Seasonal Thermal Performance of Geothermal Piles

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Introduction: Interest of the construction industry in energy piles (building foundation piles used as ground heat exchangers coupled to a geothermal heat pump) is increasing, owing to the savings in installation costs with respect to conventional borehole heat exchangers.

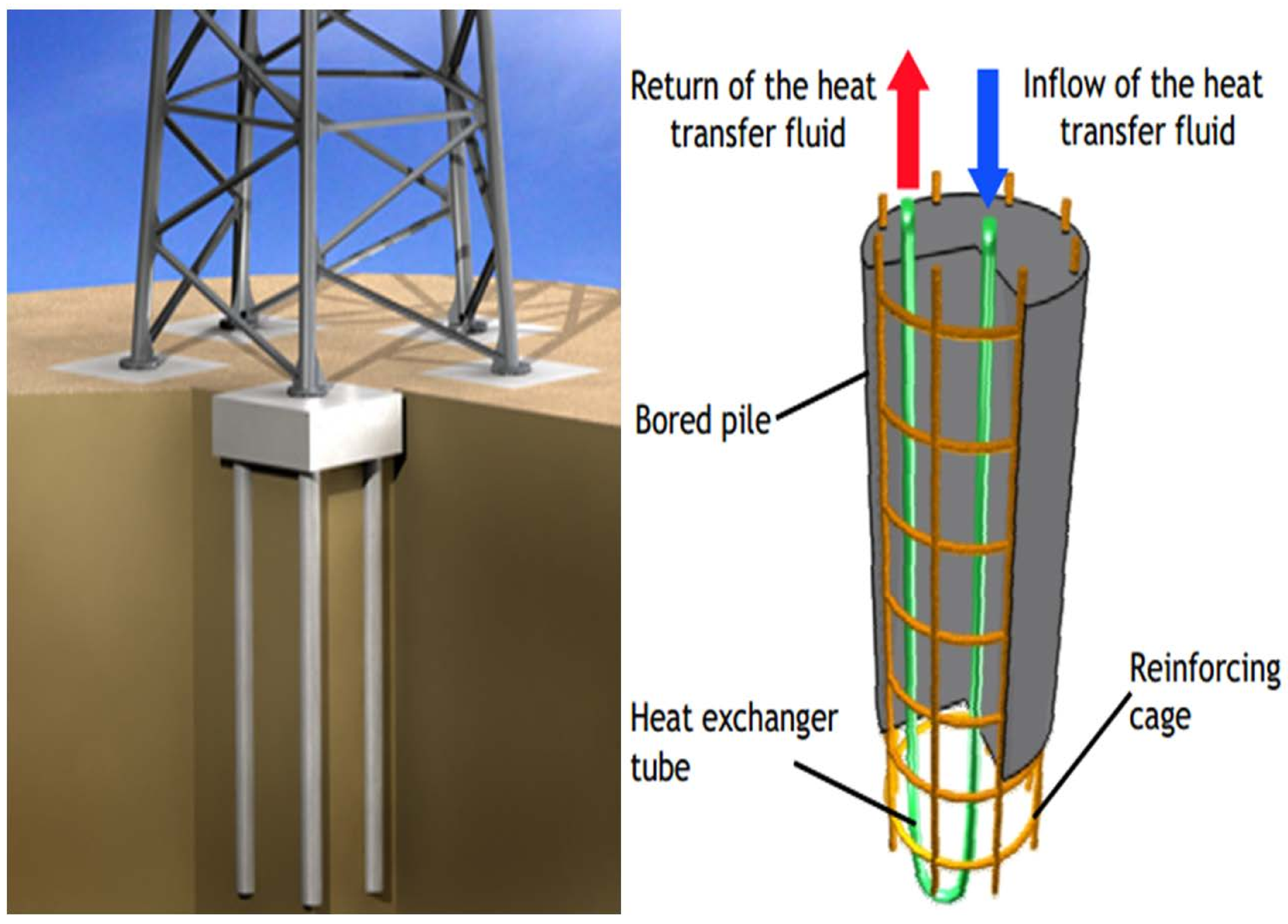

Figure 1. Schematics of a geothermal pile

Current design methodologies are based on classic analytic models and "magic numbers" given by a few technical standards. More complex approaches, needed to improve the accuracy of heat transfer predictions, are under development and validation.

Computational Methods: The seasonal thermal performance of a single pile is simulated by COMSOL Multiphysics 4.1. 3 typical heat exchanger layouts (i.e., "double U", "W", and "triple U") are examined.

