

EXTENSIVE GEOTHERMAL HEAT USE IN CITIES – ENERGETIC AND ECONOMIC COMPARISON OF OPTIONS FOR THERMAL REGENERATION OF THE GROUND

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ABSTRACT

Geothermal energy as a heat source for heat pumps is increasingly unused in the city of Zürich. However, as indicated by other authors, the renewable potential for shallow geothermal heat use is limited due to the fact that natural regeneration in the absence of ground water flow is slow. Constant heat extractions from dense geothermal heat pump installations continuously cool down the affected ground layer.. In this case boreholes have to be drilled deeper or regenerated in order to avoid freezing around the borehole. The aim of this simulation study is to find the most economic geothermal heat pump concept, which does not lead to borehole freezing after 50 years of operation in areas with dense installations (an exemplary mean geothermal heat extraction of 35kWh/m²/a was supposed for this study). Therefore a multi-family house with a standard ground source heat pump was simulated for a period of 50 years in Polysun. Various solar concepts, an air heat exchanger concept, a geo cooling concept and also a system without regeneration were added to the system. These concepts were compared under the assumption that all neighboring installations are using an equivalent regeneration strategy as the simulated system

For the different system concepts, highly variable total borehole length were needed to avoid freezing, reaching from 1020m for a system with a large glazed collector field to 2160m for the un-regenerated case. The heat cost of the analyzed system concepts was in the range of 21 - 27 Rp/kWh. The most cost-effective system concepts according to this analysis are the air heat exchanger or unglazed collectors. Increasing the total borehole meters was not only one of the most expensive options, but also the least sustainable, since the continuation of ground temperature decrease after 50 years was more pronounced with this option than for any other option.

Keywords: geothermal potential, borehole regeneration, g-function, borehole interaction, regeneration costs

INTRODUCTION

According to the energy concept of the city of Zürich in 2050 (EK2050, efficiency scenario A), about 44 % of the total useful energy for heating and domestic hot water will be provided by heat pumps – 38 % or 450 GWh a⁻¹ of these will be delivered by geothermal heat pumps [1, 2]. This consumption is 10 times higher than today, with about 44 GWh a⁻¹ heat extraction in 2013. According to the study “geothermal borehole potential in the city of Zürich” [3] (in German) a geothermal heat extraction, as provided in the EK2050, is only sustainable if it is actively regenerated at locations with a high density of borehole heat exchangers (BHE). Objects with only one or a few BHE are usually just designed for heat removal. And only the mutual influence of the object’s own BHE’s is usually considered. In the Swiss guideline (SIA 384/6) it is mentioned, that in the case of local accumulation the mutual interaction has to be considered and the effect has to be compensated by seasonal recharging. However, the established planning tools do not provide means to consider the influence of neighboring installations. In this paper a method for considering neighboring installations in the form of a regular field of equal BHE is introduced. This method was used to compare different

regeneration concepts according to the annual energy extraction, the total needed borehole length and the resulting energy costs.

METHOD

One exemplary multifamily house with a geothermal heat pump was simulated with different regeneration systems. The exemplary system was supposed to be suited in an area with high geothermal energy usage. In order to be able to compare different system concepts that lead to a different degree of regeneration, the following assumptions were made:

1. The probe lengths for each variant were customized to fulfill the SIA 384/6 requirement of ground source temperatures above $-3/0$ °C after 50 years of operation.
2. All neighboring boreholes are subjected to the same heat extraction and injection rate profile as the simulated system.
3. Neighboring geothermal installations are supposed to be placed in a regular pattern of single boreholes with a distance of 20 m. This is equivalent to a mean geothermal heat extraction of 35 kWh/m²a.

