Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Proposal of New Data Collecting Spreadsheet for Geothermal Heat Pumps Statistics - An Outcome of IEA Geothermal Working Group Activities

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Keywords: direct use, geothermal heat pump (GHP), ground-source heat pump (GSHP), statistics, IEA Geothermal

ABSTRACT

Geothermal or ground source heat pump (GSHP) applications became dominant in direct use of geothermal heat covering more than 55% of worldwide heat uses in 2015. The major application of GSHP is still for heating individual residential houses, especially in northern Europe. The number of large installations for office buildings and apartment houses is recently increasing in Europe and North-East Asia. GSHP installations at public and commercial buildings are not only used for heating but also for cooling, and energy utilization in cooling mode is getting more and more important.

Although the contribution of GSHP to global thermal energy uses is getting bigger, official statistics (e.g. of the International Energy Agency; IEA) of worldwide energy uses do not consider this type as independent renewable energy source despite the fact that IEA classifies heat pumps (from air, ground, water, and waste sources) as a renewable energy source. The International Geothermal Association (IGA) collects data for GSHP installations through the World Geothermal Congress (WGC) every five years. However, in their geothermal utilization statistics WGC only accounts for the heating mode of GSHP, because cooling with GSHP does not extract but stores heat in the ground. However, cooling with GSHP is getting more important and has a huge potential worldwide. As no other statistics consider this important energy utilization, IEA Geothermal has devised a new statistical scheme as a result of Working Group activities.

Data for the new statistical scheme of IEA Geothermal is collected through an Excel spreadsheet with input options for installations like individual residential houses, commercial/institutional/multi-family buildings and others such as greenhouses, separately. By adopting a concept of gross and net energy production with input of equivalent full load hours and seasonal performance factors which are different not only for each installation type but also depending on heating or cooling, annual thermal energy use and renewable energy production are automatically calculated for heating and cooling application, separately. The information sources and the accuracy of the information can also be added, allowing to evaluate the reliability of the statistics. Additionally, the new statistical questionnaire of IEA Geothermal includes a separated sheet for 'free cooling', if data is available. This questionnaire comes with a user guide for better understanding of the underlying principle. IEA Geothermal started collecting the new geothermal statistical information from the participating countries in 2018 with this new scheme. Overall, this new statistical questionnaire bridges the gap between the official energy statistics and the industry association statistics, and at the same time specifies the individual query values and includes the increasingly important cooling application. IEA Geothermal suggests that it is considered as a reference for revising the data collection format of WGC in future. Reliable and comparable geothermal energy statistics are an important pillar in communication activities towards politicians, decision makers and the general public.

1. INTRODUCTION

Geothermal or ground source heat pump (GSHP) became dominant in direct use of geothermal heat covering more than 55% of worldwide heat uses in 2015 (Lund and Boyd, 2016). The major application of GSHP is still for heating, but cooling is becoming more and more important.

Although the contribution of GSHP to global thermal energy uses is exponentially growing, official statistics (e.g. of the International Energy Agency; IEA) of worldwide energy uses do not consider this important type as independent renewable energy source although IEA classifies heat pump systems as renewable energy source (IEA, 2014). The International Geothermal Association (IGA) collects data for GSHP installations through the World Geothermal Congress (WGC) every five years. However, WGC accounts for heating application of GSHP only in geothermal utilization statistics because cooling with GSHP does not extract from the ground but heat the ground. No energy statistics consider geothermal cooling so far. But because cooling with GSHP is getting more important, IEA Geothermal Technology Collaboration Programme (IEA Geothermal) started to devise a new statistical scheme (Song et al., 2015). As an outcome of the Working Group activities of IEA Geothermal, we propose a new spreadsheet for collecting application data. In this paper, we explain the important definitions as a guideline of the new statistical scheme and describe how to use the spreadsheet. This new statistical questionnaire of IEA Geothermal shall serve as a template for national and international surveys on energy statistics.

2. DEFINITIONS USED FOR GEOTHERMAL DATA COLLECTION - GSHP STATISTICS

In this chapter, we summarize concept underlying the new statistical scheme by reviewing important definitions of terminologies and variables used for the scheme. Tables 1 and 2 in the appendix are examples of the new spreadsheets and detailed guidelines follow at the next chapter.

