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Risk and Uncertainty in Engineering Computations
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Università Degli Studi di Napoli Federico II

Centro Studi P.LIN.I.V.S

Analyses of Resistance of Openings to Pyroclastic Flows

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CONTENTS

MAIN ACTIONS AND EFFECTS

EARTHQUAKES (EQ)	• **Horizontal and vertical cyclic action proportional to masses**	• Damage to structures and/or non-structural elements
PYROCLASTIC FLOWS (PF)	• **Non-cyclical impact** surface action **(0.5-10 kPa),** • **Thermal stress (150/400 °C).**	• Damage to structures and/or non-structural elements, • Openings, • Fire damage inside.
ASH FALL (AF)	• **Uniform vertical static pressure on roofs**	• Collapse of the roofing slabs
LAHAR (LH)	• **Non-cyclical impact** surface action **(20/90 kPa),** • **Temperature effect (<100°C).**	• Damage to structures and/or non-structural elements especially on the ground floor

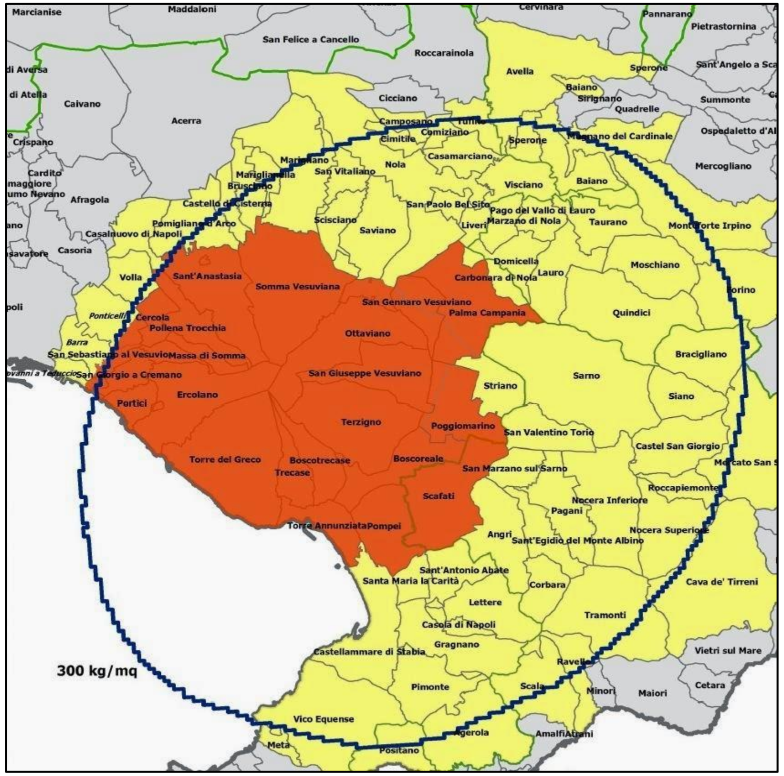
SOURCE: Spence R., Zuccaro G., Petrazzuoli S., Baxter P.J., (2004b). **The resistance of buildings to pyroclastic flows: theoretical and experimental studies in relation to Vesuvius.**

Montserrat Experience (Lesser Antilles)

SOURCE: Baxter P.J., Boyle R., Cole, Neri A., Spence R., Zuccaro G., (2005). The impacts of pyroclastic surges on buildings at the eruption of the Soufrière Hills volcano, Montserrat

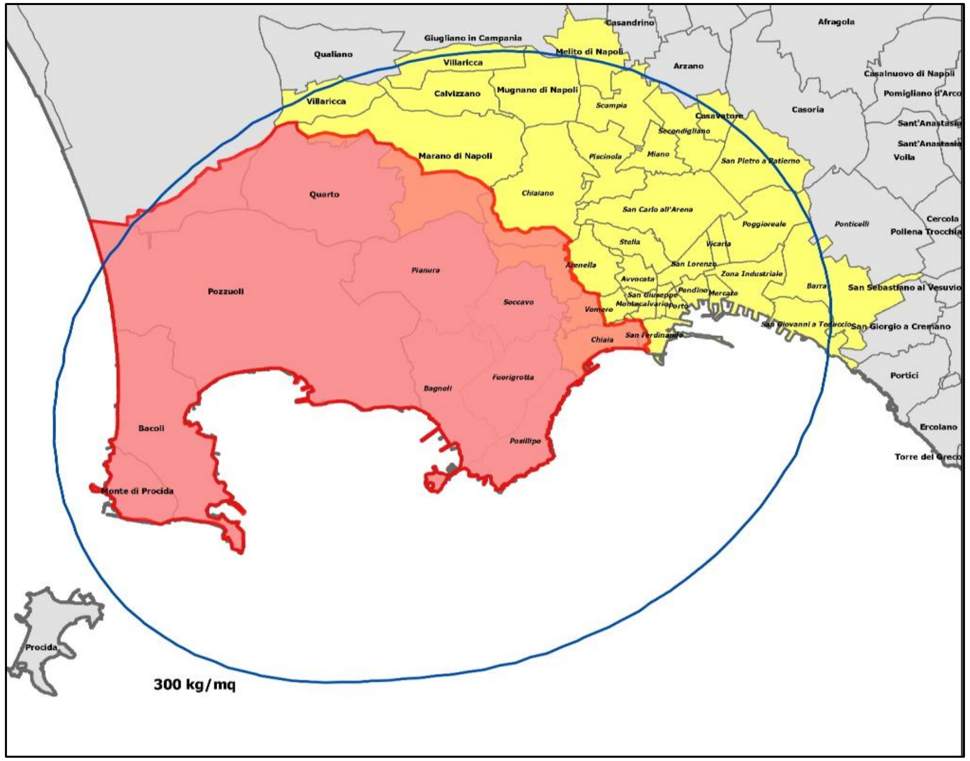
REFERENCE SCENARIO: VESUVIUS AND CAMPI FLEGREI

SOURCE: Civil Protection Department
«Scenari Eruttivi e Livelli di Allerta per il Vesuvio» (2010)



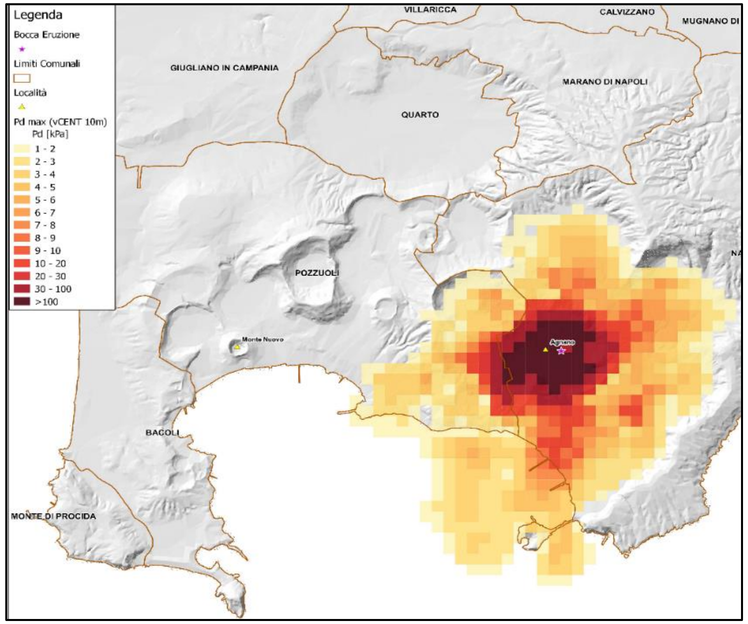
- the formation of a sustained **eruptive column** 18 km high and with a total erupted mass of 5.0 e^{11} kg;
- the fall of **volcanic bombs** and **blocks** in the immediate vicinity of the crater and smaller particles (ash and lapilli) even several tens of kilometers away;
- the formation of **pyroclastic flows** that would flow along the slopes of the volcano for several kilometers.

SOURCE: Civil Protection Department
«Scenari Eruttivi e Livelli di Allerta per Campi Flegrei» (2012)



- the formation of a sustained **eruptive column** 12 km high and with a total erupted mass of 1,2 e^{11} kg;
- the fall of **volcanic bombs** and **blocks** in the immediate vicinity of the crater and smaller particles (ash and lapilli) even several tens of kilometers away;
- the formation of **pyroclastic flows** that would flow along the slopes of the volcano for several kilometers.

