

Deep Groundsourced Heat Exchanger with Coaxial Pipe, Closed Water Circuit – Improvement Proposals in Project Development and Technical Pipe Conception

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Keywords: project development, risk management, hydrogeothermal well exploration, drilling diameters, pipe conception

ABSTRACT

The direct use of deep geothermy by a Deep groundsourced heat exchanger with coaxial pipe, closed water circuit (DGHE) enables to mine heat in a highly profitable, riskless and ecological way anywhere a sufficient base load heat demand is located. Furthermore it is one way of examining hydrogeothermal wells without risky investments in seismics. Projects can be started by test drillings and being finished as DGHE in case of non-profitable well usage.

This paper shows a technical concept to dimension the bore hole diameter in a way that, if deep ground wells are found, the drilling allows a rededication for hydrogeothermal usage. Thus the DGHE exchanger provides a basic concept for low-risk discovering dublette power plant locations.

Furthermore this business strategie paper provides technical and project development improvement proposals. In an active energy-centered-design process this pipe generates heat up to 750kW that could be sold to municipal energy suppliers in a 20 or more years lasting contract with defined prices per kWh and quantity from 4.5 to 5.5 GWh. Cost per unit geothermal heat is thereby equal or below actual heat prices.

1. INTRODUCTION

In contrast to doublet-systems and hot dry rock techniques deep groundsourced heat exchanger are basically independent of geological conditions. This allows a next-to-consumer installation and avoids wide-ranging district heating grids. They are characterized by less complicated engineering and high durability. The capacity ranges from 500 kW_{th} up to 750 kW_{th}. This comparatively low capacity is consistent with a risk-free investment while operating costs and costs of maintenance are virtually negligible. These parameters result in a long lasting heat supply with consistent prices and constant revenues.

The principles of deep groundsourced heat exchangers go back to the 1920th. Due to the high costs of drilling already existing bore holes were rededicated. For example in the beginning of the 1990th a doublet-drilling in Prenzlau, Mecklenburg-Vorpommern (Germany), was finished as a closed water circuit as the aquifer became impermeable. In the last years the concept of deep groundsourced heat exchangers became more and more relevant as oil and gas prices destabilized the heat supply of many town councils in Germany, Austria and Switzerland. Because of this deep groundsourced heat exchangers were installed in Weggis and Bad Weisbach in Switzerland and in Altheim in Austria in the end of the 1990th. Recently finished projects in Germany are Aachen in 2006 and Arnsberg in 2007.

2. FUNCTIONAL PRINCIPLE OF DEEP HEAT EXCHANGERS

The deep geothermal heat exchanger consists of an outer steel pipe (casing) and a thin production pipe coaxial in the casing. Cold water is pumped into the annulus of the geothermal well. On the way down to the bottom of the well it takes up heat from the surrounding rock. Once at the base of the heat exchanger the hot water flows back to the surface via the central production pipe. The heat exchanger has a closed water circulation and does not use hot fresh water in the subsurface. A deep heat exchanger therefore avoids many problems and risks of open hole water mining. An infiltration of salinated deep ground wells is as impossible as an outflow. The steel casing is connected to the surrounding rock by high performance and shrink-free concrete.

Back on the surface the hot water passes cascade like through radiators as well as ceiling- and floor-heating systems thus supplying heat to buildings, bathes and many more. In summer, the geothermal heat may serve as driving energy for an adsorption cooling machine. Once the previously hot water has cooled down it is conducted back into the geothermal heat exchanger and water circuit closes.

