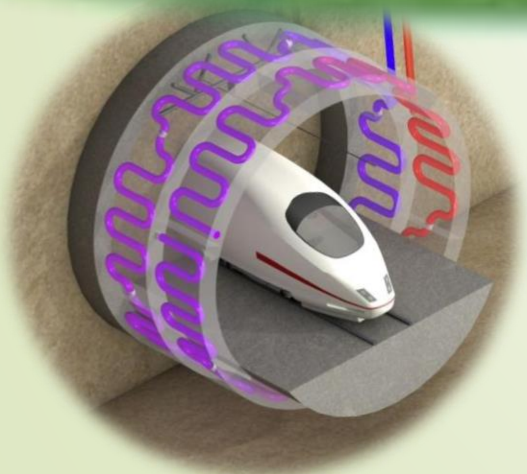
COMSOL CONFERENCE 2016 MUNICH

Tunnels, a new potential for sensible heat storage in rock:

3D numerical modelling of a reversible exchanger within tunnel



Chaima SOUSSI, Olivier FOUCHÉ, Gonzague BRACQ, Sophie MINEC

Email: soussichaima@gmail.com

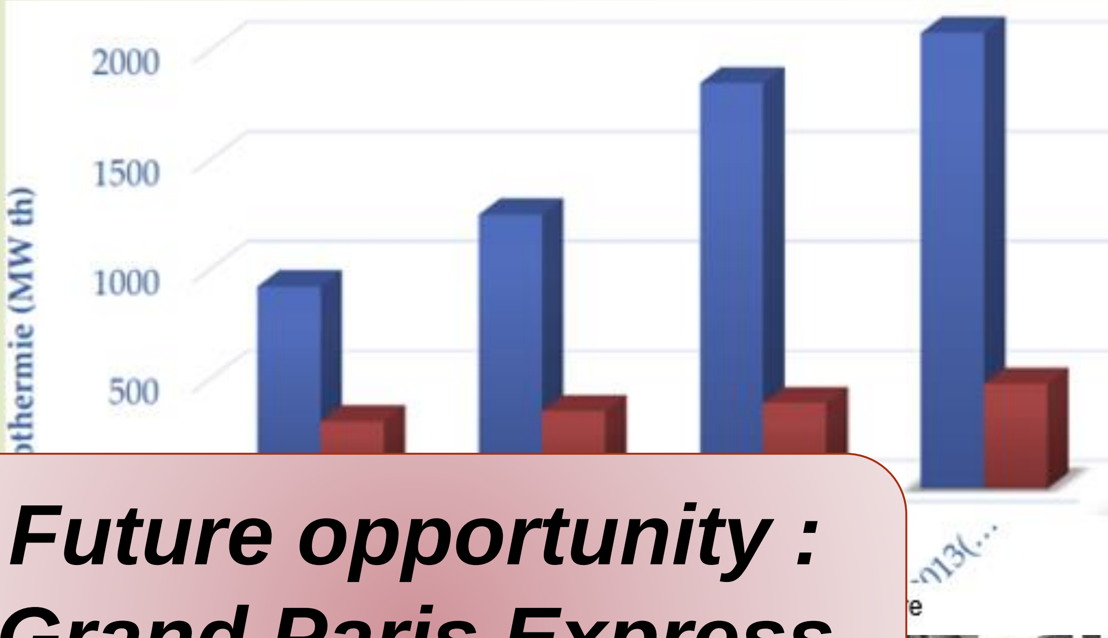
Outline

- Introduction and context
- Principle and feedback
- 3D Numerical modelling
- Results and discussion
- Conclusion

Introduction and context

Increasing the contribution of geothermal energy in the energy mix by developing geothermal heat pumps

The National Project
«Ville 10D– Ville d'idées »
Improving the contribution of the underground resources in the urban development



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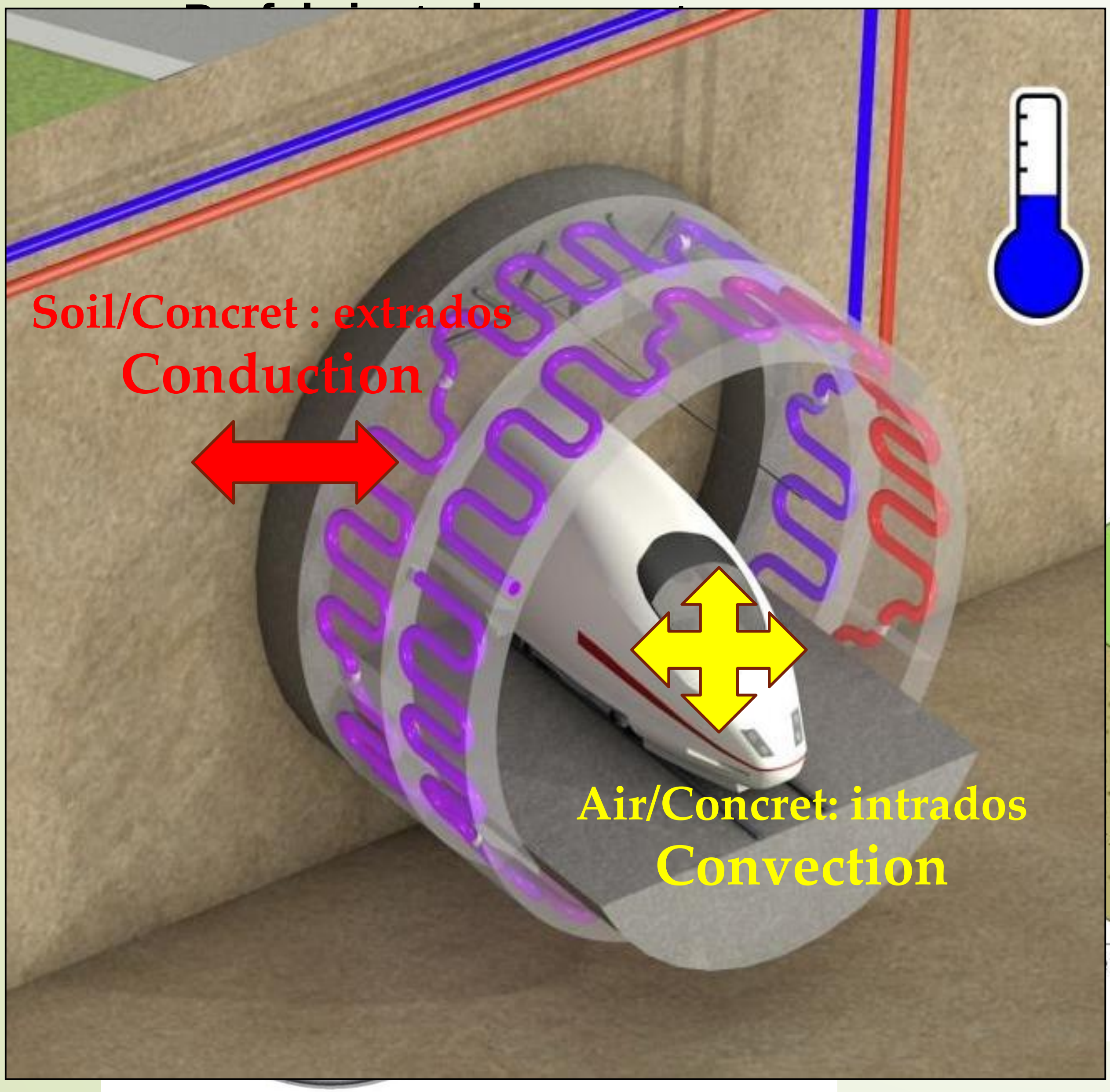
Future opportunity :
Grand Paris Express
205 km of metro lines

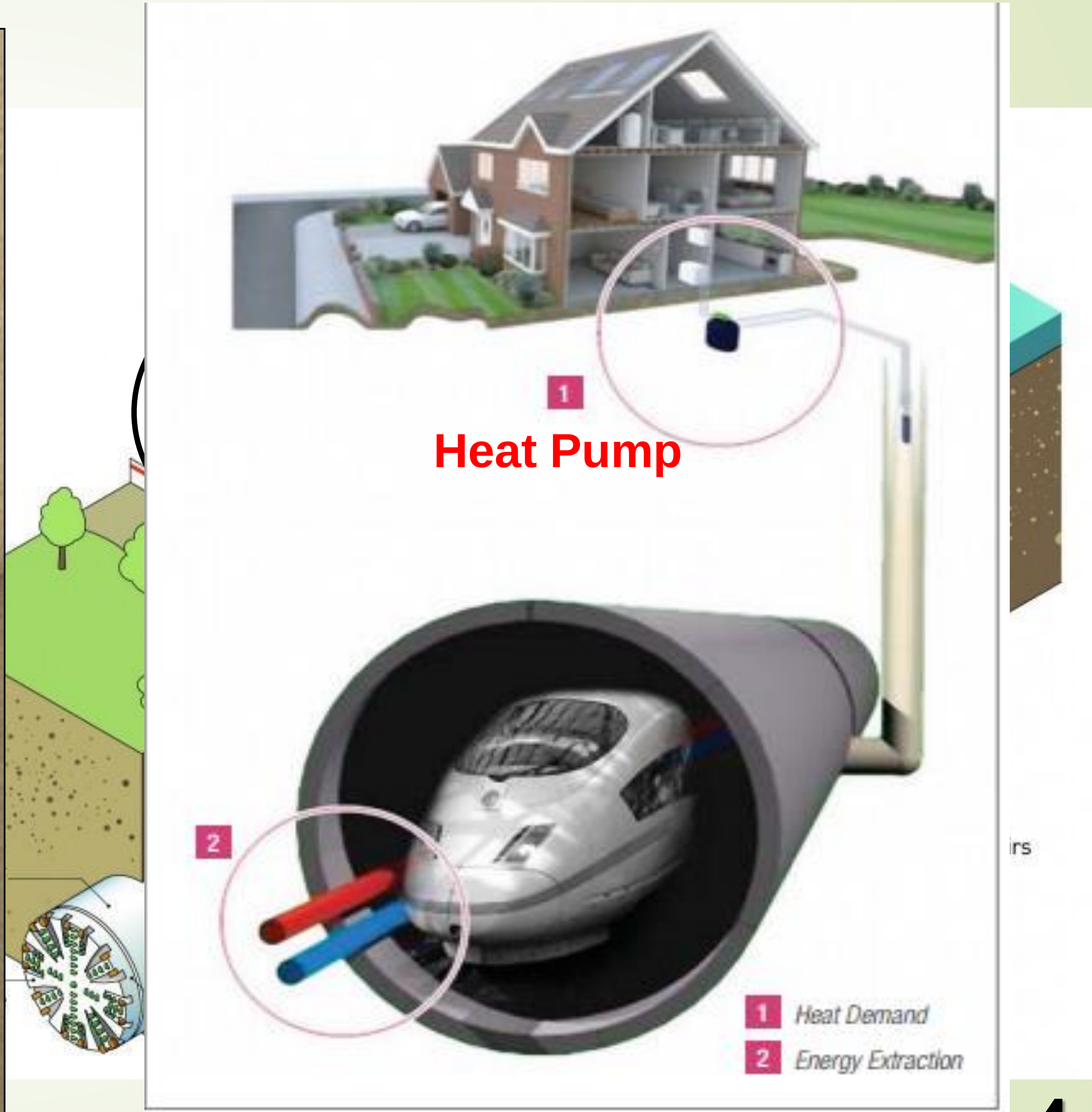
Duration: 4 to 5 years from January 2013
Budget: 5 million €.
Partners: 30 organizations

