USING DEEP GEOTHERMAL ENERGY FOR HIGHER EFFICIENCY AND LOWER COSTS IN LARGE HEAT PUMPS

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Abstract: Today, it is mostly groups of conventional geothermal earthprobes that are used for supplying buildings that have a heating requirement of more than 100 kW. Drilling is typically carried out to a depth of 100 to 200 metres. As more output is required, the number of earthprobes is increased, and this gives rise to the following problems: the space requirement increases due to the minimum distance that has to be maintained between earthprobes, and the costs for connecting the earthprobes to the heat pump are also higher. In addition, a longer installation time is required.
The aim of the project is to define the best drilling methods for geothermal earthprobes at depths of between 300 and 800 metres, and to compare them with existing technologies. Obtaining heat from these depths means that fewer drillings are required, and the efficiency of the overall system can thus be increased (source temperature above 20° C, no need for an antifreeze agent). Drilling to these depths increases the potential for utilising geothermal energy for the production of room heating, and the principle of “one building, one borehole” reduces the negative impacts on the environment from the use of geothermal energy.

Key Words: heat pumps, geothermal, efficiency

1 INTRODUCTION

The focus of the study is on the following two heat sources: deep vertical geothermal earthprobes and deep aquifers. The aim is to compare these with the two reference systems currently in use, namely shallow vertical geothermal earthprobes and ground water.

The aim is to consider all occurring costs and compare the systems. Deep systems have higher investments but lower running costs through higher efficiency. The project will also determine the threshold to be reached in order for the method to become competitive at these depths.

The following data have to be determined for each system:

- Energy potential for practical application
- Current cantonal procedures, and amendments that may be required
- Hydrogeological and thermal characterisation of the capture of geothermal energy

- Development potential of existing technologies for reaching the foreseen depths while remaining economically competitive
- Thermal characterisation of the overall system of energy capture: exchange or increase of temperature through the use of heat pumps, distribution of heat
- Economic characterisation of the overall system of heat capture: exchange or increase of temperature through the use of heat pumps, distribution of heat
- Technological and economic comparisons between the two deep earthprobe systems and shallower systems
- Preparation of technical data sheets to help engineers and project managers decide on the application of heat pump systems that attain annual performance coefficients of around 4.0 (renovation) and close to 6.0 (new) in direct collaboration with the involved industry associations.

This report presents the initial findings relating to the drilling methods and the comparison of the potential for cost reduction between a system comprising a series of shallow earthprobes and a system comprising several deep geothermal earthprobes.

2 DRILLING METHODS

In the initial stage of the project the aims are to examine the existing methods for drilling to depths of 500 to 800 metres, and to compare the costs of each method, in order to define the existing options in terms of deep drilling.

Down-the-hole hammer and rotary drills are currently used for placing vertical geothermal earthprobes at depths of 100 to 200 metres and 300 to 400 metres respectively.

These methods can also be used for drilling to depths of up to 800 metres, subject to certain conditions.

2.1 Comparative evaluation of methods

The advantages and disadvantages of the utilised (or utilisable) drilling methods for exploiting geothermal resources at depths of up to 800 metres largely depend on the materials that are used and the geological conditions that exist on site. The machines are fairly similar for both the down-the-hole hammer and the rotary method.

2.1.1 Down-the-hole hammer method

With the down-the-hole hammer method, the rock (loose or indurate) is penetrated using a rotation action combined with impaction. In most machines the tool rotates in the opposite direction to that of the tubing, which reduces the risk of blockages caused by cuttings.

In all cases, the machine comprises a drill, a compressor and a container for collecting the cuttings and drill water. The latter is either injected with air originating from the compressor in order to bring up the cuttings, or it comes from underground if this is aquiferous and saturated (or there are sufficient quantities of water). Volumes are normally fairly low.

The dimensions of the required bore site are fairly modest, and this means that drilling can be carried out in practically all situations that are commonly encountered, including new or renovated buildings, rural or urban zones, etc.

As a rule, compressors are used that can deliver a pressure of around 25 bar, or between 30 and 35 bar in the case of the most powerful machines.

