TECHNICAL ARTICLE SHALLOW GEOTHERMAL · BOREHOLE HEAT EXCHANGERS

BHE field and balance ratio over 25 years

Why BHE fields cool down – and what thermal recharge decides

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ABSTRACT

A BHE field is not a well but a store. If, year after year, far more heat is extracted from a dense field than is returned, the fluid temperature falls over decades. The article explains the balance ratio and the line-source calculation and shows, with a study for a hotel resort on the Baltic coast, that recharge decides between operation and depletion.

KEYWORDS · Borehole heat exchangers · BHE field · Balance ratio · Regeneration · VDI 4640 · Long-term simulation

1 Background

Systems up to 30 kW are designed from tabulated values, which VDI 4640 Part 2 relates to 50 years of operation [1], [4]. In a dense field, the cooled zones of neighbouring boreholes overlap; the centre cools more, increasingly each year. Larger systems must therefore be simulated with the actual load profile.

2 Balance ratio

The ratio of heat returned to heat extracted governs:

$$\beta = Q_{rec} / Q_{ext} \quad (1)$$

Q_{ext} annual heat extraction · Q_{rec} annual thermal recharge from cooling, solar thermal, waste heat or surface water

With β close to 1, the field acts as a seasonal store. With small β, the temperature of dense fields drifts over decades. Back-analyses of monitored Swiss fields confirm the model; if anything, it overestimates the cooling [3].

3 Calculation

Each borehole acts as a line source; superposed in time and space, the following applies [5]. The infinite line source overestimates the cooling (safe side); g-functions capture end effects [2].

$$\Delta T(r,t) = q' / (4\pi\lambda) \cdot E_1(r^2 / (4at)) \quad T_f = T_0 - \Sigma\Delta T - q' \cdot R_b \quad (2)$$

q' extraction per metre · λ thermal conductivity · $a = \lambda/(\rho c)$ · R_b borehole thermal resistance · T_f mean fluid temperature

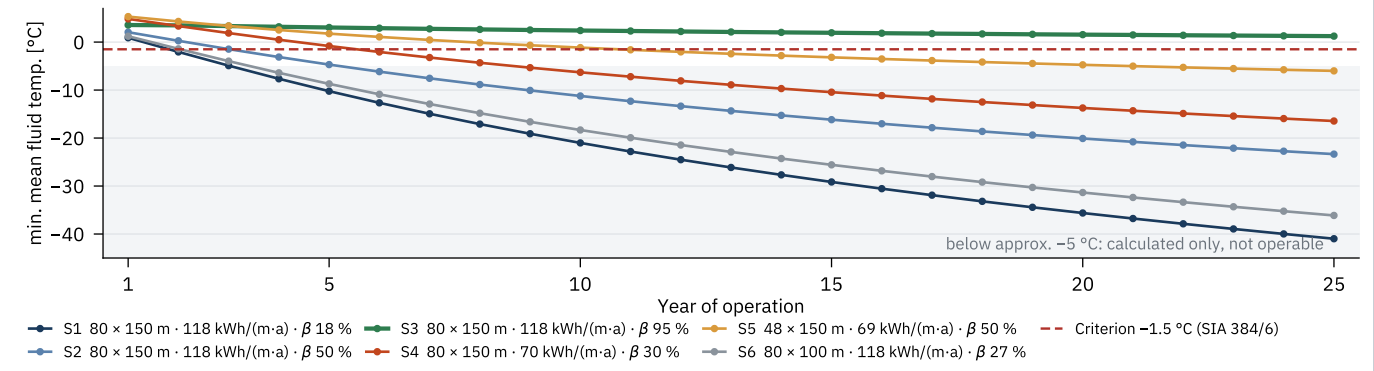


Figure 1. Minimum mean fluid temperature over 25 years, six variants (boreholes × length) on a 7 m grid (hotel resort study, Baltic coast, anonymised; infinite line source, λ = 2.3 W/(m·K), T_0 = 10 °C, R_b = 0.09 m·K/W). Only with 95 % recharge does the field stay above the criterion; the other variants fail it long before the 50 years to which SIA 384/6 refers.

4 Example: hotel resort

A hotel with year-round base load is to extract approx. 1 410 MWh/a from the field; cooling returns only approx. 18 %. Criterion: mean fluid temperature ≥ −1.5 °C to SIA 384/6 [6]; VDI 4640 Part 2 leaves the limit open. Lower load (S4), a smaller field with lower load (S5) and shorter boreholes (S6) fail it at β of 27 to 50 %. Only 95 % recharge from seawater keeps the fluid at approx. +1 °C after 25 years.

Table 1. Minimum mean fluid temperature in year 25 (calculated)

Case	Boreholes × length	Extraction	β	$T_{f,min}$
S1	80 × 150 m	118 kWh/(m·a)	18 %	−41 °C
S2	80 × 150 m	118 kWh/(m·a)	50 %	−23 °C
S3	80 × 150 m	118 kWh/(m·a)	95 %	approx. +1 °C
S4	80 × 150 m	70 kWh/(m·a)	30 %	−16 °C
S5	48 × 150 m	69 kWh/(m·a)	50 %	−6 °C
S6	80 × 100 m	118 kWh/(m·a)	27 %	−36 °C

5 Recommendations

- Derive the balance ratio from the load profile before fixing borehole number and length; plan recharge explicitly.
- Simulate over the service life, usually 50 years; agree the limit temperature with the water authority early.
- Confirm λ and R_b by a thermal response test [7] before sizing.

STANDARDS AND REFERENCES

[1] **VDI 4640 Part 2:2019-06** Thermische Nutzung des Untergrunds – Erdgekoppelte Wärmepumpen
[2] **Eskilson, P. (1987)** Thermal Analysis of Heat Extraction Boreholes. PhD thesis, Lund
[3] **Pahud, D. (2015)** Simulationen gemessener Erdwärmesondenfelder. Final report, BFE, Bern
[4] **Schäfer, I. (2019)** Auswirkung der neuen VDI 4640 Blatt 2 auf die Planung. 5. Willicher Praxistage, 6 Nov. 2019
[5] **Carslaw, H. S.; Jaeger, J. C. (1959)** Conduction of Heat in Solids. 2nd ed., Oxford
[6] **SIA 384/6:2021** Erdwärmesonden
[7] **VDI 4640 Part 5:2020-07** Thermal Response Test