Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Toward a Better Way of Estimating Energy Utilization with Geothermal Heat Pumps: a Collaborative Study Under Annex VIII of IEA Geothermal

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Keywords: geothermal direct use, geothermal heat pumps (GHP), IEA Geothermal, capacity factor, load factor

ABSTRACT

Ground-source heat pumps or geothermal heat pumps (GHP) have become the main type of geothermal direct use, making up more than 50% on a worldwide basis. We have seen a dramatic increase in GHP installation during the last decade and this high growth rate is expected to continue in the future. The contribution of GHPs to world geothermal statistics is larger, in terms of installed capacity, than in thermal energy produced because of their low capacity factor or equivalent full load hours per year.

Different load factors among the various types of utilization, such as heating residential houses, office buildings, and green houses, are often not considered by estimating capacity factors. In contrast to large-scale district heating systems, it is almost impossible to monitor flow rate or thermal load for GHPs, except in applications for large office buildings. Therefore, there is significant uncertainty in the statistics for geothermal energy use with GHPs, both on national and world levels.

In order to determine a method for estimating geothermal energy utilization with GHPs as accurately as possible, Annex VIII - Direct Use of Geothermal Energy, a major activity of the International Energy Agency Geothermal Implementing Agreement (IEA Geothermal) initiated a collaborative task (Task D) starting with the comparison of methods used in computing the national statistics of several countries. Each country has its own approach for estimating thermal usage, mostly reflecting major utilization type and climate condition. However, there may be found a recommended method or reference table, if the statistics for each application type and the standard load pattern of each type are made available. Many countries do not separate cooling with GHPs from heating, which causes another uncertainty in the statistics.

The main objective of Annex VIII Task D- Guidelines on Statistics for Geothermal Heat Pump Applications, is to develop a suitable form of statistical table to be adopted both for national and for world statistics. The table will include all types of GHP utilization, and consider cooling as well as heating. This will hopefully lead to comparable statistical data, and less confusion. The GHP statistical work is part of the Annex VIII development of guidelines for geothermal direct use statistics.

1. INTRODUCTION

IEA Geothermal has recently initiated a new activity, Task D, under Annex VIII – Direct Use of Geothermal Energy to devise a useful guideline for estimating geothermal energy production with geothermal heat pumps (GHPs) or ground-source heat pumps (GSHPs). Worldwide, GHP installations have shown remarkable increase over the last decade, and GHPs have become the main geothermal direct utilization method, amounting to more than 50% of world direct use (Lund et al., 2010). This increasing trend is expected to continue for the next decade, and will expand to countries beyond Europe and North America, and especially in mid-latitude and sub-tropical regions.

Heating of residential buildings with GHPs has been a major application in some leading countries, especially in northern Europe, and their performance enhancement is still a significant topic of research and development. On the other hand, cooling is another important GHP application, especially for office buildings anywhere in the world and for residential buildings in countries of mid-latitude and sub-tropical climate. However, we often find that there is a significant gap in perception between the geothermal community and the general public or even the professionals in the energy area, especially in the renewable energy sector. For example, the World Geothermal Congress (WGC) guideline (Lund et al., 2010) does not account for cooling with GHPs in geothermal utilization, while IEA statistics include all thermal (heating and cooling) energy utilization in ‘renewable heat’ (IEA, 2012). Of course, the WGC statistics request asks for separate data for GHP cooling to take it into account for estimating fossil energy savings and CO_2 emission reductions. However, in practice, the separation of heating and cooling is not considered in the national statistics of some countries, thus leading to considerable uncertainty regarding the total heat production from geothermal direct uses. GHPs consume electricity (sometimes gas, but we disregard its portion) to provide heating or cooling, so that one must remove that portion of electricity when estimating geothermal utilization or ‘pure geothermal contribution’. But again, this fundamental principle is often disregarded in the national statistics of some countries.