The average drilling speed is around 20 metres per hour.

2.1.2 Rotary method

With the rotary method, penetration is effected through abrasion and crushing, without impaction, i.e. solely by means of rotation. The borehole is kept open by injecting mud mixtures with differing densities. However, this method calls for the use of a special pump and a sand filter.

The disadvantages associated with the use of mud are the quantities that are required (which can become problematic when drilling is carried out to greater depths), its removal, and the necessity to adapt the permeability of the shaft if the aim is to drill for underground water.

In the case of aquiferous terrain, the mud mixture can conceal hydrogeological information to some extent (especially the presence of water), but can also fill in gaps and/or fissures in the encountered rock formations, and thus interfere with the subsequent flow of underground water. In situations in which the rock formations contain numerous fissures, the loss of mud can be considerable and thus render this method unsuitable.

The drilling speed is around 6 to 8 metres per hour, which is roughly three times slower than with the down-the-hole hammer method.

2.2 Requirements for drilling to depths of between 300 and 800 metres

It is possible to drill deeper with the methods currently in use, but this requires a modification of the available materials, and the costs are considerably higher.

2.2.1 Machines currently in use

The overall cost of machines that are currently in use and are capable of drilling to a depth of around 400 to 500 metres is in the region of 700,000 Swiss francs.

The cost of machines for drilling to greater depths is almost twice as high, namely around 1,300,000 Swiss francs.

In order to drill to greater depths, the length of the drill and tubing has to be increased, and this results in much higher masses that require a higher pumping capacity than most machines currently in use are able to produce (around 20 tonnes).
It is also important to note here that the weight of drills and tubings varies according to their diameter, which is larger when drilling is to be carried out to greater depths.

A larger drill diameter is required because the diameter of the earthprobes is greater (32 mm for a depth of up to 160 metres, 40 mm for a depth of up to 400 metres, and 50 mm for greater depths), and this means that more space is required for their placement in the drill (drill diameter of 127 mm for 32 and 40 mm earthprobes, and drill diameter of 153 mm for earthprobes over 50 mm).

With a diameter of 178 mm, the mass of the rods is in the region of 35 kg per metre, i.e. a total of 17,500 kg at 500 metres, and 28,000 kg at 800 metres. The mass of the tubings has to be added to this, namely 11,500 kg at 500 metres, and 18,400 kg at 800 metres.

2.2.2 Drilling costs

The cost of drilling a borehole for geothermal earthprobes using the down-the-hole hammer method is currently around 80 Swiss francs per metre for a maximum depth of 160 metres. This amount increases to around 85 Swiss francs per metre for a depth of up to 400 metres, and to 120 Swiss francs per metre for a maximum depth of around 800 metres.

These figures, which include drilling, the required equipment and the cementing of the earthprobes, probably reflect the lowest level of costs.

Higher figures in excess of 600 Swiss francs per metre for drilling to a depth of 500 metres have been cited for some projects.

Furthermore, these figures do not generally take account of the additional costs that may be incurred due to the need to case lengthy segments of the borehole. At one of its sites, a company found it had to case the shaft over a length of more than 200 metres in order to recut a section that was severely fractured, although the rock formation had been reached at a depth of around 10 metres.

Casing may also be required in certain hydrogeological conditions that call for measures to protect the underground water resources.

2.2.3 Drill rods and tubing

For the calculation of supplementary costs it is also necessary to take account of the need to purchase tubing and drill rods in order to reach the envisaged greater depths.

While the length of the drill rod is necessarily defined by the required drilling depth, the length of the tubing depends on the geology of the site, which could result in the need for additional lengths in order to protect the underground water resources.

To drill to a depth of around 200 metres, rods and tubing are required that currently cost around 70,000 Swiss francs. For drilling to a depth of 500 metres, these costs increase to approximately 250,000 Swiss francs, and for a depth of 800 metres the costs are around 400,000 Swiss francs.

2.2.4 Drilling fluid

As we have seen, the compressors used for injecting air in the down-the-hole hammer method have a limited pressure of between 30 and 35 bar.

