KARAKAS
FRANÇAIS

ZSoil Day 2025

Thermo-active barrettes: design of heat exchangers based on in-situ testing and numerical simulations in ZSoil

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Outline

1. In-situ testing on energy barrettes
2. Numerical modelling using ZSoil
3. Results and discussion
4. Conclusions

01 In-situ testing on energy barrettes

Barrettes as deep foundations and their thermal activation

TRT testing

Deep foundations for high-rise buildings

Tour des Cèdres – Lausanne, CH

- 140m high-rise tower in west Lausanne
- Foundation system
  - Barrettes
  - Large-diameter piles
- Soil strata
  - Soft clays deposits down to 35-40m deep
  - Thin gravelly moraine layer
  - Molasse bedrock with variable stiffness at ~40 m depth



Diaphragm walls

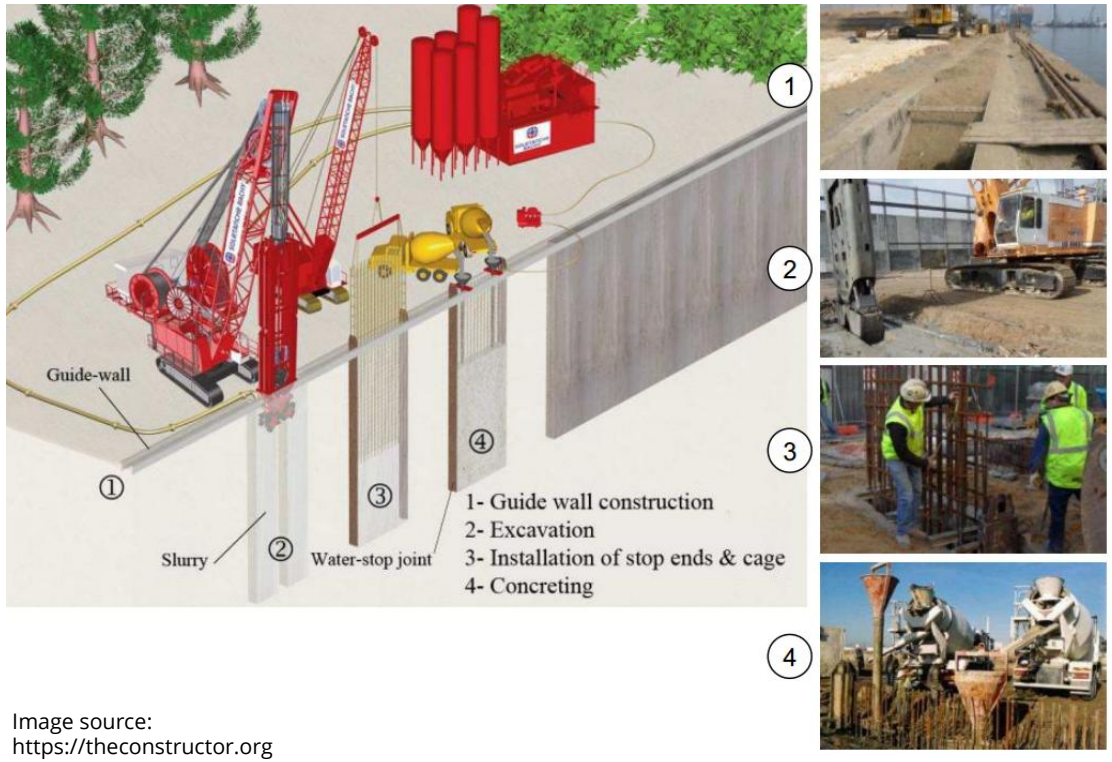


Image source:
https://theconstructor.org

Construction

1. Construction of guide wall
2. Excavation of the panel
3. Installation of reinforcement
4. Wall concreting

Geothermal barrettes as deep foundations

Case study

- Barrette foundation for a 140m high-rise tower in Lausanne, Switzerland
- Diaphragm walls: reinforced concrete deep foundations
- Geothermal tubes attached to the reinforcement cage





Images, source – Karakas & Français SA

Geothermal barrettes as deep foundations

The test project

- Trial barrette in 2024
- Depth: 46m
- Testing and optimizing construction technique
- Geothermal activation
- Complexity of installation
- Two different heat exchangers layouts





Images, source – Karakas & Français SA

Geothermal barrettes as deep foundations


S type


3U type

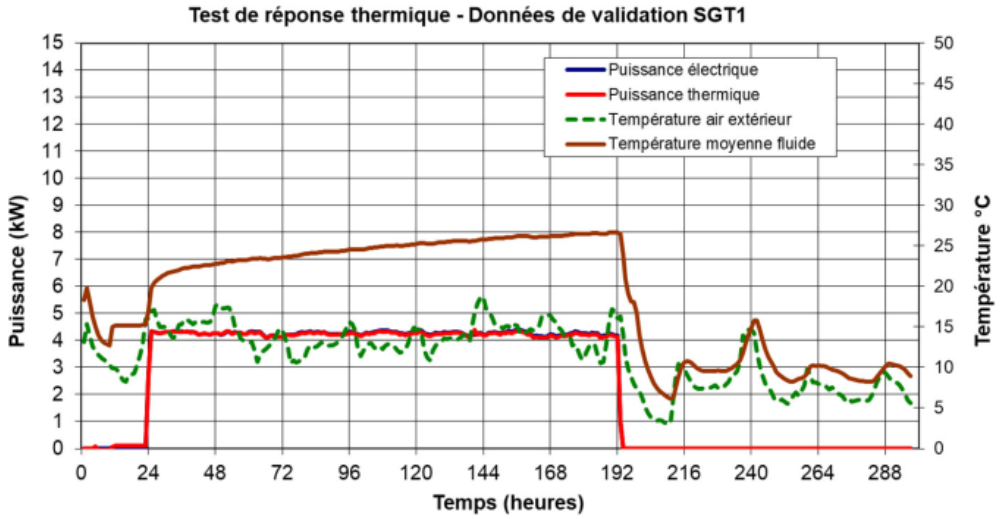


Thermal in-situ testing

Challenges and testing procedures

- Absence of an established framework for thermal testing
- Installation of two different heat exchangers configurations
- We adopted the TRT testing technique
- Absence of standardised interpretation semi-analytical models
- Simultaneous TRT testing on two heat exchangers circuits
- Data interpretation requires advanced numerical modelling





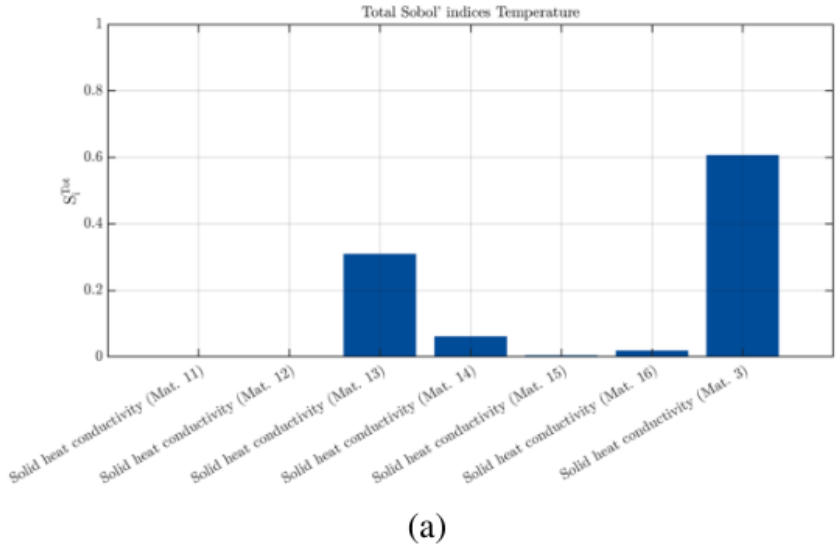
02 Numerical modelling

Validation against in-situ test

Determination of thermal potential

Validation against in-situ testing

- **Development of the first FE model by K-F**
  - Geometrical model
  - Basic curve fittings to determine thermal parameters based on TRT measurements
- **Master thesis project of Zuzanna Nytko, supervision Prof. Andrzej Truty, Politechnika Krakowska (PK)**
  - Sensitivity analysis for thermal parameters
  - Parameter optimisation based on metamodeling (PCE)
  - Other coupled thermo-mechanical analyses