Neighbor G-Function

The software polysun uses the g-function approach based on the work of Eskilson [4] to include long term effects in the simulation of borehole heat exchangers. The influence of the neighboring geothermal installations was included in the form of a neighbor g-function. This was defined as the effect of a regular field of BHE to the BHE in the center. The neighbor g-function was generated using a new semi analytical model [5] with the assumption that all boreholes in are subjected to the same heat extraction rate density. With this assumption g-functions for regular fields with increasing size were generated. This g-functions are plotted in figure REF. It can be seen that an increase from 41x41 to 101x101 BHE has a very small effect on the g-function of the field (deviations can be spotted above $\log(t/tES)=2$ which represents more than 1000 years for typical borehole depths). For this reason the g-function of the 101x101 BHE field is supposed to be representative for an infinite field. Because of the superposition principle, the neighbor g-function can be calculated by subtracting the g-function of a single BHE (with an equivalent heat extraction distribution along the borehole) from the g-function of the entire field. The effect of the neighbors corresponds to an additional temperature drop of the BHE by around 7K after 50 years for the assumptions made above. Because of assumption 2, (all neighboring boreholes are subjected to the same heat extraction and injection rate profile as the simulated system) the neighbor g-function can simply be added to the g-function of the BHE of the exemplary system for long-term simulations.

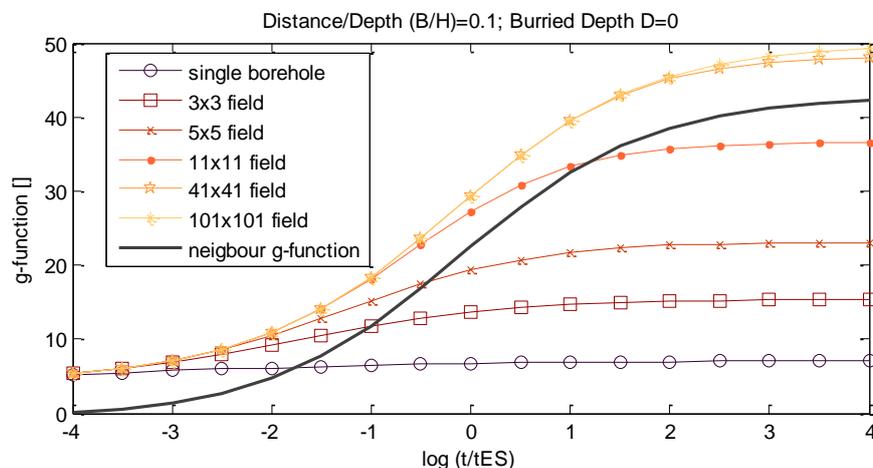


Figure 1: G-functions for increasing field sizes and resulting neighbor g-function.

Simulation

A multi-family house (renovated according to the Swiss energy label “Minergie”) with 12 apartments, 260 m² south roof surface was simulated for a period of 50 years in Polysun. The building has an annual heating demand of 72 MWh and a hot water consumption of around 40 MWh. A standard ground source heat pump system (50 kW) extracts 87 MWh heat from the soil within the first year of operation in order to meet the total heating demand.

The following regeneration concepts are investigated:

- No regeneration (basic variant)
- Geo cooling
- Unglazed absorbers (60 m², 260 m²)
- Glazed collectors (60 m², 132 m²)
- Glazed collectors with additional solar storage (60 m², 138 m²)
- Air heat exchanger (60 kW)
- Unglazed selective absorbers (60 m², 218 m²)
- Unglazed PVT-collectors (60 m², 260 m²)

For comparison, all simulations are based on the same hydraulic (basic variant). The regeneration with the air heat exchanger and the solar regeneration are integrated as shown below. The solar regeneration concept is also simulated with an additional solar storage, to demonstrate the utility. The concept geo cooling regenerate the soil with passive solar gains in summer over the floor heating system of the building.

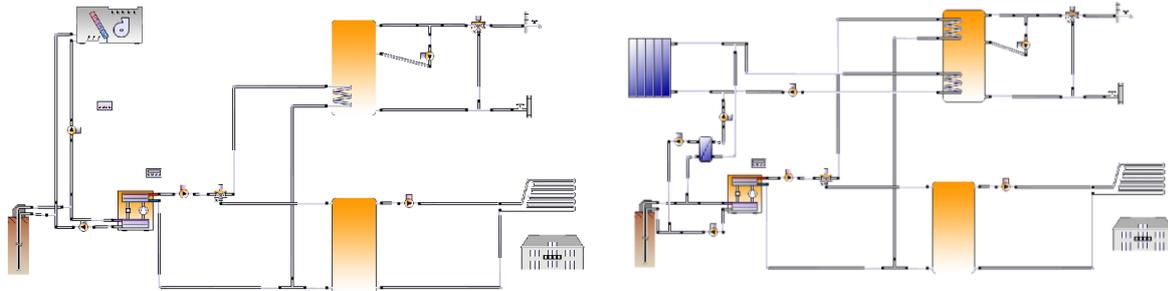


Figure 2: Simulated regeneration concepts with a) an air heat exchanger b) solar collectors.