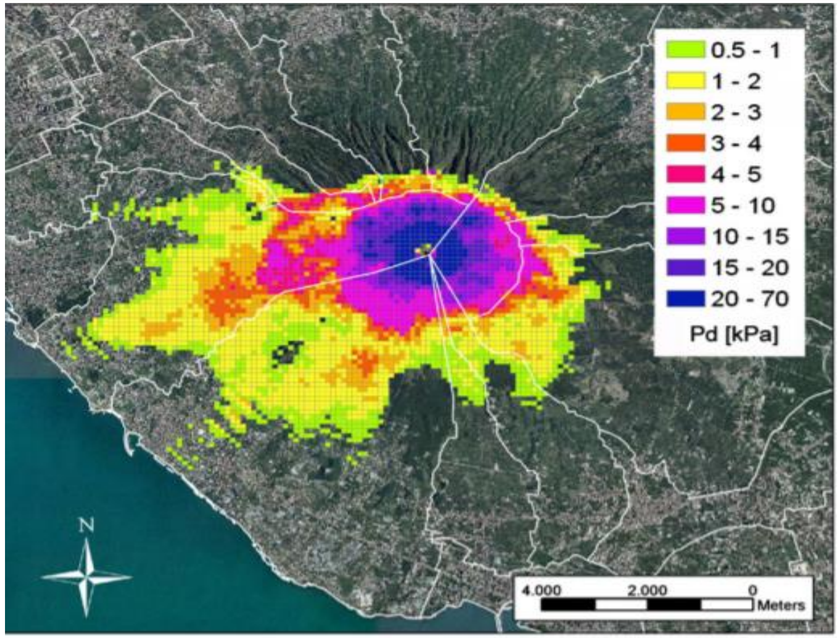
REFERENCE PRESSURE AND TEMPERATURE

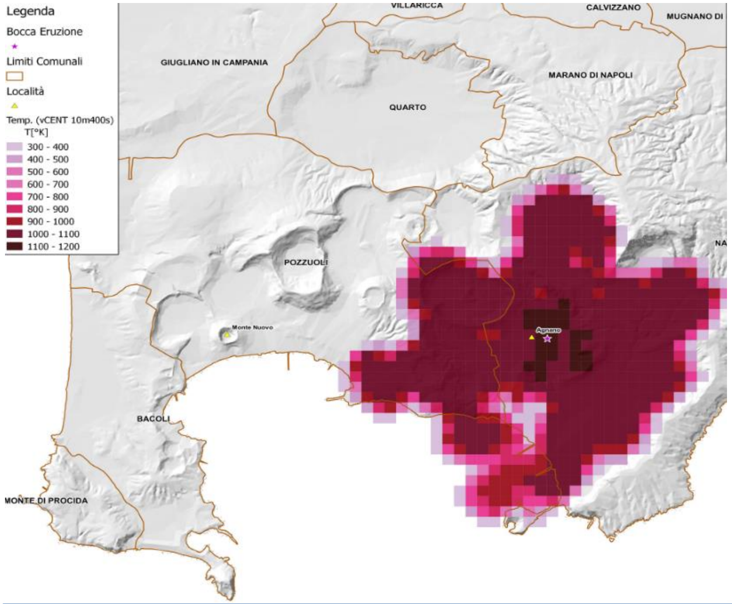


Pressure Campi Flegrei

Reference pressure: 5 kPa

Pressure Vesuvius

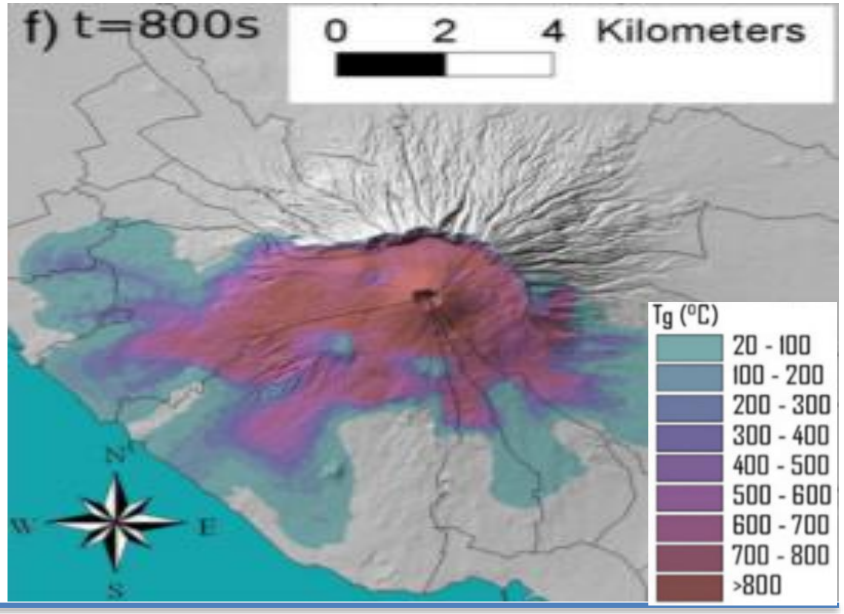




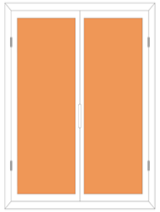
Temperature Campi Flegrei

Reference Temperature: 400 °C

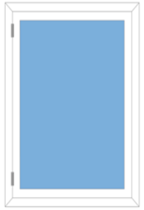
Temperature Vesuvius



A	Wood
B	UPVC
C	Aluminium
D	Iron
E	Armoured iron



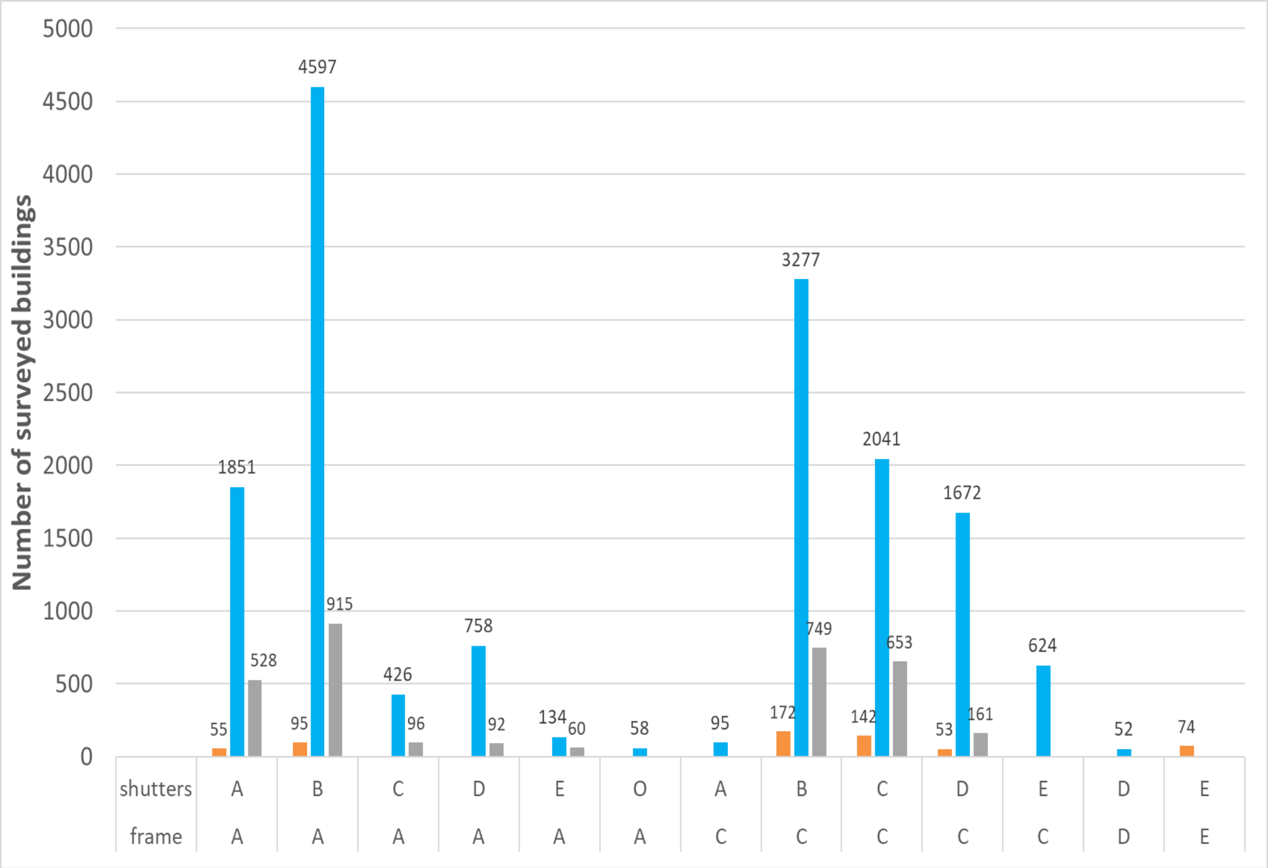
LARGE
A ≥ 1,5 m^2



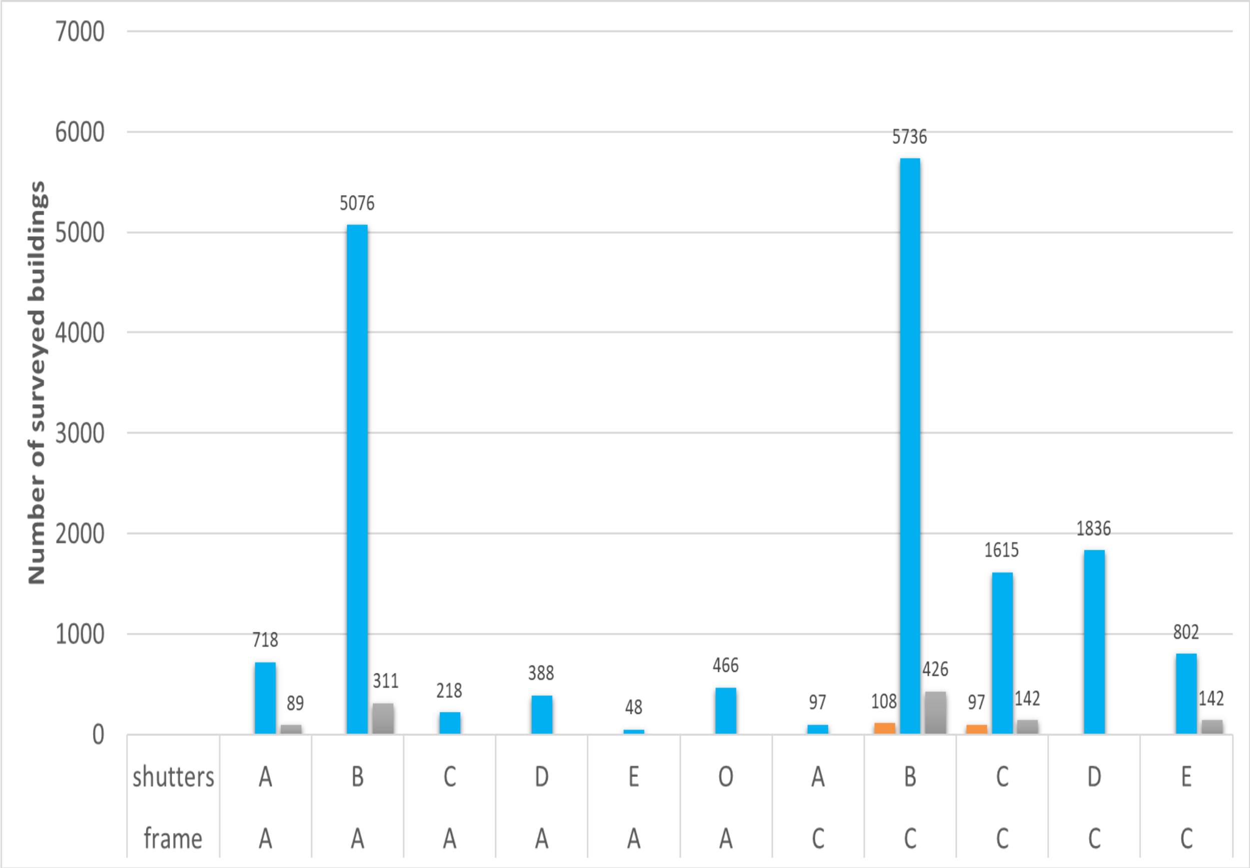
MEDIUM
0,5 < A < 1,5 m^2

SMALL
A < 0,5 m^2

Windows in Vesuvio area

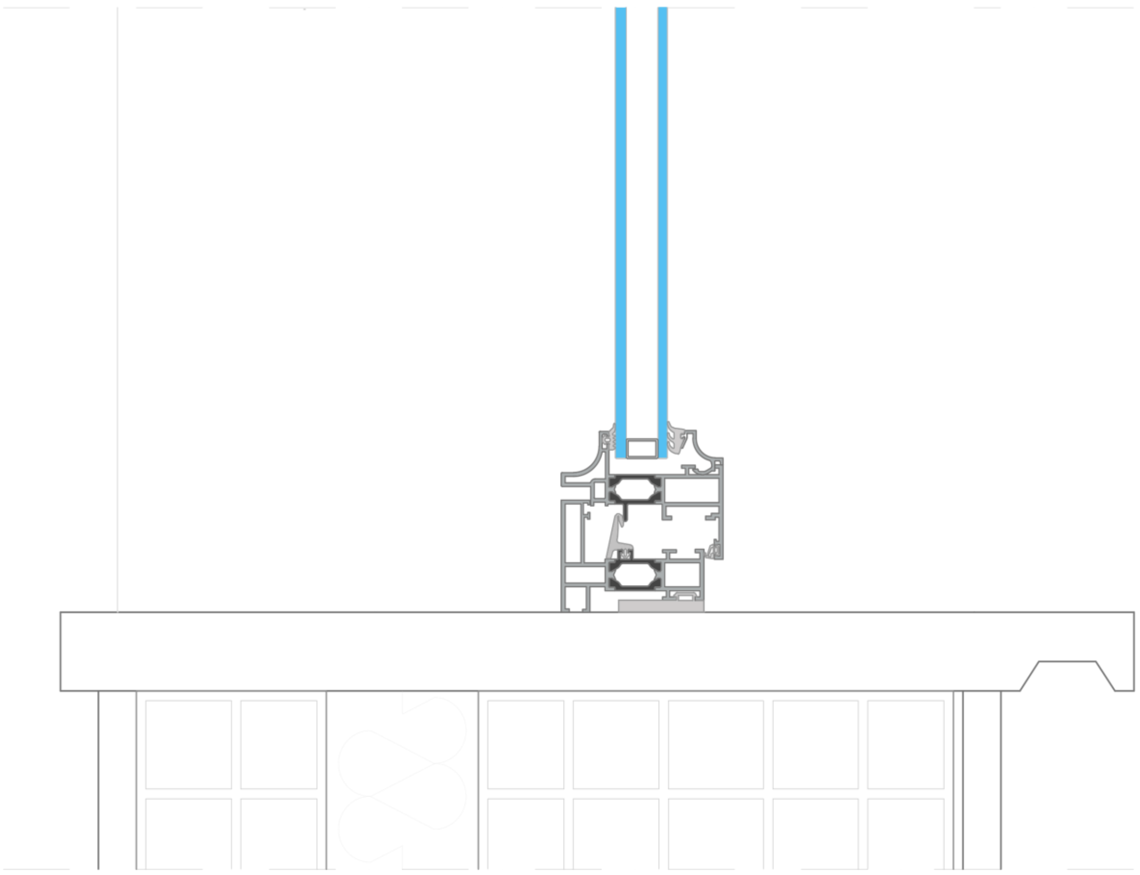


Windows in Campi Flegrei area

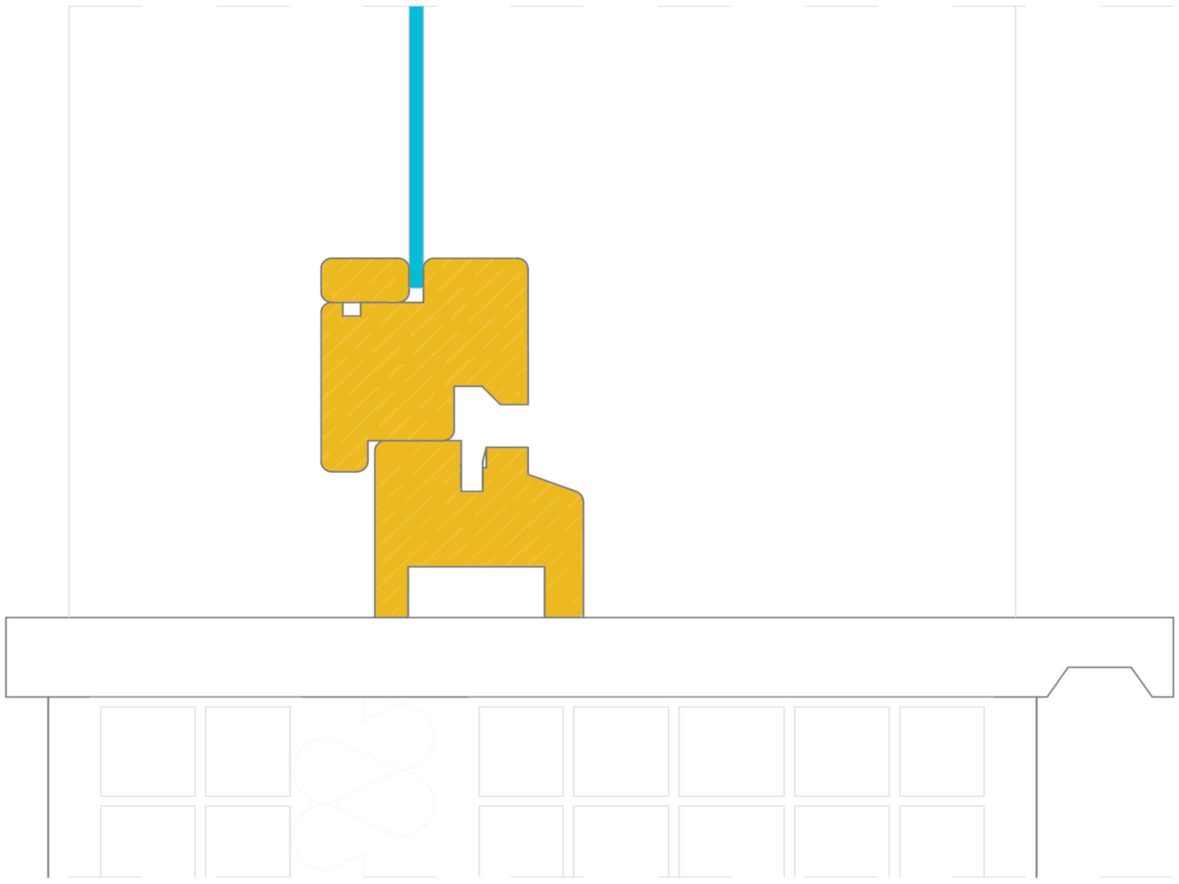


GEOMETRICAL MODEL

Aluminium Thermal Break



Wood



MECHANICAL ASSESSMENT

1. Solid Mechanics

$$\nabla \cdot \sigma + b = 0$$

Materials

Aluminium

$$\varepsilon = \frac{\sigma}{E} + K \left(\frac{\sigma}{\sigma_y}\right)^{\frac{1}{n}}$$

Wood and Glass

$$\sigma = C : \varepsilon_{el}$$

Applied load

