BHE Field Design by Superposition of Effects in Space and Time

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Main objective: quick evaluation of the long-term performance of BHE fields with unbalanced seasonal heat loads and no groundwater movement. The method allows to determine, for a period of 50 years, the mean temperature at the interface between the most critical BHE (the central one in the field) and the ground, with reference to any BHE field subjected to a time periodic heat load with a period of one year and arbitrarily given monthly heat loads.

Numerical model

Hp: Slowly variable heat load and axial temperature gradient neglected $\rightarrow$ 2D heat conduction problem in an infinite solid medium.

Only one BHE is considered, subjected to a unit step heat load with a duration of 1 month; the temperature changes in the ground due to the surrounding BHEs and to the real heat load are evaluated afterwards (superposition of the effects in space and time).

Dimensionless governing equations:

$$\frac{\partial T^*}{\partial \tau^*} = \nabla^{*2} T^*$$

$$-\left(\nabla^* T^* \cdot \mathbf{n}\right)\Big|_{S_B} = \frac{1}{\pi} F(\tau)$$

$$\left(\vec{\nabla} T \cdot \vec{\mathbf{n}}\right)\Big|_{S_G} = 0$$

$T = 0$ initial condition

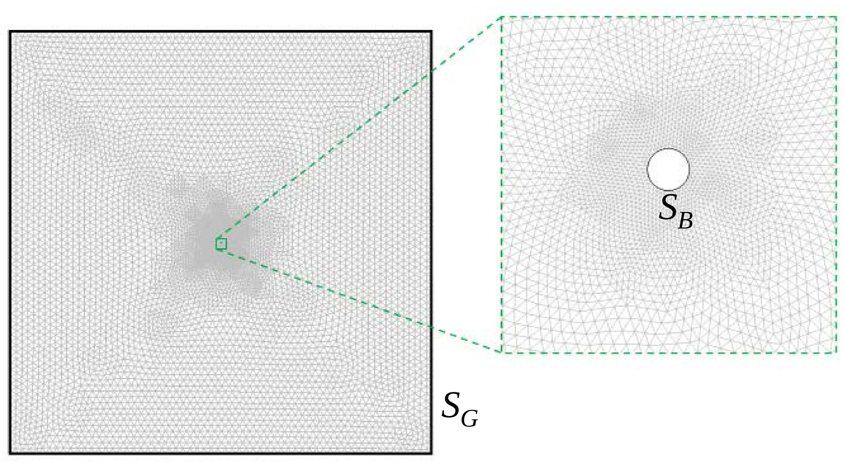

Fig 1. Square computational domain around the BHE and mesh.

Time superposition of effects:

$$F(\tau) = H(\tau) - H(\tau - \tau_1)$$

$$\sum_{j=0}^{11} A_j F(\tau - j\tau_1)$$

$$\sum_{i=0}^{N} \sum_{j=0}^{11} A_j F(\tau - i\tau_0 - j\tau_1)$$

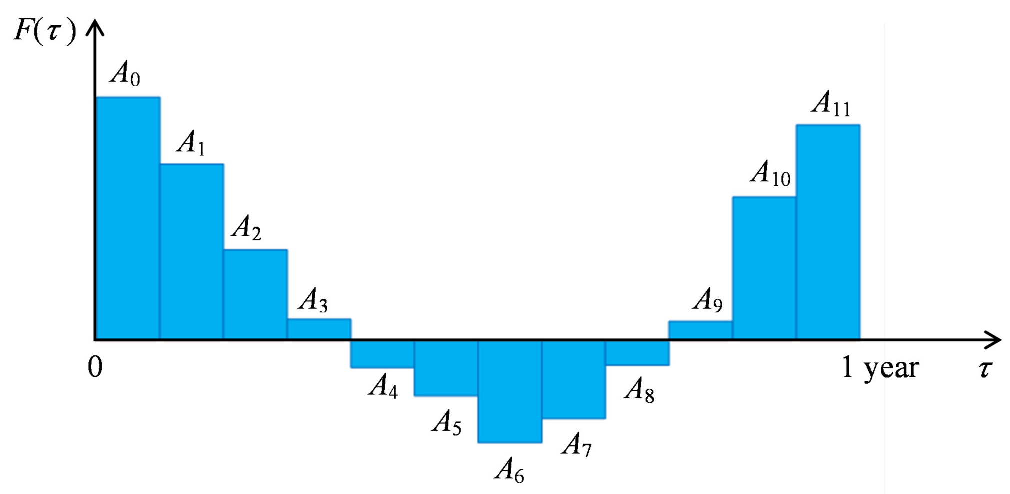

Fig 2. Weighted superposition of twelve one-month step function.

