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Performance

-Based Design

Fully-Developed Fires

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Purpose

"To save lives and property"

Society: That the building can be accepted

- Mainly Lives, but also
- Major Losses
- Cultural Heritage
- Prestige.

Client: Also Property and market share.

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Parametric fire

Philip Thomas and Kunio Kawagoe at Mount Athos

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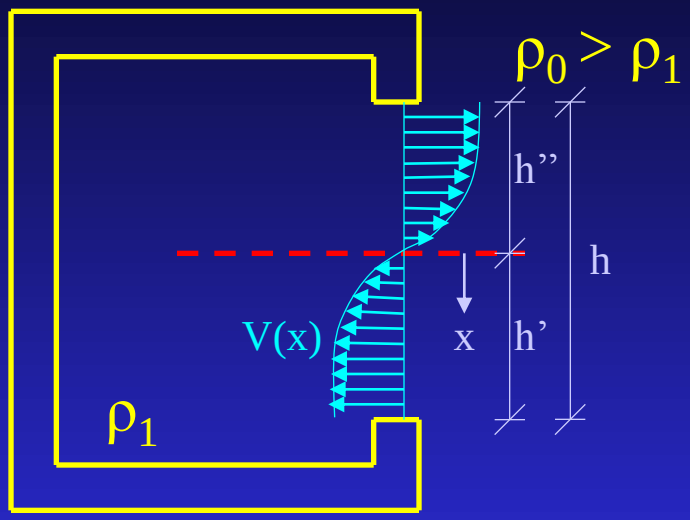
Parametric fire Opening Factor

$$O = \frac{A\sqrt{h}}{A_{tot}}$$



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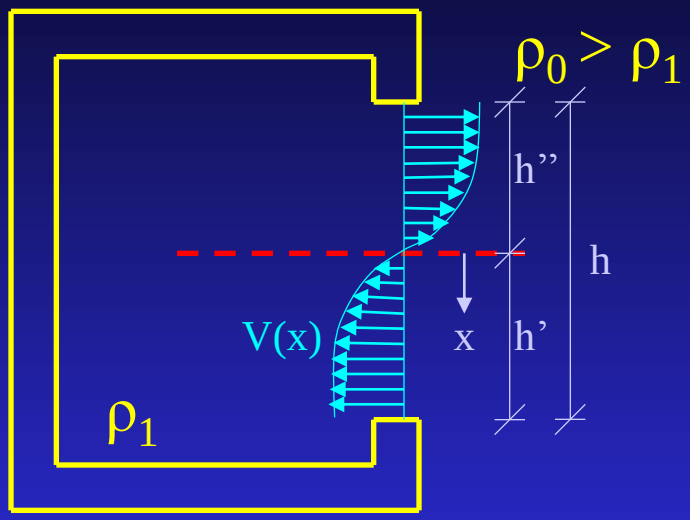
Parametric fire Opening Factor

$$O = \frac{A\sqrt{h}}{A_{tot}}$$



Bernoulli :

$$\frac{1}{2}\rho_0 \cdot (v(x))^2 = g \cdot x \cdot (\rho_0 - \rho_1)$$

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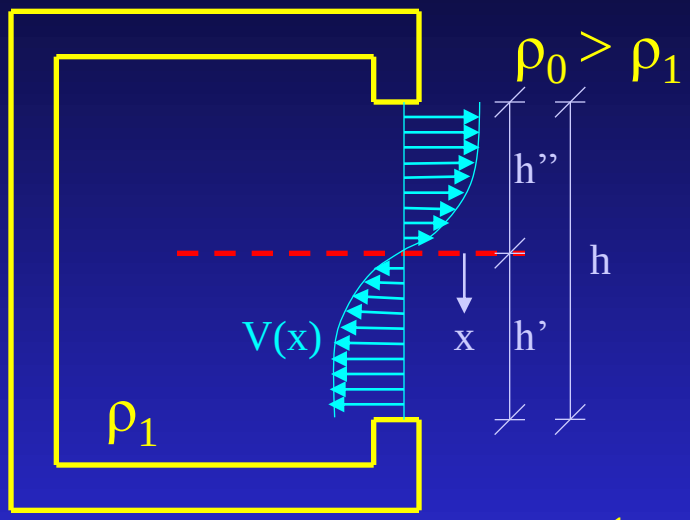
Parametric fire Opening Factor

$$O = \frac{A\sqrt{h}}{A_{tot}}$$



Bernoulli :

$$\frac{1}{2}\rho_0 \cdot (v(x))^2 = g \cdot x \cdot (\rho_0 - \rho_1)$$

$$\text{Average velocity}: v_M = \frac{1}{h}\int_0^{h'} v(x)dx = \frac{1}{h}\sqrt{2g\frac{\rho_0 - \rho_1}{\rho_0}}\int_0^{h'} \sqrt{x}dx$$

$$= \frac{1}{h}\sqrt{2g\frac{\rho_0 - \rho_1}{\rho_0}}\frac{2}{3}(h')^{3/2} = C^*\sqrt{h}$$

for h' proportional to h.

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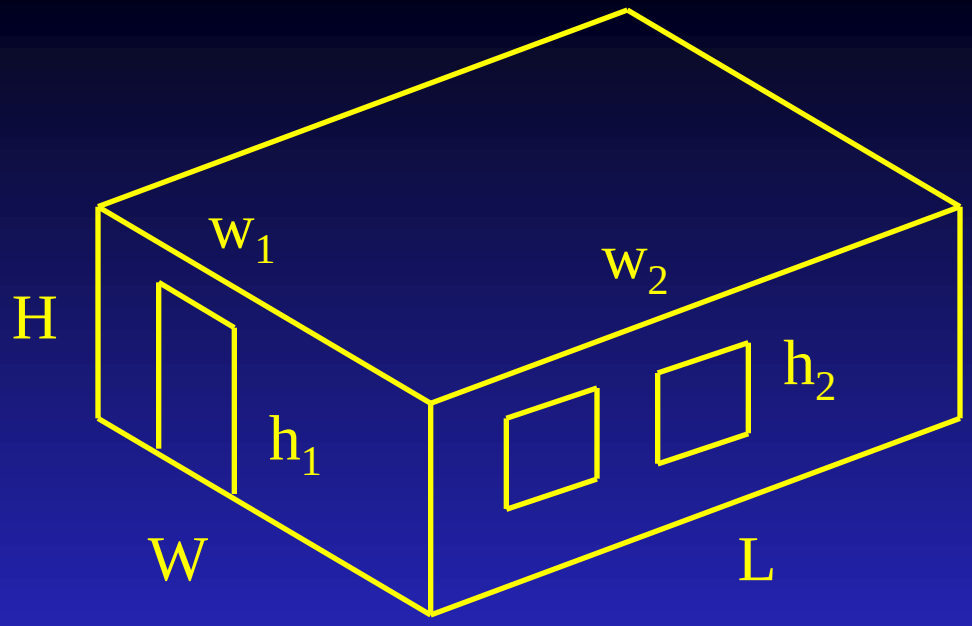
Parametric fire