Derived from the simple engineering advantages result in the variety of applications, project planning, coordination and financing:

- The application of deep heat exchangers is nearly independent from the geological situation in the bedrock. That means that choice of location is dedicated by customers needs and not by e. g. permeable aquifers or longlasting deep ground wells. Deep heat exchangers are likely being installed anywhere a base load heat demand above 500kW exists.
- Due to the closed water circuit no aquifer has to be found: The success of the drilling is not hooked on detecting deep ground wells. This risk is a widespread deterrence of financing hydrogeothermal power plants. Furthermore seismological investigations are not needed.
- The technical risk of drilling is very low. The track is plain vertical and without any branches or junctions.
- The input of pure water into the closed circuit reduces effects of corrosion and beware of deposits or mechanical abrasion. Subsurface applications do not consist of any alteration parts. E. g. the circulating pump is aboveground, so that costs of maintenance are reduced to a minimum.

- The expected life time of a deep heat exchanger is at a minimum of 40 years. Exclusion of air and insignificant corrosion may lead to a realistic duration of 50 – 60 years.
- Running costs solely result from driving the circulating pump. The work of the pump is supported by the different density of hot and cold

water, thus allowing operation of the circuit with minimum costs per annum.

- The drilling concept of Stoltenberg Energie allows a hydrogeothermal usage in case of detecting deep ground wells.