Installed capacity (MWt)

Installed capacity, also known as nameplate capacity or rated capacity, refers to the intended technical full-load sustained (maximum gross) output of a GSHP. Note that a GSHP provides both heating/Domestic Hot Water (DHW) and cooling, and the nameplate

capacity often slightly differs from each other. We recommend to use 'Heating capacity' of the nameplate capacity. In Table 1, the table element "Installed Capacity" under "New Installation in 2018" refers to the sum of the newly installed capacity in 2018. The table element "Total Installed Capacity" refers to the cumulative installed capacity in a country.

Coefficient of Performance (*COP*)

COP is the most commonly used dimensionless measure to quantify the performance of a heat pump and expressed by

$$COP = \text{Thermal Output (kW)} / \text{Electricity Input (kW)}$$

$$= Q / E_{GSHP} \quad (1)$$

In heating mode, "Thermal Output" or "Total Usable Energy" of a GSHP (Q) is the sum of "Geothermal Energy G" and the "Electricity Input E_{GSHP}" (See Figure 1).

$$Q = G + E_{GSHP} \quad (2)$$

$$E_H = G = Q - E_{GSHP}$$

$$= Q \times (1 - 1/COP) \quad (3)$$

Note we can define the heating energy production (E_H) that equals to the geothermal energy (G). For cooling application, on the other hand, energy flow is reversed (the lower right diagram of Figure 1) and expressed as equation (4).

$$G = Q + E_{GSHP} \quad (4)$$

In cooling, GSHP supplies heat to the ground instead of extracting from it, and it is the main reason why geothermal community generally does not account for the cooling energy of GSHP in considering geothermal utilization. This seems reasonable when considering thermodynamic principle. However, if geothermal community does not consider cooling application of GSHP, then this important quantity will be missed in global renewable energy statistics. Therefore, for the sake of maintaining consistency, we define '*Cooling energy production with help of ground*' as follows:

$$E_C = Q_C - E_{GSHP}$$

$$= Q_C \times (1 - 1/COP_C) \quad (5)$$

This new definition for cooling is comparable to equation (3) and can be accepted reasonable because amount of cooling benefit by subtracting electricity portion is '*free of charge*' and from the renewable source. Here, the subscript C stands for cooling application. Sometimes the term *COP* is confused with Seasonal Performance Factor (*SPF*). In this new scheme, we use *COP* when it is a nameplate value of GSHP for specified input and output temperatures, while *SPF* is a real measured value for a certain period time. Note that *COP*s and *SPF*s for heating and for cooling are different from each other even for the same GSHP so that a special care must be taken in putting the corresponding values.

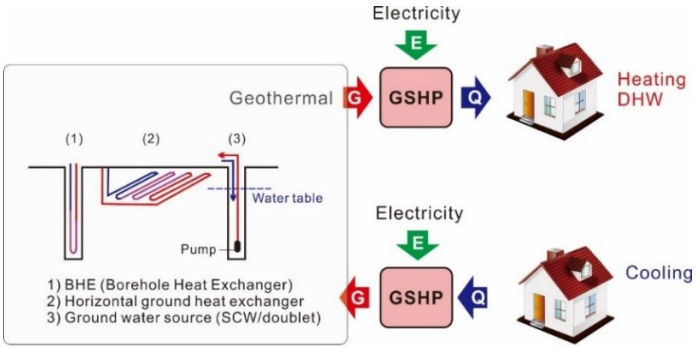


Figure 1: A schematic diagram showing energy flows of GSHP in heating and cooling modes.

System COP

System COP is used for the performance of the GSHP system including the electricity to run the ground loop circulation pump for a closed-loop system or the water pump for a groundwater-source system (E_{CP}) and is expressed by

$$System\ COP = \text{Thermal Output} / \text{Electricity Input}$$

$$= Q / (E_{GSHP} + E_{CP}) \quad (6)$$

Thus, *System COP* is always less than *COP*. Again, *System COP* in this scheme refers a nameplate value, while SPF_2, which will be explained later, is from real monitoring. In many cases, there is no separate monitoring of electricity to run a circulation pump. In such a case, one may use the maximum allowable pump power for a closed-loop system (50 W/kWt; Energy Saving Trust, 2007) as follows:

$$System\ COP = Q / (E_{GSHP} + E_{CP})$$

$$= Q / (Q/COP + 0.05 \times Q)$$

$$= COP / (1 + 0.05 \times COP) \quad (7)$$

Although the pump power for groundwater-source (open-loop) heat pump systems often exceeds 50 W per kWt of heat/cold production, because *COP* of an open-loop system is generally higher than that of a closed-loop system (e.g. borehole heat exchanger), this can be used as an approximation.