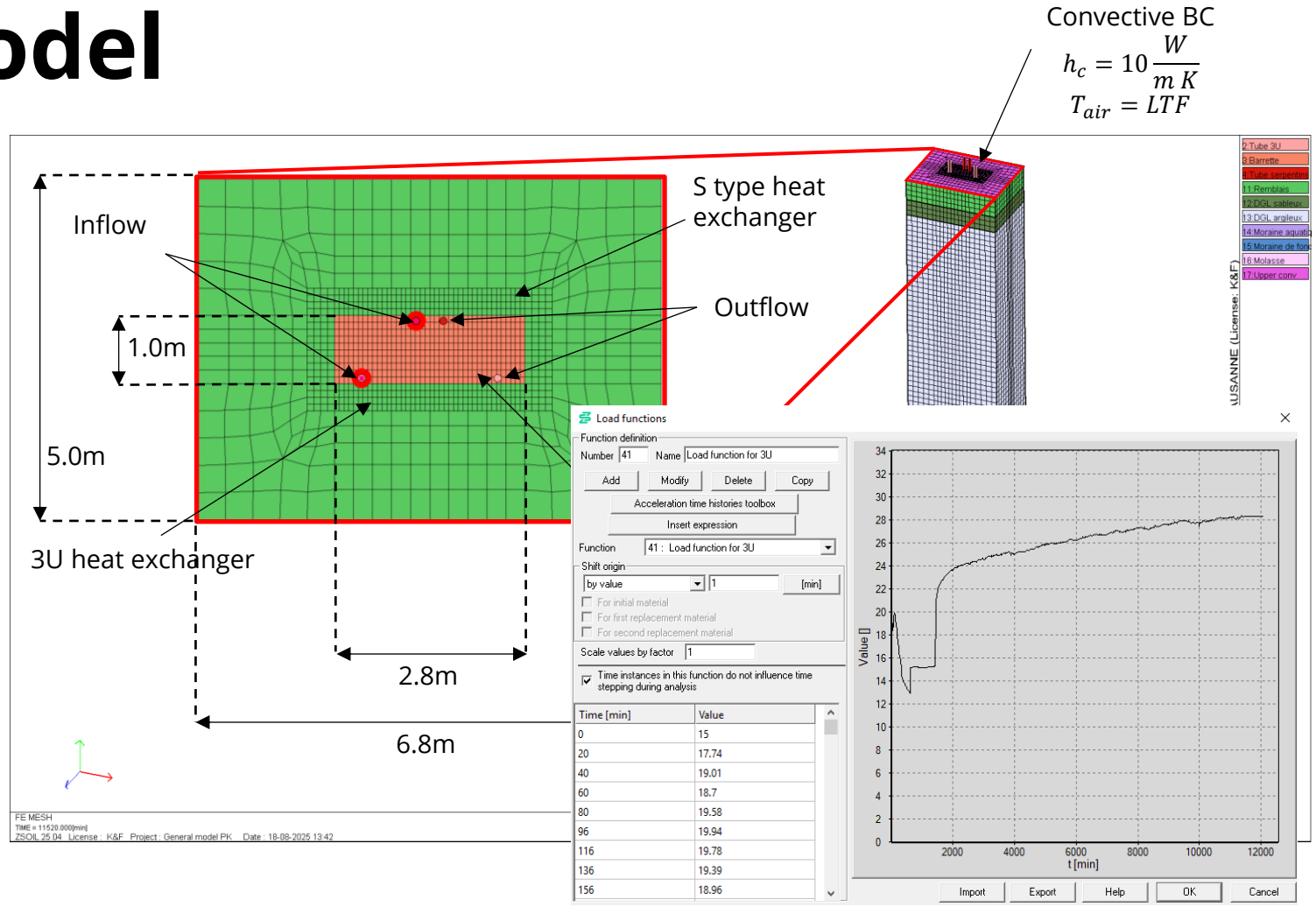


(a)

Numerical model

3D transient thermal simulation – PK model

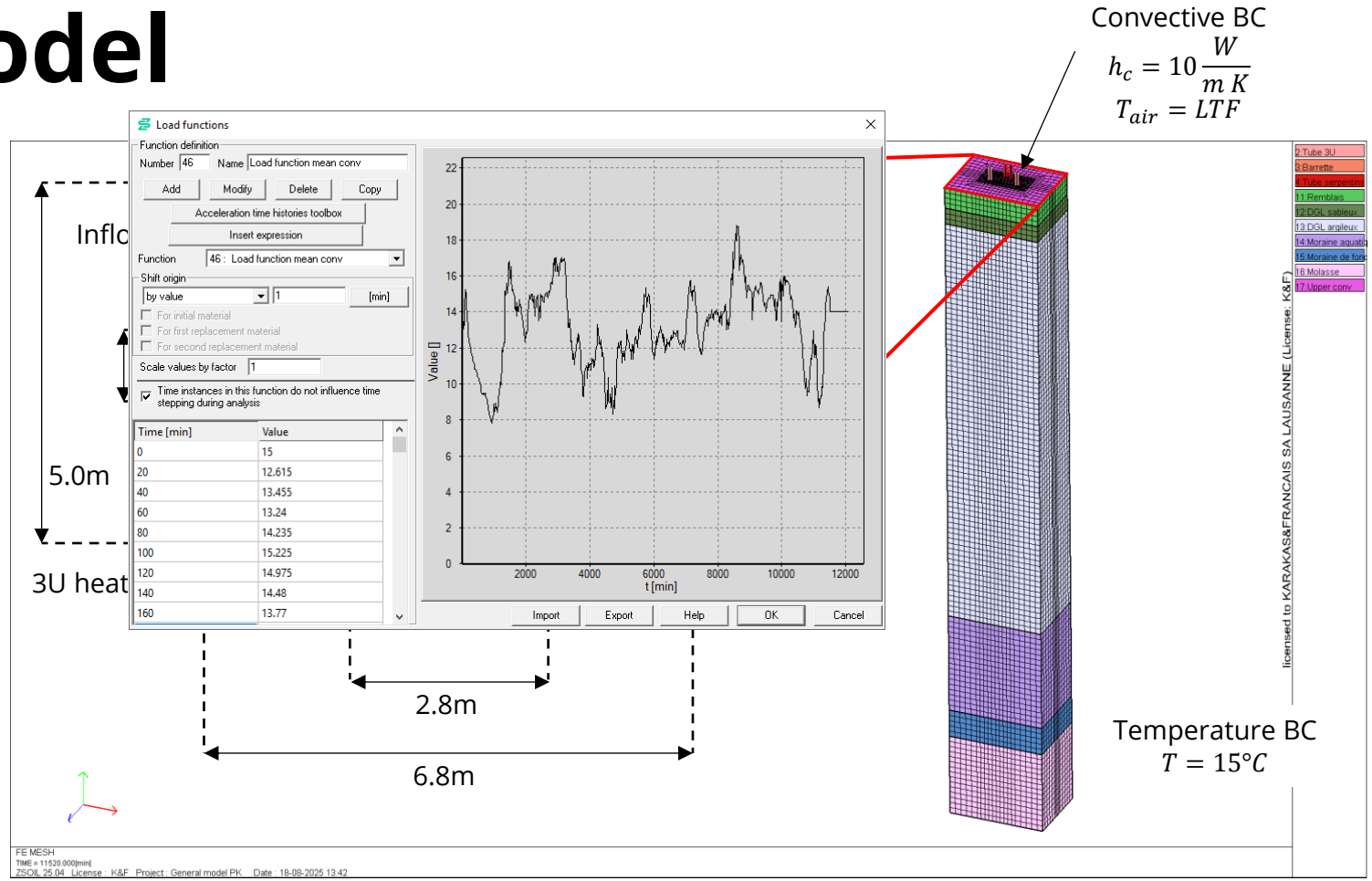
- Imposed inflow fluid temperature
- Constant temperature on the model's boundaries
- Convection at the top
- No explicit definition of groundwater table



