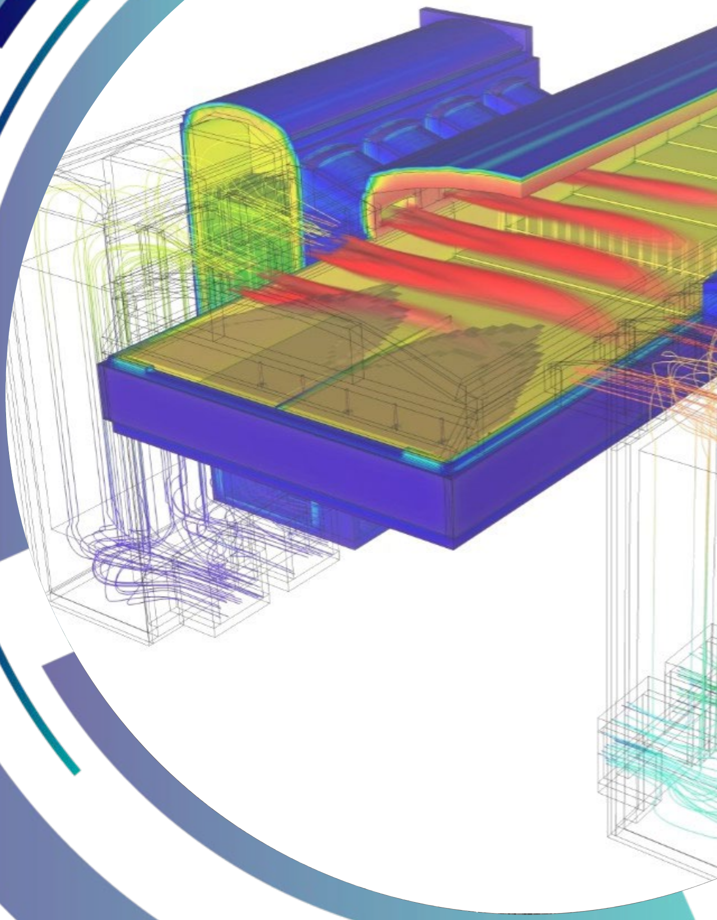
From Siemens to Simulation
Understanding and Optimizing Regenerators



Malte Sander[1], Tomáš Denk[1], Miroslav Trochta[1], Jiří Brada[1], Fabiano Rodrigues[2], Mohamed Lazrak[2]

[1]Glass Service, [2]SEFPRO

October 8th, 2025

86th Glass Problems Conference, Toledo (OH), USA

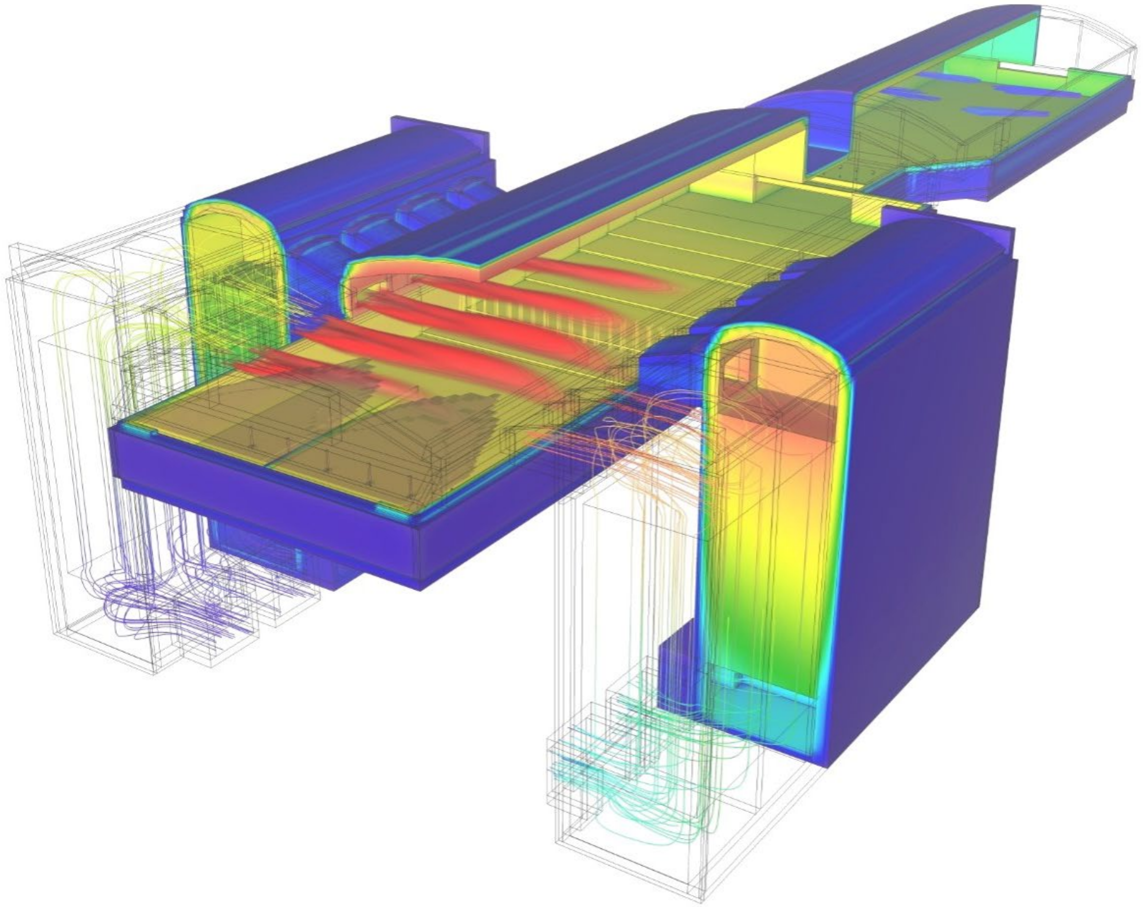
Together we shape a carbon-neutral glass industry, for a brighter future

We are continuously **supporting you** throughout your furnace's life cycle.

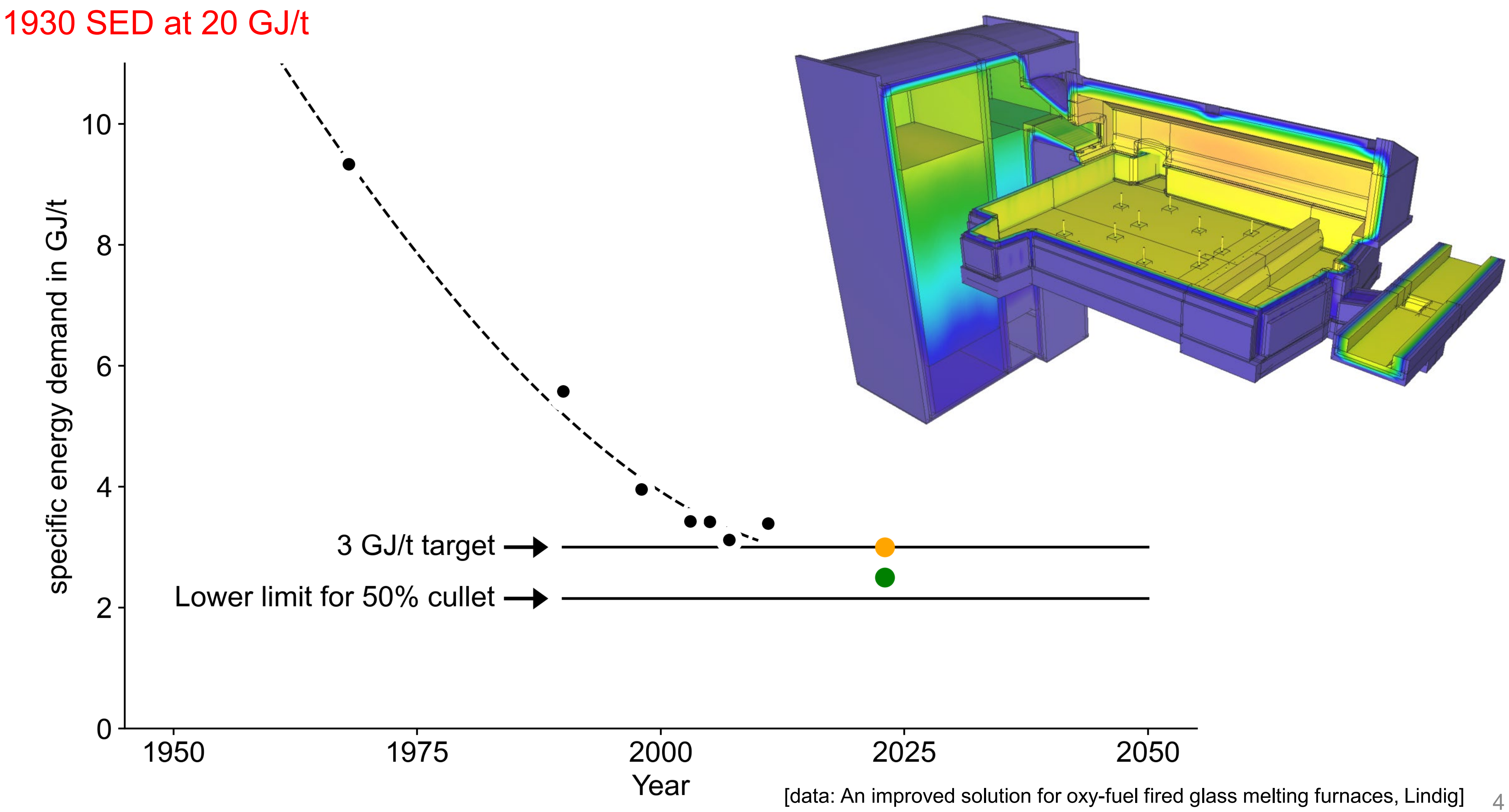
Our goal is to propose solutions to improve your furnace performance and **contribute to your journey towards decarbonization**.