Piles

Diaphragm walls

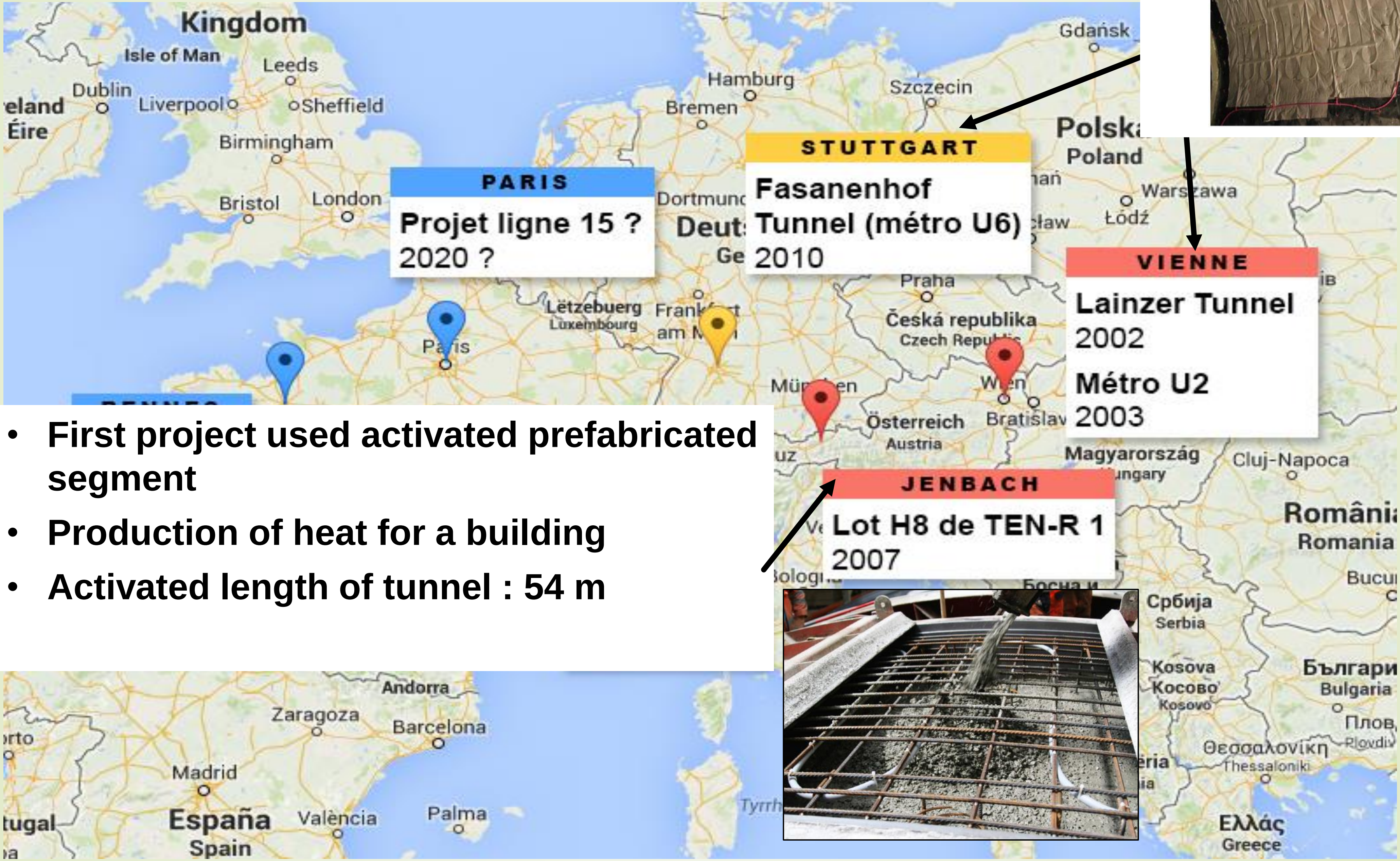
Principle of this new technology





Feedback

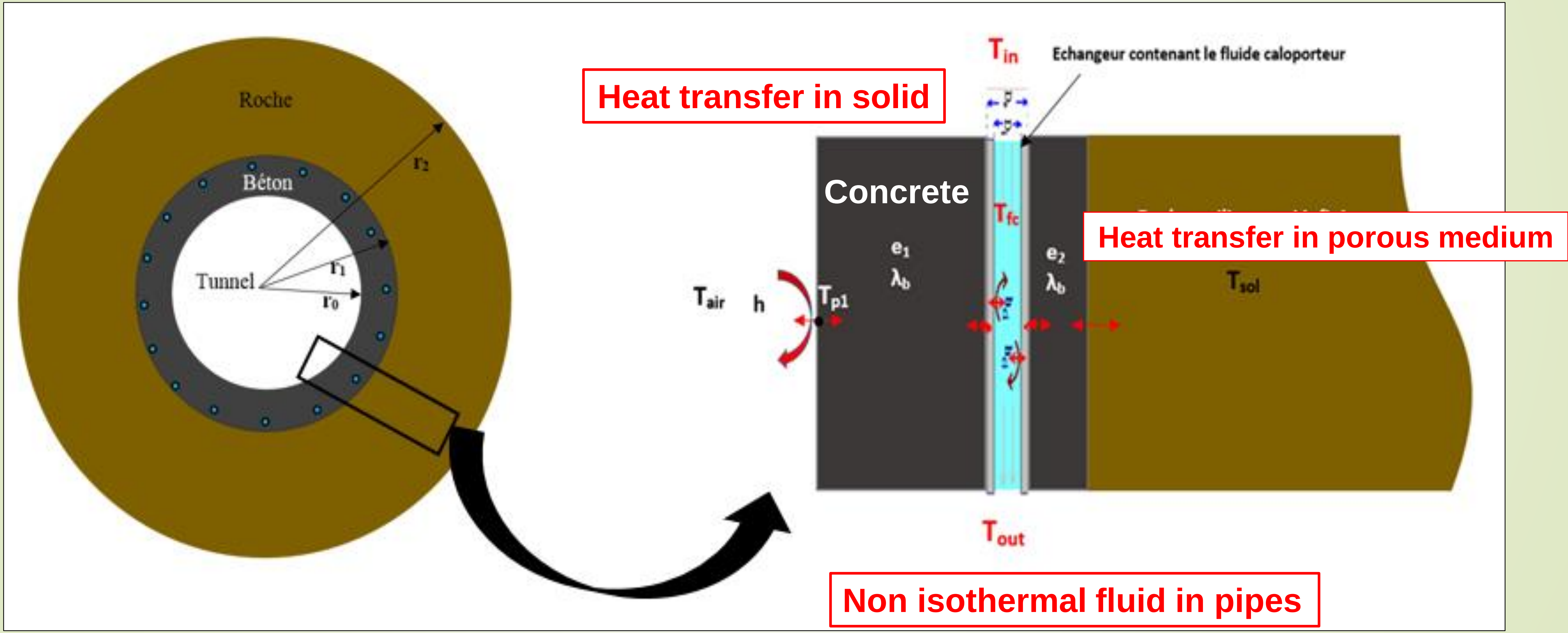
- Traditional method



- First project used activated prefabricated segment
- Production of heat for a building
- Activated length of tunnel : 54 m

3D Numerical modelling

❖ ***Physics***



❖ Equations

❖ Heat transfer in solid

$$\rho C_p \frac{\partial T}{\partial t} = \lambda \nabla^2 T$$

❖ Non isothermal fluid in pipes

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u . \nabla T = \nabla . (\lambda \nabla T) + f_D \frac{\rho}{2 d_h} |u|^3 + Q_{paroi}$$

❖ Heat transfer in porous medium

Continuity equation

$$\rho_w . div(u) = 0$$

Darcy's law

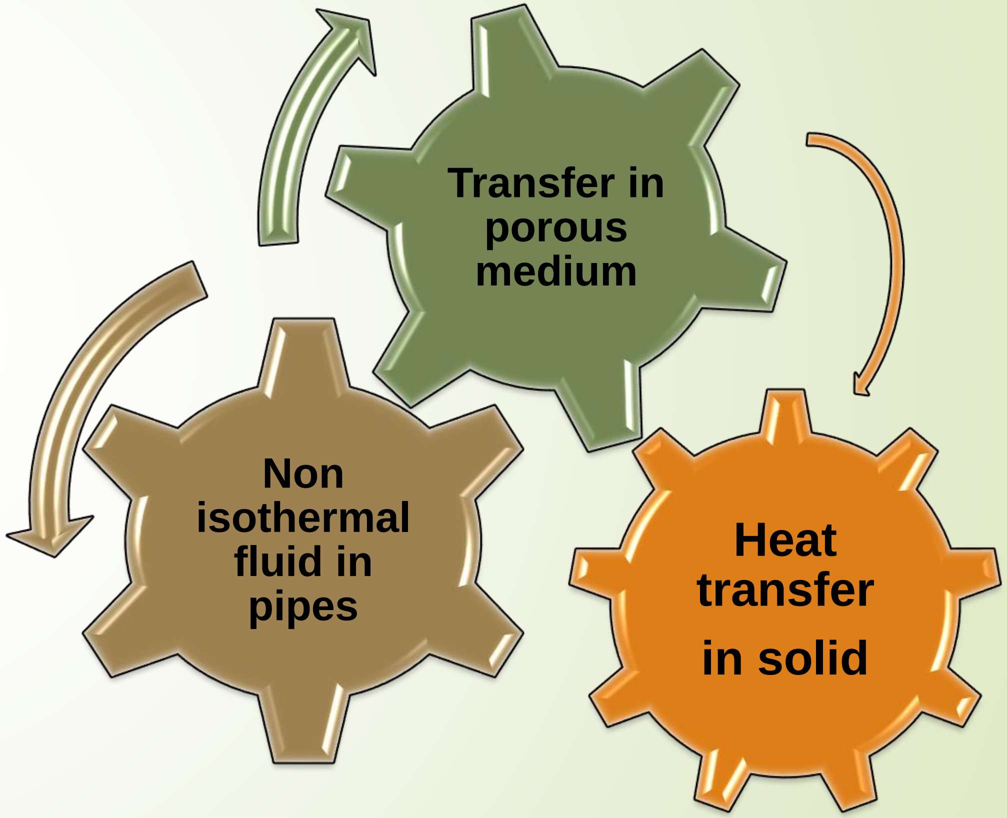
$$u = -\frac{K}{\mu} \nabla (p + \rho g z)$$

Heat equation

with

$$\begin{cases} (\rho C_p)_{eq} = n \rho_w C_{p,w} + (1-n) \rho C_p \\ \lambda_{eq} = n \lambda_w + (1-n) \lambda \end{cases}$$

Coupled physical phenomena



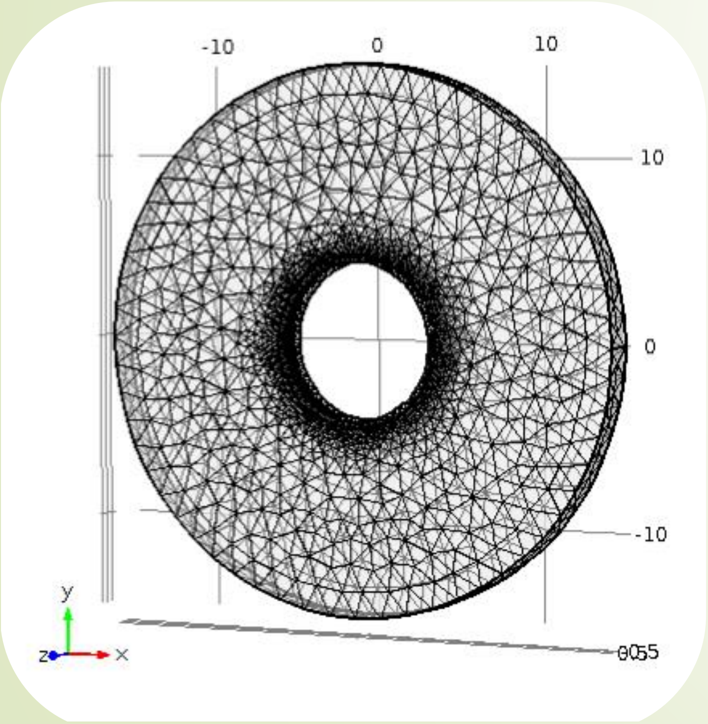
❖ 3D Model

- Outer diameter of the tunnel =9.5 m
- Thickness of the concrete ring =40 cm
- Width of a ring = 1.8 m
- Inner pipe diameter 21mm.

