KU LEUVEN

Structural reliability of temporary aluminium tented structures

9th of April 2019 – IStructE HQ London
Tom Molkens

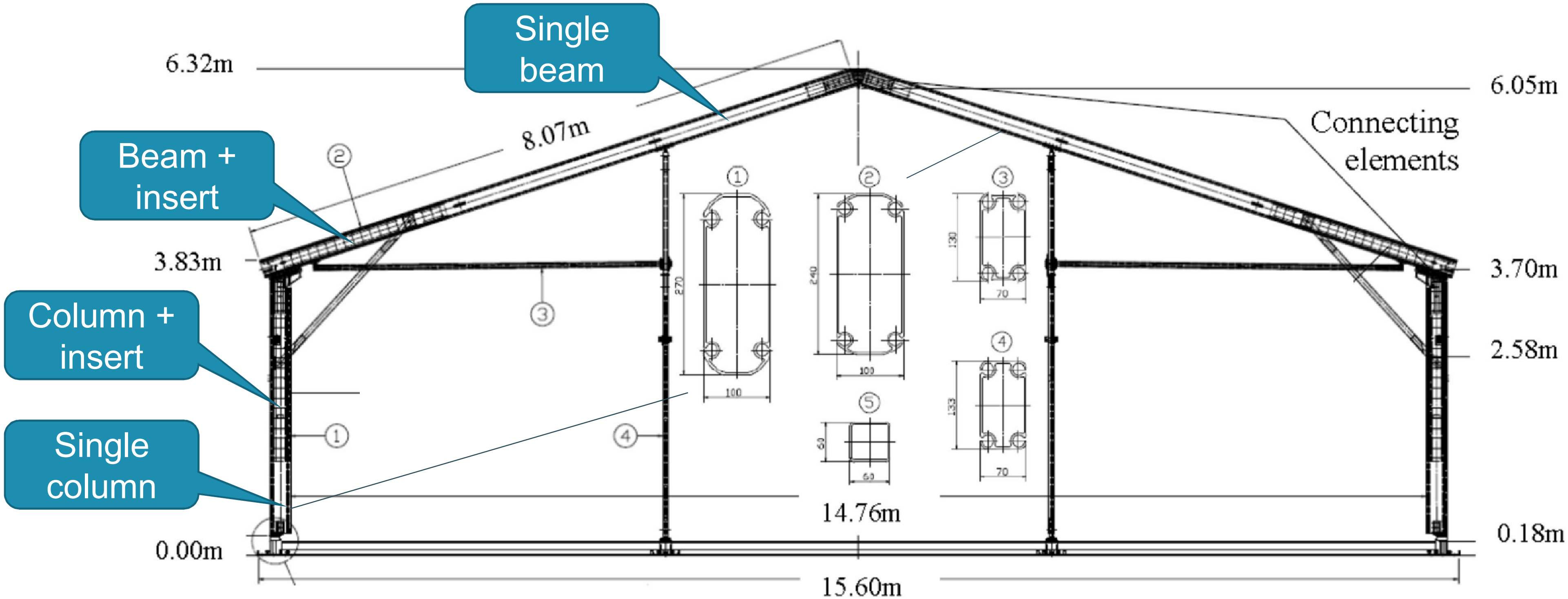
STRUCTURES IN FIRE FORUM

Tented structures

Some examples

Structural system

Typical cross-section for a 15 m span solution (highly concave sections)



Faculty of Industrial Sciences and Technology, Technology Cluster Construction, Campus De Nayer
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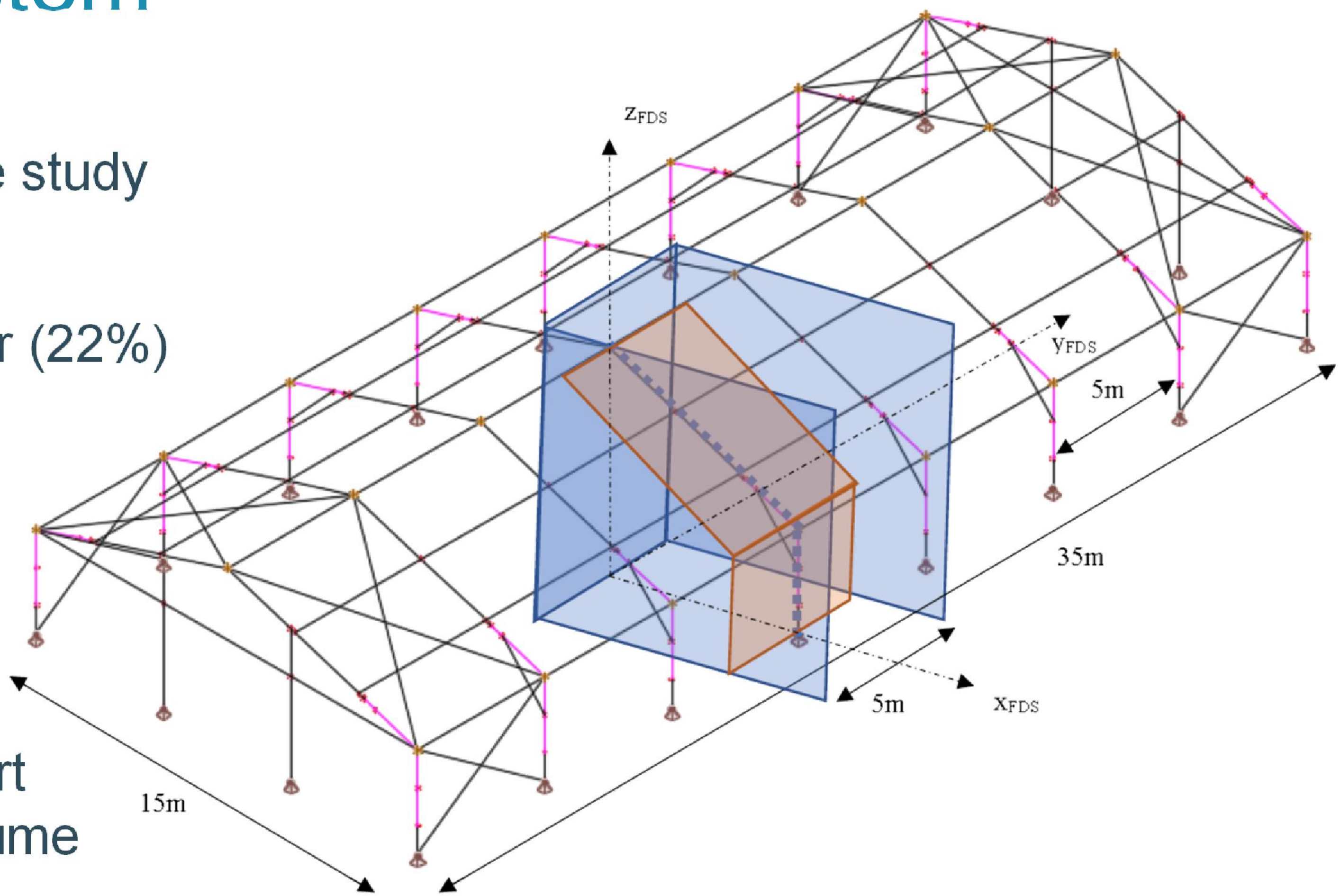
Structural system