Why do we need new furnace designs?

- The furnace design has an impact on the **glass quality** and **specific energy demand**.
- Stronger regulations on emissions (e.g., NOx, dust).
- End consumer demand for more environment-friendly packaging.
- Alternative energy carrier (e.g., biogas, hydrogen, electrons)
- Changing demand



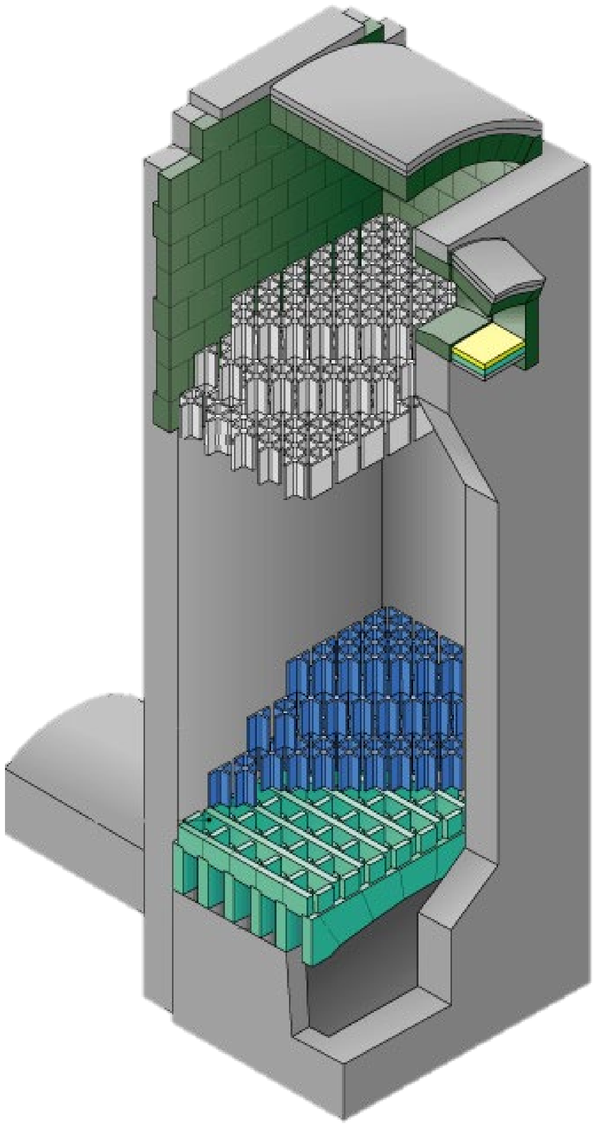
Specific energy demand



[data: An improved solution for oxy-fuel fired glass melting furnaces, Lindig]
[data: Prospects and physical limits of processes and technologies in glass melting, Conradt]

From complex reality to simplified mathematical model

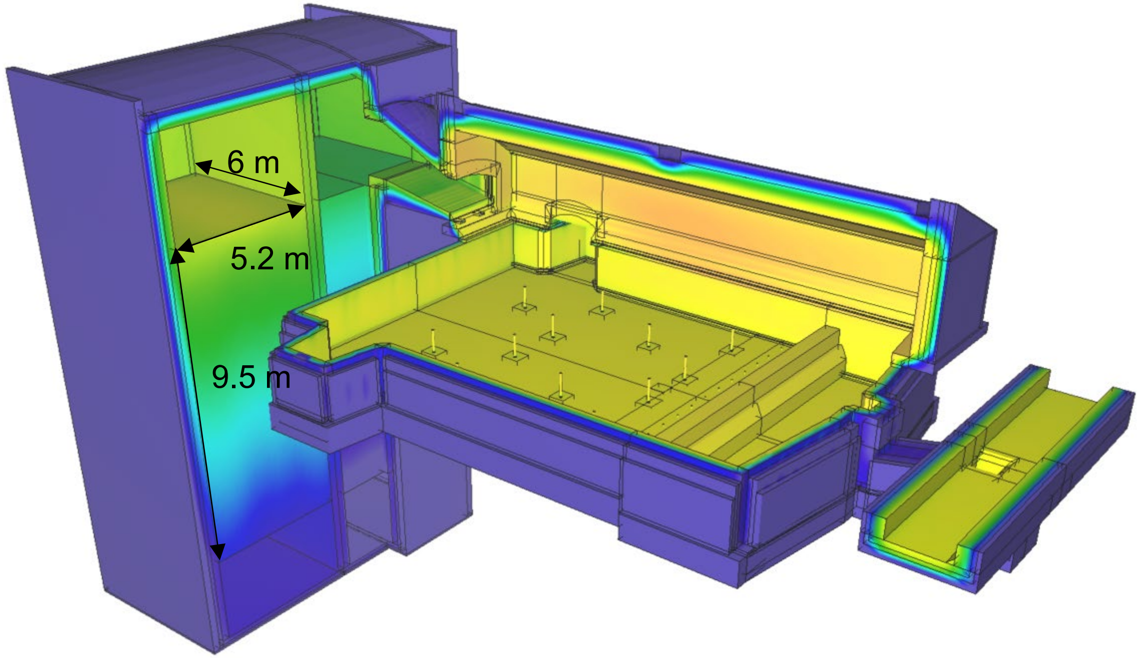
- Computational power and memory are not sufficient to simulate the exact gas flow and temperature distributions when detailed regenerator models are used in a furnace simulation.
- Simplifications help to accelerate the computation process.
- Precise approximations are needed for a correct result.



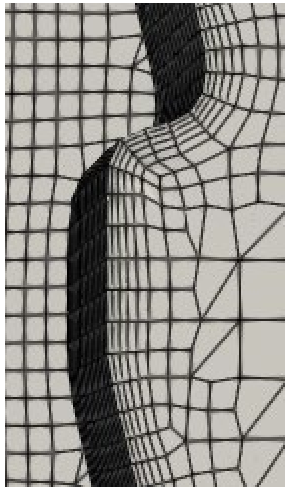
Why Darcy porous wall approximation?

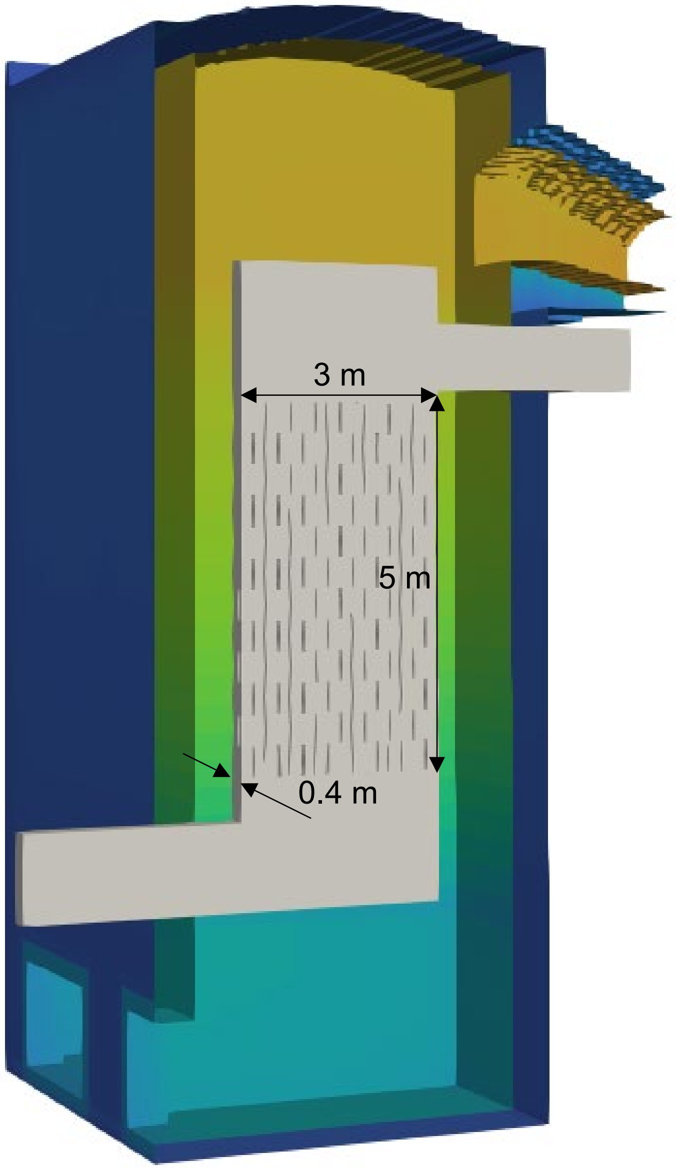
Regenerators are important components of the simulation, as they help achieve realistic temperatures in the furnace. Replacing them with representative boundary conditions (BCs) is challenging.

The container furnace has approximately 100 times more checkerwork than can be reasonably simulated in detail.



