"Current issues on innovative GSHP application in Asia and Pacific region"
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Estimating energy production with GSHP
- its importance in geothermal direct-use statistics

Yoonho SONG

KIGAM 한국지질자원연구원
Korea Institute of Geoscience and Mineral Resources

Contents

- Background
- Issues regarding GSHP statistics
- Review of existing guidelines
  - World Geothermal Congress
  - EU Directive
- Principle / methods of measuring and estimating thermal energy production with GSHP
- Discussion and Suggestions

Background

- Geothermal or Ground-source heat pump (GSHP) has huge potential
  - Almost all over the world
  - High capacity factor in mid-latitude countries for heating and cooling as well as cold countries of big heating load
  - Will become more and more important in world geothermal direct-use

- In order to further increase deployment in near future
  - To device and disseminate more effective technologies to utilize thermal energy and/or capacity in shallow earth
  - To provide correct method of estimating potential impacts of GSHP in terms of energy saving and CO_2 emission reduction
  - To help decision makers and public acknowledging the benefits of GSHP in terms of energy saving and environmental protection

Issues

- Uncertainty of estimating energy production by GSHP
  - Difficult to get accurate statistics on installation
  - Even more difficult to estimate load profile and operation period or capacity factor
  - Capacity factor (or full load hours) is strongly dependent on application type so it is hard to define a value representing a country
- Separating heating and cooling
  - In some countries, statistics are lumpsum of heating & cooling
  - Cooling COP is different from heating COP $\Rightarrow$ different 'pure geothermal contribution' (even there is free cooling)
- Is cooling geothermal use or not?
  - In thermodynamic principle, cooling is not utilization of geothermal heat
  - However, if we don't account it for, who else will categorize such an important application? (In IEA statistics, renewable cooling is included in 'renewable heat')

General aspects of geothermal statistics

- Geothermal power generation: fairly accurate and timely data
- Conventional direct use: estimated (inaccurate) and late data
  - Difficult to measure
  - Disseminated nature
  - Possible reluctance by users (hot spring business)
- GSHP
  - Much more disseminated
  - Almost impossible to measure for smaller systems
  - Then, how can we argue that how much TOE we can produce by 2020 or 2030?
  - Furthermore, GSHP 'consumes' other energy (electricity):

    Thermal output = geothermal energy + electrical energy

WGC guideline

- Based on flow rate or capacity factor:

  Thermal energy (TJ/yr)

  = flow rate in loop (kg/s)×[inlet temp.(°C)-outlet temp.(°C)] ×0.1319

  or

  = rated output energy (kJ/hr) ×[(COP-1)/COP] × equivalent full load hours/yr × 10^{-9}

- WGC report accounts only for heating
  - Cooling energy is used for 'Energy saving' and 'CO_2 emission reduction'
  - Many countries do not separate heating and cooling
  - Many countries even do not account for electrical energy to run GSHP

  ⇒ A lot of ambiguity in world statistics of GSHP contribution

EU guideline and studies

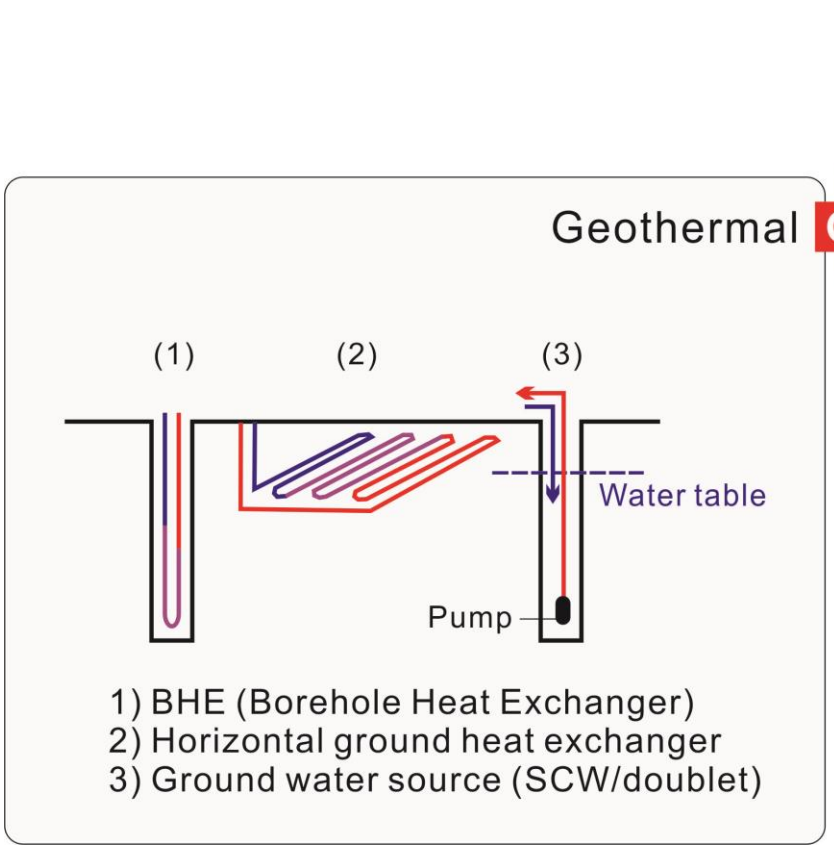
- EU Directive 2009/28/EC
  - To define share of energy from renewable source
  - Annex VII for heat pump: $E_{RES} = Q_{usable}*(1-1/SPF)$
    (only $SPF > 1.15*1/\eta \cong 2.5$ is considered as RES)
  - EU Decision (2013/114/EU)
    $Q_{usable} = H_{HP} * P_{rated}$
    H_{HP}: equivalent full load hours of operation
    SPF: the estimated average seasonal performance factor
    ($=SPF_{H2/C2}$; $SCOP_{net}$ or $SPER_{net}$)