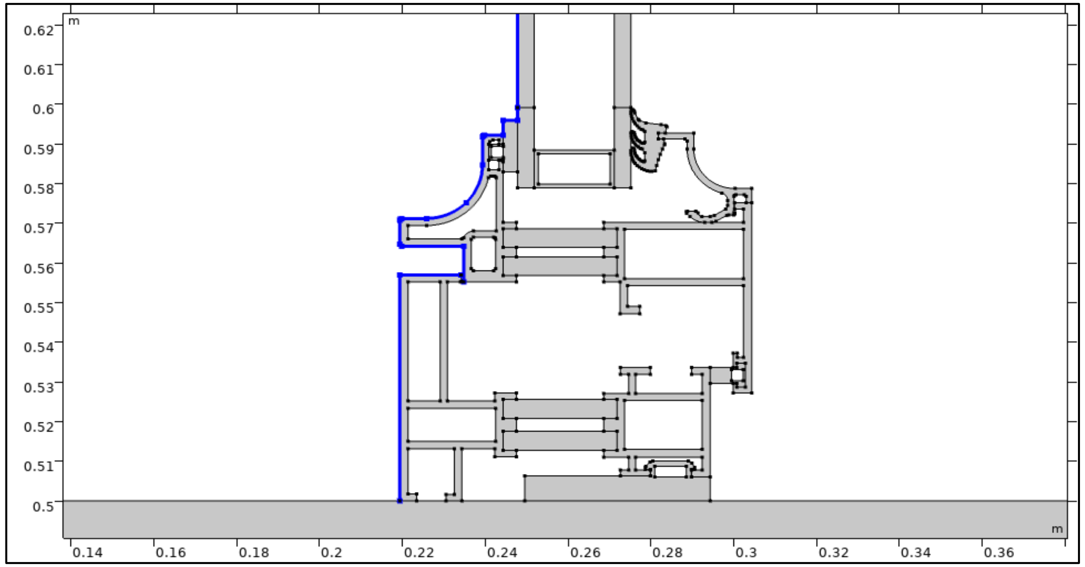
$$\sigma \cdot \boldsymbol{n} = F_A \longrightarrow F_A = \frac{F_L}{d}$$

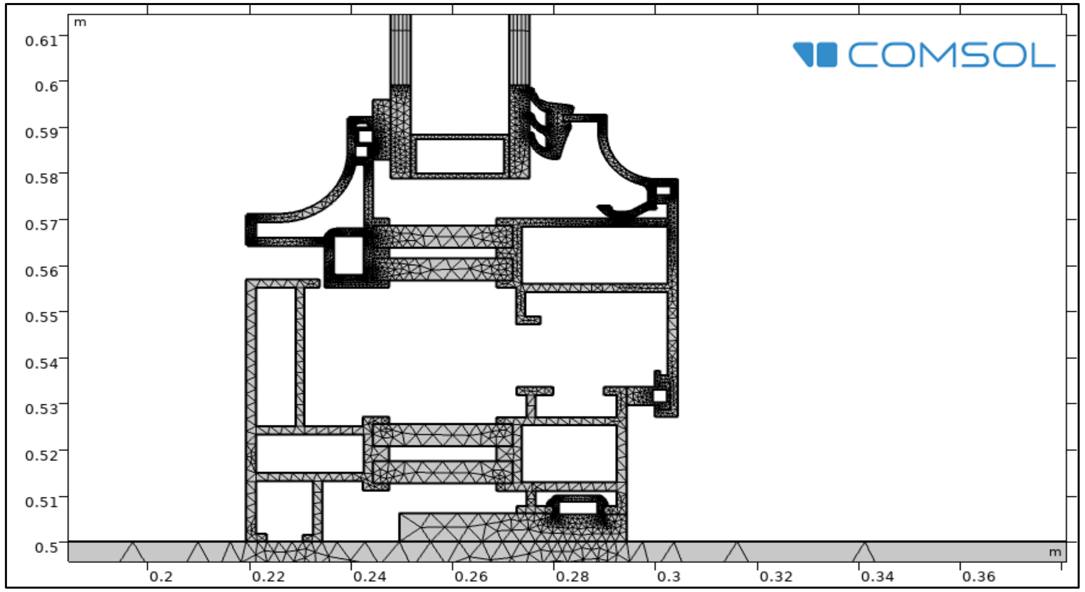
$$F_L = 5[kN/m] * f(t) \longrightarrow f(t) = range\,(0,0.01,1)$$

Stop Condition (glass)

comp1.StressMax > 40[MPa]

40[MPa] = glass breaking tension





GLASS BREAKING PRESSURES

Frame	Glass								
Aluminium	SODA LIME GLASS								
	Large			Typical			Small		
	4mm	5mm	6mm	4mm	5mm	6mm	4mm	5mm	6mm
	0,6 kPa	1 kPa	1,3 kPa	2 kPa	3 kPa	4,3 kPa	5,3 kPa	8 kPa	10 kPa

Frame	Glass								
Wood	SODA LIME GLASS								
	Large			Typical			Small		
	4mm	5mm	6mm	4mm	5mm	6mm	4mm	5mm	6mm
	2 kPa	2,3 kPa	3,3 kPa	4,6 kPa	6,6 kPa	9,6 kPa	8,6 kPa	14,6 kPa	22,6 kPa

2. Thermal Stress

Heat transfer in solid

$$d_z\rho C_p \frac{\delta T}{\delta t} + d_z\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = d_z Q + q_0 + d_z Q_{ted}$$

$$\mathbf{q} = -K\nabla T$$

Thermal expansion

$$\varepsilon_{th} = \alpha(T)\left(T - T_{ref}\right)$$

$$F_{inel}{}^{-1} \rightarrow F_{th}{}^{-1} F_{inel}{}^{-1}, F_{th} = I + \varepsilon_{th}$$