Detailed simulations:
~30-100 mil. cells
First cell 1 mm thick
k-ω SST, DOM
~20-100 HPC nodes
~1-2 days

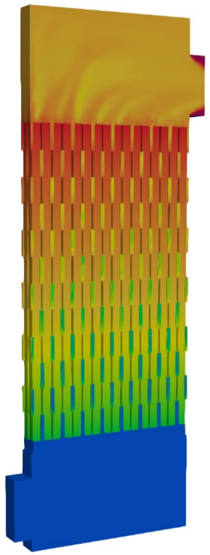




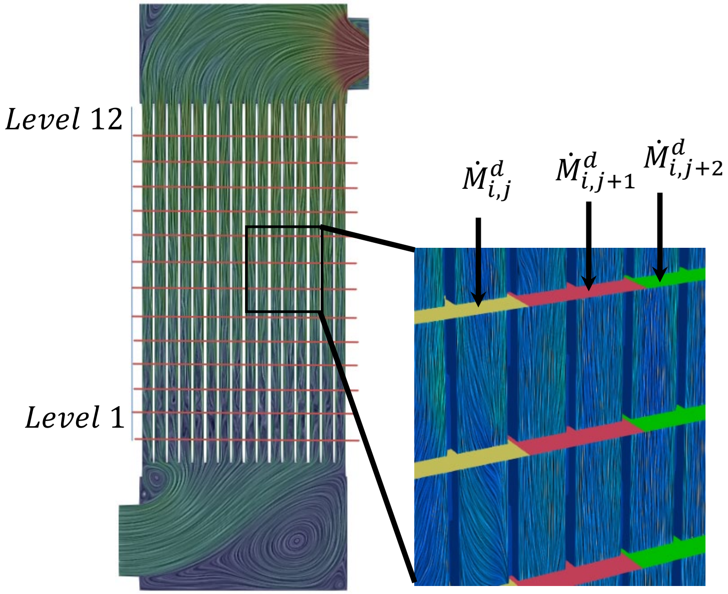
Methodology

- The goal is to identify 6 Darcy porous wall parameters
  - ➢ viscous and inertial coefficients for X, Y, and Z axis
- There are 4 detailed simulations per checker type - exhaust and firing regime, 2 different flow rates for each
- Large number of relatively fast Darcy porous wall (DPW) simulations

Detailed simulation



Flow rates through sampling planes



Explore hyperspace of porous wall parameters


```yaml
run:
  runCasesInParallel: 16
caseParameters:
  Type3-exhaust-run2-0001:
    porousHorizontalC1: 106.232343445845
    porousHorizontalC2: 221.019773029989
    porousVerticalC1:   1943.2249649798
    porousVerticalC2:   9.40745878253418
  Type3-exhaust-run2-0002:
    porousHorizontalC1: 1636.07547151742
    porousHorizontalC2: 556.508428237119
    porousVerticalC1:   6996.82691656663
    porousVerticalC2:   0.118490007914075
  Type3-exhaust-run2-0003:
    porousHorizontalC1: 1031.63469391523
    porousHorizontalC2: 117.843302725931
    porousVerticalC1:   16.3100224833314
    porousVerticalC2:   0.179212683802665
  Type3-exhaust-run2-0004:
    porousHorizontalC1: 5143.11665316849
    porousHorizontalC2: 30.3183496786245
    porousVerticalC1:   59.2204085372423
    porousVerticalC2:   8.79739940221749
  Type3-exhaust-run2-0005:
    porousHorizontalC1: 915.233688116297
    porousHorizontalC2: 17.951177889686
    porousVerticalC1:   273.33014591969
    porousVerticalC2:   8.9981273901166
  Type3-exhaust-run2-0006:
    porousHorizontalC1: 7111.40505608771
    porousHorizontalC2: 72.1779806188558
    porousVerticalC1:   4815.36471373865
    porousVerticalC2:   0.6004237749824
```


Porous wall approximation fitness

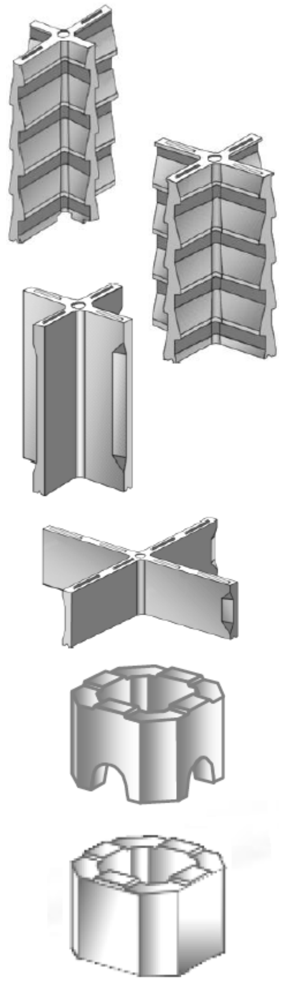
$$f(x) = \sum_{i=1}^{12} w_i \sum_{j=1}^{8} \left(\dot{M}^d_{ij} - \dot{M}^{pw}_{ij} \right)^2$$

$$\nabla p = \left(\frac{1}{2} \rho F |U| + \mu D \right) U$$

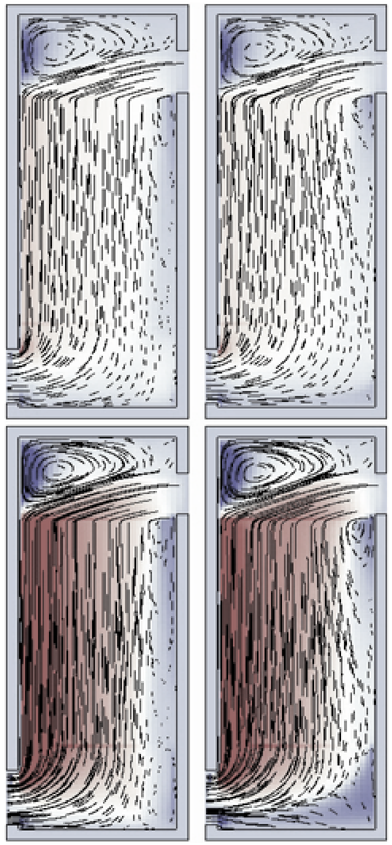
Methodology

Searching for DPW parameters through brute force would require an excessive amount of CPU time

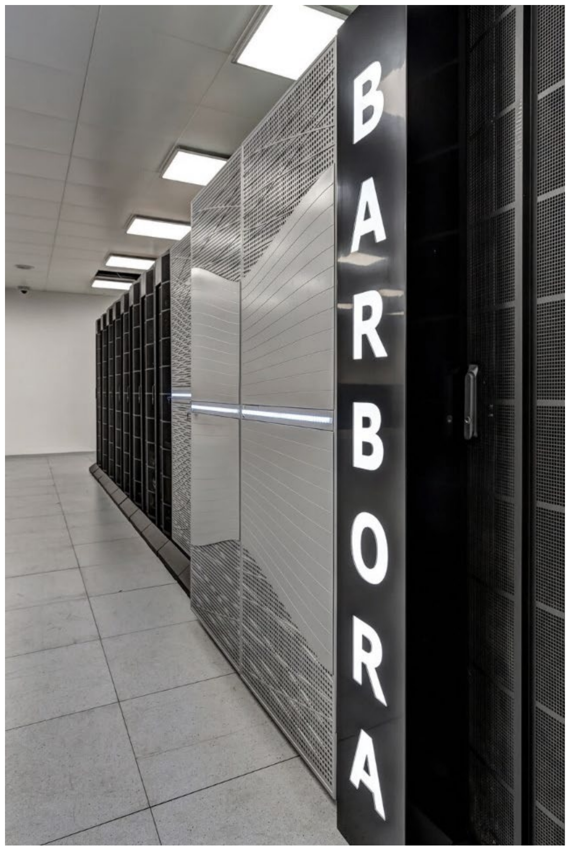
6 Checker Types



~5,000-12,000 cases
~4-10 cases/node-hour



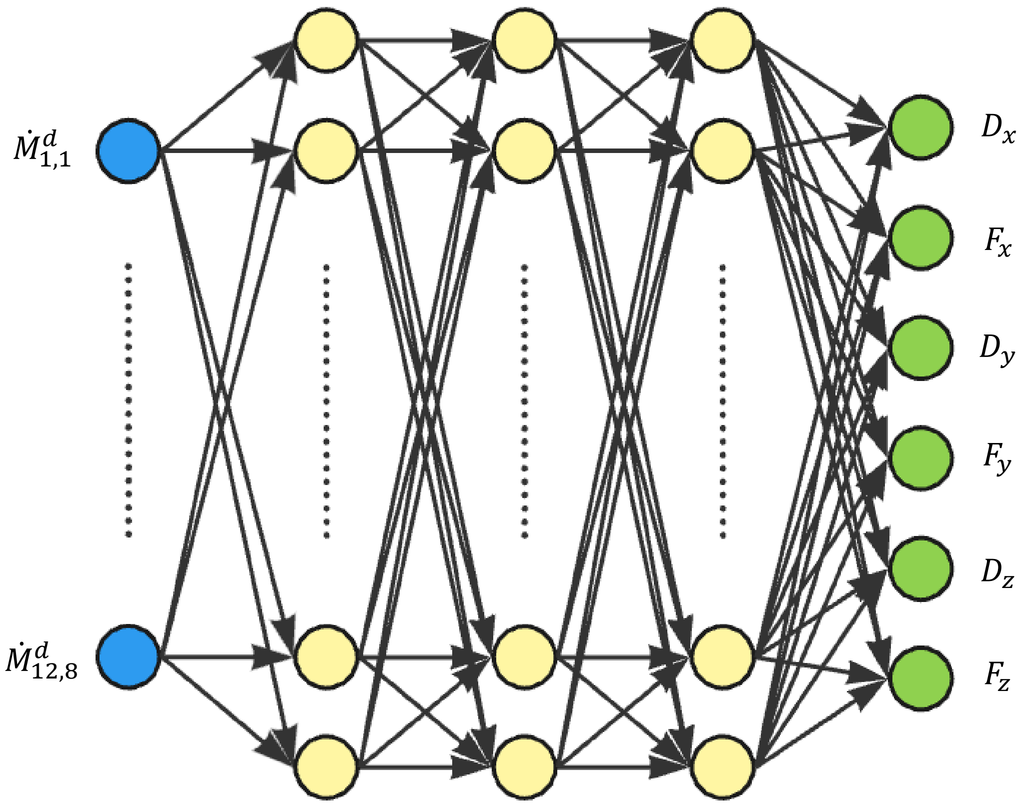
~150-750 node-days



Methodology

- Training dataset: ~1,500-2,000 sets of 96 flow rates through sampling planes and 6 Darcy porous wall (DPW) parameters
- Trained neural network was expected to produce the best DPW parameters when flow rates from detailed simulation are introduced as input