Seasonal Performance Factor (*SPF*):

The *SPF* is an average of the *COP* from real monitoring of a GSHP for a certain period time, typically over a season of heating or cooling, or a year. SPF_1 is from a measured *COP* of a GSHP, while SPF_2 is from a measured *System COP* as illustrated in Figure 2. If one does not have a separate monitoring of the electricity necessary to run the ground loop circulation pump, then we recommend to use a nominal value as used in *System COP* estimations, as shown in equation (6). We use SPF_H for heating, SPF_C for cooling, and subscript 1 and 2 for *COP* and *System COP*, respectively; for example, SPF_{H1} and SPF_{C2}.

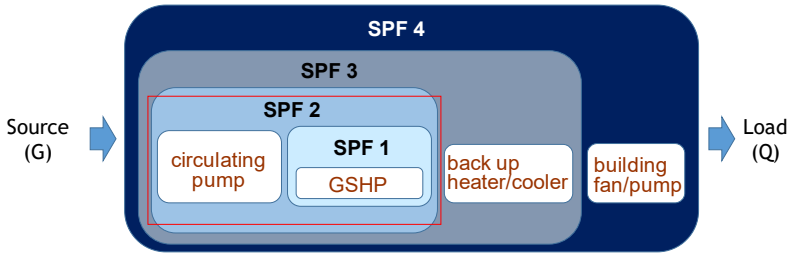


Figure 2: Adopting the definition of system boundaries for heat pump system in European SEPEMO-Build project (modified from Nordman, 2012).

Equivalent Full Load Hours (*EFLH*):

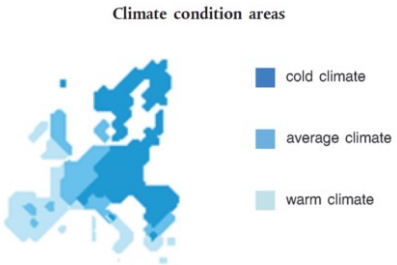
Equivalent Full Load Hours per year is a total period (in hours) of the system operation with its full load per year and is often used as capacity factor of the system. For example, if a house is heated with a typical unit (12 kWt) for 10 hours/day and 180 days/year, then

$EFLH$ = 10 hrs/day × 180 days/year = 1,800 hrs.

Another example; if a building is equipped with a larger system of 240 kWt (three heat pumps of 80 kWt each), and only 2/3 of the system are working for 8 hours/day and 150 days/year, which may mean that the building is not fully occupied, then

$EFLH$ = 8 hrs/day × 150 days/year × 2/3 (load factor) = 800 hrs

If no information on the *EFLH* of the GSHP is available, then it may be referred to EU Decision 2013/11/EU, which provides estimates of the *EFLH* for heating of residential houses in Europe according to climate condition as shown in Figure 3.



	Warm		Average		Cold	
	EFLH	SPF_{H2}	*EFLH*	SPF_{H2}	*EFLH*	SPF_{H2}
Ground-Air	1,340	3.2	2,070	3.2	2,470	3.2
Ground-Water	1,340	3.5	2,070	3.5	2,470	3.5

Figure 3: Examples from EU Decision 2013/11/EU for heating.

Energy from Renewable Source (E_{RES}):

E_{RES} is, as defined in EU Directive 2009/28/EC and EU Decision 2013/114/EU, the '*net*' energy from GSHP, while "Geothermal Contribution *G*" (equations (3) and (5)), is the '*gross*' energy production:

$$E_{RES} = Q - E_{GSHP} - E_{CP}$$
$$= Q \times (1 - 1/SPF_2) \quad (8)$$

This quantity will be used in calculating the energy saving and CO_2 emission reduction through utilization of GSHPs.