Opening factor



$$A_{tot} = 2(H \cdot L + W \cdot L + H \cdot W)$$

$$A = \sum_i h_i w_i \qquad h_{ave} = \sum_i \frac{w_i h_i^2}{A}$$

$$O = \frac{A\sqrt{h_{ave}}}{A_{tot}}$$

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Parametric fire

Opening factor

$$O = O_v + O_h$$

$$O_v = \frac{A_v \sqrt{h_v}}{A_{tot}}$$

$$O_h = \frac{A_h \sqrt{4h_h}}{A_{tot}},$$

h_h = Vertical distance from centre of gravity for vertical openings to the inside surface of the ceiling

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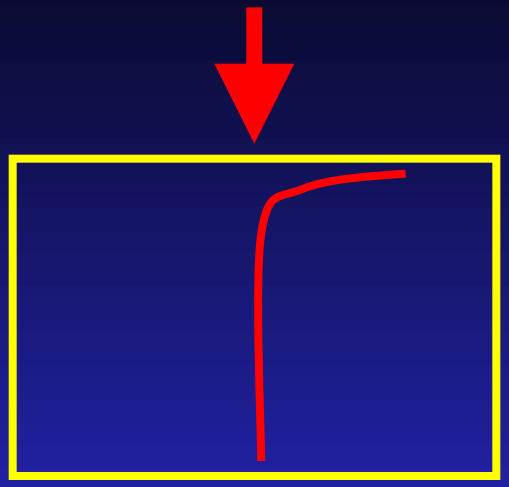
Parametric fire

Thermal inertia

(Danish: Berøringstallet)



$$b = \sqrt{\rho c \lambda} \quad \left[J / m^2 s^{½} K \right]$$

ρ = Desity $\left[kg / m^3 \right]$

c = Heat capacity $\left[J / kgK \right]$

λ = Conductivity $\left[W / mK \right]$

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Parametric fire

Fire course

$$T = 20 + \frac{345 \log_{10}(8\Gamma t + 1)}{1 + 0.04(t / t_d)^{3.5}} \quad [°C]$$

$$\Gamma = \frac{(O/b)^2}{(0.04/1160)^2} \quad [-]$$

=1.0 for a standard fire compartment

$$t_d = 7.80 * 10^3 q / O \quad [\text{min}]$$

= Time for end of the heating phase

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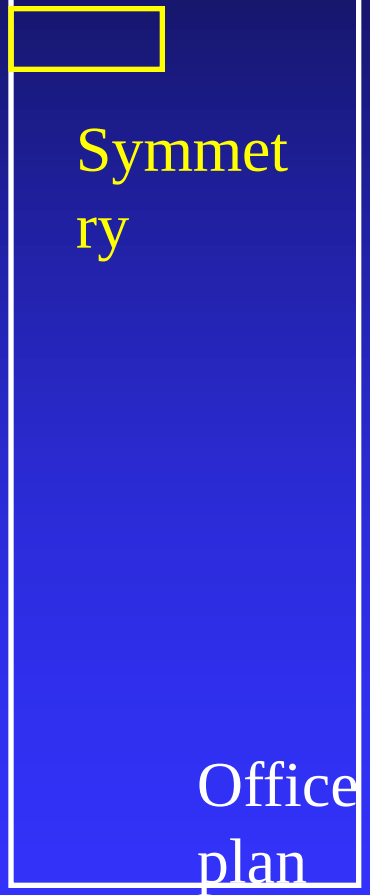
Parametric fire