Numerical model

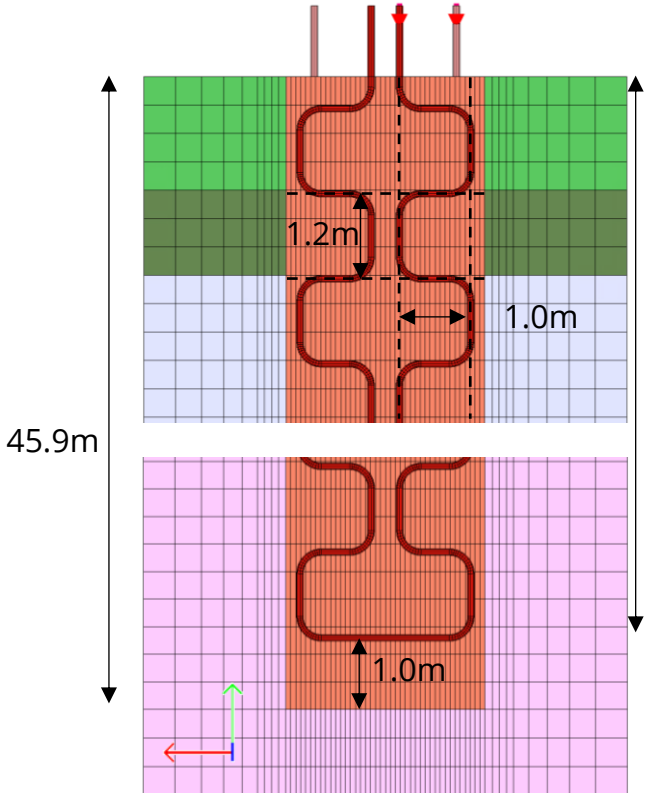
3D transient thermal simulation – PK model

- Imposed inflow fluid temperature
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Heat exchangers details

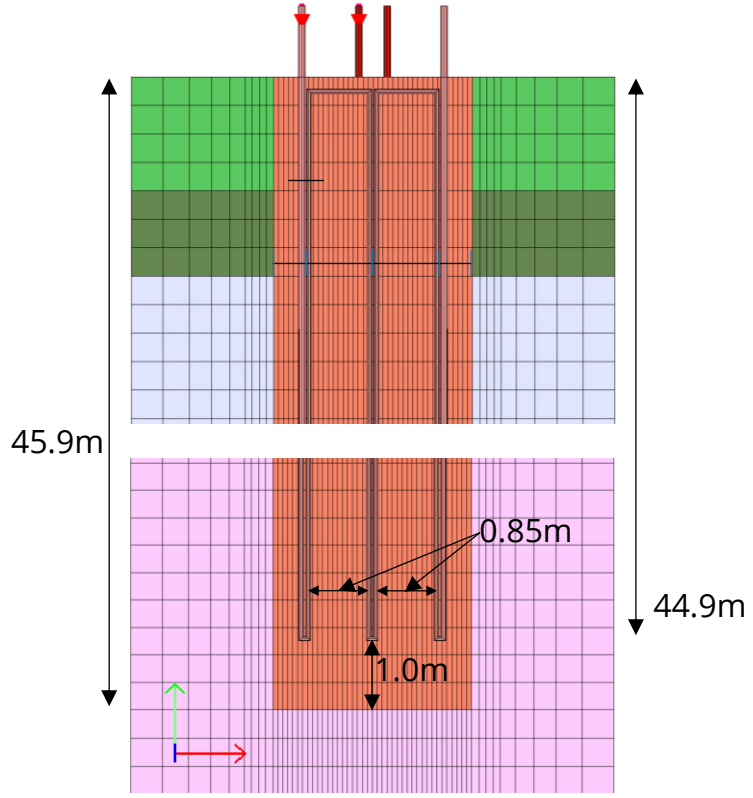
- S type heat exchanger



Input data

- Pipe diameters :
  - $\emptyset_{3U} = 32mm$
  - $\emptyset_S = 25mm$
- Pipe thickness : $t = 5mm$
- Pipes lengths :
  - $L_{3U} = 272.3m$
  - $L_S = 145.2m$
- Flow rates :
  - $\dot{Q_{3U}} = 1.04 \frac{m^3}{h}$
  - $\dot{Q_S} = 0.89 \frac{m^3}{h}$

- 3U type heat



Heat exchangers details

Heat exchanger material properties

Explicit PIPE option does not require to fill some of the listed parameters

Pipe geometry →

Pipe thermal properties →

Fluid flow in pipes →

Fluid thermal properties →

Borehole heat exchangers

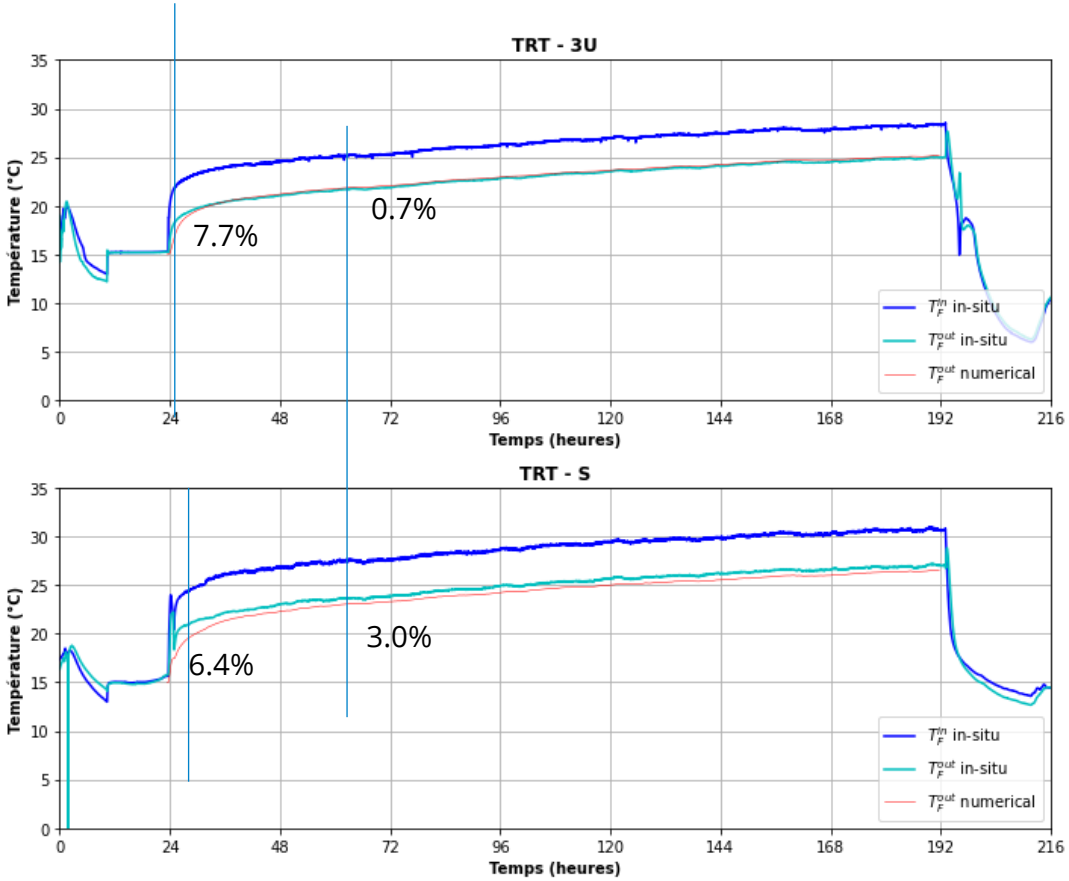
Parameter	Value	Unit
BHE type	PIPE (no gr...	
Borehole diameter	0.15	[m]
Pipe distance (w)	0.06	[m]
Pipe outer diameter	0.032	[m]
Pipe wall thickness	0.0025	[m]
Pipe thermal conductivity	0.6	[W/m/C]
Pipe OUT outer diameter	0.032	[m]
Pipe OUT wall thickness	0.0029	[m]
Pipe OUT thermal conductivity	0.38	[W/m/C]
Refrigerant vol. flow discharge	0.01733	[m^3/min]
Refrigerant vol. flow discharge type	Parallel	
Refrigerant thermal conductivity	0.6	[W/m/C]
Refrigerant dyn. viscosity	1.6667e-08	[kN/m^2*min]
Refrigerant vol. heat capacity	4200	[kJ/m^3/C]
Refrigerant density	0.000274444444	[kN/m^4*min^2]
Grout thermal conductivity	2.3	[W/m/C]
Grout vol. heat capacity	2190	[kJ/m^3/C]