Free Cooling:

In mild climate regions, where dehumidification with heat pump is not needed, space cooling can be done simply by applying a Fan Coil Unit (FCU) to circulating water pipe through ground water well or borehole heat exchanger. In case of such '*Free Cooling*', only the ground circulation pump is in operation whereas the heat pump is switched off. Because E_{GSHP} is zero in equation (5) and thus the *COP* cannot be defined, "Total Usable Energy" or "Thermal Output *Q*" equals to "Cooling Energy Production E_C". On the other hand, E_{RES} can be estimated by using equation (9), and then can be used to calculate the energy saving and CO_2 emission reduction.

$$E_{RES} = Q - E_{CP} \quad (9)$$

Note that the 'Installed capacity' of a GSHP cannot be used for '*Free Cooling*' because there is no electricity contribution to "Thermal Output". Instead, '*Running Capacity*' from actual measurement of average temperature and flow rate should be used as follows.

$$Capacity_{Running} = m_{ave} \times (T_{out} - T_{in}) \times C_v \,, \quad (10)$$

where m_{ave} is the average flow rate (L/sec), T_{in} and T_{out} the inlet and outlet water temperature of the cooling system (°C), C_v the volumetric heat capacity of ground circulating water (= 4,184 J/L-K). The reason why '*Running Capacity*' is used here is that the circulation pump is often running with partial load in '*Free Cooling*' and that is why average flow rate is used, too.

3. GUIDELINE FOR SPREADSHEET "GSHP STATISTICS"

Table 1 in the appendix shows a spreadsheet for GSHP statistics proposed by IEA Geothermal including sample data. The spreadsheet is a kind of standalone so that one can find explanations and options to choose by clicking the red triangles at the upper right corner of the items, if available. In the following each item is described in more detail.

Category of installations

Because running hours of GSHP vary significantly according to the size and/or site of installation, we separate 'Individual Residential Houses' and 'Commercial/Institutional/Multi-family Buildings'. For other applications like greenhouses, fish farming, snow melting, and so on, where full load hours may be notably different from building applications, the table elements 'Others1' and 'Others2' can be used, if necessary. Note that if there are some of these applications but with only tiny fraction of energy utilization, then it is not necessary to separate these.

'Producing type (A/M)'

For the sake of compatibility with international official statistics, we consider other categorization as well (Select one of the two by clicking the icon);

- A: Auto Producer (GSHP for their own heating/cooling purpose)
- M: Main Activity Producer (GSHP for commercial service).

We assume that all the GSHPs for 'Individual Residential Houses' are of 'Auto Producer' type, while we separate 'Commercial/Institutional/Multi-family Buildings', 'Others1' and 'Others2' into the two types. If one does not have separate information, then it is recommended to use 'No separate information'.

'New Installation in 2018' as of December 31, 2018

- 'Number of heat pumps': for countries having individual heat pump sales inventory, then put the number of GSHP and typical capacity (kW)

  ⇒ 'Installed capacity (MW)' = Number of heat pumps × typical capacity / 1000

- 'Installed Capacity (MW)': for countries without individual heat pump sales data
- 'Information Source': select one of the five options by clicking the icon
  - O: Official Data
  - O+C: Official Data + Correction from Reliable Sources
  - ER: Reasonable Estimation (please specify at 'Further Remarks')
  - ES: Simple Estimation (please specify at 'Further Remarks')
  - S: Other Statistics (please specify at 'Further Remarks')

'Typical Capacity (kW)'

Typical capacity of installation is rather arbitrary number. Default value for 'Individual Residential Houses' appears "<17.5", but user may modify all values to fit their country's representative numbers.

'Total Installation'

Same guidelines as for 'New Installation in 2018' but with cumulative number and installed capacity of all heat pumps in the country.

'Heating vs. Cooling (without free cooling)'

If the official data of e.g. a country are just lump sum of heating and cooling, we recommend to try to separate them with representative heating and cooling guide of building HVAC (Heating, Ventilation, and Air-Conditioning) code, if any. '*Free Cooling*' applications should not be included here, if any, instead we provide the separate data sheet.

'Equivalent Full Load Hours (EFLH) per Year'

- 'Hrs' is hours separately for heating/DHW and cooling
  - For heating only, and if there is no information on EFLH, one may refer to the examples in EU Decision 2013/11/EU as shown in Figure 3.
  - For cooling, include only cooling with GSHP. If there are some '*Free Cooling*' applications, please use the separate sheet.
- 'Information level' is for estimating the reliability of the data for the sake of future analysis because accuracy of official statistics is quite different from country to country. Furthermore, even in the same country, there may exist monitoring systems for large installations whereas no monitoring is done for individual houses. Select one of the five options by clicking the icon
  - A: actual monitoring + yearly correction according to climate (as in Switzerland)
  - B: actual monitoring of a certain year(s) (as in Germany)
  - C: some monitoring + building HVAC code (as in Korea)
  - D: building HVAC code (or EU Decision 2013/114/EU)
  - E: just estimation (please specify at 'Further Remarks')

Note that in most countries or regions, there is a reference of heating and/or cooling load (for example, peak load in kW/m^2 and monthly load in running hours) when a building is designed. HVAC code here stands for such a reference.