This limit could interfere with the progress of drilling to beyond a depth of 300 to 400 metres, due to the column of water present in the drill. If the resulting load cannot be compensated, the cuttings will no long ascend and drilling will become impossible.

For the rotary method, the column of mud also interferes with the placement of the earthprobes, since its density prevents placement using gravity. The earthprobes have to be pushed mechanically into place with the aid of a special rod.

2.2.5 Injection and cementing

The earthprobes are cemented into the encasing rock by injecting a mixture normally made of cement and bentonite (clay) into the borehole. The injection process takes place from the bottom upwards.

The greater the depth of the borehole, the higher the pressure that is required to inject the product intended to cement the earthprobe into the borehole, and beyond a certain level there is a risk that the injection pressure could damage the earthprobes by crushing them. It is therefore necessary to control the pressure in the earthprobes during the cementing phase, i.e. to proceed in stages.

The installation of the supplementary injection tubes and the resulting manipulations also result in additional costs for deep drilling.

2.2.6 Earthprobes

In view of the increased length and diameter of the earthprobes, their costs are also considerably higher, as are those for their transport (bulk, weight, etc.).

Approximate figures are indicated in the table below for earthprobes comprising two U circuits.

Drill depth (metres)	Diameter of earthprobe (millimetres)	Unit price (CHF per metre)
200	32	10
500	50	15
700	63	23
900	75	32

