Key Issues for Renewable Heat in Europe (K4RES-H)

Contract EIE/04/204/S07.38607

Deliverable 8 : An objective methodology for the calculation of the energy delivery of geothermal systems, where measurement would be too costly

Objective:

In smaller RES-H-systems, energy delivery is often not measured but can be calculated on the basis of scientific parameters. This report proposes sound methods to calculate the energy output of small RES-H systems.

When determining the contribution of geothermal energy sources it is not always possible to specify the exact frames of reference. For this reason we use the term geothermal energy production, defined as follows:

> *Geothermal energy production is the production of the energy in form of heat beneath the surface of the solid earth (heating and cooling).*

To define the RES-heat production, in this project K4RES-H, we address the total amount of produced renewable and useful heat (net heat production).

This definition comprises the following specifications:

- The heat is measured directly after the conversion what means that all storage and transfer issues are neglected.
- Auxiliary energy supply within the conversion process is only considered when being a considerable amount of more than 5 % (i.e.in the case of heat pumps).
- K4RES-H recognizes heat which is produced for sale as well as that for the own consumption. Consequently, the IEA differentiation between “public producer” and “autoproducer” is neglected.
- In cogeneration only the total amount of useful heat demand is considered as it is defined in the EC Cogeneration Directive

1. General Overview about existing Calculation Methods for Geothermal Energy

1.1 Methods for deep geothermal energy

In deep geothermal systems, due to their size and complexity, data from monitoring should be available in general. However, in some specific circumstances this might not be possible, and only for those few cases a calculation method should be allowed.

There are basically two ways to estimate the heat delivery:

plant side estimation: Calculation of the renewable heat output from the nominal, installed capacity (ground), the number of full load hours and the system efficiency. This method can be used for smaller plants (without monitoring), in agriculture etc.; in general this is the default method for smaller geothermal heat pump plants (shallow geothermal energy).

load side estimation: Calculation of the renewable heat from geothermal plants from the demand side. Based on the definition of the number of equivalent households connected to the geothermal plant and considering an average heat demand of these households, the total heat delivered to the households can be calculated. This method only works for district heating networks, and it is the least desirable. In such installations typically a monitoring system should be installed.

The details of the plant side estimation are similar ot those for shallow geothermal discussed in section 2 of this document.

1.2 Existing calculation methods for shallow geothermal energy (ground source heat pumps)

In Austria, a method is used that is based on nominal data combined with a long term study on a number of installed systems. The average nominal capacity is derived from this study and multiplied with the number of installations (from sales statistics). The number of full load hours is needed to calculate the total heat pump contribution. An average lifetime of 20 years is assumed for the installations.

In France, a method for calculating heat delivery from heat pumps is based on the estimation of the average heat demand of an installation. Since heat pumps are mainly used in small residential buildings, the heat demand is estimated for an "average" housing characterised by a global heat loss coefficient with a global efficiency (emission, distribution, control etc.). This housing is exposed to a typical climate by assuming the number of degree days for this climate. In order to obtain the renewable contribution, an average COP for the heat pumps is estimated. The number of installations is derived from market statistics (manufacturers or manufacturer associations). Since the heat demand per housing is calculated by the degree days, the impact of solar gains is neglected. The method does not use the substitution method. Also, the efficiency for the production of electricity from primary energy is not considered. Domestic hot water production is not taken into account.

In Germany, there is not yet an "official" method used, however, in publications typically a method based on the number of units, an average heating capacity per unit, and the annual hours of operation is applied. In order to achieve the geothermal heat data, these values for the GSHP heating output have to be corrected with the annual COP.
A method exists on how to extrapolate the annual mean COP from the heat pump heating capacity and some system parameters (heat supply temperature, average temperatures on the ground side, etc). This method is described in guideline VDI 4650, and was used mainly to justify a minimum annual COP which had to be achieved in certain FIS.

In the Netherlands, only geothermal heat pumps are considered as a renewable energy source : the contribution of heat pumps to renewable energy production is the heat output of the pump, minus its own energy usage. Only net production is considered to determinate the energy production or savings.
The internal energy usage of the heat pump and any supplied energy is converted using the substitution method to primary energy carriers and deducted from heat production (expressed in avoided primary energy). In projects where cold storage is combined with a heat pump for renewable cooling, the energy saving must be attributed to cold/heat storage. Only the saving on heat counts under heat pumps.