Space superposition of effects:

$$T^*_{1\times5} = T^*_{S_B} + 2T^*_{40} + 2T^*_{80}$$

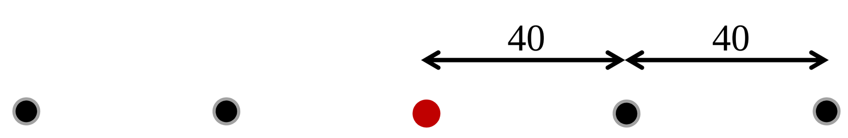

Fig 3. Determination of the temperature of the most critical BHE for a 1x5 BHE field.

Parameters

$$Fo = \frac{\alpha_g \tau_0}{D^2} = 2500, 4400, 6300$$

$$L^* = \frac{L}{D} = 0.5, 40, 50, 60, 70, 80, 90, 100, 120, 140, 160$$

Results

For each value of Fo and L^*, the dimensionless temperature T^* has been evaluated numerically as a function of τ^*/Fo and interpolating functions have been determined:

$$T^*_{S_B} = \begin{cases} B_1 \,\mathrm{Ln}(1 + B_2\, \tau^*/Fo)\,; & 0 \le \tau^*/Fo < \dfrac{1}{12} \\ \dfrac{B_3}{\left(\tau^*/Fo\right)^{B_4}} + \dfrac{0.008}{\tau^*/Fo}\,; & \tau^*/Fo \ge \dfrac{1}{12} \end{cases}$$

$$T^*_{L^*} = C_1 \left[\left(\tau^*/Fo\right)^{C_2} \cdot \mathrm{Exp}\left(\frac{C_3}{\tau^*/Fo} \right) \right]^{-1} \;;\; \tau^*/Fo > 0$$