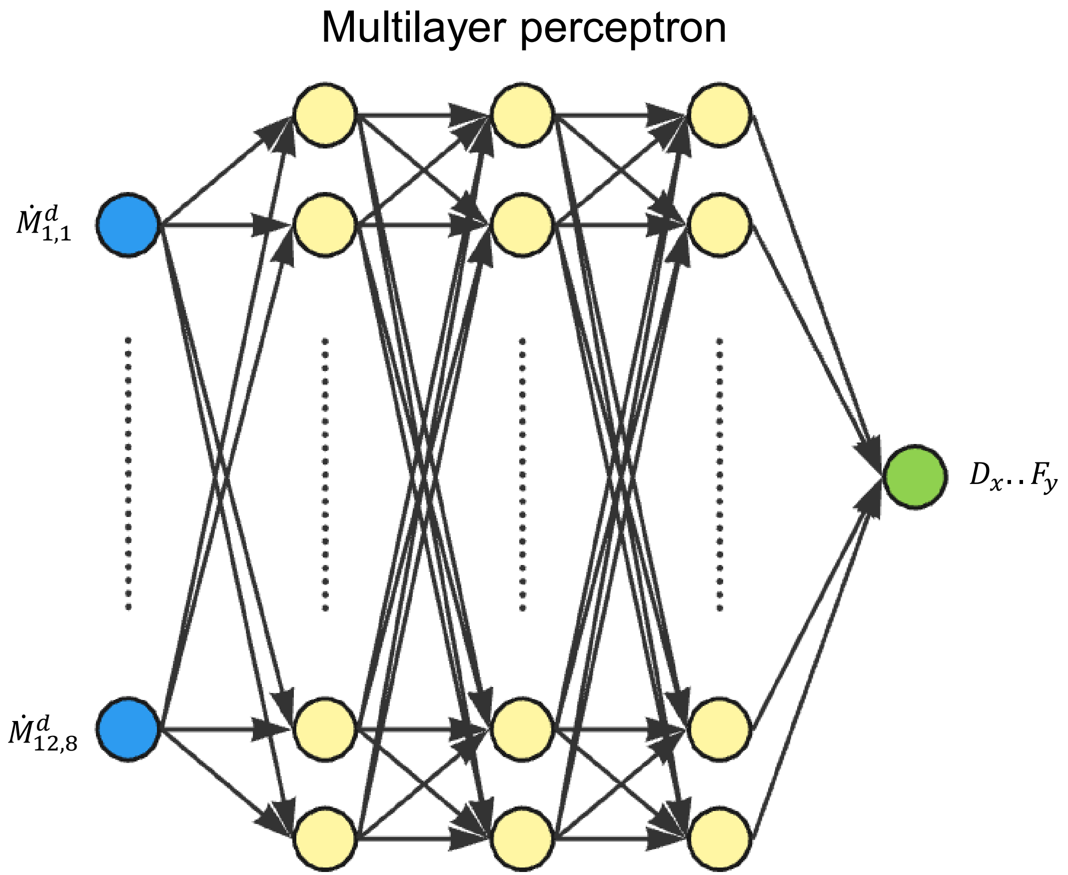
Multilayer perceptron



Methodology

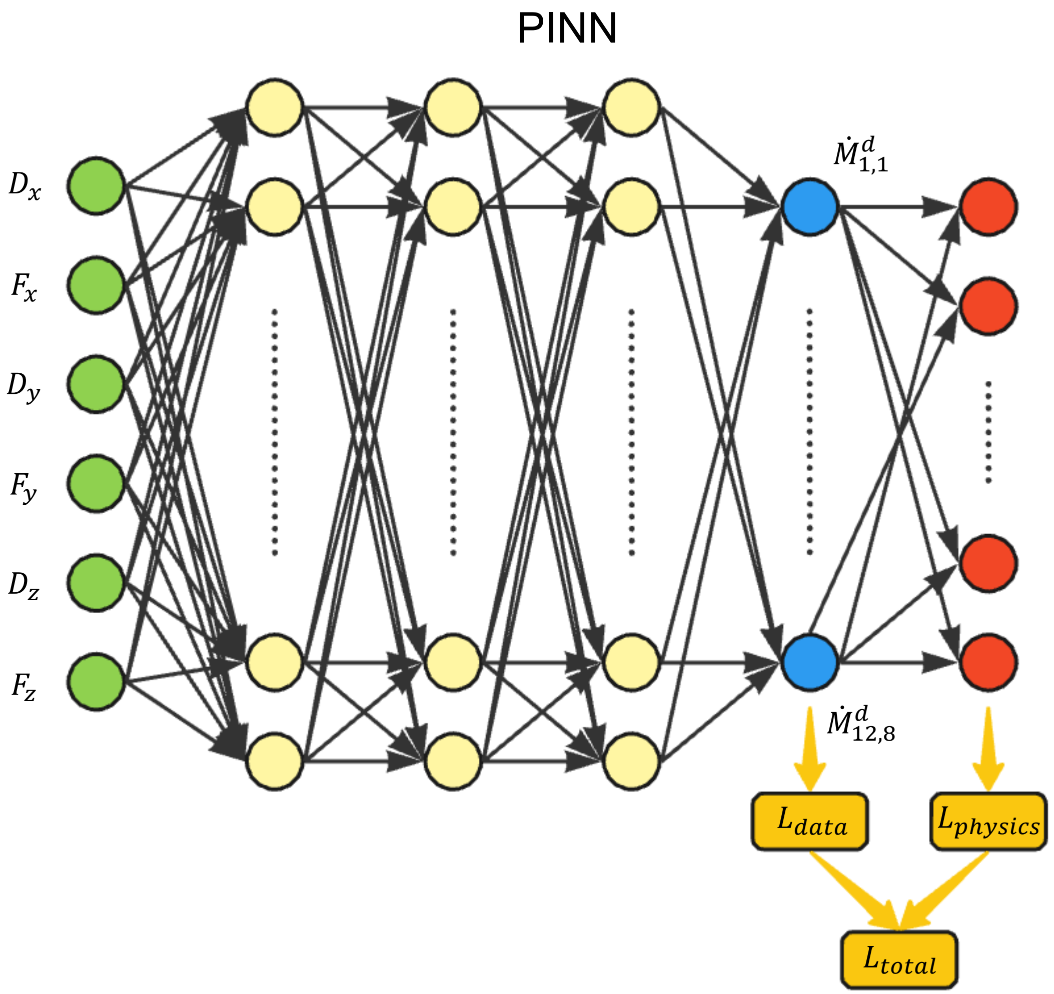
- Training dataset: ~1,500-2,000 pairs of 96 flow rates through sampling planes and 6 Darcy porous wall (DPW) parameters
- The trained neural network was expected to generate the optimal DPW parameters when flow rates from the detailed simulation were provided as input

- Neural networks trained to provide DPW parameters one by one performed better
- Validation of obtained DPW parameters revealed significant discrepancy when compared to flow rates from the detailed simulation



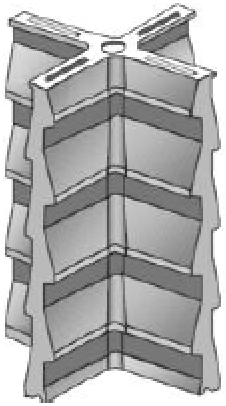
Methodology

- Initial exploration and training dataset: ~1,500-2,000 pairs of 96 flow rates through sampling planes and 6 Darcy porous wall (DPW) parameters
- The trained neural network served as a fast substitute for DPW simulation and provided flow rates through sampling planes
- Optimization algorithm assessed DPW parameters
- Additional exploration and training focused on the 2-5 most promising DPW parameter sets
- The number of considered DPW parameter sets was on the order of ~10^6 for each checker type