1.3 Experiences, complexity and ability to transfer to other countries

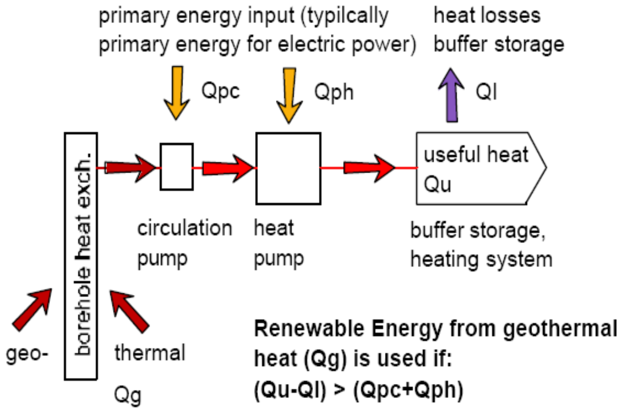
Summary: Where calculation methods exist, they are usually based on the number of heat pumps and certain assumptions for parameters required to derive the heat output from that number:

- average heat output per unit
- average operation hours (full-load hours) per year
- average annual COP

Hence the accuracy of such calculation depends heavily upon the accuracy of the parameter assumptions. Monitoring of at least a sample of GSHP-plants in a certain region under comparable climatic conditions is a prerequisite to get reliable data on COP and operation hours.

Technical Basis

In all ground source heat pump systems (GSHP), there is a basic difference between the heat output to the heating system, and the geothermal heat input into the system (Qg in the figure below). The auxiliary energy (mainly Qph in the figure) is always higher than 5 %, and is typically in the order of 20-30 % of the final energy output. Thus it cannot be neglected.



Energy flow in a GSHP system

For Ground Source Heating and Cooling, the basic data concern the number of installations, the location, the applications : space heating, industrial, agricultural…, the electricity use by the installations (GWhe)., the thermal capacity (MWth) and the net heat production (TJth).

For larger systems, direct measurement is suggested. However, also for the deep geothermal systems, some calculation might be required, when the geothermal potential of a specific resource or of a whole region is considered. An example is included in the appendix.

2. Individual Calculation Methodology (shallow geothermal only)

2.1 Name of the Calculation Methodology:

Suggestion for a calculation method in K4RES-H

Short description of the Calculation Methodology and field of application

It is suggested to basically use a method based on the number of heat pumps, average heat output per unit, average operation hours (full-load hours) per year, and average annual COP. The heat output than can be calculated to:

$$P = Q_{mean} * h_a$$

With :

- P : the annual heat delivery [kWh/a]
- Q_{mean} : the heating capacity (heat output) of the heat pump [kW]
- h_a : the annual operation hours (full-load hours, depending on the climate) [h/a]

This calculation will result in the total heat delivered. It is good for reasons of evaluating FIS success, where it is not important to look only at the geothermal fraction of the heat supplied, provided a minimum COP is made mandatory (e.g. an annual average COP of 3.8). For the purposes of a geothermal energy statistic, however, only the heat from the ground should be considered, and the heat output corrected by the annual average COP. The formula then should be completed as follows:

$$P = Q_{mean} * h_a * ((COP-1)/COP)$$

With :

- P : the annual geothermal heat delivery [kWh/a]
- Q_{mean} : the heating capacity (heat output) of the heat pump [kW]
- h_a : the annual operation hours (full-load hours, depending on the climate) [h/a]
- COP . the seasonal mean COP

For residential applications, some values for the basic data can be given in a certain range:

- for the average heating capacity (e.g. 5-20 kW_{th}),
- for the assumption of a seasonal COP (e.g. 3-4)
- for a number of equivalent full-load hours per year (e.g. 1,800-2,200 h/a)

2.2 Identification of typical systems within the subsector

Heat sources/sinks (ground side of the system):

- Ground heat collectors (horizontal loops): These are usually installed in only 80-160 cm depth.
- Borehole heat exchangers (vertical loops): Those are vertical or graded boreholes up to ca. 250 m deep, equipped with pipes as heat exchangers. This is the type of installation most widely used in Central and Northern Europe. One or two borehole heat exchangers heat or cool residential houses, fields of borehole heat exchangers are used for offices, commercial buildings, whole subdivisions, etc.
- Energy piles, concrete building parts in the ground: are constructions necessary for static reasons, that can be equipped with heat exchangers pipes in new buildings.
- Heat from mines and tunnels (by pumping water)

Possible other applications than heating (and cooling):

- Heat storage: Warmth from summer in winter, and cold from winter against summer heat: feasible through geothermal energy.
- Other applications : Traffic areas free from snow and ice, bridges, airports, sport arenas .