Borehole heat exchangers

Parameter	Value	Unit
BHE type	PIPE (no gr...	
Borehole diameter	0.15	[m]
Pipe distance (w)	0.06	[m]
Pipe outer diameter	0.025	[m]
Pipe wall thickness	0.0025	[m]
Pipe thermal conductivity	0.6	[W/m/C]
Pipe OUT outer diameter	0.032	[m]
Pipe OUT wall thickness	0.0029	[m]
Pipe OUT thermal conductivity	0.38	[W/m/C]
Refrigerant vol. flow discharge	0.014833	[m^3/min]
Refrigerant vol. flow discharge type	Parallel	
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Grout thermal conductivity	2.3	[W/m/C]
Grout vol. heat capacity	2190	[kJ/m^3/C]

Validation against in-situ test

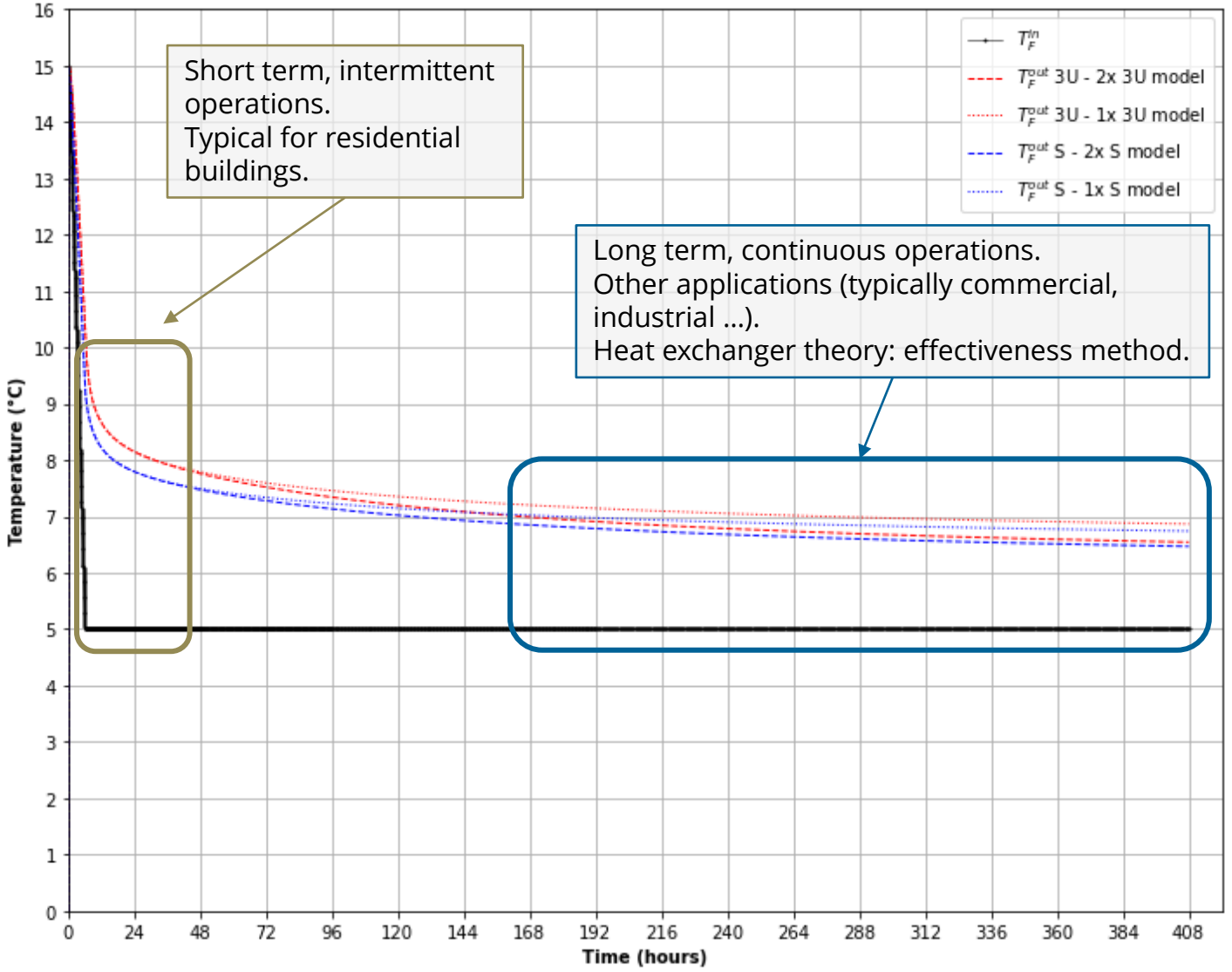
- Important: to set suitable time step and mesh dimensions for heat exchanger calculations
  ⇨ strictly follow BHE pdf in ZSoil
- Input parameter: inflow temperature
- Control parameter: **outflow temperature**
- Error range
  - S 3% - 6%
  - 3U 1% - 8%



Energy modelling in ZSoil

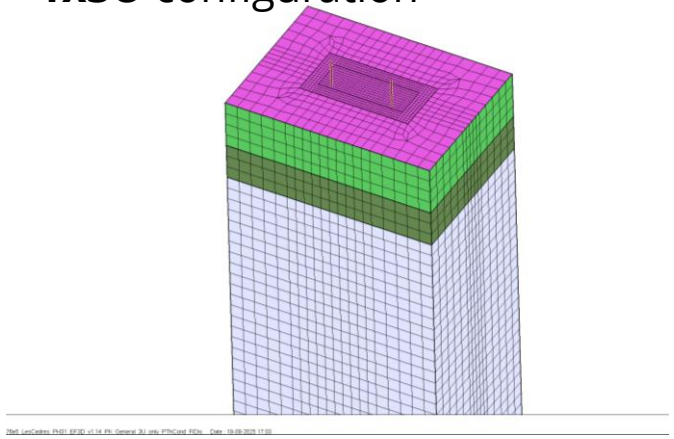
What's the thermal power retrieved from the energy geostructure?