'Total Usable Energy **Q** (GWh)'

This will be automatically calculated with

$$Q = \text{'Total Installed Capacity (MW)'} \times EFLH / 1000$$

'COP or SPF1'

- 'Value': input COP or SPF_1
- 'COP/SPF/Other': select one of the three options by clicking the icon
  - COP: COP of GSHP
  - SPF: SPF_1 based on monitoring
  - Other: Others (please specify at 'Further remarks')

'Energy Production **E** (GWh)'

This will be automatically calculated using equation (3) for heating ('pure geothermal contribution') and (5) for cooling ('cooling energy production with help of ground')

'System COP or SPF2'

- 'Value': input System COP or SPF_2. Default is calculated value using equation (6)
- 'COP/SPF/Other': select one of the three options by clicking the icon
  - Est: default calculation
  - SPF: SPF_2 based on monitoring
  - Other: Others (please specify at 'Further remarks')

'Net Energy Production $\mathbf{E}_{RES}$ (GWh)'

This will be automatically calculated using equation (7).

4. GUIDELINE FOR SPREADSHEET "FREE COOLING"

Table 2 in the appendix shows the separate spreadsheet for free cooling statistics with a sample dataset. This is for future uses when sufficient information is available. However, if there is any data source available, then we recommend to fill the table and to feedback.

Necessary information specific for this table can be found at '*Free Cooling*' in Chapter 2 'Definitions' except the followings:

- 'Number of locations': put the number of locations using '*Free Cooling*'
- 'Included in GSHP?': considers whether all or some of these locations are included in GSHP installation sites. For cooling application of GSHP, sometimes we don't need to run compressor of GSHP, and '*Free Cooling*' means that we supply cooling by just running the circulation pump. Select one of the three options by clicking the icon
  - A: all
  - S: some of these
  - N: all are separate installations only for free cooling

5. DISCUSSION AND CONCLUSIONS

We propose a new spreadsheet for GSHP statistics as an outcome of IEA Geothermal Working Group activities pursuing a future statistical scheme not only for IEA Geothermal reports but also for world geothermal statistics. Major features of the new scheme are 1) specifying commercial and private uses, 2) separating heating and cooling applications, 3) clarifying gross and net productions, and 4) including '*Free Cooling*' for future uses. Considering that available information is different from country to country, we include separate columns describing the reliability of the input values.

The most important step for making reliable statistics is to report as accurate values of installation capacity as possible. Once we have a reliable information on the installation capacity, the next important step would be estimates on energy utilization with GSHP which absolutely depends on the reasonable estimates of EFLHs according to the load types such as residential houses, commercial and public buildings, greenhouses, and so on. Because the load characteristics of building types are significantly different from each other, sample monitoring for more than a year is essential for reasonable estimates. However, monitoring is not always possible, especially for small installations, so that we also have to use other references such as building HVAC standards for the specified load types, if any.

If the geothermal community accepts our proposal on the new statistical scheme for GSHP application, we can add other important features such as energy saving and CO_2 emission reduction factors as the next step. Energy saving factors from utilization of renewable energy sources can be in the form of fossil fuel saving or carbon dioxide emission reduction. WGC guideline (Lund et al., 2011; Lund and Boyd, 2016) states fossil fuel saving and CO_2 emission reduction for heating, while CO_2 emission reduction only for cooling. However, we would argue that because cooling with GSHP can be defined as energy production with the help of the ground we can use the fossil fuel saving factors (Mongillo, 2005) for cooling applications as well. Furthermore, for cooling, we may consider electricity saving and CO_2 emission reduction comparing to air-source heat pump or air-conditioner. Because cooling applications of GSHPs will continuously increase especially for large office buildings and in developing countries of (sub-) tropical region, we expect that the contribution of GSHPs to fossil fuel saving and CO_2 emission reduction will be seen remarkable by adopting the new statistical scheme proposed here.