Applied temperature

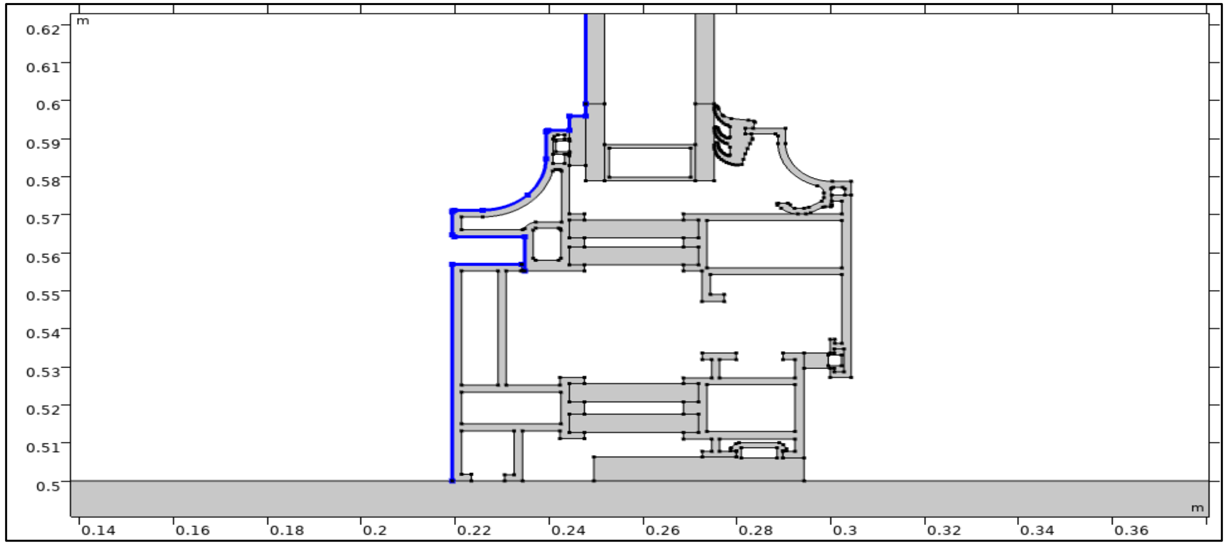
$$T = T_i + sin(T) * t * P$$

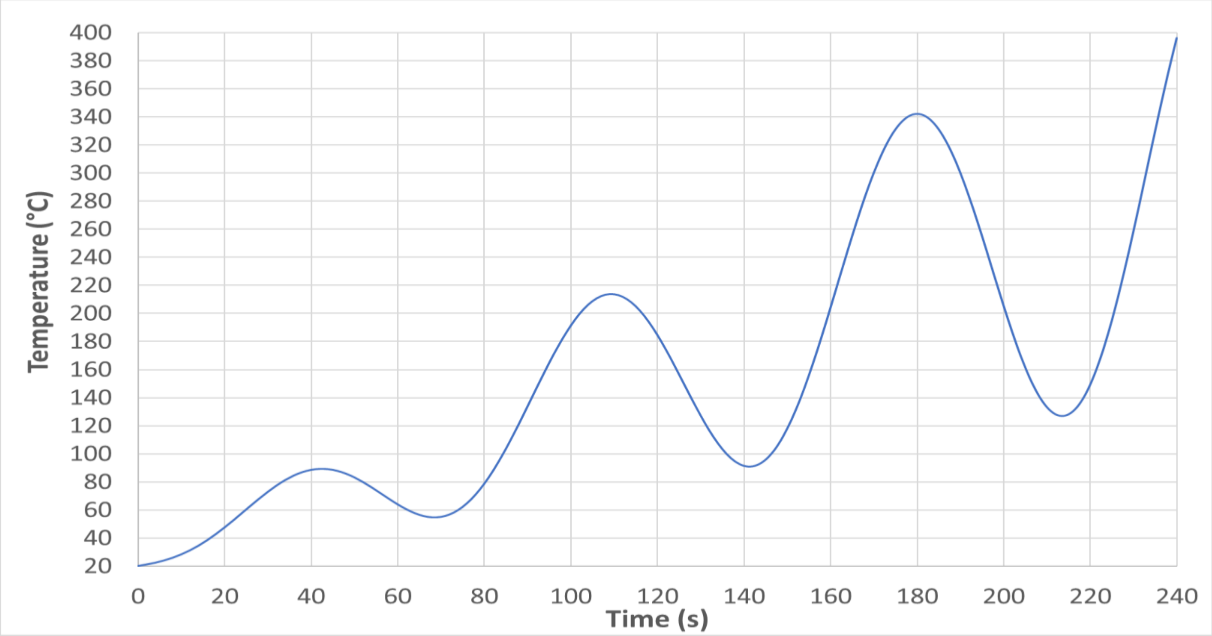
Stop Condition (glass)