- Energy modelling can be computationally expensive
- Find a heat exchanger thermal input to be representative of real applications
- Constant temperature inflow
- Study different heat exchanger configurations

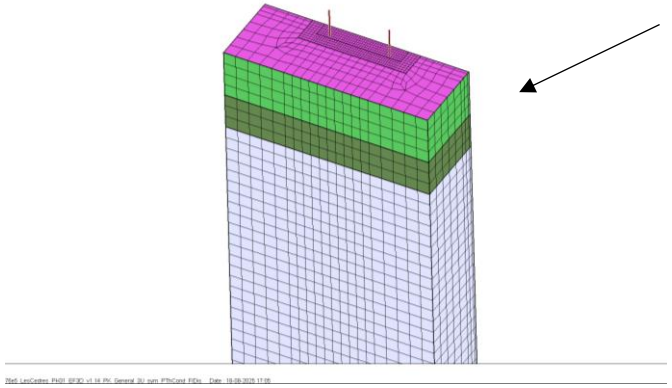


Search for the optimal HE setup

1x3U configuration

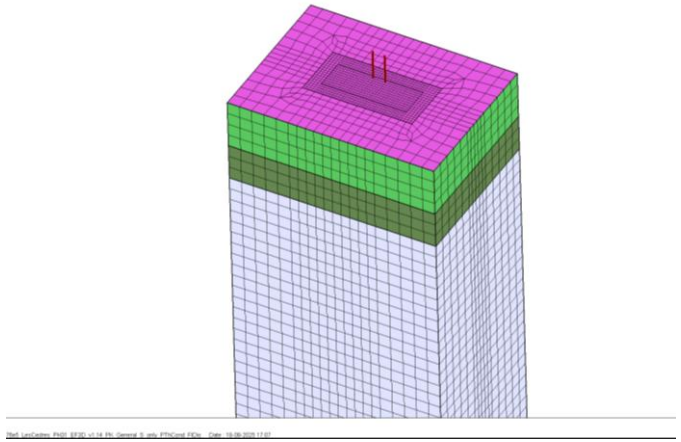


2x3U configuration

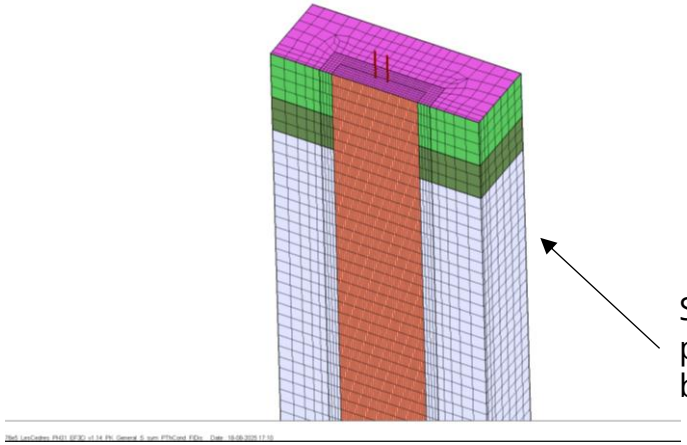