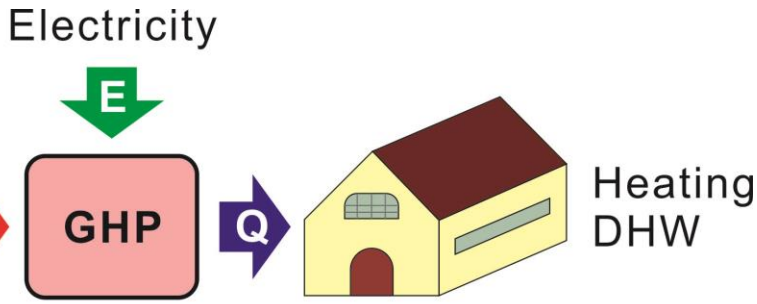
η: power system efficiency
$\cong$ 0.455 as of 2010
(EU Decsision 2013/114/EU)

- For system efficiency validation (not only for GSHP)
  - Annexes under IEA Heat Pump Centre (research on HP statistics as well)
  - IEE (Intelligent Energy Europe) project SEPEMO
  - Fraunhofer ISE studies in Germany, SP reports in Sweden, FAWA in Switzerland, EST in UK,,,

Energy flow in GSHP system for heating

We need to know G, but most of information are on Q not G!

