VETROLIGNUM Workshop – 15/02/2019
University of Zagreb – Faculty of Civil Engineering

Structural Glass Systems under Fire: Overview of Design Issues, Experimental Research and Developments

UNIVERSITÀ DEGLI STUDI DI TRIESTE

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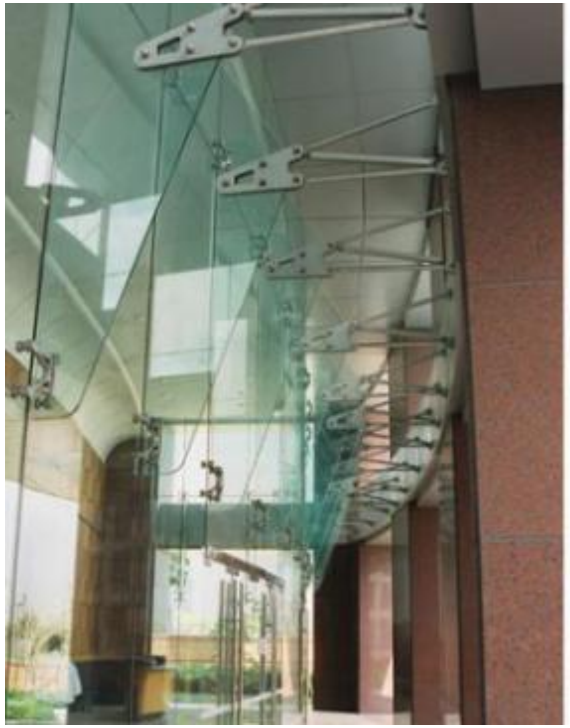
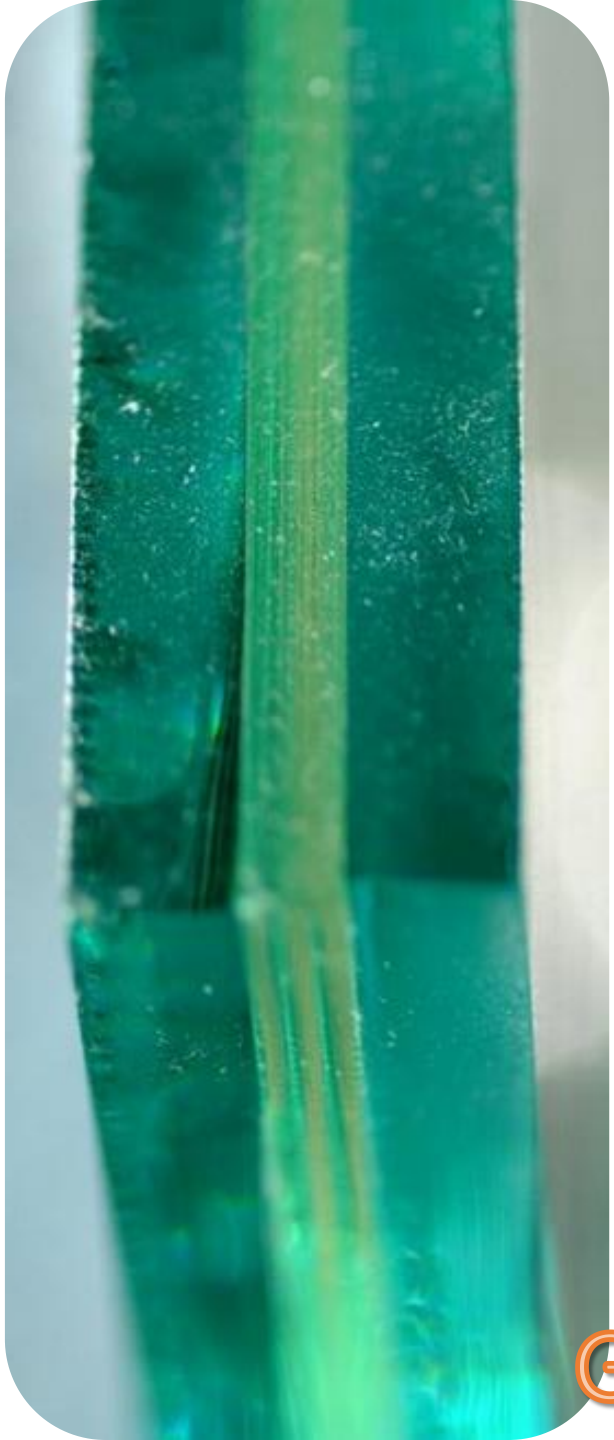
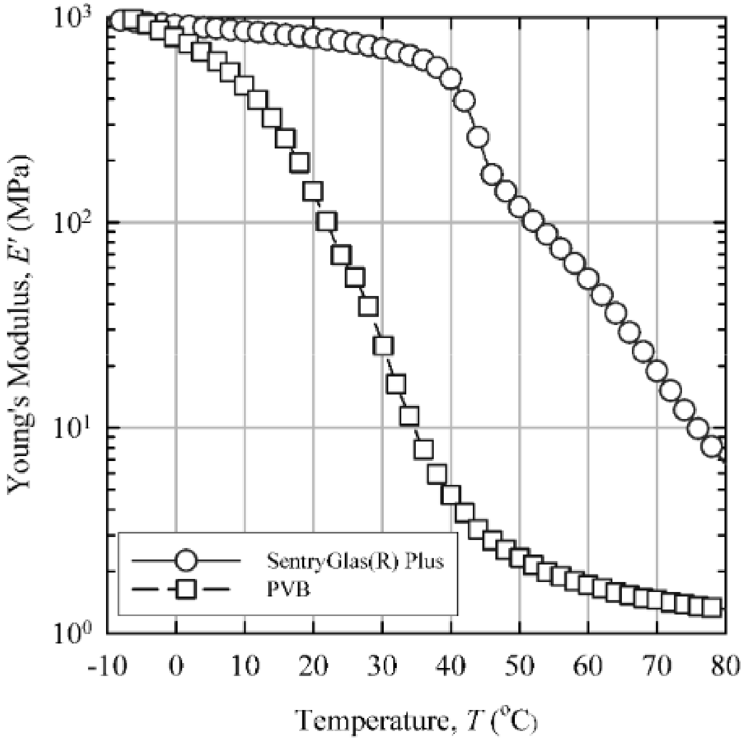
Introduction



Glass structures under ordinary temperatures

Glass structures under ordinary temperatures





KEY MECHANICAL PROPERTIES:

➢ GLASS
- MOE
- Tensile resistance
- Compressive resistance (local effects)

➢ INTERLAYERS
- Reference MOE (load duration)
- Temperature effects
- Other local/long term aspects

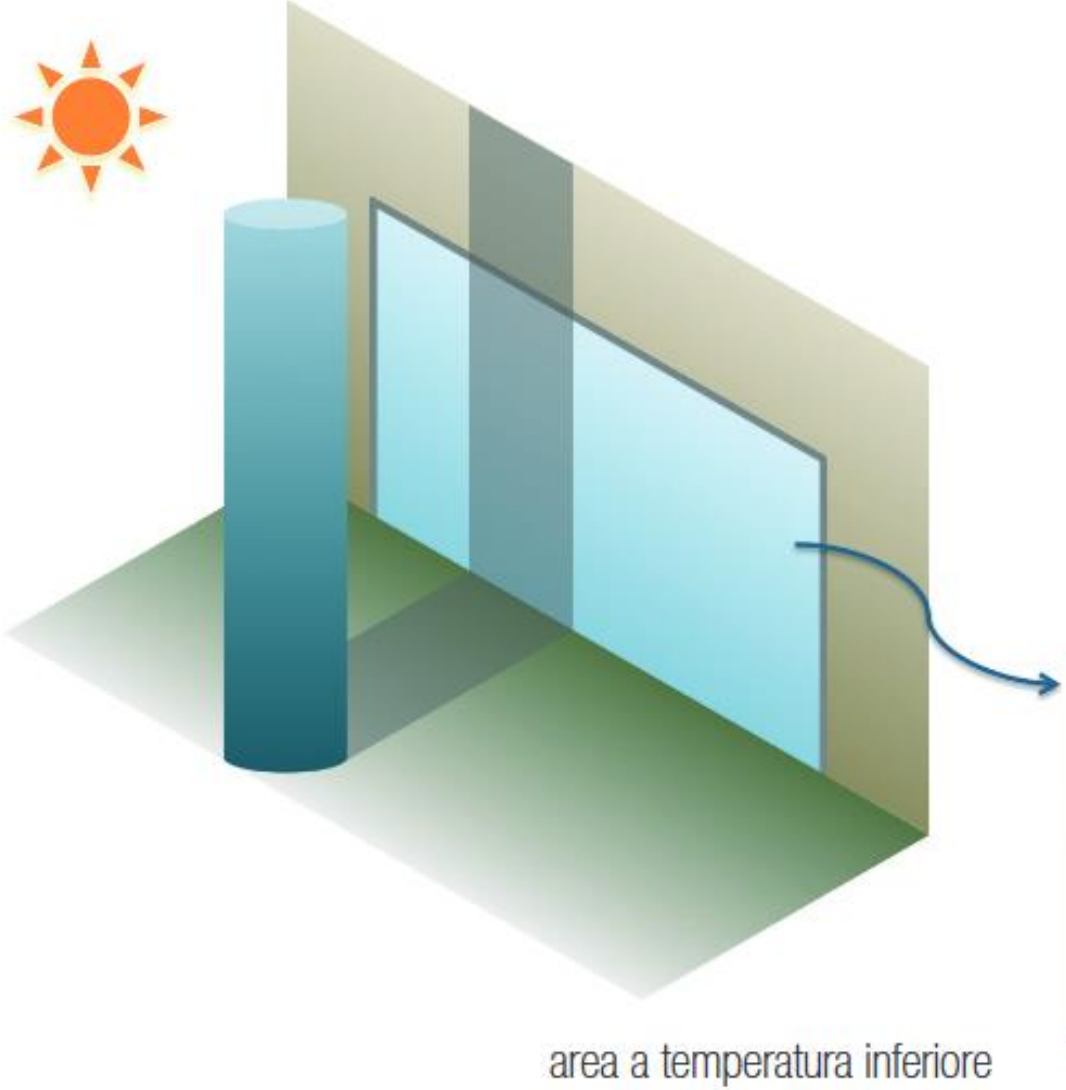
➢ CONNECTIONS

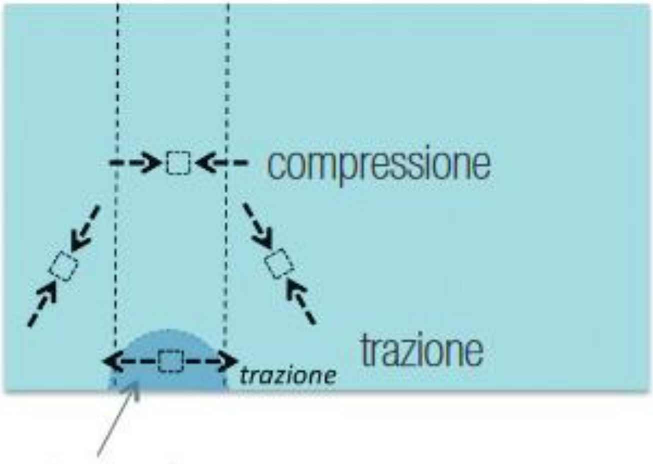
Mechanical? Adhesives? Materials? Etc.