Table 1: *Overview of drilling costs based on depth*

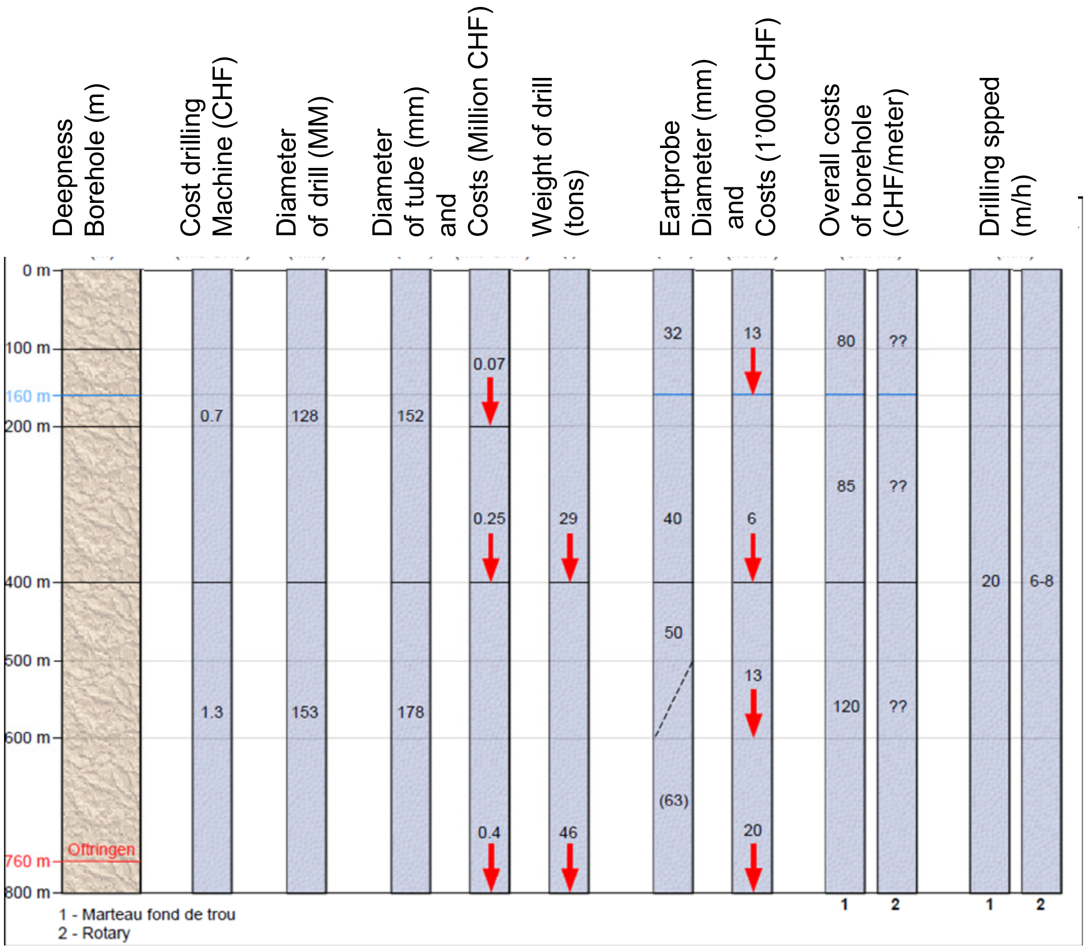

Figure 1: Overview of drilling methods and their characteristics based on depth

3. POTENTIAL FOR THE REDUCTION OF INSTALLATION COSTS

Two reference systems have been used as the basis for evaluation and comparison with deep geothermal drilling: groups of shallow earthprobes (maximum depth, 200 metres) and use of ground water. The costs of different groups of earthprobes have been calculated with the aid of a model developed for this purpose. It incorporates the costs of the various additional tasks associated with the installation of a group of earthprobes.
For a heating requirement of 50 to 500 kW, the costs of a group of shallow earthprobes increase progressively as shown in Figure 2 below.

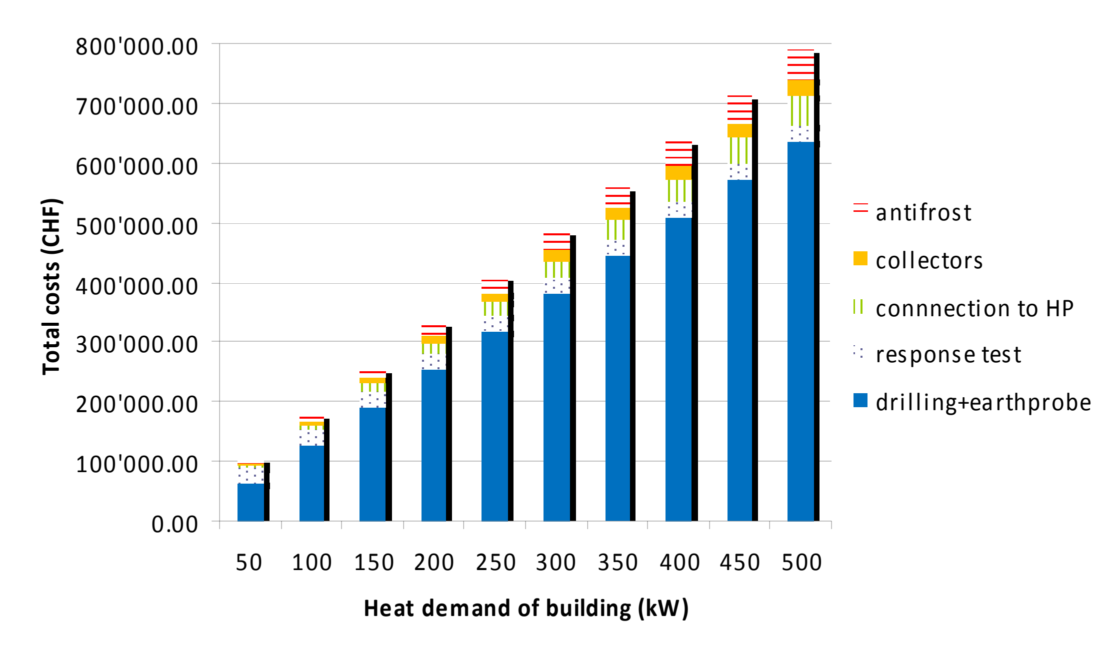

Figure 2: Progression of total installation costs of a group of geothermal earthprobes at a depth of 150 metres, based on heating requirement (hypothesis, 50 W per metre)

It appears that the additional costs (for glycol, connections, collectors, etc.) reach and exceed 100,000 Swiss francs with a heating requirement of 300 kW. Figure 3 shows the progression of supplementary costs.

