

CORRECTION

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# Correction to: An efficient hybrid model for thermal analysis of deep borehole heat exchangers

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After publication of our article it was brought to our attention that we had omitted to include the credit line for Figure 1. The corrected Figure 1 caption with the credit line is given below:

“Schematic of heat transfer process for deep borehole heat exchanger: inverse loop (left) and forward loop (right). Reproduced with permission from Elsevier from Bär et al. *Energy Procedia* 76 (2015) 351–360; this work is licensed under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).”

There were a number of errors found in the references section. The corrected references are given in this Correction article.

We apologize to readers for these errors.

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### References

- Abdelaziz SL, Ozudogru TY, Olgun CG, Martin JR II. Multilayer finite line source model for vertical heat exchangers. *Geothermics*. 2014;51:406–16.
- Bandos TV, Montero A, Fernández E, Santander JLG, Isidro JM, Pérez J, et al. Finite line-source model for borehole heat exchangers: effect of vertical temperature variations. *Geothermics*. 2009;38(2):263–70.
- Bär K, Rühaak W, Welsch B, Schulte D, Homuth S, Sass I. Seasonal high temperature heat storage with medium deep borehole heat exchangers. *Energy Procedia*. 2015;76:351–60.
- Bauer D, Heidemann W, Müller-Steinhagen H, Diersch HJG. Thermal resistance and capacity models for borehole heat exchangers. *Int J Energy Res*. 2011;35(4):312–20.
- Beier RA, Acuña J, Mogensen P, Palm B. Transient heat transfer in a coaxial borehole heat exchanger. *Geothermics*. 2014;51:470–82.
- Carslaw HS, Jaeger JC. *Conduction of heat in solids*. Oxford: Clarendon Press; 1947. p. 257–65.
- Chen C, Shao H, Naumov D, Kong Y, Tu K, Kolditz O. Numerical investigation on the performance, sustainability, and efficiency of the deep borehole heat exchanger system for building heating. *Geotherm Energy*. 2019;7(1):1–26.

- Claesson J, Hellström G. Multipole method to calculate borehole thermal resistances in a borehole heat exchanger. *HVAC&R Res.* 2011;17(6):895–911.
- De Carli MD, Tonon M, Zarrella A, Zecchin R. A computational capacity resistance model (CaRM) for vertical ground-coupled heat exchangers. *Renew Energy.* 2010;35(7):1537–50.
- Diersch HJG. *FEFLOW: finite element modeling of flow, mass and heat transport in porous and fractured media.* Berlin: Springer; 2014.
- Erol S, Bertrand F. Multilayer analytical model for vertical ground heat exchanger with groundwater flow. *Geothermics.* 2018;71:294–305.
- Eskilson P. Thermal analysis of heat extraction boreholes. Doctoral Thesis, Department of Mathematical Physics, University of Lund, Sweden; 1987.
- Hellstrom G. Ground heat storage thermal analysis of duct storage systems. Doctoral Thesis, Department of Mathematical Physics, University of Lund, Sweden; 1991.
- Hellstrom G, Sanner B. Earth energy designer: software for dimensioning of deep boreholes for heat extraction. Lund: Lund University; 1994. p. 185–92.
- Holmberg H, Acuña J, Næss E, Sønju OK. Deep borehole heat exchangers, application to ground source heat pump systems. In: *Proceed World Geothermal Congress.* 2015.
- Kim EJ, Bernier M, Cauret O, Roux JJ. A hybrid reduced model for borehole heat exchangers over different time-scales and regions. *Energy.* 2014;77:318–26.
- Kolditz O, Bauer S, Bilke L, Böttcher N, Delfs JO, Fischer T, et al. OpenGeoSys: an open-source initiative for numerical simulation of thermo-hydro-mechanical/chemical (THM/C) processes in porous media. *Environ Earth Sci.* 2012;67(2):589–99.
- Le Lous M, Larroque F, Dupuy A, Moignard A. Thermal performance of a deep borehole heat exchanger: insights from a synthetic coupled heat and flow model. *Geothermics.* 2015;57:157–72.
- Li M, Lai ACK. Heat-source solution to heat conduction in anisotropic media with application to pile and borehole ground heat exchangers. *Appl Energy.* 2012;96:451–8.
- Li M, Lai ACK. Analytical model for short-time responses of ground heat exchangers with U-shaped tubes: model development and validation. *Appl Energy.* 2013;104:510–6.
- Li M, Lai ACK. Review of analytical models for heat transfer by vertical ground heat exchangers (GHEs): a perspective of time and space scales. *Appl Energy.* 2015;151:178–91.
- Li M, Li P, Chan V, Lai ACK. Full-scale temperature response function (G-function) for heat transfer by borehole ground heat exchangers (GHEs) from sub-hour to decades. *Appl Energy.* 2014;136:197–205.
- Li XX, Hu XM, Zhang ZW. Calculation method of thermal response radius for vertical borehole heat exchangers. *Transact Chin SocAgricEng.* 2015;31(17):248–53.
- Liu J. Discussion on several basic problems of underground heat transfer process of ground source heat pump system. Doctoral Thesis, Tongji University, China; 2010.
- Mingzhi Y, Tenteng M, Kai Z, Ping C, Aijuan H, Zhaohong F. Simplified heat transfer analysis method for large-scale boreholes ground heat exchangers. *Energy Build.* 2016;116:593–601.
- Molina GN, Blum P, Zhu K, Bayer P, Fang Z. A moving finite line source model to simulate borehole heat exchangers with groundwater advection. *Int J ThermSci.* 2011;50(12):2506–13.
- Rees SJ, He M. A three-dimensional numerical model of borehole heat exchanger heat transfer and fluid flow. *Geothermics.* 2013;46:1–13.
- Rivera JA, Blum P, Bayer P. Ground energy balance for borehole heat exchangers: vertical fluxes, groundwater and storage. *Renew Energy.* 2015;83:1341–51.
- Saadi MS, Gomri R. Investigation of dynamic heat transfer process through coaxial heat exchangers in the ground. *Int J Hydrog Energy.* 2017;42(28):1–17.
- Sapinska-Sliwa A, Rosen MA, Gonet A, Sliwa T. Deep borehole heat exchangers—a conceptual and comparative review. *Int J Air Cond Refrig.* 2016;24(1):1630001–15.
- Schulte DO. Simulation and optimization of medium deep borehole thermal energy storage systems. Doctoral Thesis, Technische Universität, Darmstadt; 2016.
- Schulte DO, Rühaak W, Oladyshkin S, Welsch B, Sass I. Optimization of medium-deep borehole thermal energy storage systems. *Energy Technol.* 2016;4(1):104–13.
- Seama KF, Rosen MA. Review of the modeling of thermally interacting multiple boreholes. *Sustainability.* 2013;5(6):2519–36.
- Welsch B, Rühaak W, Schulte DO, Bär K, Sass I. Characteristics of medium deep borehole thermal energy storage. *Int J Energy Res.* 2016;40:1855–68.
- Welsch B, Schulte DO, Rühaak W, Bär K, Sass I. Thermal impact of medium deep borehole thermal energy storage on the shallow subsurface. In: *EGU General Assembly Conference Abstracts.* 2017.
- Zarrella A, Emmi G, De Carli M. A simulation-based analysis of variable flow pumping in ground source heat pump systems with different types of borehole heat exchangers: a case study. *Energy Convers Manag.* 2017;131:135–50.

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