Glass structures under ordinary temperatures

Glass structures under thermal loads

Glass structures under thermal loads



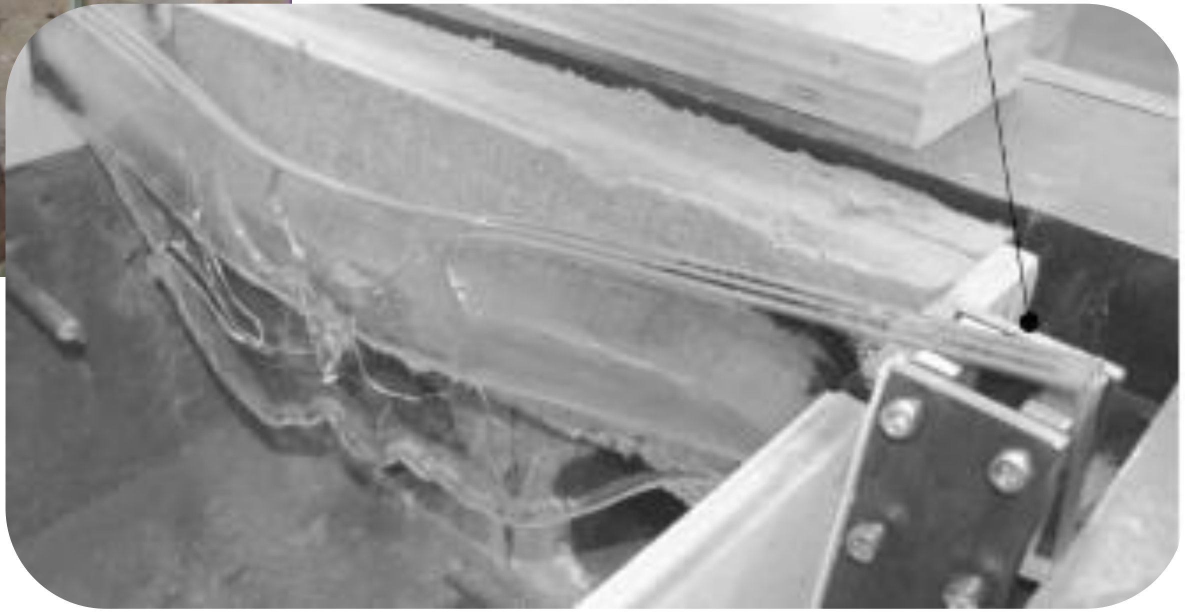


Thermal shock

Glass structures under thermal loads

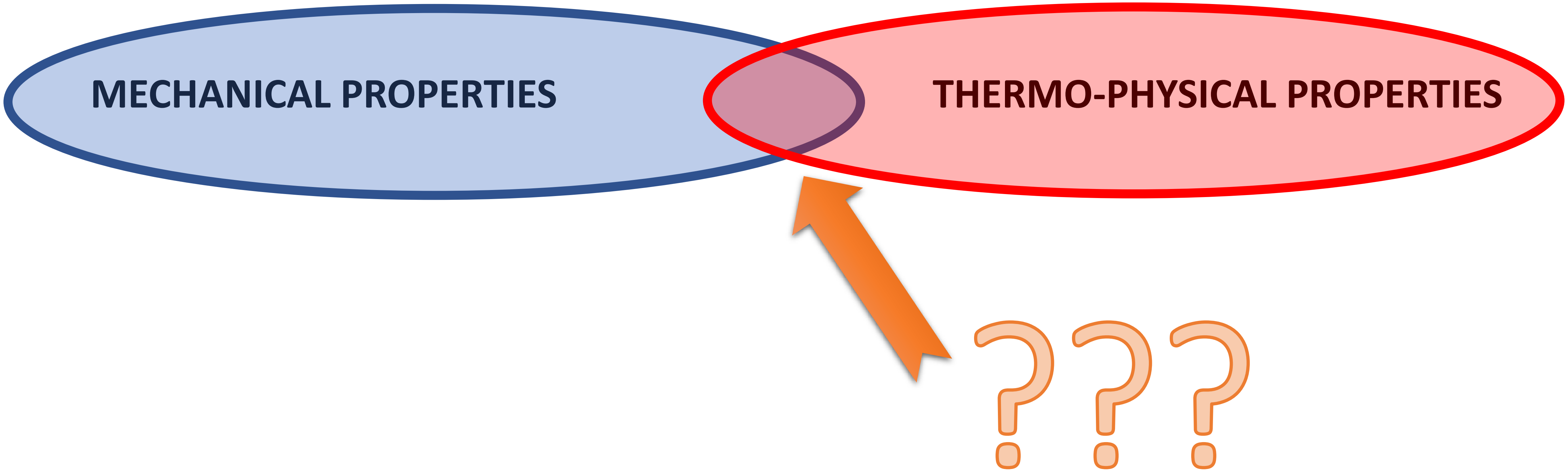
Facades in fire conditions

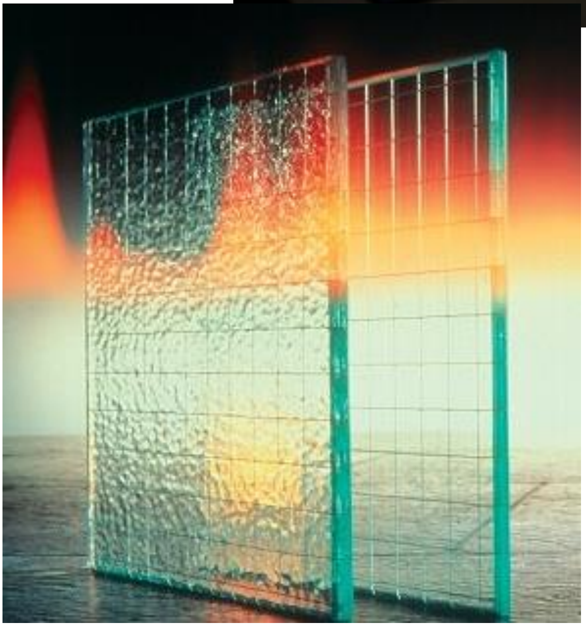
Glass structures under thermal loads



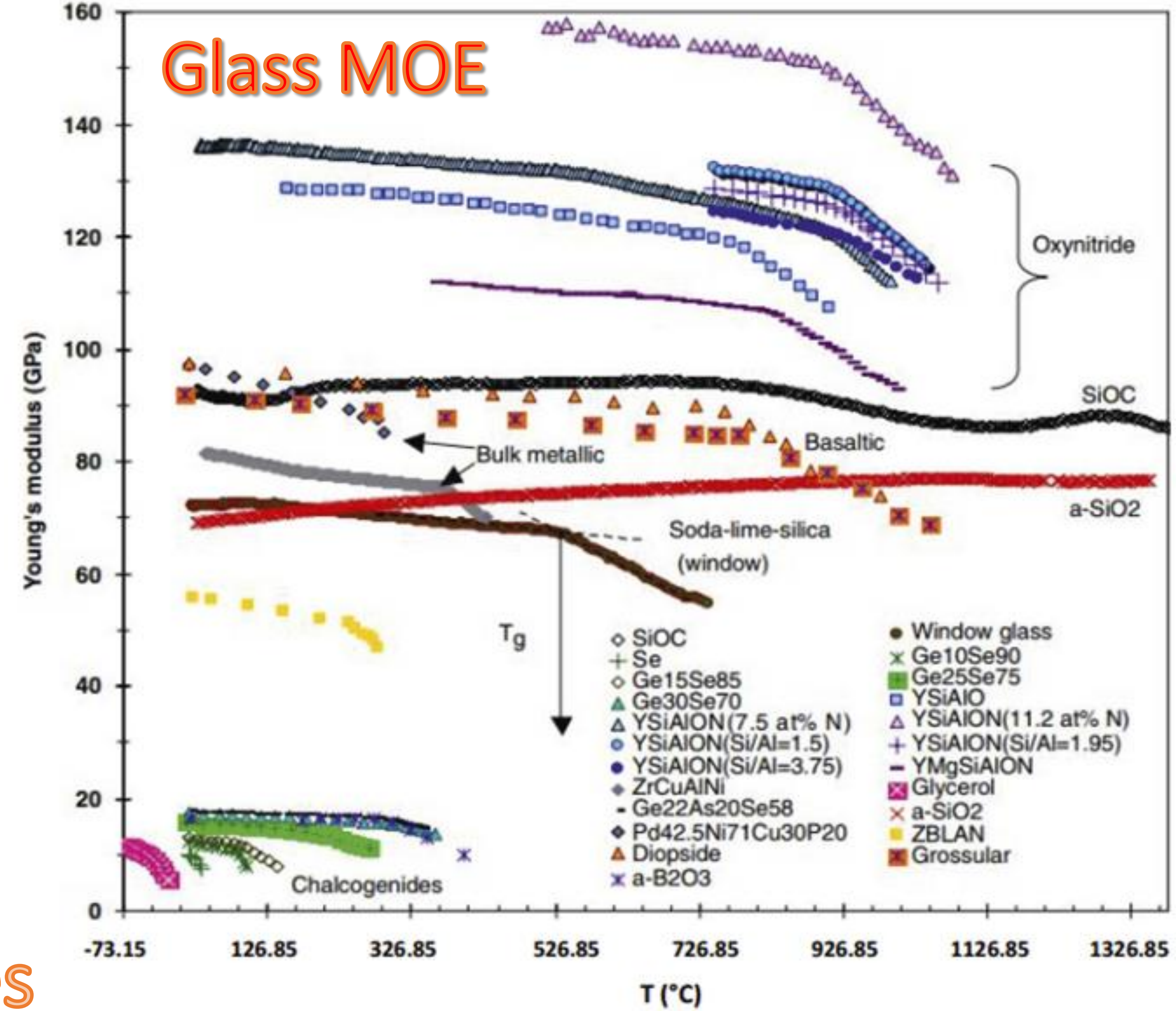
Load-bearing elements in fire conditions

Glass structures under thermal loads



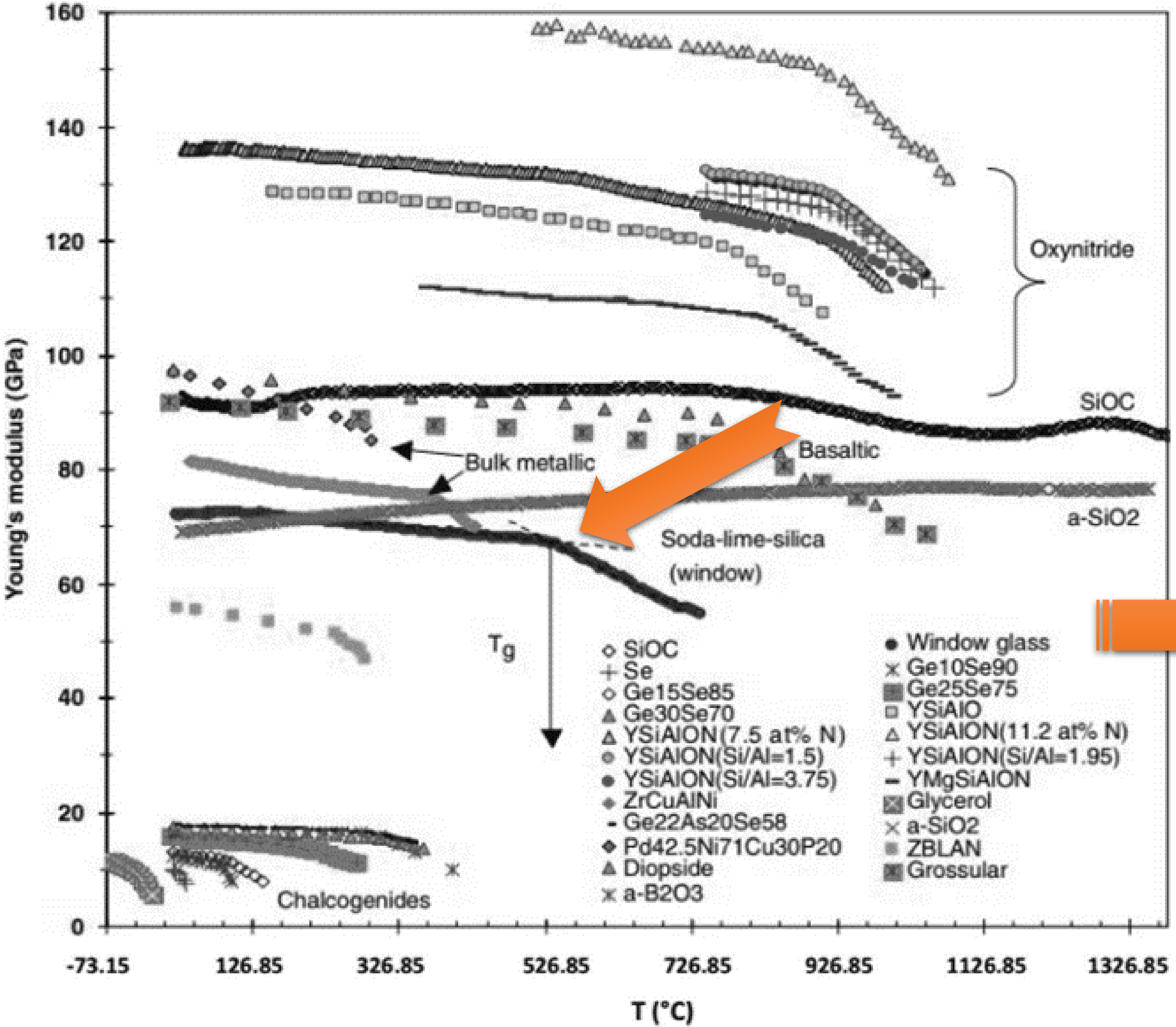


Glass MOE

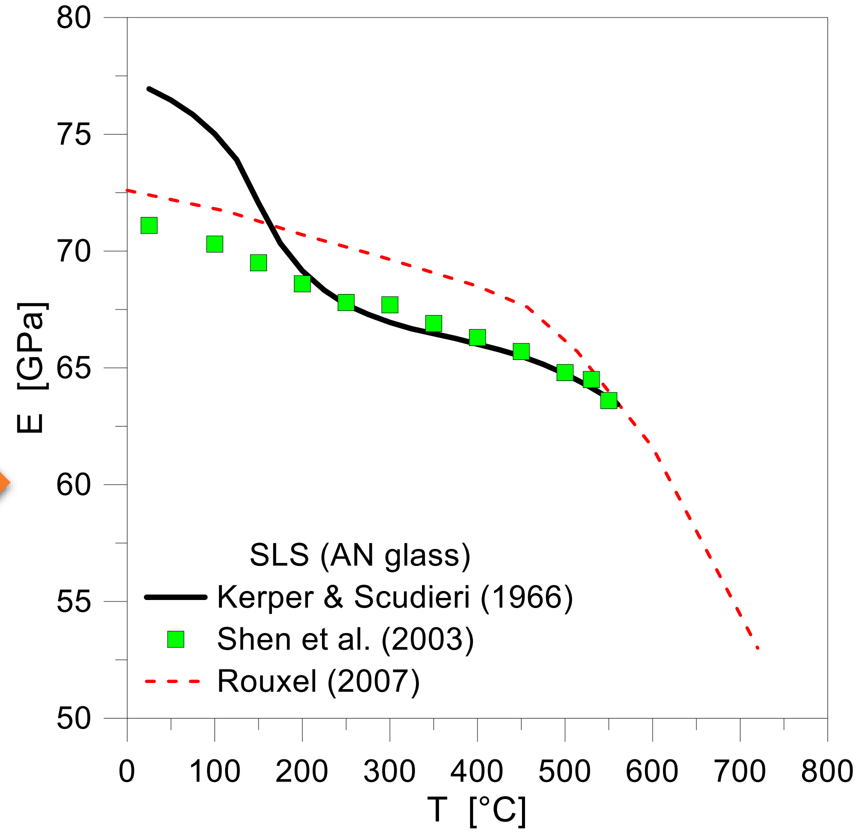


Material properties

Glass MOE

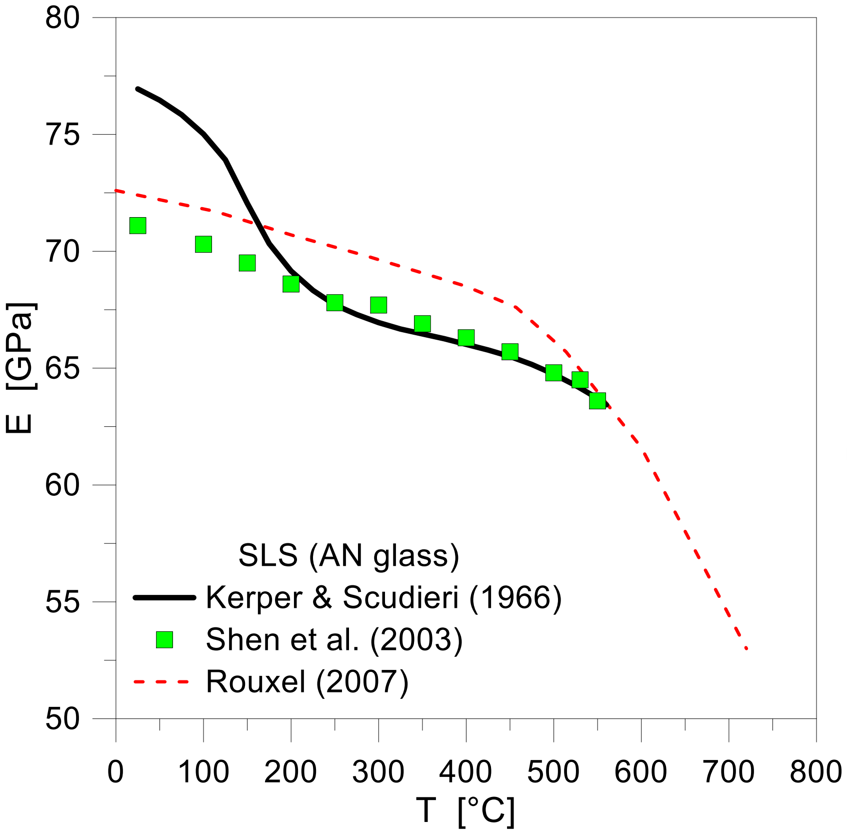


Young's modulus (GPa)
T (°C)
Oxynitride
SiOC
Basaltic
Bulk metallic
a-SiO2
Soda-lime-silica
(window)
Tg
Chalcogenides
SiOC
Se
Ge15Se85
Ge30Se70
YSiAlON(7.5 at% N)
YSiAlON(Si/Al=1.5)
YSiAlON(Si/Al=3.75)
ZrCuAlNi
Ge22As20Se58
Pd42.5Ni71Cu30P20
Diopside
a-B2O3
Window glass
Ge10Se90
Ge25Se75
YSiAlO
YSiAlON(11.2 at% N)
YSiAlON(Si/Al=1.95)
YMgSiAlON
Glycerol
a-SiO2
ZBLAN
Grossular



E [GPa]
T [°C]
SLS (AN glass)
Kerper & Scudieri (1966)
Shen et al. (2003)
Rouxel (2007)

Glass RESISTANCE



Glass MOE

&

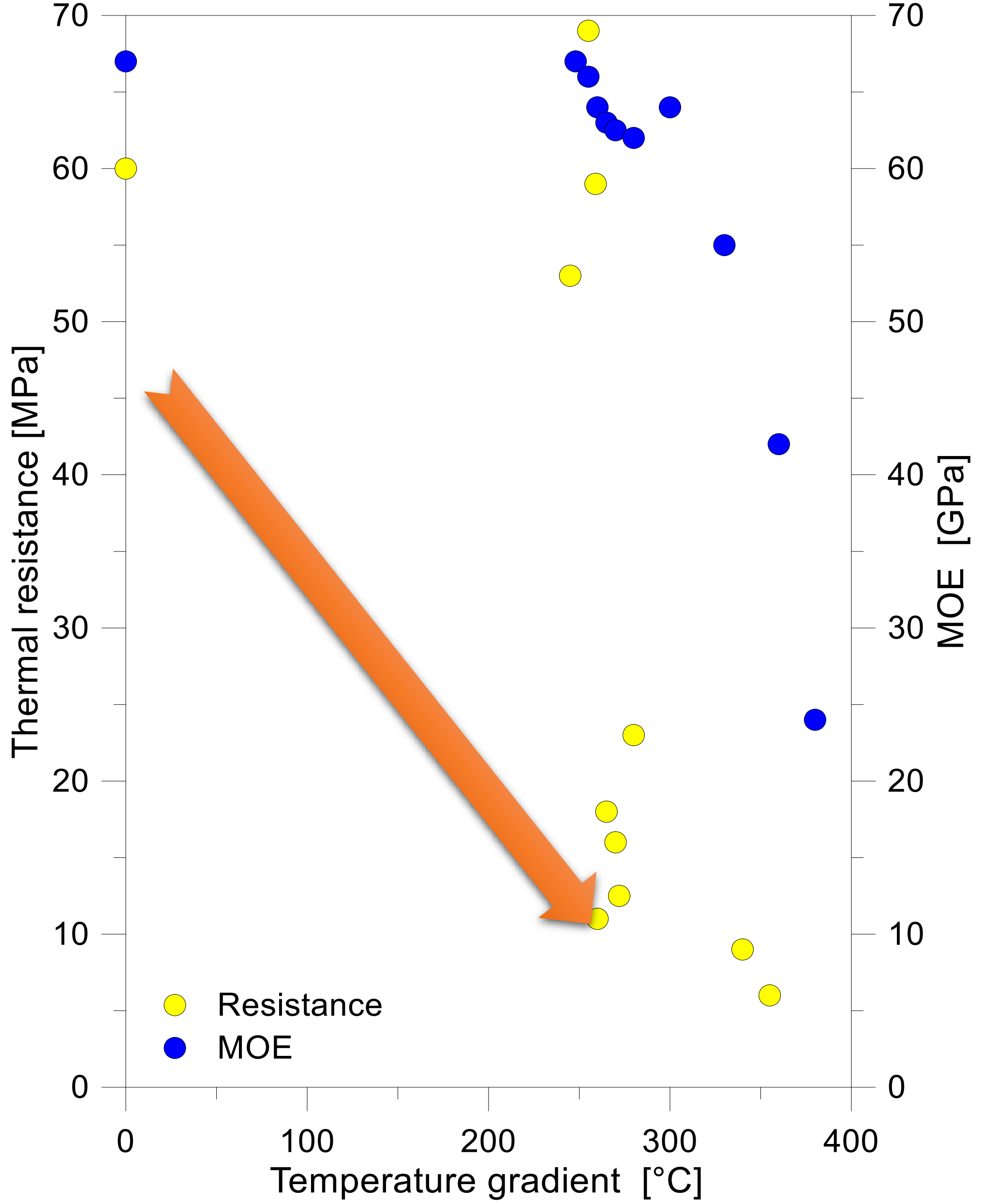
- FEW experimental data of literature are available to assess the **tensile resistance variation** of ordinary glass
- Based on Kerper & Scudieri (1966) on HS and FT glass:
  - ➢ no losses for temperatures up to 375C (less than 5% variation, compared to room temperature), for FT specimens
  - ➢ substantial decrease for temperatures higher than 500C (fire exposure of several hours) and 550C (15 minutes of fire exposure)
  - ➢ Chemically HS glass showed a pronounced resistance degradation with the temperature increase, up to 5% loss at 200C (500 hours of fire exposure), 5.8% at 260C (500 hours) and 100% at 600C (6 hours).
- NO experimental data are available to assess the **compressive resistance** of glass under fire / heating