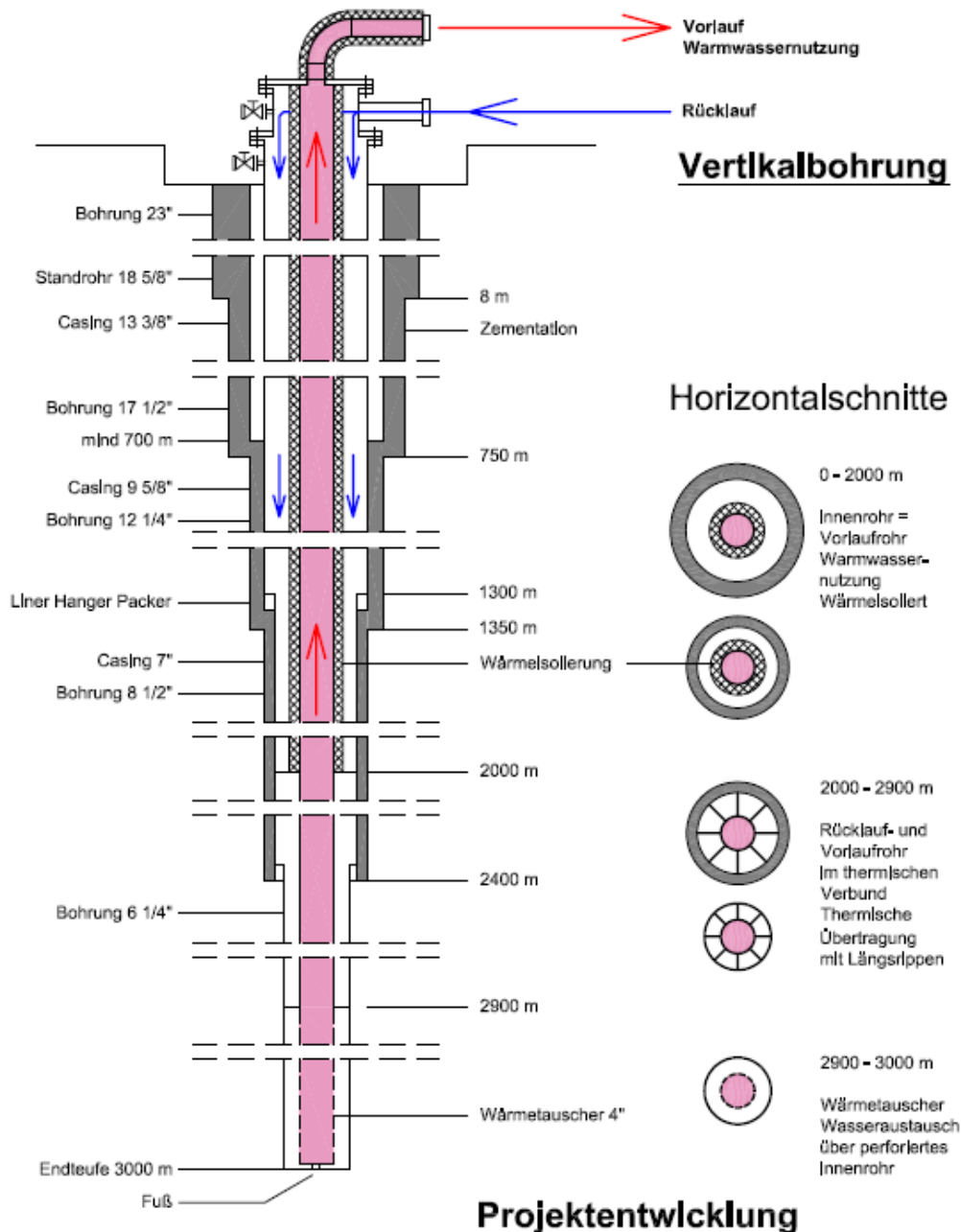


Figure 1: Scheme of a DGHE

3. PROJECT DEVELOPMENT

3.1 Project Location

The location of a geothermal drilling is influenced by several factors, which are due to the current use of the project location and unchangeable size of a rig and its equipment. Furthermore the heat capacity and the exploration technique play a decisive role.

The needed size for adequate drilling operations is approximately 50m x 50m (2500m²). Part of the equipment has not to be stored on the usually rectangular bore location (e. g. portable office units, current generator). The basement must be solid to bank the rig on concrete foundation and the access roads to and from the bore location must be suited for heavy loads transit.

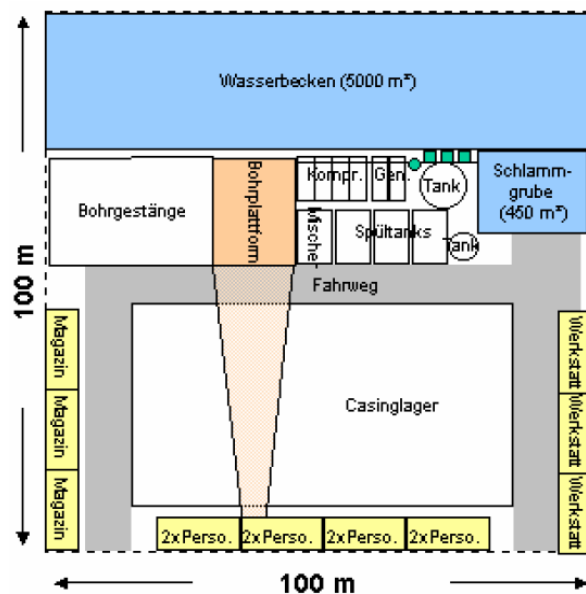


Figure 2: Scheme of an ideal bore setting

Despite the required space for a deep borehole and an appropriate access proximity to heat demand is necessary. While the costs for a local link are about 300 €/m and could be minimized, the heat loss is insignificant.

3.2 Drilling Conception

Subsequent a drilling concept is introduced which minimizes the technical risks and costs without excluding a possible potential of hydrogeothermal usage by technical restrictions.

The concept of implementing deep heat mining is due to an geological situation based on a deep heat exchanger with coaxial pipe and closed water circuit. This basic concept avoids expensive seismological examinations and opens up a wide range of lucrative alternatives.

Constitutive to the basic concept two alternatives are introduced which can be realised if geological parameters are better than expected. The dimensions of the bore hole of the basic concept have to be specified for any possible geological advantage to be used for deep heat mining. This means that amongst others starting point and diameter are useable for one-bore heat exchanger as well as doublet-like exploration of deep ground wells from Buntsandstein.