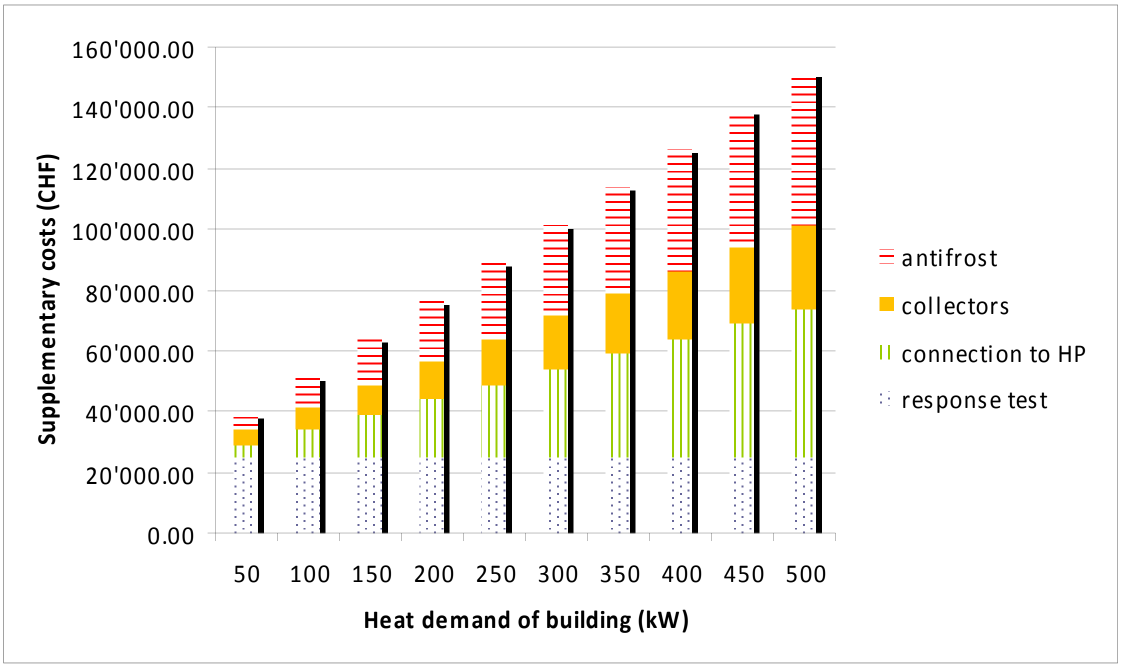

Figure 3: Progression of supplementary costs for the installation of a group of geothermal earthprobes at a depth of 150 metres, based on heating requirement (hypothesis, 50 W per metre)

With a system of vertical deep geothermal earthprobes, the number of required earthprobes is lower (approximately 50 kW of heat per earthprobe at a depth of 800 metres, versus 5 earthprobes at 150 metres for the same output). Thus the costs for connecting earthprobes and collectors are greatly reduced. Furthermore, the ground temperature at a depth of between 500 and 800 metres is above 20° C, which means that the use of antifreeze (glycol) is no longer necessary. The costs are therefore reduced further.

The space required for installing a group of earthprobes is a factor that should be taken into consideration. For example, for 300 kW (heat), 25 earthprobes at 150 metres are required, or 240 linear metres for earthprobes in a row, or 2,500 square metres for a group of earthprobes in staggered rows (minimum distance of 10 meters between earthprobes because the dimensioning is for heating only). At a depth of 800 metres, 5 deep earthprobes would be required, or 40 linear metres for earthprobes in a row, or 200 square metres for a group of earthprobes in staggered rows (minimum distance of 10 metres between earthprobes). The space requirements can be reduced by a factor of between 6 and 10. This aspect can play a crucial role for existing buildings and/or in zones with a high population density.