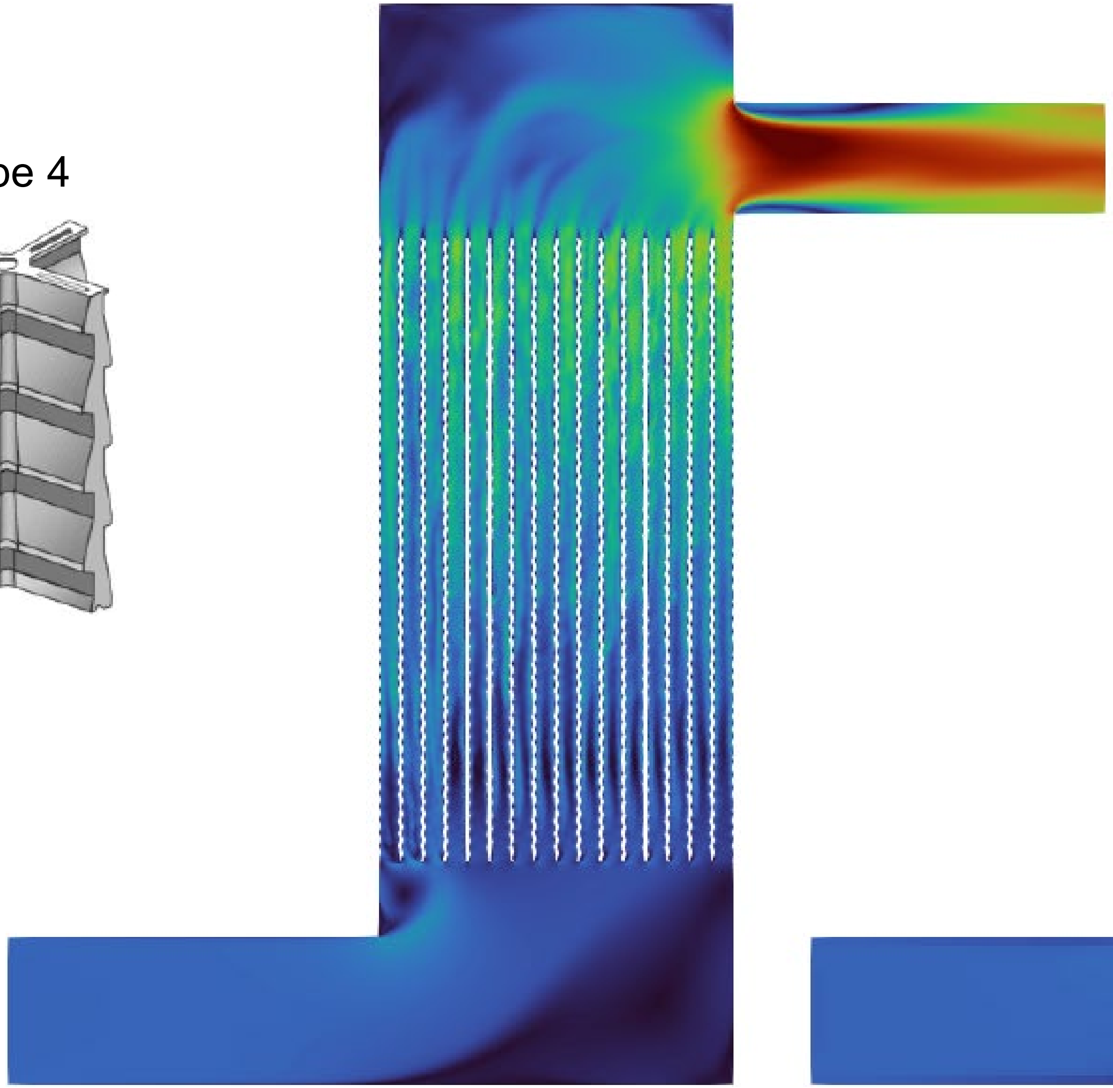


Results - Velocity Magnitude

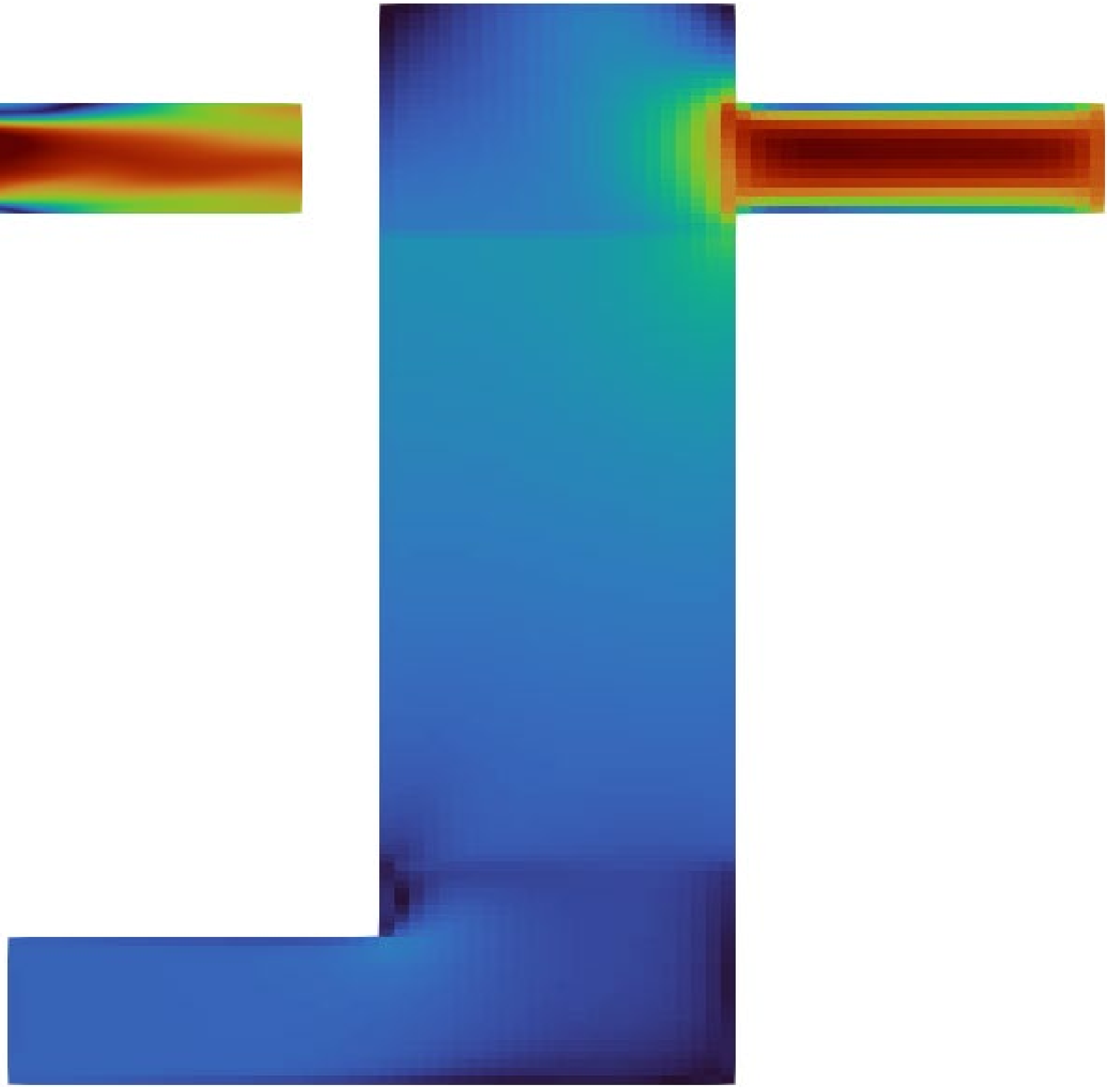
Type 4



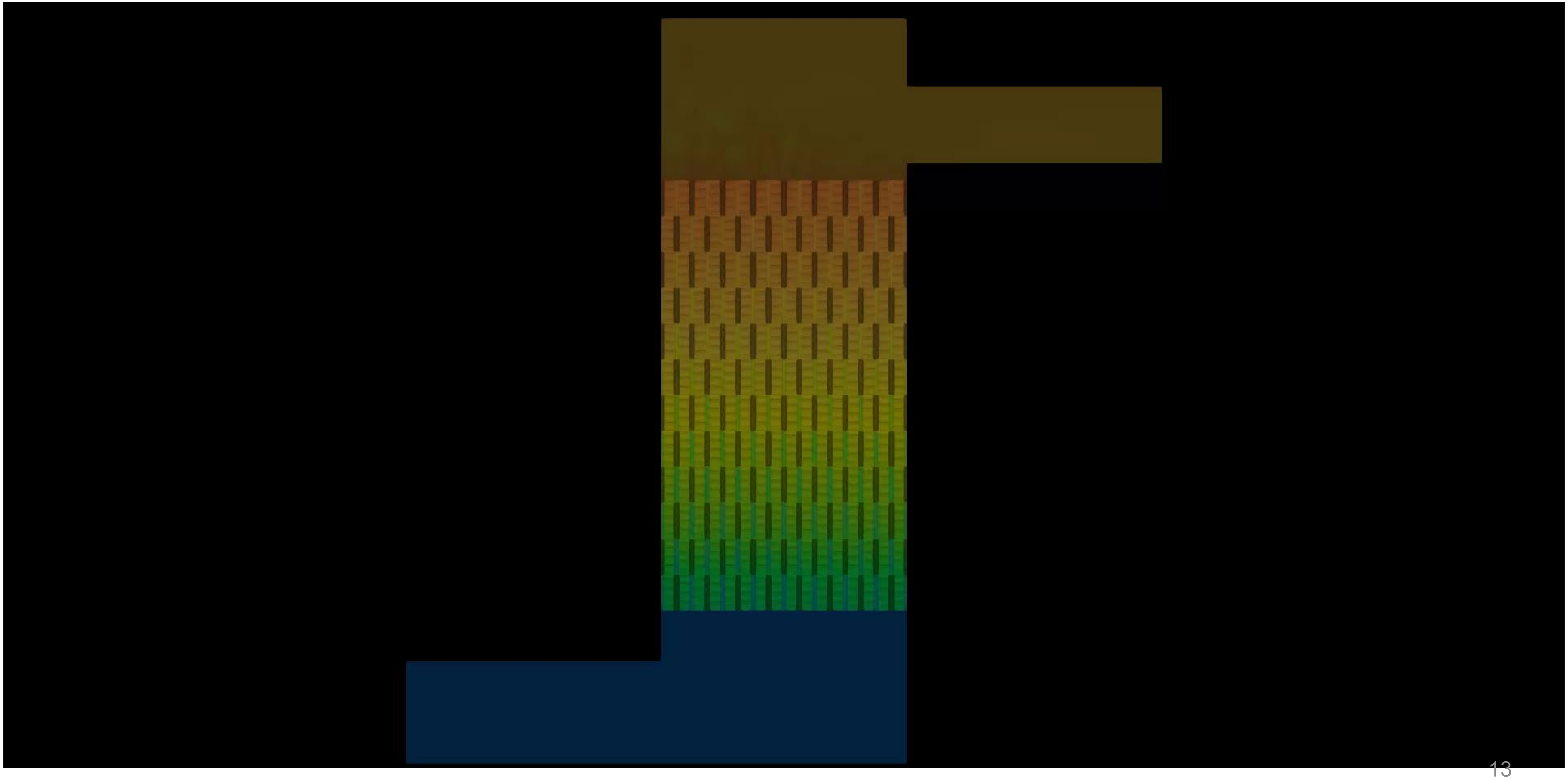
Detailed



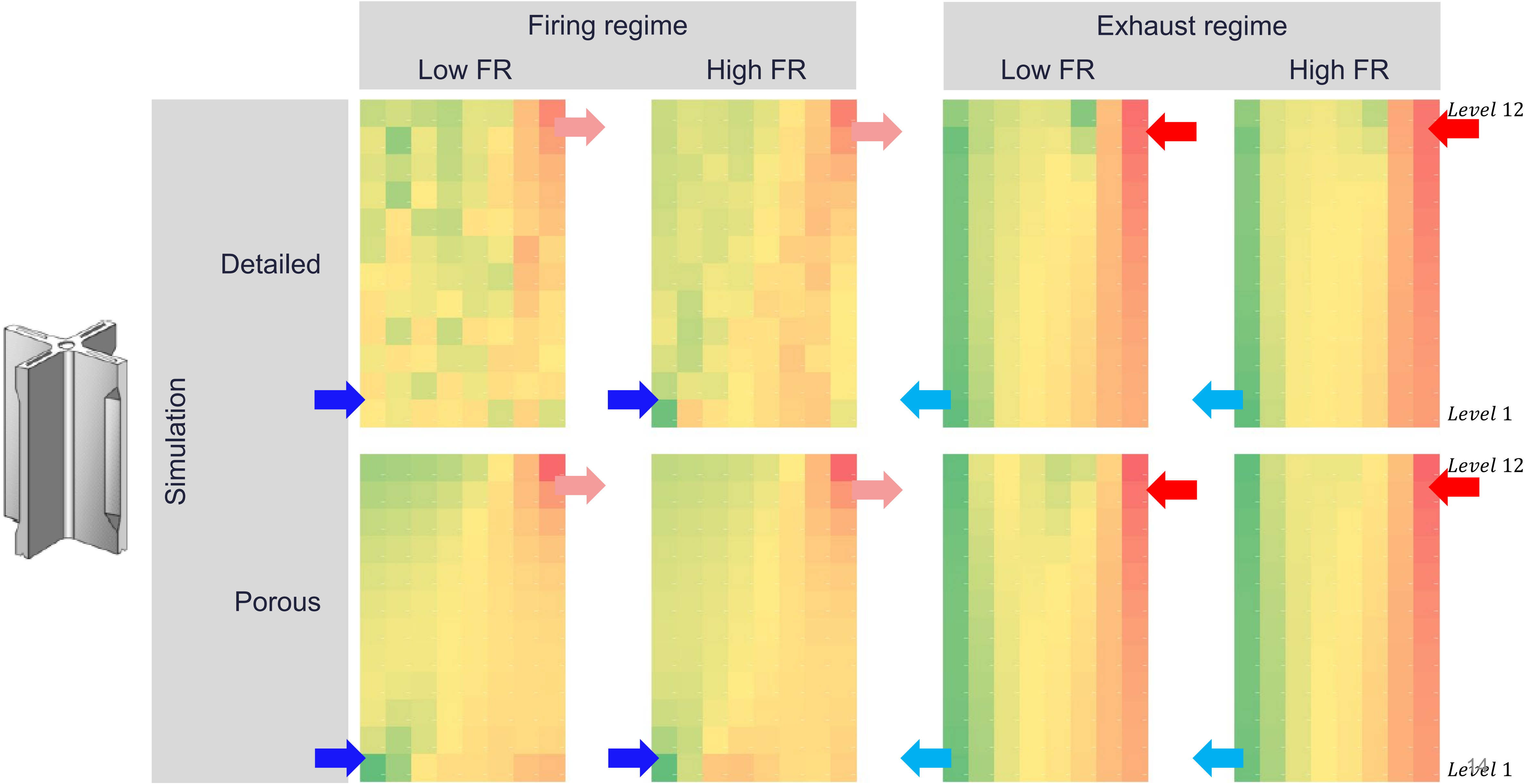
Porous



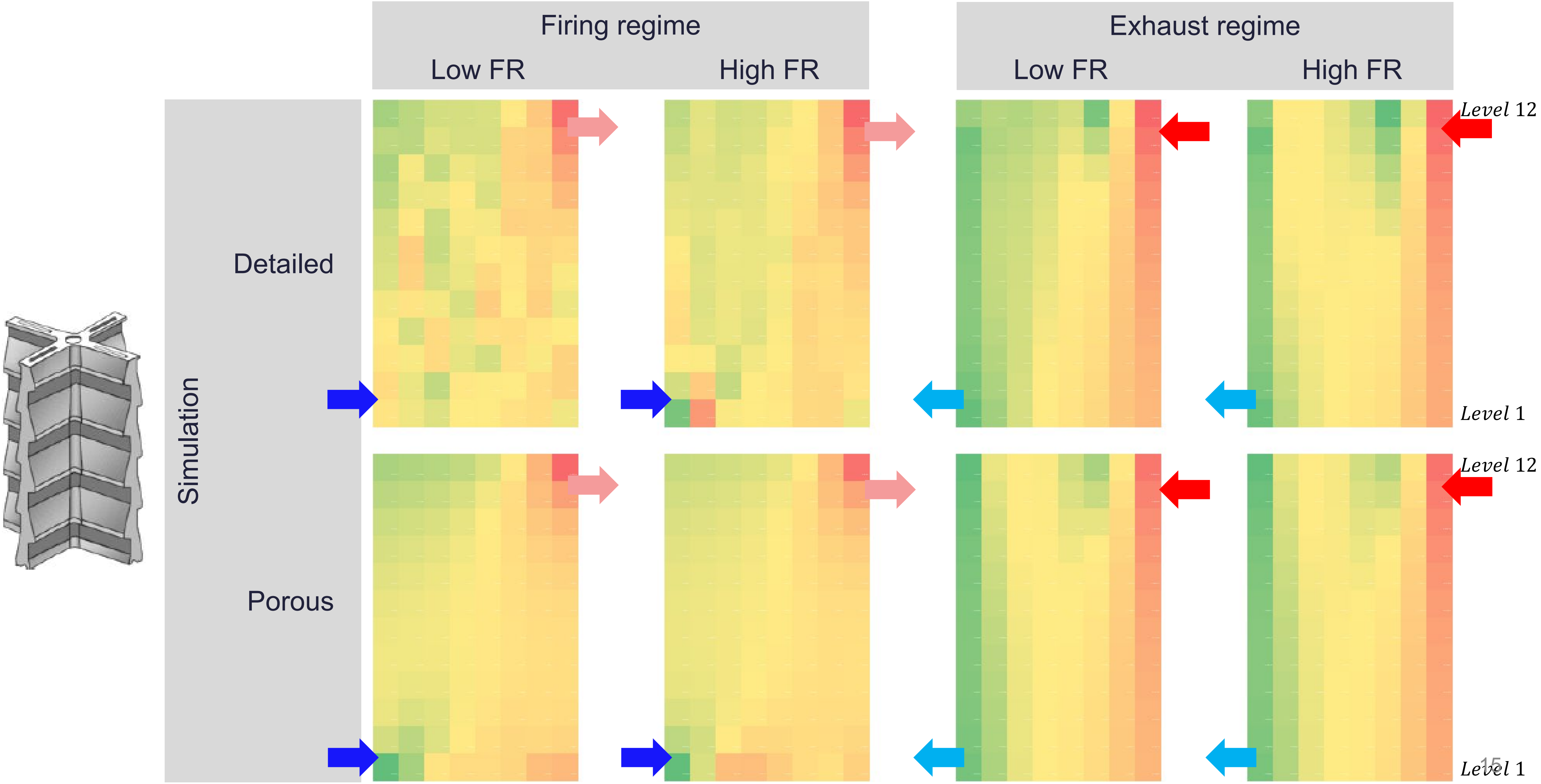
Results - Type 4



Results - Type 3 Flow Rates



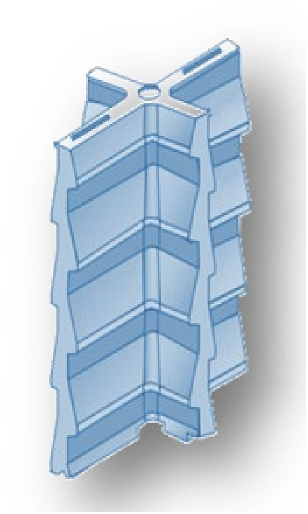
Results - Type 4 Flow Rates