Isometric view of case study

Outer skin = PES-fiber (22%) + PVC coating (78%), percentages refer to part of weight

Cell is highlighted equal to 1/7th by ½ part or 1/14th of global volume



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Structural system

Outer skin = canvas – softening temperature 200°C, melting @ 250°C

Out of tests no fire propagation with local fire, only melting of the canvas

+/- 650 gr/m² = 0,0065 kN/m²

CARACTERISTIQUES TECHNIQUES / *TECHNISCHE DATEN*

	Précontraint 502 S2-8604S	**Précontraint 702 S2-8604S**	**Normes / *Normen***
Fil / *Garn*	1100 dtex PES HT Traité anti-capillarité / *Anti docht-ausrüstung*	1100 dtex PES HT Traité anti-capillarité / *Anti docht-ausrüstung*	TERSUISSE
Poids / *Gewicht*	590 g/m²	750 g/m²	EN ISO 2286-2
Largeur / *Breite* Autres laizes disponibles : nous consulter / *Andere Breiten auf Anfrag*	250 / 267 cm	250 / 267 cm	
Résistance rupture (chaîne/trame) / *Reißkraft (Kette/Schuß)*	280/280 daN/5 cm	280/280 daN/5 cm	EN ISO 1421
Résistance déchirure (chaîne/trame) / *Weiterreißkraft (Kette/Schuß)*	28/28 daN	30/28 daN	DIN 53.363
Adhérence / *Haftung*	10/10 daN/5 cm	10/10 daN/5 cm	EN ISO 2411
Finition / *Schlußbehandlung*	Formule S2 vernis fluoré soudable / *Formel S2 fluorklack schweißbar*	Formule S2 vernis fluoré soudable / *Formel S2 fluorklack schweißbar*	
Transmission lumineuse / *Lichtdurchläßigkeit*	19%	13.5%	NFP 38 511
Réaction au feu / *Brennverhalten* 502S Translucide / *Transluzent*	**M2**/NFP 92-507 • **TEST 1**/NFPA 701 • CSFM T19 • **CLASSE A**/ASTM E84 • **B1**/DIN 4102-1 • BS 7837 • **1530.3**/AS/NZS • **Classe 1**/UNI 9177-87 • **M2**/UNE 23.727-90 • **VKF 5.3**/SN 198898 • Large scale CAN ULC S109 • **Schwerbrennbar Q1-Tr1**/ONORM A 3800-1 • **G1**/GOST 30244.94		
Réaction au feu / *Brennverhalten* 702S Translucide / *Transluzent*	**M2**/NFP 92-507 • **TEST 2**/NFPA 701 • CSFM T19 • **B1**/DIN 4102-1 • BS 7837 • **1530.3**/AS/NZS • SITAC/SINTEF/ETA/SIS 650082 • **Schwerbrennbar Q1-Tr1**/ONORM A 3800-1 • **M2**/UNE 23.727-90 • **VKF 5.3**/SN 198898 • **CLASSE 1**/UNI 9177 • CAN ULCS 109 • CAN ULCS 102 • **G1**/GOST 30244.94		
Euroclasse / *Euroklasse*			**B-s2,d0**/EN 13501-1
Températures extrêmes d'utilisation / *Maximale anwendungstemperaturen*	-30°C/+70°C	-30°C/+70°C	
Système de management de la qualité / *Qualitätsmanagement*			ISO 9001

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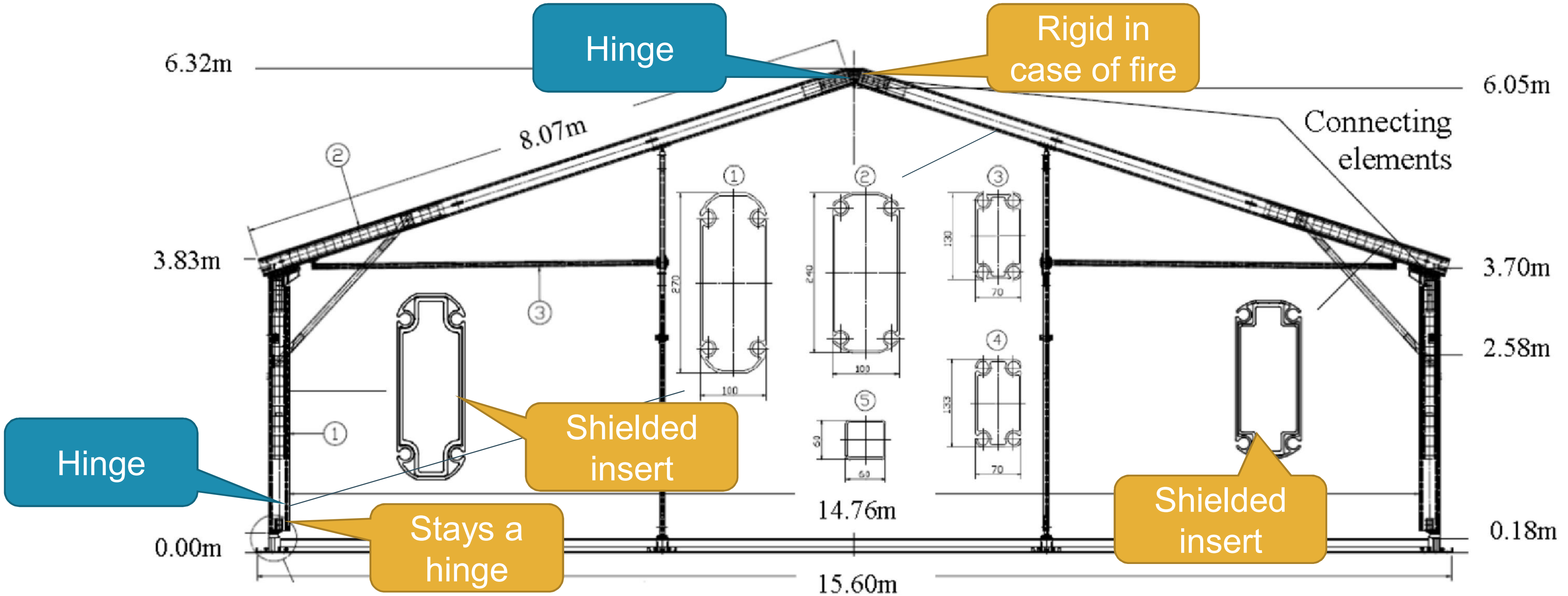
Structural system