In the phase step of the work, the project will determine the threshold to be reached in order for the method to become competitive at these depths through learning curves.
The methods used for drilling to depths of up to 800 metres are currently more expensive than those used for shallower depths. By transposing the learning curves established for groups of shallow earthprobes (see Figure 4), the project aims to determine the installation costs of deep earthprobes after this initial stage. In this way it will be possible to assess the viability of the “one building, one borehole” concept for heat output above 100 kW when the technology is fully developed.

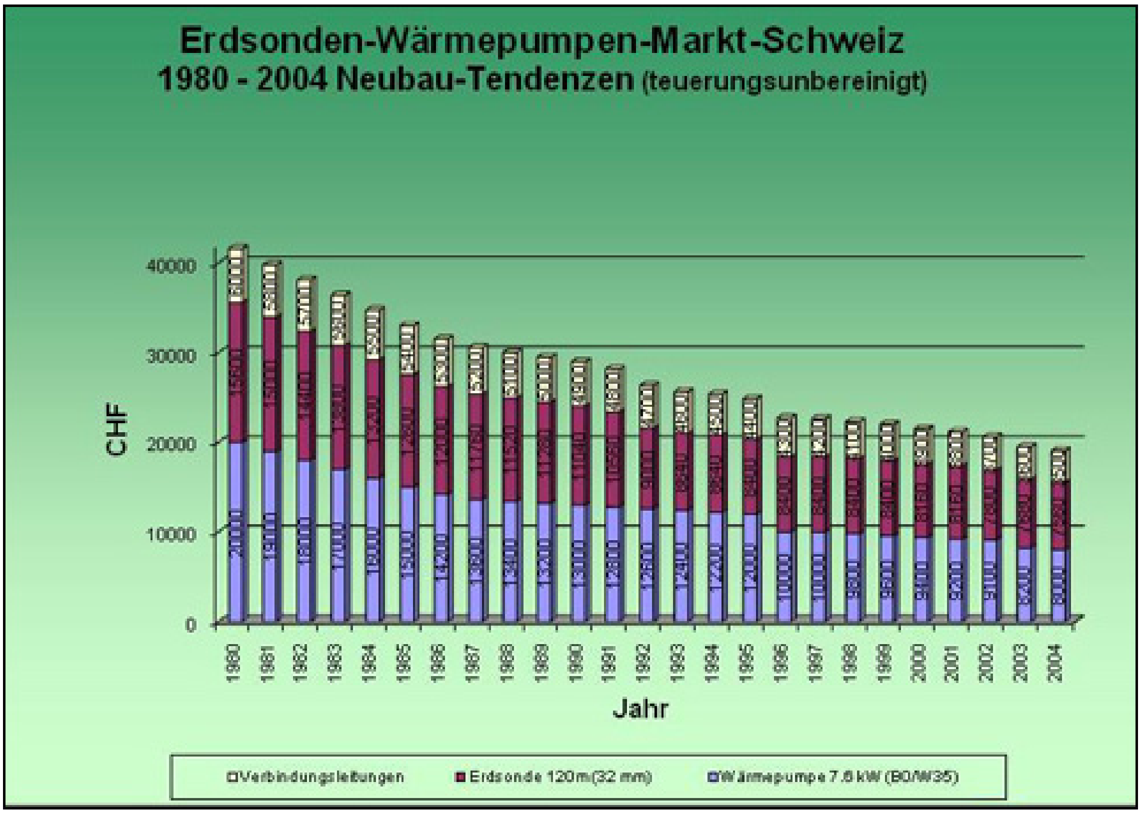

Figure 4: Learning curve for groups of shallow earthprobes for total costs over the years of heat pump, borehole with heat exchanger and connection between borehole and heat pump.. Sources: SwissEnergy and FWS

The first step will be to determine the hydrogeological characteristics at these depths so that we will be able to simulate the behaviour of the overall heating system and compare this with the behaviour of a system with shallower earthprobes.
Finally, although financial benefits will be obtained as the result of the increased efficiency, deep drilling will also give rise to additional costs and it will be necessary to determine the acceptable threshold for making a move onto the market.

4 SOURCES

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