IEA Geothermal started collecting the new geothermal statistical information from the participating countries in 2018 with this new scheme. Overall, this new statistical questionnaire bridges the gap between the official energy statistics and the industry association statistics, and at the same time specifies the individual query values and includes the increasingly important cooling application. IEA Geothermal suggests that it is considered as a reference for revising the data collection format of WGC in future. Reliable and comparable geothermal energy statistics are an important pillar in communication activities towards politicians, decision makers and the general public.

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Table 1. A sample questionnaire spreadsheet for GSHP statistics

Sample Questionnare for GSHP statistics

* Please locate cursor to the red triangle at the upper right corner to see explanations on that column

	Producing type (A/M)	New Installation in 2018			Typical Capacity (kW)	Total Installation			Heating vs. Cooling (without free cooling)	Equivalent Full Load Hours (EFLH) per Year		Total Usable Energy Q (GWh)	COP or SPF1		Energy Production G (geothermal contribution) (GWh)	System COP or SPF2		Net Energy Production E_{RES} (GWh)
		Number of heat pumps	Installed Capacity (MW)	Information Source		Number of heat pumps	Total Installed Capacity (MW)	Information Source		Hrs	Information level		Value	COP/SPF/Other		Value	Est/SPF/Other	
Individual Residential Houses	A		12.4	O+C	< 17.5		208.4	O+C	Heating/DHW	1,800	D	375.2	3.73	COP	274.6	3.14	Est	255.8
									Cooling	540	D	112.5	4.75	COP	88.9	3.84	Est	83.2
Commercial/Institutional/ Multi-family Buildings	A		117.0	O+C	50~150		1,117.7	O+C	Heating/DHW	570	D	637.1	3.73	COP	466.3	3.14	Est	434.4
									Cooling	590	D	659.5	4.75	COP	520.6	3.84	Est	487.7
Commercial/Institutional/ Multi-family Buildings	M		0.0	S			0.0	S	Heating/DHW	0	D	0.0	3.73	COP	0.0	3.14	Est	0.0
									Cooling	0	D	0.0	4.75	COP	0.0	3.84	Est	0.0
Others1 (Greenhouses/Fish farming/Snow melting,,,)	A		0.0	S			0.0	S	Heating/DHW	0	D	0.0	3.5	COP	0.0	3.00	Est	0.0
									Cooling	0	D	0.0	4.5	COP	0.0	3.50	Est	0.0
Others2 (Greenhouses/Fish farming/Snow melting,,,)	M		0.0	S			0.0	S	Heating/DHW	0	D	0.0	3.5	COP	0.0	3.00	Est	0.0
									Cooling	0	D	0.0	4.5	COP	0.0	3.50	Est	0.0
No separate information			0.0	O			0.0	O	Heating/DHW	0	D	0.0	3.5	COP	0.0	3.00	Est	0.0
									Cooling	0	D	0.0	4.5	COP	0.0	3.50	Est	0.0
Total			129.4				1,326.2		Heating/DHW			1,012.3			740.9			690.3
									Cooling			772.0			609.5			570.9

* Note: If there are many other types of installation which significantly contribute to utilization, then please use 'copy' and 'paste' to put another rows below 'Others2'

Please do not change values in these cells. Automatically calculated.

* Further Remarks' including explanations regarding options selected at the sheet:

* Others 1 (if any):

* Others 2 (if any):

Table 2. A sample questionnaire spreadsheet for Free Cooling

Sample Questionnare for Free Cooling

* Please locate cursor to the red triangle at the upper right corner to see explanations on that column

	Producing type (A/M)	New Installation in 2018					Total Installation					Equivalent Full Load Hours (EFLH) per Year		Energy Production G (geothermal contribution) (GWh)	System COP or SPF2		Net Energy Production E_{RES} (GWh)
		Numer of locations	Average temperature difference ΔT (°C)	Average flowrate (L/sec)	Installed Running Capacity (MW)	Included in GSHP?	Numer of Locations	Average temperature difference ΔT (°C)	Average flowrate (L/sec)	Total Running Capacity (MW)	Information Source	Hrs	Information level		Value	Est/SPF/Other	
Individual Residential Houses	A	12	5.0	1.0	0.251	A	120	5.0	1.0	2.510	O+C	360	D	0.904	20.00	Est	0.859
Commercial/Institutional/ Multi-family Buildings	M	24	5.0	10.0	5.021	S	240	5.0	10.0	50.208	O+C	360	D	18.075	20.00	Est	17.171
No separate information					0.000					0.000				0.000			
Total		36			5.272		360			52.718				18.979			18.030