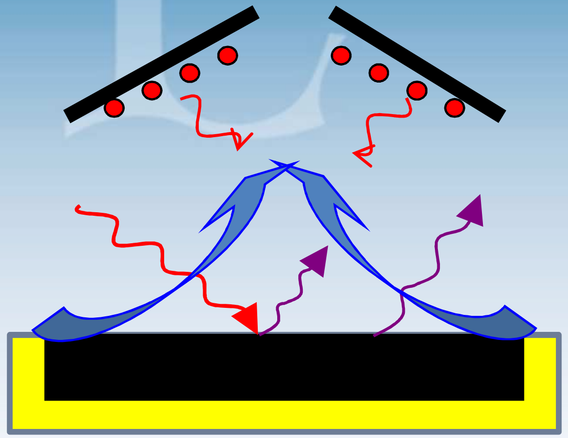
3rd kind
Heat transfer depending surface temperature

$$q_s = h\,(T_g - T_s) = -k\,\frac{\partial T}{\partial x}$$



The three kinds of boundary conditions

No	Kind of Boundary condition	Formula
1	Prescribed surface temperature:	$T_{x=x_0} = T_s$
2	Prescribed surface heat flux:	$-k\left.\frac{\partial T}{\partial x}\right\rvert_{x=x_0} = \dot{q}_0''$
3a)	Natural boundary condition (convection)	$-k\left.\frac{\partial T}{\partial x}\right\rvert_{x=x_0} = \dot{q}_0'' = h\left(T_g - T_s\right)$
3b)	Natural boundary condition (mixed boundary condition, given convection and radiation conditions, equal radiation and gas temperatures)	$\dot{q}_0'' = \varepsilon\sigma\left(T_f^4 - T_s^4\right) + h_c\left(T_f - T_s\right)$
3c)	Natural boundary condition (mixed boundary condition, given convection and radiation conditions, different radiation and gas temperatures)	$\dot{q}_0'' = \varepsilon\sigma(T_r^4 - T_s^4) + h_c\left(T_g - T_s\right)$ or $\dot{q}_0'' = \varepsilon\left(\dot{q}_{inc}'' - \sigma T_s^4\right) + h_c\left(T_g - T_s\right)$



Thermal/fire exposure

$$\dot{q}''_{tot} = \dot{q}''_{abs} - \dot{q}''_{emi} + \dot{q}''_{con}$$

$$\dot{q}''_{tot} = \varepsilon\, \dot{q}''_{inc} - \varepsilon\, \sigma\, T_s^4 + h_{con}\left(T_g - T_s\right)$$

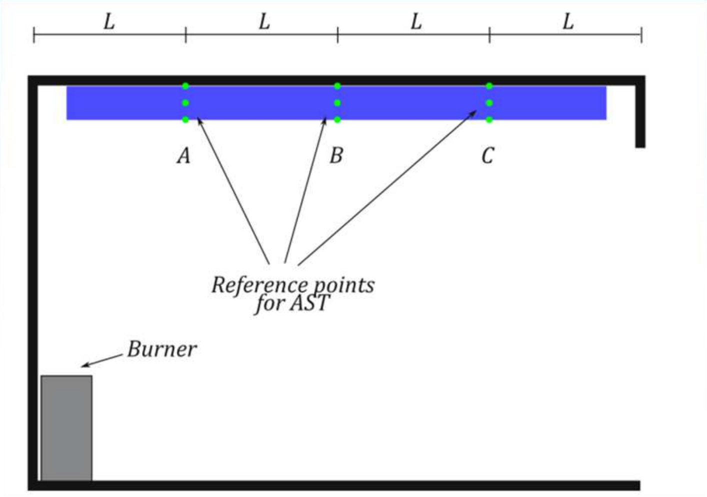
$$\boxed{\dot{q}''_{inc} \equiv \sigma\, T_r^4}$$