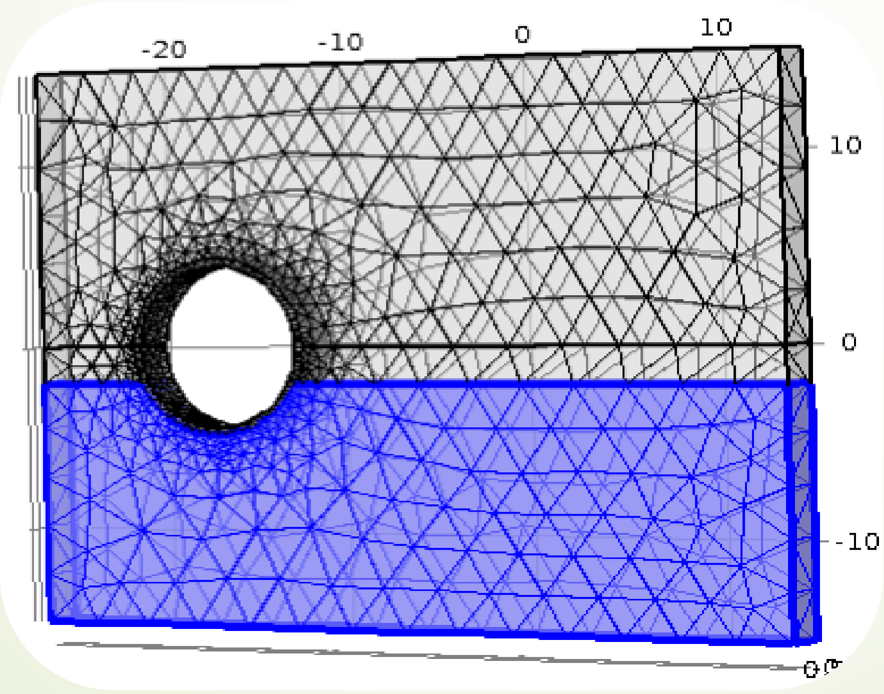
❖ Mesh

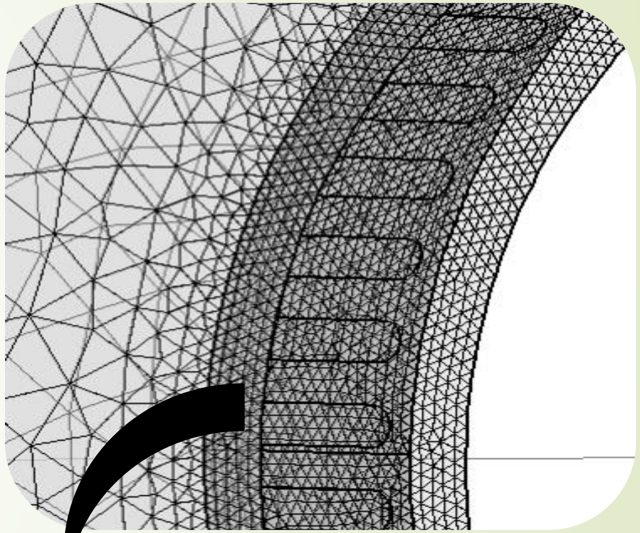
- Defined by user
- Linear elements for pipes
- Tetrahedrons for concrete and rock