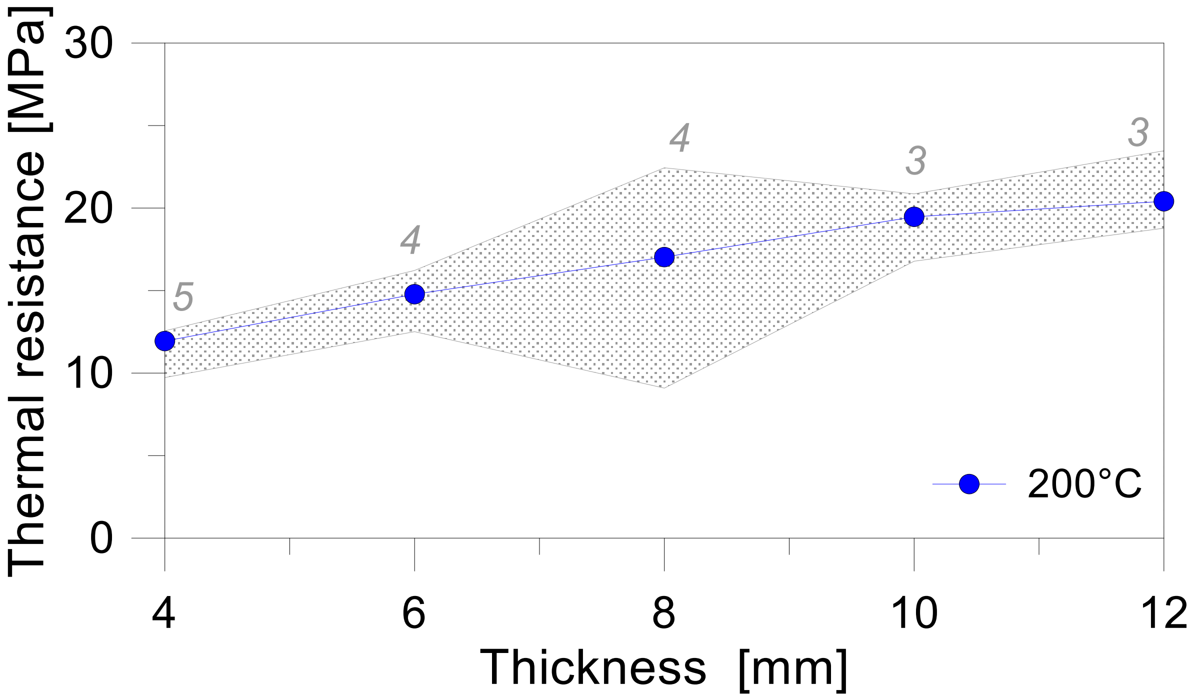
Glass THERMAL RESISTANCE....based on standards

GLASS TYPE	LIMIT VALUES (°C)		
	As-cut or arrissed	**Smooth ground**	**Polished**
Float or sheets ≤12mm thick	35	40	45
Float 15mm or 19mm thick	30	35	40
Float 25mm thick	26	30	35
Patterned	26		
Wired patterned or polished wired glass	22		
Heat strengthened	100		
Tempered	200		
Laminated	Smallest value of the component panes		

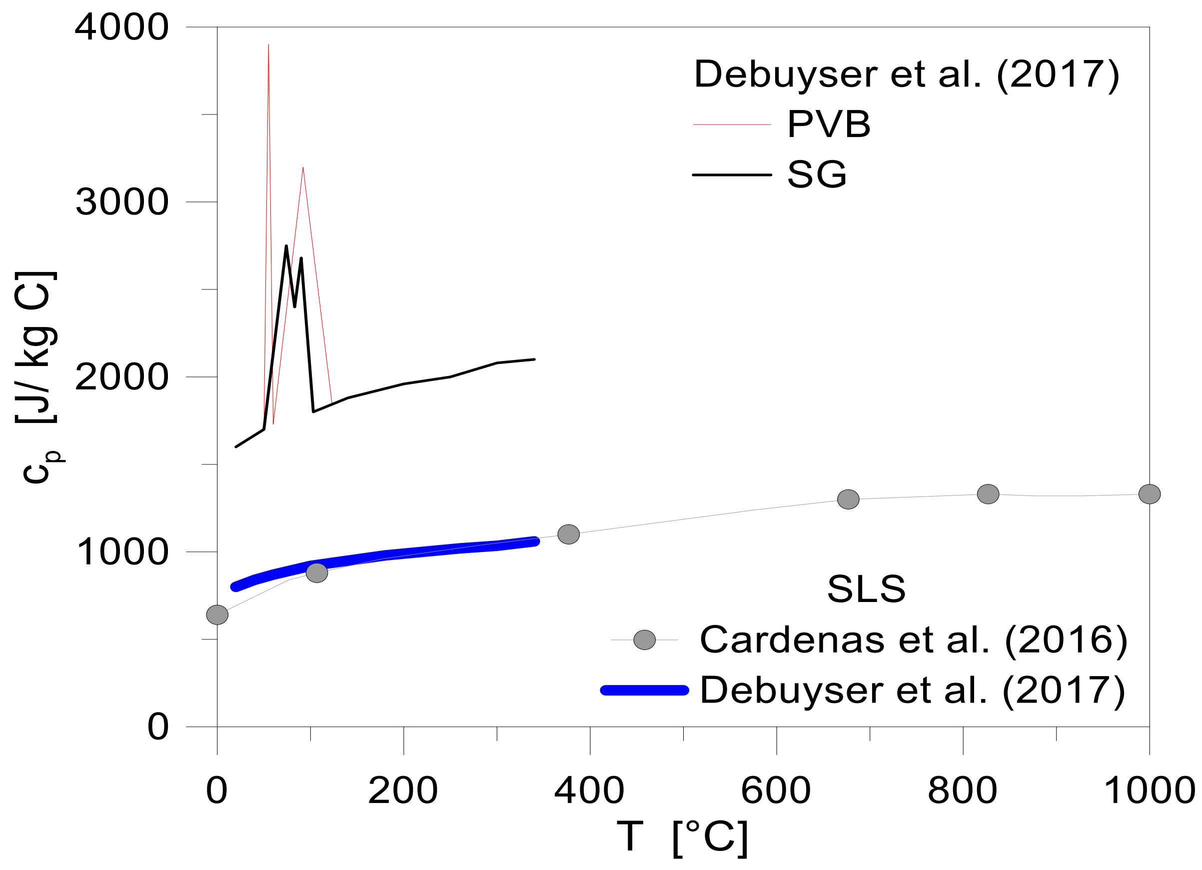
TABLE 2 Allowable temperature gradients, according to prEN thstr:2004 provisions

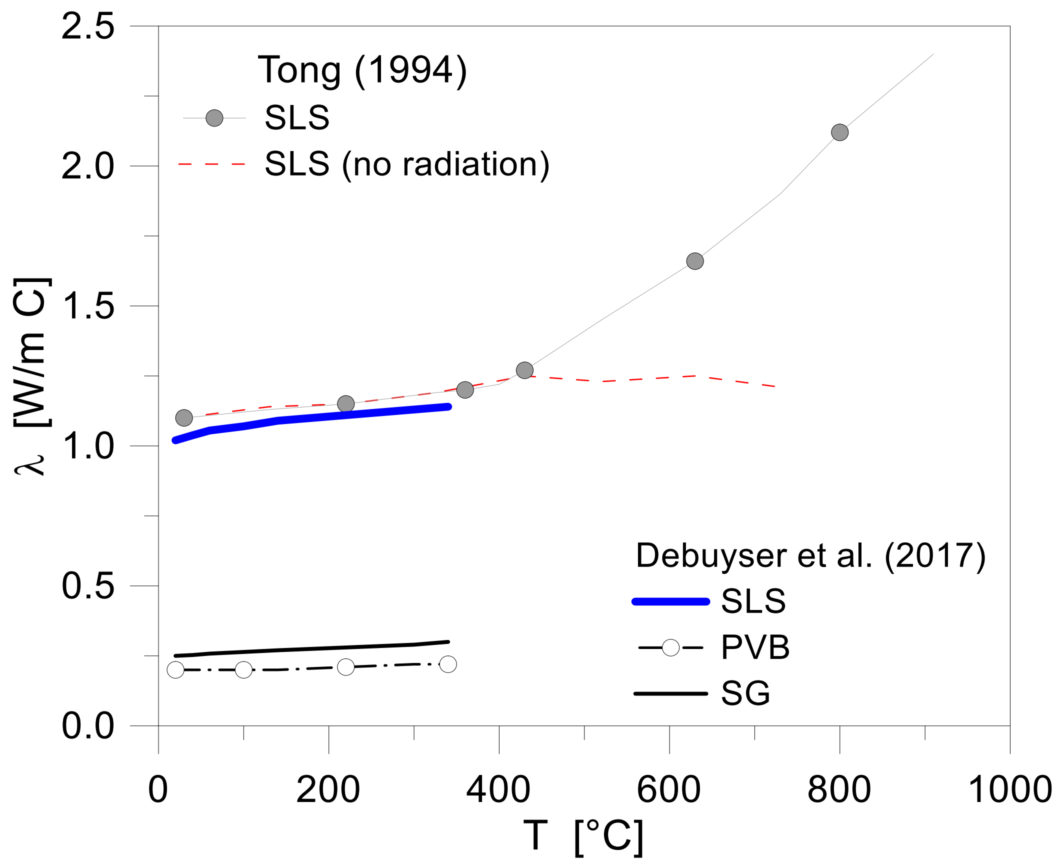
Glass THERMAL RESISTANCE....based on experiments





Thermal conductivity, specific heat





+ other materials interacting with glass

Experiments!! -FIRE- Walls/facades/enclosures

Reference	Test typology / setup	Specimen size / loading	Glass type	Additional FR tools
Mejicovsky (2007)	Frame supported, double LG (special setup for heat transmission)	F / T	SLS (FT)	-
Machalická et al (2016)	Frame supported, double LG	F / T	FR	Gel-filling layer
Manzello et al (2007)	Frame supported, double LG + monolithic (furnace)	F / T	FR	Gel-filling layer
Yang et al (2011)	Frame supported, monolithic	F / T	FR	-

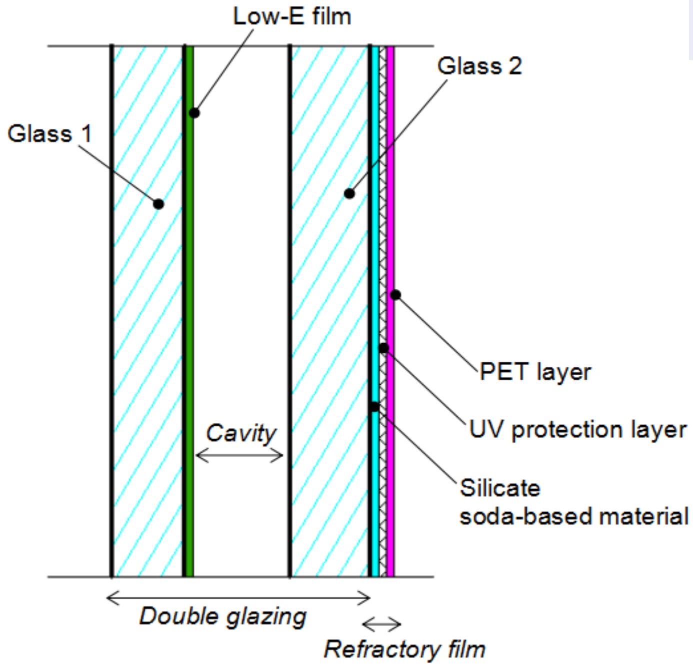
Experiments!! -FIRE- Walls/facades/enclosures

Experiments!! -FIRE- Floors & overheads

Reference	Test typology / setup	Specimen size / loading	Glass type	Additional FR tools
Siebert and Maniatis (2008)	LG, frame supported	F / n.a.	n.a.	n.a.
Davis (2013)	LG, frame supported	F / M	SLS (FT) bonded to FR glass	Liquid laminating film

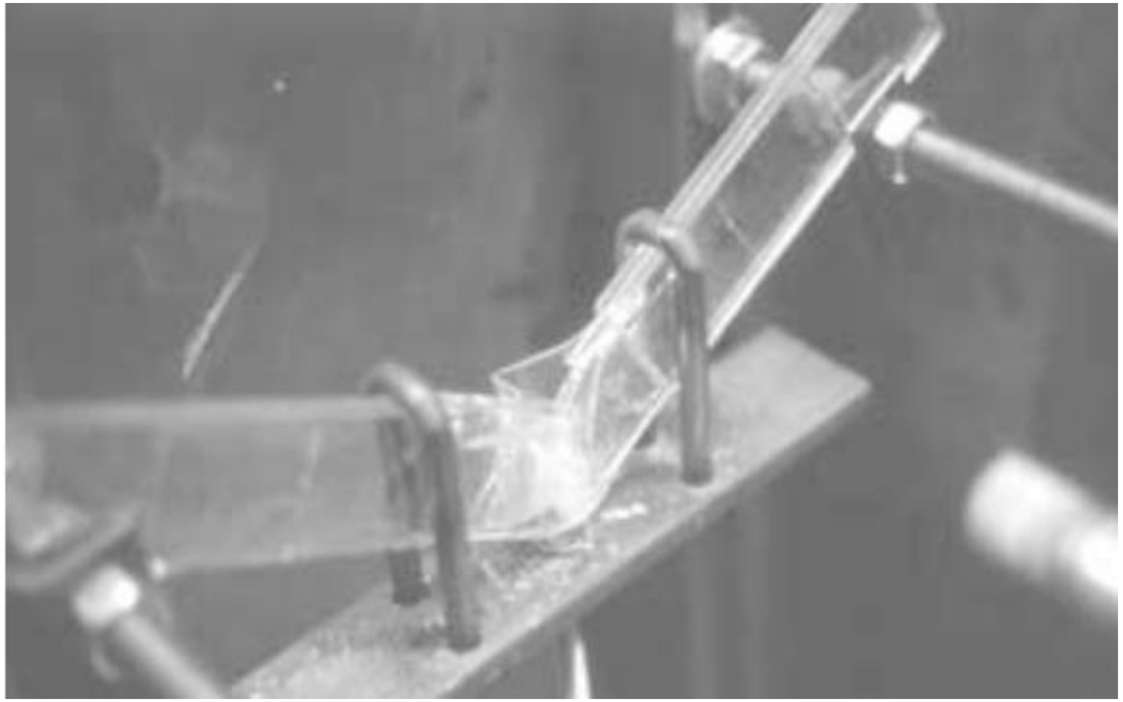
Experiments!! -FIRE- Window retrofit

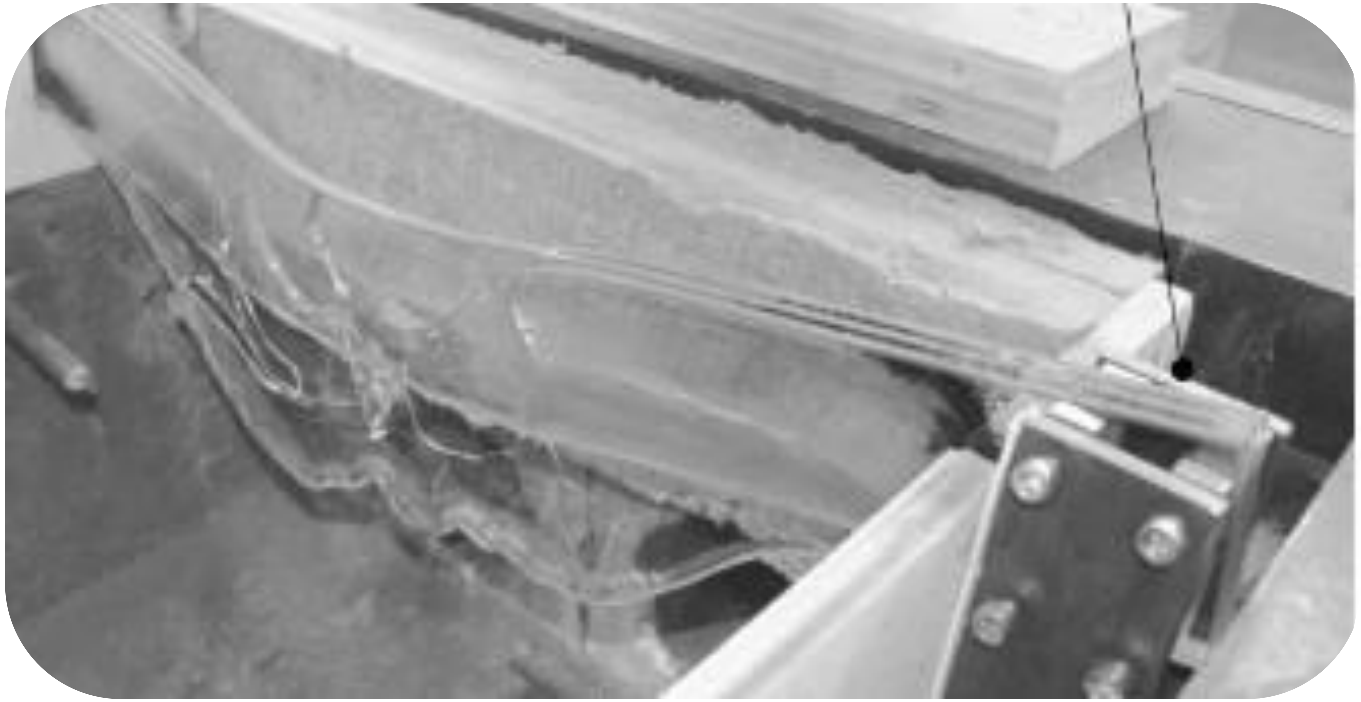
Reference	Test typology / setup	Specimen size / loading	Glass type	Additional FR tools
Koudijs and Csoke (2013)	Double glazing unit	F / T	SLS (AN, HS)	Low-E coating
Misawa et al (2013)	Double glazing unit	F / T	SLS (AN)	Low-E coating + refractory film



Experiments!! -FIRE- Beams

Reference	Test typology / setup	Specimen size / loading	Glass type	Additional FR tools
Veer et al (2001)	4 point-bending; monolithic, triple LG, insulated + segmented beams (glass flame, bespoke setup)	S / M	SLS (AN)	Intumescent protective coating
Bouka et al (2003)	4 point-bending; triple LG (glass flame, bespoke setup)	S / M	SLS (AN), FR glass	Epoxy interlayers
Louter and Nussbaumer	4 point-bending; triple LG	F / M	SLS (AN, HS, FT)	-