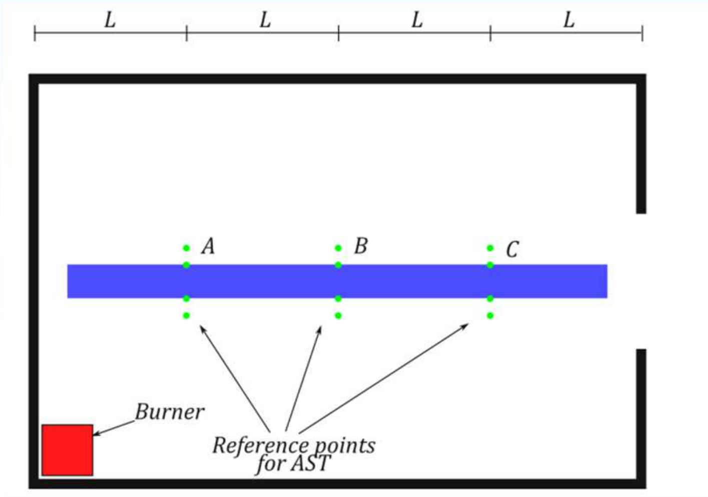
$$\dot{q}''_{tot} = \varepsilon\, \sigma\, (T_r^4 - T_s^4) + h_{con}\left(T_g - T_s\right)$$

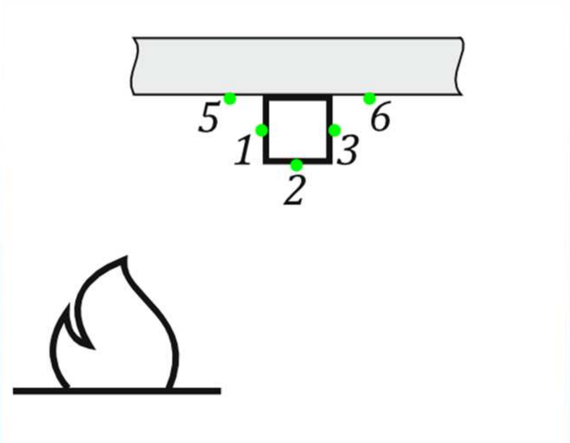
The thermal/fire exposure consists of two parameters:

$\dot{q}''_{inc}(\equiv \sigma\, T_r^4)$ and T_g

Setup - CFD

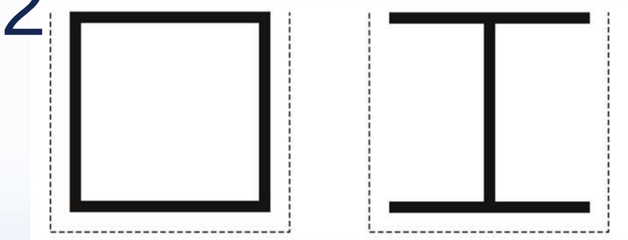

L
L
L
L
A
B
C
Reference points for AST
Burner


L
L
L
L
A
B
C
Burner
Reference points for AST

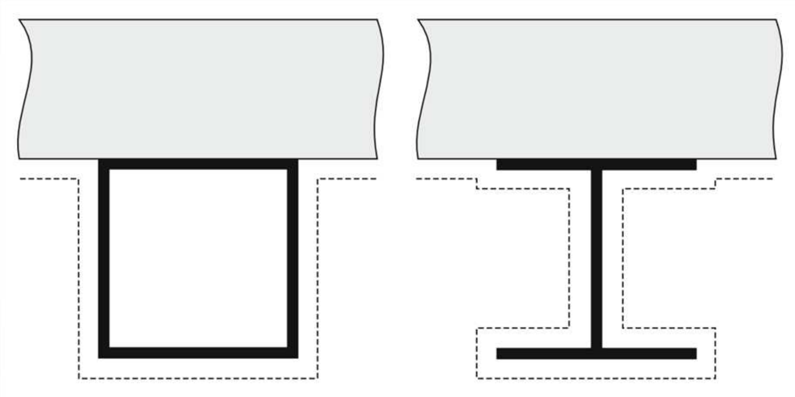

5
6
1
3
2

Setup – Thermal response

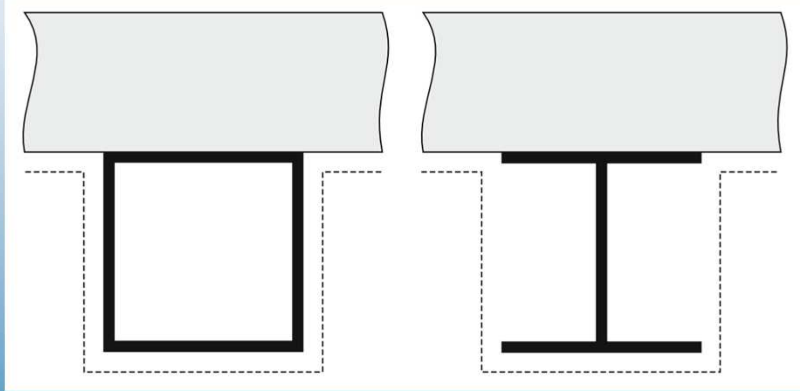
1 and 2



3



4 and 5

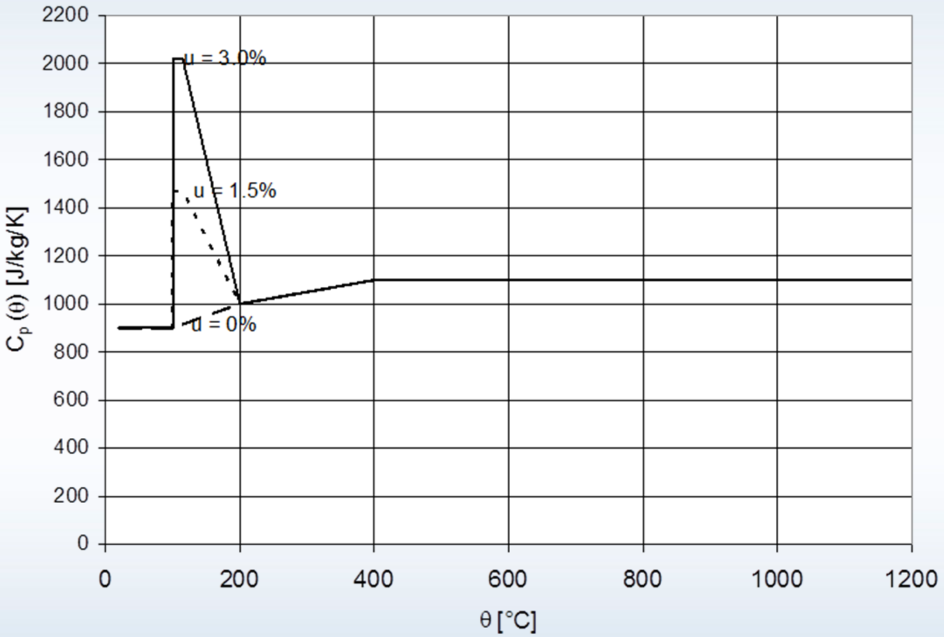


Thermal response calculations

H- section	Lower flange	Web	Upper flange
Method 1	869℃	869℃	869℃
Method 2	877℃	877℃	868℃
Method 3	877℃	876℃	764℃
Method 4	857℃	851℃	731℃
Method 5	729℃	658℃	559℃