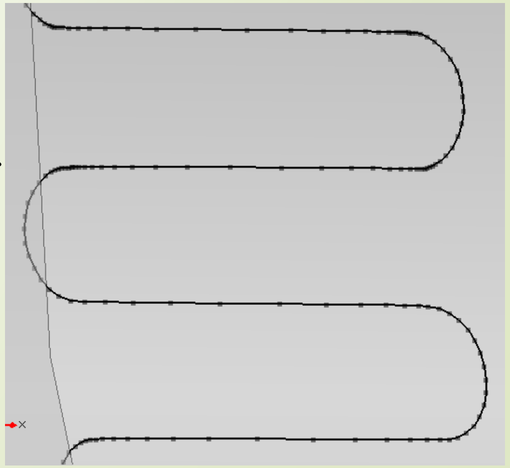
Model without water table



Model with water table

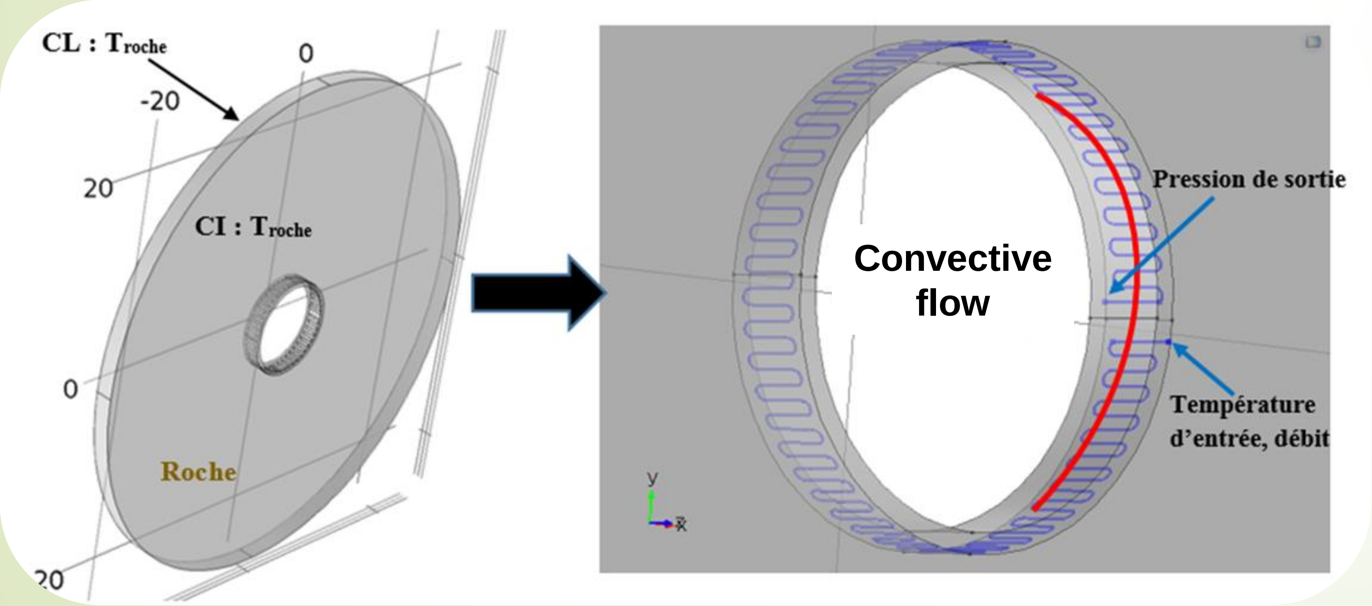




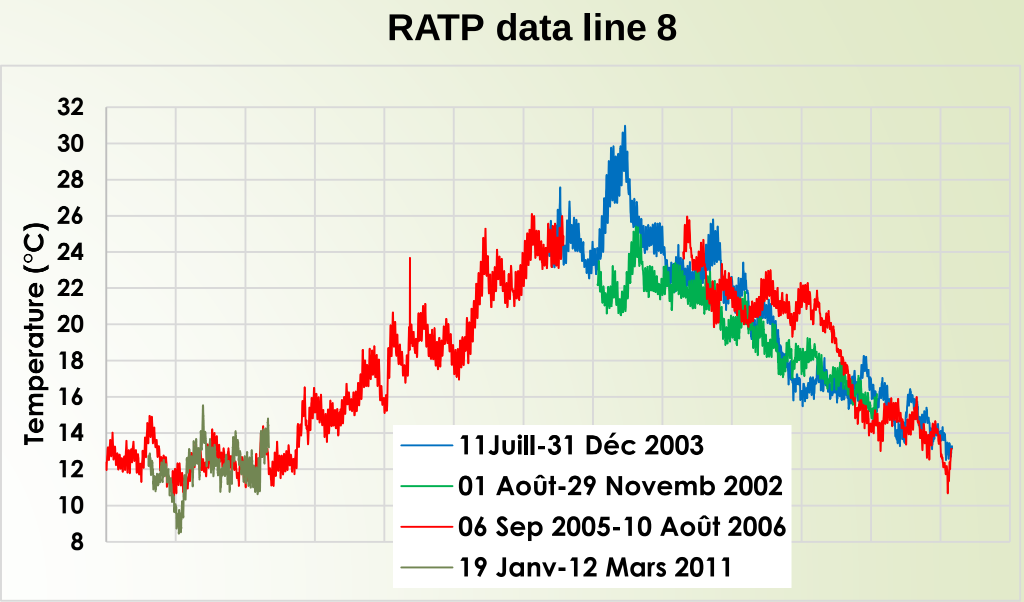


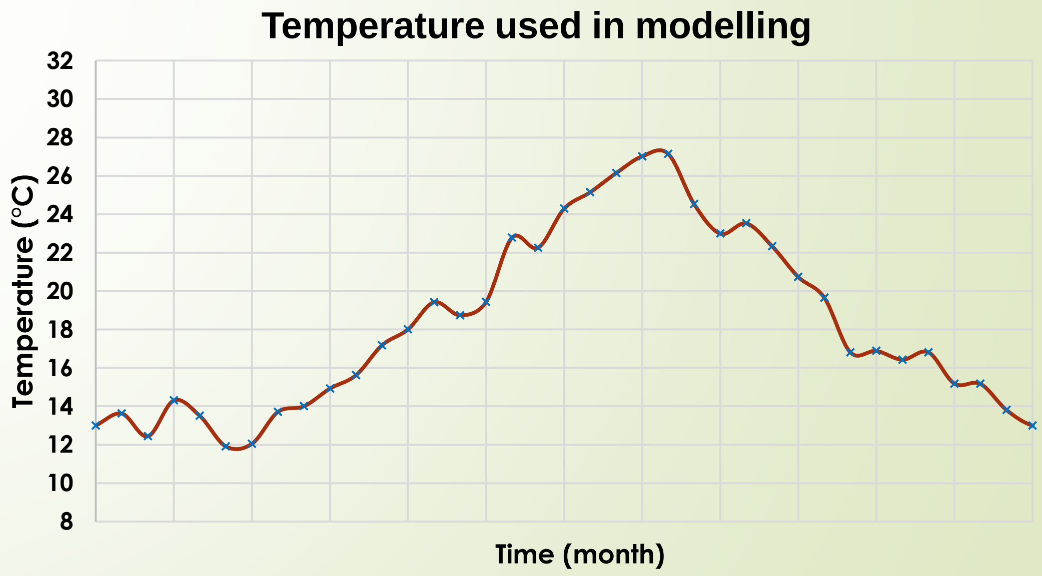
❖ *Initial / boundary conditions*

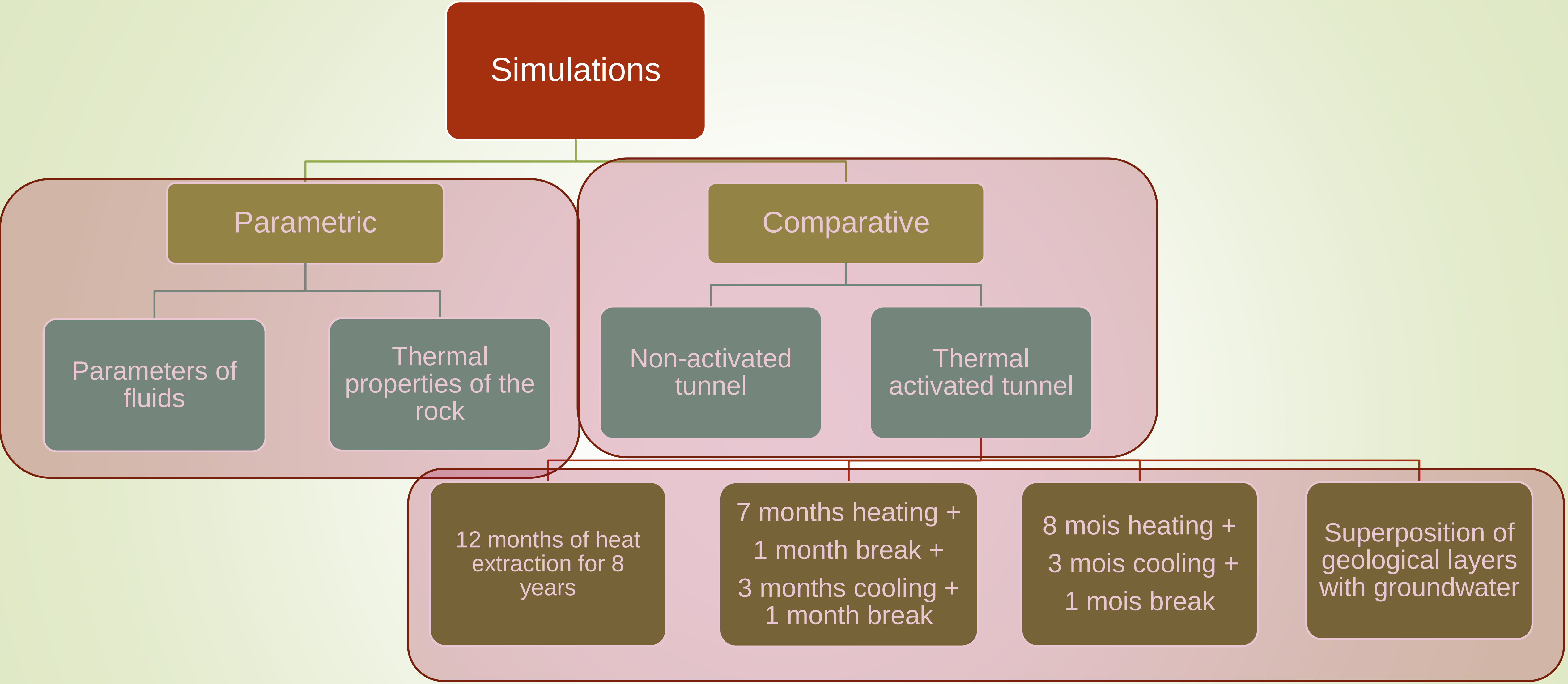
- Rock temperature T_{roche}
- Convective flow
- Inlet fluid temperature T_{in}
- Fluid flow rate
- Fluid outflow pressure
- Groundwater velocity



Temperature of the tunnel's air

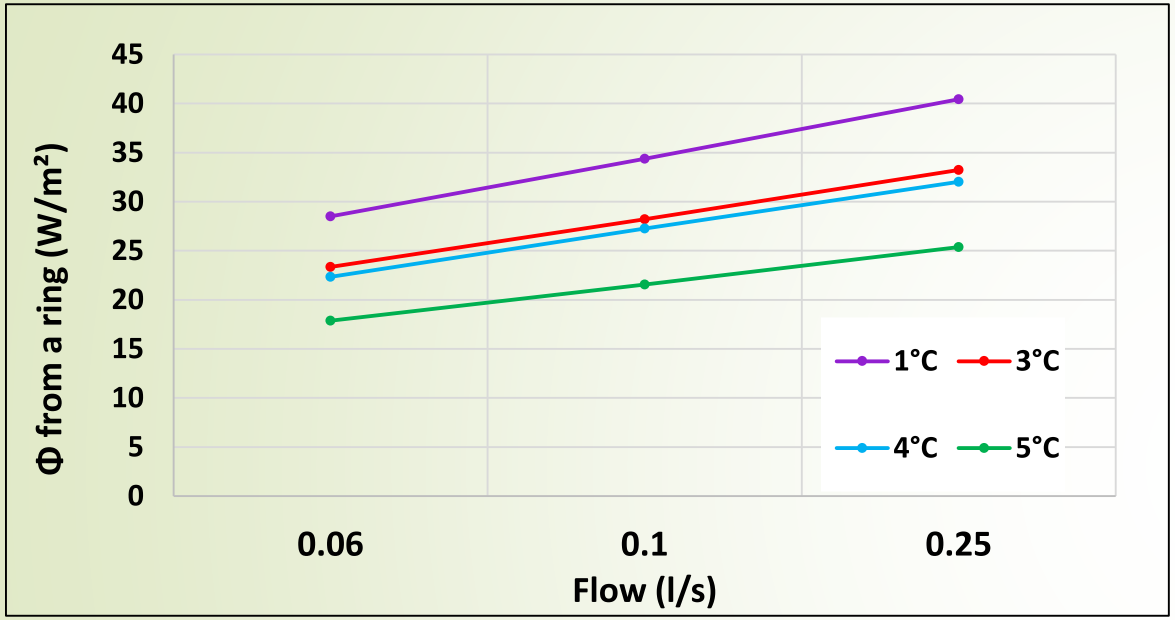


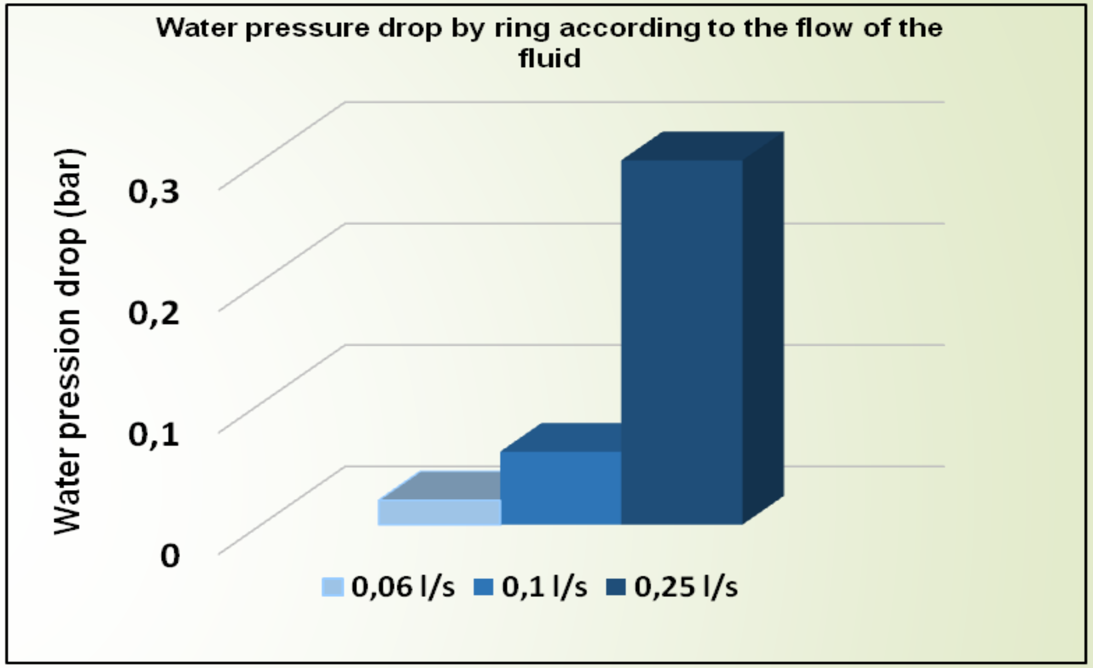



Simulations
Parametric
Comparative
Parameters of fluids
Thermal properties of the rock
Non-activated tunnel
Thermal activated tunnel
12 months of heat extraction for 8 years
7 months heating +
1 month break +
3 months cooling +
1 month break
8 mois heating +
3 mois cooling +
1 mois break
Superposition of geological layers with groundwater

Results and discussion

Fluid parameters





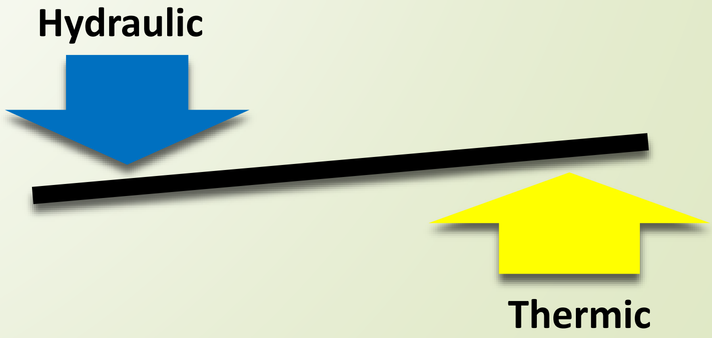
A wide range of heat flux of 15 W / m to 40 W / m²

