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Heat supply by shallow geothermal energy in Karlsruhe

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Introduction

Heat energy for space heating and domestic hot water represents 33% of the energy demand in Germany [1]. Regarding the limited availability of fossil fuels and the global goal of reducing CO_2 emissions, renewable resources and new energy systems are urgently required to provide sustainable energy for the future. Can shallow geothermal energy supply the heat energy for old buildings having a high heat demand, or is it necessary to refurbish these buildings to meet the demand?

Study Site

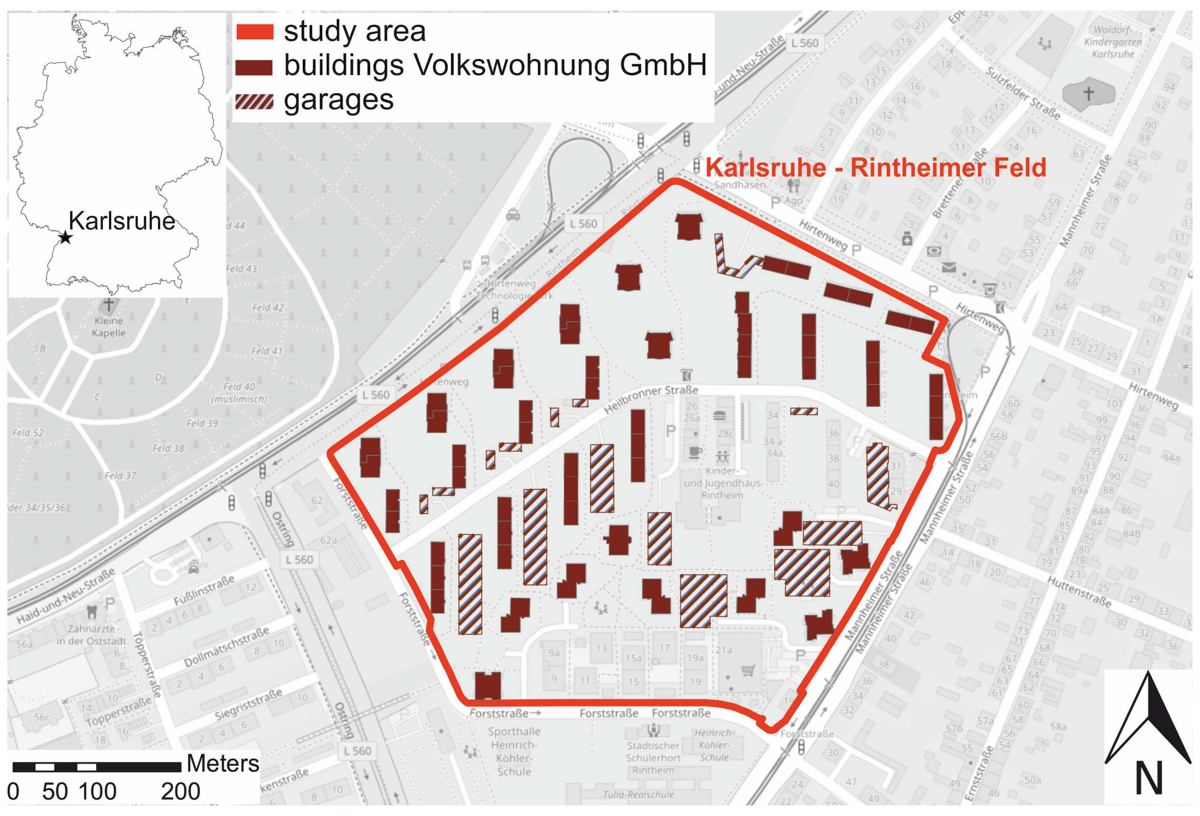

Fig. 1: Location of the study site: Rintheimer Feld is an urban quarter in the eastern part of Karlsruhe. 31 multi-family houses owned by the housing association 'Volkswohnung GmbH' were refurbished between 1998 and 2014. The primary energy consumption for heating and domestic hot water was 197 kWh/m² before and 44 kWh/m² after refurbishment [2].

