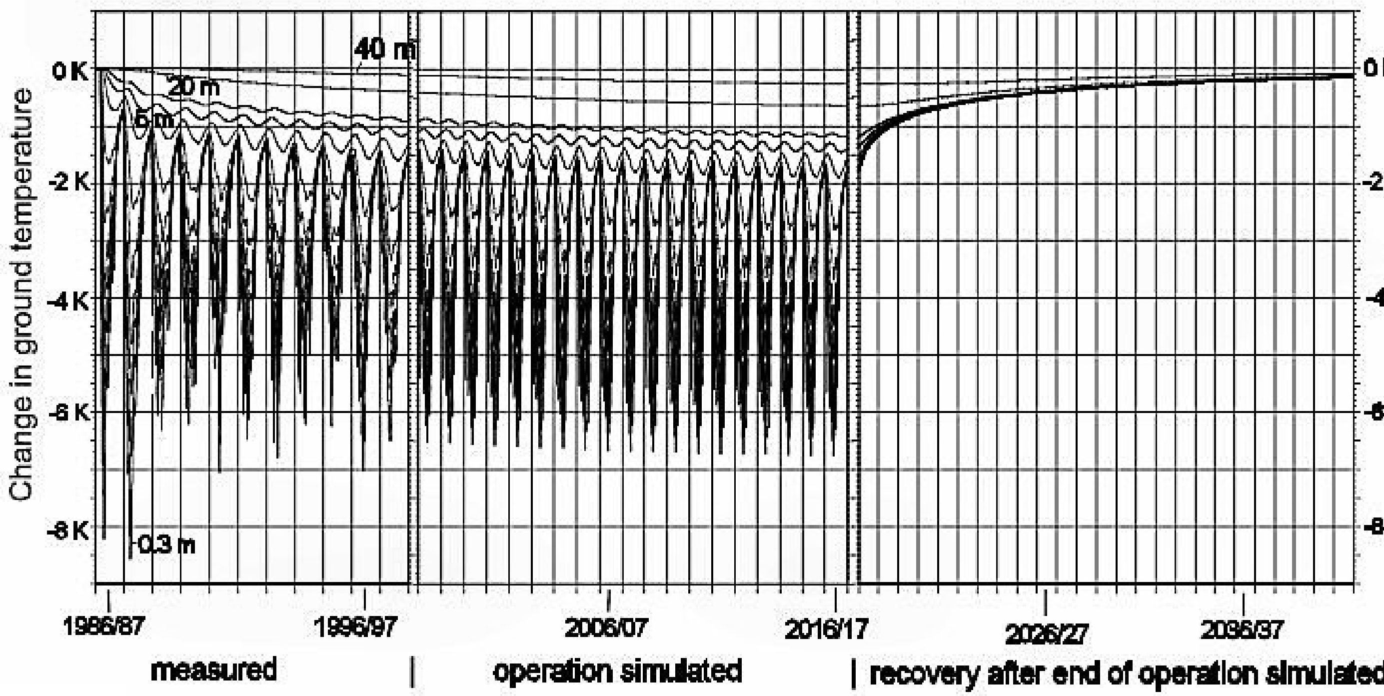

Changes in ground temperature at various distances from the BHE over many heating seasons, measurement and extrapolation (simulation) for the system in Elgg, Zurich, Switzerland.

Heat Replenishment

The above graph (Rybach & Eugster of Switzerland) illustrates the long term ground temperature variations for a small (10 metre borehole) ground source heat pump. It shows that a small isolated GSHP will eventually reach an equilibrium point with only about a 1 degree temperature depression over a 25 year period, or about 2 degrees if the system is used for a century (the likely minimum lifetime of a house). However, the temperature depression (even for a shallow hole) spreads out to cover a wide circle, exceeding 80 meters in diameter over the 30 year period and extrapolating to over 200 meters over the home's lifetime.

If someone installs another GSHP in the general region of the initial one then the temperature depressions are additive. It would take only a small number of installations within the 200 metre circle to depress the ground temperature to the point where none of the systems would work properly.

In Canada we have colder winters so the typical borehole depth is 120 meters, not 10 meters, and the amount of heat extracted from the ground per unit of area is typically about 6 times greater than in the cited example. While the deeper borehole will extract heat from a larger ground volume the rate of heat replenishment is the same for both cases so the long term temperature depression would be roughly 6 times greater. The practice in Canada is to use less efficient ground heat exchangers, typically delivering about 35 watts/metre of tubing vs. 70 watts for the Swiss system. The consequences are that the annual temperature steps are only half as great but the long term trend is for a much more linear drop in temperature, and consequently a much more severe loss in performance over an extended period of time.