Behaviour in ambient conditions / in case of fire



Codes

European code for temporary and tent structures

- EN13782 (2015): Temporary structures – Tents – Safety
- Reduction of (snow)loads and fire extinghuisers …

American code ASCE7-16 allows a decreased design period

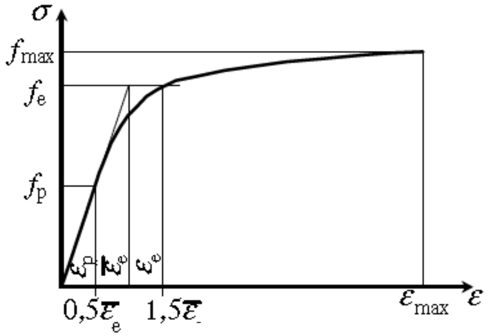
- ASCE/SCI 7-16 (2016): Minimum design loads and associated criteria for buildings and other structures

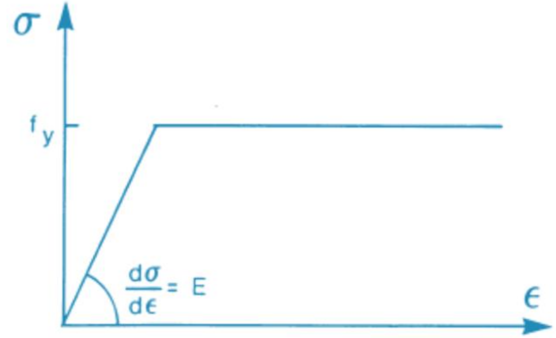
Decreasing the design period = allowing a higher risk of failure. Is this the best practice for a funfair with over to 5000 people in a temporary structure (CC3) ?

Aluminium

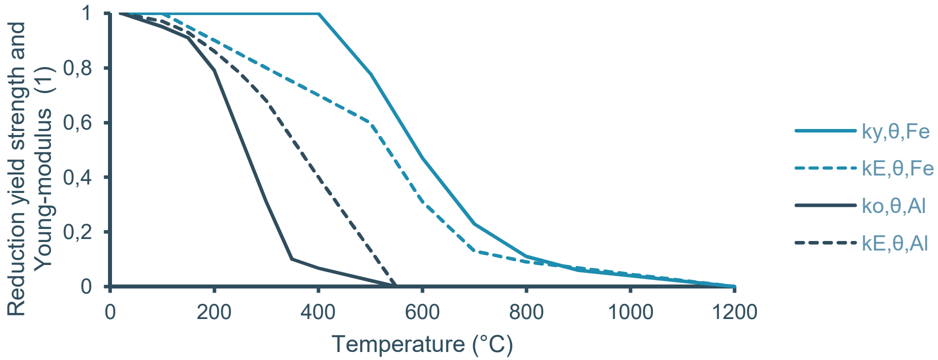
EN-AW6061_T6, extruded profiles versus steel (as comparison)

- Ambient





- Fire



Fire scenario

- Transfer from fire in an enclosure to an open fire

Uniform temperature over compartment → Dissepearing enclosures → Realistic temperature distribution ? → Local fire approach

Nominal fires with fixed temperature-time relation: R in time & θ-domain

Depending on possibilities all to max 78% (Ozone) of roof surface

Two-zone model approach? Hot top layer Uniform $q_{fi,d}$

FDS-model from 1/14th of the volume. Opening = f(θ) Wooden block

Fire scenario

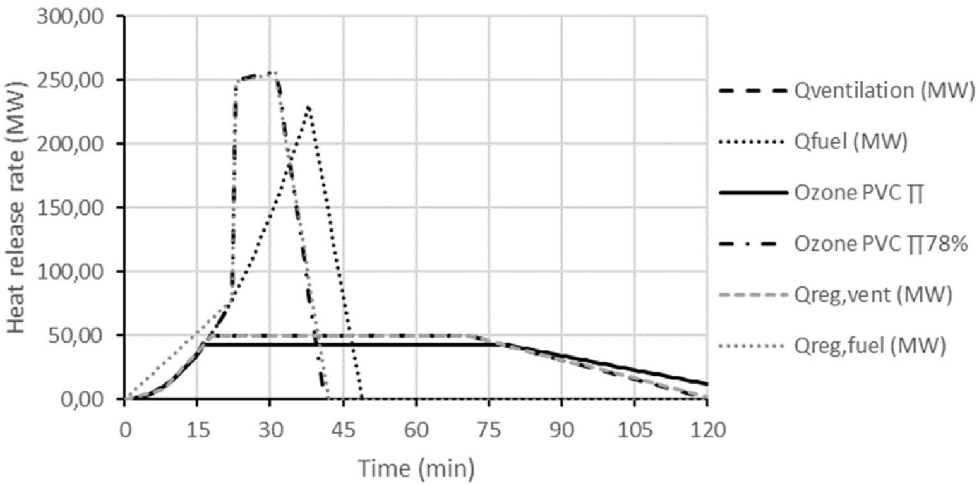
Estimation of heat release rate (HRR); EN 1991-1-1 annex E:

- Theatre; $q_{fi,d}$=365 MJ/m² & t_{α}=150s
- Fuel-controlled:

$$Q = \left(\frac{t}{t_\alpha}\right)^2 \cdot 10^6$$

- Ventilation controlled:

$$Q_{max} = m \cdot H_u \cdot A_v \cdot \sqrt{h_{eq}}$$



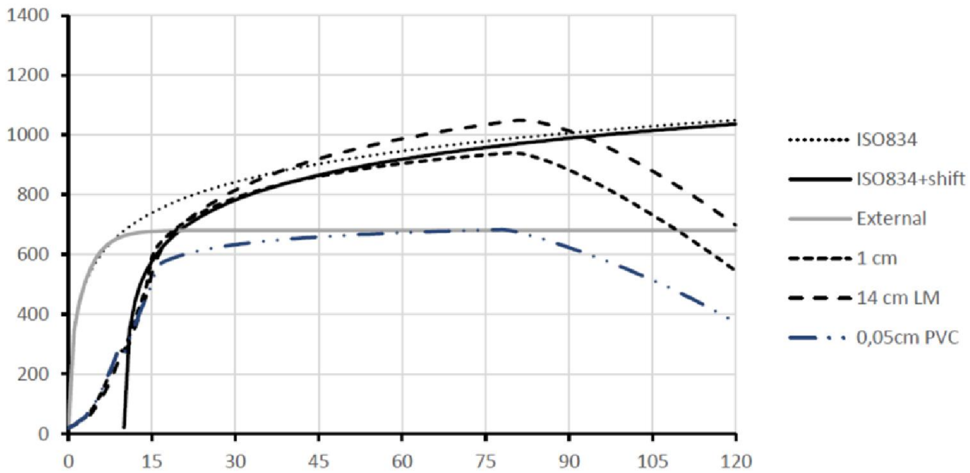
- Ozone (max 78% roof opening)

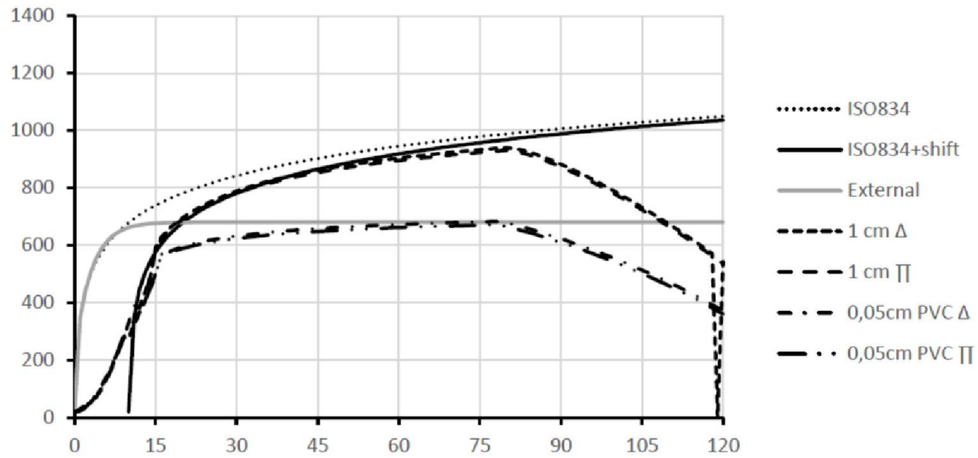
→ Worst case scenario = to conservative ?

Fire scenario

Nominal fire as reference (ISO and External) & two zone model - Ozone 3.04:

- Influence thin outer skin (1 or 14 cm light masonry and 0,5 mm canvas)
- Double pitch (Δ) do not allow roof openings →Beam shape (Π) with same V&O

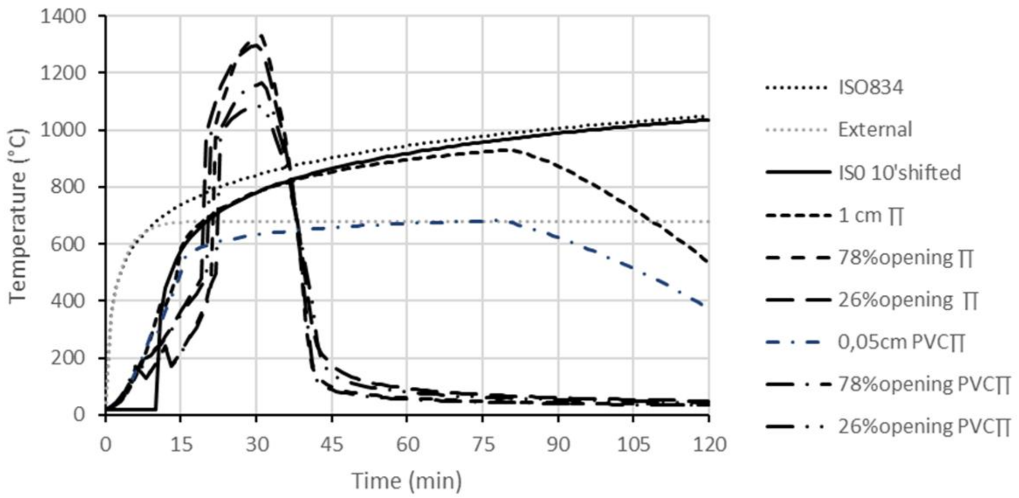




Fire scenario

Nominal fire as reference (ISO and External) & two zone model - Ozone 3.04:

- Roof full of circular openings = maximum of π/4 or 78%
- To verify sensibility a simulation with 26% is also worked out (1/3rd)