Symmetry plane at barrette axis

1xS configuration



2xS configuration



Symmetry plane at barrette axis

03 Results and discussion

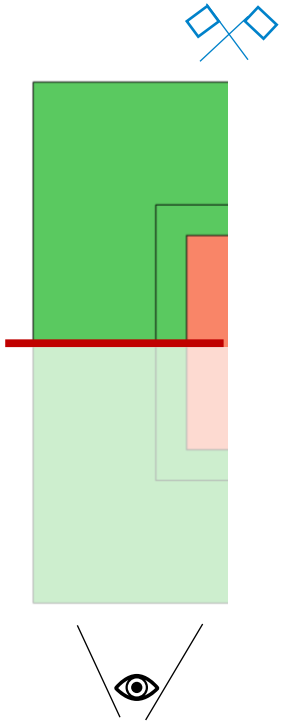
Heat exchanger results in ZSoil

Heat exchangers layout comparison

ZSoil as a decisive tool to help decision making process

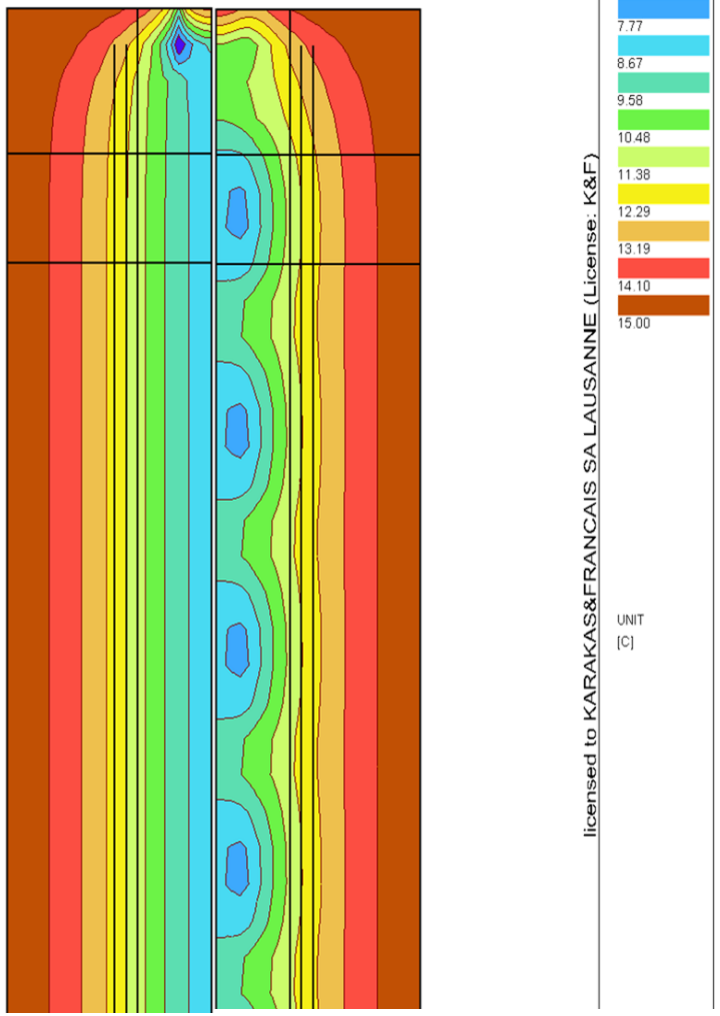
Soil temperature distribution

Section



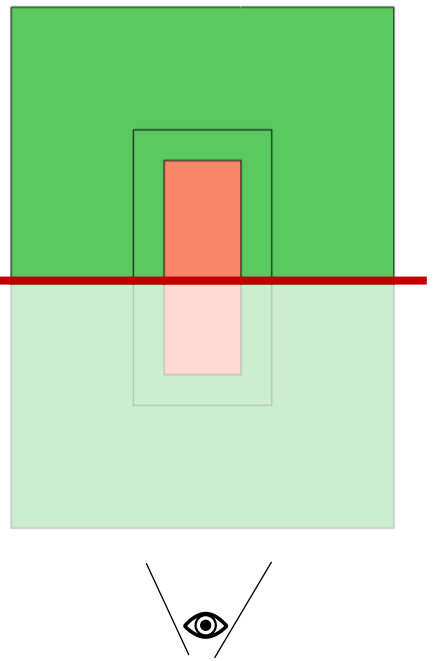
