Iceland Liechtenstein Norway grants

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Optimization of Shallow Geothermal Energy Resources for Green Transition OptiSGE

Simulation Tools

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Different approaches to modelling

Single borehole

- Grouted
- Groundwaterfilled

Several boreholes

- Scaling up from single boreholes
- Simplifying boreholes
- Interacting/not interacting

Different approaches to modelling

Single borehole

- Grouted

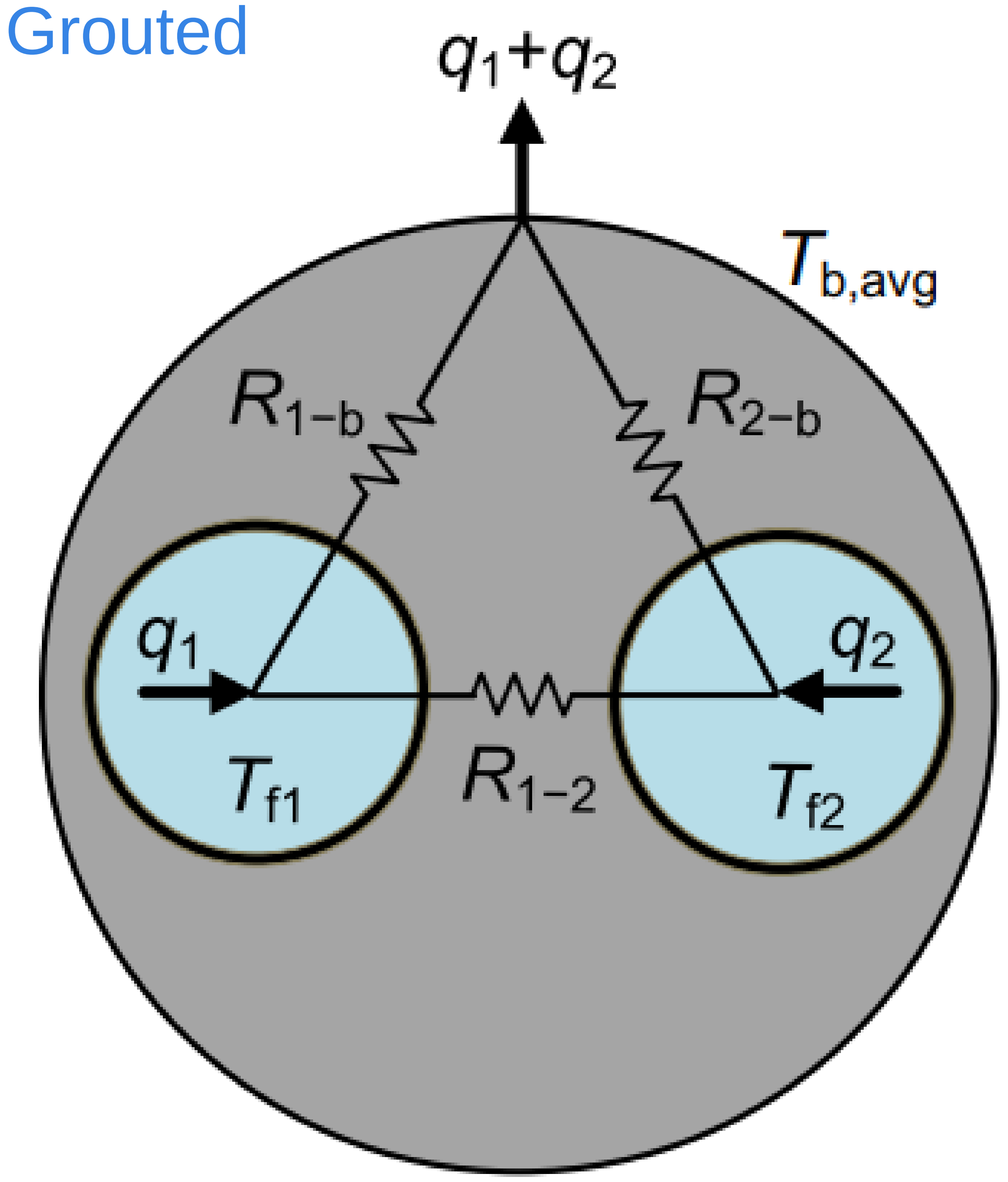


Fig. 1. Δ resistance network for a single U-tube in a borehole.

$$R_b = \frac{1}{4\pi\lambda_g}\left[\beta + \ln\left(\frac{\theta_2}{2\theta_1(1-\theta_1^4)^\sigma}\right)\right] \quad (12)$$

$$R_b = \frac{1}{4\pi\lambda_g}\left[\beta + \ln\left(\frac{\theta_2}{2\theta_1(1-\theta_1^4)^\sigma}\right) - \frac{\theta_3^2\left(1-\frac{4\sigma\theta_1^4}{1-\theta_1^4}\right)^2}{\frac{1+\beta}{1-\beta}+\theta_3^2\left(1+\frac{16\sigma\theta_1^4}{(1-\theta_1^4)^2}\right)}\right] \quad (13)$$

where θ_1, θ_2, θ_3, σ and β are all dimensionless parameters. They are defined as:

$$\theta_1 = \frac{s}{2r_b}, \quad \theta_2 = \frac{r_b}{r_{po}}, \quad \theta_3 = \frac{r_{po}}{s} = \frac{1}{2\theta_1\theta_2}, \quad \sigma = \frac{\lambda_g - \lambda}{\lambda_g + \lambda},$$
$$\beta = 2\pi\lambda_g R_p \quad (14)$$