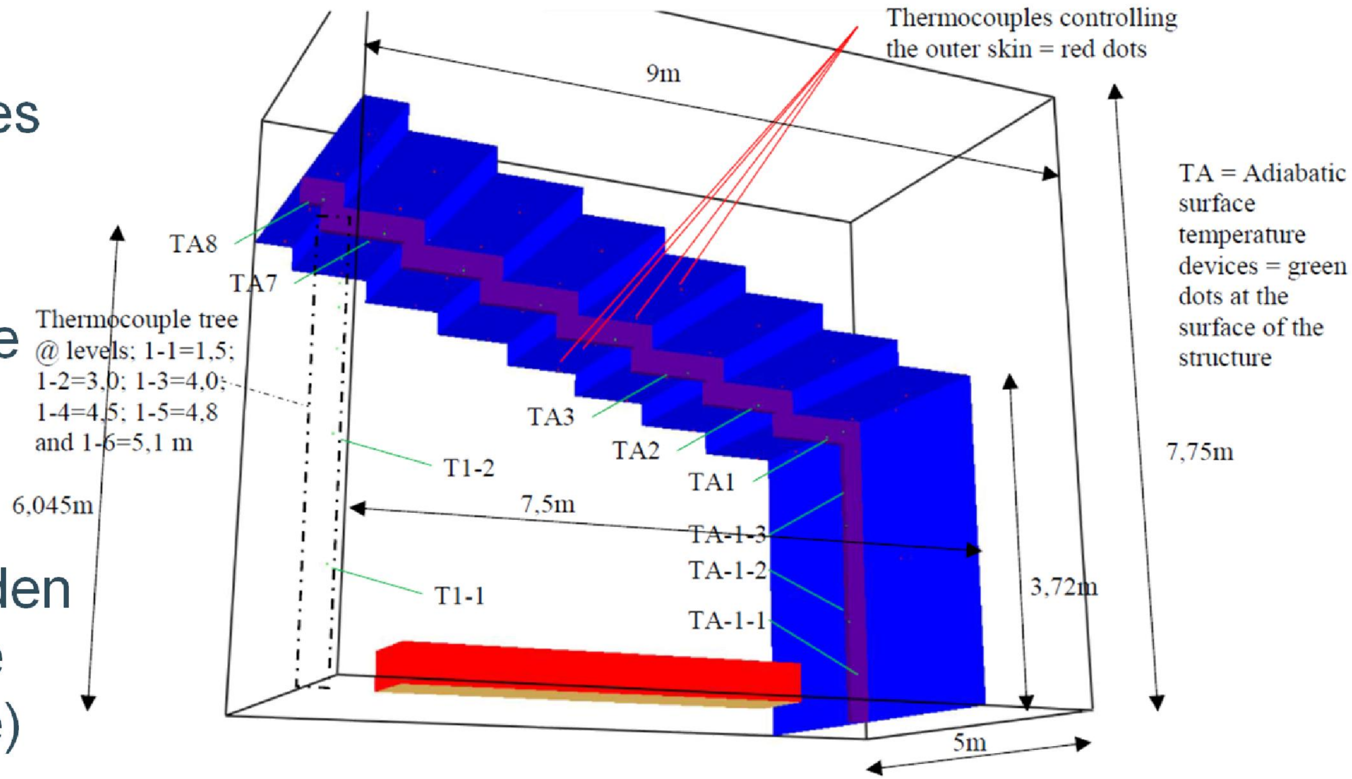


- Influence of material becomes irrelevant with roof openings (for metallic structures).
- Minor difference between 26 or 78% of roof openings
- Shifted ISO fire becomes useless

Fire scenario

FDS 6.7 model

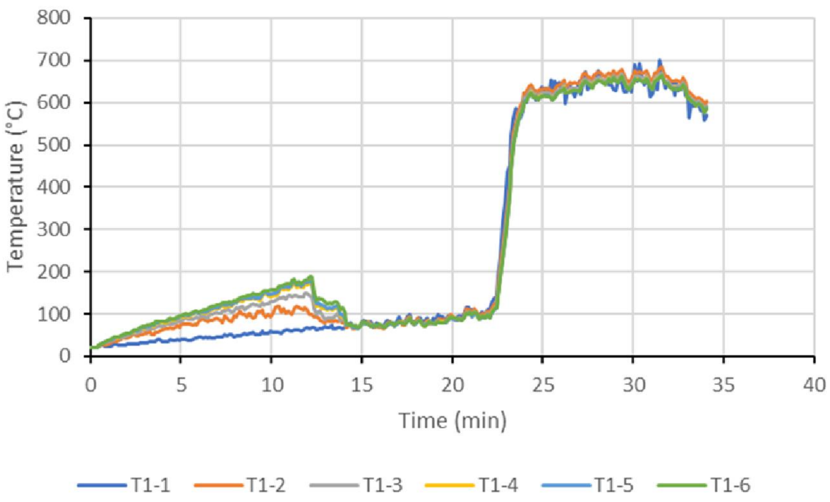
- Thermocouple devices to control opening outer skin
- Adiabatic on structure
- Thermocouple tree
- Fire load of theatre concentrated in wooden beam volume (no fire at the bottom surface)