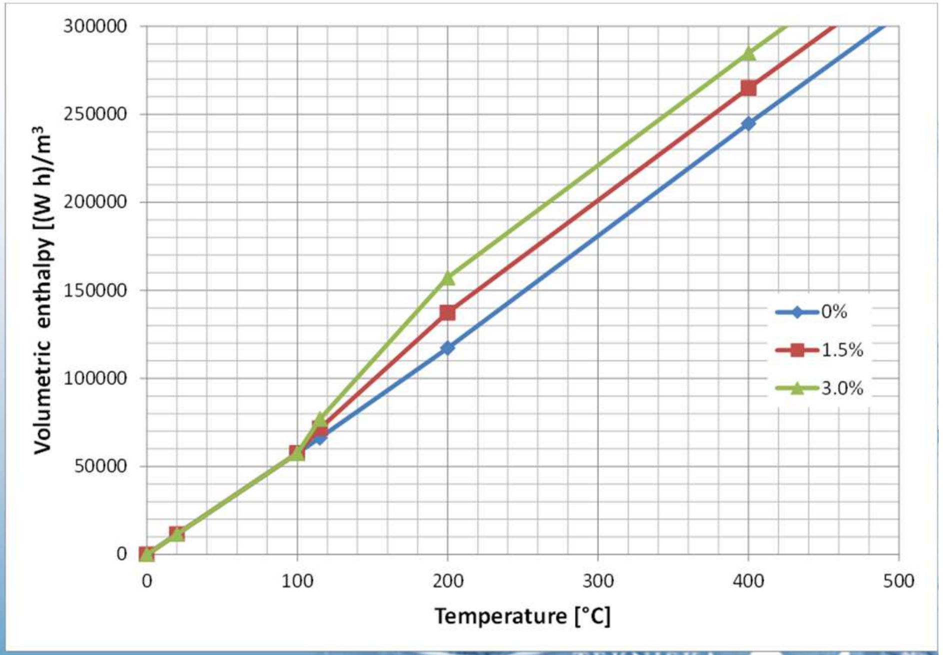
1. Eurocode
2. Uniform fire exposure but no concrete
3. Uniform fire exposure
4. Uniform fire exposure and shadow effects
5. Uniform fire exposure and shadow effects

Specific heat and enthalpy Concrete Eurocode



Replace the cρ with the enthalpy

$$e(T) = \int_0^T c\rho \, dT + \sum_i l_i$$



Gypsum

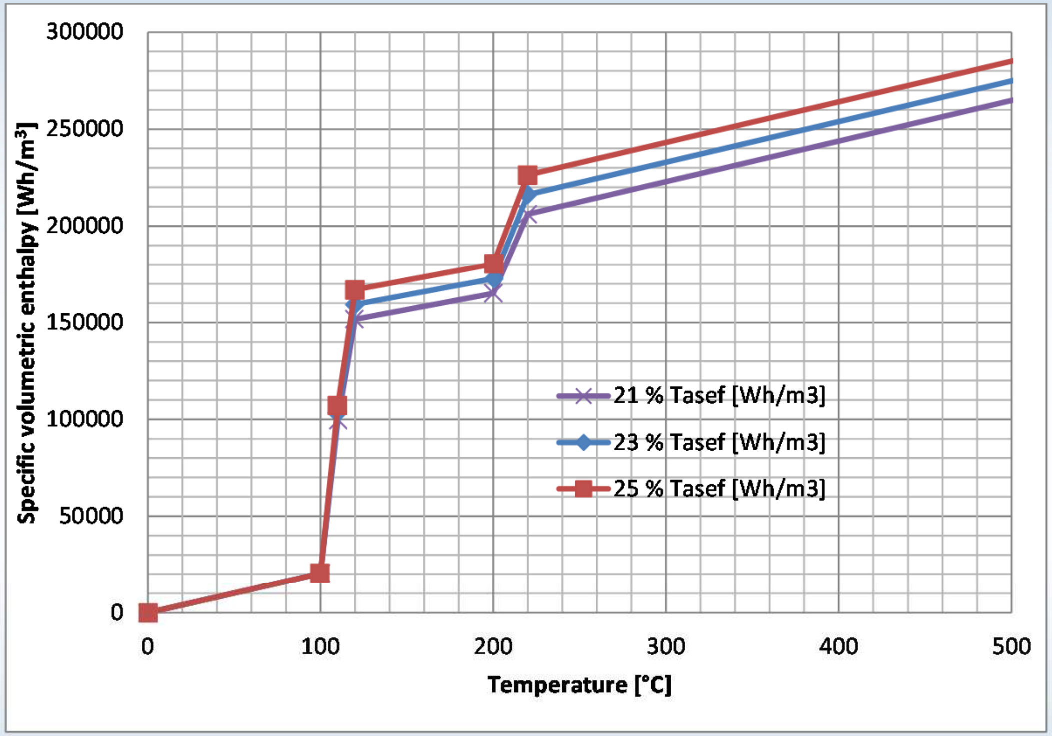


Figure 1 Temperature-Enthalpy curve, showing the reactions associated with dehydration of water between 100 – 240 °C at three different hydrations (21 – 25 %).