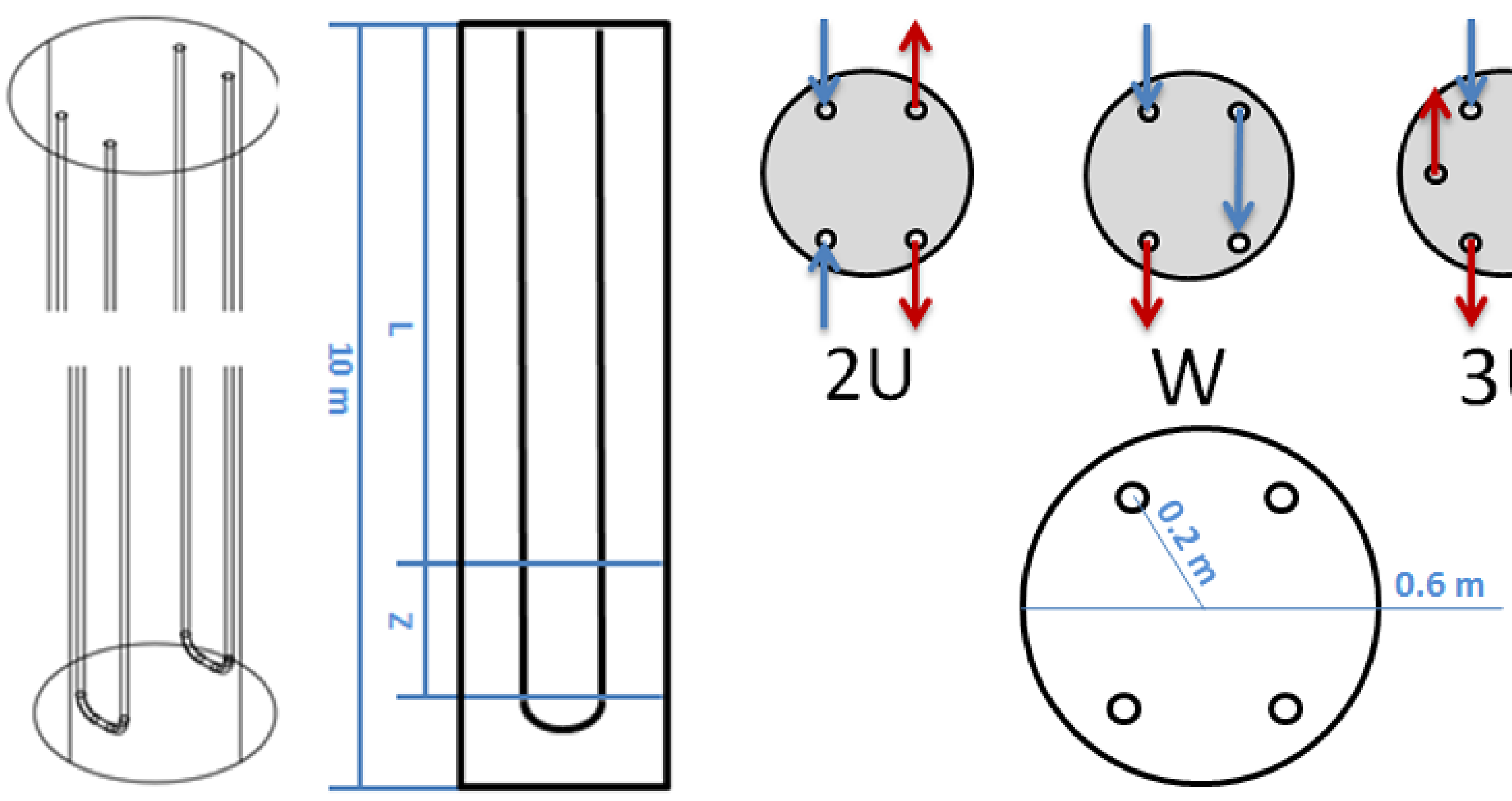

Figure 2. Simulated heat exchanger layouts and dimensions

Fourier heat conduction is solved in the concrete structure of the pile and in the surrounding ground, modeled as a semi-infinite medium. As for the pipeline, the water bulk temperature is obtained as follows:

$$T_w(s) = \left(T_{w0} - T_{c0} + \frac{m}{\lambda}\right) e^{-\lambda s} + ms + T_{c0} - \frac{m}{\lambda} \quad \text{with}$$

$$\begin{cases} m = \dfrac{T_c(L) - T_{c0}}{L} \\ \lambda = \dfrac{\pi D U}{\dot{m}_w c_w} \end{cases} \quad \text{and assuming} \quad T_c(s) = T_{c0} + ms$$

to solve the 1D energy balance $\dot{m}_w c_w \dfrac{dT_w}{ds} + UPT_w = UPT_c(s)$