Basic concept: For the deep heat exchanger with coaxial pipe a depth of 3000m is intended. Into the starting point

with 23" diameter a standpipe with 18 5/8" is rammed down to 8m. This is necessary for drilling down to 700m by air lifting and saving the bore hole with a 17 1/2" steel casing. Afterwards the drilling is followed by a vertical undirected boring with 12 1/4" down to 1.500m and saved with 9 5/8"-steel casing attached with isolating foam cement. The drilling is continued from the 12 1/4"-casing with 8 1/2" respectively 6 1/4"-chisel for reaching the targeted depth which is core-drilled, geophysically examined and tested for injection and extraction. If the results of stimulation turn out negative for hydrogeothermal usage the drilling is completed as a deep heat exchanger.

Alternative A: If the results of stimulation turn out positiv, which means that both pump- and injection rates are sufficient and the geochemical situation and water quantity allow a hydrogeothermal use the basic concept can be modified to a doublet system. For this purpose a branch is drilled out off the 12 1/4"- casing in depth of 1.500m. This branch intersects the targeted depths at a minimum distance of 500m of the vertical drilling. If the following extraction and injection tests fail, the vertical bore and branch allow for a double heat exchanger with two isolated 3 1/2"- production pipes. The pressureless water circuit is conveyed through the annulus and controlled by two seperated pumps for both branches each.

Alternative B: If the investor pursues a risk-sensitive concept, the drilling can be deepened independently of testing with 12 1/4"-chisel and completed with 9 5/8" casing. If necessary the bore can be tapered on a drilling diameter of 8 1/2"with 7"-Liner-casing. The goal horizon is cored, geophysically examined and tested for permeability. If the results are positive, i.e. the pumping and/or injection rates are sufficient as well as water chemistry and temperature permits a hydrogeothermal use, the basic concept can be further modified, in order to realize a doublet. For this purpose a branch is driven out of the 9 5/8"-casing and intersects the goal depths at a distance of at least 500 m of the vertical drilling. If the pumping tests in the branch run positively, the drilling can be completed to a doublet, whereby the branch is sealed and serves as injection bore, while the vertical drilling mines the well. The brine could possibly be used for balneological purposes. If the water temperatures are above 100 °C, a power generation by KALINA-turbine could be considered. The capacity depends on the productivity of the aquifer and the temperature differences between flow and return. If the pumping and injection test of the branch turn out negatively, the vertical drilling and branch could be completed to a double heat exchanger. The expected capacity can be determined on basis of a numeric simulation depending upon detailed specification and geological conditions.

By using this exploration concept based on a riskfree heat exchanger a completion to a doublet-system is possible at least costs and risk. Drill head and casing diameters are sized for serving both possibilities.

3.3 Project Process

The process starts with planning, bid invitation and administrative authorization. The planning phase could be finished within three to 6 months; depending upon the requirements of the bidding procedure this phase could be realized within four months. Contemporaneously the mining permission and operating plan can be done. As far as subsidies and/or a public builder are involved, the bid invitation often follows a stare and complex regulation process.

The site preparation takes place within four weeks, drilling work depending on depth takes two to three months. If the reservoir characteristics are to be examined, for coring of the reservoir and testing two months have to be taken into account. After completion of the drilling the bore hole is equipped with a conveying tube and linked into the heating grid. Installation and test run need about two months for a deep heat exchanger. Simultaneously the site is recultivated. Altogether the project requires about 12 months.

4. PROJECT PARAMETERS

4.1 Main Factors

Several production cost estimations of heat from geothermal plants have been undertaken in the past. Following influencing variables could have been identified:

- Geology - temperature level, flow rate, construction period
- Drilling technique - drilling depth, feed pumps, stimulation
- Installation configuration - heat exchanger, heat pumps, peak load boiler, BHPP
- Heat demand structure – peak load capacity, load curve, annual load duration curve, hours of operation at full power equivalent, supply and return temperature levels
- Market conditions - interest rate, energy prices, taxes, subsidies

These and many further analyses permit conclusion on applicable reference values:

- The economy of geothermal heating plants is substantially affected by customers demand structure.
- All analyses of sensitivity show that the heat production costs of geothermal heating stations decrease with increasing capacity.
- The hours of operation at full power equivalent substantially determines the project profitability. Therefore the economical use of deep geothermal heat is only applicable covering base load heat demand.
- In all examined cases higher costs of deeper drillings led to higher temperature levels and to smaller heat production costs. This is also due to the correlating reduction of conventional peak load coverage.
- Use of heat storage facilities to increase the relative contribution of geothermal heat was often not included, because costs of installation with a capacity from 100 MWh th are too high.
- Prices of fossil fuels are crucial to strongly affect the competitiveness of geothermal heat installations.
- Due to the high share of fixed costs of geothermal heating installation economical examinations must consider different market scenarios for fossil fuels.

- A further important variable for the plant interpretation is apart from the capacity also the temperature demanded by the energy customer. This determines the conception of additional heating system by heat pump and peak load boiler or BHPP. A reduction of the supply and return temperature leads to an substantially increased portion of geothermal heat.
- For the better utilization of the geothermal potential by an increase of temperature spreading heat pumps can be used in the mean load range. To what extent the use of heat pumps is however energetic and economically meaningful is to be examined due to the location-specific and conditions. Whether the additional investments in the heat pumps and the resulting operating costs lead to a significant reduction of drilling costs is a crucial fact.

All analyses focus on the good deal of capital costs for the geothermal drillings for heat production. Therefore special attention has to be put on the capital costs. The costs of a drilling operation can be divided into five main factors:

- Site Preparation
- Drilling (rent of rigs and drilling crew)
- Equipment (e.g. borehole head, pipe systems, cementation)
- Consumables (e.g. fuels, flushing, drilling heads, bottomhole assemblies, water, insurance)
- Service (crane rent, inspections, weldings, drilling management, borehole measurements, flushing engineer, drillingdredge removal)

The costs of drilling completion (e. g. pump, probe heads) can only be measured individually. For a hydrothermal drilling costs of at least 500,000 to 600,000 € have to be taken into account. The cost structure is similar to drilling and completion of deep ground closed heat exchangers.

4.2 Risk and Rentability

Revenues of a geothermal heat project are due to heat capacity, heat flow volume and heat tariff. Upper price limit is set by competing heat prices relating to gas, oil, woodchips etc. Costs per unit are mainly affected by capital costs and costs of operation such as operating current for pumps or energy input for peak, reserve or if necessary mid-load supply. Geothermal heat projects hit break even on average after 10 years. During the first period EBITDA lie below repayment, interest and reinvestments, so that launching a geothermal heat project requires a solid leverage of often more than 30%. Due to the high starting investment (municipal) investors realize only „0%“ return on investment and during the calculatory investment period of up to 30 years often no more than 10% ROI. In contrast to geothermal power projects heat projects show a rising EBITDA-curve. Sales expansion by grid expansion or increasing demand of heat customers causes just under proportional progression of operating costs as long as the capacity lies above mid-load. Heat customers benefit disproportionately from increasing sales volume and thus cost degression per MWh due to constant capital cost and low operating cost relation. These powerful economies of scale are significantly visible in a rising EBT.

To determine the risk of geothermal heat projects, hydro geothermal doublet plants are well detailed in literature. The sensitive parameters of a hydrogeothermal exploration are independent of their usage, even if their effects on rentability are differing. Especially the economical benefit of a hydrogeothermal heat project is mainly driven by uncalculated cost increasing in the drilling phase and tends to turn the project into economic inefficiency. Independently of the final heat exploration technique hydrogeothermal as well as DGHE are affected by underground situation in terms of drilling expenses. Already smaller aberrations of proposed well production or temperature or in case of DGHE thermal conductivity of the rock diminishes rentability. In this face of risk special attention must be paid to planning, close supervision and drilling contracts. Insurances for well productivity or lost-in-hole even if actual possible are often way too expensive for geothermal heat projects.