Heat extraction and hydraulic loss increase with fluid flow

Finding an equilibrium between the thermic and hydraulic problems

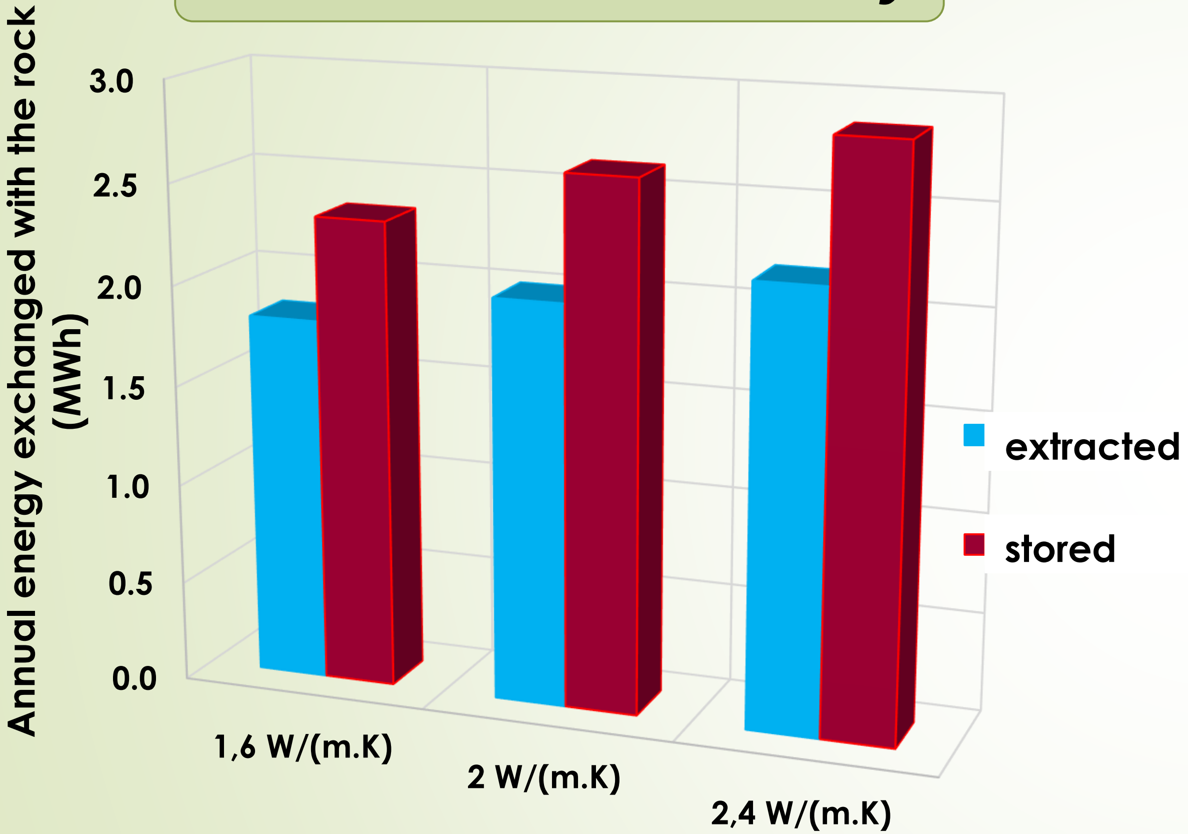
Fixed parameters

T_{in} in winter: 4 ° C and flow rate: 0.1 l / s



Thermal properties of the rock

❖ Thermal conductivity

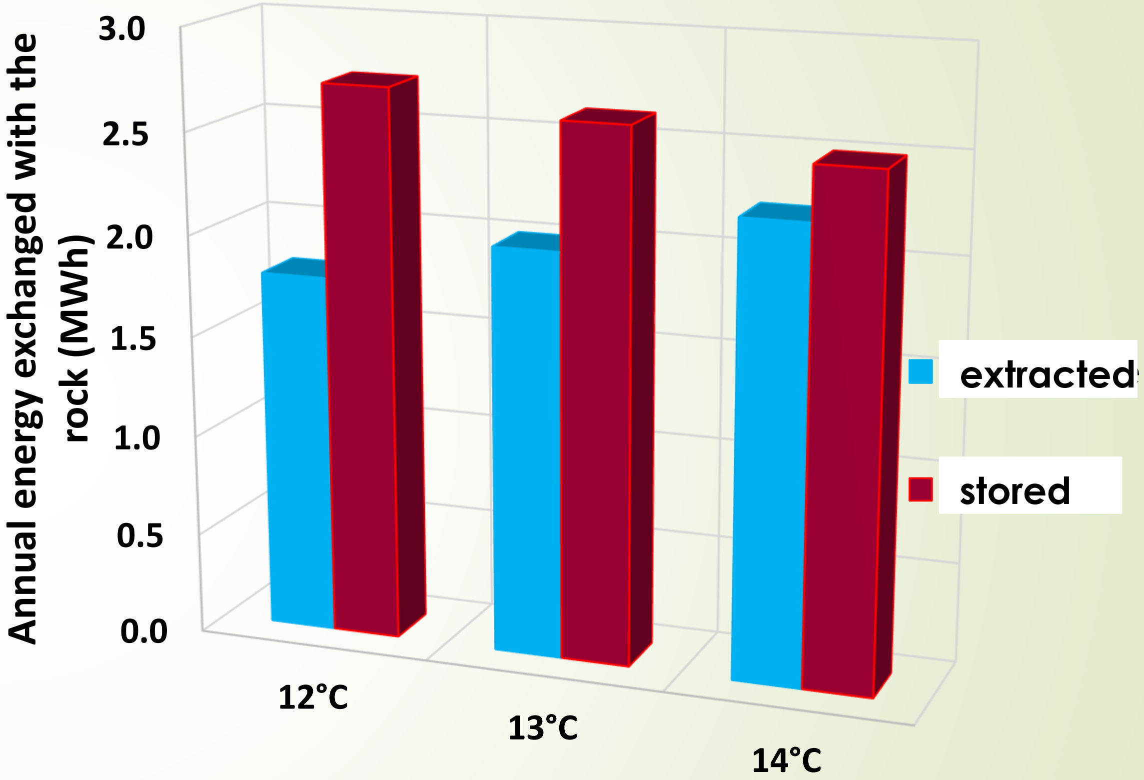


➢ Energy exchanged increases with the thermal conductivity:

Extracted ≈2 MWh / year / ring

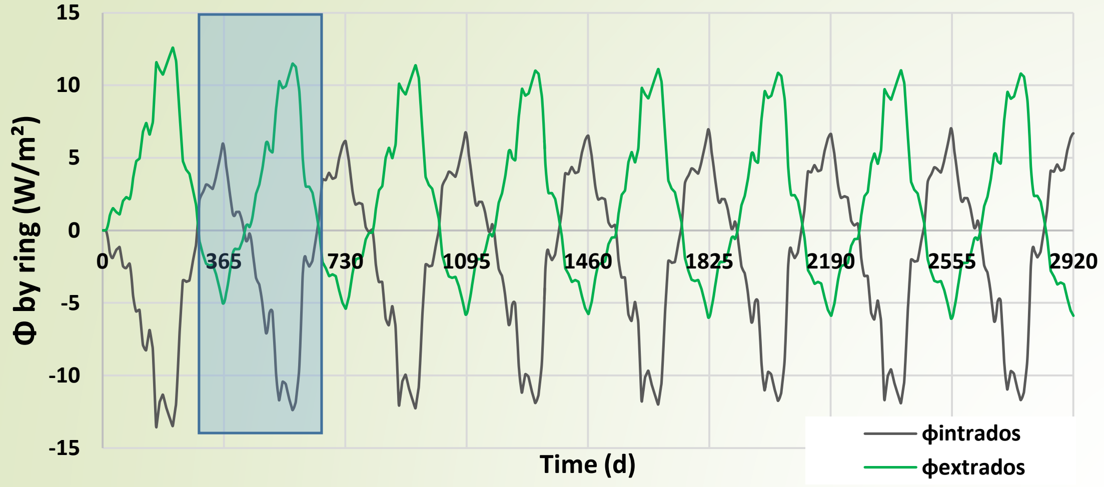
Injected ≈2.5 MWh / year / ring

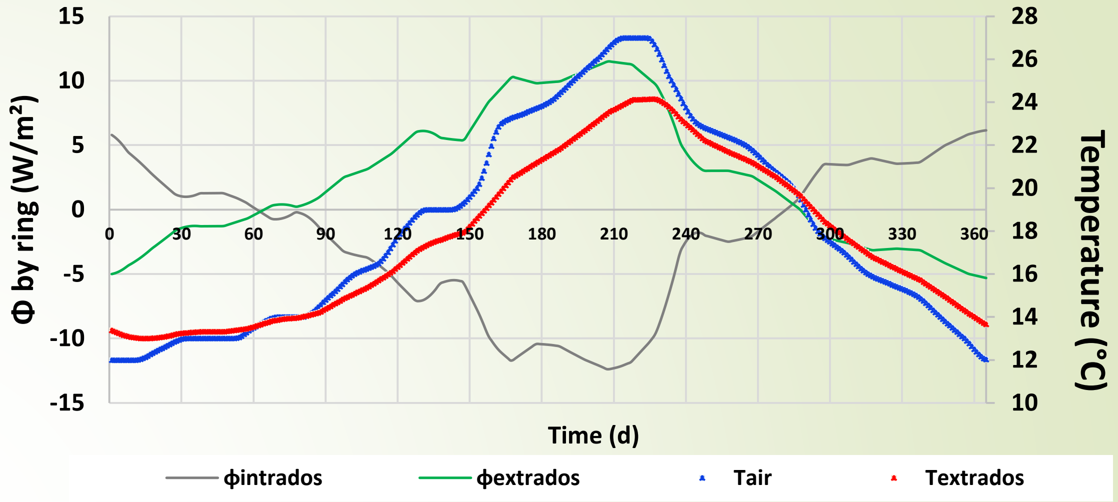
❖ Temperature



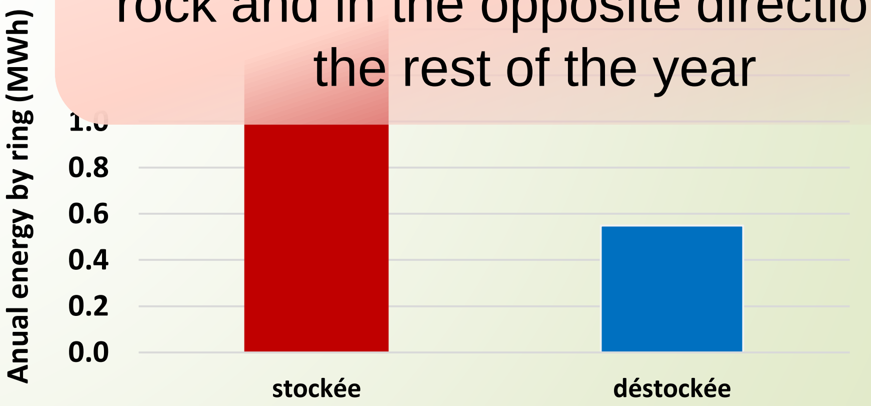
➢ Stored energy decreases with temperature
➢ Extracted energy increases with temperature
➢ Decrease of the difference

Non activated tunnel



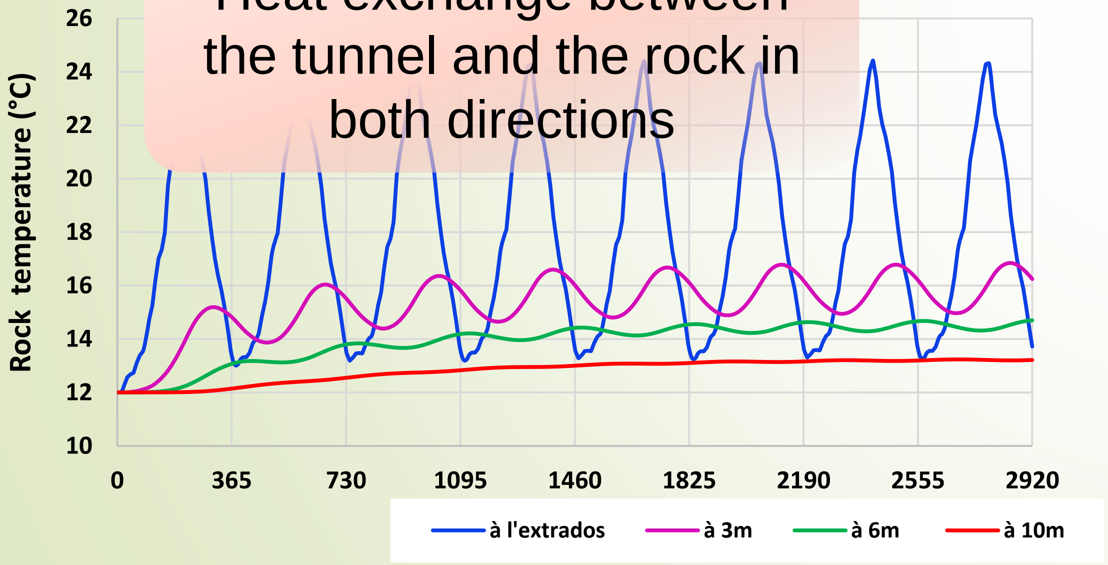


From march to mid-september, the heat diffuses from the tunnel to the rock and in the opposite direction in the rest of the year