RESULTS

In this section, the simulation results are presented. The annual net energy extraction of the BHE and the annual regeneration energy are shown in following Figure 3 for the first and the fiftieth year of operation. The sum of net energy and regeneration energy give the gross energy extraction. The difference between gross energy of the concept with glazed panels and gross energy of the basic variant is a result of the direct use of solar energy for water heating. The graph shows that with an additional solar storage significantly more solar energy can be used directly. Regeneration concepts with a strong dependence on the difference between ground and ambient temperature (air heat exchanger, unglazed collectors), show a lower net extraction after 50 years of operation. This is due to the decreasing ground temperature and accordingly a higher efficiency of the regeneration system. None of the variants to the left of the black line reaches a full (100%) regeneration even after 50 years. Thus the soil temperature will still decrease slightly after 50 years. Only the glazed solar collectors (132 m²) and the selective solar absorbers (218 m²) are able to regenerate from the first year to 100 % (shown below the black bar). With these regeneration strategies sustainable use of geothermal energy is guaranteed independent of the considered time horizon.

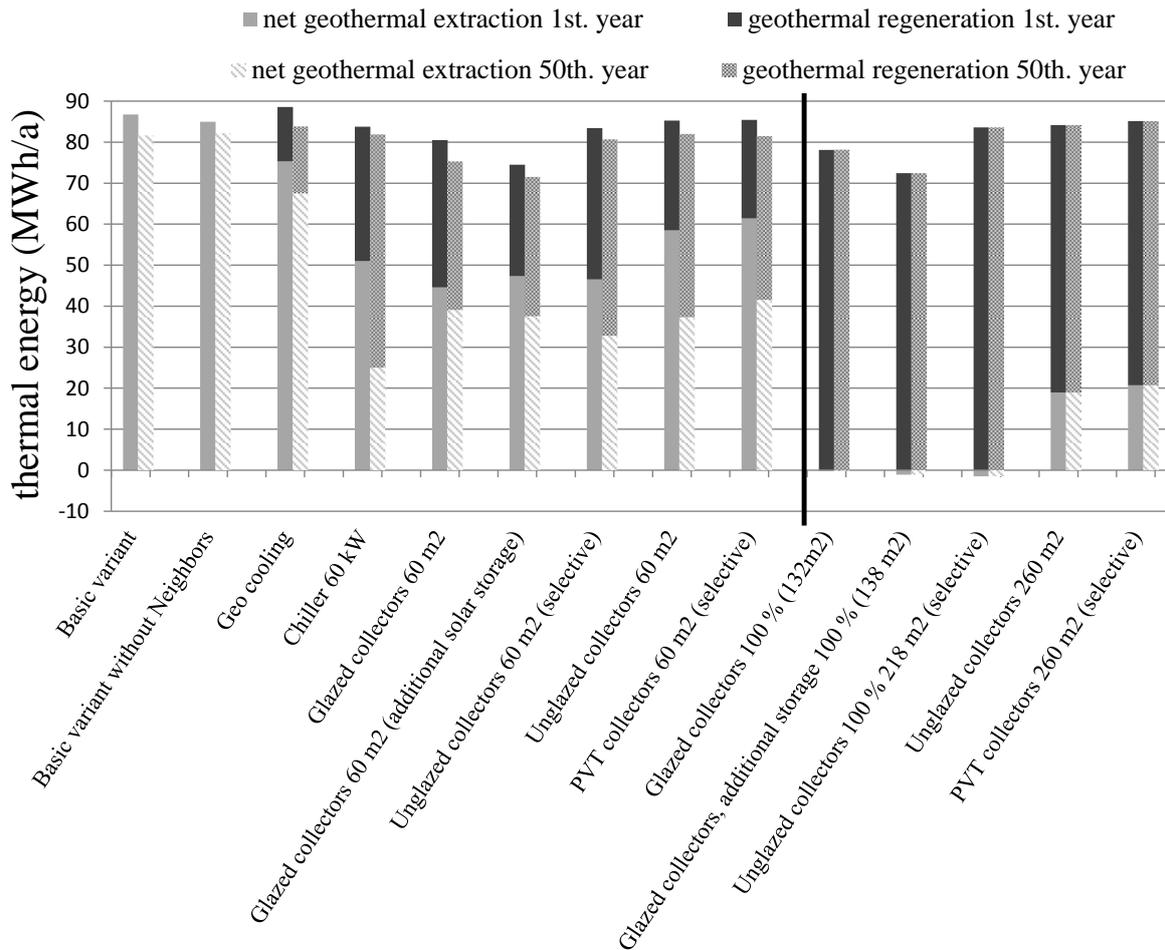


Figure 3: Net geothermal heat extraction and geothermal regeneration in the first and fiftieth year of operation.