$$R_b = \frac{R_{1-b}R_{2-b}}{R_{1-b} + R_{2-b}}$$

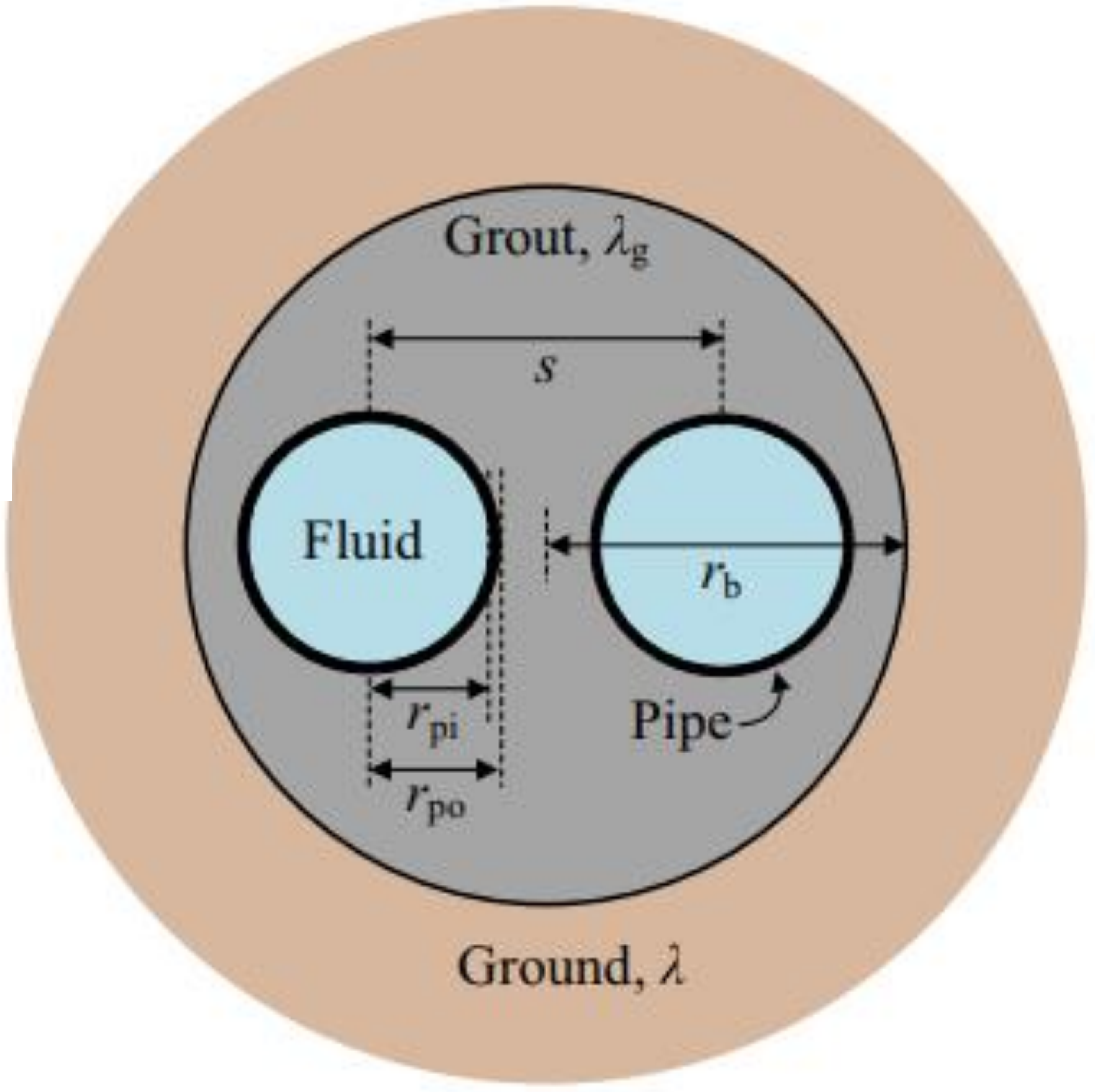


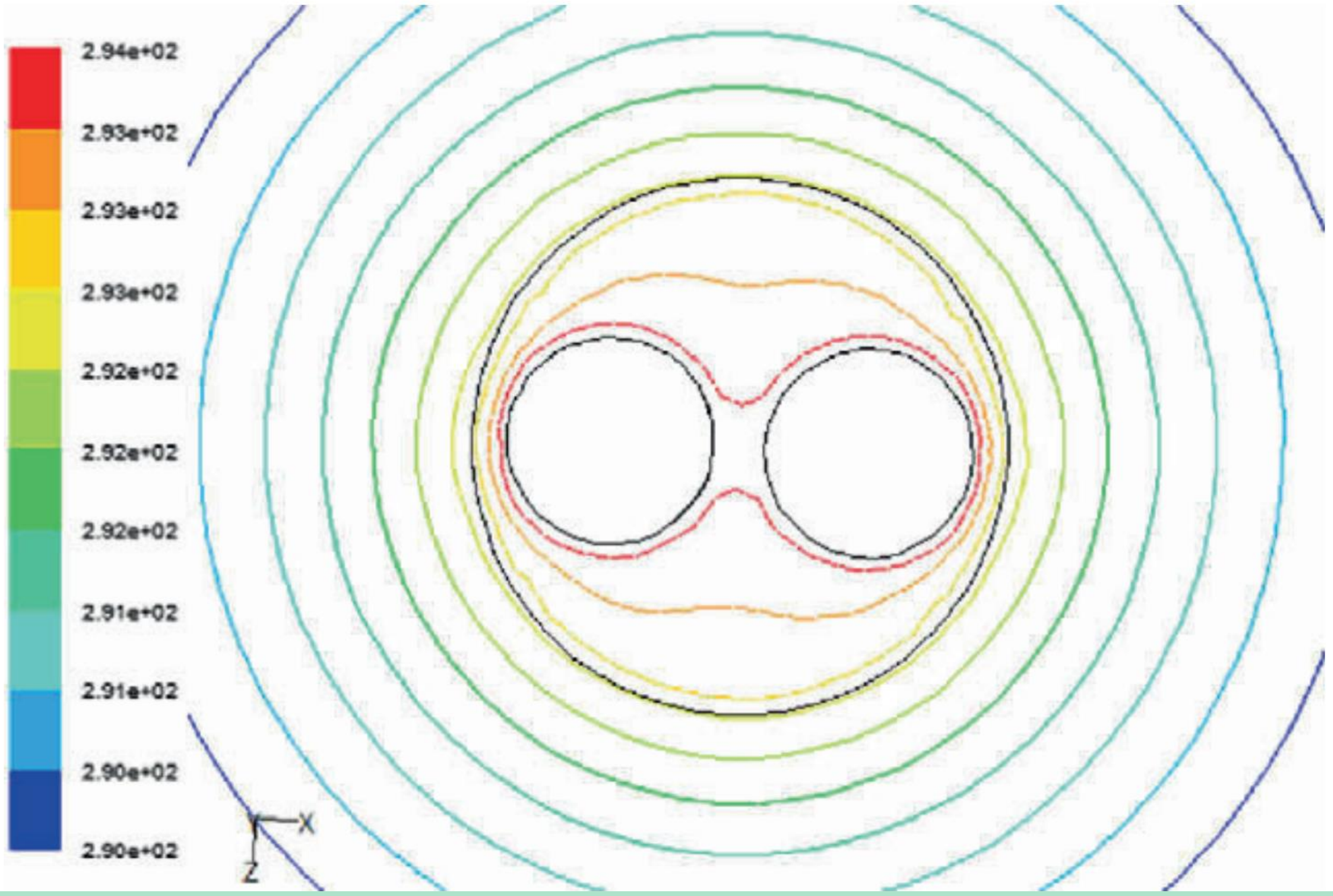
Fig. 2. Notations and dimensions defining pipe size and spacing for a borehole with a single U-tube.