Large Flat Compartments



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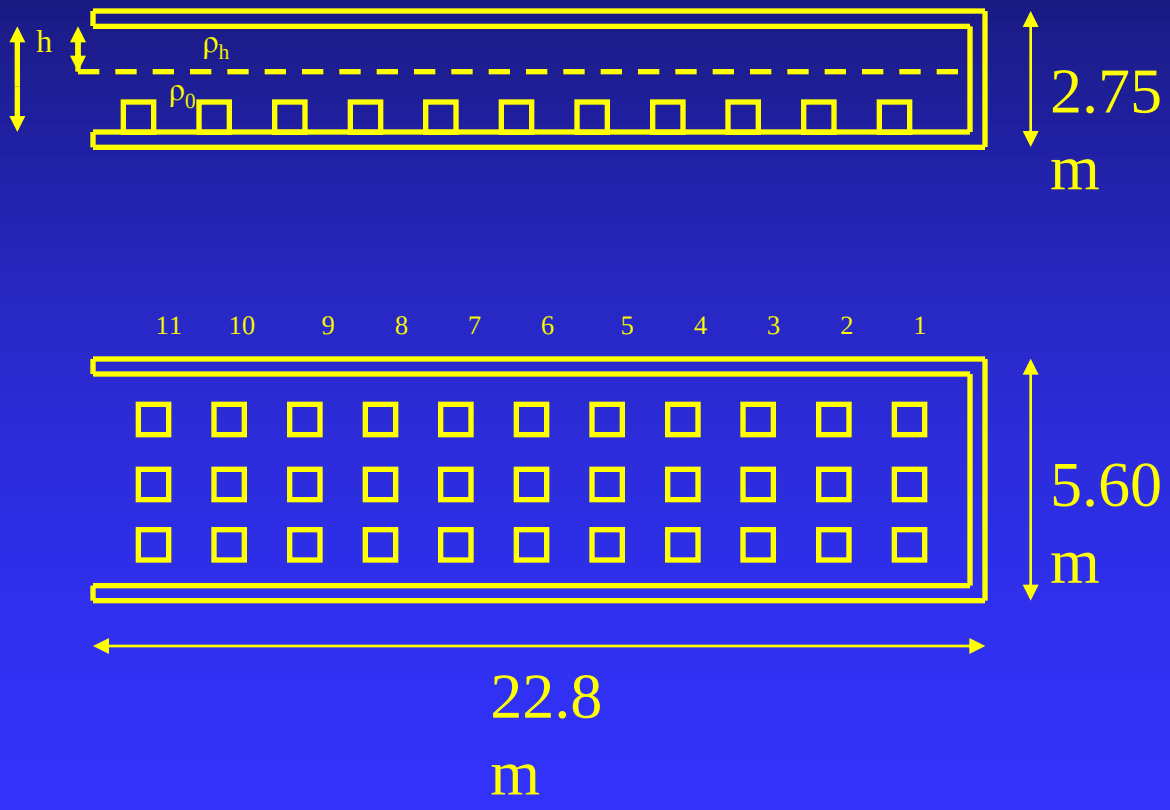
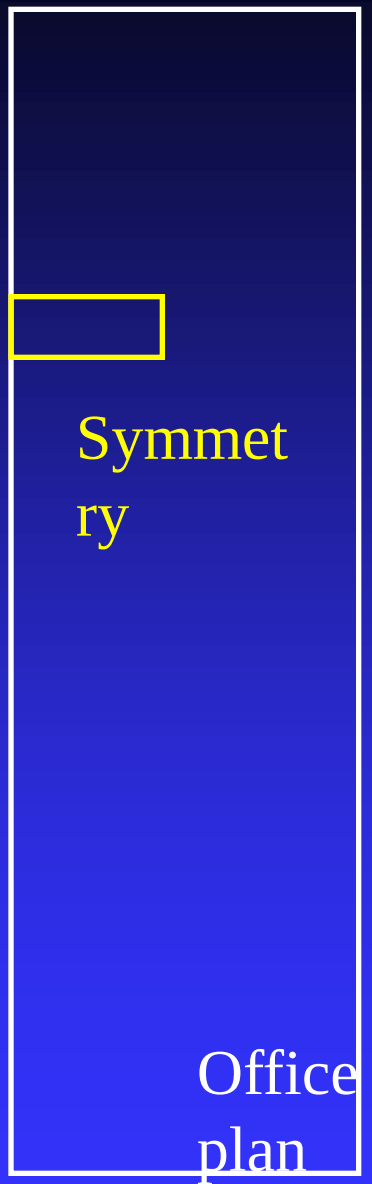
Parametric fire

Large Flat Compartments





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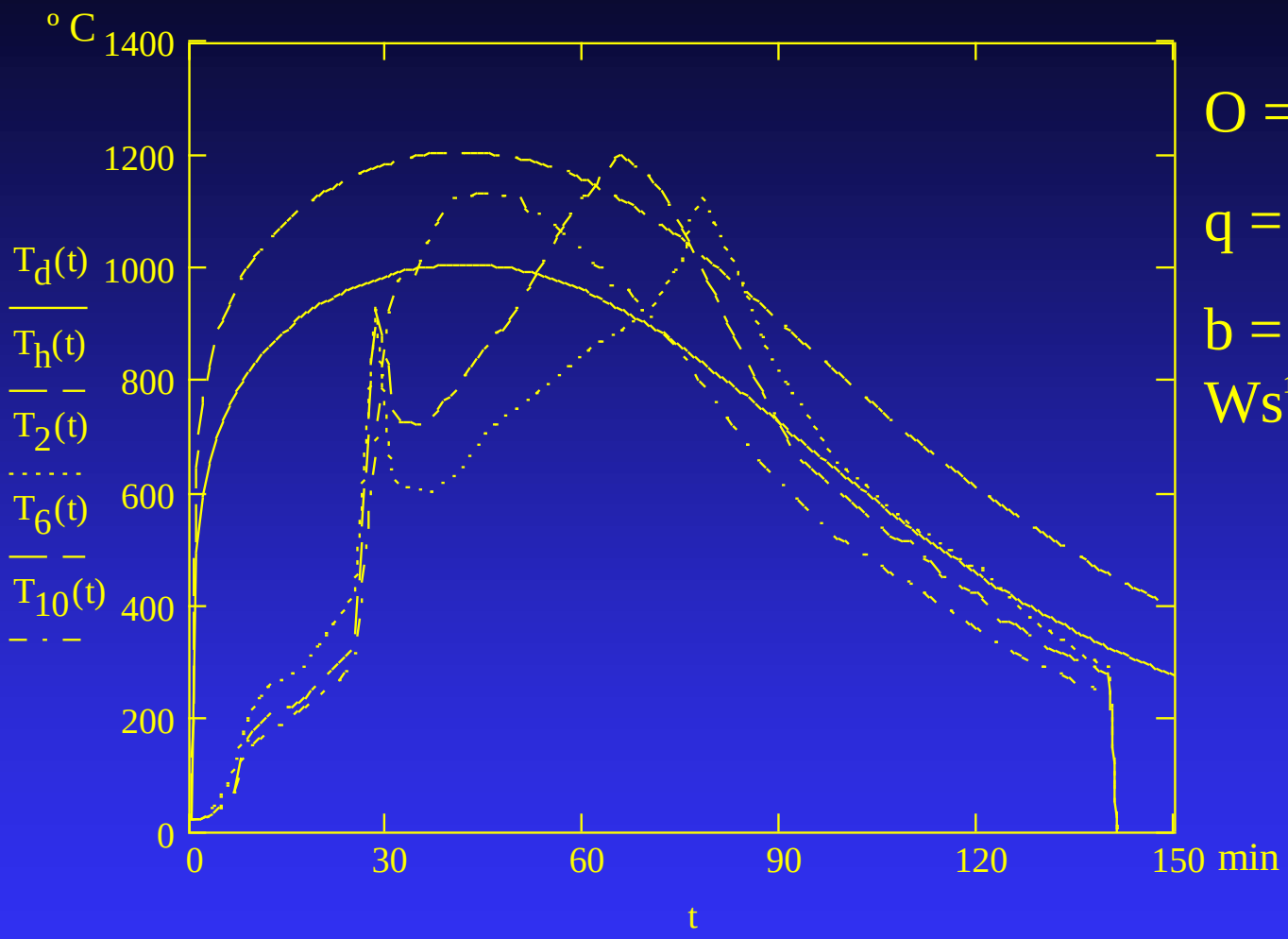
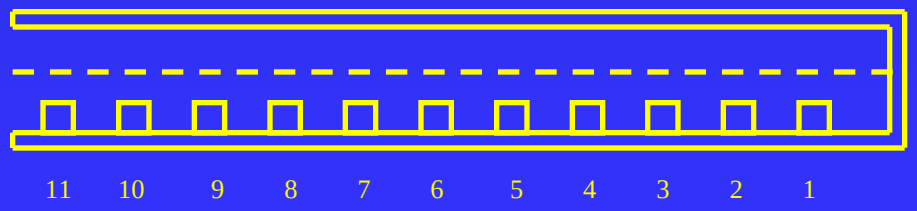
Parametric fire Influence of the cooling curve shape