The sensitive reaction of project's net yield underlines the financial fragility of geothermal heat projects. First each project is confronted with the general economic risks such as budget excesses, increases in interest, time delays etc. For the delimitation of these risks the classical instruments of each project management are to be used. A basic step - how it is proposed in this paper - is to undertake economical simulations to prequantify different project scenarios in economical, technical, ecological and energetical way and updating the results in the course of project. This allows quantifying and building up adequate financial resources to face unexpected happenings. This monetary risk quantification can also be used to predetermine drilling contracts or debt guarantees. In general initiators of geothermal heat projects must carry the technical drilling risks for the drilling contractor doesn't complete the drilling at all or in given time. Part of this risk can be formally devolved to the drilling contractor by switching from day-rate to turnkey contracts. This switch is economically limited by the sensitive project rentability if market conditions allow these contract instruments at all.

The geological risk of non or partially productive well exploration represents the main risk of a hydrogeothermal project and is in case of implementing a DGHE of minor importance. The geological risk can be reduced by reprocessing of old and accomplishing new seismic explorations. The remaining risk must be covered either by own capital or a risk insurance. Insurance concepts that cover these risks are presently infeasible. Due to insufficient experience and the small number of realized projects the offered insurance-policies are too expensive for geothermal heat projects. In dependence of the location-specific risks 10% to 20% of the drilling costs have to be taken into account. Operating risks are in contrast to power production with ORC or Kalina non significant.

Finally the usual contract, tax and local concerns have to be examined to successfully develop and realize a geothermal project. Unnecessary conflicts on initiator or partner level have to be avoided. This is even more important for intercommunal projects with often diverging local needs and financial budgets. A Public Private Partnership (PPP) is often a favourable constellation to cover risks in a financial adequate relation on private side and reassure investment by a long-term contract by municipality.

5. IMPROVEMENT PROPOSALS

If aboveground heat demand structure is seized in detail, it is possible to develop meaningful scenarios which subsequently serve as basis for further options. In general DGHE is about to cover base load heat demand. Existing supply temperatures are set to be fixed parameters, while later adaption of heat exchangers, optimization of operating hours and circulation volume of the DGHE must be undertaken and iteratively updated in scenario analysis. To determine capacity spectrum of the DGHE following technical and economic limitations have to be considered:

A geothermal heating installation is only to be appropriately specified on comprehensive data. Besides annual heat demands also frequency of heat loads has to be taken into account for assessing dependencies of the heat loads over time. Therefore load curves, which represent consumption in certain time intervals, are useful.

Potential heat demand has to be compared to heat supply dedicated by existing and flaring utilities. In the first step age and capacity of existing utilities are not to be put up for examination. Because operating flaring utilities - in this case a DGHE - have to run as long as possible to realize high and therefore economic yearly operation hour numbers, flaring utilities are to cover base load heat demand. The often depreciated existing utilities will cover peak load in times of higher demand like winter times.

From measured data of the DGHE in Weggis (Switzerland) an average heat-conductance of 127 W/m is noted and realized a capacity of about 100 kW. Prenzlau's DGHE generated an average capacity of 80 - 120 kW in natural circulation without circulating pumps. This data serves as reference, but leaves following aspects unconsidered.

Heat-conductance capacity of a DGHE in top division is negativ: heat flows out of the probe water circuit into the shell surrounding rock. In deeper segments heat-conductance of the surrounding rock becomes disproportionately high and compensates heat-loss in top divisions. Existing DGHE in Weggis and Prenzlau do not use any isolation to lower heat losses.

Drilling and isolation concepts can be adjusted to local geothermal conditions (kinds of rock, heat flow, hydrogeothermal situation). Because Weggis and Prenzlau were formerly havarized hydro geothermal drillings, adaptabilities could not be complemented.

Annual operation hours as well as flow- and return temperatures diverge per site and demand specific adjustments. In general DGHE are more efficient when the temperature-level is lowered and temperature spread is increased. Besides utility adaption heat pumps leading to a reduced return temperature, circulation volume and operating hours of DGHE can be optimized to geothermal conditions while buffer bridge this gap.