Quantity of heat stored > extracted

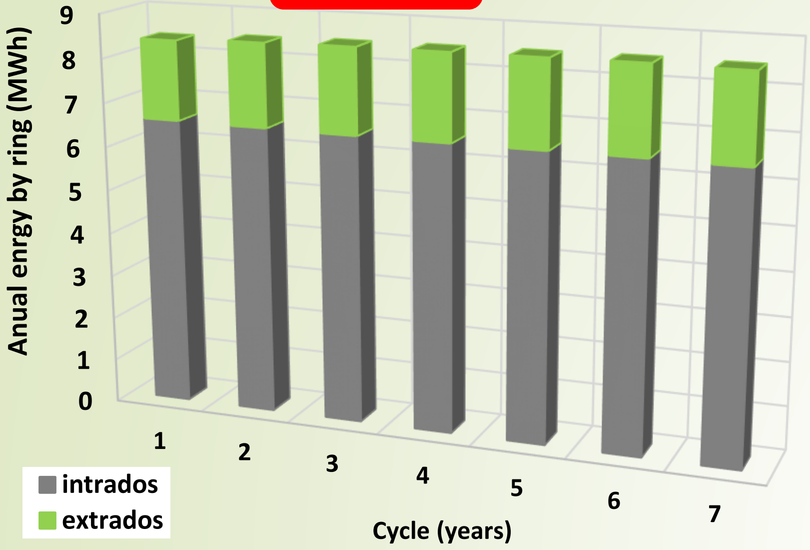
Heat exchange between the tunnel and the rock in both directions



Warming of the rock

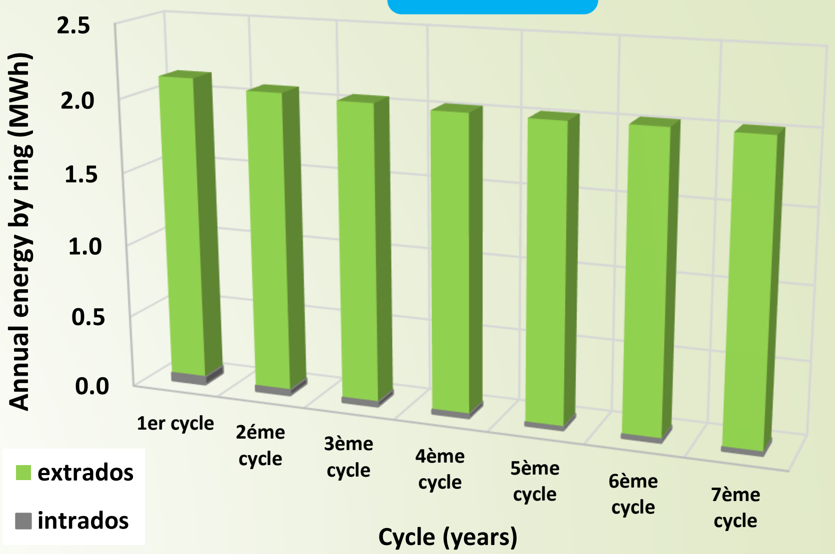
Thermal activated tunnel

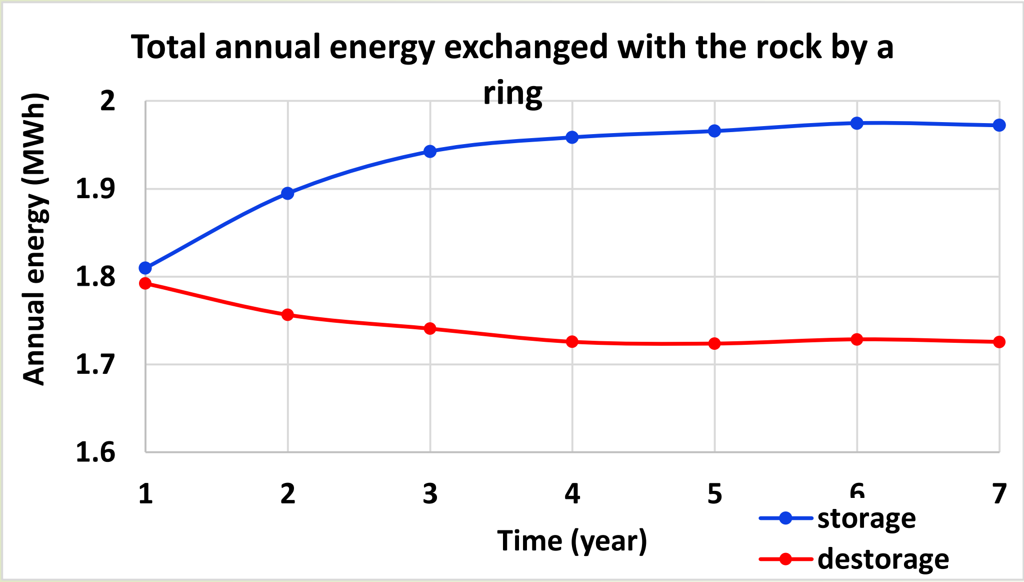
Heating

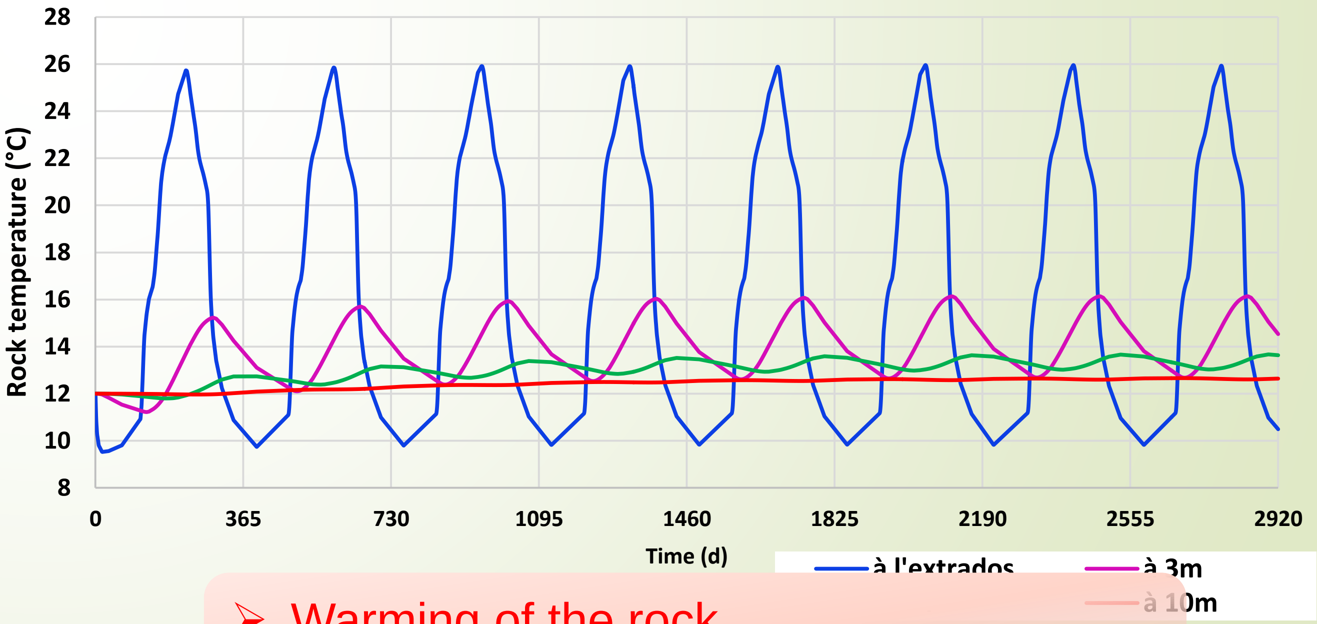


- The air in the tunnel is responsible for 2/3 of the production of heat in winter;
- All the heat is distributed in the rock in summer.

Cooling





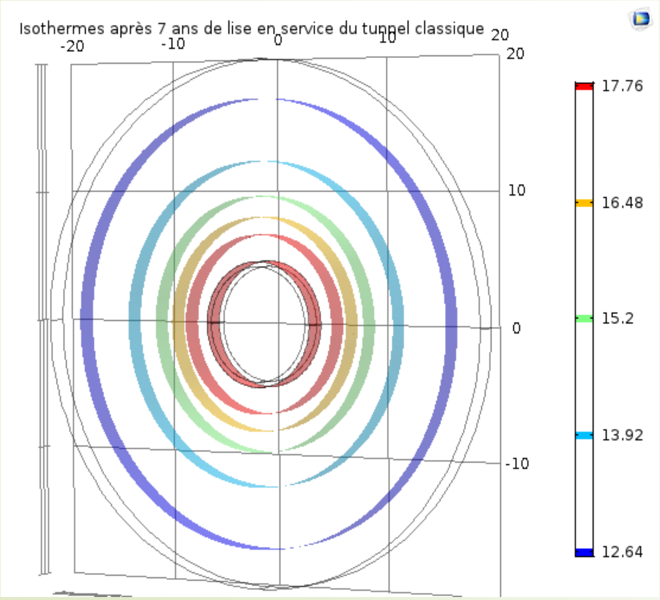


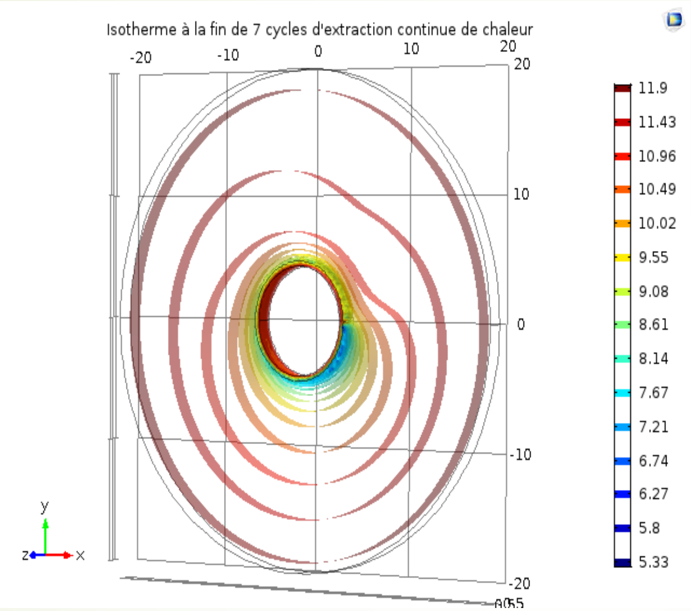
Equilibrium after 4 years of operation, with an excess of heat storage about 0.2 MWh / year