3U sym — S sym

Terrain surface



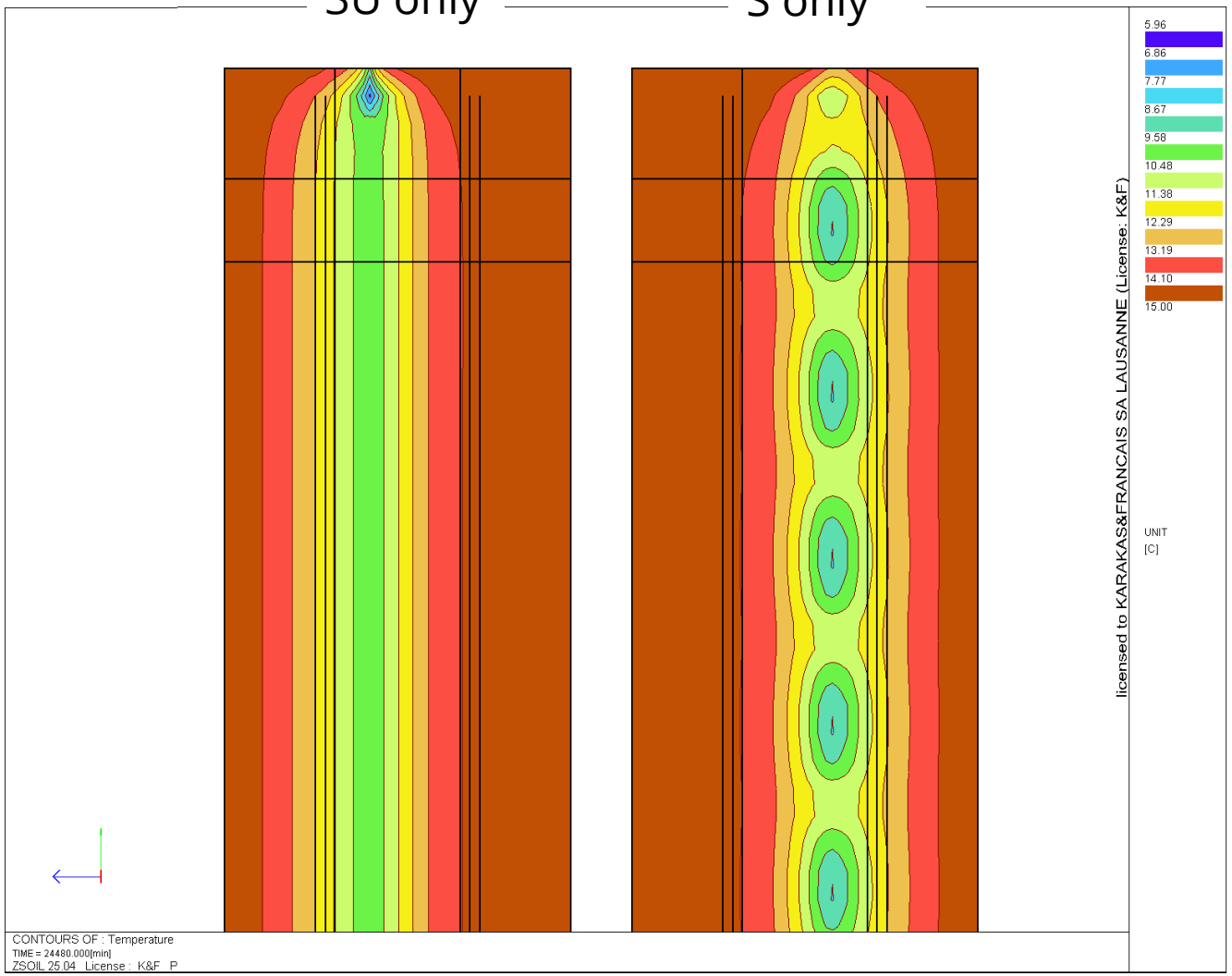
Soil temperature distribution

Section

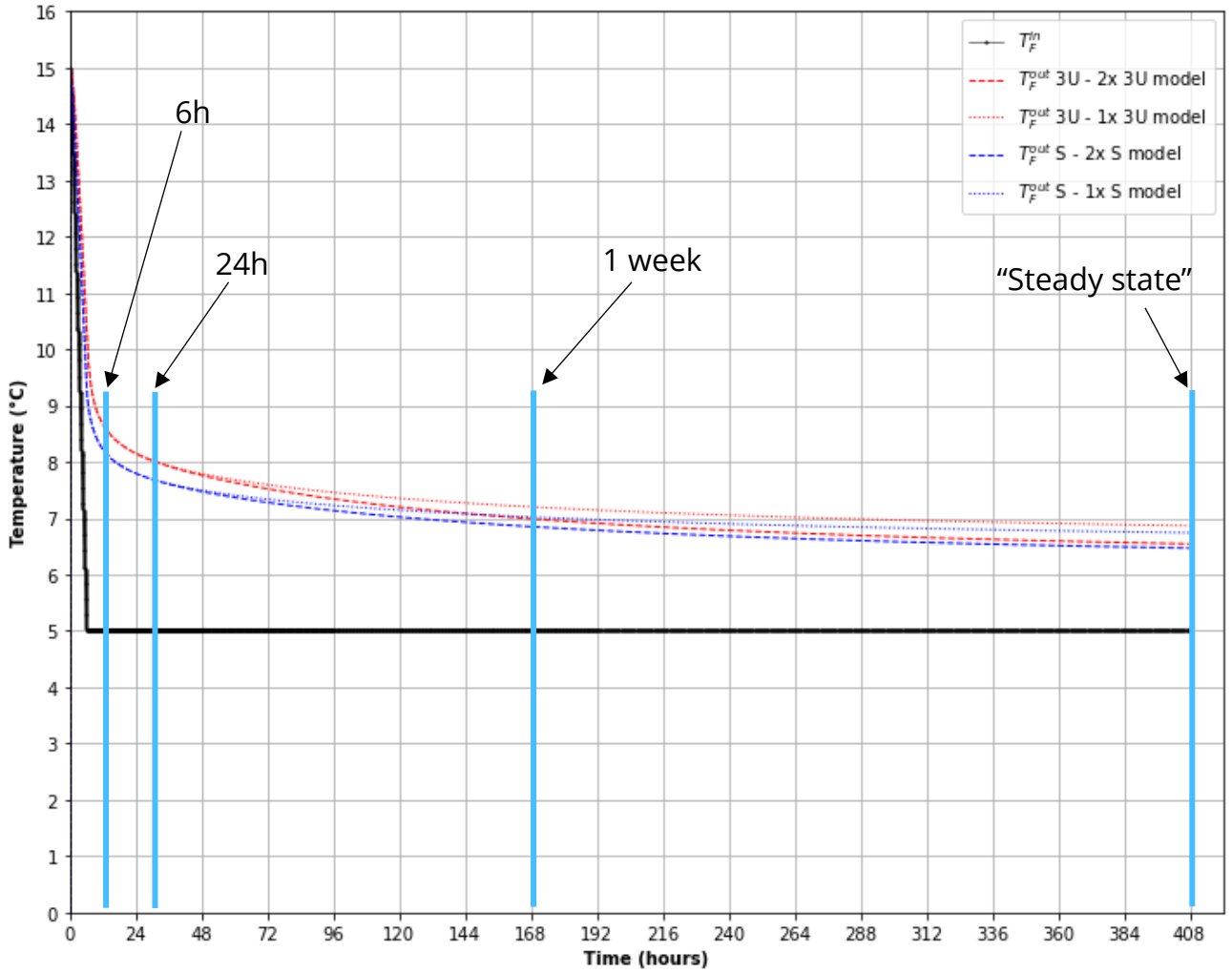


3U only

S only



Heat exchanger temperature

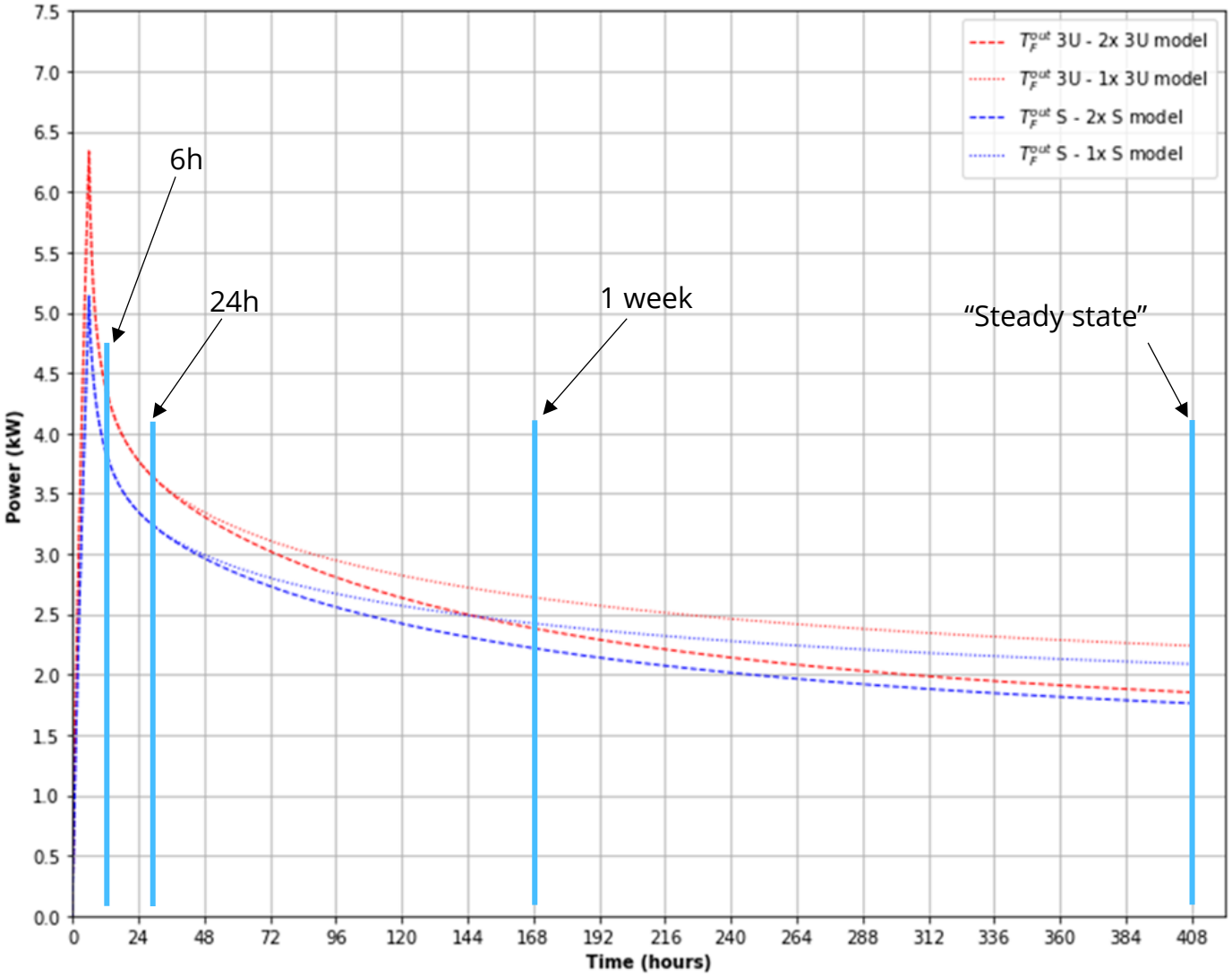


From temperature to power

Thermal power depends on :

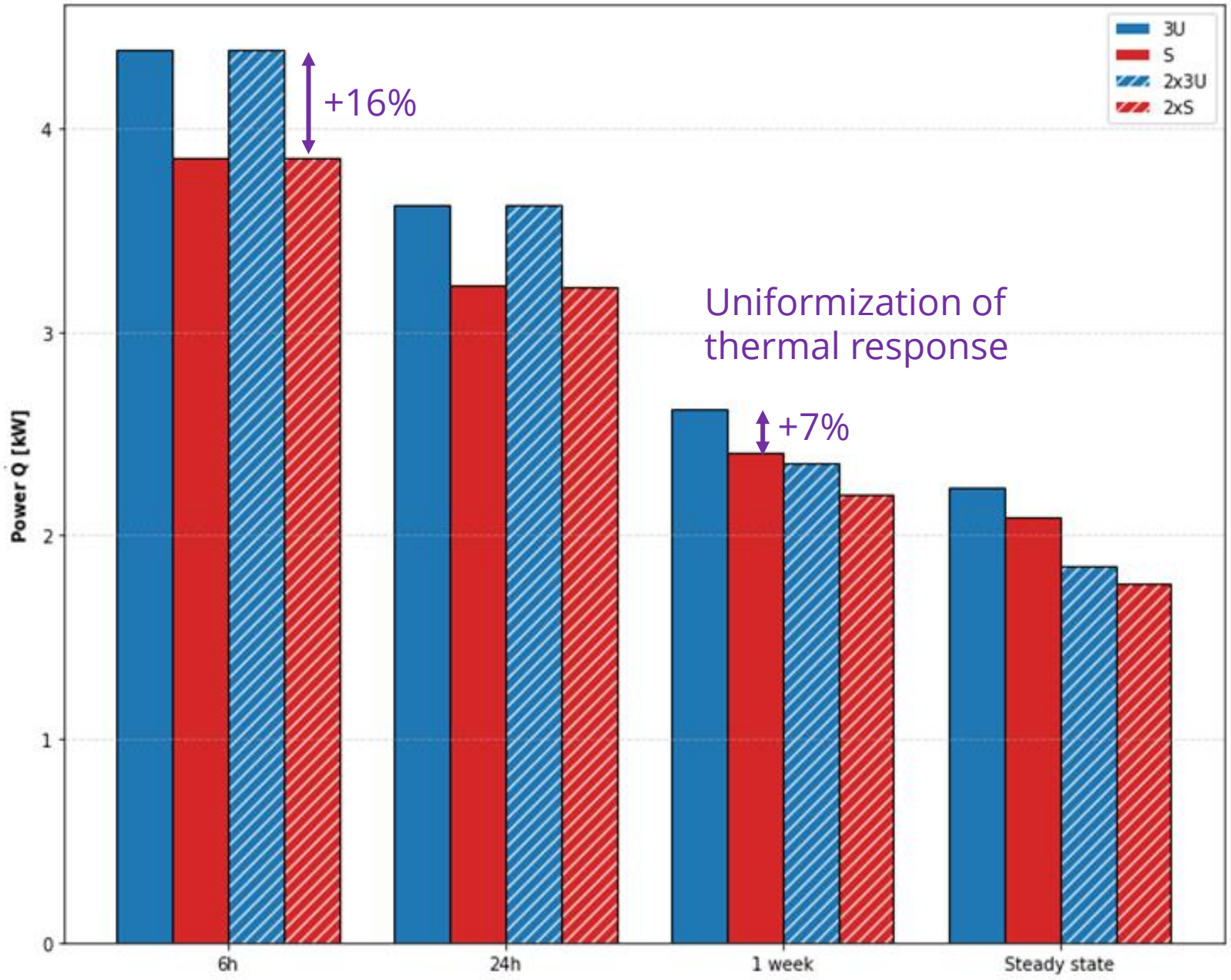
- Fluid type
- Flow regime
- Pipe geometry, layout