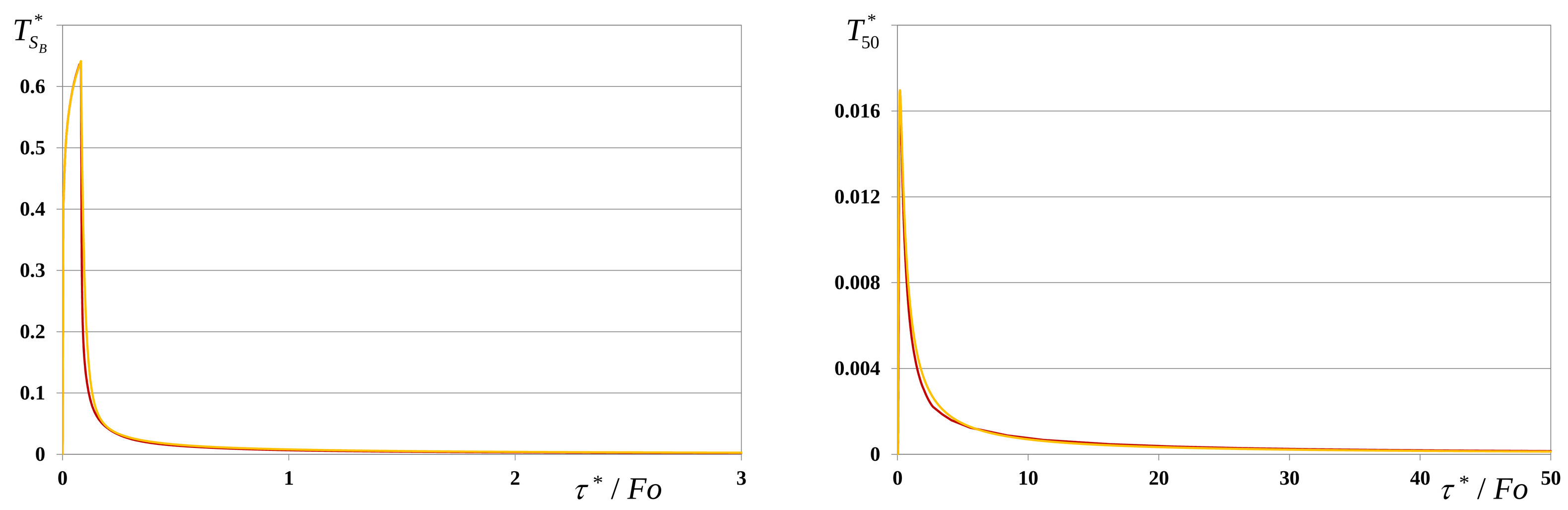

Fig 4. Computational values in red, interpolating function in orange.

Examples and Conclusions

Typical heat load for residential buildings placed in North-Centre Italy; dimensionless distance between adjacent BHEs equal to 40; Fo = 4400.

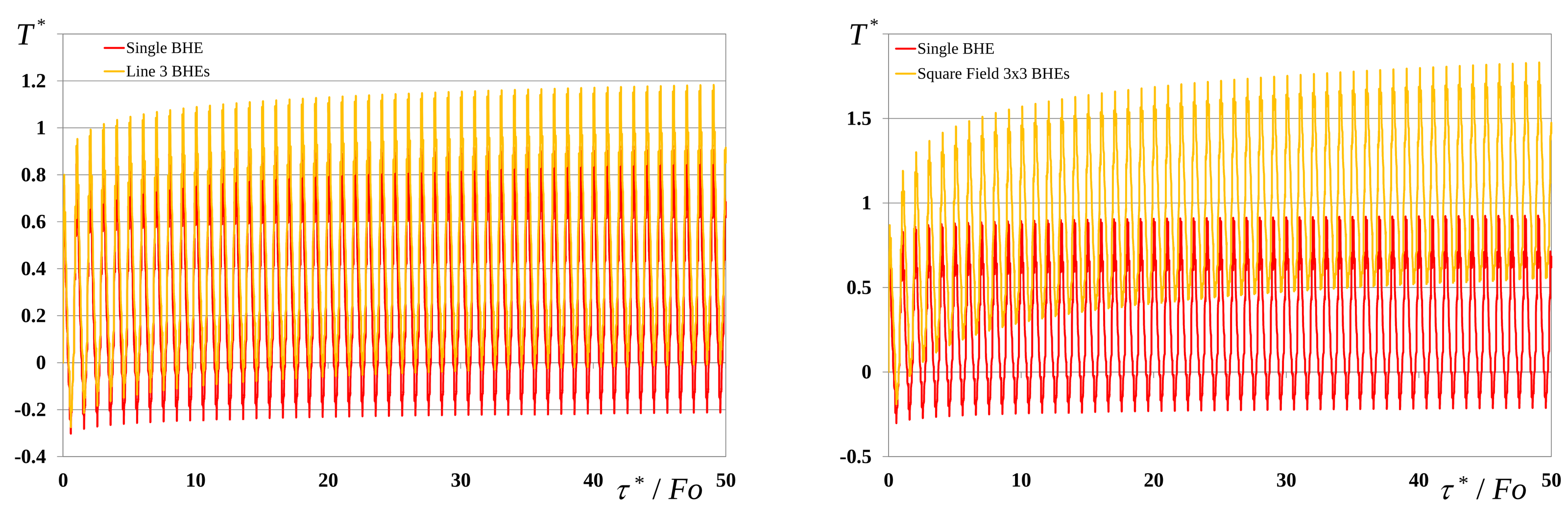

Fig 5. Dimensionless temperature on the BHE surface, for a single BHE and for the most critical BHE in a line of 3 BHEs (acceptable) and in a square field of 3×3 BHEs (critical).

The method allows a quick evaluation of the time evolution of the dimensionless temperature at the surface of the most critical BHE for a period of 50 years, for any BHE field, with a minimum distance of 40 diameters between adjacent BHEs, which can be considered as a part of a square field with a maximum side length of 320 diameters.

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