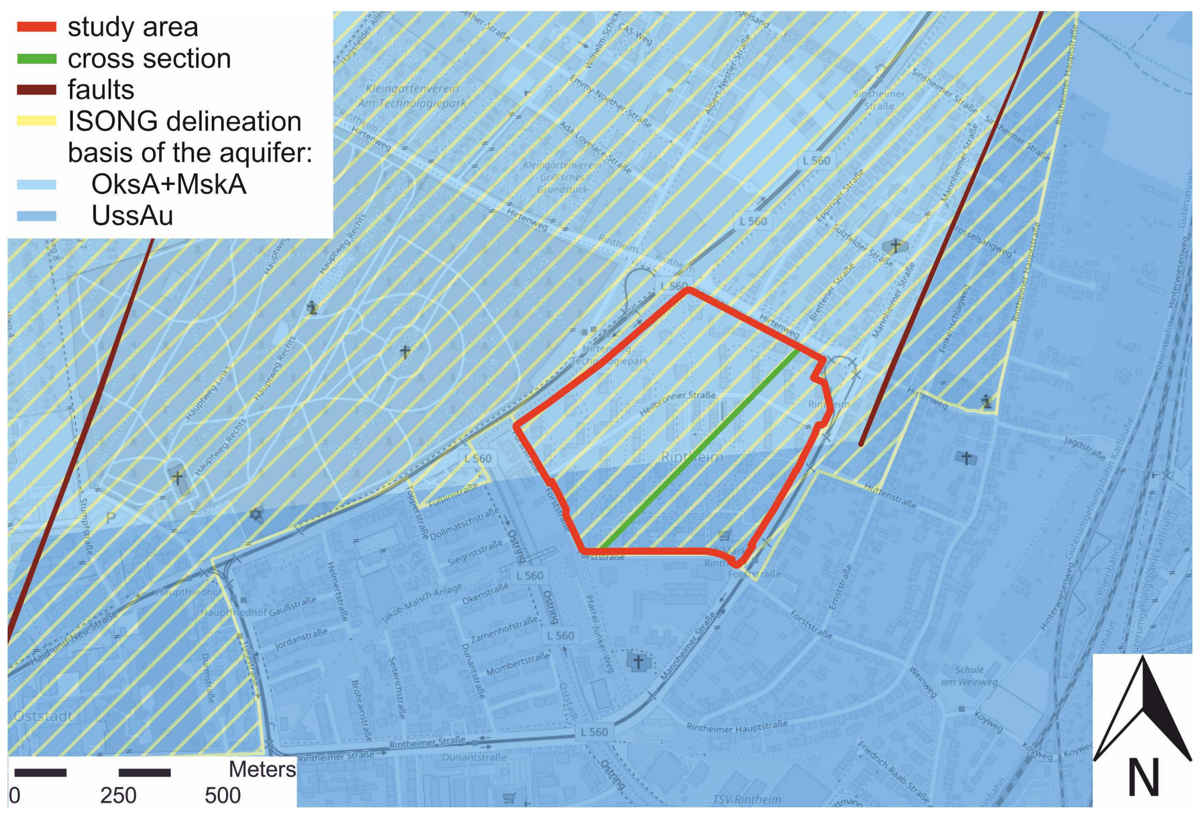

Fig. 2: Basis of the aquifer formed by either the gravel-sand layer (OksA+MskA) or the sand-silt layer (UssAu); area with a limitation of the drill depth defined by the 'Informationssystem Oberflächennahe Geothermie für Baden-Württemberg' (ISONG) and the cross section for the energy flow approach (Tab. 1).