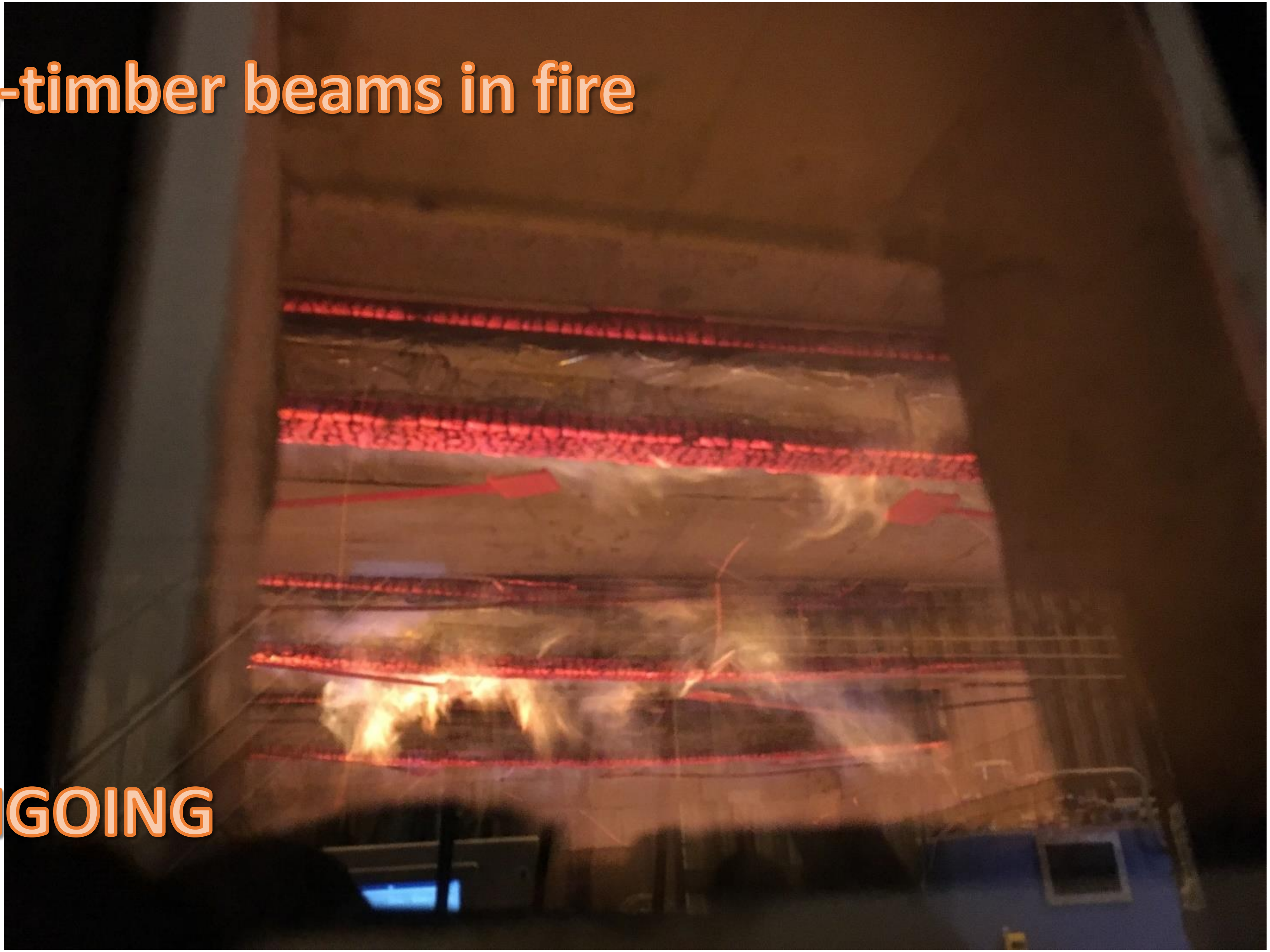




…and further ongoing experimental research…

Glass-timber beams in fire

Glass-timber beams in fire

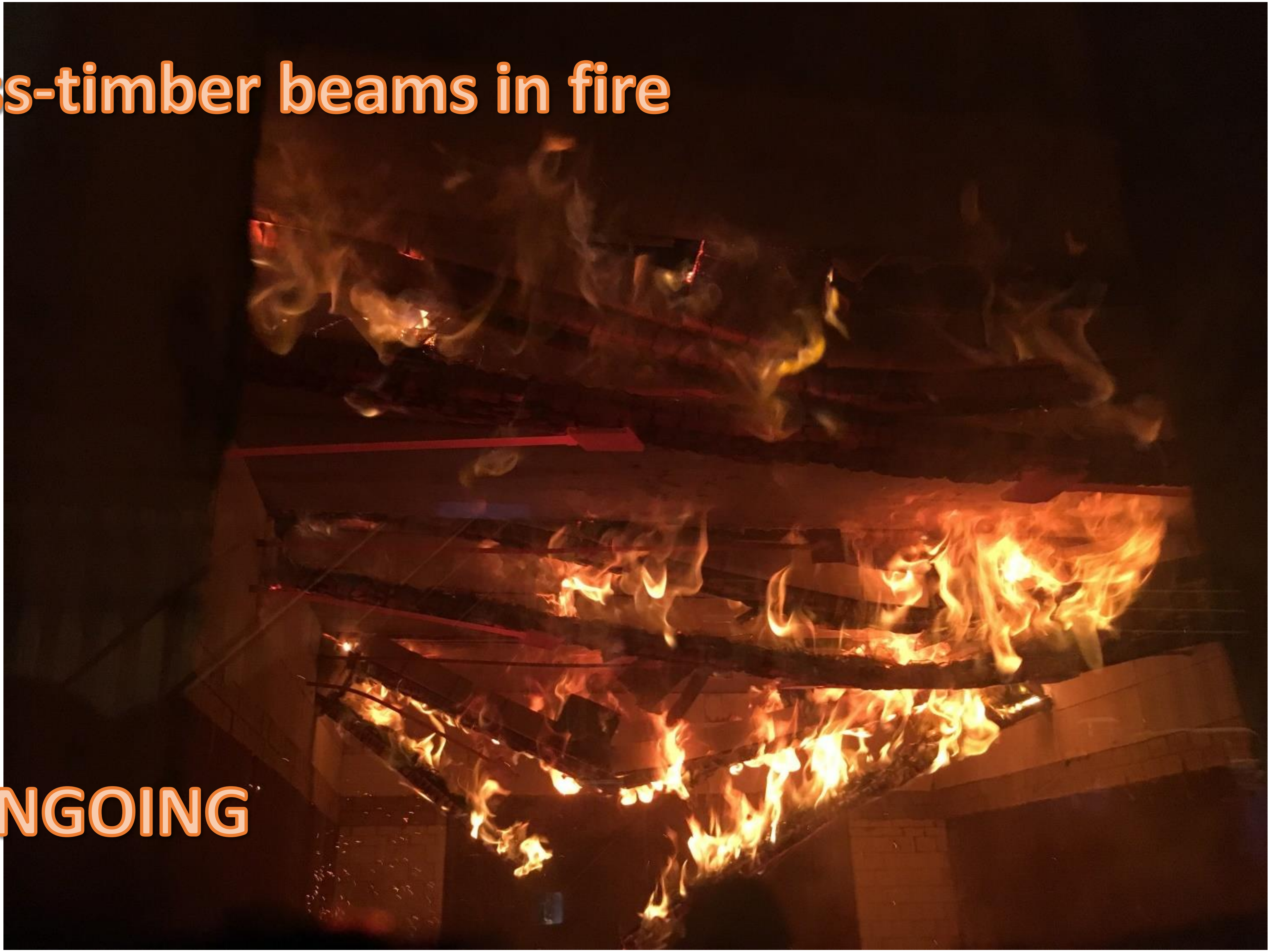


ONGOING

Glass-timber beams in fire

ONGOING

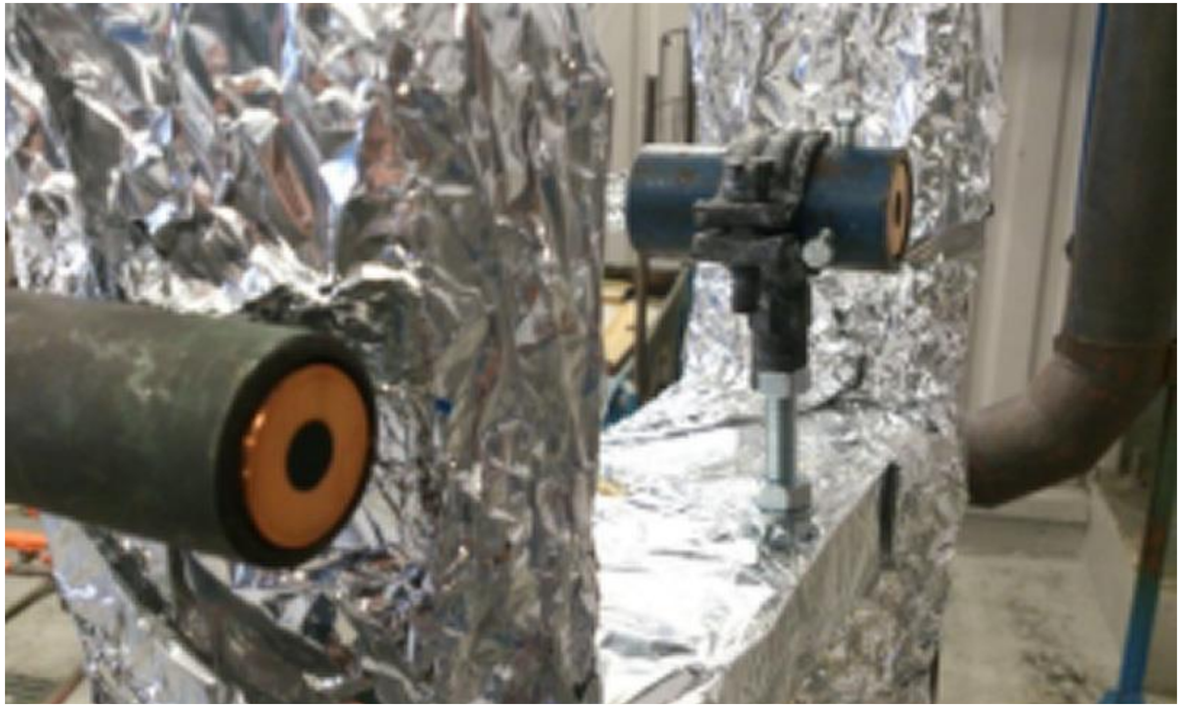
Glass-timber beams in fire



ONGOING

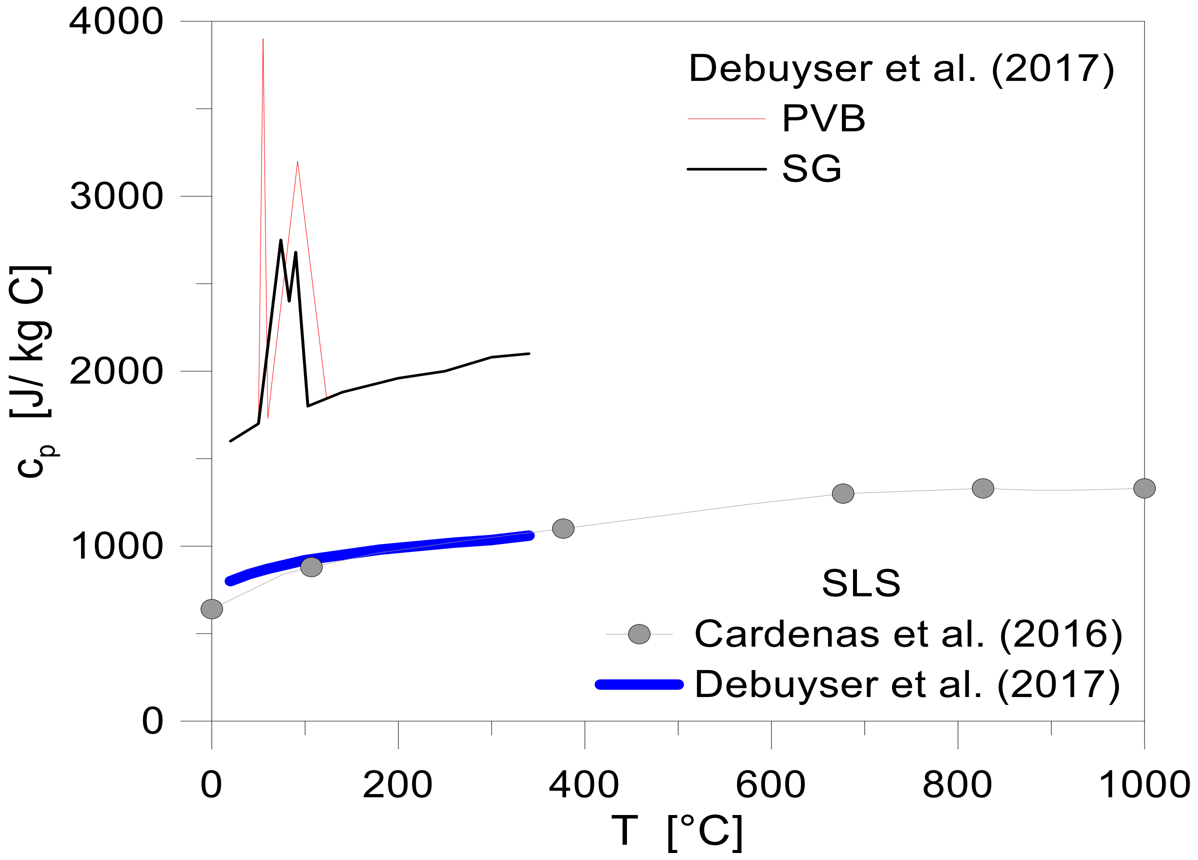
Glass panels under radiant heating (SMALL SCALE)

Samples 185 × 285 mm, annealed glass



Debuyser, M., Sjöström, J., Lange, D., Honfi, D., Sonck, D., & Belis, J. (2017)
Behaviour of monolithic and laminated glass exposed to radiant heating
Construction and Building Materials, 130, pp.212–229

Glass panels under radiant heating (SMALL SCALE)



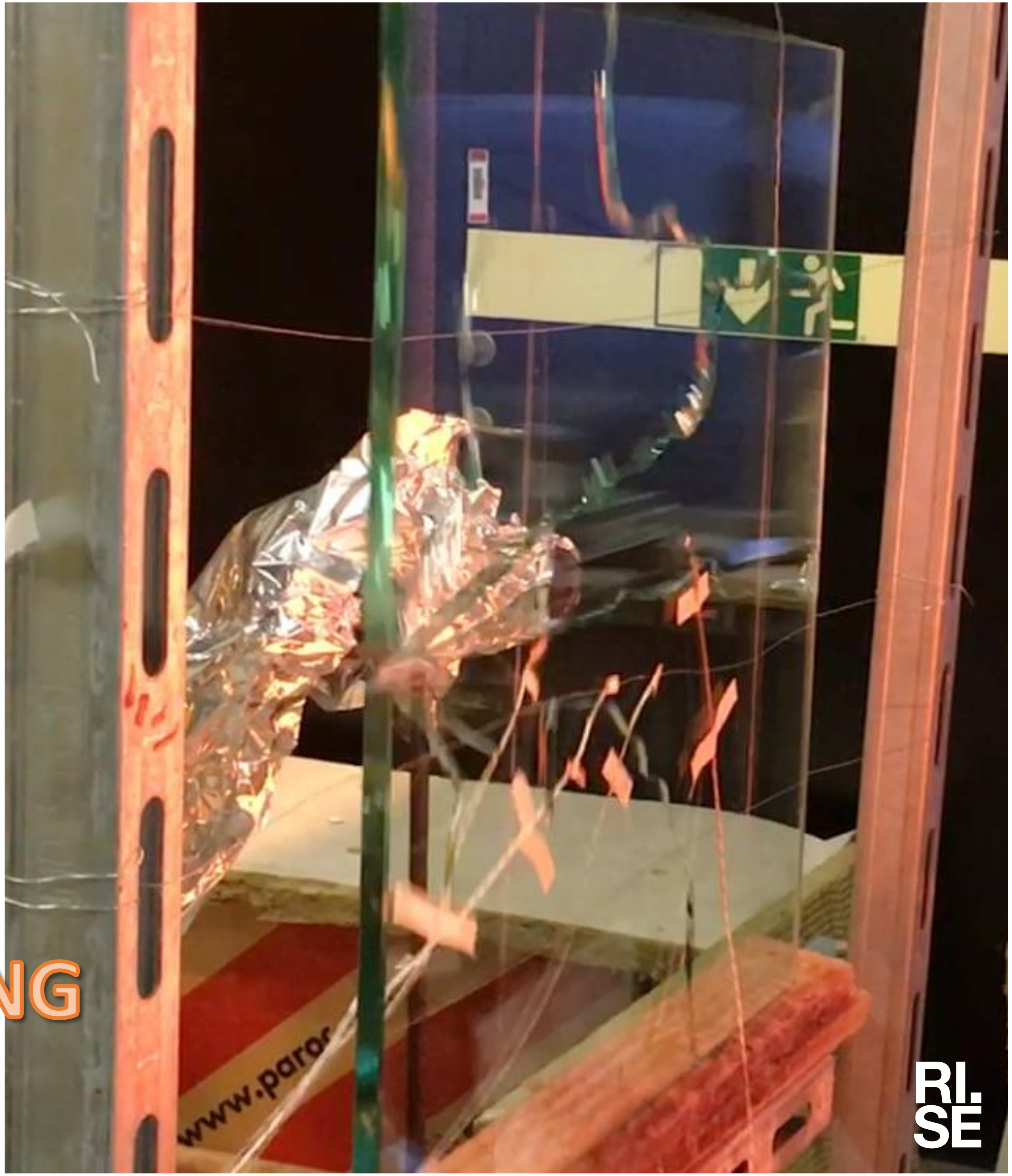
Debuyser, M., Sjöström, J., Lange, D., Honfi, D., Sonck, D., & Belis, J. (2017)
Behaviour of monolithic and laminated glass exposed to radiant heating
Construction and Building Materials, 130, pp.212–229

Glass panels under radiant heating (LARGE SCALE)