O = 0.034 $m^{½}$

q = 179 MJ/m^2

b = 586.5 $Ws^{½}/m^2K$



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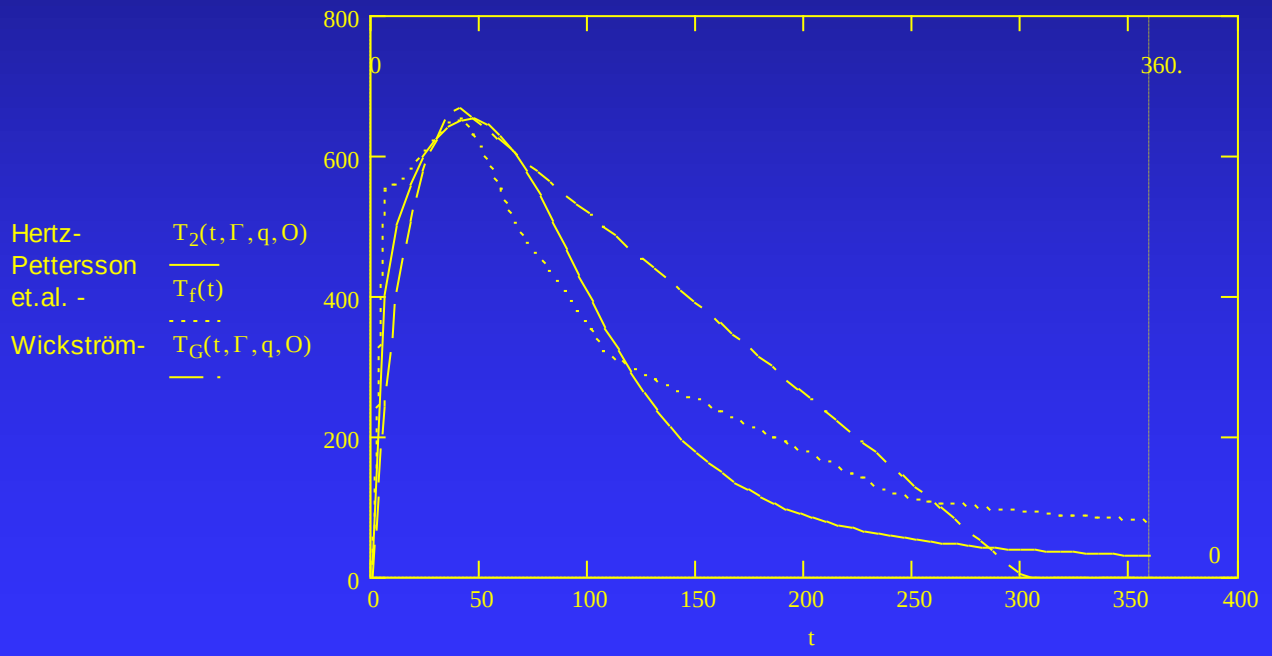
Parametric fire course

$$T = 20 + \frac{345\log_{10}(8\Gamma t + 1)}{1 + 0.04(t/t_d)^{3.5}} \quad [°C]$$

$$O = 0.02 m^{½}, \quad q = 100 MJ/m^2, \quad t_d = 39 min$$

$$\rho = 1700 kg/m^3, \quad c = 1000 J/kgK, \quad \lambda = 0.80 W/mK$$

$$b = 1166 J/m^2 s^{½} K, \quad \Gamma = 0.247$$



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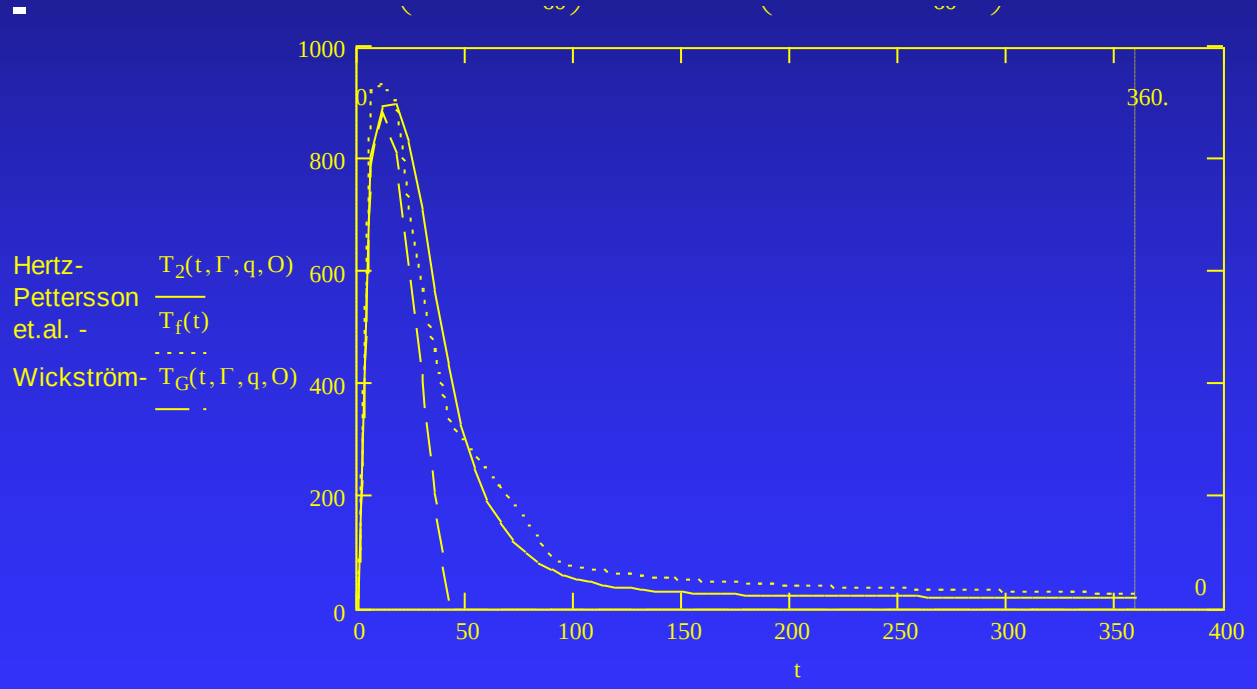
Parametric fire course