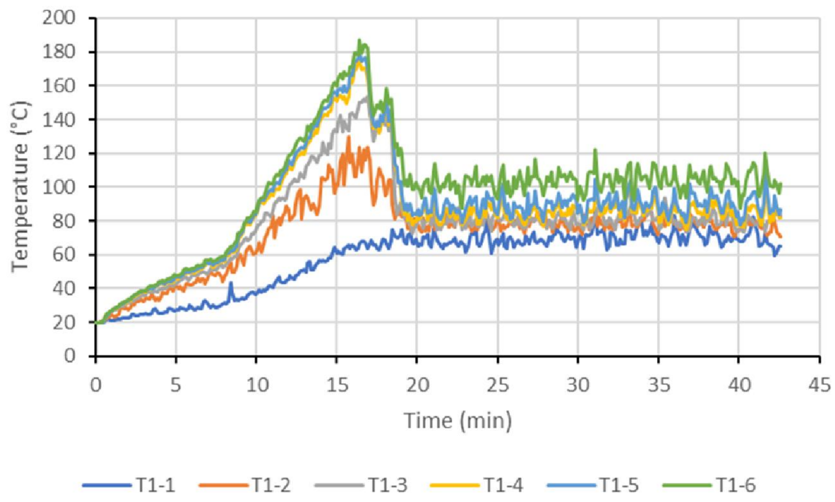


Fire scenario

FDS 6.7 model – results of temperature tree

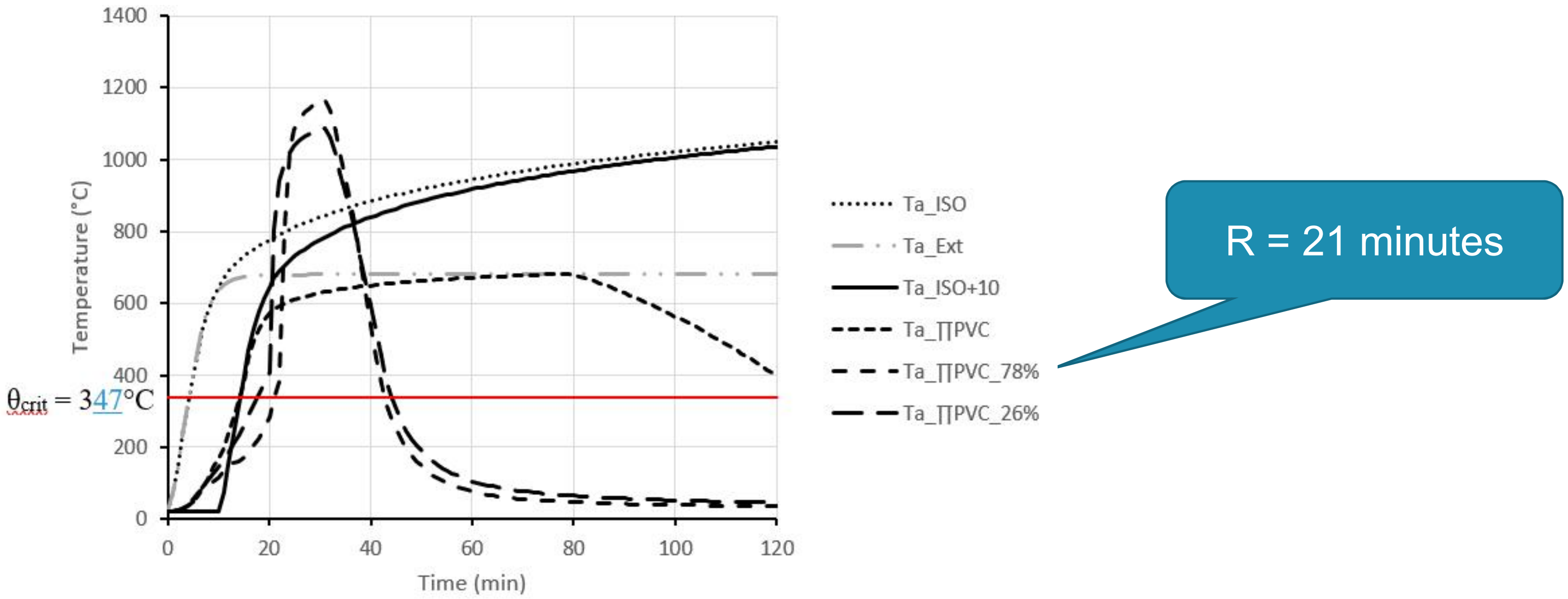
Fuel-controlled and Ventilation-controlled





Thermal response

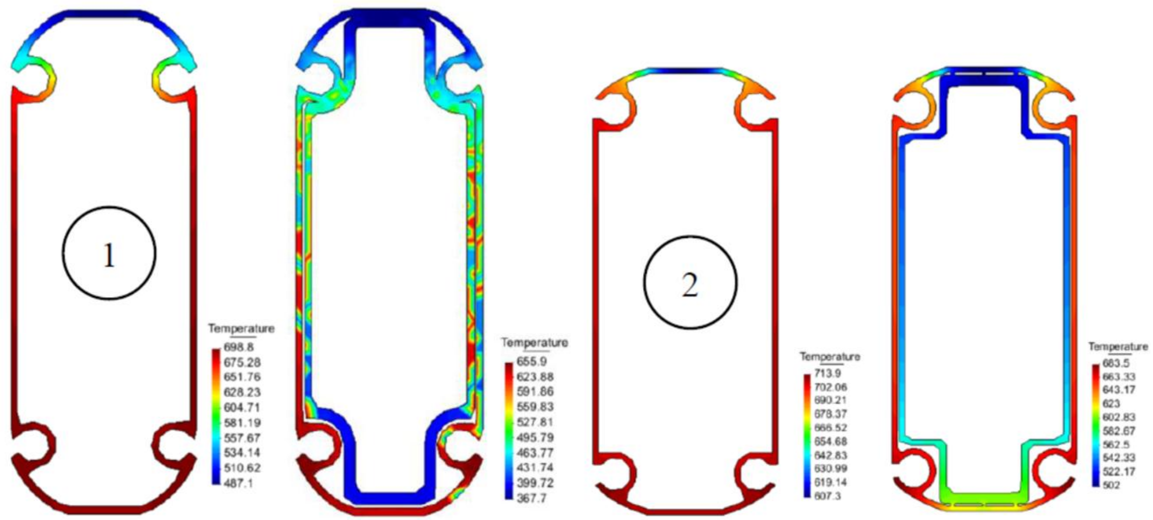
- With nominal fires and Ozone → EN1999-1-2 with uniform heating