Method

Three steps to evaluate the satisfaction rate of the heat demand for the three different shallow geothermal systems: horizontal ground source heat pump (HGSHP), vertical ground source heat pump (VGSHP) and groundwater heat pump (GWHP):

1. GIS analysis:
   - Determination of the spatial input parameters for the second step and illustration of the results with ArcMap.
2. Estimation of the geothermal potential for the three different systems:
   - Four different approaches and seven scenarios considering geological and legal limitations (Tab. 1 and Fig. 3).
3. Satisfaction rate before and after refurbishment:
   - The result of each scenario is balanced against the measured heat consumption before and after refurbishment (Fig. 4).

Tab. 1: Equations to estimate the geothermal potential of each system and the nomenclature of the input parameters.

Geothermal System		Equations
HGSHP		$E = q_{HGSHP} * t * A$
VGSHP		$E = q_{VGSHP} * t * l * n$
GWHP	plume	$\Delta T(x,y,t) = \frac{Q * \Delta T}{4 * p * m * v_a * \sqrt{\pi * \alpha_T}} * exp\left(\frac{x-r}{2 * \alpha_L}\right) * \frac{1}{\sqrt{r}} * erfc\left(\frac{r - v_a * {}^{t}/_{R}}{2 * \sqrt{v_a * \alpha_L * t/R}}\right)$; $r = \sqrt{x^2 + y^2 \frac{\alpha_L}{\alpha_T}}$
	energy flow	$E = Q * t * \Delta T * c_{pw}$

Nomenclature			
E	energy (kWh/a)	ΔT	temperature difference (K)
q_{HGSHP}	heat extraction rate (W/m²)	p	porosity (-)
q_{VGSHP}	heat extraction rate (W/m)	m	thickness of the aquifer (m)
t	time (s/a)	v_a	tracer velocity (m/s)
A	area (m²)	α_L, α_T	thermal dispersivity (m)
l	length of one BHE (m)	x, y	coordinates
n	nr of BHE (-)	R	retardation (-)
Q	volume flow (m³/s)	c_{pw}	volumetric heat capacity of water (J/m³ K)