Figures and formulae from Javed and Spitler, 2017

Different approaches to modelling

Single borehole

- Groundwaterfilled



From: Gustafsson et al., 2010

From: Spitler et al., 2016

$$Nu_{ann} = 0.14(Ra^*_{ann})^{0.25} \quad 4.0E7 > Ra^*_{ann} > 1.3E6 \tag{26}$$

$$Nu_{po} = 0.30(Ra^*_{po})^{0.25} \quad 4.1E7 > Ra^*_{po} > 1.8E6 \tag{27}$$

$$Nu_{BHW} = 0.20(Ra^*_{BHW})^{0.25} \quad 2.9E7 > Ra^*_{BHW} > 5.4E5 \tag{28}$$

$$Ra^*_{ann} = \frac{g\beta q''_{po} D_H^4}{k_{ann}\nu_{ann}\alpha_{ann}} \tag{20}$$

$$Ra^*_{po} = \frac{g\beta q''_{po} D_H^4}{k_w \nu_w \alpha_w} \tag{21}$$

$$Ra^*_{BHW} = \frac{g\beta q''_{BHW} D_H^4}{k_w \nu_w \alpha_w} \tag{22}$$

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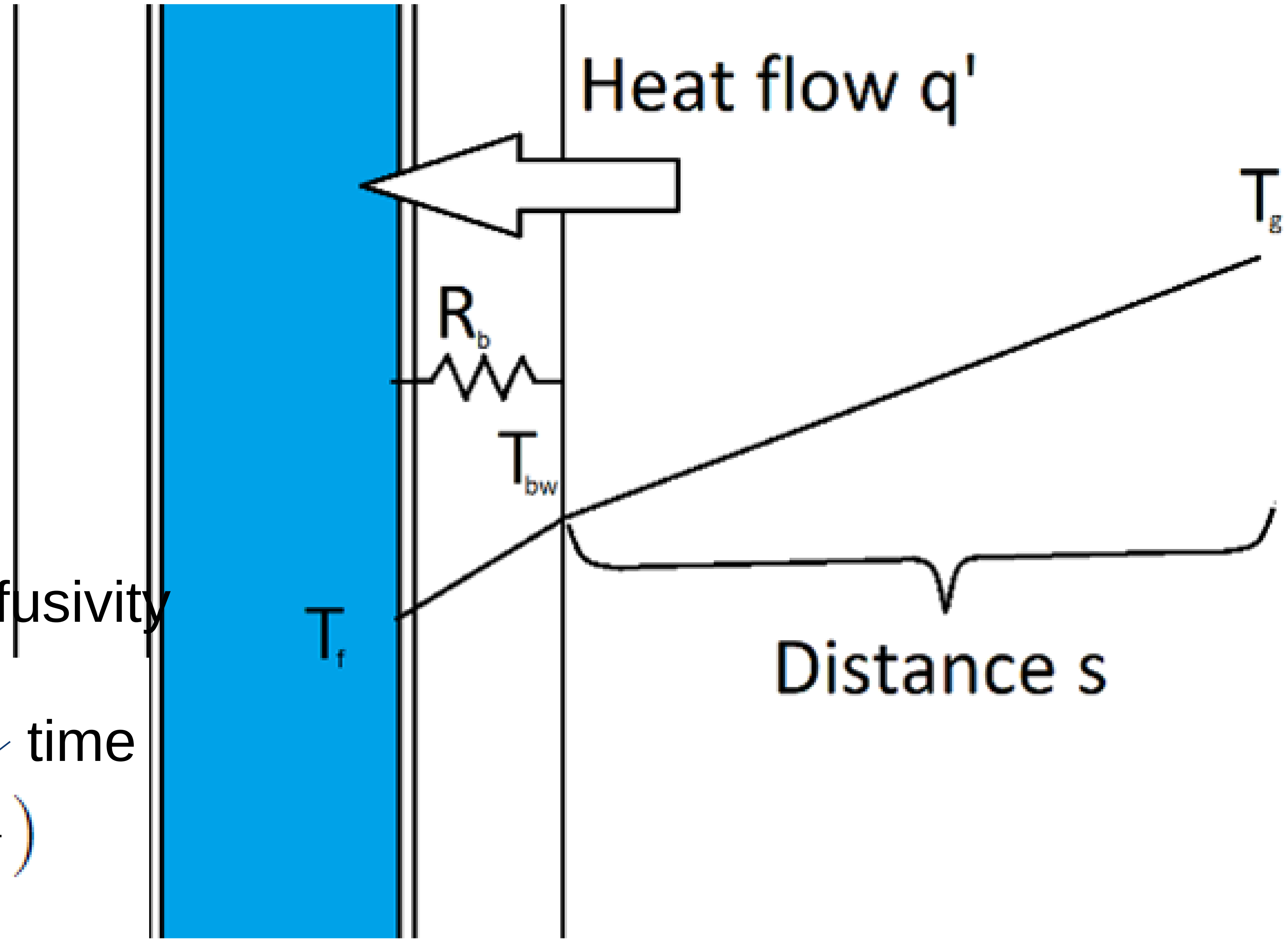


Simplest model: infinite line source:

Heat flow per m

Thermal diffusivity of ground

time

$$T_f = T_g + q' R_b + \frac{q'}{4\pi\lambda} ln(\frac{4\alpha t}{r^2 e^\gamma})$$

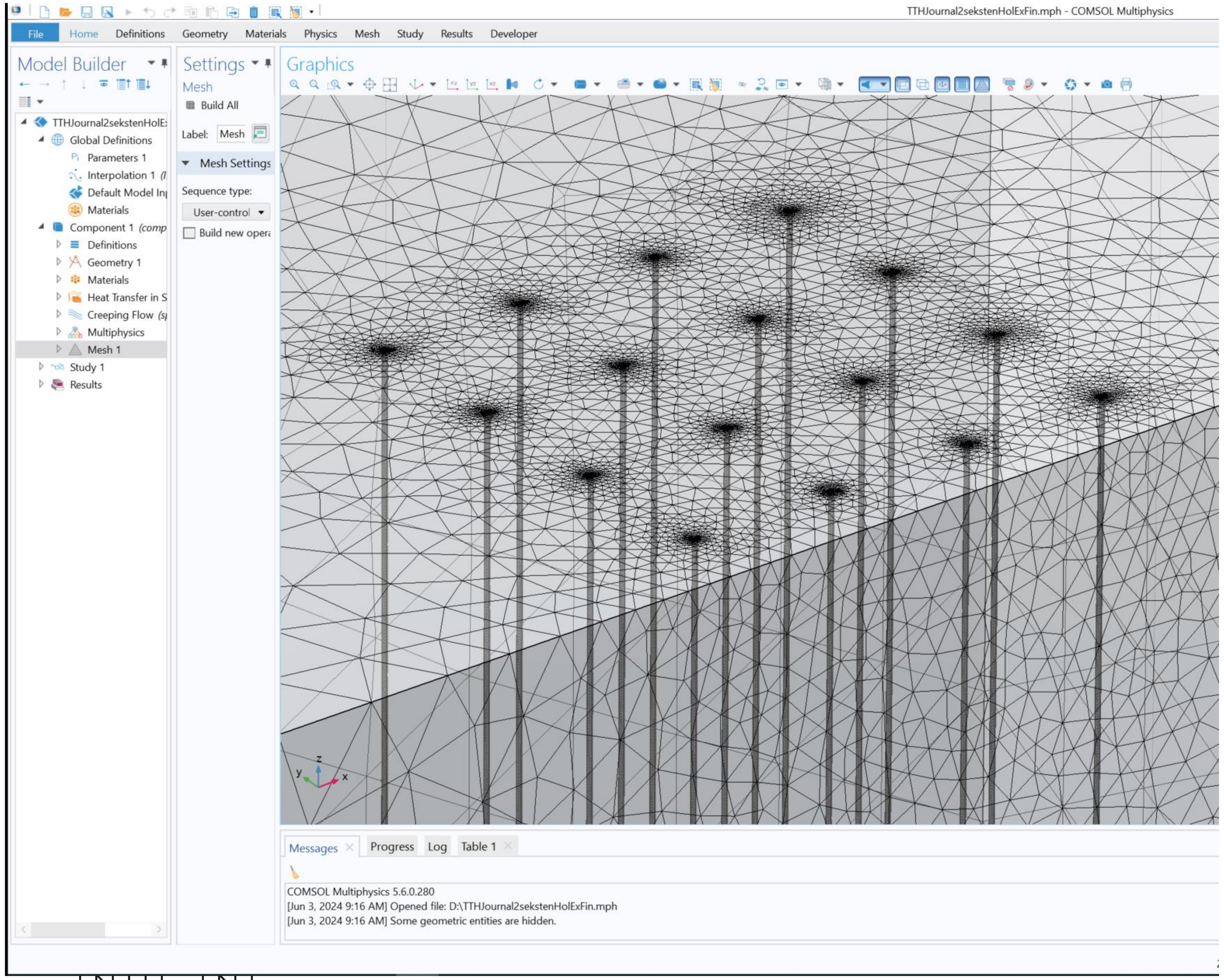
Initial ground temp.