comp1.T Polymide > **120[°C]**

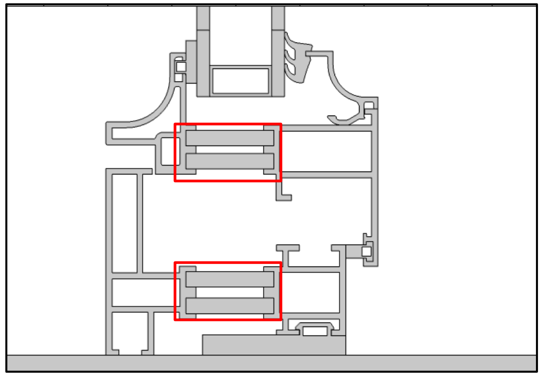
comp1.T EPDM > **50[°C]**

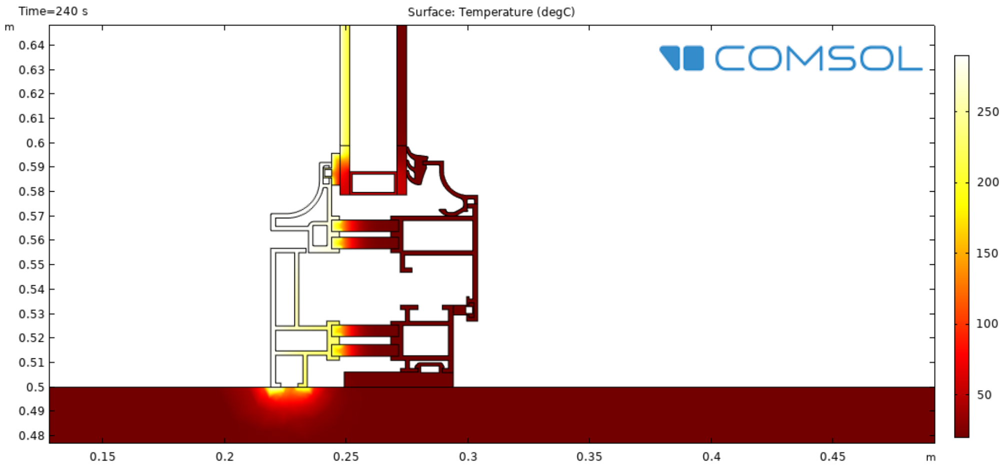
comp1.T Glass > **52[°C]**

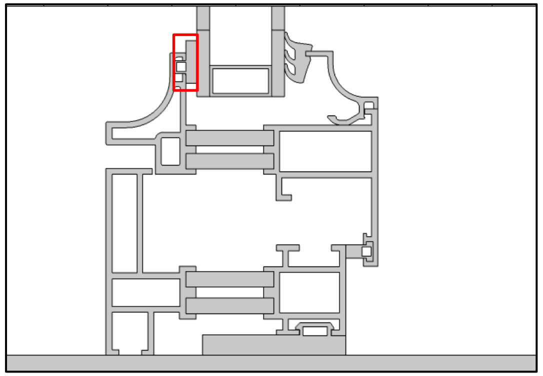




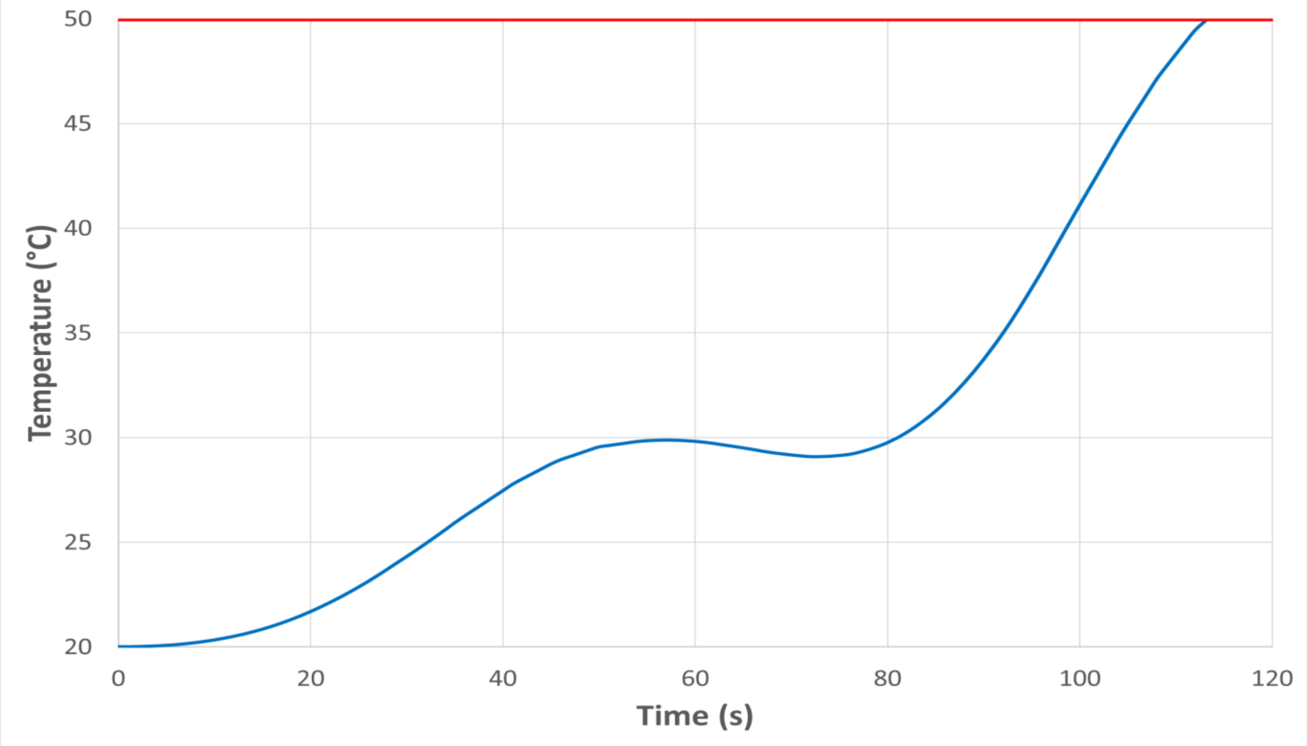
THERMAL ASSESSMENT



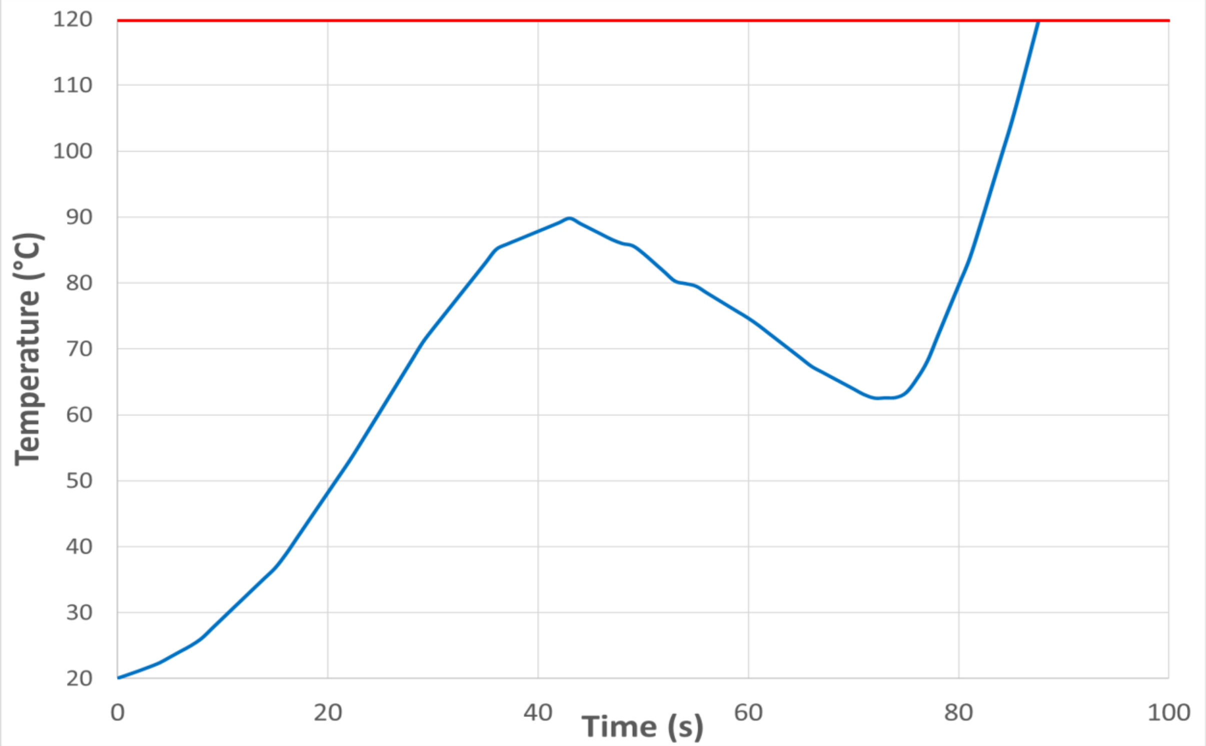




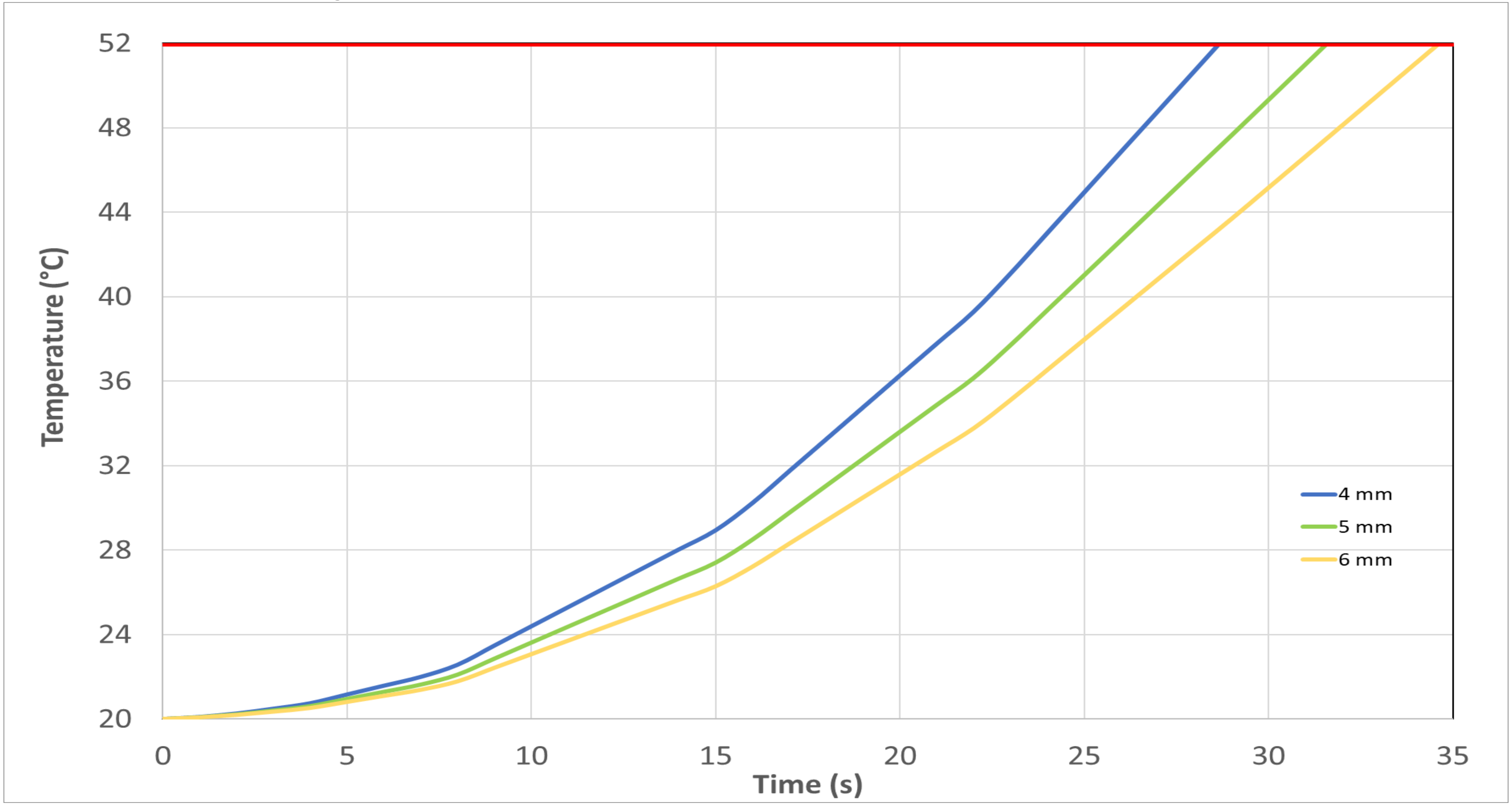
Reached temperature by polyamide



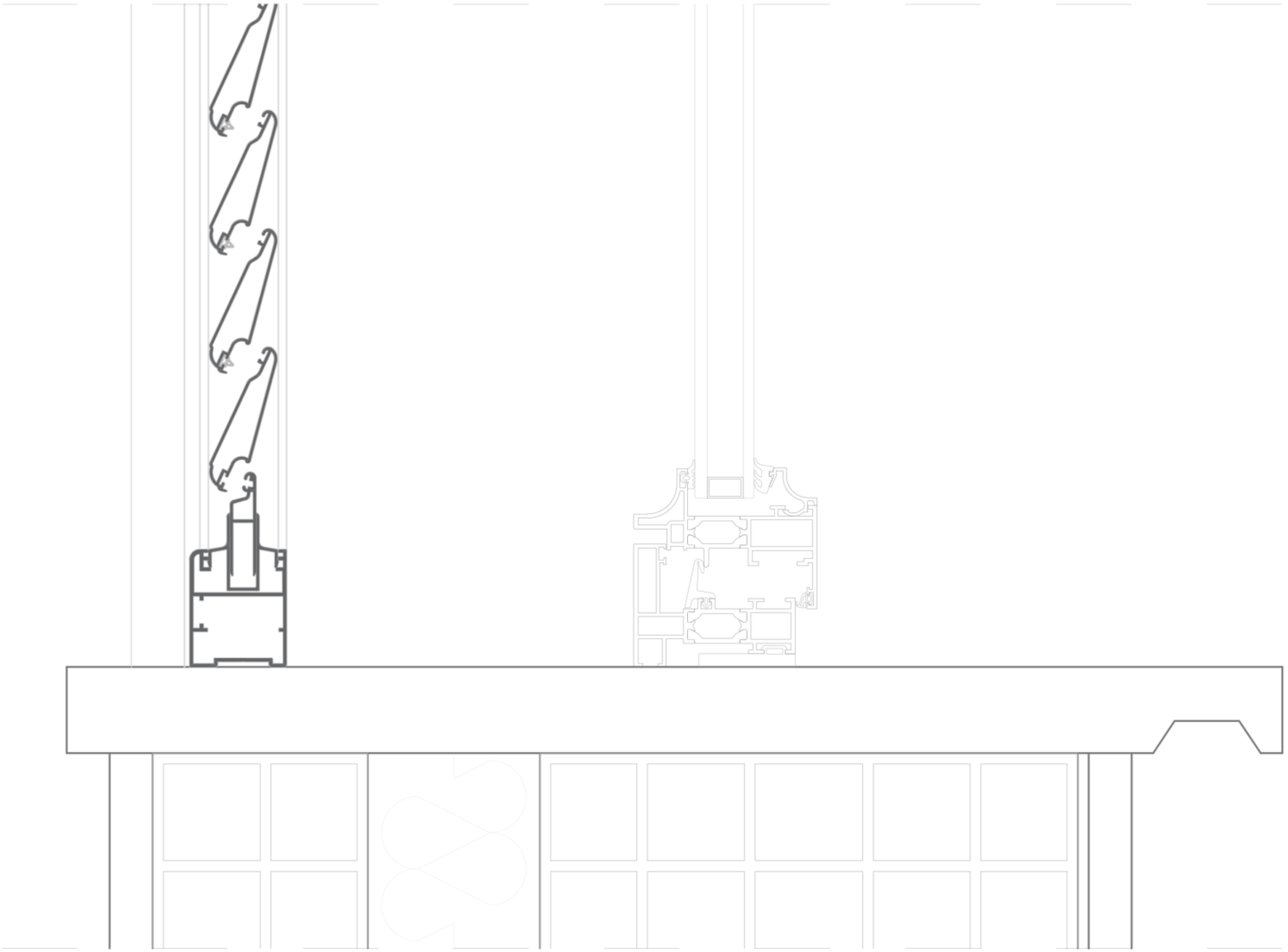
Reached temperature by EPDM



Reached temperature by glass



SHUTTERS



FLUID DYNAMICS ASSESSMENT

1. Turbolent Flow (k-ε)

$$\rho(\mathbf{u_{fluid}} \cdot \nabla)\mathbf{u_{fluid}} = \nabla \cdot [-p\mathbf{I} + \mathbf{K}] + \mathbf{F} \quad (4.1)$$