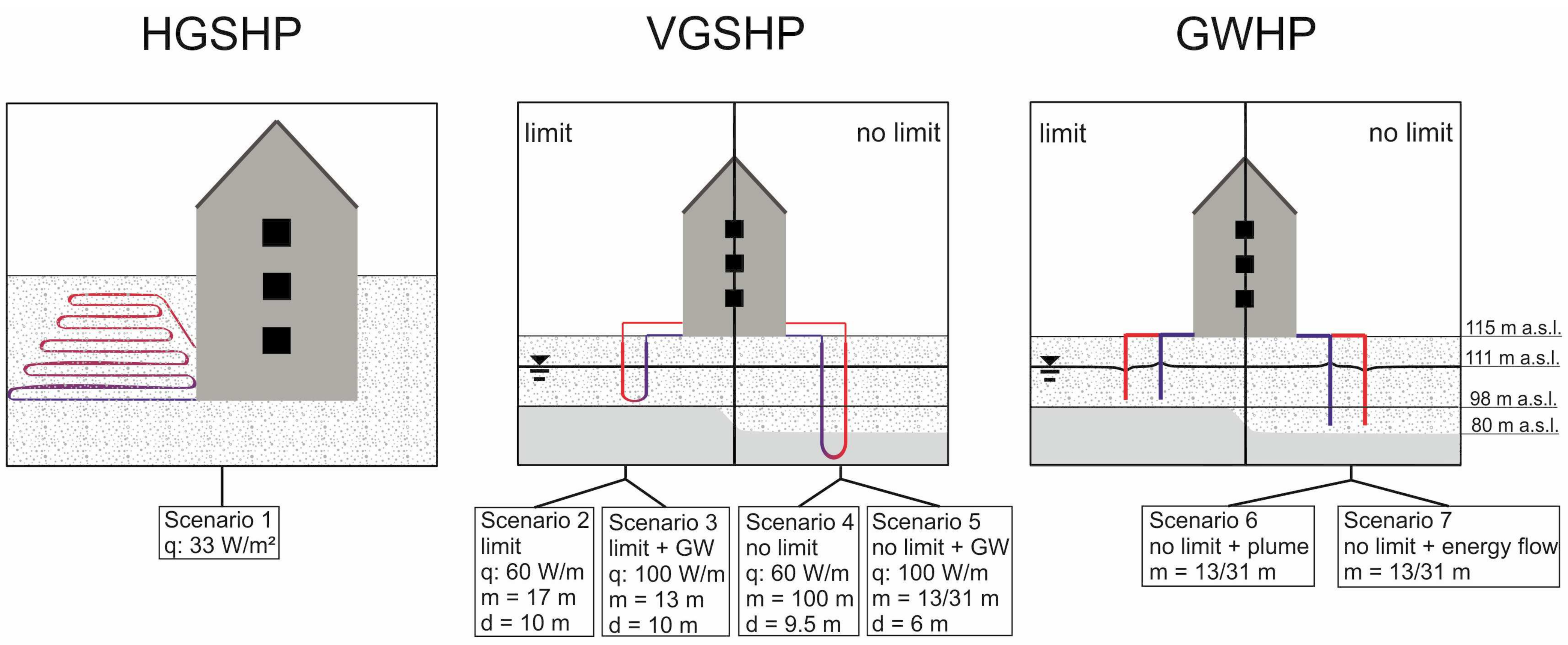

Fig. 3: Seven calculation scenarios for the three different shallow geothermal systems. The scenarios consider variable heat extraction rates q (depending on groundwater flow GW), aquifer thickness m and a limitation of the drill depth (limit, no limit) and a fixed as well as a variable borehole heat exchanger (BHE) spacing d. The cross section (see Fig. 2) shows the variation in aquifer thickness within the study site, ground level and the depth of the water table.