→ verification in temperature domain, based on element verification

Thermal response

- Concave sections subjected to 15 min of ISO fire

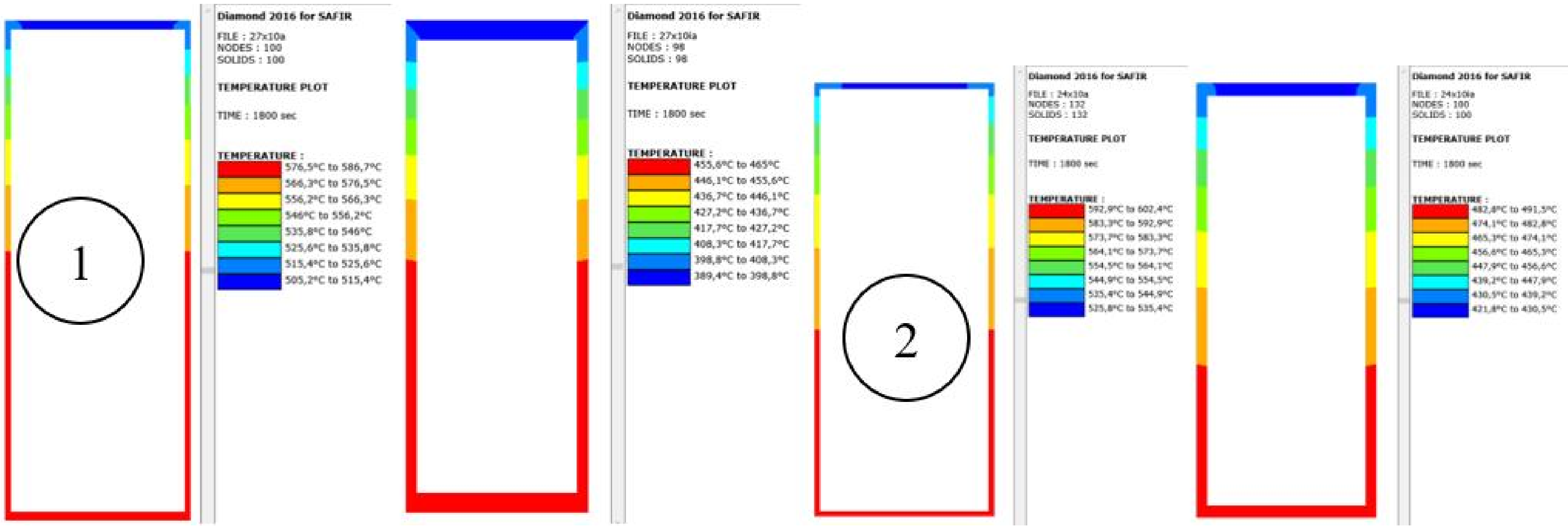


→ geometrical properties ?

→ postprocessing ?

Thermal response

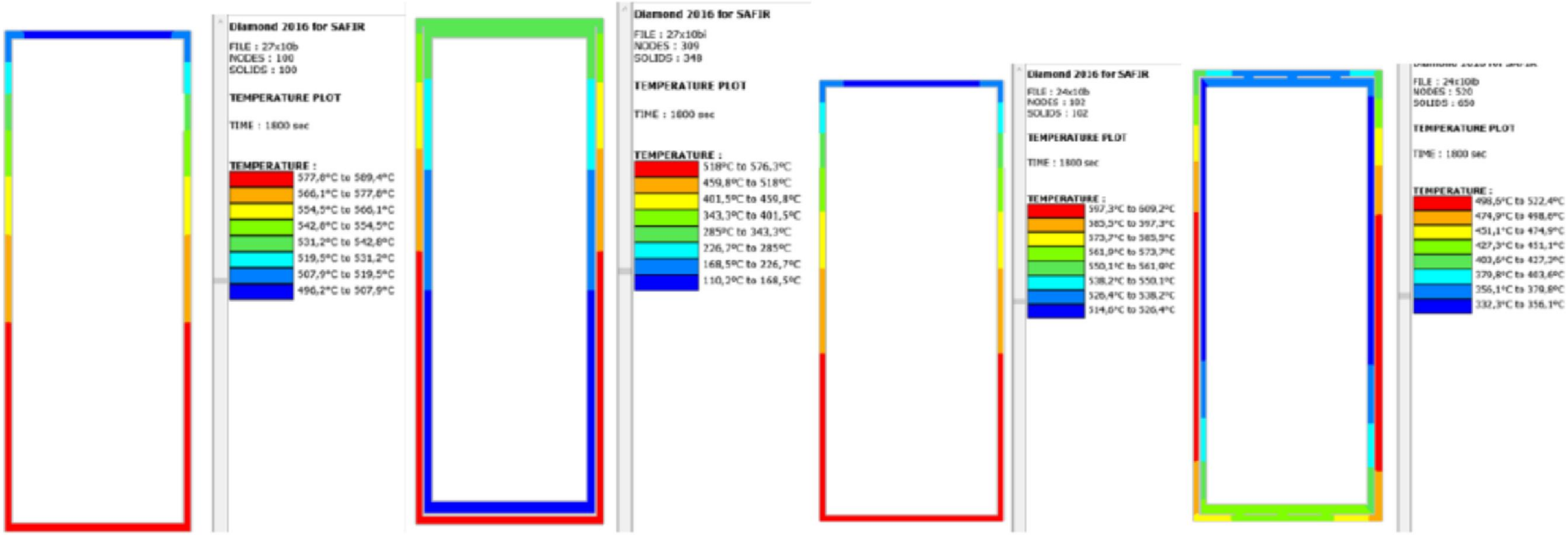
- Simplification to a single RHS (with equal geometrical properties)