Borehole radius

Thermal resistance between collector and borehole wall

Thermal conductivity of ground

Different approaches to modelling



Several boreholes

- Scaling up from single boreholes

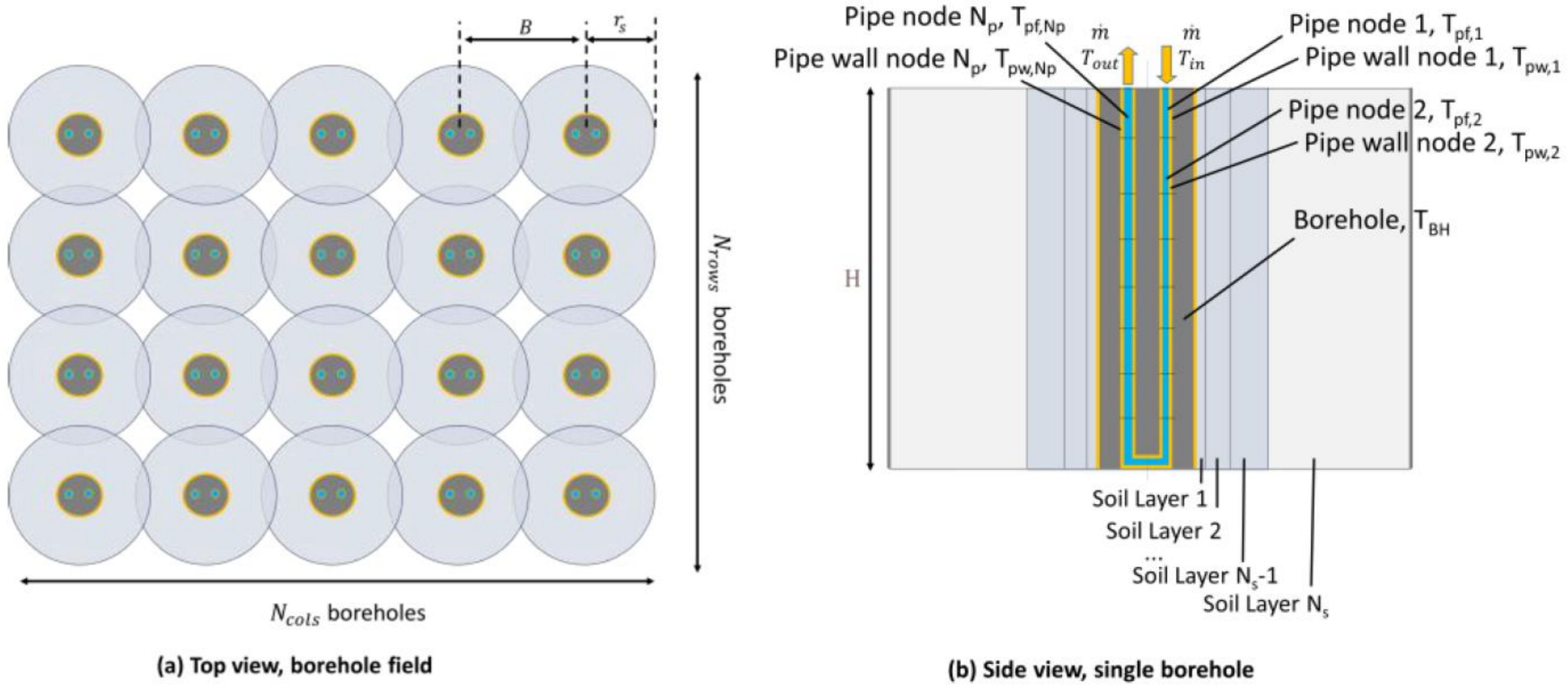


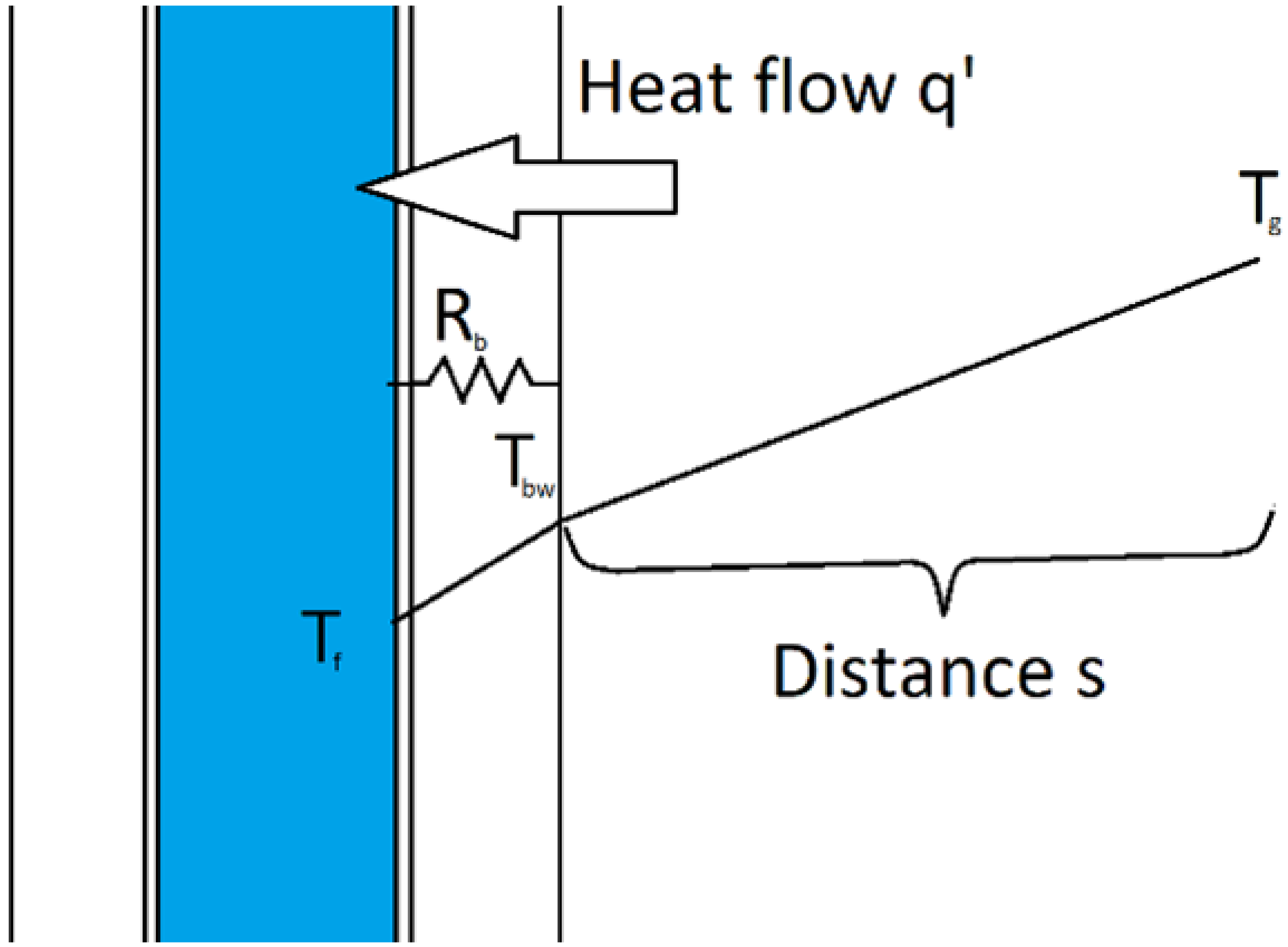
Figure 1 Geometry of (a) the modelled borehole field and (b) a single borehole, side view.