	Concrete	Soil
Thermal conductivity [W/(m K)]	1.8	1.8
Volumetric heat capacity [kJ/(m^{3}K]	1678	2216

Table 1. Thermophysical properties of the pile and the ground

A mix of structured and unstructured mesh has been used. Tetrahedral elements have been applied near the U-end of the pipe. The remaining domain is covered by means of the swept method.

Results: In the present energy diffusion problem, stationary solutions do not exist. The decay of heat transfer performance of the ground source is observed during 4 months of continuous operation, corresponding to a typical heating season in Mediterranean countries. Thermal performance parameters are shown in Table 2.

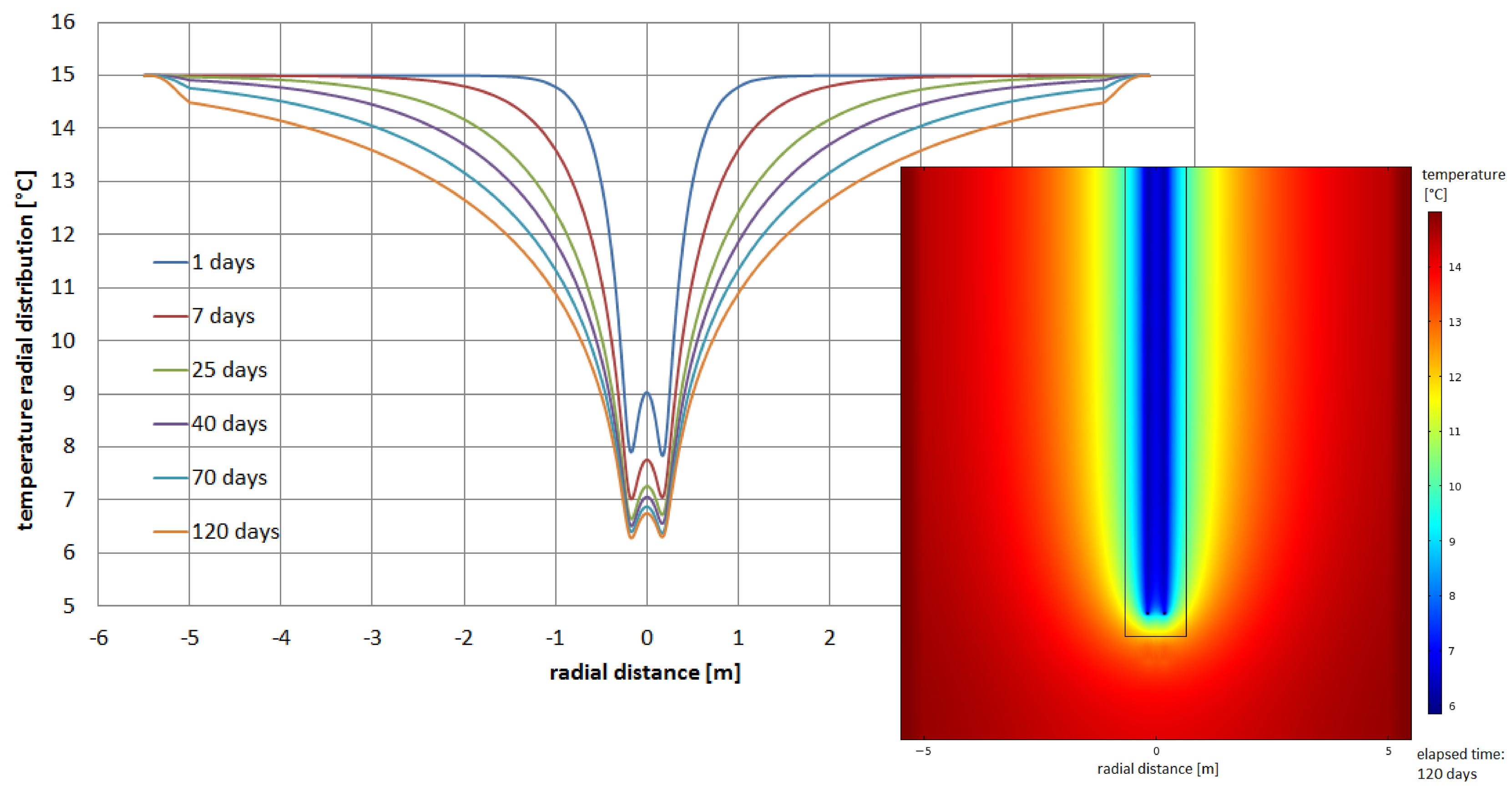

Figure 3. Evolution of the radial temperature distribution

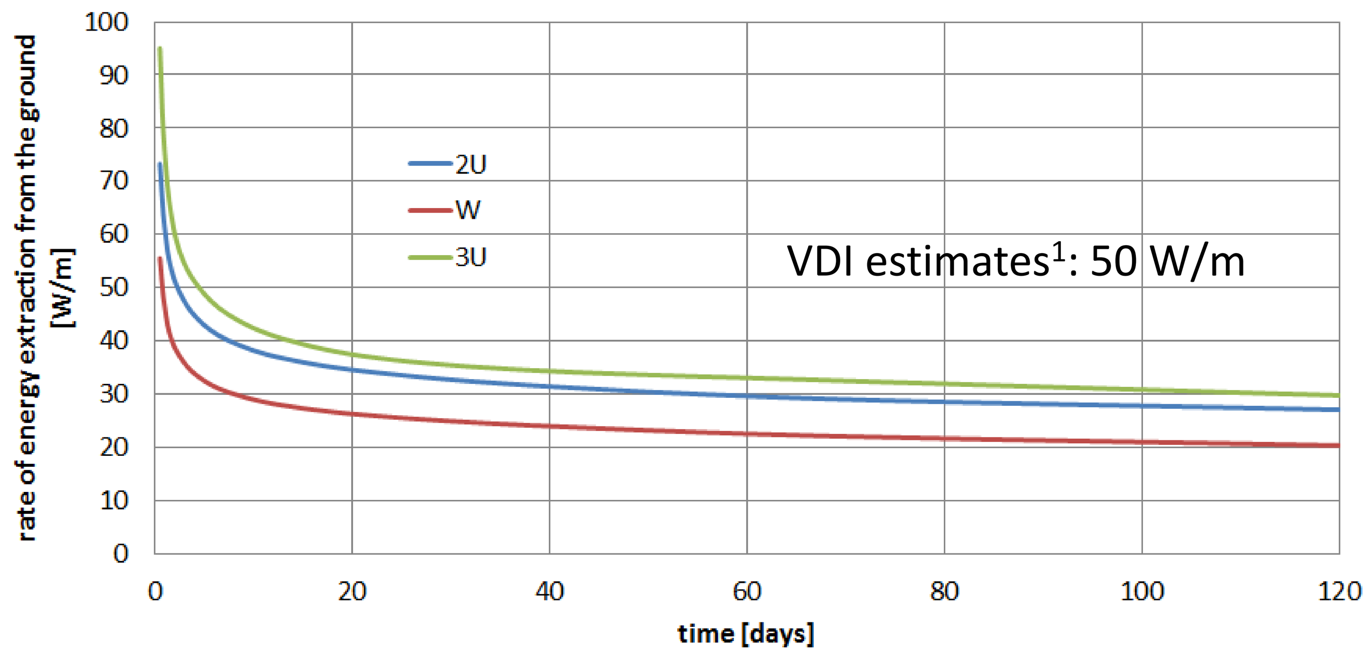

Figure 4. Energy extraction rate vs. time for the 3 configurations

	2U	W	3U
Mass flow rate ($\dot{m}_w$) [kg/h]	0.141	0.283	0.094
Water inlet temperature (T_{w0}) [°C]	5	5	5
Reynolds number of the internal flow	9000	18000	6000
Thermal transmittance of the pipe (U), including internal convection [W/(m^{2}K)]	210.4	220.5	202
Borehole thermal resistance (R_b) [m K/W] based on: - infinite linear source model[2,3]	0.128	0.25	0.095
- infinite cylindrical source model[2,3]	0.296	0.42	0.92
- CTI estimates[4]	0.105	n.a.	0.075
Hellström-efficiency[5] based on: - infinite linear source model	0.65	0.49	0.71
- infinite cylindrical source model	0.19	0.14	0.2

Table 2. Imposed parameters and main results after 120 days

References:

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5. G. Hellstrom, "Ground Heat Storage – Thermal Analysis of Duct Storage Systems – Theory", Doctoral Thesis, University of Lund, Sweden, 1991