Optimizing regenerators in glass furnaces

GS GLASS SERVICE SEFPRO BRIGHTER SOLUTIONS TOGETHER

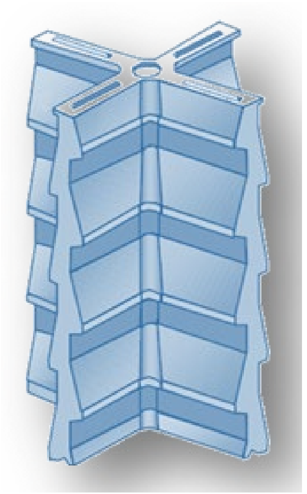
Industrial case study



Type 8 :

Channel size:
150 x 60 mm

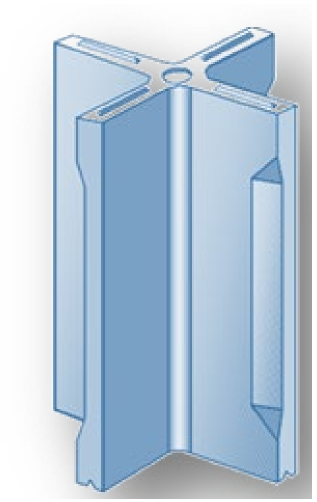
Specific exchange area:
28.8 m^2/m^3



Type 4:

Channel size:
150 x 150 mm

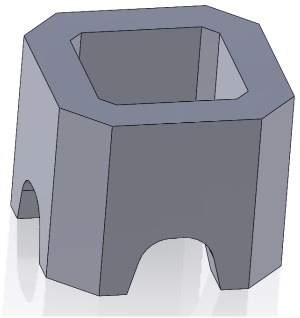
Specific exchange area:
18.5 m^2/m^3



Type 3:

Channel size:
150 x 150 mm

Specific exchange area:
17.8 m^2/m^3

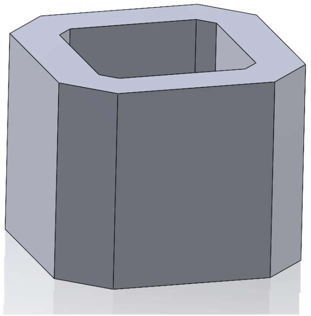


Open Chimney Block:

Height : 175 mm

Channel size:
140 x 140 mm

Specific exchange area: 16.6 m^2/m^3



Closed Chimney Block:

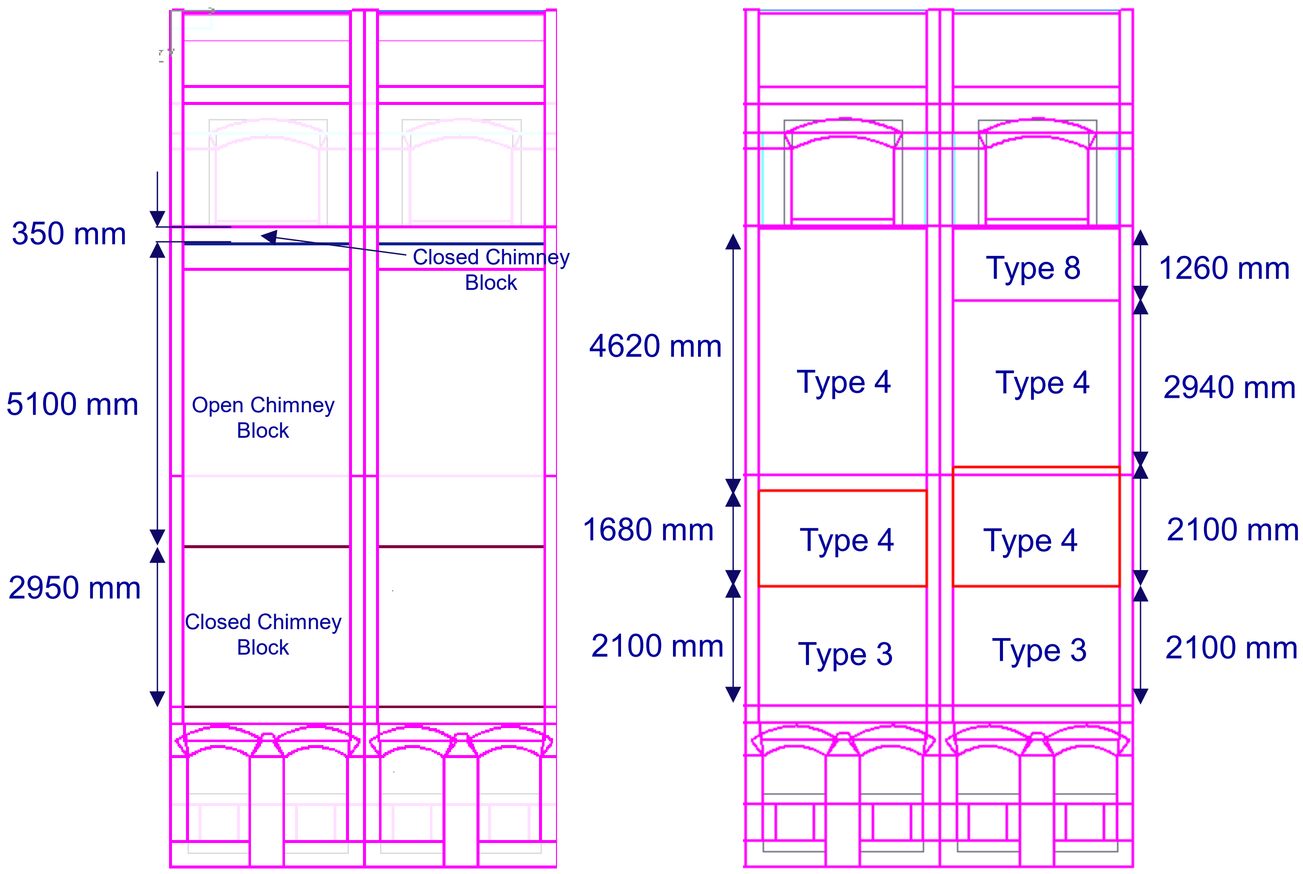
Height : 175 mm

Channel size:
140 x 140 mm

Specific exchange area:
15.9 m^2/m^3

Industrial case study

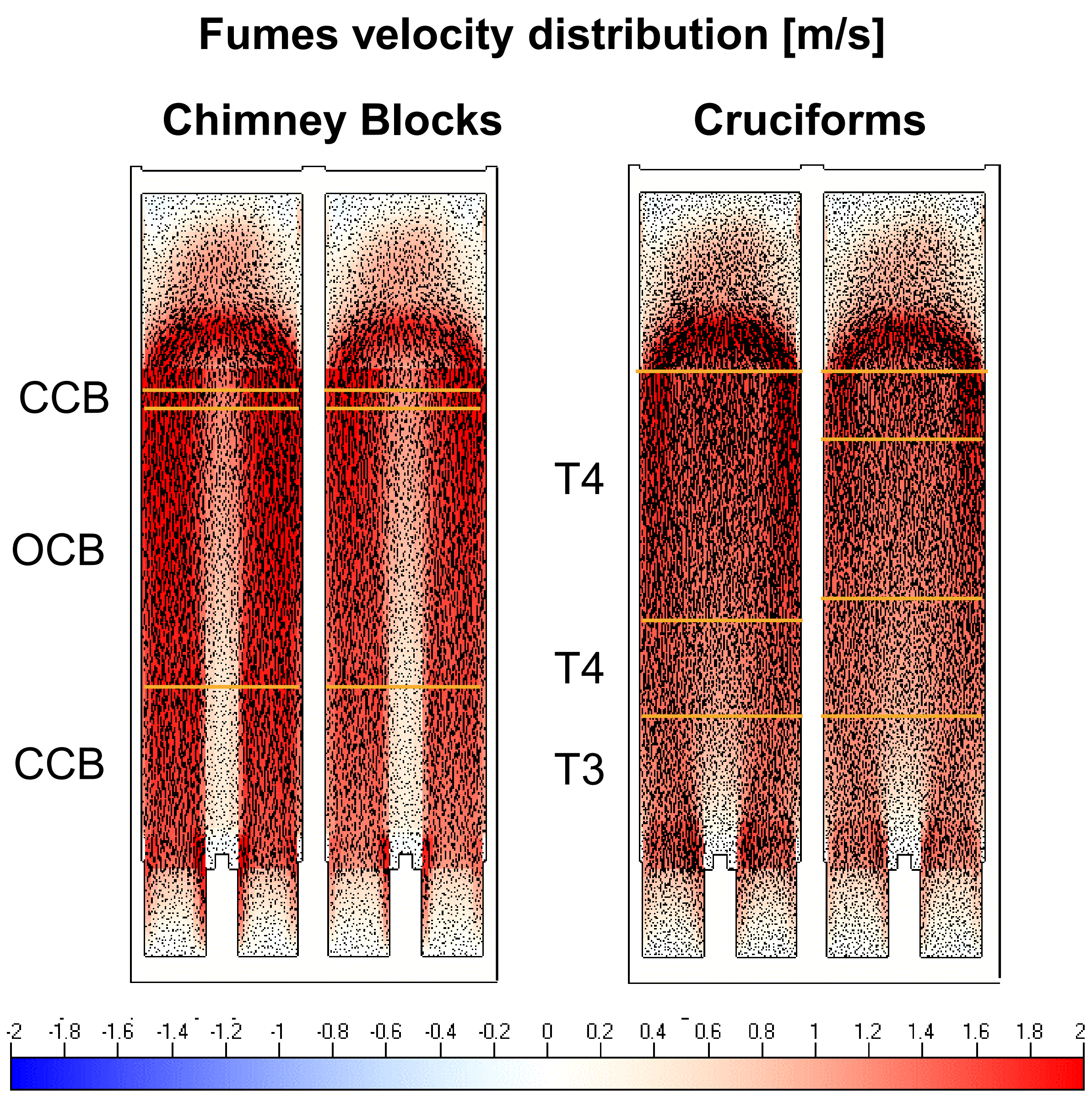
- Porous wall approximation was used in the framework of regenerators modelling
- Comparison of Cruciforms and Chimney blocks checkpacks
- Identical operating conditions, pitch and total height



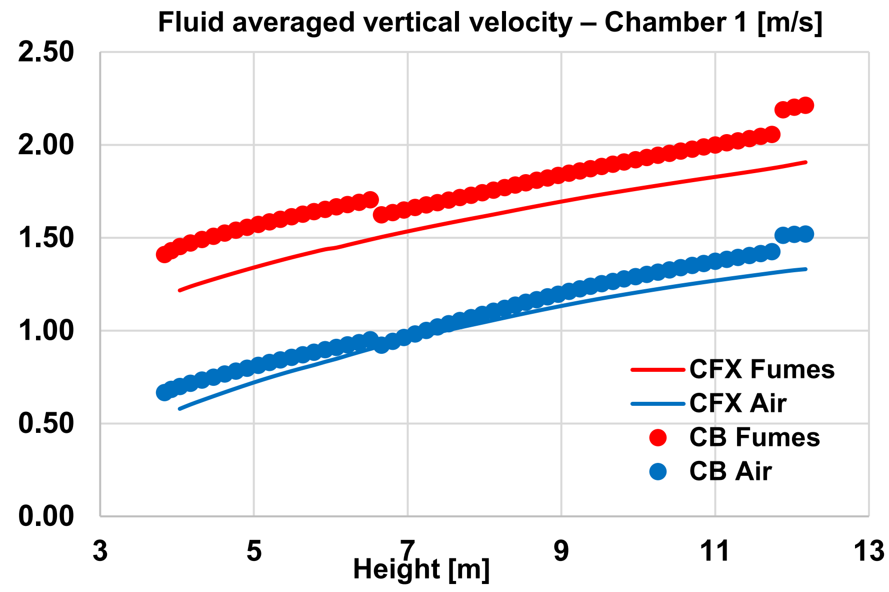
Same pitch : 180 mm

	T3-T4-T8 vs CCB-OCB-CCB		
	Cruciforms	Chimney blocks	Difference CXF vs CB
Channel section [mm]	150 x 150	140 x 140	+7%
Specific area (avg) [m²/m³]	18.0 (19.5)	16.3	+10% (20%)