Figure 4 shows the entire borehole length of the different regeneration variants to meet the SIA 384/6 requirement of $-3/0^{\circ}\text{C}$. By considering the neighboring fields twice as many borehole meters are needed in order to meet the requirements.

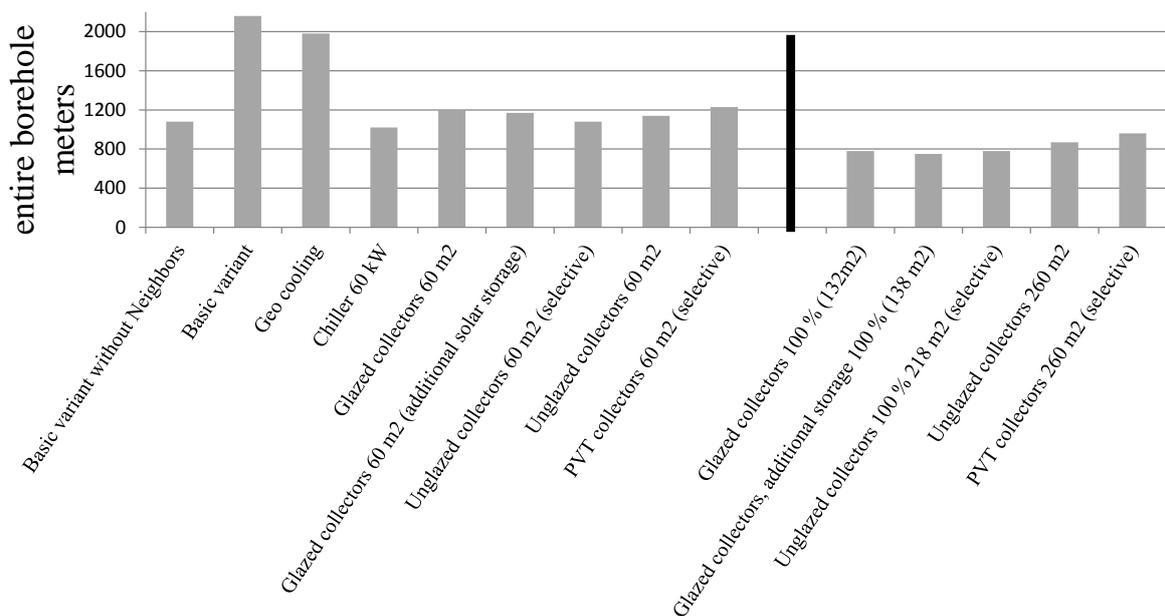


Figure 4: Entire borehole meters of different system concepts.

Figure 5 shows the heat costs of the investigated systems. The costs include the BHE with heat pump, the needed storages, the hydraulics and piping between BHE and system. The extra investments in the air heat exchanger or the collectors are taken into account with piping, hydraulic and heat exchanger in the respective regeneration concept. It has been calculated using the current electricity price of 23.4 Rp/kWh. The annual price increase in the electricity is estimated with 1.4 %, according to the information of the City of Zürich. The effect of neighboring objects leads to additional costs in the range of 2,200 – 4,500 Fr/a. This means an increasing in costs of 10 – 21 % compared to a single object (without neighbors). With the assumptions made in this work the most cost effective concepts are the air heat exchanger or unglazed collectors. However, both techniques are not suitable to achieve complete regeneration. A complete regeneration is possible with glazed collectors or selective absorbers, but it requires a collector area of 132 m² or an absorber area of around 218 m², which increases the costs up to 25 or 27 Rp/kWh.