Technical specifications of the DGHE will lead to a higher heat-abstraction. For example spiral formed divisions realize a non laminar drift:

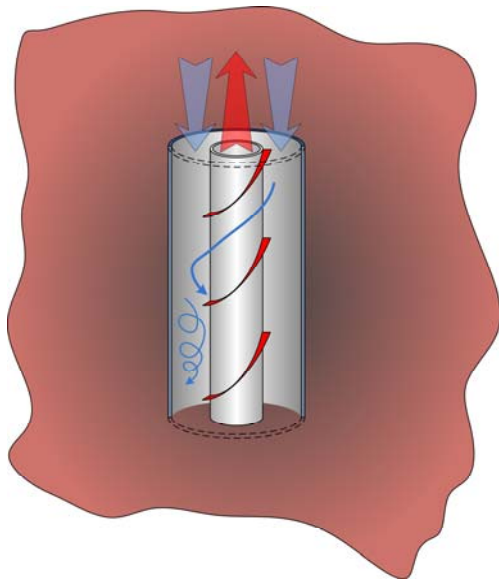


Figure 3: convoluted flukes on inner pipe

A geothermal optimized cementation concept leads to a higher heat influx:

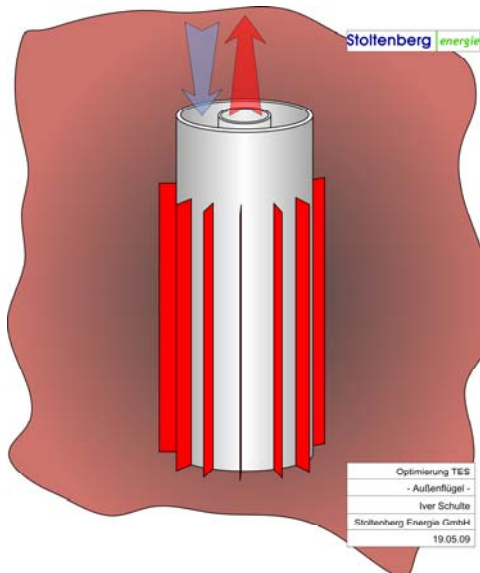


Figure 4: proposed system for optimisation of the outer shell of a casing in terms of heat conductance

Combining a geothermally optimized probe and operation concept the capacity of a DGHE can be raised up to 200 W/m with significant higher input temperatures. Compared to energy prices for kWh of conventional generated heat from oil and gas, a cost saving effect and thus profitability of an investment in deep heat exchangers results at an annual base load of more than 5.500 hours per year. Corresponding selling prices are shown in following figure

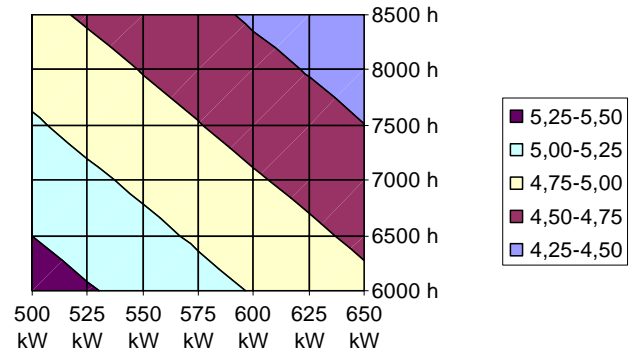


Figure 5: Selling prices in dependency of capacity and operating hours

These criteria limit the number of possible customers and thus locations are to be preferred which use the deep heat exchanger to it's full capacity, like the integration into the return of large combined heat and power stations.

The technical concept of a deep geothermal heat exchanger provides means to use this renewable energy at nearly any place at any time. This is why the European Union ranks the DGHE as eligible with a high potential of reproducibility.