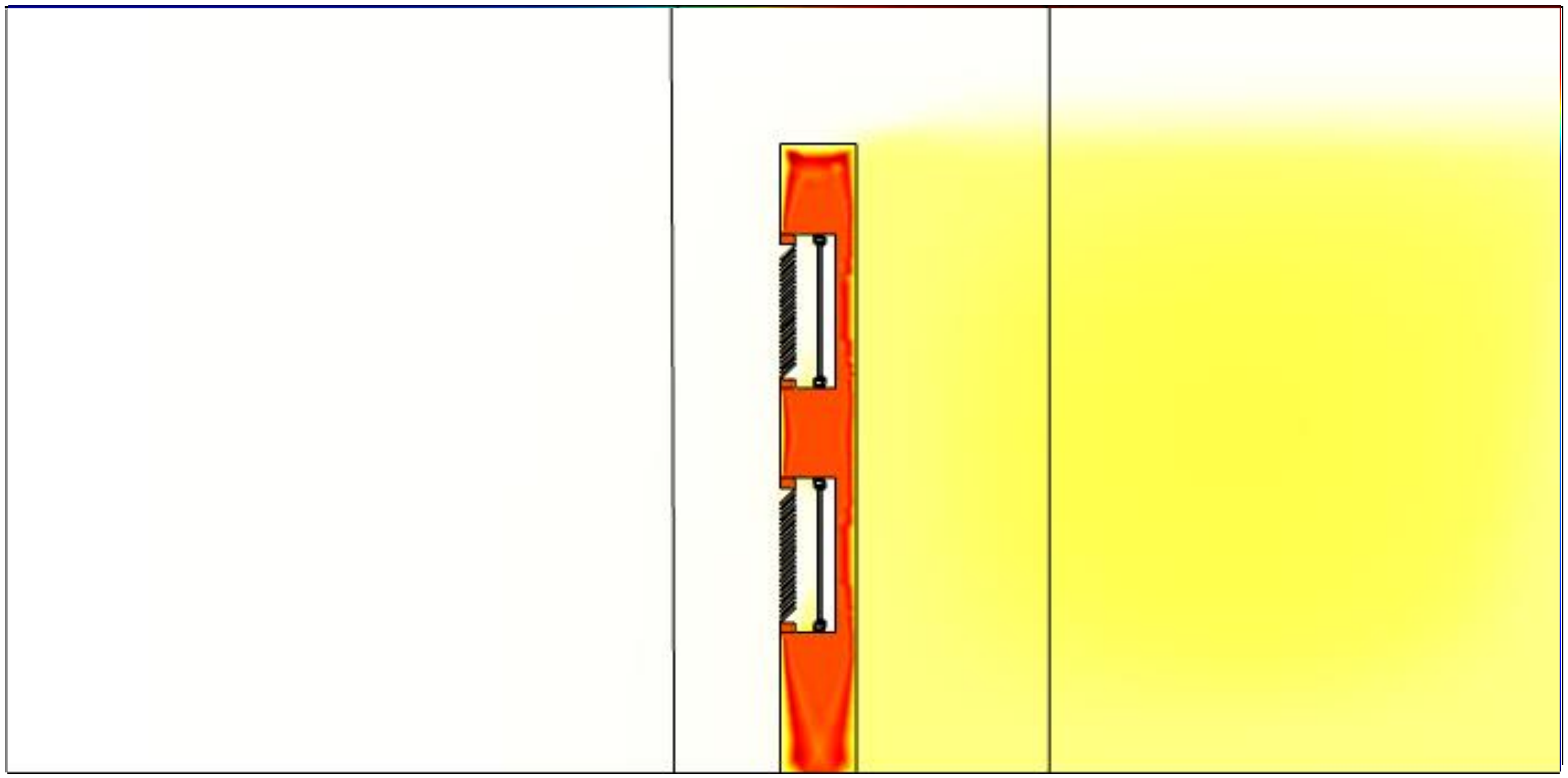
$$p\nabla \cdot \mathbf{u_{fluid}} = 0$$