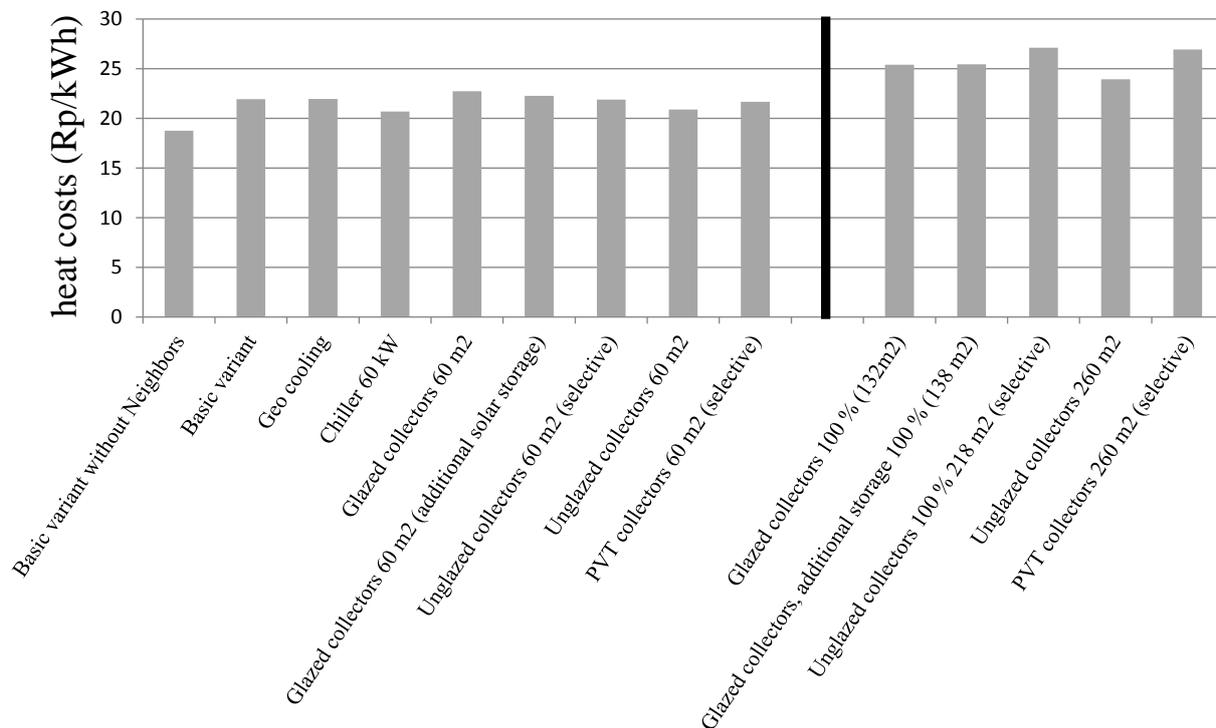


Figure 5: Heat costs of different system concepts.

CONCLUSION

This study was done to compare different methods for the regeneration of BHE from an energetic and economic point of view. The following statements can be made with the results of this simulation study:

- With the assumptions made in this study (geothermal energy extraction of 35 kWh/m²/a) neighboring installations lead to an additional drop of the ground temperature by 7K when not compensated by longer boreholes or BHE regeneration.
- Already by partial regeneration, the long term cooling can be counteracted. This allows higher density of BHE and / or a longer operating times.
- Total regeneration is possible with large area of glazed or unglazed selective collectors. But this leads to higher heating costs compared to concepts with partial regeneration.

- Extending the entire probe length instead of regenerating is both, economically and from the perspective of sustainability one of the worst options.
- The differences between the heating costs with different methods of regeneration are low. Therefore none of the regeneration methods are favoured. The regeneration method can be chosen depending on the specific situation.

The systems with partial regeneration and with consideration of the neighbor effects need a similar total borehole length than the unregenerate system without considering the neighbors. For this reason a change in BHE design is not urgently needed, also for areas where a high geothermal heat extraction density is foreseen for the future. However, new and existing ground source heat pump systems have to be equipped with (at least partial) regeneration systems when a critical extraction density is reached in the neighborhood.

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