- Warming of the rock
- Negligible changes from the 4th cycle

Comparison between thermal activated and non-activated tunnel

❖ *The temperature distribution around the tunnel*

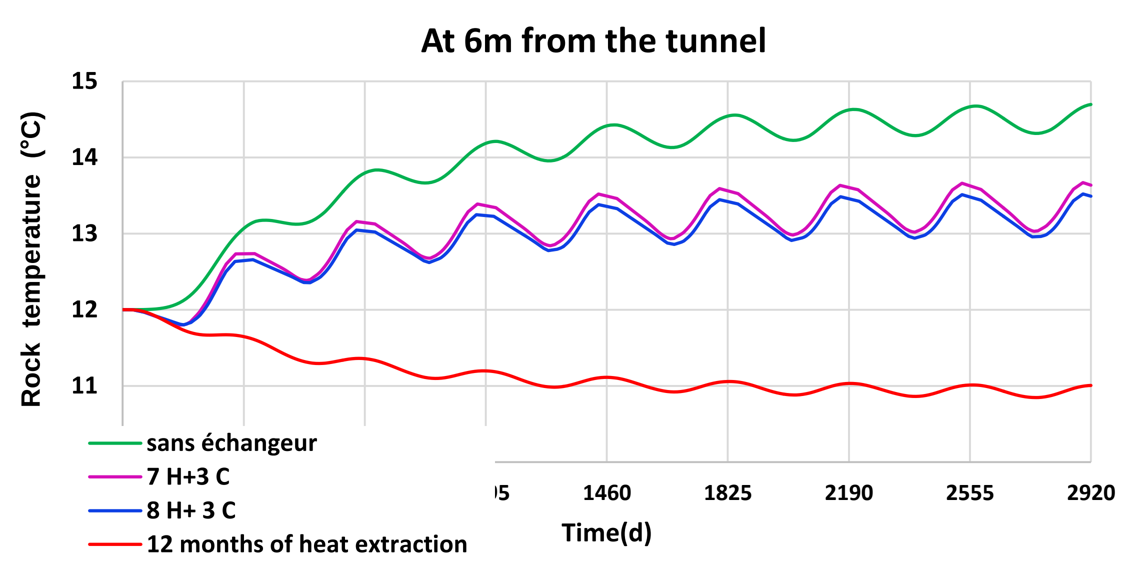


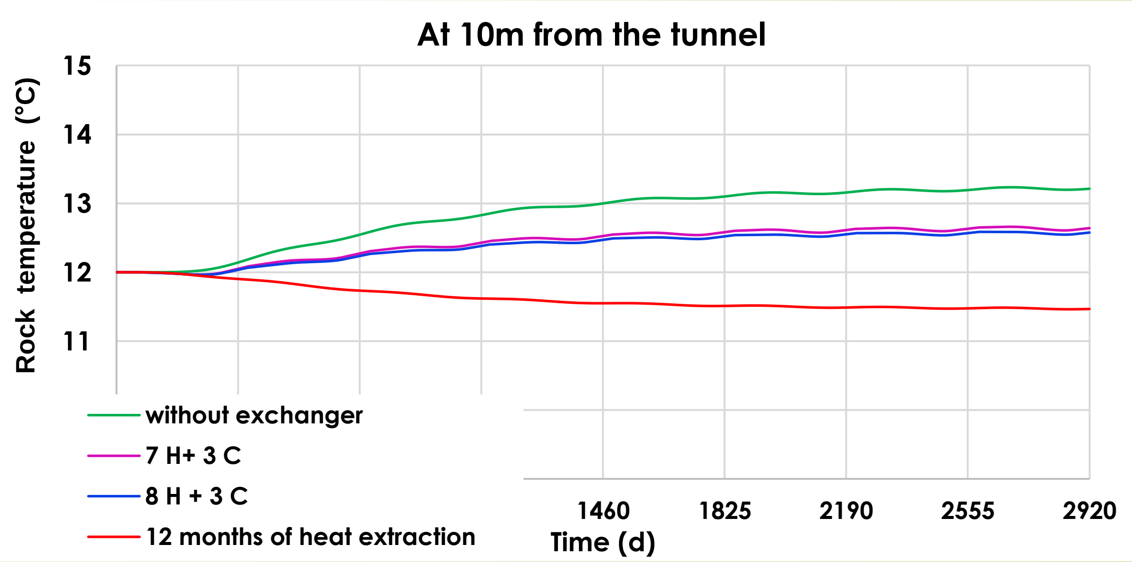


Radial shape around non-activated tunnel

Snail shape around activated tunnel

❖ *The temperature profile in the rock*

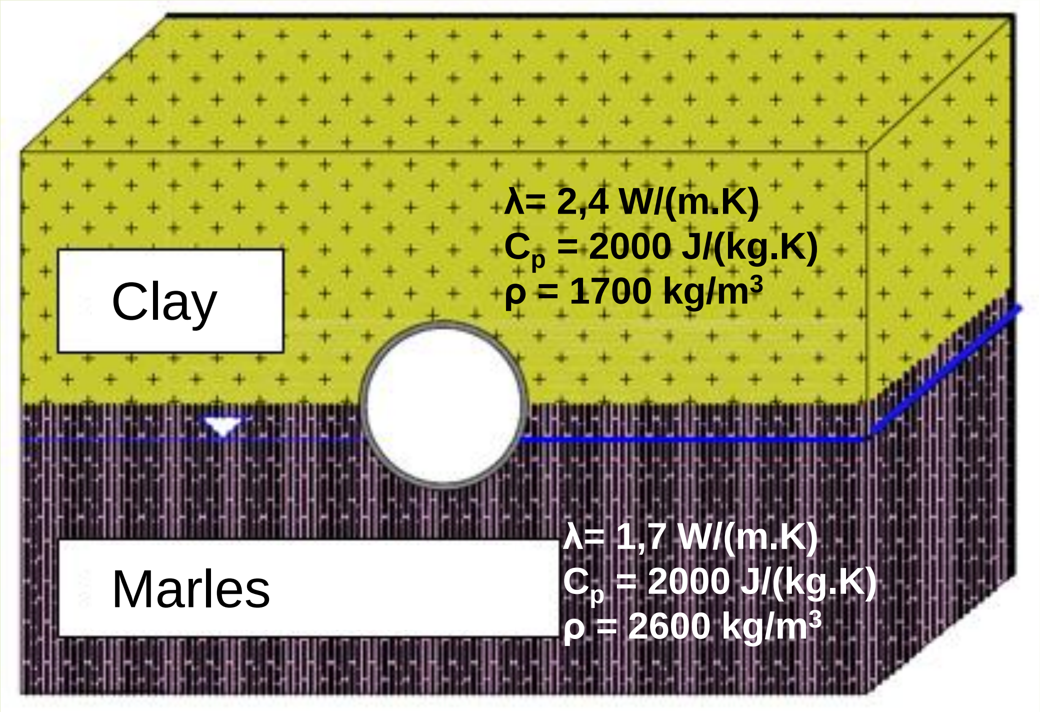


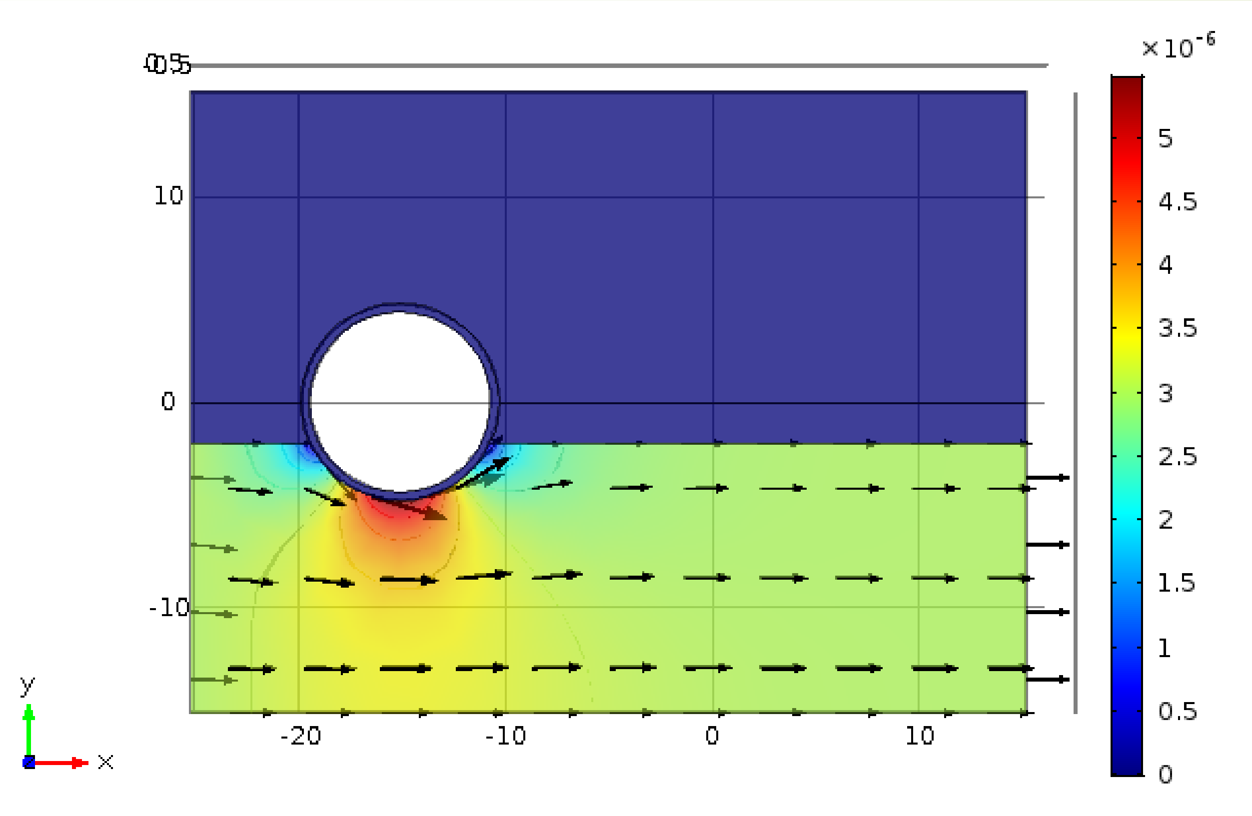


The exchanger system reduces thermal disturbance of the rock.