$$T = 20 + \frac{345\log_{10}(8\Gamma t + 1)}{1 + 0.04(t/t_d)^{3.5}} \quad [°C]$$

$$O = 0.08 m^{½}, \quad q = 150 MJ/m^2, \quad t_d = 14.6 min$$

$$\rho = 1700 kg/m^3, \quad c = 1000 J/kgK, \quad \lambda = 0.80 W/mK$$

$$b = 1166 J/m^2 s^{½} K, \quad \Gamma = 3.958$$



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Opening Factor

Fire course	Ope-ning factor	T_{max} in slab with 30mm cover	Reduction of concrete strength 150mm section		Reduction of column strength 200x300 x4000mm	
	$m^{½}$	°C	Hot	Cold	Hot	Cold
200 MJ/m²	**0,02**	**413**	**0.75**	**0.43**	**0.61**	**0.33**
200 MJ/m²	0,04	378	0.81	0.53	0.63	0.38
200 MJ/m²	0,08	320	0.83	0.63	0.64	0.40
200 MJ/m²	0,12	280	0.84	0.67	0.65	0.44
300 MJ/m²	0,04	459	0.73	0.40	0.53	0.29
60 minutes St. Fire	(0,04)	350	0.81	-	0.54	-
60 minutes St. Fire + cool	(0,04)	464	0.70	0.37	0.52	0.28
120 minutes St. Fire	(0,04)	528	0.56	-	0.33	-
120 minutes St. Fire + cool	(0,04)	613	0.36	0.00	0.26	0.04

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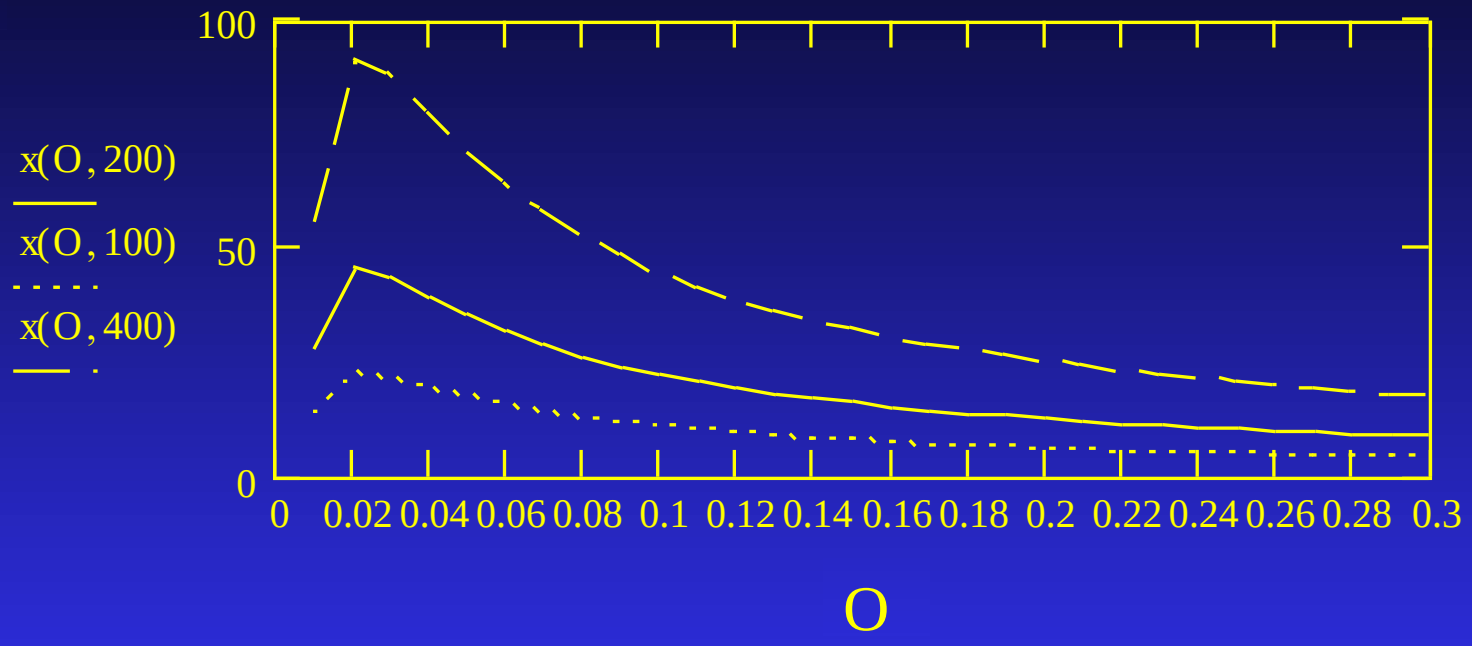
Parametric fire



Maximum charring depth of structural pine wood for fire loads of 400, 200 and 100 MJ/m^2 as a function of the opening factor

$$x(O,q) = (1.25 - \frac{0.035}{O + 0.021})\frac{8}{12} \cdot 0.0175 \cdot \frac{q}{O}$$

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Parametric fire

For a steel structure protected by an intumescent paint of 0.086 $m^2{}^oC/W$ and exposed by a fire with a fire load of 210 MJ/m^2 that the temperature will be largest for the opening factor **0.02 $m^{½}$** for ratios of fire exposed surface and volume **up to 200 m^{-1}**

which means **all HEB** profiles

Heavy HEA profiles **until HEA 160** and

Heavy IPE profiles **until IPE 300**

For more slender profiles the temperature will be largest for larger opening factors.