Results

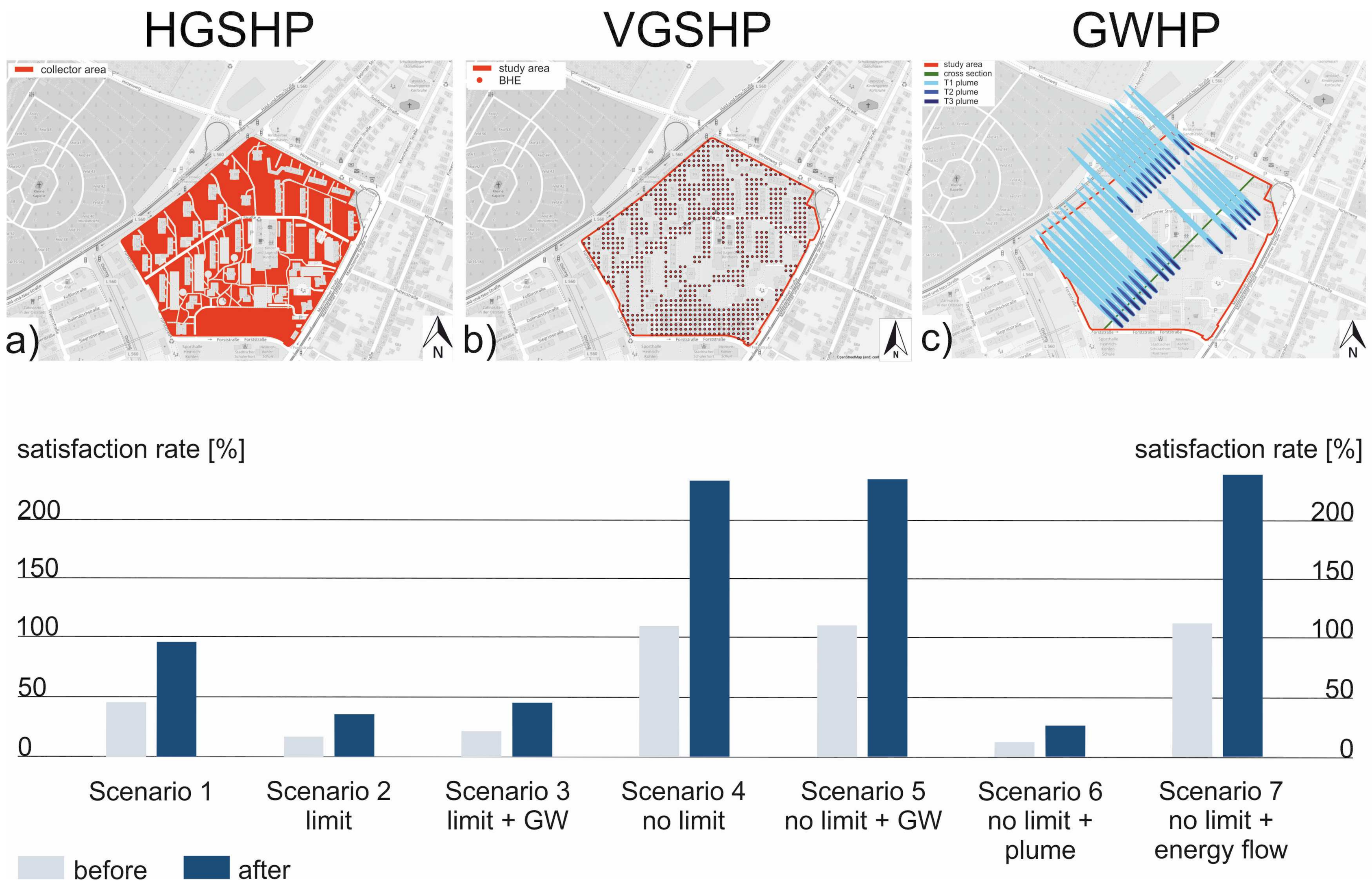

Fig. 4: Results of the seven scenarios before and after refurbishment: 5a) in red: area which can be used for HGSHP installations, 5b) equally distributed boreholes for a 10 m BHE spacing, 5c) ΔT= 1 K, ΔT= 2 K and ΔT= 3 K temperature plumes and the cross section of the energy flow approach. The scenarios consider a limitation of the drill depth (limit), groundwater flow (GW) and individual approaches (see Tab. 1).

Conclusion

- The heat demand for heating and domestic hot water in an urban area can be satisfied by shallow geothermal energy even in case of an old, non-refurbished building stock.
- Satisfaction rate of the heat demand of at least 100%:
  - with VGSHP: In case of no limitation of the drill depth and an optimal BHE spacing.
  - with GWHP: In case of no limitation of the drill depth and the application of the energy flow approach.
- Assumptions and limitations:
  - Analytical solutions provide only an approximation of the geothermal potential and the extent of the temperature plumes.
  - Uncertainties regarding the geological and hydrogeological input parameters.
  - Limitation of the drill depth and its delineation by ISONG due to groundwater protection.
- Recommendations for authorities:
  - Incorporation of shallow geothermal systems for heat supply in urban energy management.
  - Permanent maintance and update of the geological data basis is required.

References

[1]: Bundesministerium für Wirtschaft und Energie (BMWi): Energiedaten: Gesamtausgabe, Berlin. Available from: www.bmwi.de/Redaktion/DE/Artikel/Energie/energiedaten-gesamtausgabe.html (Accessed 5 March 2018), 2018.
[2]: Jank, R.: Integrales Quartiers-Energiekonzept Karlsruhe-Rintheim: Optimierungsmethoden, Praxiserfahrungen mit technischen Innovationen, Umsetzungsergebnisse, Volkswohnung Karlsruhe GmbH., 2013.