ONGOING

RI. SE

ONGOING



ONGOING

RI.
SE

ONGOING

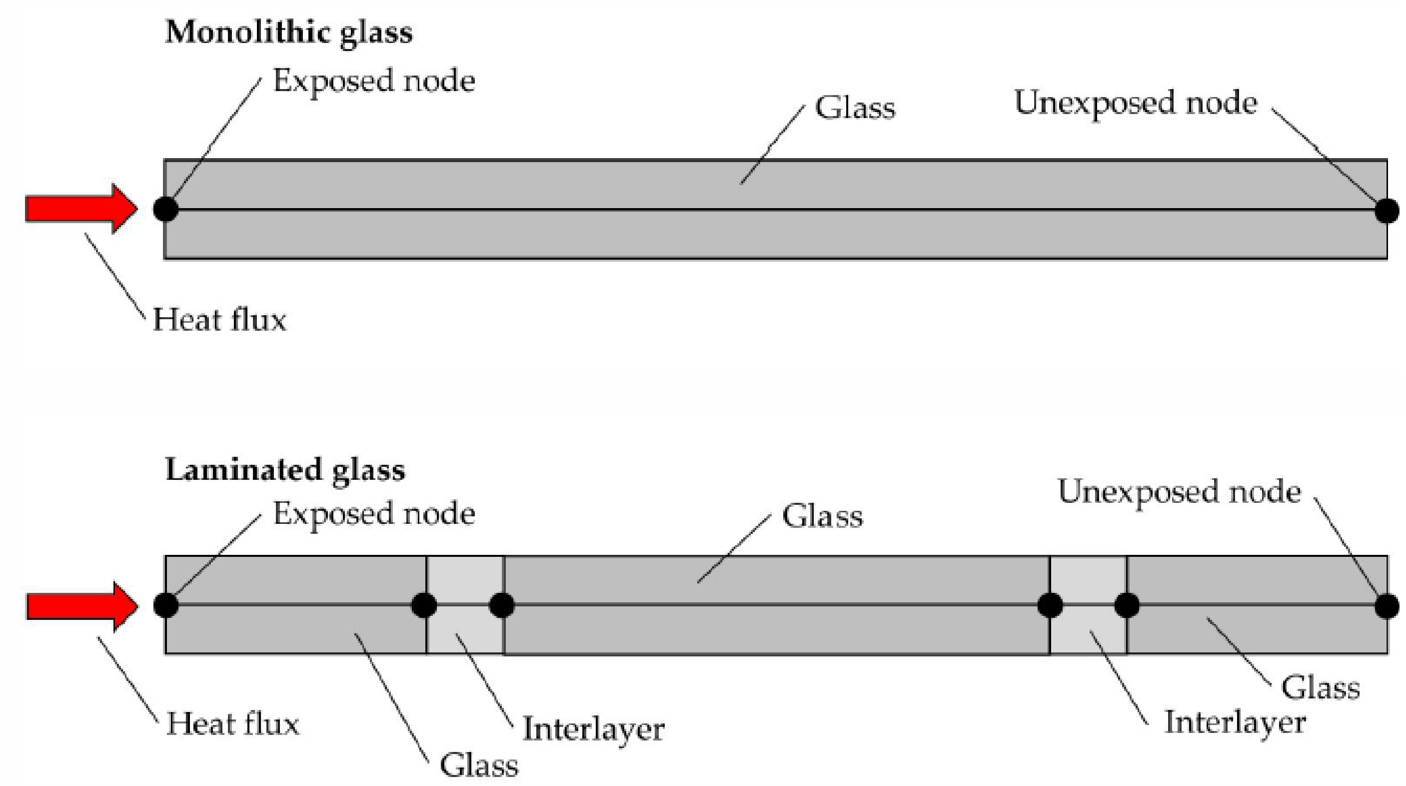
ONGOING

RI.
SE

Numerical analysis of glass systems under thermal exposure

Potentials and limits

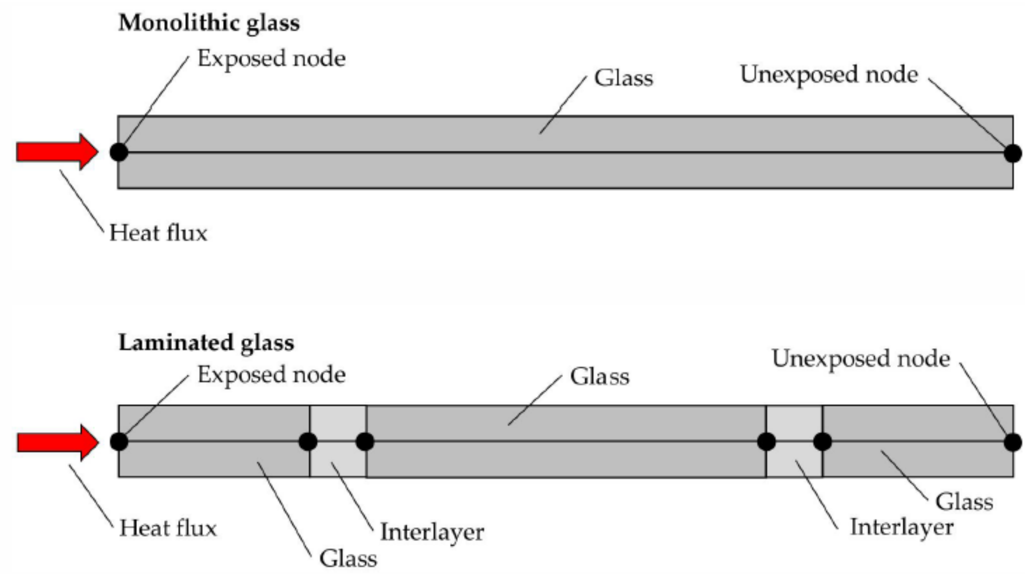
Simplified one-dimensional models (1D)

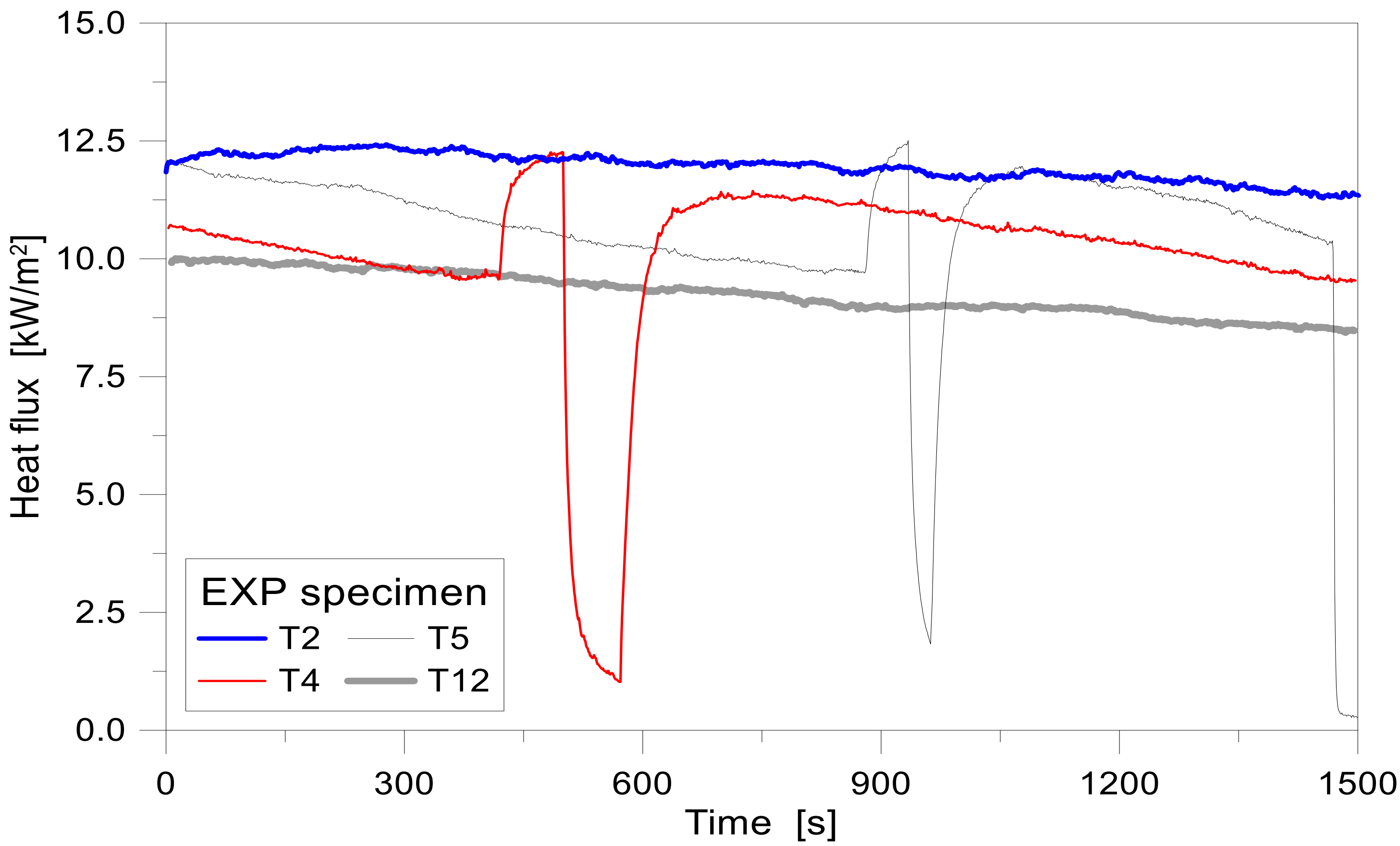


Diffusive heat transfer elements

Radiant heating

Simplified one-dimensional models (1D)



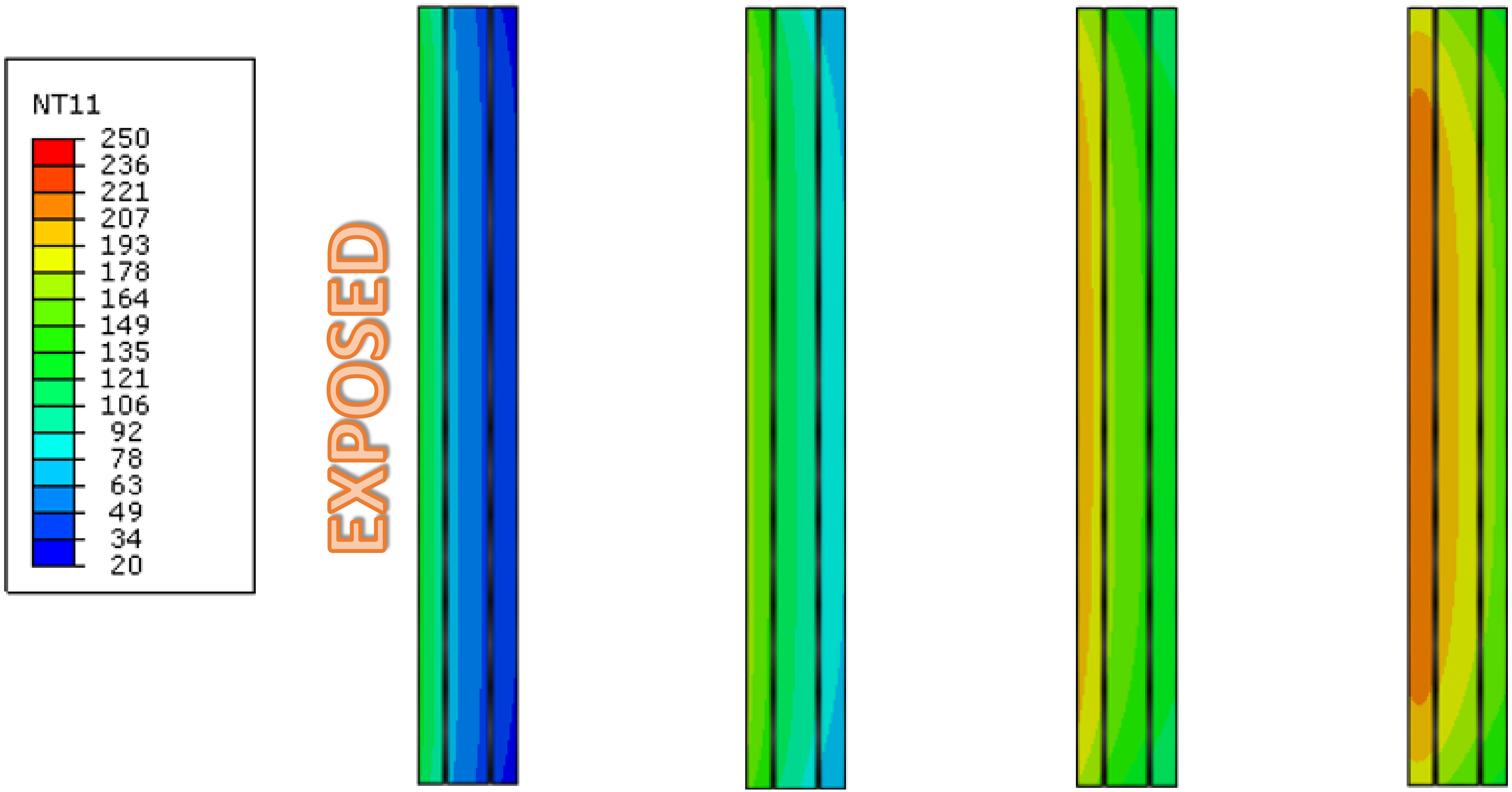


INPUT
exerimental heat flux
+ reliable thermal properties

Temperature trend
Temperature gradient

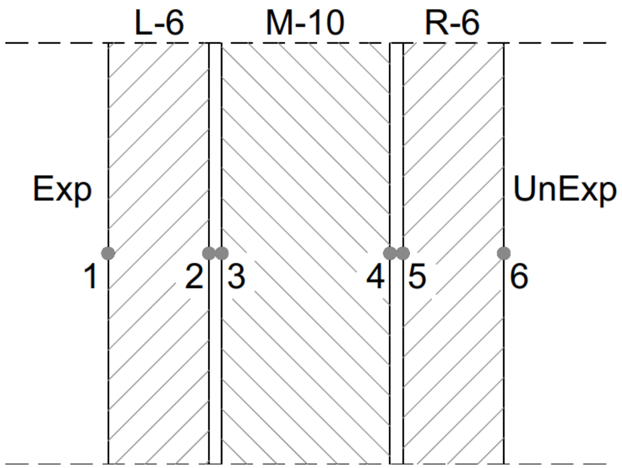
Simplified shell models (2D)