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Opening Factor

for **Industrial Housing** with unknown customers

Slow fires are usually more severe for structures than fast fires.

A small opening factor is therefore on the safe side to apply.

It is recommended to apply:

0.02 $m^{½}$

For all categories

If the building is not known.

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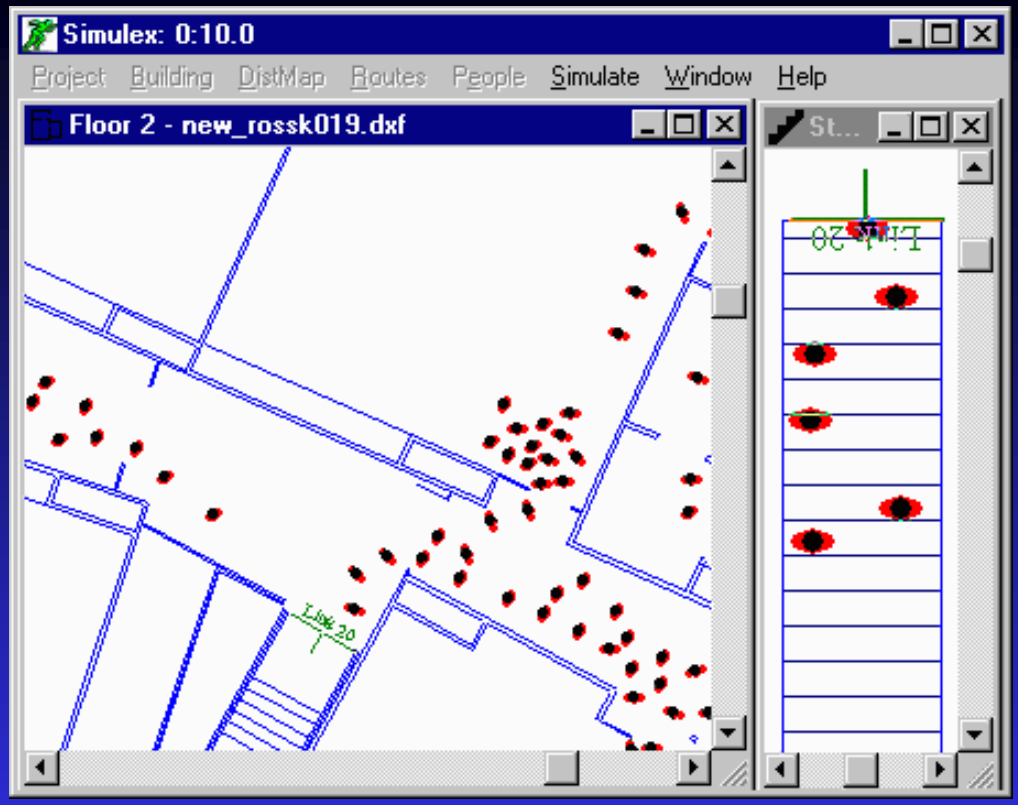
Evacuation



Criteria of importance for risk assessment for evacuation: Radiation, Visibility, Toxicology and Structural Stability.

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Dansk Byggeri,
Erhvervs og Byggestyrelsen,
COWI A/S,
Betonelement-Foreningen,
Rambøll A/S
MT Højgaard A/S,
Spæncom A/S
Københavns Kommune