IEA Geothermal started publishing an annual data compilation, ‘Trends in Geothermal Application’, in 2010 through Annex X - Data Collection and Information (www.iea-gia.org). Different from geothermal power generation, for which we can get fairly accurate statistics, data for geothermal direct uses are characterized by a higher level of uncertainty. Statistics on GHPs are the most ambiguous, and suffer from inaccurate estimates of both installed capacity and energy production. Even if assuming that accurate information for installed capacity is available, there is not a small uncertainty in estimating energy use or production because the method for producing national statistics is quite different from country to country. Because renewable heat is becoming more and more important for achieving the renewable energy target of individual countries, IEA Geothermal has initiated a new Task for GHP statistics and opens this issue to the geothermal community. This Task aims to devise a reasonable (or acceptable) set of tables as a guideline for estimating heating and cooling energy production with GHPs. There are reasonable standards in some countries, thanks to their long history of GHP installations and field studies. However, a good standard in one country may not be applicable in other countries simply because some necessary information is not available. Therefore, our target is not to make one single standard, but rather to provide a set of tables as guidelines considering each country's different level of available information. This is the reason we started our work gathering information from participating countries (in IEA Geothermal), and we aim to expand it to other countries by opening this Task D to the geothermal community at the WGC.

2. CURRENT ISSUES AND WORK SCOPE OF THE TASK

Although the remarkable increase in GHP installations and energy production in the last decade is well known, there is also significant uncertainty in the statistics related to GHPs. First of all, due to the distributed nature of the GHP installations, and their much smaller capacities compared to district heating systems, there are many countries in which accurate statistics for GHP sales are not available. Secondly, even if we know the exact installed capacity, it is difficult to know the load profile, which depends on the operational period, or to estimate the capacity factor. The capacity factor, which can be defined as full load hours per year divided by 8,760 (24×365) hours per year, strongly depends upon the application types, e.g., office building, residential house, greenhouse, and so on; therefore it is not desirable to choose one representative value for a country, or even for a town.

There may be another obstacle to the production of accurate statistics, that is the distinction between heating and cooling. In some countries other than North America, official statistics do not separate heating and cooling, but instead, provide just a lump sum of heating and cooling. Furthermore, in some countries, the electricity consumption used to drive GHPs is not accounted for when estimating the geothermal energy utilization. Considering that the coefficient of performance (COP) of GHPs is generally between 3.0 and 4.0 for heating, ignoring the COP in the statistics will lead to a significant overestimate of worldwide statistics for geothermal direct use. Note also that the COP is strongly dependent, e.g., on source temperature, so accurate estimates are possible when proper monitoring of the annual performance or average seasonal performance factor (SPF) of the GHP system are considered.

In many cases, the COP stands for the value measured in the laboratory under constant operating conditions. The manufacturers give COP values for their heat pumps, but in Europe to receive subsidies, the COP of a heat pump must be measured by an independent test center. There is a European Norm (EN 14511-2; www.en-standard.eu) which defines how to measure the COP. On the other hand, The SPF is defined as the seasonal average value of "real" heating systems. It is influenced by different factors like climate, heat demand, utilization only for heating, or for water heating in summer, etc. Also, there are different SPFs according to the system boundaries under consideration. As an example, in Switzerland, only the heating period (heating degree days) is considered and the basis for the SPF in Switzerland is the FAWA study (Erb et al, 2004), in which 236 small heat pumps systems were studied. .

The other issue is the cooling energy production with GHPs. WGC official statistics do not account for cooling energy with GHPs, though it is accounted for when estimating fossil fuel saving and greenhouse gas emission reduction (Lund et al., 2010). In fact, currently there are no other statistics available regarding geothermal cooling, with or without GHPs. The geothermal community does possess such information, however, should it needs to be provided explicitly to both the international energy community and policy makers. As a matter of fact, IEA statistics include cooling energy in 'renewable heating and cooling' or simply 'renewable heat', but there is no clear distinction made regarding the geothermal cooling contribution.

Therefore, in order to provide a better way of estimating thermal energy production with GHPs, the new IEA Geothermal Annex VIII Task D was developed with the following work scope:

- Collection of information from IEA Geothermal participating countries, and expand to other countries, if available
- Comparison of collected information with the WGC guideline and other frameworks
- Analyses of uncertainty
- Discussion of possible ways to enhance the reliability of the statistics using existing information
- Devise some recommended methods considering each country's information level
- Publish guidelines as a deliverable

Targeted time line for completion of Task D "Guidelines on Statistics for Geothermal Heat Pump Applications" is the end of 2015; and as of May 2014, we have information from the three countries; Japan, Korea and Switzerland.