Radiant heating



EXPOSED

>> Time

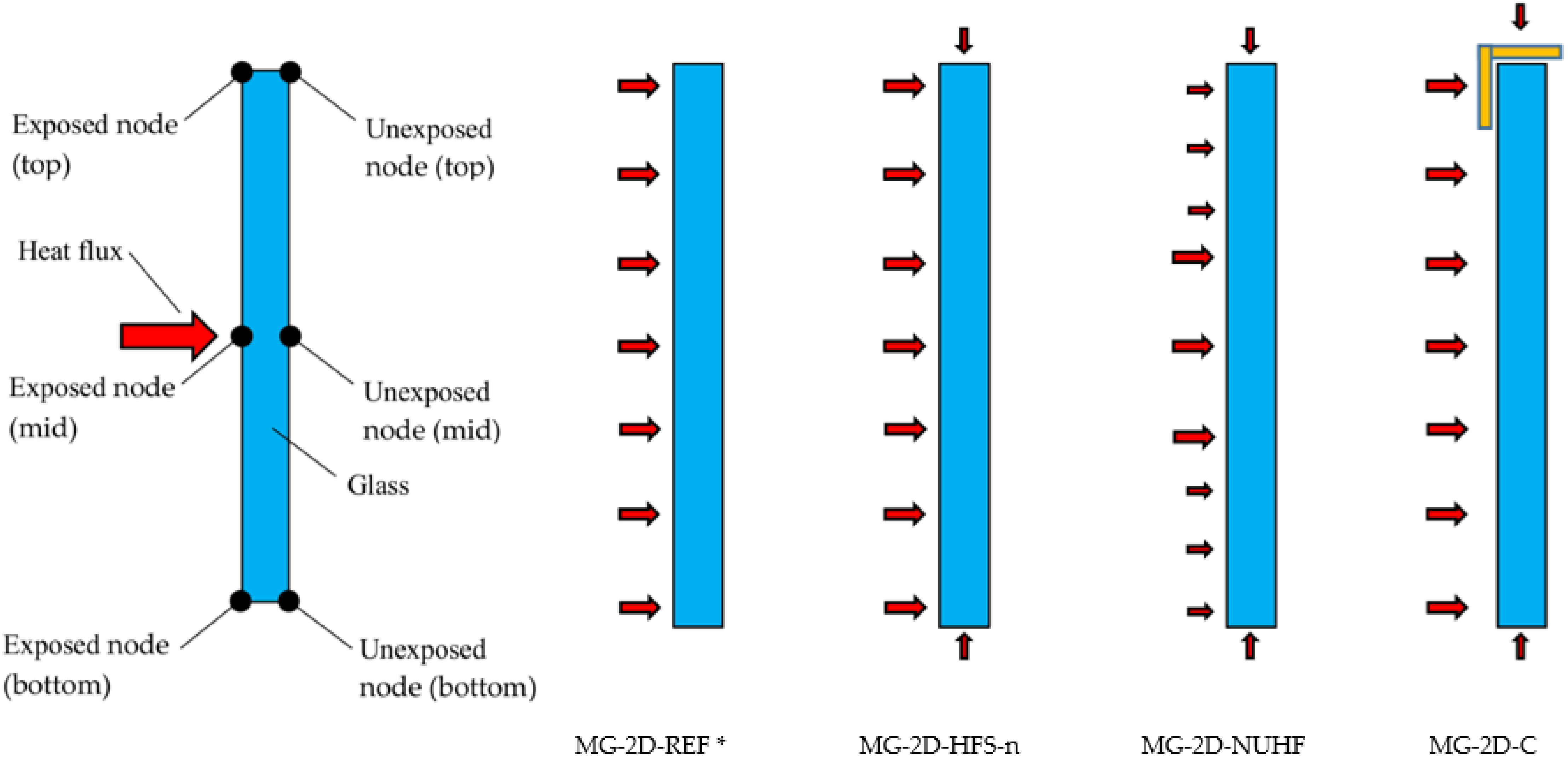


Distribution in thickness and section

NO size effects

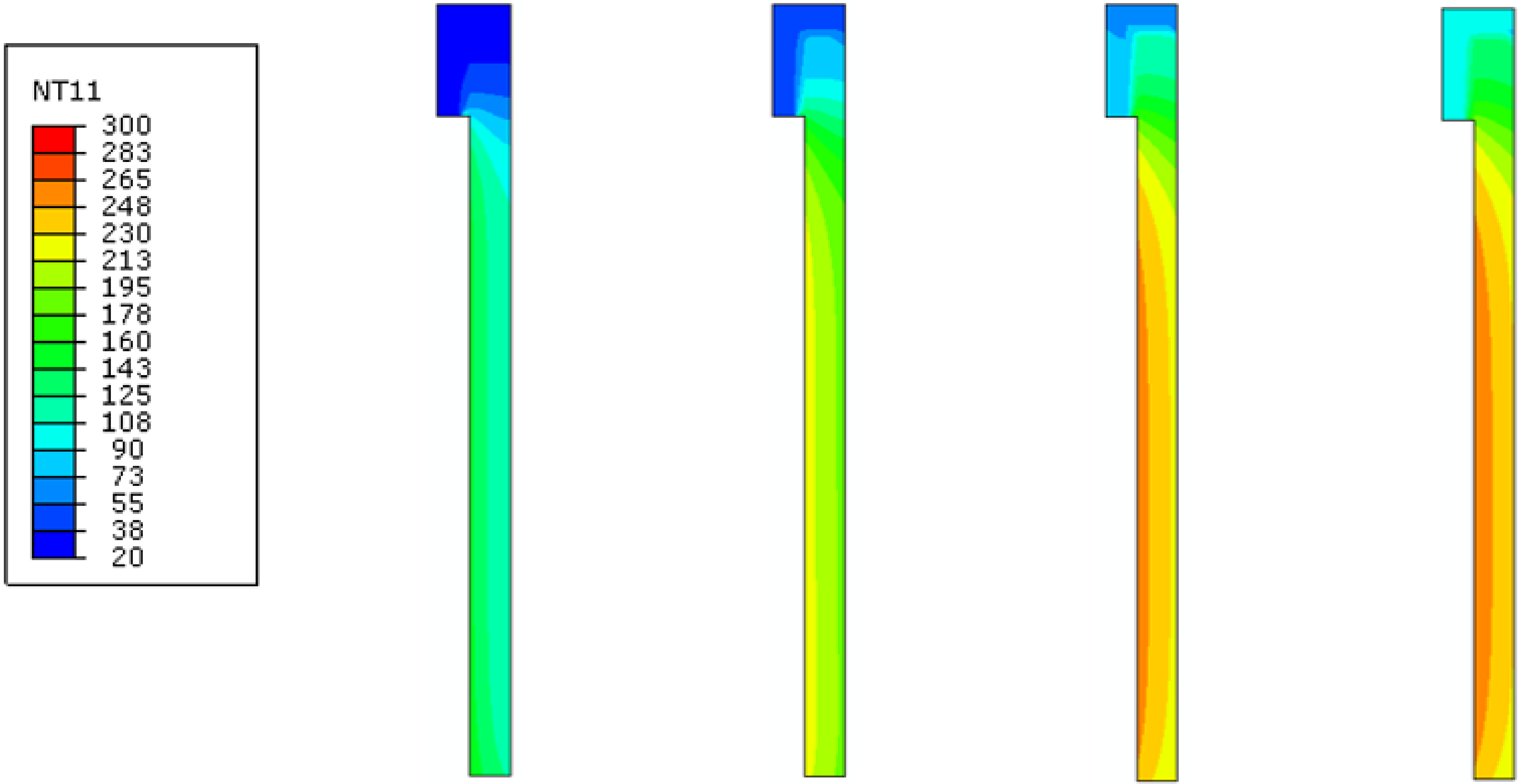
Simplified shell models (2D)

Radiant heating



Simplified shell models (2D)

Radiant heating



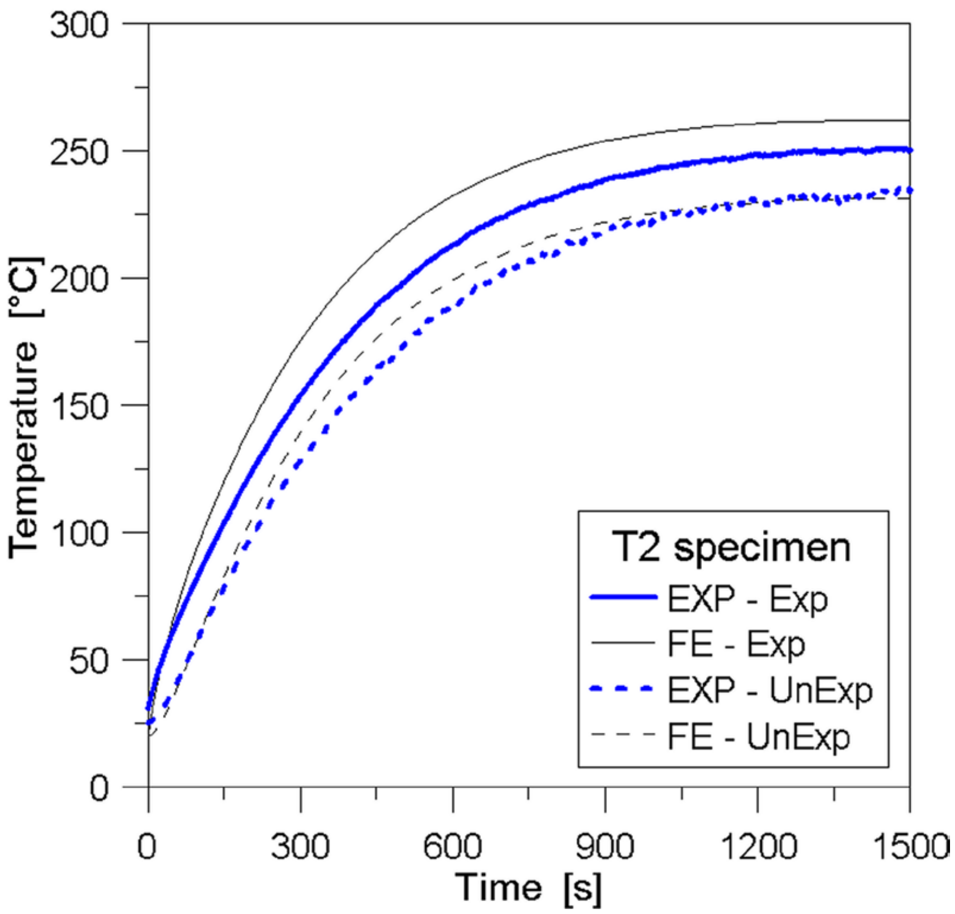
>> Time

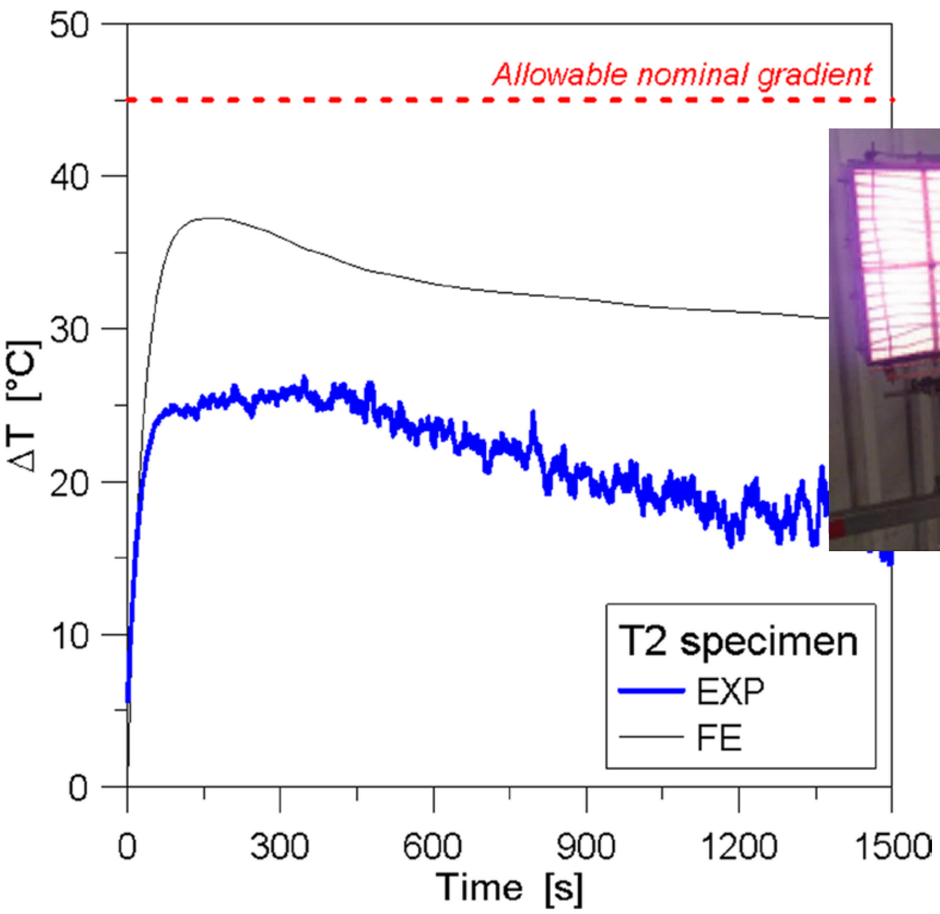
Local effects

But NO size effects

Simplified shell models (2D)

Radiant heating



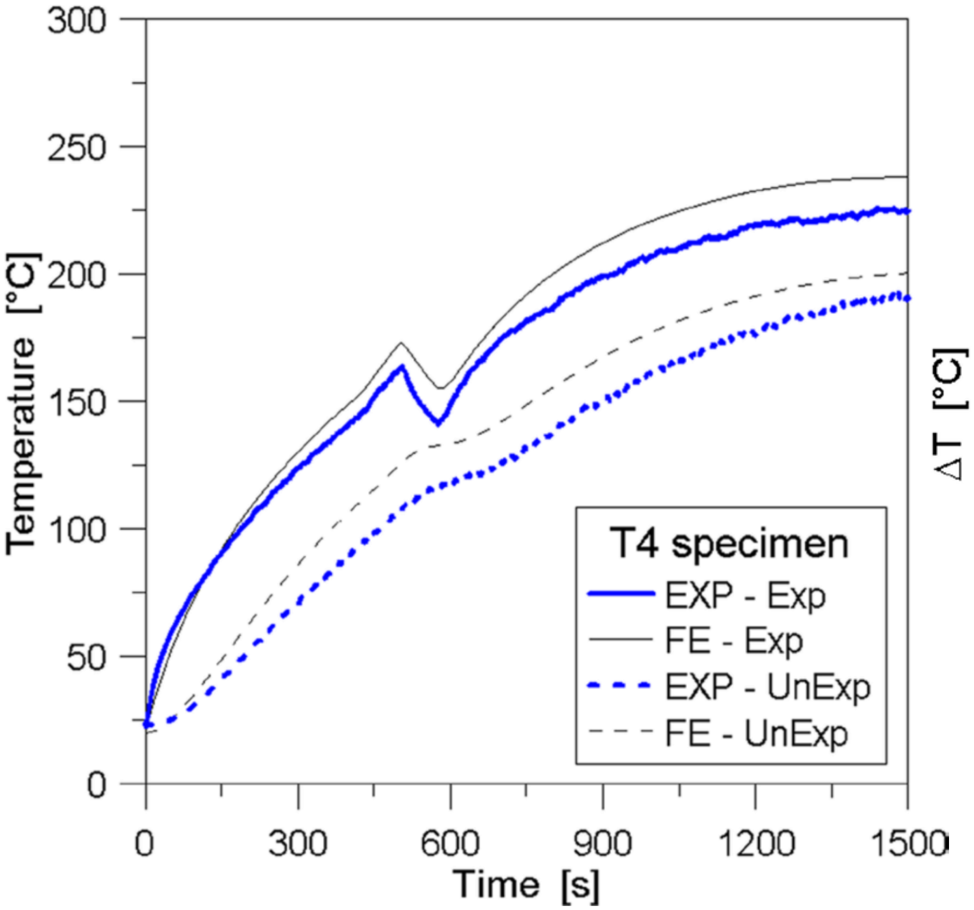


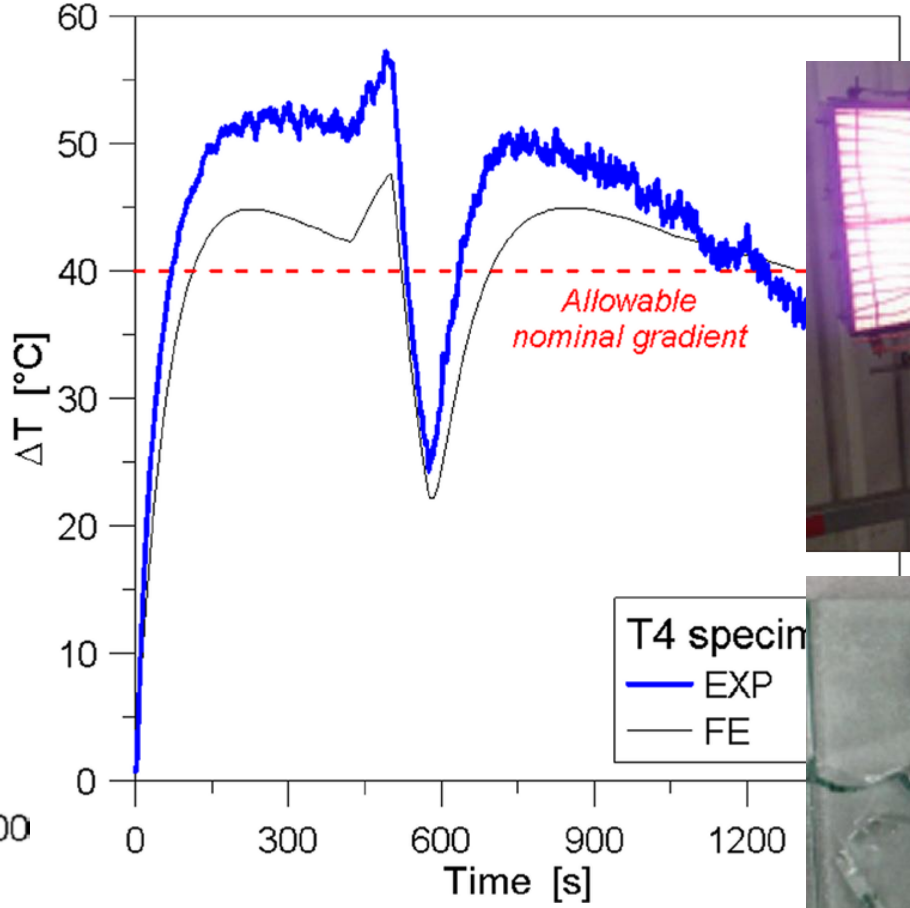
Thermal gradient

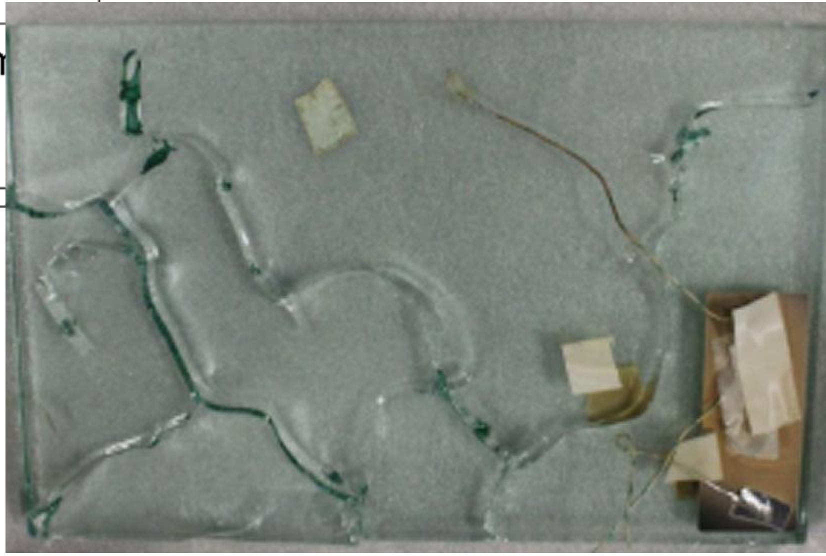
10mm MG

Simplified shell models (2D)