$$w = \frac{A_{total,no\ intersect} - A_{intersect}}{A_{total,no\ intersect}},$$

From: Harsem et al., 2024

g-function and transfer functions

$$T_b = T_g - \frac{q'}{2\pi k} g\left(\frac{t}{t_s}, \frac{r_b}{H}, \frac{B}{H}\right)$$



Several boreholes

- Scaling up from single boreholes

Different approaches to modelling

FDM
Finite Difference Method

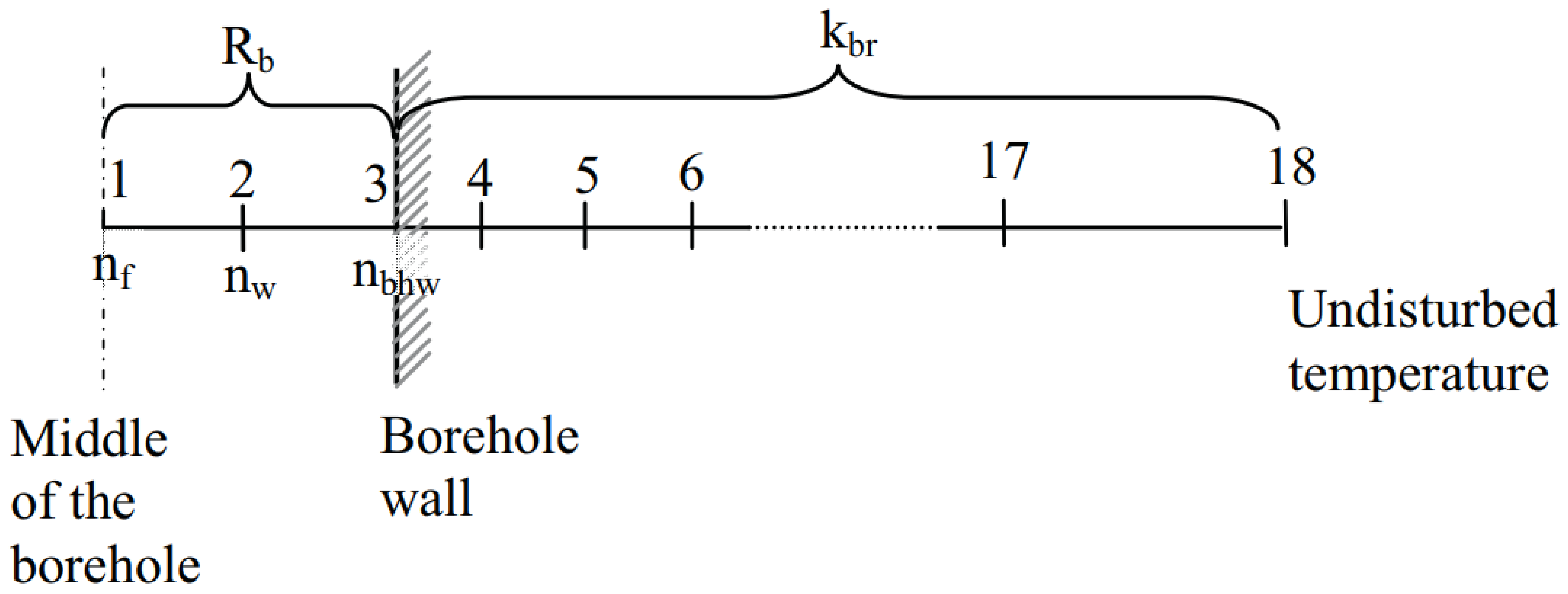
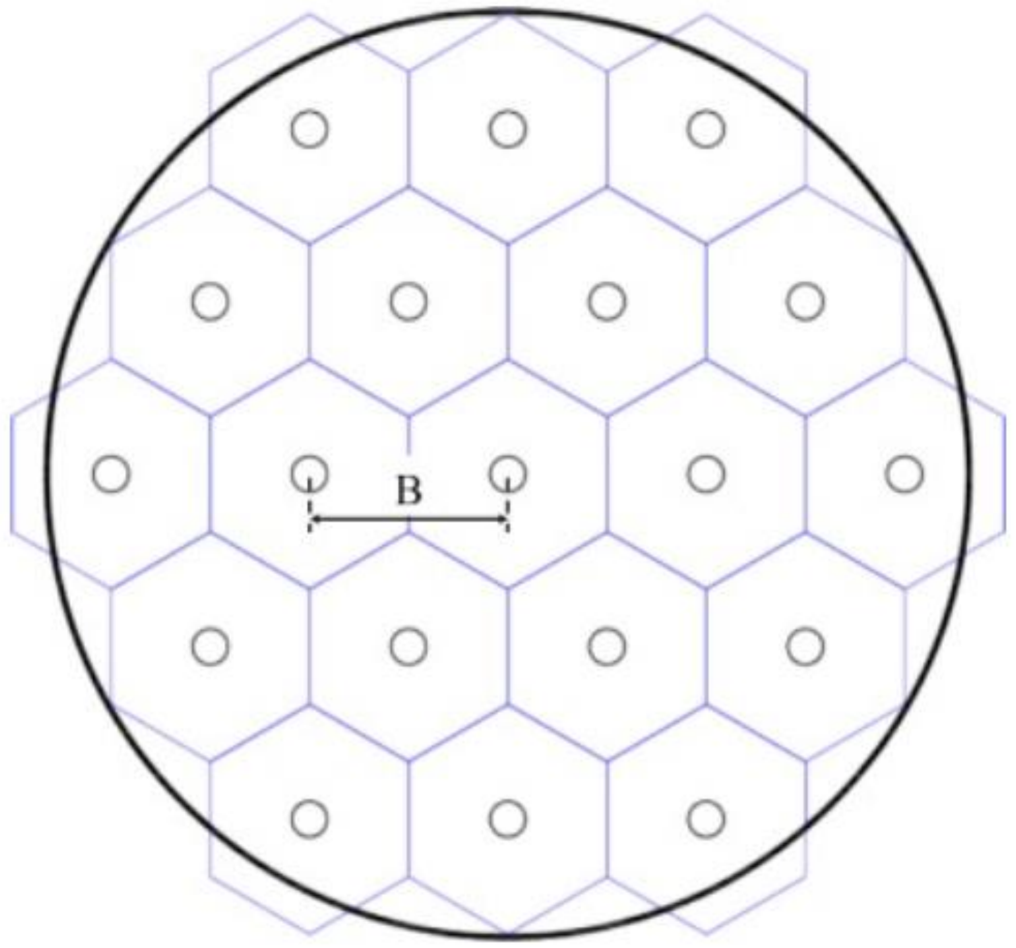


Figure 1. Model description with nodal mesh and heat transfer parameters

From Gustrafsson and Westerlund 2010.