3. REVIEW OF WGC STATISTICAL METHOD AND ITS IMPLICATION

Whatever the source of energy, most of the countries provide fairly accurate and timely statistics on electricity generating capacity and production. On the other hand, statistics on direct heat use are characterized by estimated values, frequently reported well after deadlines, because it is difficult, or impossible, to monitor the extracted energy (from time-varying flow rates and temperature differences), and the usage is generally at distributed sites. Consequently, data is often time consuming to collect, and sometimes not available. In addition, there is sometimes reluctance by users, such as hot spring businesses, to provide data. For GHPs, which are characterized by their small capacity and wide distribution, measurement or monitoring is almost impossible due to both, economic and technical reasons.

Figure 1 shows a conceptual scheme of how a GHP provides heating, cooling and/or domestic hot water (DHW) supplies. Accurate information on the pure geothermal contribution 'G' can be achieved by monitoring flow rate and temperature difference on the geothermal side, or by monitoring both 'Q' (heat output) and 'E' (electricity used by GHP). However, because it is not efficient, if not impossible, to make such measurements at all the smaller installations, estimates of thermal utilization may be made using the rated capacity and COP as in the WGC guideline (Lund et al., 2010).

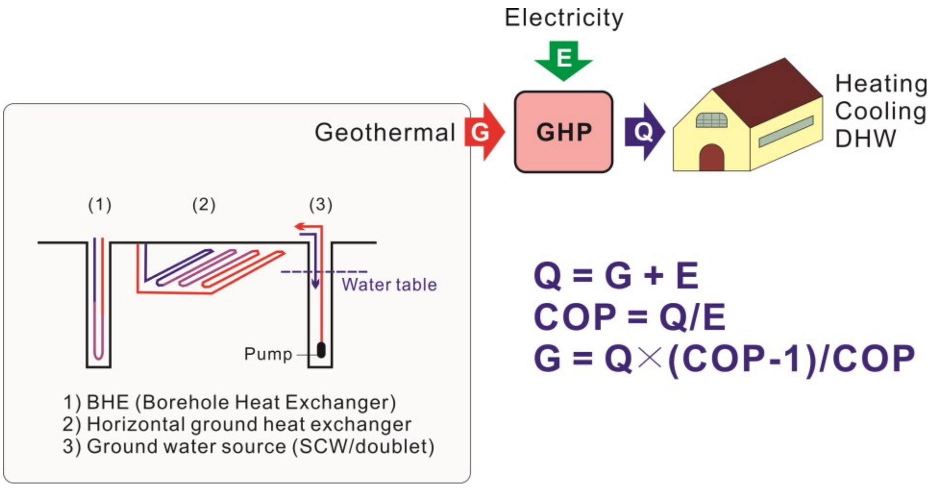

Figure 1. A conceptual sketch showing how a GHP provides heating, cooling and/or DHW supplies.

In the WGC guideline, there are two ways of estimating thermal energy utilization. The first method, which would be an ideal case, is based on flow rate measurement (Lund et al., 2010):

$$\text{Thermal energy (TJ/yr)} = \text{flow rate in loop (kg/s)} \times [\text{inlet temp. (°C)} - \text{outlet temp. (°C)}] \times 0.1319, \quad (1)$$

where 0.1319 is equal to: 3,600 second/hour × 24 hours/day × 365 days/year × 4.184 (kJ/kg/°C) × 10^{-9}.

When direct monitoring of flow rate and temperature cannot be performed, which is the case for most systems, the thermal energy production can be estimated by following another WGC guideline method:

$$\text{Thermal energy (TJ/yr)} = Q_{rated}\ \text{(kJ/hr)} \times [\text{(COP-1)/COP}] \times \text{equivalent full load hours/yr} \times 10^{-9} \quad (2)$$

Equation (2) may be a practical way of estimating thermal energy production, and we assume that many country reports for the WGC follow this method for providing GHP statistics. Rated capacity is a name plate value and the COP is also one of the officially approved values determined by the source temperature. Although the actual COP, or measured SPF, of a GHP will deviate from its name plate or approved value, we can assume that the uncertainty due to this deviation is not significant in estimating the thermal energy; and thus the estimate is acceptable within a reasonable uncertainty level, say less than 10%. However, equivalent full load hours, which in turn can be expressed in terms of capacity factor, vary widely according to the application type, and are often not well addressed in country reports.