The replenishment process After the first year of operation the ground temperature returns to within a fraction of a degree of its original value. That often gives rise to the mistaken idea that the ground has recovered. However, even for a short borehole like this 10m example nearly all of the heat "recovery" is due to the lateral flow of heat from the ground surrounding the borehole. Since that heat is in turn being replenished primarily by more lateral heat flow in the subsequent years the fact is that the heat is hardly being replenished at all, the system is just gradually eating away at the natural deposit of heat that was originally stored in the ground. The amount of heat stored in the ground is grossly inadequate to heat a whole city, or to handle even a small number of homes in a neighbourhood, but it would suffice for a single isolated application, such as for a farmhouse. The limiting factor is the replenishment process.

The primary source of replenishment heat is the sun. The sun heats the surface of the earth and maintains an average temperature a few meters below the surface that is about the same as the average annual temperature for the site. That heat diffuses down and can eventually replace extracted heat but the ground is a pretty good insulator so the power per square metre of surface area is quite modest and it takes a long time for the heat to diffuse down to where it is needed. In the case of a 120m borehole it takes about 10 years for the first year's heat to reach the bottom (depending on the rock type). There is nothing that we can do to speed up the heat transport velocity or to increase the replenishment rate so the performance of GSHP's cannot exceed those limits by employing better heat pump hardware, such as DX systems, aquifer heat pumps or quad heat exchangers. The only viable alternative is to replenish the ground heat by injecting heat as is done in AE systems.

There are two other replenishment processes at work. Initially there will be some heat flow coming up from depths below the borehole that will add to the replenishment from the surface. However, that source will diminish with time as the heat in that volume is extracted. There is a small vertical contribution coming from deep in the ground, where the rock is very hot, but that source has to penetrate through kilometres of rock so its effect is minimal. In some cases ground water may bring in substantial amounts of heat from far away, but groundwater is a carrier, not a source of heat. If there happen to be other GSHP's in the upstream path then the groundwater will decrease the available heat rather than increase it.

Heat pumps often use underground aquifers as the heat source. If the system has an input aquifer that is well separated from the output aquifer then for the annual cycle such systems will provide a much more constant feed temperature than a borehole system because they are not subject to the temperature drop that occurs in the ground immediately surrounding a borehole. However, over a long period of time and over the affected ground volume the aquifer systems are subject to exactly the same limitations as the borehole systems – they are both only capable of extracting whatever heat originally existed in the ground, plus the modest amount of heat that becomes available from the surface each summer..

Another variant is to use horizontal heat exchange tubes that are below the frost line but still close to the surface. For such systems the heat is replaced every year so they quickly reach an equilibrium pattern that is sustainable. The problem in this case is that the surface area that is required is too large to make such systems generally applicable for urban applications.

Theoretical limits The same problems can also be considered from a theoretical point of view. Over a period of time a GSHP will create a temperature depression that will extend over an area that will normally extend far beyond the property lines of the building. If the magnitude of that depression exceeds 3 degrees the performance will be adversely affected. A suburban home typically occupies about 80 square meters of land, so if the nominal borehole depth is 120 meters the total volume is 9600 cubic meters. If the ground is, say, limestone then the original-heat capacity will be approximately 16,000 kWh. If the house uses 12,000 kWh of heat per year and the natural rate of replenishment is minimal (as will be the case if most of the neighbouring homes also use GSHP's) then the natural heat would be capable of heating the home for only 1.33 years, after which that home and all of the neighbouring homes will lose most of their heating. If the housing density is higher or if the building is large then this period will be reduced commensurately. This severe limitation is frequently overlooked at present because of the current low incidence of GSHP's in any given community.

Implications One implication is that a GSHP will work just fine if it is isolated from other such installations by a distance of a kilometre or more. However, if other units are subsequently installed in the vicinity then they will soon begin to interfere with each other and eventually they will all be incapacitated..

In the case of an AE system there is no net heat flow from an installation to a neighbouring one, no annual temperature depression, and the ground temperature can cycle over a wider range so the ground storage capacity is more than adequate for the cited case. However, for larger buildings it is important to determine that this storage capacity is adequate, especially where multiple boreholes are used. In most cases such buildings will use deeper boreholes in order to meet the extraction power requirement so the storage capacity is increased in proportion. In some cases, for example in a downtown area, the use of the AE-Street configuration can be used to distribute the storage.