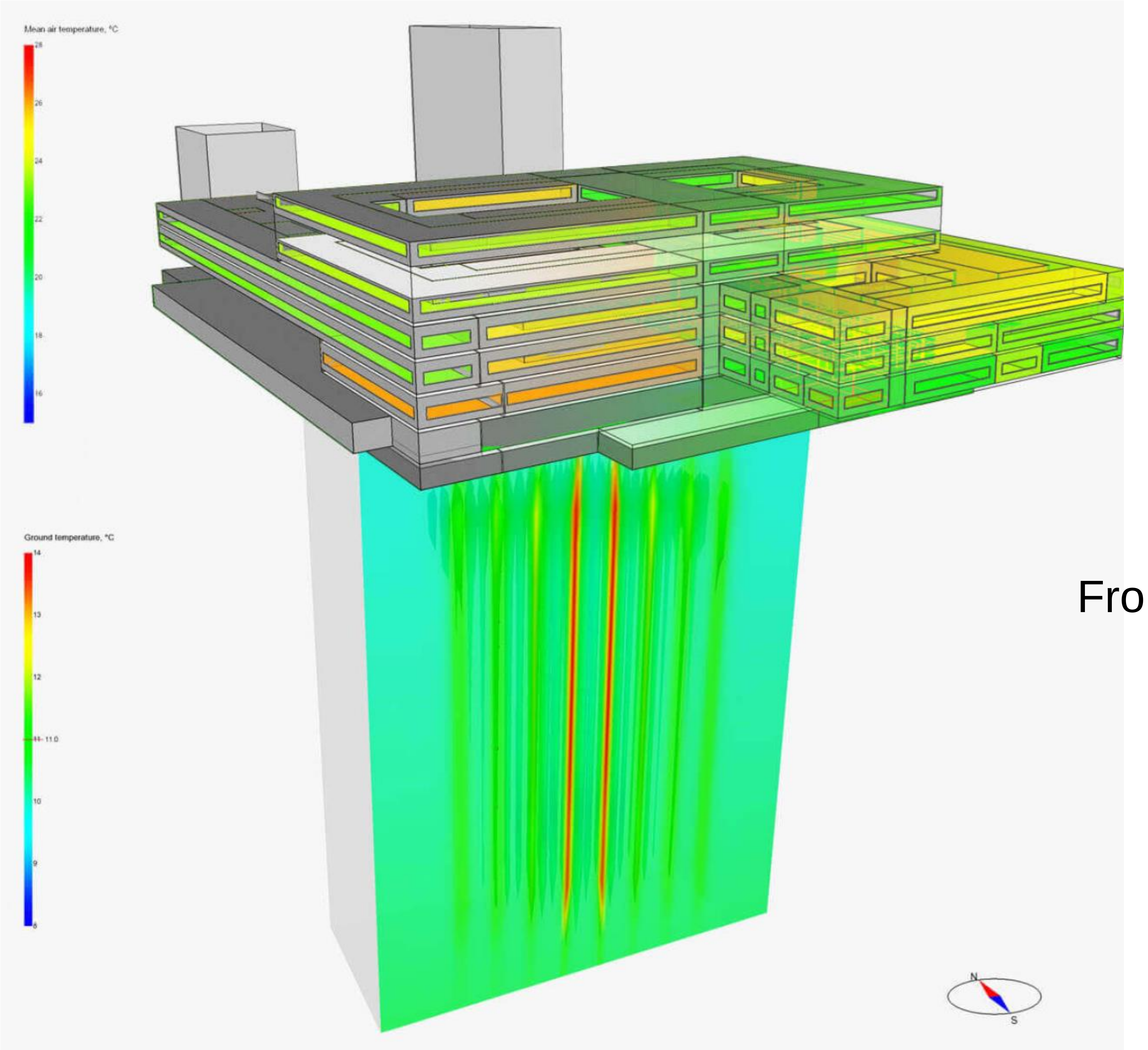
Several boreholes

- Simplifying boreholes



From: Park et al., 2018: Hellström's Duct Storage Model (DST model).

Different approaches to modelling



Several boreholes

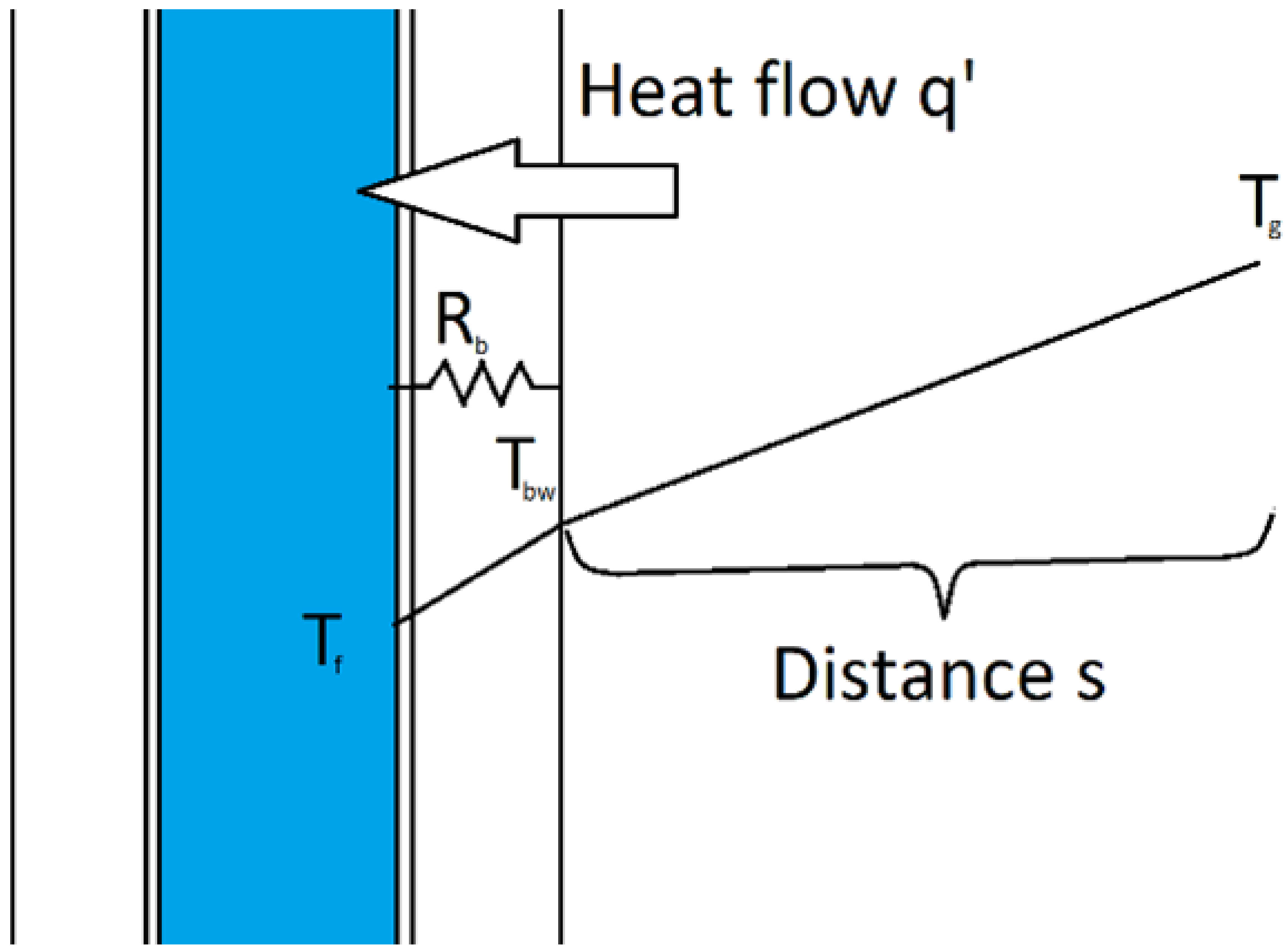
- Simplifying boreholes
- Interacting/not interacting