2.3 Input parameters / load factors

According to the K4RES-H methodology, the following table helps to understand the importance of the parameters:

Input parameters	Are these parameters easily to gather and available?	What do you do, if data are not available?	What influence does this have on the accuracy?
Number of GSHP units	relatively easy for new installations, based on sales numbers from associations, statistical offices, etc.; a problem arises with the existing stock before reliable sales statistics began, and with GSHP being abandoned	Estimation (in particular for the pre-existing stock and the abandoned plants)	This is the most important factor, as all calculation takes it as the basis. Any errors will strongly and directly reflect in the accuracy of the results.
Average heating capacity in 2.3.1.: Q_{mean}	Could be part of the sales statistics, in capacity classes	Estimation, maybe extrapolation from some sales figures	high influence, because it is directly multiplied with the number
Average annual full-load hours in 2.3.1: h_a	This value is depending on the climate and type of application, so it can differ quite widely throughout Europe. A regional approach is required.	Estimation can be based on the climate (e.g. degree-days) and type of use (heating only, heat + DHW, offices)	high influence, because it is directly multiplied with the number
Seasonal COP in 2.3.1.: COP	Can only be derived from sample measurements in certain climate and for various heat pump types; calculation from rated COP (in factory) using e.g. VDI 4650; plain estimation		high, but less than the parameters before

A specific problems for GSHP is given for the number of sales, in the fact that the different types of heat sources for the heat pump are often not distinguished, so a guess on the fraction of GSHP in the total heat pump sales has to be made.

The heat pump output and efficiency (COP, see appendix) should be given according to standards EN 255, EN 14511, or other applicable standards of the member states.

As further steps, the countries need to agree on the methodology of sampling and calculation. Reliable statistics of the sales numbers should be established in all countries, distinguishing at least the heat sources (groundwater, ground incl. direct expansion) and some capacity classes (e.g. <5 kW, 5-10 kW, 10-15 kW, 15-25 kW, 25-50 kW, 50-100 kW, 100-250 kW, and exact values for those above). For the full-load hours and COP, more monitoring campaigns are required to get sufficient data for extrapolation, and for calibration of methods to calculate the values from climatic data, etc.

2.3.1 Calculation procedure and output

The formula already shown in section 2.2 is used :

$$P = Q_{mean} * h_a * ((COP-1)/COP)$$

With :

- P : the annual geothermal heat delivery [kWh/a]
- Q_{mean} : the heating capacity (heat output) of the heat pump [kW]
- h_a : the annual operation hours (full-load hours, depending on the climate) [h/a]
- COP . the seasonal mean COP

The result than can be multiplied with the number of GSHP in a given area.

2.3.2 Accuracy of the calculation method

The calculation method itself is very accurate, if the input parameters are known. So please see for the discussion of accuracy section 2.3
Taking into account the possibilities to obtain values for the input parameters, the overall accuracy can be considered less accurate (<25 % deviation).
To increase accuracy, the heat pump stock (number and size) would have to be counted in more detail and in higher regional resolution.
For the COP, average values are known for plants following guidelines (like VDI 4640) in certain climatic areas. However, these do not exist for many regions in West, East and South of Europe.

2.3.3 Experiences and ability to transfer to other countries

Experiences are good, as no other means exist for the time being to assess the heat delivery of small-scale geothermal systems (ground source heat pumps). Verification on a regional scale or larger has not been done yet, only local studies or regional samples show that the results are acceptable.

2.3.4 Further steps to be done

More monitoring campaignes will be necessary to establish in particular the validity of COP assumptions for areas outside the past GSHP market regions. Monitoring of a sample of plants will also be required as ongoing activity, in order to verify the development of COP with increasing efficiency of plants.
NB: The COP measured in factories / laboratories for the heat pump under standard conditions is not the same as the average COP in a certain system. The system COP, which eventually controls the heat delivery, only can be measured within the system on site.