587°C 465°C 602°C 492°C

Thermal response

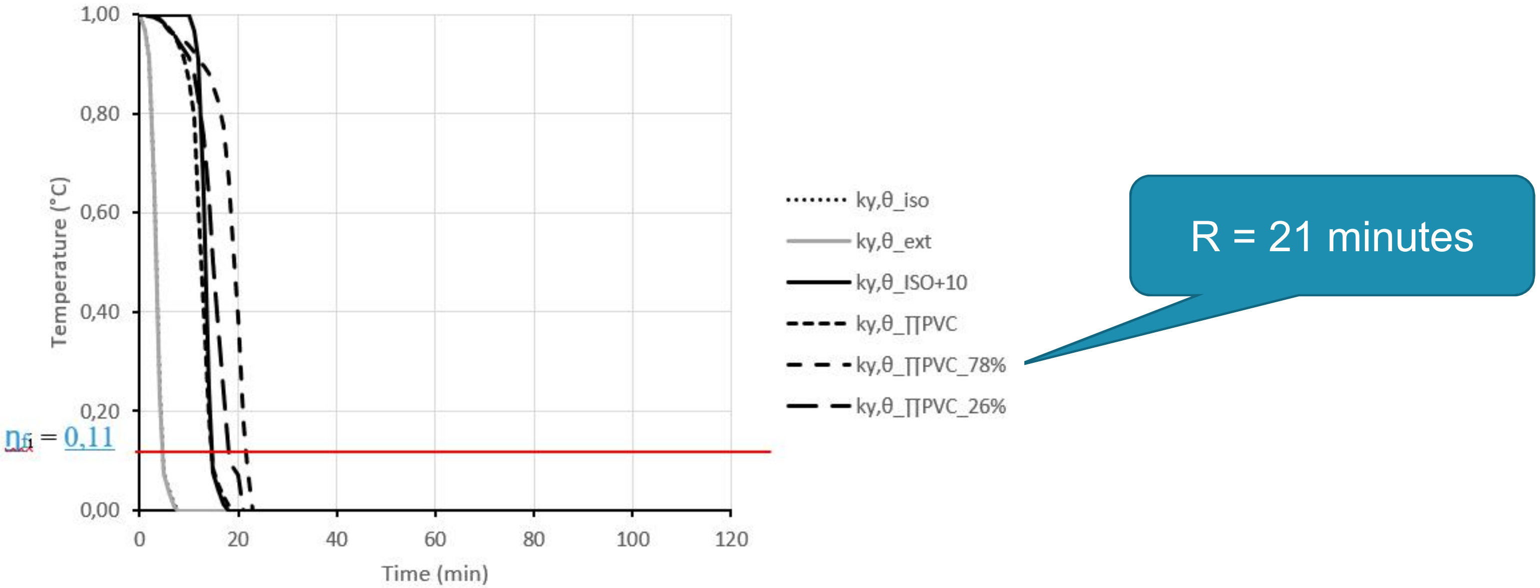
- Simplification to a double RHS (outer + insert)



589°C	576°C	609°C	522°C

Mechanical response

- With nominal fires and Ozone → EN1999-1-2 with uniform heating



- Based on element approach

Mechanical response

- Simplification to a single RHS (with equal geometrical properties)

Property	Column			Column + insert			Beam			Beam + insert		
	Real	App.	ratio	Real	App.	ratio	Real	App.	ratio	Real	App.	ratio
Surface (mm²)	3113	2560	0,82	6367	5176	0,81	2254	2004	0,89	4533	4112	0,91
Inertia (cm⁴)	2719	2635	0,97	5268	5217	0,99	1589	1483	0,93	3145	3055	0,97
Elastic section modulus (cm³)	201	195	0,97	390	386	0,99	132	124	0,94	262	255	0,97
Plastic section modulus (cm³)	265	234	0,88	525	469	0,89	171	153	0,90	342	316	0,92

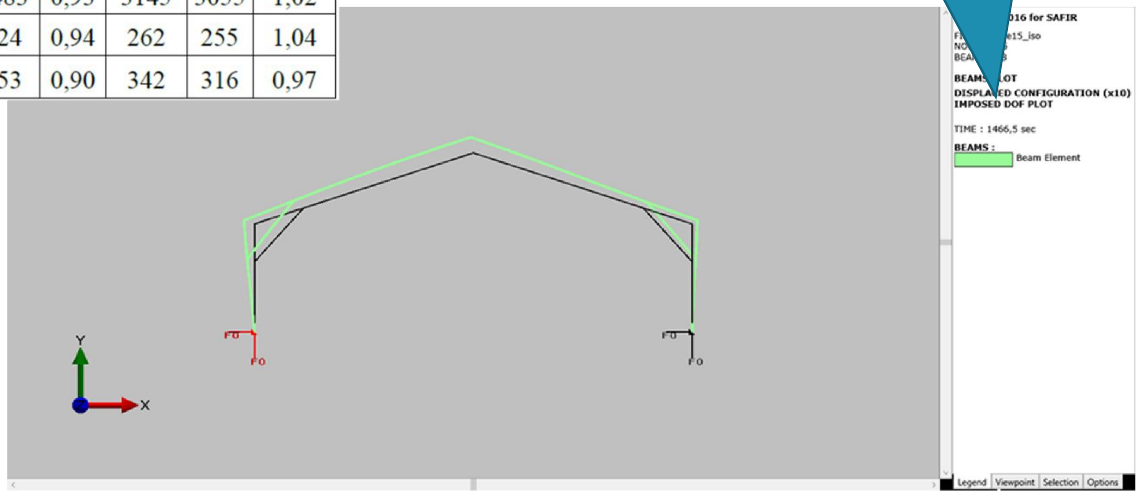
R = 25 minutes

Mechanical response

- Simplification to a double RHS (outer + insert)

Property	Column			Column + insert			Beam			Beam + insert		
	Real	App.	ratio	Real	App.	ratio	Real	App.	ratio	Real	App.	ratio
Surface (mm^2)	3113	2634	0,85	6367	5710	0,90	2254	2004	0,89	4533	4112	0,94
Inertia (cm^4)	2719	2464	0,91	5268	5243	1,00	1589	1483	0,93	3145	3055	1,02
Elastic section modulus (cm^3)	201	183	0,91	390	388	1,00	132	124	0,94	262	255	1,04
Plastic section modulus (cm^3)	265	227	0,85	525	488	0.93	171	153	0,90	342	316	0,97

R = 24,4 minutes



Conclusions

- Small difference in failure time between Ozone and FDS can be explained due to the application of the same HRR, nevertheless a benefit of about 4 minutes could be found.
- The simplification of a section with an insert by the mean of a single section with a higher wall thickness can lead to an overestimation of the fire resistance. The outer part becomes hotter, will fail earlier while the inner part is not anymore capable to withstand the loads.
- A fire resistance of 25 minutes was achieved by the mean of the heat release rate calculated by Ozone (worst case scenario). The application of the EN1991-1-2 formulation will deliver higher rates as the HRR develops slower.

To be continued…

What we're doing together with John Hopkins University (Thomas Gernay)

- Effective stress method to deal with class 4 sections
- Direct coupling between FDS and SAFIR
- Effect thermal creep ?
- …

With Veldeman group and Serge Ferrari ?

- Real scale test to find out the "real" HRR and aluminium temperatures
- …