Effect of groundwater flow

❖ Behavior of the water table around the tunnel

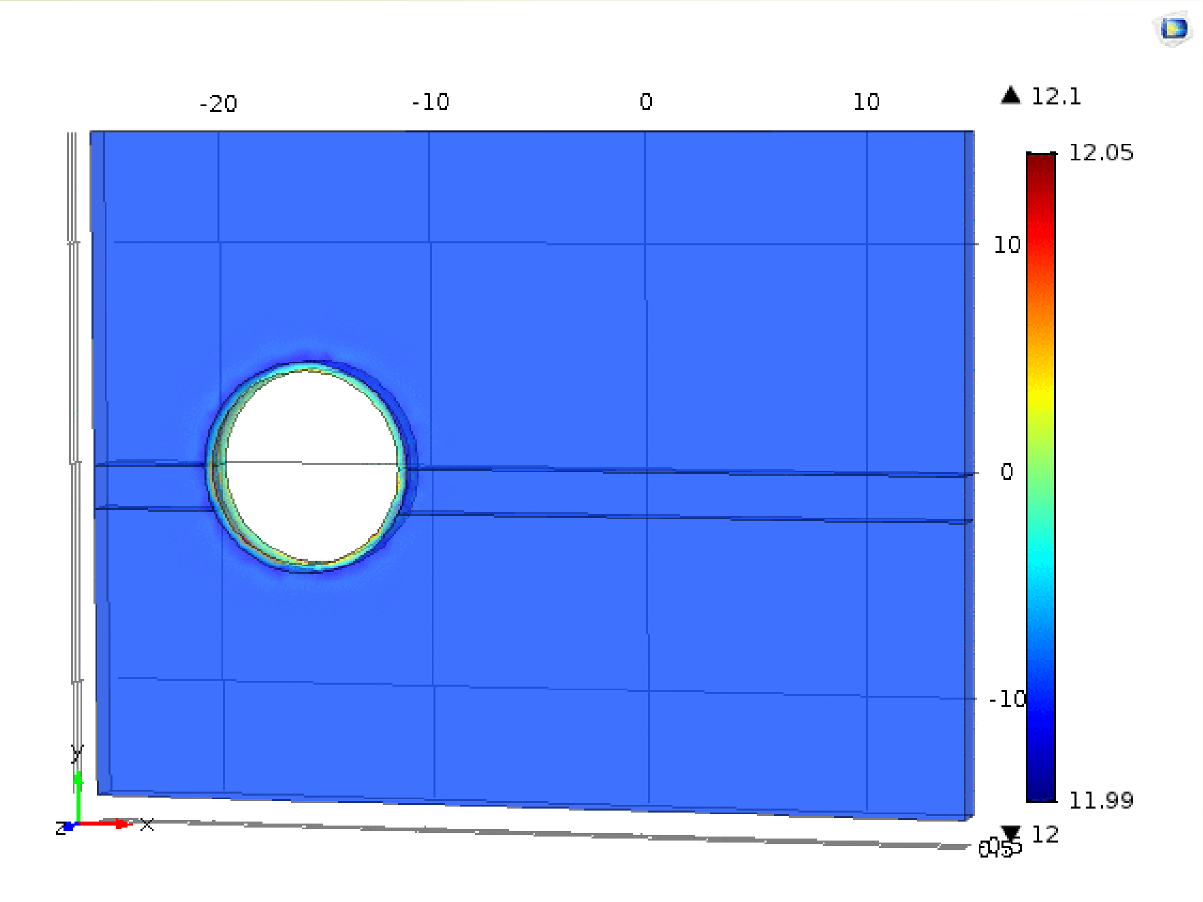




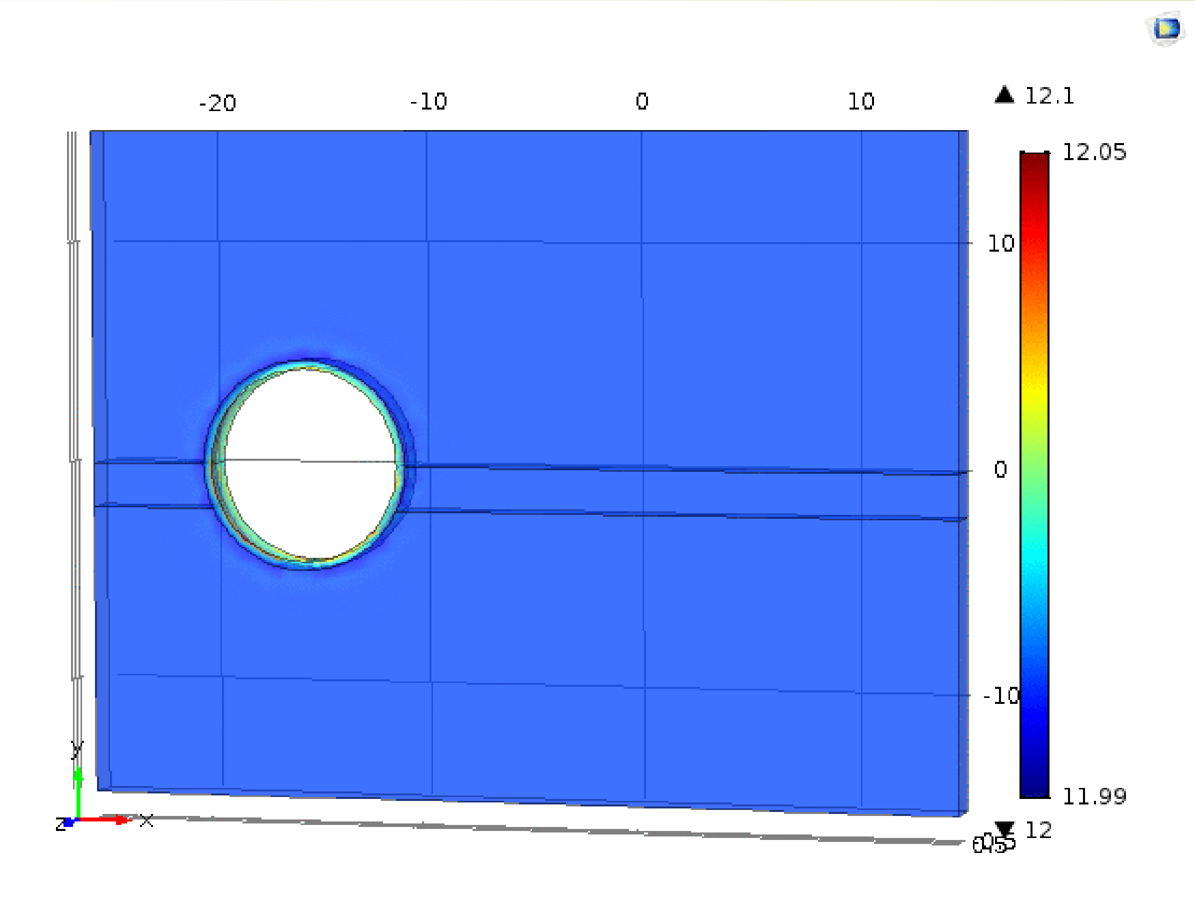
- Superposition of two geological layers
- Groundwater level is 2m below the interface

❖ *Effect of the groundwater on the thermal equilibrium of the rock*

Velocity 3.10^{-5} m/s



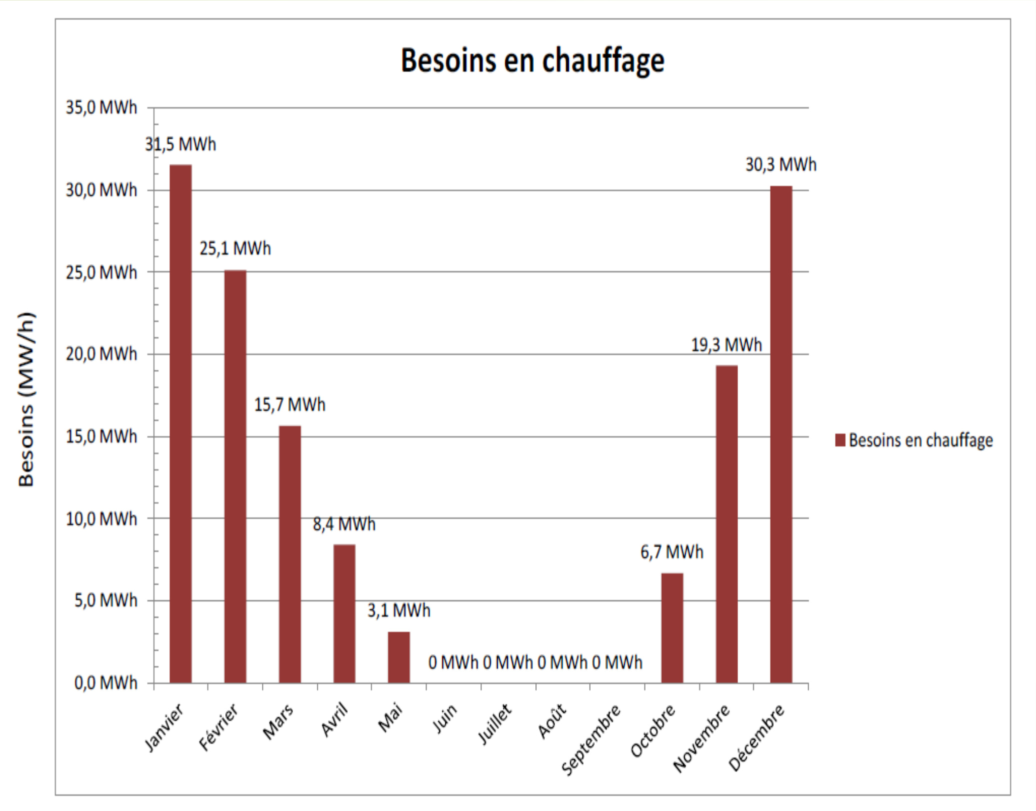
Velocity 3.10^{-6} m/s



The velocity of the groundwater has a great influence on the thermal equilibrium of rock and thus the heat exchange

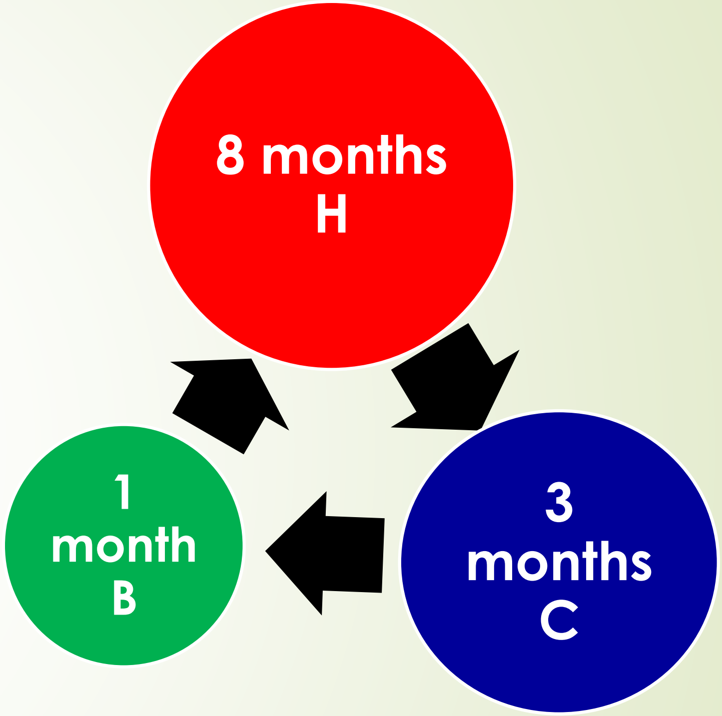
Response to heating needs, case of new offices

Heating needs



Annual needs : 140 MWh

Scenario adopted



Heating production

8.5 MWh/ year/ ring ≅ 4.7 MWh/ year/ ml

30 meters linear of the tunnel = 17 rings must be activated

Conclusion

- Ecological benefits: reducing consumption of fossil energy and thermal disturbances of the rock,
- Stable and sustainable system,
- In the case of absence of groundwater flow, the fluid properties have more remarkable effect than that of the thermal properties of the rock,
- Velocity of the groundwater has a great influence on the behavior of the system: rapid flow allows the thermal regeneration but not the heat storage in the rock.

Thanks for your attention

For more information:

Poster will be presented

today at **16:00 - 18:00**