Other factors like number and rated output have to be collected more precisely.

2.4 3. Conclusion

For the large number of small-scale shallow geothermal installations (ground-source heat pumps), a method to calculate the (renewable) heat output is required. It is suggested to basically use a method based on the number of heat pumps, average heat output per unit, average operation hours (full-load hours) per year, and average annual COP (in order to get the renewable portion).

This method can already be used with acceptable accuracy in the countries with a developed ground source heat pump market (e.g. Sweden, Germany, Austria, as the necessary input factors there are known empirically. These input factors, however, may vary widely throughout Europe, according to climatic and geologic differences, and traditions in the heating and construction industry.

Monitoring campaigns with a representative number of installations are required to calibrate the calculation method empirically:

- for new countries and regions,
- to improve accuracy in existing markets,
- and as ongoing activity in order to keep track of the technological development.

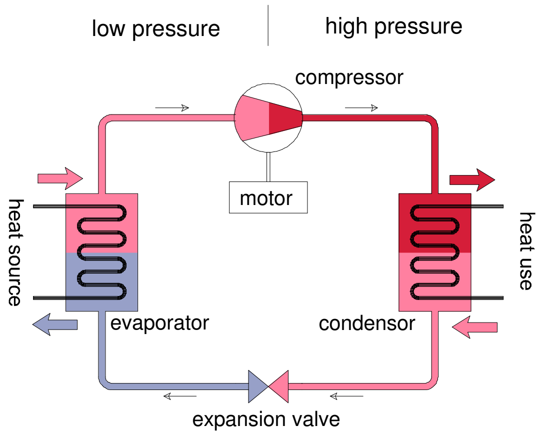
With these calibration activities in the background, the calculation method can be the tool of choice to assess the heat delivery from small-medium shallow geothermal plants

For the deep geothermal and large shallow geothermal plants, the heat delivery should be monitored by measurement, and calculations only used in exceptional cases where no measurement is available. The relevant calculations methods are not well developed and they will, due to the diversity of plants, never deliver acceptable accuracy.

APPENDIX:

A) The Coefficient of Performance (COP)

A heat pump is a devise which allows transport of heat from a lower temperature level to a higher one, by using external energy (e.g. to drive a compressor). The most common type of heat pump is the compression heat pump as shown in the figure.



Schematic of a compression heat pump

The thermodynamic principle behind a compression heat pump is the fact that a gas becomes warmer when it is compressed into a smaller volume. This effect is common experience e.g. for cyclists when adjusting air pressure in the tyres: The air pump gets warmer in the process.

In a heat pump, a medium with low boiling point ("refrigerant") is evaporated by the ground heat, the resulting vapour (gas) is compressed (by using external energy, typically electric power) and thus heated, and then the hot gas can supply its heat to the heating system. Still being in the high pressure part, the vapour now condenses again to a liquid after the useful heat has been transferred. Finally, the fluid enters back into the low-pressure part through an expansion valve, gets very cold and can be evaporated again to continue the cycle.

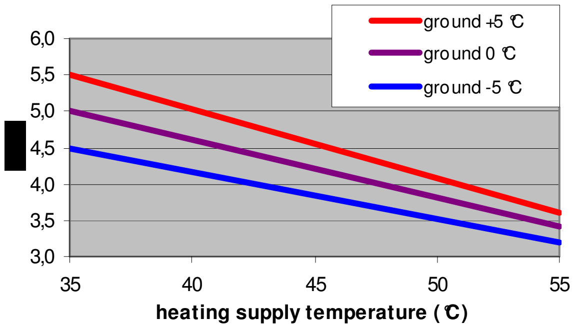
An alternative is the absorption heat pump, where heat at higher temperature (e.g. from a gas burner) is used to activate, by boiling a gas out of a liquid, a desorption-absorption cycle, which again offers a low-temperature side to take in heat from the ground, and a high temperature side to supply heat to the user.

In both cases, the amount of external energy input, be it electric power or heat, has to be kept as low as possible to make the heat pump ecologically and economically desirable.