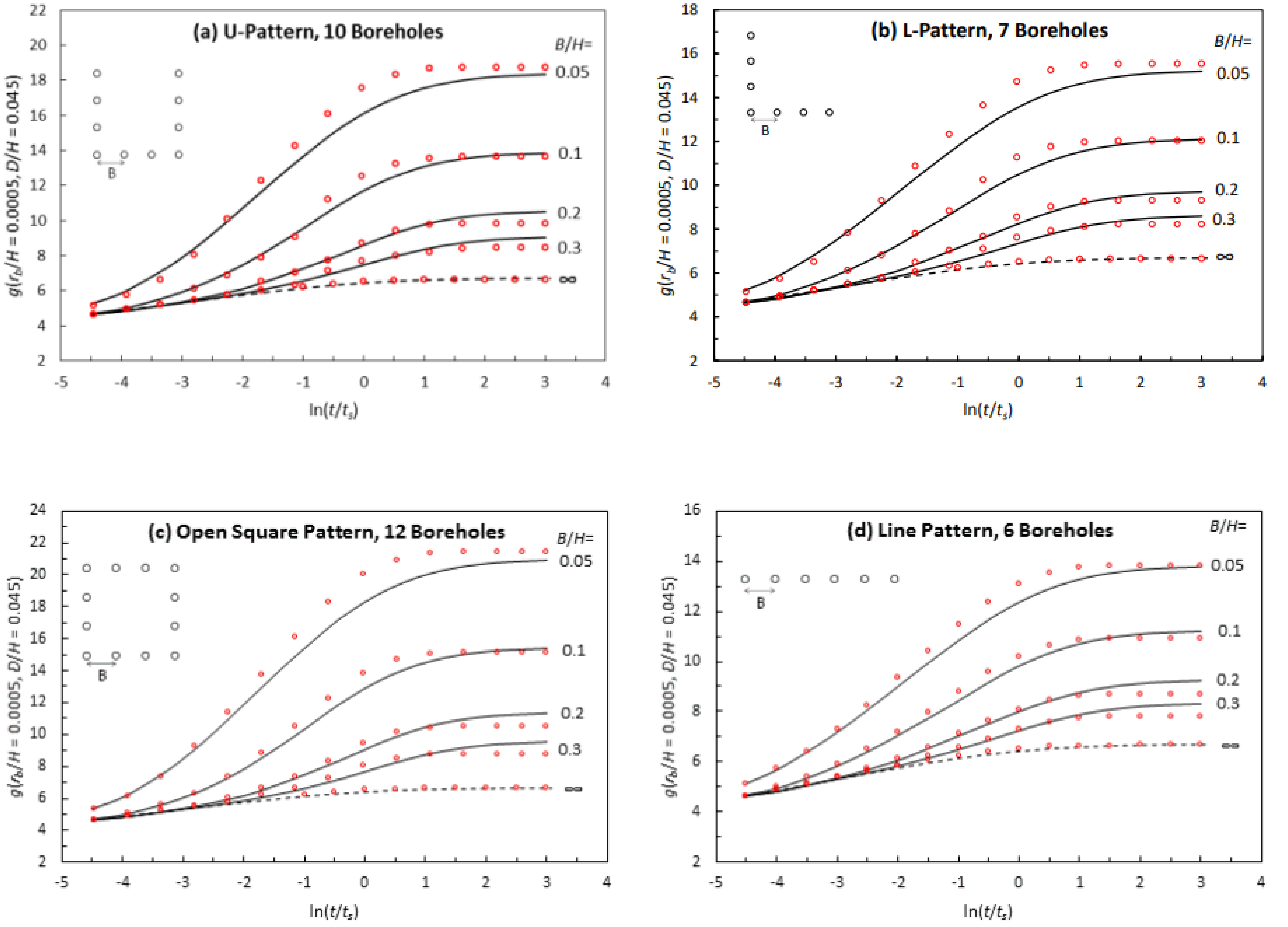
From: Equa Simulation AB, 2023.

g-function and transfer functions

$$T_b = T_g - \frac{q'}{2\pi k}\, g\!\left(\frac{t}{t_s}, \frac{r_b}{H}, \frac{B}{H}\right)$$

$$g_{b\,x,y} = \sum_{i=1}^{xbores} \sum_{j=1}^{ybores} g_{i,j}$$





From: Chiasson and Elhashmi, 2017

Tools

Not complete list

- DST model – TRNSYS
- g-function – python (pygfunction) and TRNSYS
- Superposition borehole model – TRNSYS and Modelica
- MoBTES - Modelica
- IDA ICE
- FEFLOW
- Fluent
- COMSOL