4. EXAMPLES OF SOME COUNTRIES

As of May 2014, Task D has information on national statistics from the three countries: Japan, Korea and Switzerland. Although the number of countries providing information is far from enough to allow intensive analysis, it is useful for starting discussion by determining how the information level differs from country to country. For Japan and Korea, national statistics are based on application to office buildings, which have rather low capacity factors or full load hours per year. Measurements of equivalent full load hours are not available in the statistics of the two countries; instead a rough assumption of load factors (0.5 - 0.7) is used. Also, both countries do not separate heating and cooling; instead, they just provide a lump sum. The most serious concern may be the electricity consumption of the heat pump, which is not considered in the GHP statistics. This means the annual geothermal energy utilization can be significantly overestimated.

On the other hand, reflecting a rather long history of GHP installations, Switzerland has set up a fairly reasonable method for estimating energy production based on GHP sales data and performance monitoring results (e.g., Geowatt AG, 2013; Basics, 2007; Erb et al., 2004). The Swiss method can be summarized as followings:

- Collect annual sales data and apply a replacement rate (based on modeling of the distribution of the lifetime of heat pumps, assuming a maximum lifetime of 45 years)
- Categorize GHP according to heat source types (brine/water or water/water) and capacity (<5 kW, 5-10 kW, 10-20 kW, 20-50 kW, 50-100 kW, 100-300 kW, > 300 kW)
- Apply a 'standard running time' (annual full load hours) determined from a statistical analysis for calculating annual thermal production: 1,932 hr/yr for brine/water and 1,634 hr/yr for water/water (field data for plausibility check)
- Apply a climate condition in form of heating degree days
- Apply an annual average SPF (COP=1.194 SPF) to estimate the 'pure geothermal contribution'

Note that brine/water corresponds to a GHP with a borehole heat exchanger or shallow horizontal heat exchanger, while water/water is for a groundwater-source GHP. Considering most of the GHPs are rather small systems for individual house heating in Switzerland, and the statistics are based on the annual sales data and long term monitoring studies, the Swiss method provides a fairy accurate estimate of geothermal heat utilization. However, ‘standard running time’ or annual full load hours may not be accurate for office buildings with larger installations than 100 kW, so another standard for bigger installations need to be implemented. This is also important for estimating cooling energy production, because in Switzerland, cooling is important in office buildings. Furthermore, regarding cooling, ‘free cooling’, which only needs circulation without running the heat pump itself, should be handled separately.

5. DISCUSSION AND FUTURE PLAN

Although we have only three country cases so far, it is enough to see that the level of available information in each country is quite different, and thus it may not be easy to devise one single guideline to get a better estimate of the geothermal energy utilization for the national statistics. Therefore, we should aim to develop a set of tables that consider the available information in countries, or recommend the minimum information which each country should collect. The fact that electricity consumption for running GHPs is not accounted for in the statistics of two of the presented countries implies that there will be more countries which do not consider the COPs in estimating energy production. This inconsistency may partly result from an incomplete understanding, by people in the geothermal community, of how heating and cooling are generated with a heat pump.

Once the importance of the ‘pure geothermal contribution’ is accepted, separate statistics for heating and cooling should be produced at the same level of importance. Because the capacity and the COP for cooling are generally different from those for heating, even for the same system, a simple lump sum of heating and cooling should be discarded. Since cooling with GHPs is quite important in countries of mid-latitude and sub-tropical climate, we should endeavor to make separate statistics on GHP cooling, and provide those to the international energy community, as well as to policy makers on the national level.

Accurate estimation definitely depends on reasonable estimates of capacity factors or annual full load hours. A recent survey in Korea shows that full load hours of GHPs for office buildings (big installation) can be one fifth of those for residential houses (Song et al., 2015). In such a case, it is clear that one single value for capacity factor or full load hours in equation (2) can no longer provide a reasonable estimate of energy production. Therefore, we need to monitor annual COP or SPF, and full load hours at least for representative installations and should try to establish reference profiles.

There may arise additional issues as we collect more cases from other countries. And further, it may be impossible to devise a guideline acceptable to all the countries in the short term because the information level among countries is quite different. However, from the view point of the mission and strategic plan of IEA Geothermal, communicating key information is a high priority, and statistics on energy production with GHPs is indeed a timely issue we should communicate to each other.

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