Kristian Hertz

Vejledning i dimensionering af bygningskonstruktioner for fuldt udviklet brand

www.ebst.dk
www.byg.dtu.dk

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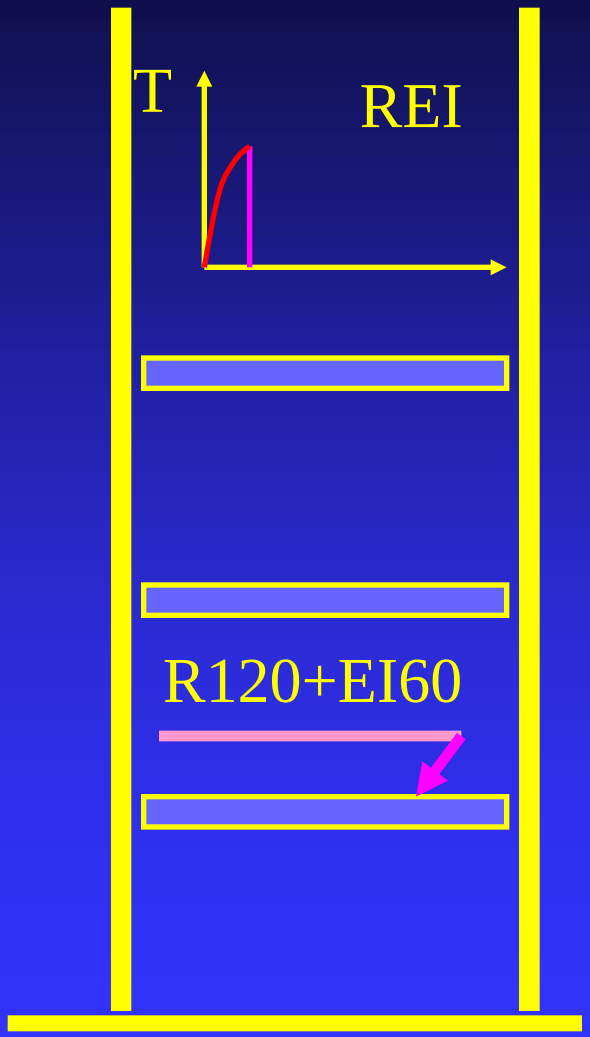
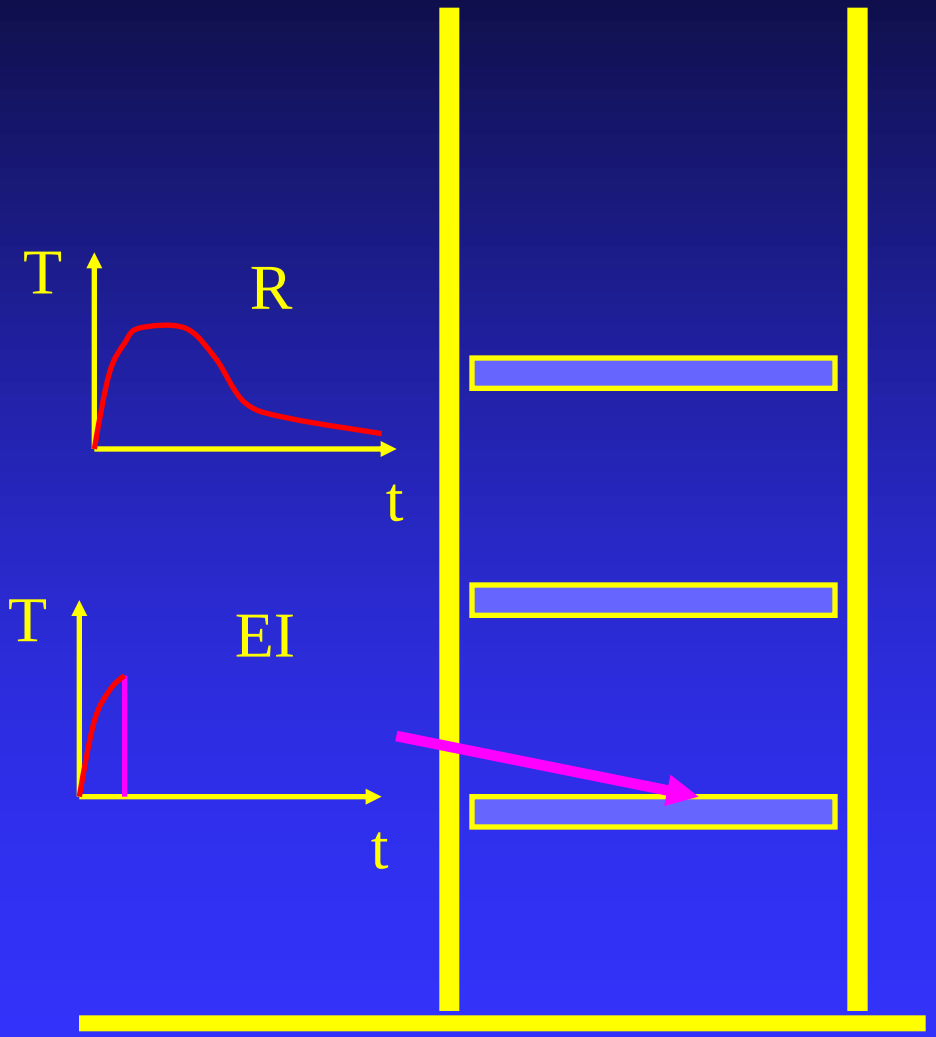
Integrity and insulation

Examples



Information



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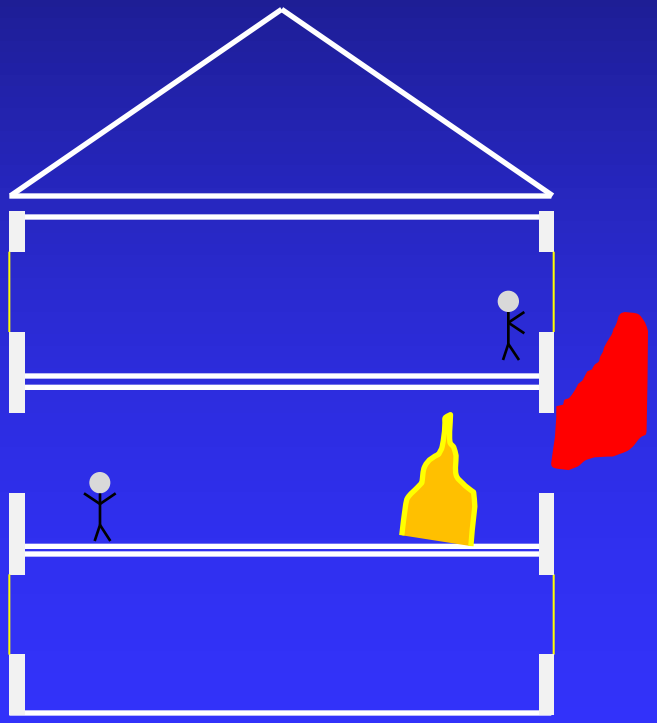
Fire Resistance

Requirements:

- R 120 min if ≥ 12 m up or
-Parametric fire ?



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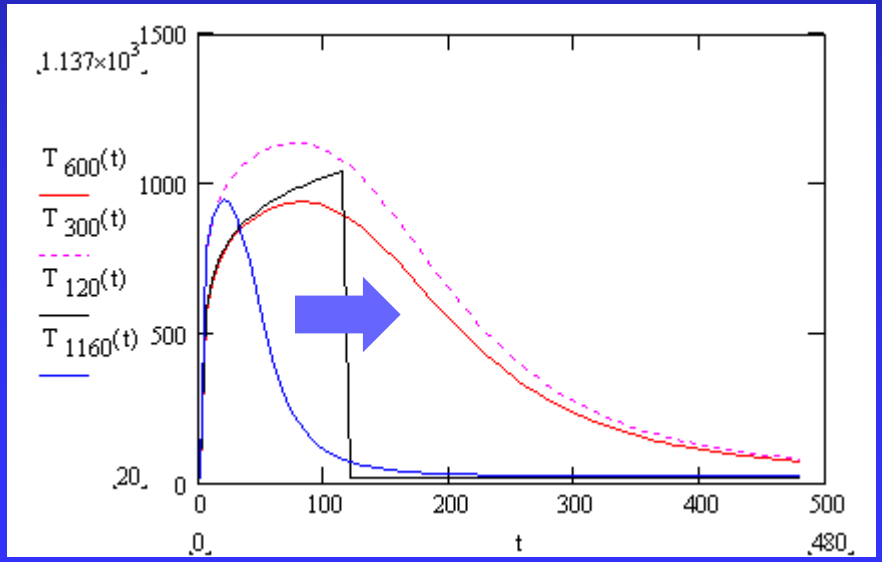
Parametric Fires in Modern Danish Buildings