Industrial case study



- More homogeneous fluid distribution for Cruciforms thanks to open channels configuration
- Lower fluid velocity within Cruciforms channels allowing for higher contact time with refractory and hence more efficient heat transfer



Industrial case study

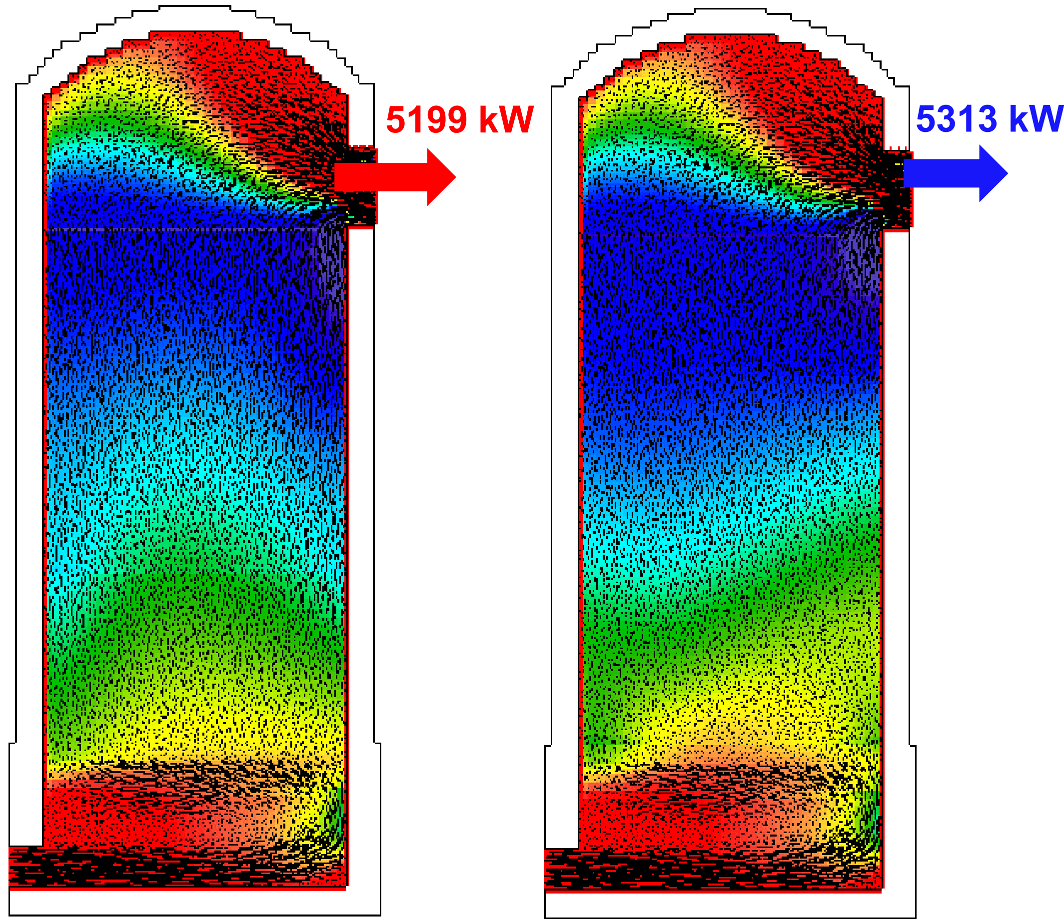
- **Cruciforms checkerpack attaining higher efficiency thanks to their improved heat exchange area and heat convection**

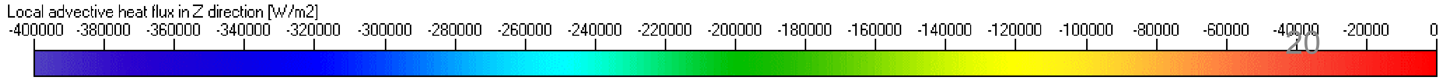
- **Higher energy efficiency leads to fuel consumption savings and thus CO_2 emission reduction**

Parameters at Boundary	P1 Chimney blocks	P1 Cruciforms	P2 Chimney blocks	P2 Cruciforms
Air inlet temperature [°C]	100			
Air outlet temperature [°C]	1265	1291 (+26°C)	1246	1297 (+51°C)
Fumes Inlet Temperature [°C]	1500		1520	
Air outlet Power [kW]	5199	5313	5113	5341
Fuel consumption reduction with CFX	2.2%		4.5%	

Port 1 Air vertical energy [z] [W/m²]

Chimney Blocks **Cruciforms**

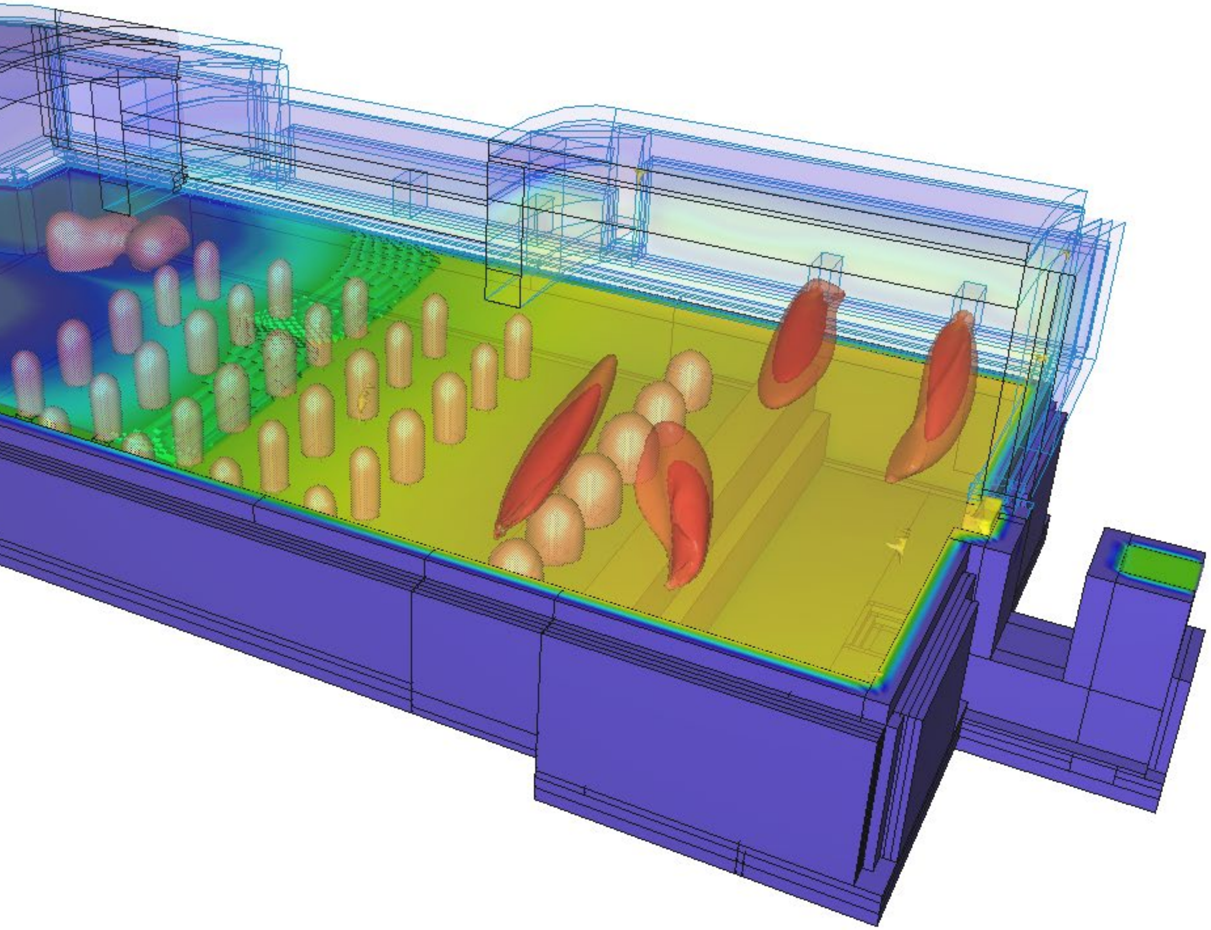




Conclusions

- ✓ A methodology for identifying Darcy porous wall parameters to approximate flow rates, as an alternative to detailed simulations, has been developed and validated
- ✓ The utilization of neural networks and machine learning significantly reduced the computational resources required to identify Darcy porous wall parameters
- ✓ Darcy porous wall parameters have been identified for two types of chimney blocks, OCB and CCB, and for four types of SEFPRO Cruciforms® T3, T4, T6, and T8
- ✓ Simulations using the Darcy porous wall approximation reliably reproduce flow patterns, with only minor differences in local flow rates
- ✓ The Darcy porous wall approximation enables extensive simulation studies of:
  - ✓ Furnace designs, including industrial-sized regenerators
  - ✓ Various combinations of checker block types to optimize regenerator performance

How we can help to optimize your furnace



- We conduct simulation studies for you based on your design.
- The modeling studies help to find the **best furnace design** or optimize the **furnace operation**.
- We supply our GFM license to customers and support them to conduct modeling studies on their own.

Save the date - TC21: Furnace Design and Operation

13th – 17th April 2026
Lyon, France

Thank you

Malte Sander
malte.sander@glass-service.eu