Radiant heating





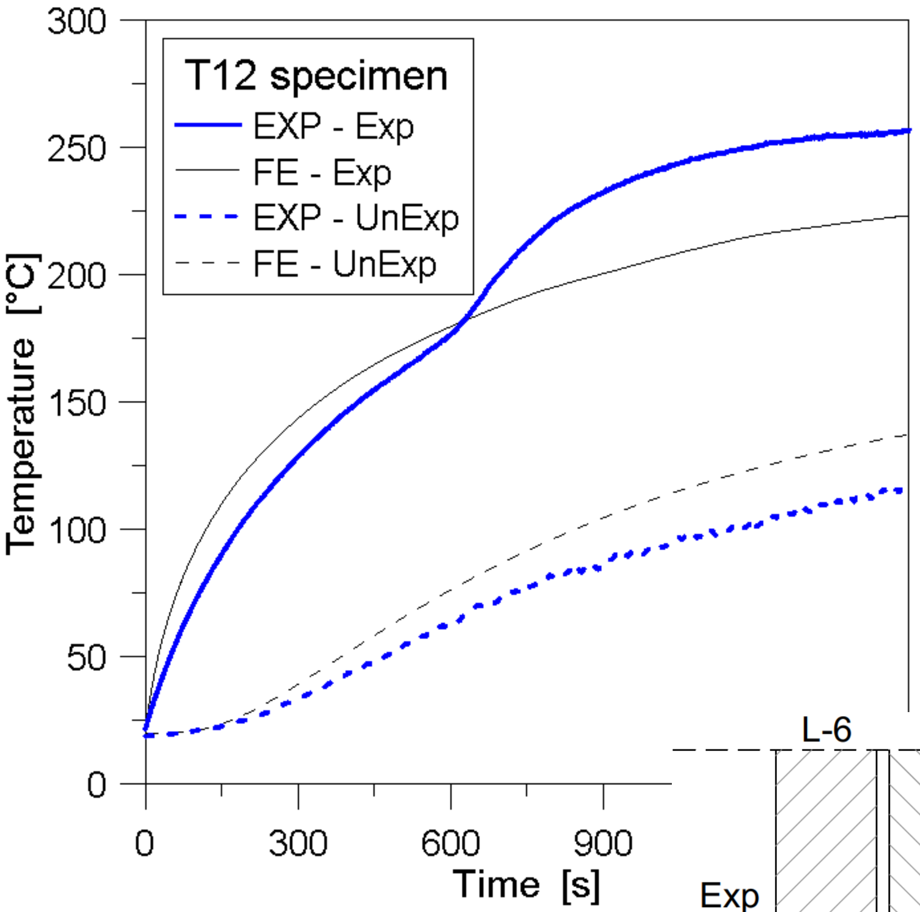


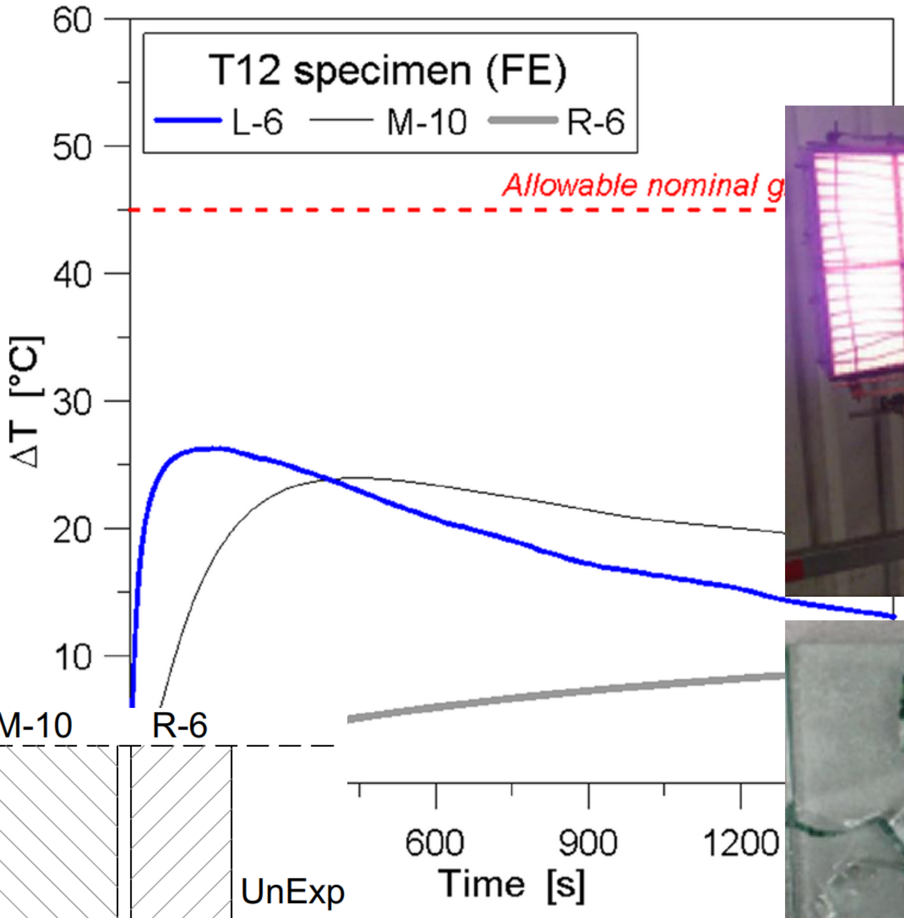
15mm MG

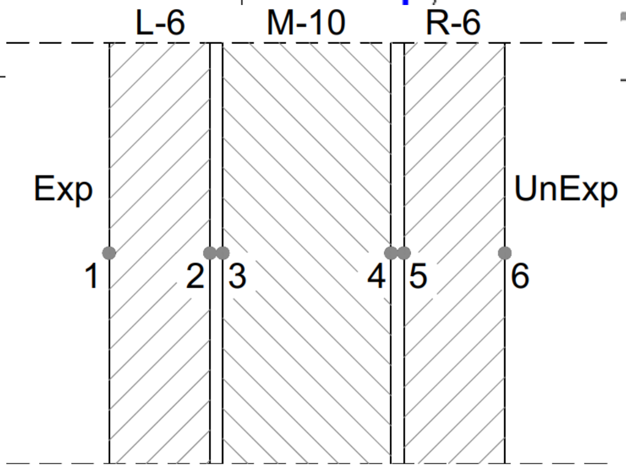
Thermal gradient

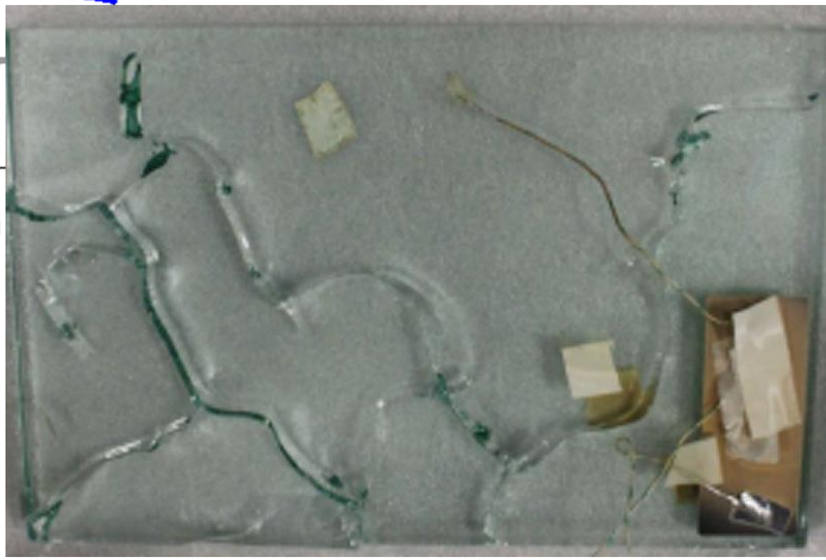
Simplified shell models (2D)

Radiant heating





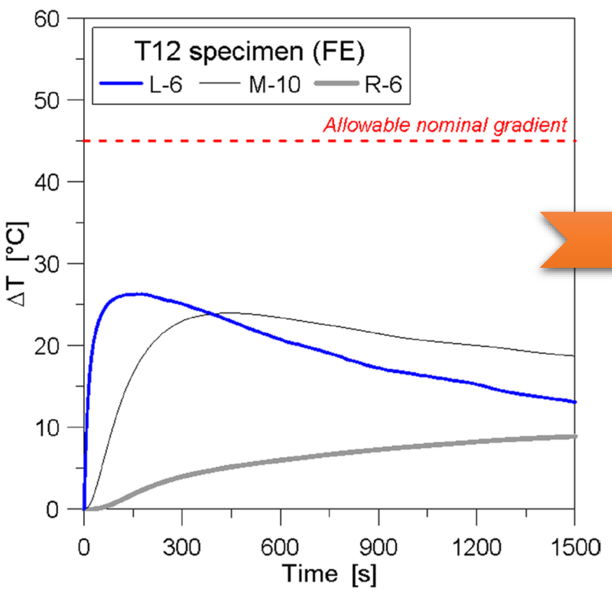


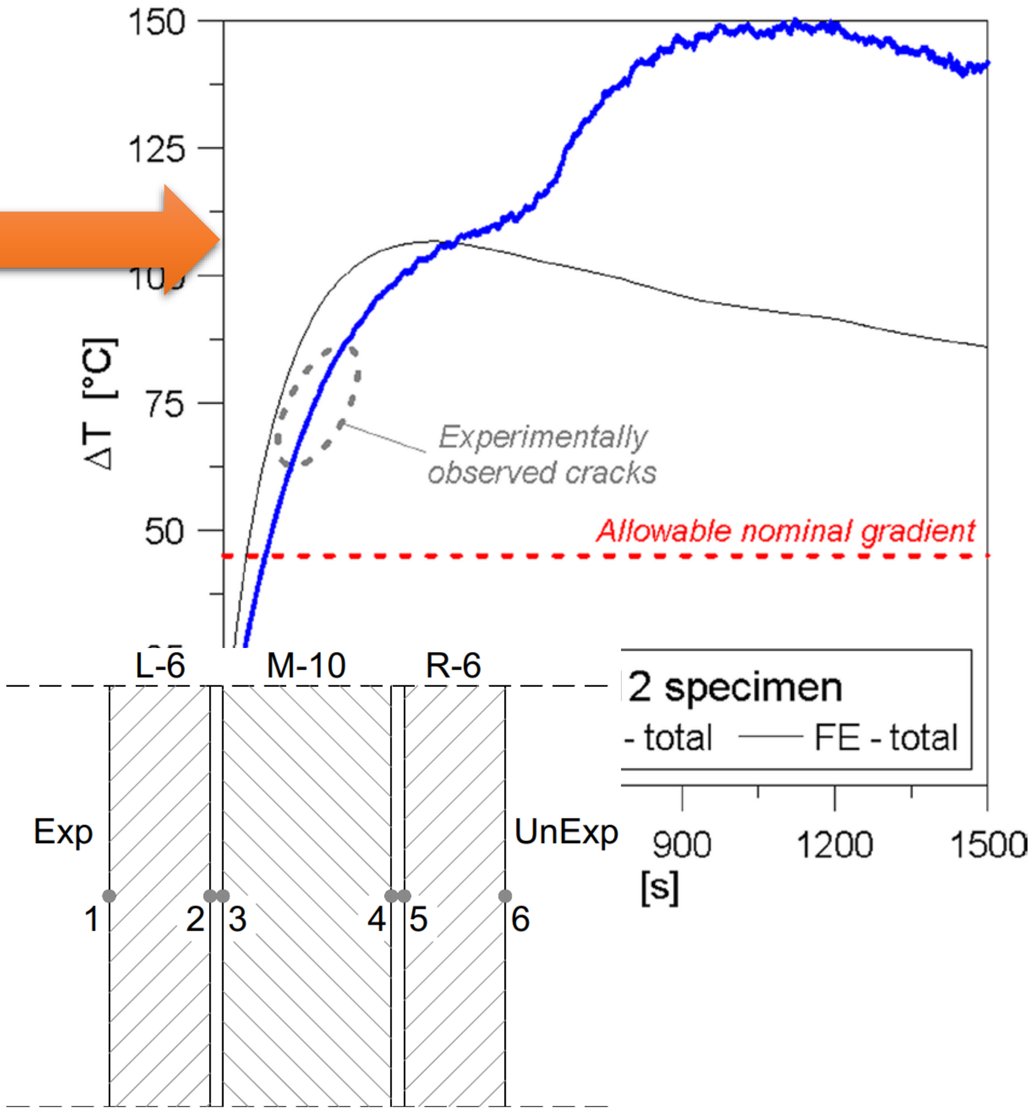


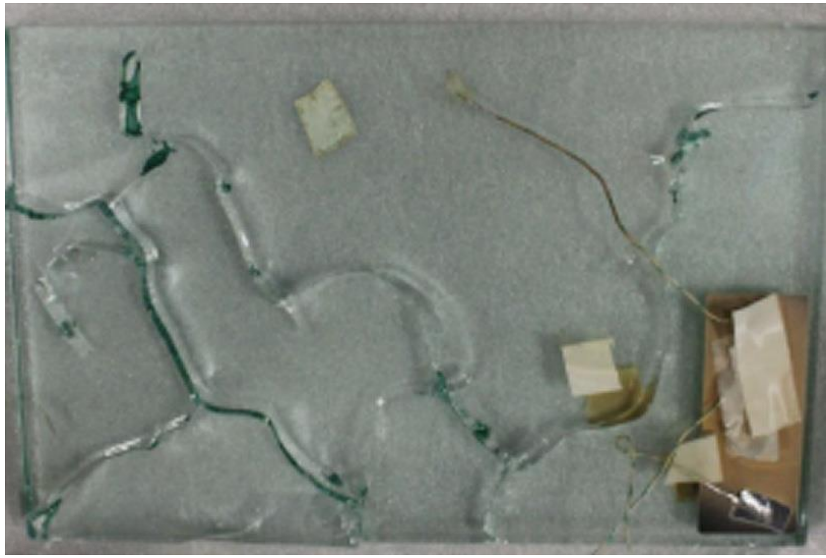
6+10+6 LG

Simplified shell models (2D)

Radiant heating



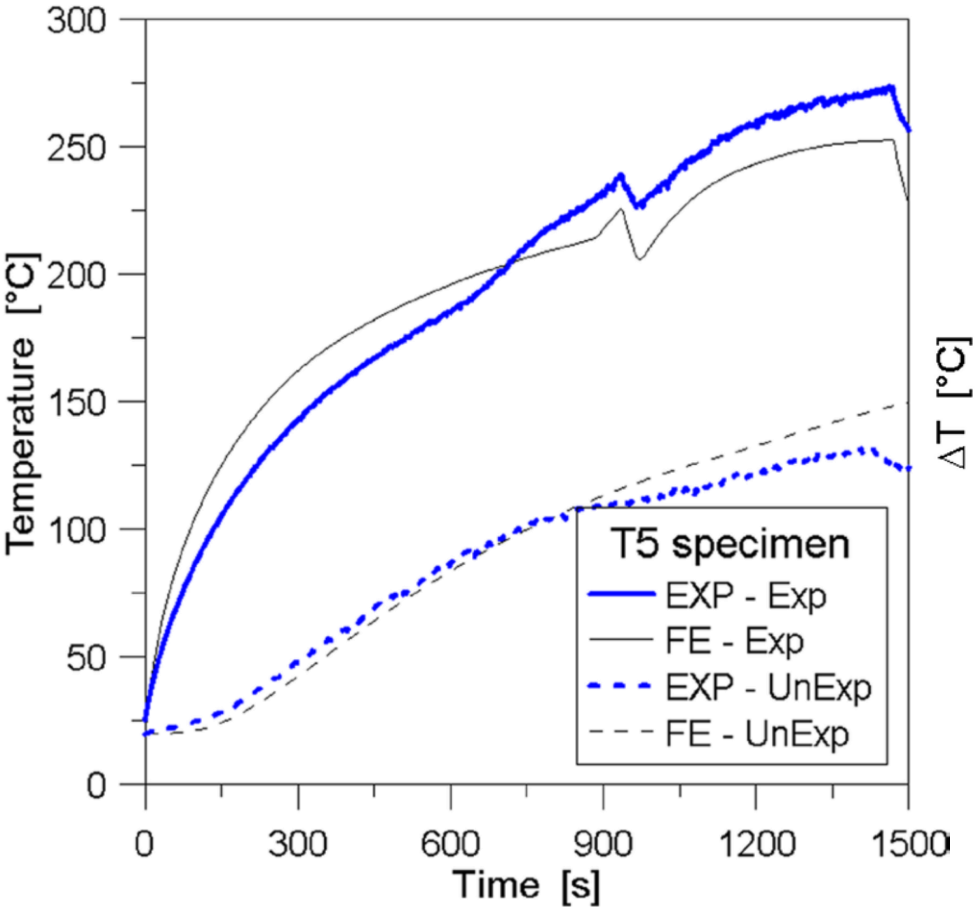


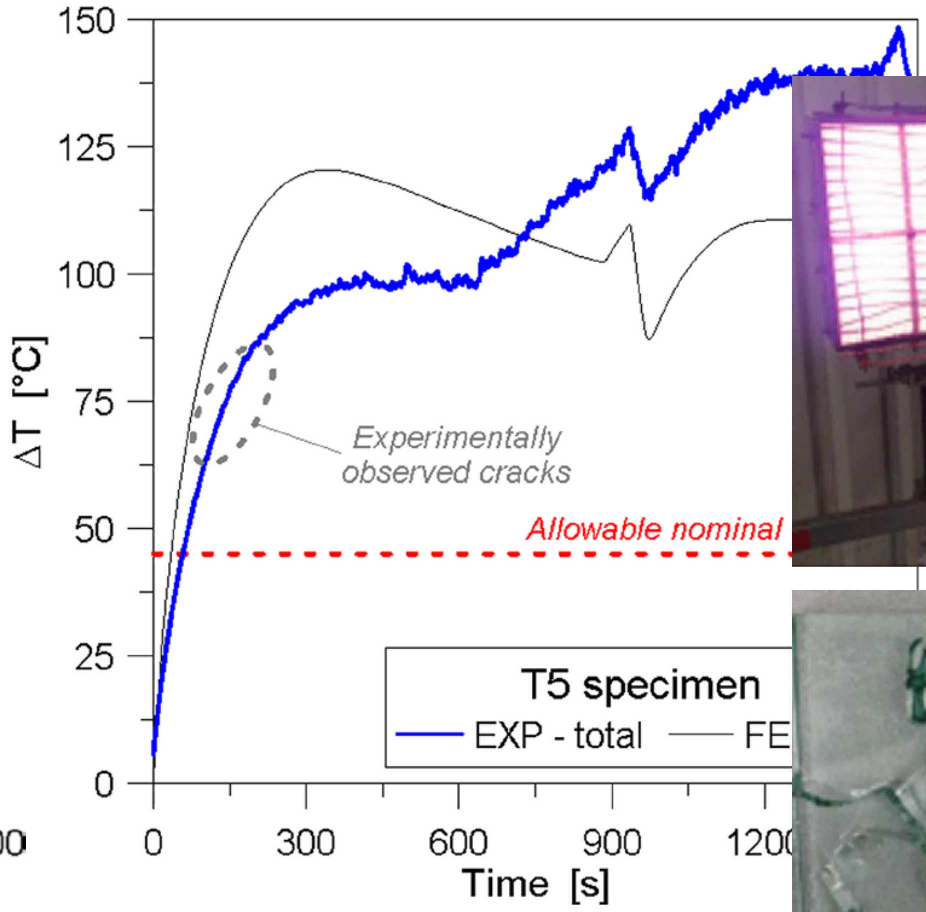


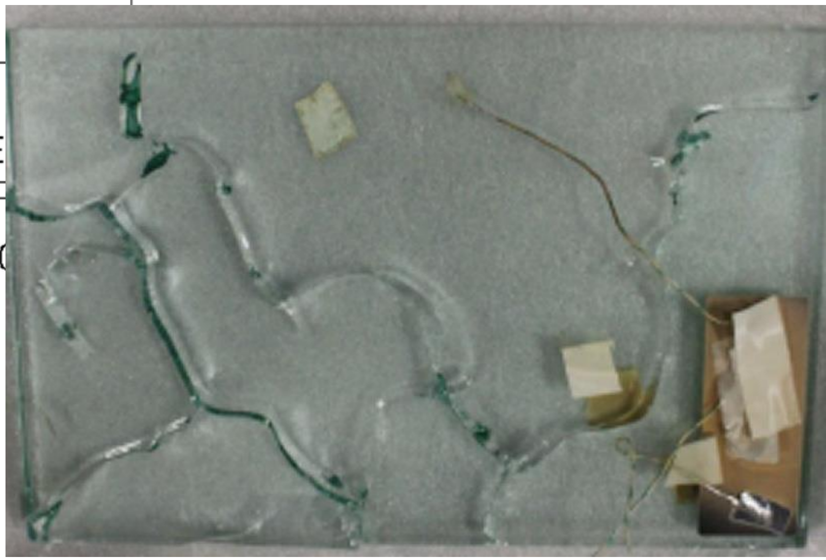
6+10+6 LG

Simplified shell models (2D)