2. Nonisothermal Flow

$$-\mathbf{n} \cdot \mathbf{q} = \rho C_p u_\tau \frac{T_w - T}{T^+}$$

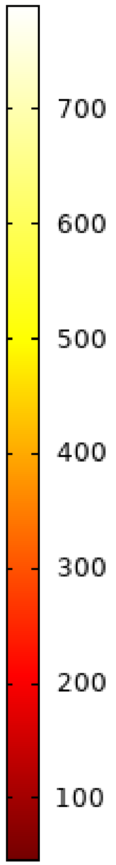
Inlet\

$\mathbf{u_{fluid}} = 25$ m/s

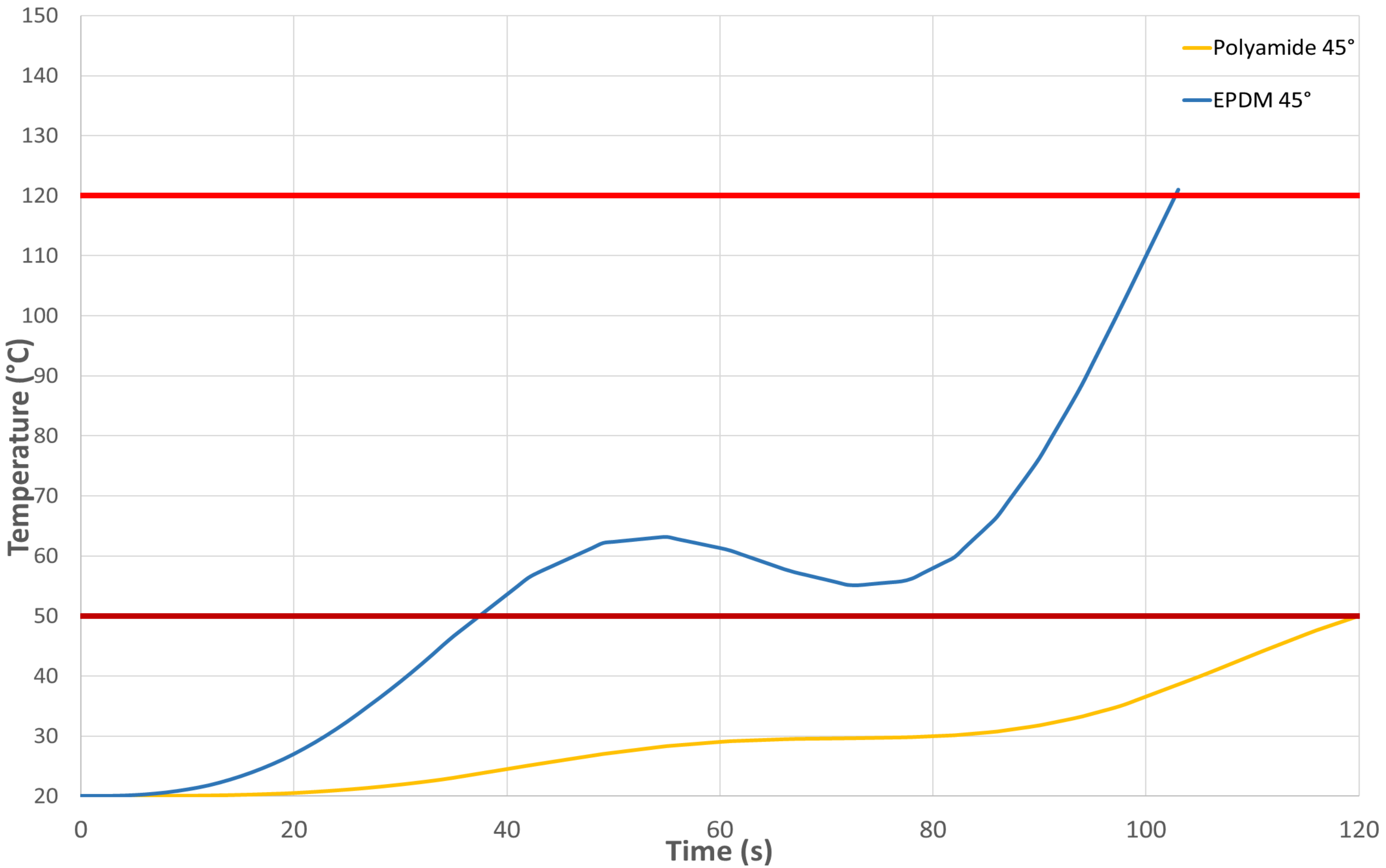


Outlet

$\boldsymbol{p} = \mathbf{0}$



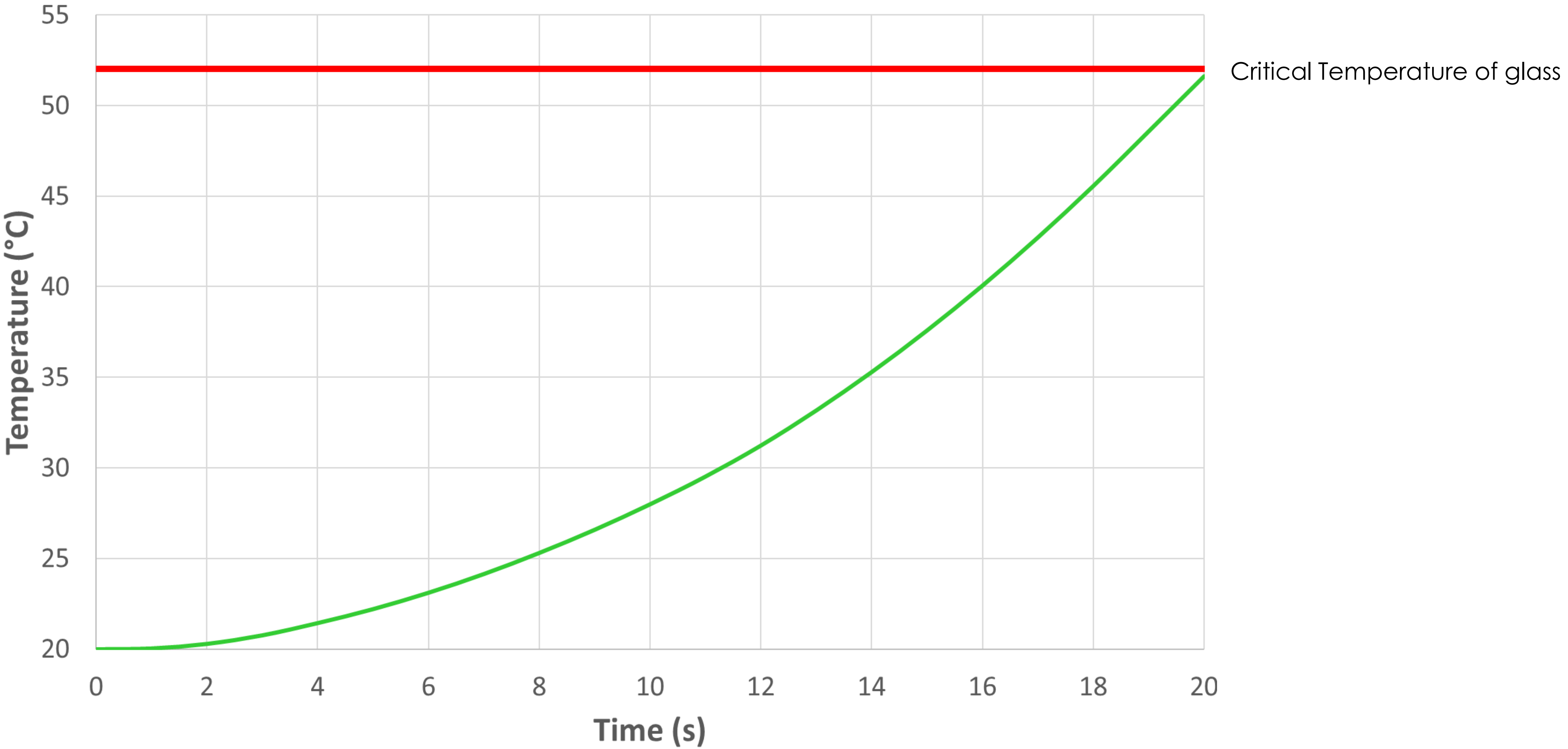
FLUID DYNAMICS AND THERMAL ASSESSMENT



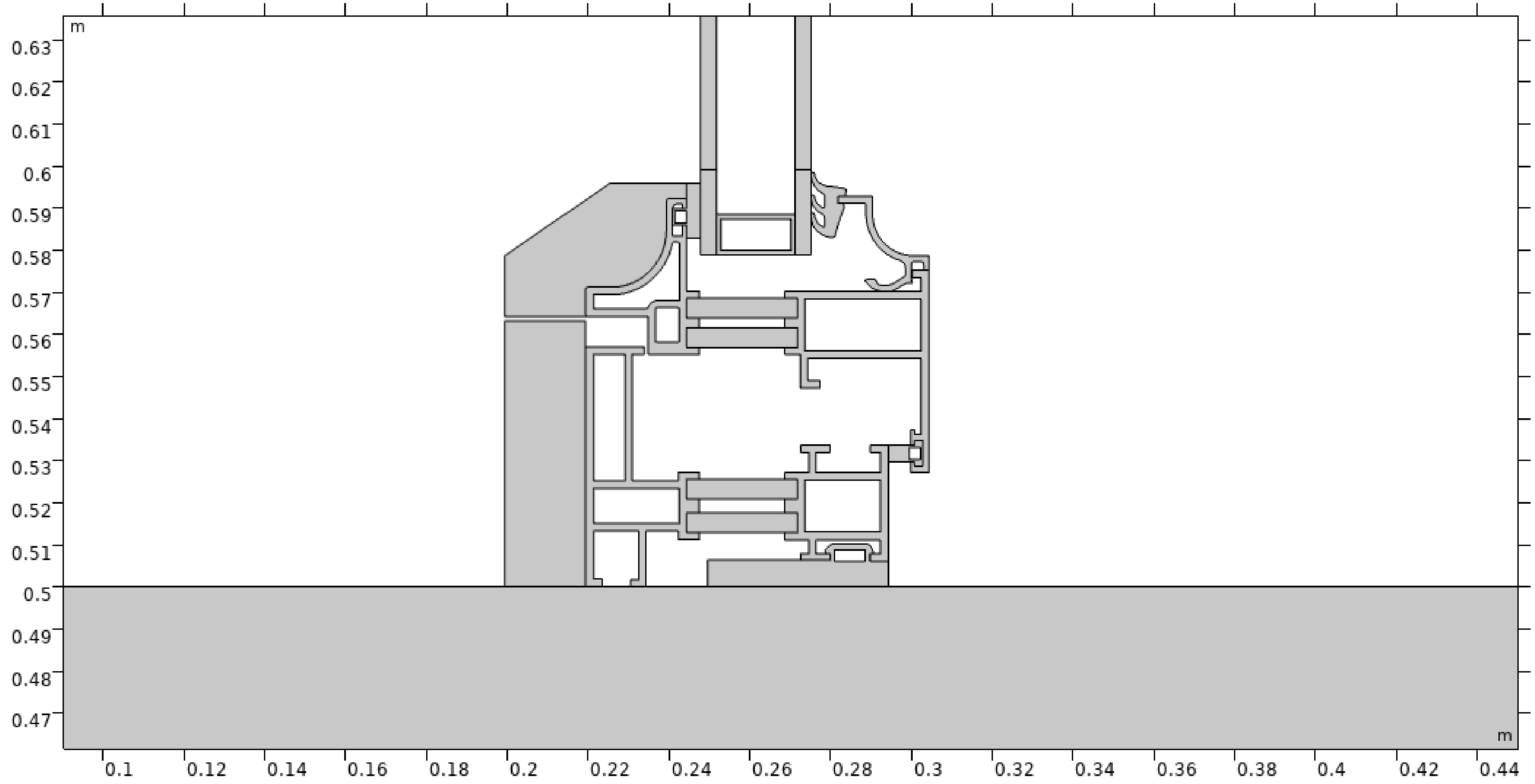
Critical Temperature of EPDM

Critical Temperature of Polyamide

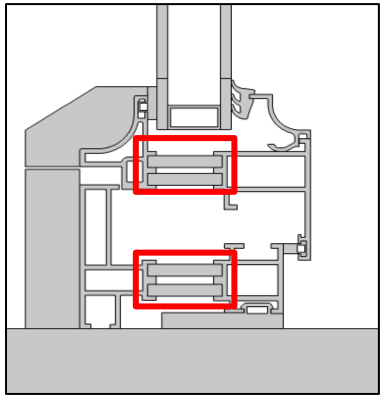
FLUID DYNAMICS AND THERMAL ASSESSMENT

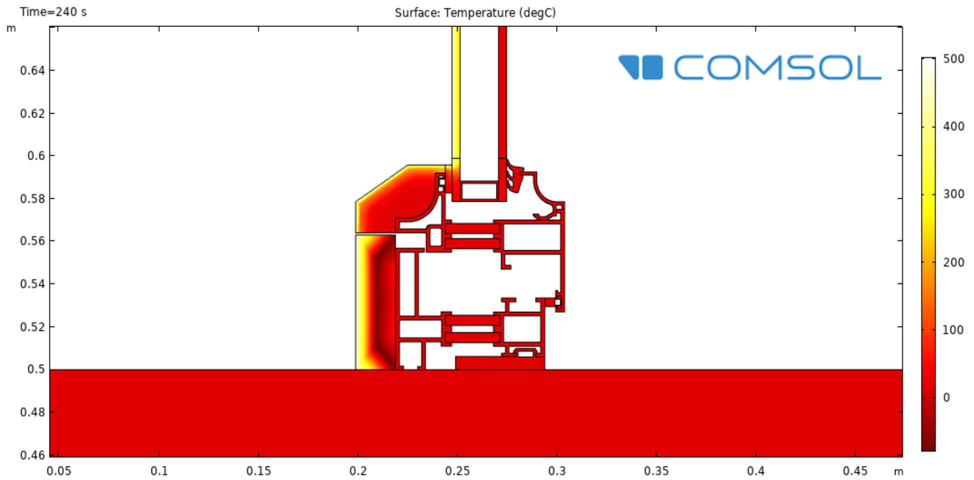


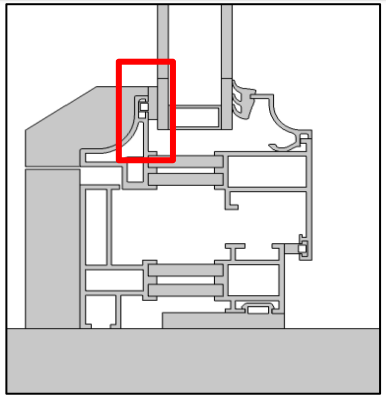
MITIGATION STRATEGY



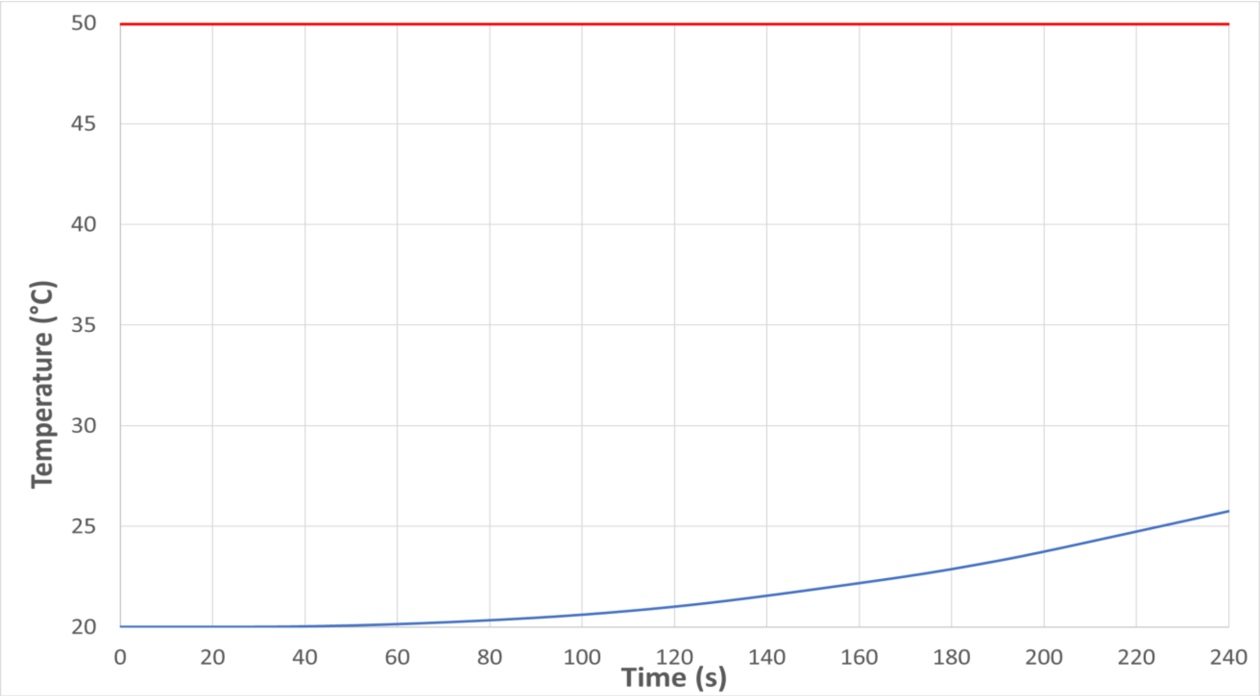
THERMAL ASSESSMENT