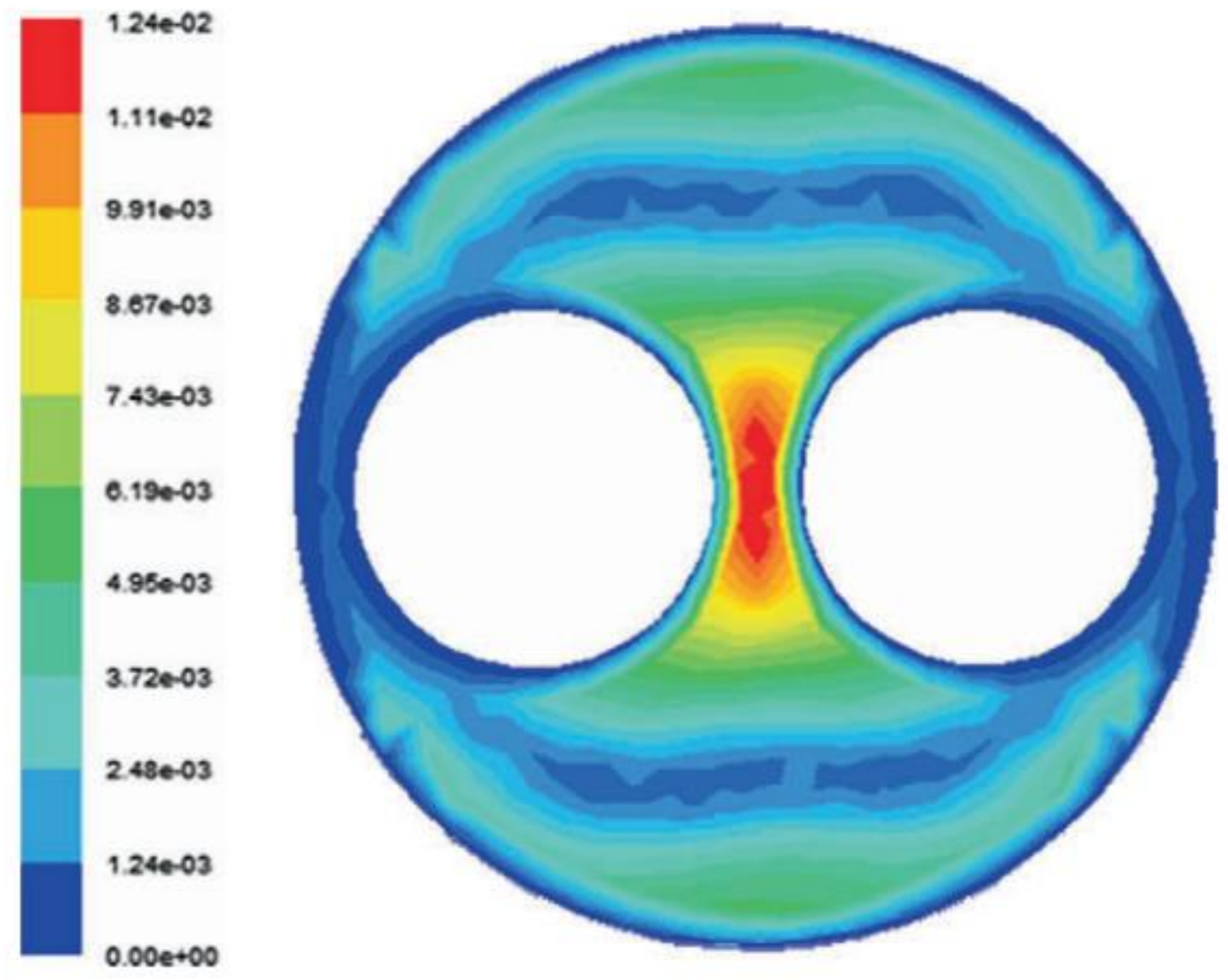
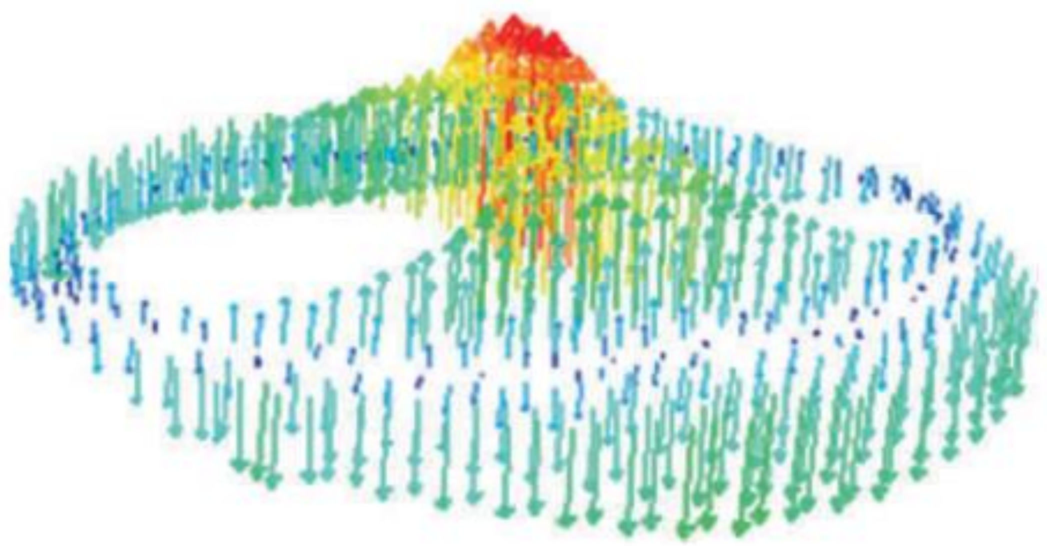


Fig. 9a. Velocity magnitude plot (m/s) at the vertical level 1.5 m.

From: Gustafsson et al., 2010

In Fig. 10a, temperature differences (ΔT) in the borehole water are shown for different simulations over a line crossing the borehole between the two U-pipe legs in the middle of the borehole length. The temperature difference is calculated as the difference to the water temperature next to the borehole wall. It may be seen that M_u2 with slightly higher heat transfer rate result in an increased temperature difference. Fig. 10b shows the vertical velocities over the same line. All of these simulations have a heat transfer rate of approximately 50 W/m. Due to the non-linearity of the density–temperature curve the lower mean temperature level of the water in M_u2 will result in smaller density differences ($\Delta\rho$), Table 2. Thus, M_u2 has lowest velocities of these three simulations and result in larger borehole thermal resistance.



Comparison of some famous models

	SBM	g-function	DST	HRSM	MoBTES	IDA ICE
Principle(s)	TRM, g-functions for neighbourghs	Numerical FDM - store solution	TRM, Cylinder volume with sources (superposition)	TRCM,	TRCM,	TRCM, superposition of contributions
Layers	No	No	Yes (not earlier)	No	Yes	Two: top+ground
Positions	Arbitary	Arbitary	Evenly spaced (can overcome)	Arbitary	Various configurations	Arbitary
Heat injection	FDM, step-pulse for heat, uniform T, parallel/serial	FDM, step-pulse for heat, uniform T, parallel only	FDM or step-pulse,	FDM, parallel only, uniform T, step-pulse	FDM, Parallel/serial	FDM, only parallel?
Inventer(s) and year	Eskilsson 1986	Eskilsson 1987	Hellström, 1991	Picard and Helsen, 2014	Formhals et al., 2020	Equa, 2018?

Sources

- Chiasson, A. D. and R. Elhashmi. 2017. Alternate Approach to the Calculation of Thermal Response Factors for Vertical Borehole Ground Heat Exchanger Arrays Using an Incomplete Bessel Function.Proceedings of IGSHPA Technical/Research Conference and Expo Denver March 14-16, 2017.
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- Spitler, J. D., S. Javed and R. K. Ramstad. 2016. “Natural convection in groundwater-filled boreholes used as ground heat exchangers.” Applied Energy 164, 352-365.

Thank you!

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