- $P = \rho_f C_{p,f} v_f A \Delta T$



Extracted thermal power per each circuit

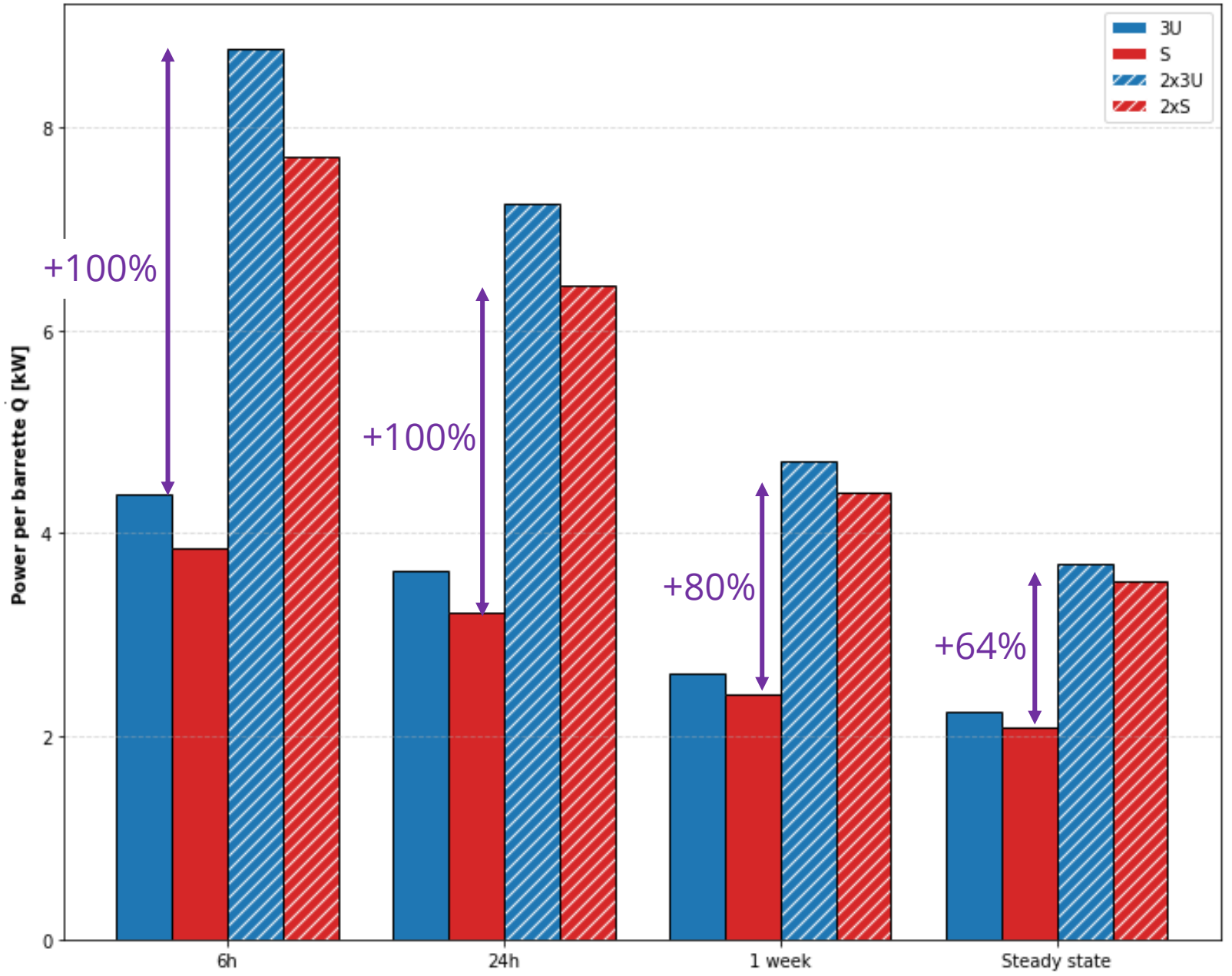
Can we retrieve more energy from 3U or S?



K — F

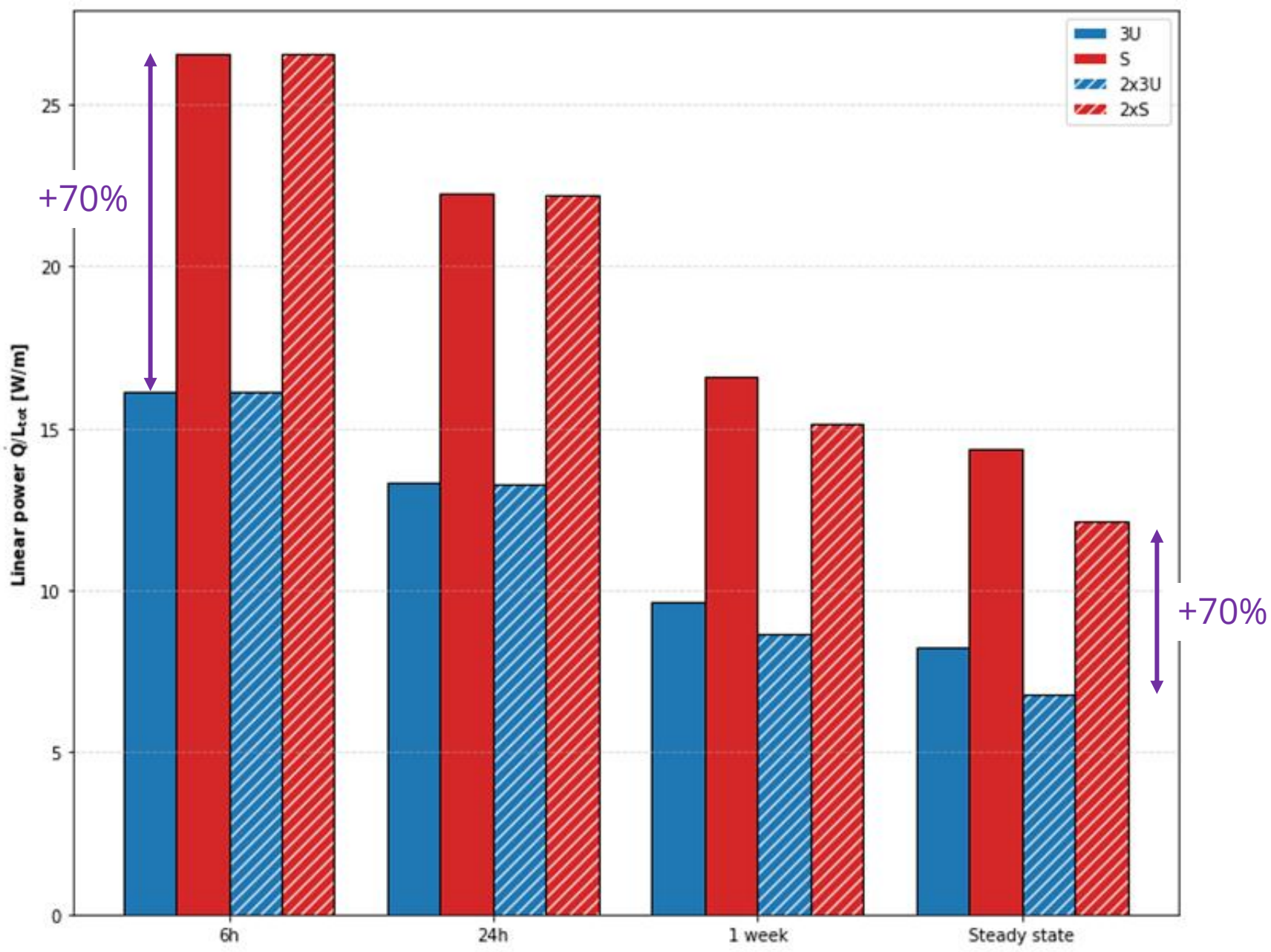
Extracted thermal power per barrette

Is it worth to install heat exchangers on both sides, or not?



Extracted thermal power per meter of tube

- Better spatial distribution of heat exchange flux
- Direct economy on pipe quantities



04 Conclusions

Conclusion

- **A numerical model was successfully validated** against in-situ tests on a thermo-active barrette in Lausanne, in collaboration with Cracow University of Technology (Politechnika Krakowska).
- **Four heat exchanger configurations were numerically assessed** using simplified yet realistic transient thermal energy simulations.
- Every barrette can retrieve up to :
  - **3 to 4 kW** for one-sided thermal activation
  - **7 to 8 kW** for two-sided thermal activation
- Despite of a thermal performance of -7 to 17% with respect of triple U, the **S configuration can be considered as the optimum layout** because it:
  - Provides better temperature distribution in the ground
  - Requires significantly less installed pipe length (≈ **50% less** compared to U), yielding direct cost savings on heat exchangers
- The **ZSoil** software proved to be an **efficient and reliable tool for transient geothermal analysis**.

Acknowledgment

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- Aubry Barellon – Orllati Real Estate

merci

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