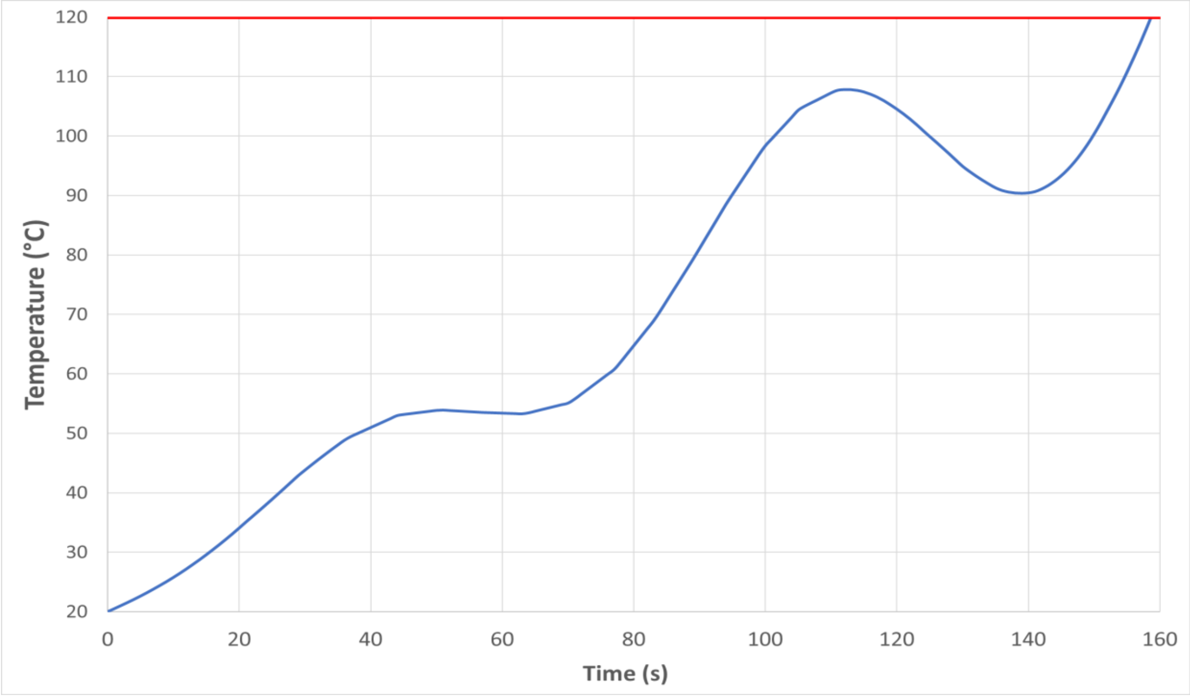




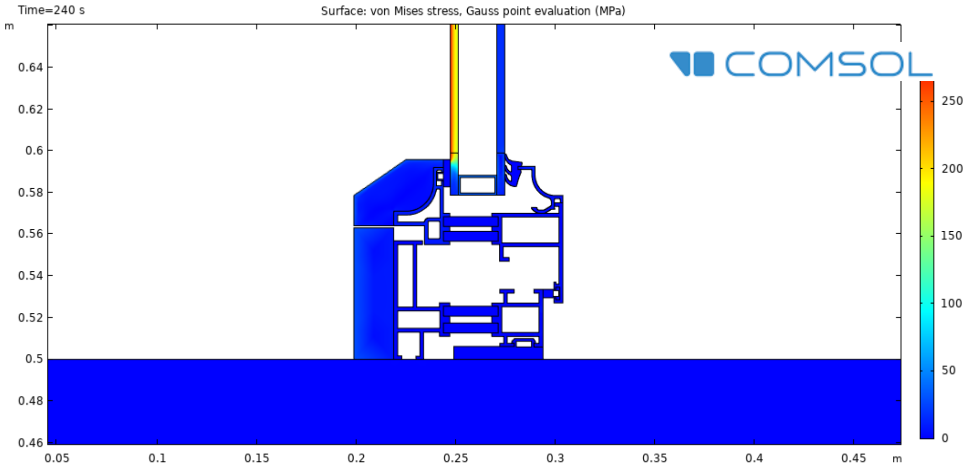
Temperature reached by polyamide



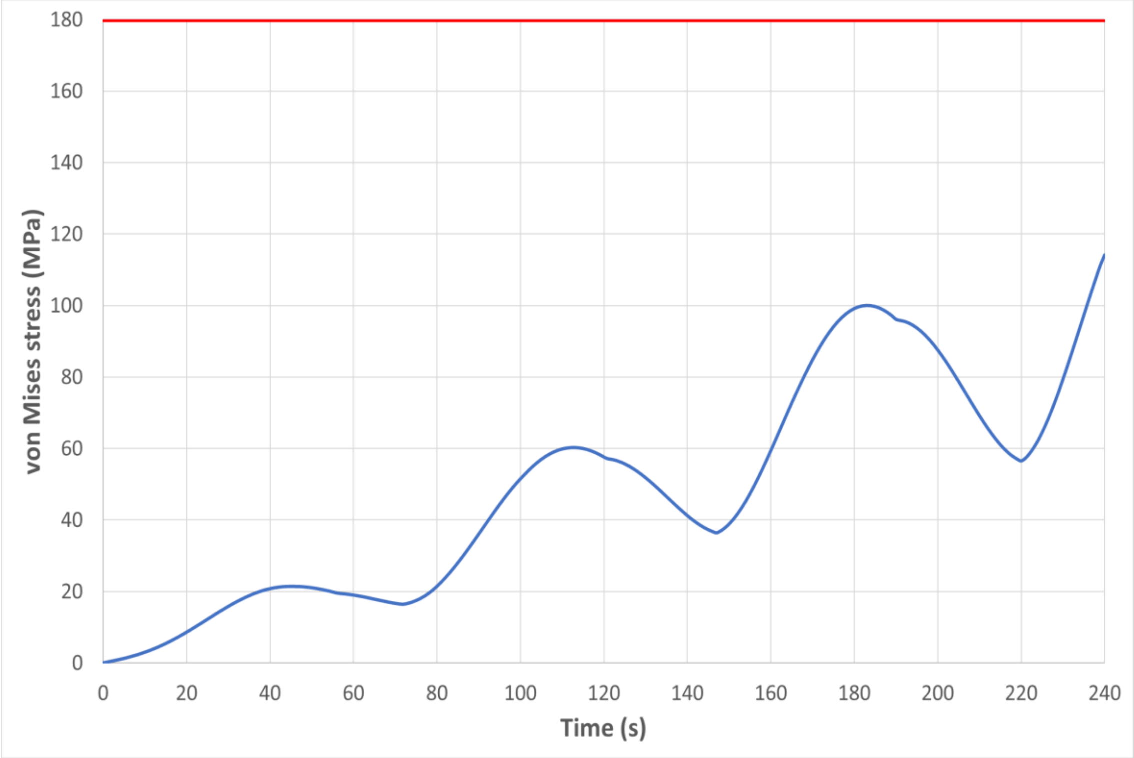
Temperature reached by EPDM



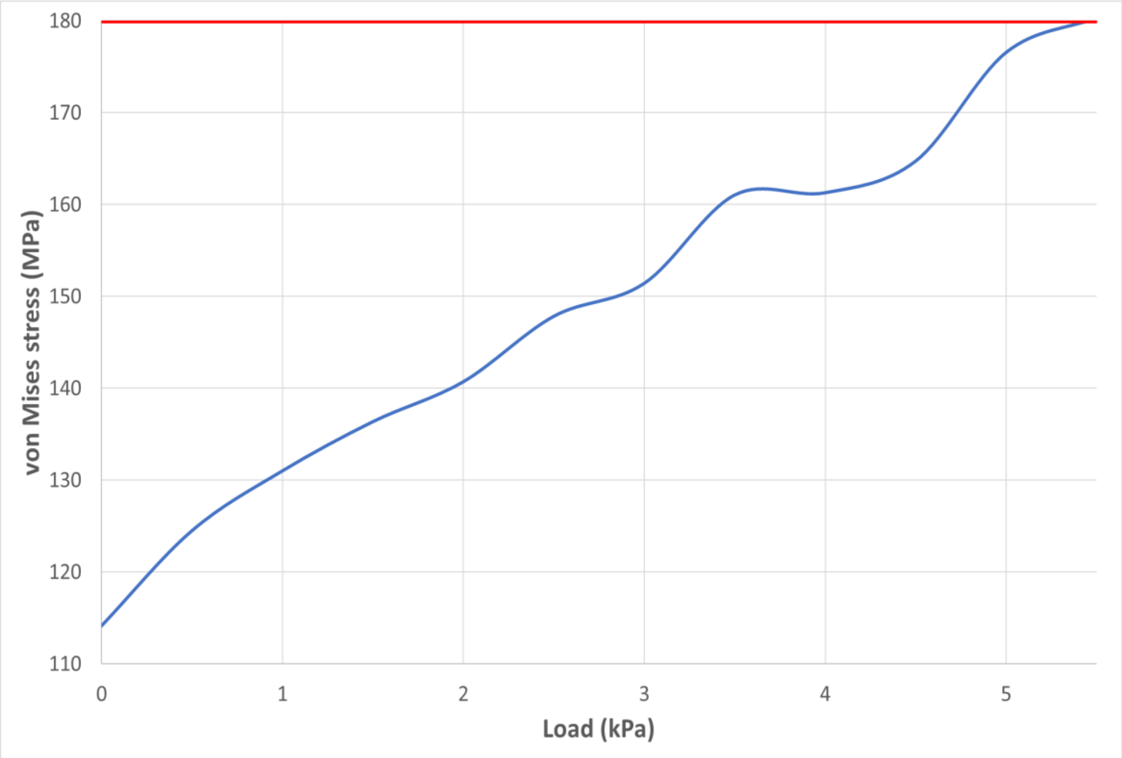
THERMAL ASSESSMENT



von Mises stress of the tempered glass due to the temperature

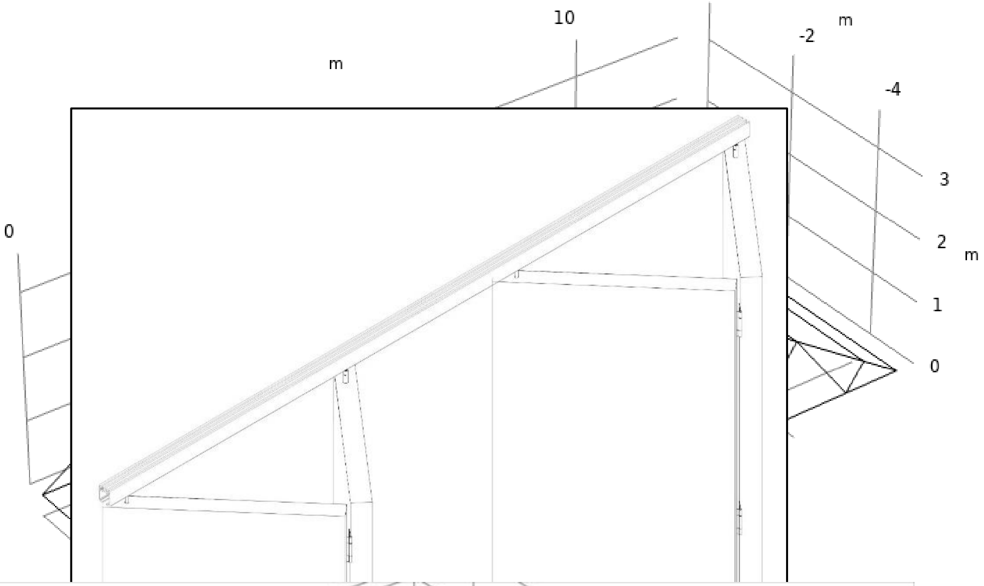


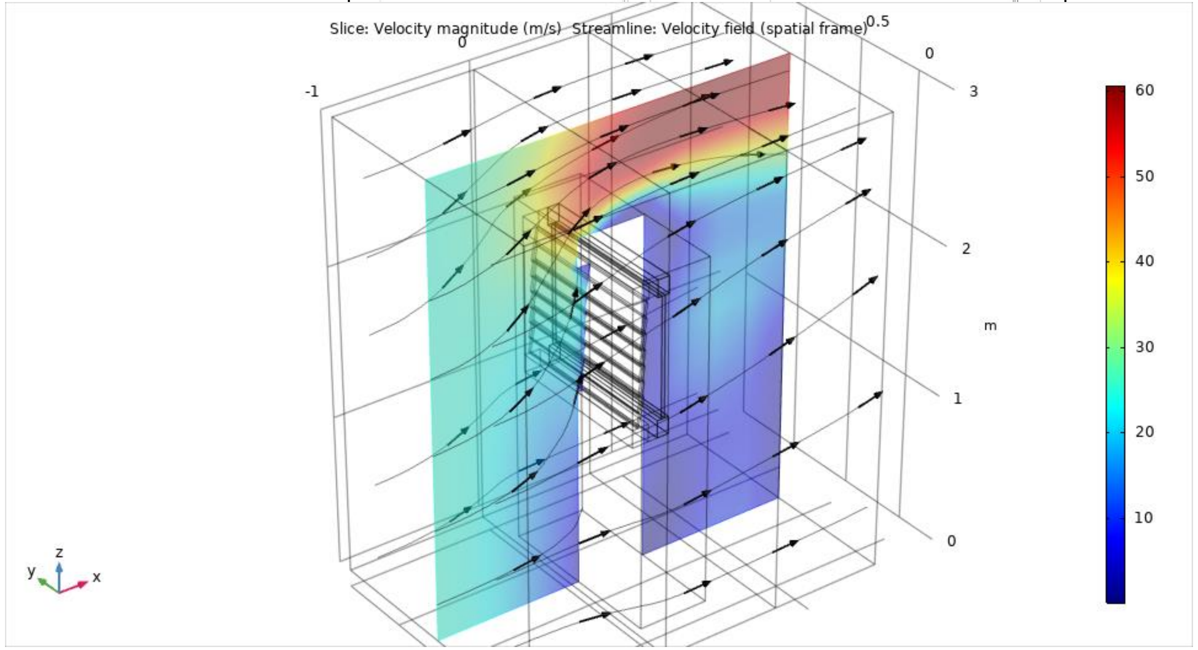
von Mises stress of the tempered glass due to the pressure



CONCLUSIONS AND PERSPECTIVES

- Analysis of ash fall roofs,
- Analysis of construction details of a new model of shutter,
- Cost-benefit analysis,
- 3D fluid dynamics analyses.





THANK YOU FOR YOUR KIND ATTENTION

Contact: mauro.iacuaniello@unina.it