Previously

Windows
2 mm 6 kg

Now:

Windows
3 x 4 mm 50 kg



Temperature-Time Curvess min

O = 0.08 m½
q = 200 MJ/ m²
b = 1160 Ws½/m²C

O = 0.02 m½
q = 200 MJ/ m²
b = 600-300 Ws½/m²C

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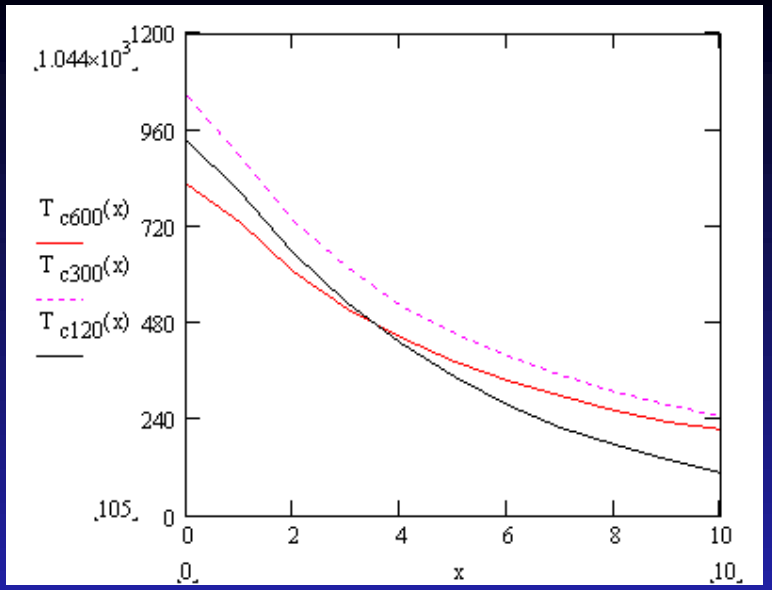
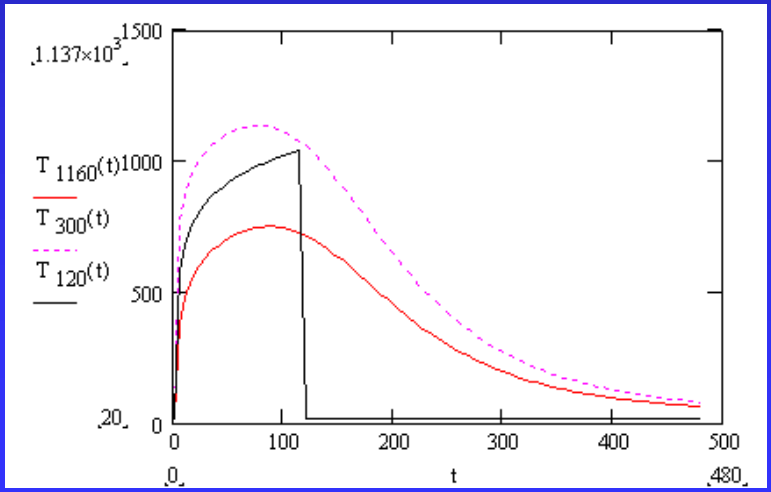
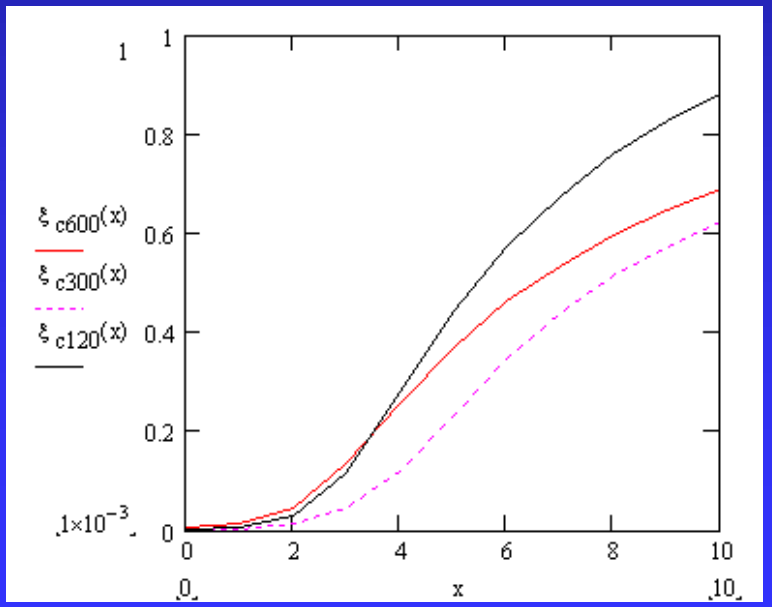


Temperature profile in depth cm



Temperature-Time Curvess min

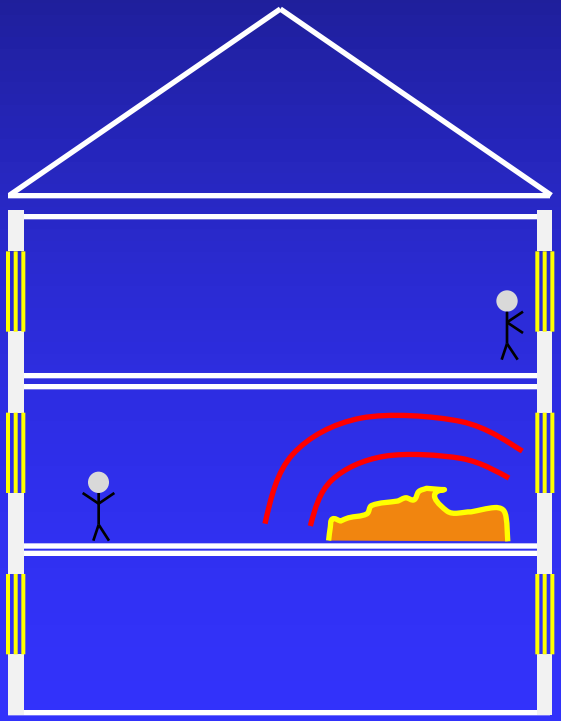


Strength Reduction of Prestressing Wires

Fire Resistance

Requirements:

- R 120 min if ≥ 12 m up or
-Parametric fire > R 120 min



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