Radiant heating



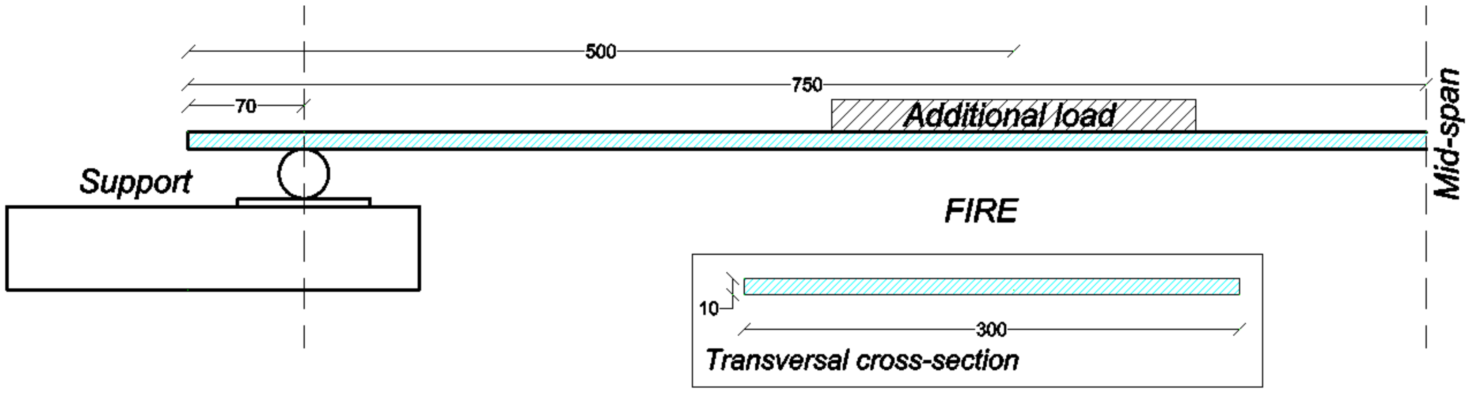


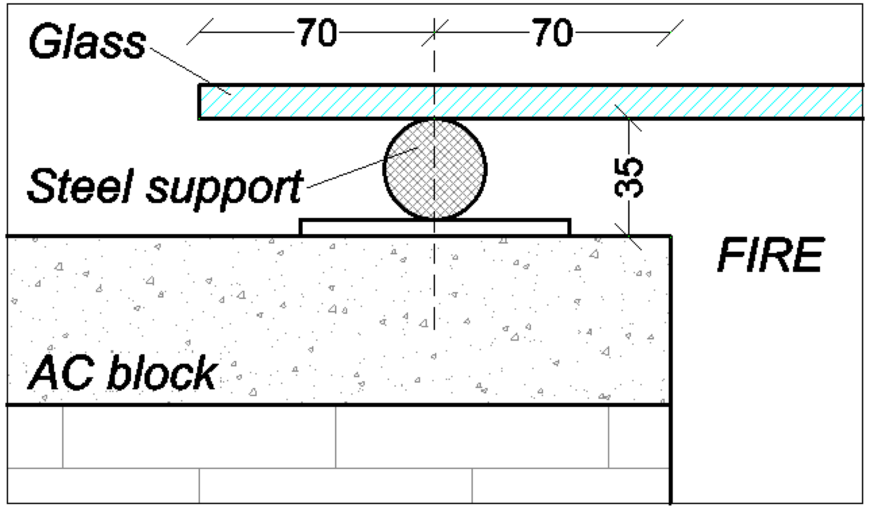


Thermal gradient

6+10+6 LG

Refined models (full 3D)

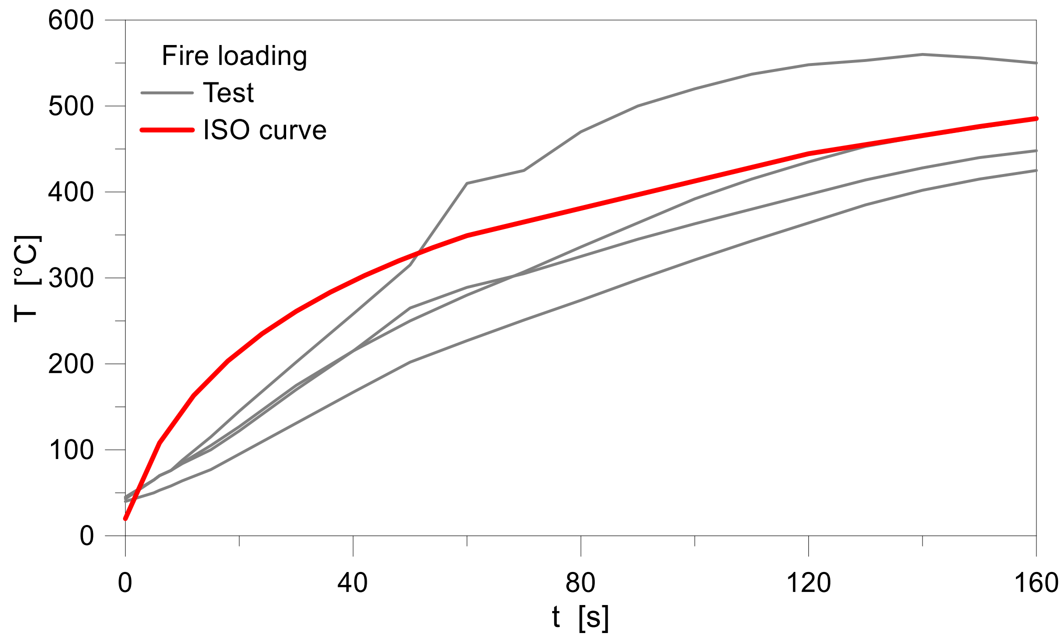




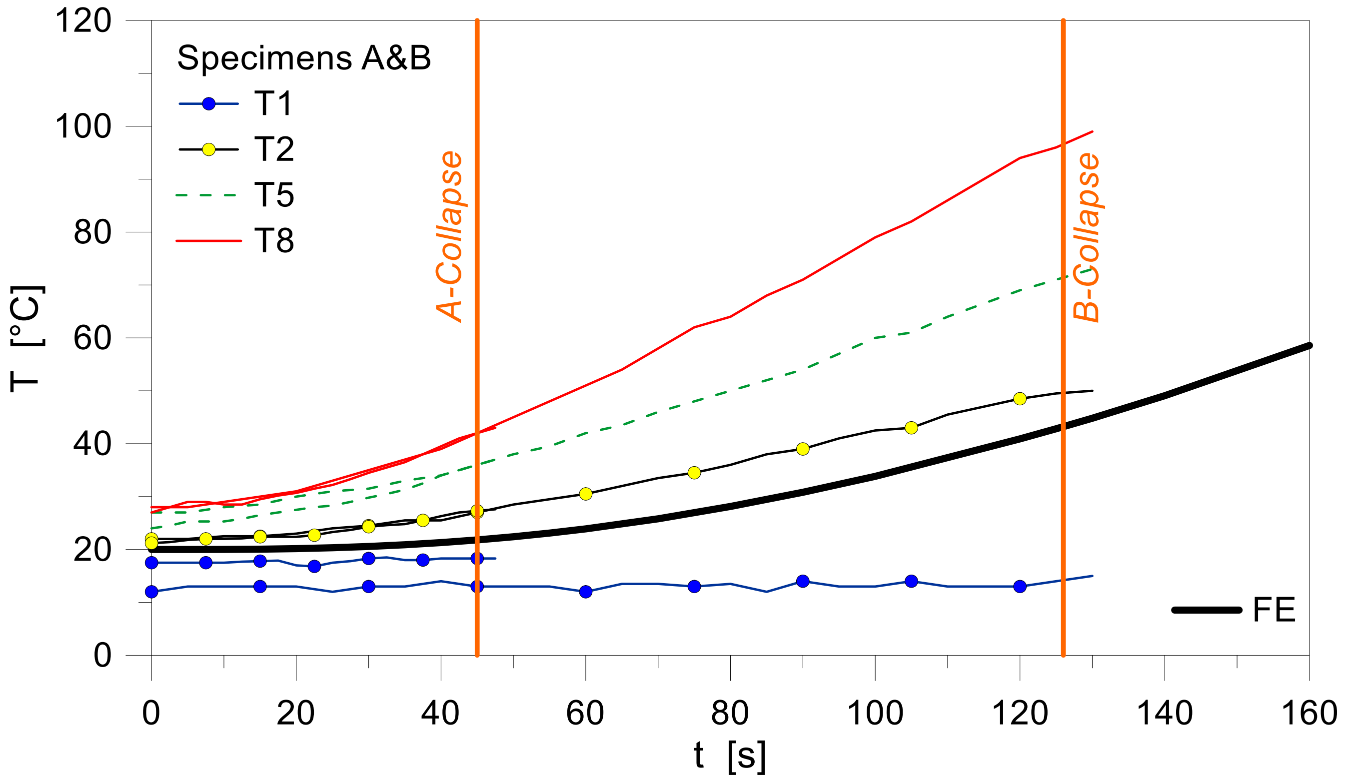
Fire (furnace test)

Uncoupled thermo-mechanical analyses

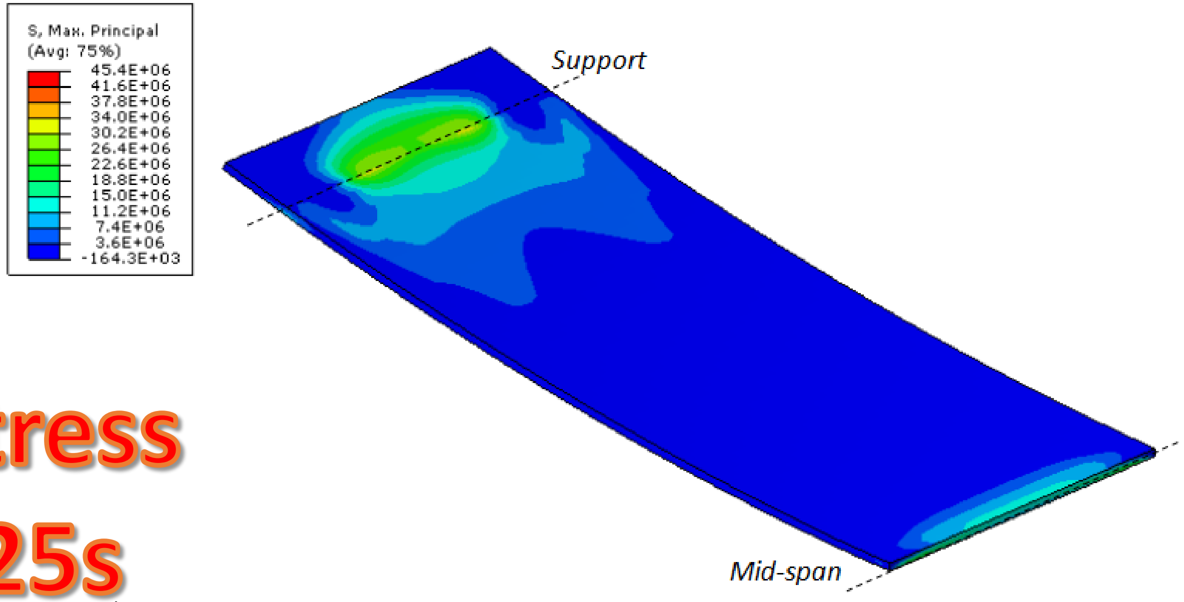
Fire (furnace test)



Premature glass failure in the region of steel supports



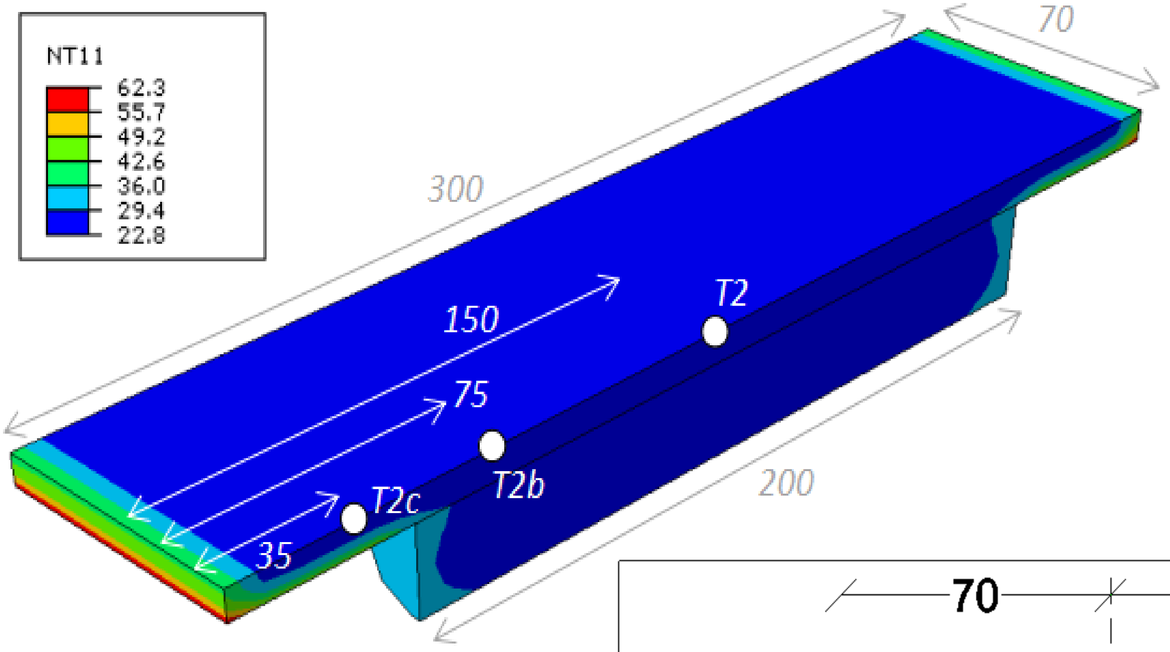
Refined models (full 3D)



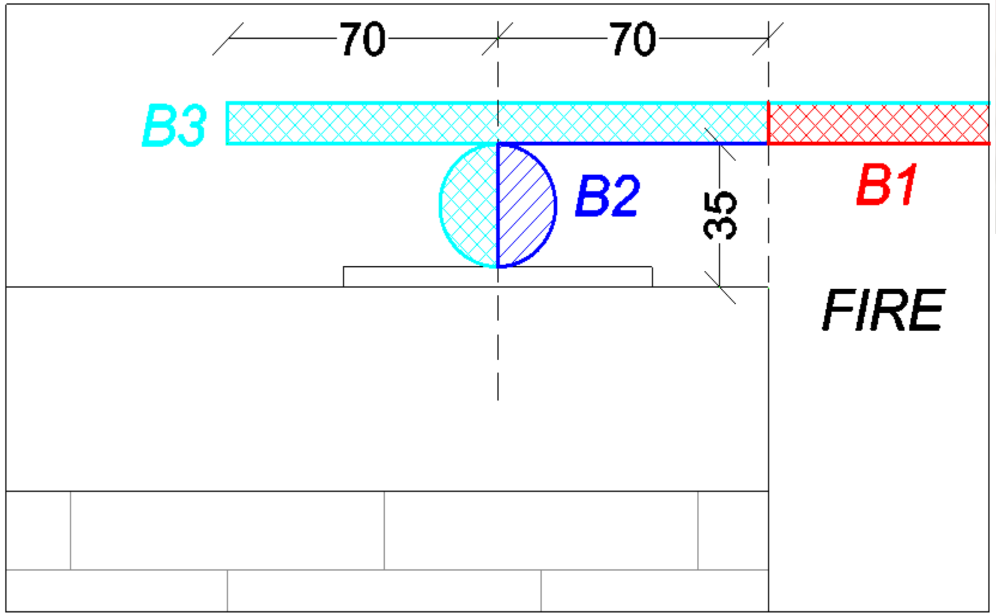
Max. stress after 125s

Fire (furnace test)

Refined models (full 3D)



Actual thermal exposure?



Fire (furnace test)

Conclusions

- Structural glass is highly susceptible to thermal loads, that could add in combination with mechanical design actions, derive from extreme climatic conditions, and/or result from accidental events (fire)
- Actually, major limits are represented by the limited knowledge of thermo-physical and mechanical properties under extreme temperature scenarios
- Further uncertainty can derive from glass in contact with other common constructional materials, like for example in the region of supports and connections
- As a result, experiments at all the levels have added value for research and design developments (materials, members, systems, assemblies)
- Within such a kind of investigation, Finite Element numerical models can represent a robust tool and capture the actual observations of experiments / real events


Thanks!