The measure for this efficiency is the COP (Coefficient of Performance). For an electric compression heat pump, it is defined as:

$$COP = \frac{useful\ heat}{electric\ power\ input}$$

The higher the COP, the lower the external energy input compared to the useful heat. COP is dependent on the heat pump itself (efficiency of heat exchangers, losses in compressor, etc) and on the temperature difference between the low-temperature (ground) side and the high-temperature (building) side.



Exemplary graph of COP versus heating supply temperature

COP can be given for the heat pump under defined temperature conditions (e.g. 5 °C ground / 35 °C heating supply), or as an average annual COP in a given plant, also called SPF (Seasonal Performance Factor).

Relevant European Standards are EN 255, EN 14511, etc.; guidelines from technical associations like VDI 4640 (for GSHP) also give more detailed rules.

B) Monitoring method for large geothermal direct use installations

In these systems, quantifying energy delivery by measurement is recommended. The systems sometimes are quite large (several MW_{th} of heat output) and can have a complex schematic. Here it is important to distinguish between the geothermal part of the system (typically for base load) and the additional, conventional energy systems providing peak load or back-up in case of interruptions of the geothermal production.

In larger geothermal systems, the flow volume of the geothermal water is measured, as well as the water temperatures from and to the wells. A good measurement point would be the heat exchanger separating the geothermal water circuit from the heating system circuit. In case of deep borehole heat exchangers (BHE), the circulation flow in the BHE, and the fluid temperatures at exit and entrance of the BHE are measured. From flow volume and temperature difference, the heat delivery can be calculated using the formula below, and can be integrated, by continuous monitoring, over the full operation period.

$$P = \rho * Cp * V * (t_{in} - t_{out})$$

With :

- P : the heat delivery [J/h]
- ρ : the volumetric mass [kg/m³]
- Cp : the mass heat capacity [J/(kg*K)]
- V : the flow volume [m^3/h]
- t_{in} t_{out} . the fluid temperatures [K]

With this method, the geothermal energy delivery can be quantified rather accurately, as is done already in almost all larger installations. The subsequent steps towards the heat use may have a few losses (circulation pumps), which generally are below 5 %. All other steps only may add energy from other sources (heat pump activation energy, energy in peak load boilers), which cannot be considered part of the geothermal energy delivery.

For the relatively large size of this kind of geothermal direct use systems, the cost for measurement equipment are acceptable. In most cases authorities will require the measuring of flow rate and temperature of water from the geothermal well as a part of the license, so this equipment has to be installed anyway. Reporting of the data has to be done to the relevant authorities (water or mining); the data could be transferred to the statistical services either through these authorities, or by enforcing a direct communication from the plant operator.

C) A method of heat calculation in a specific geothermal resource, or a region

In complement, we present shortly the methodology for heat mass calculation, permitting to calculate the geothermal potential of the site.

Heat mass stored at a given volume (H0):

$$\mathbf{H0 = [(1\text{–}p)\ \rho mcm + p\ \rho vcv]\ (Tt\text{–}T0)\ A\ \Delta z}$$

where: p = effective porosity;
ρ = density;
c = specific heat capacity;
Tt, T0 = temperature in rock and at the surface;
A = surface;
Dz = thickness;
m, v = indices indicating rock body and pore fluid

The value of H0 heat mass - in joule (J) - denotes „the geological resource" as a geophysical quantity independent from the technology and profitability of production.

We defined two more terms:

- economical and legally exploitable resource in the near future:

$$H_1 = R_0 H_0$$

where $R_0 \approx 0.1\text{–}0.2$, depending on the efficiency of exploitation and utilisation, and the temperature of re-injected water;

present economical and exploitable known reserve:

$$H_2 = R_1 H_1$$

where $R_1 < 1$.

General remarks on the static survey:

- the calculation on geothermal resource is just a snapshot, it can't consider the effects of heat quantities either exploited from or naturally recharged to the given space;

- the geological resource can be determined quantitatively according to the level and reliability of the geological-geophysical parameters;

- marginal conditions must be determined for the calculation of geological resource (e.g. minimum temperature, maximum depth);

- the exploitable geothermal resource depends on the technology of exploitation (e.g. in case of doublet system when water is re-injected:

$$T_t – T_r T_t – T_0 R_0 = 0.33$$

where T_r is the re-injection temperature);

- the determination of the present economical and exploitable known reserve can be carried out in case of a defined geothermal reservoir and in case of a particular project.