Comparison test and calculation Gypsum

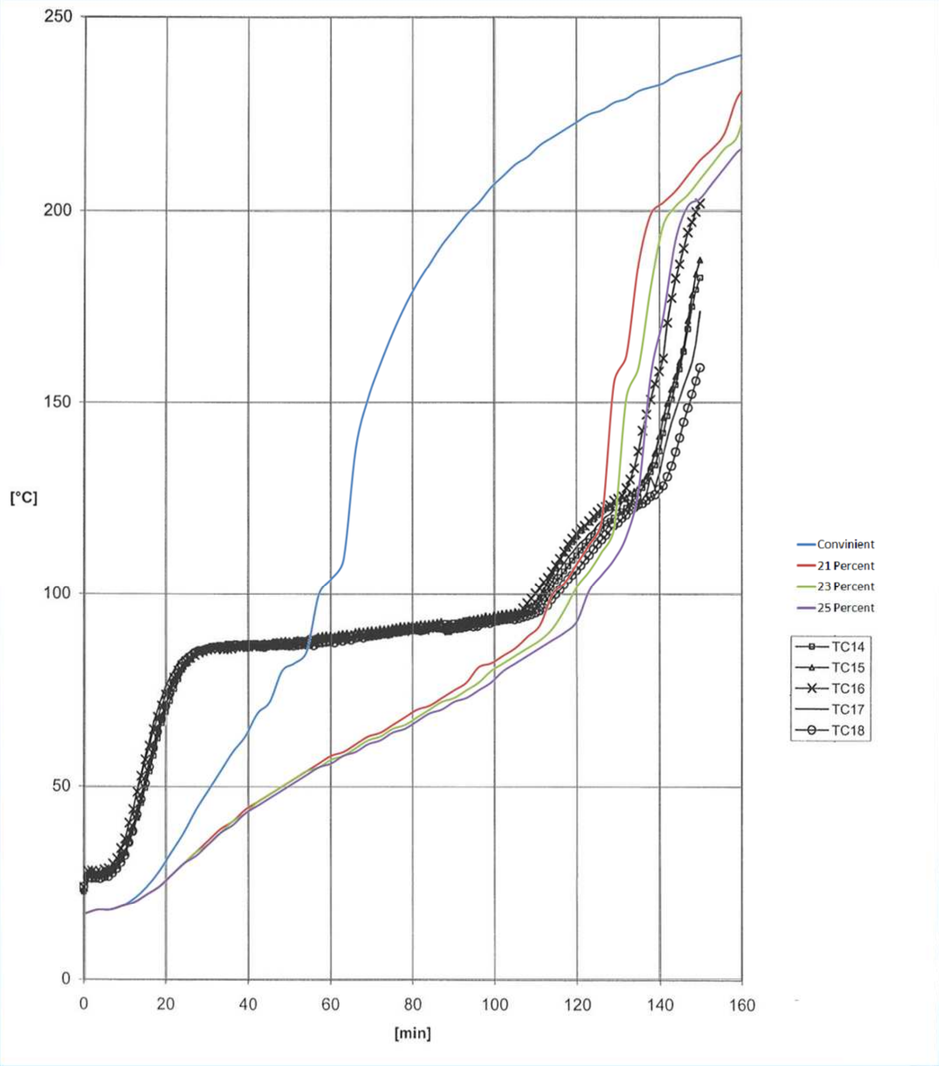


Figure 1, Comparison between values from fire test and from TASEF simulations, the colored lines represent simulations from TASEF with different enthalpies and the black lines represent thermocouple temperatures from fire test.

Summary

1. Thermal/fire exposure consists of **two** parameters, q_{inc} (or T_r) and T_g
2. They can be combined into the adiabatic surface temperature, T_{AST} for given ε and h
3. T_{AST} can be measured with plate thermometers
4. T_{AST} can be used for temperature calculations
5. ’Heat flux’ cannot be measured in fires
6. ’Heat flux’ is not a fire boundary condition