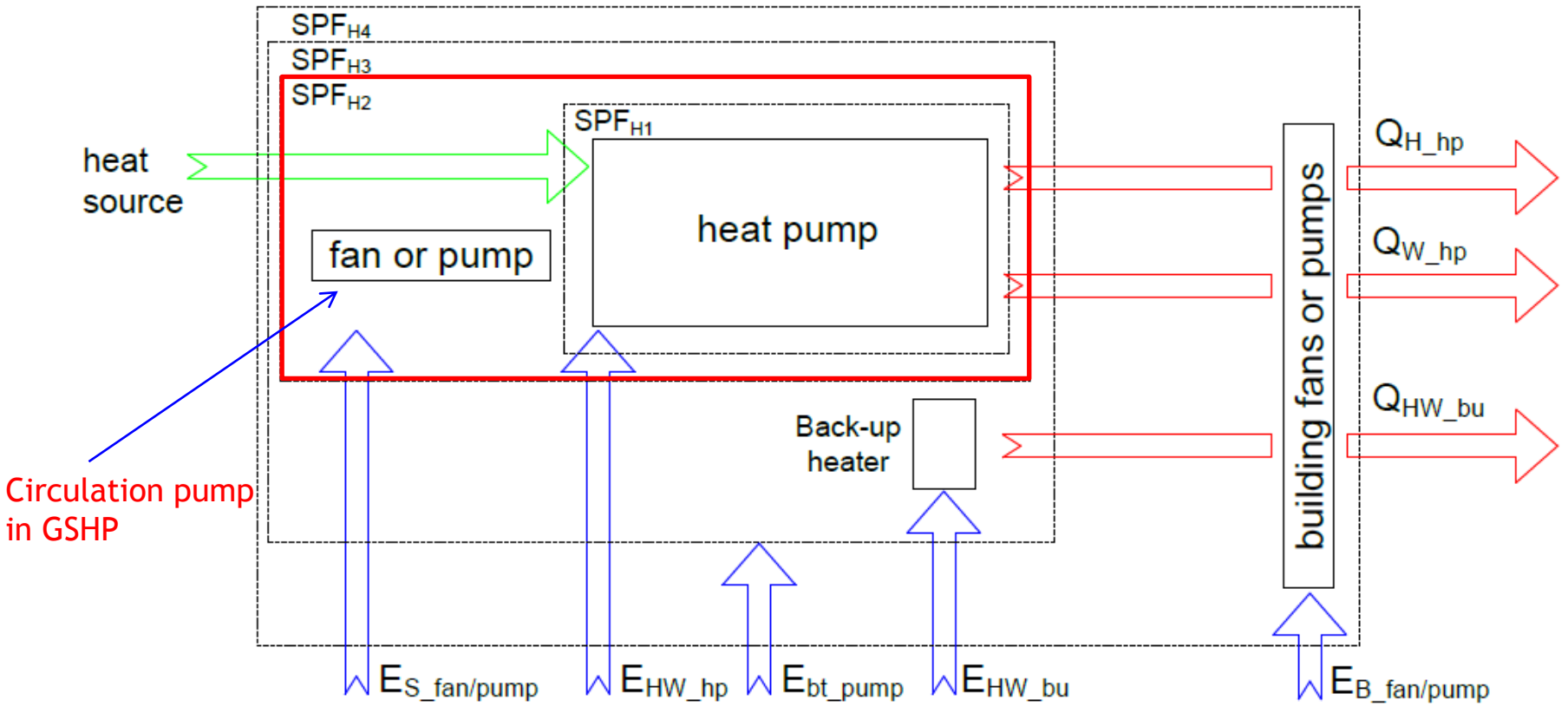




$$Q = G + E$$
$$COP = Q/E$$
$$G = Q \times (COP-1)/COP$$

cf> for cooling, $G = Q + E$

Definition of System boundaries

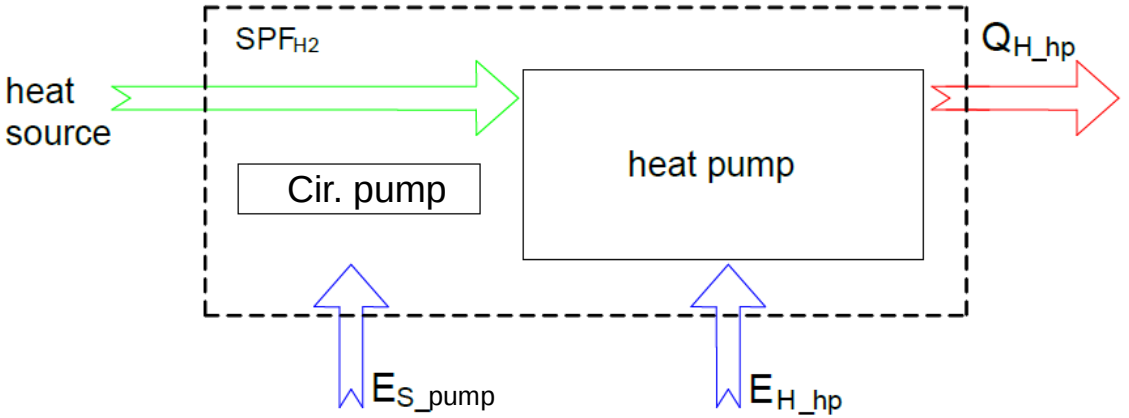


From the view point of geothermal,
we are interested in SPF_{H1} (COP) or SPF_{H2} (COP_{net})

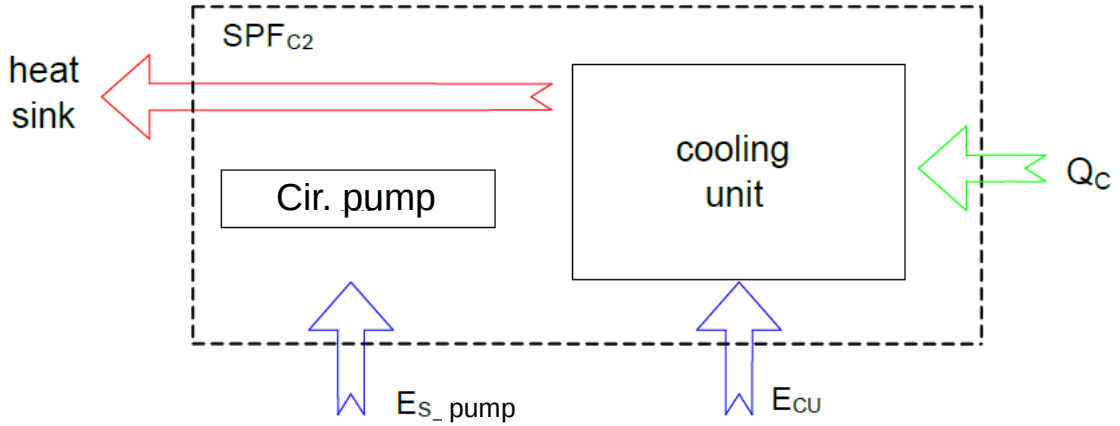
(SEPEMO build.)

For heat and cooling: SPF_{H2} vs. SPF_{C2} (COP_{net})

$$SPF_{H2} = \frac{Q_{H\_hp}}{E_{H\_hp} + E_{S\_pump}}$$



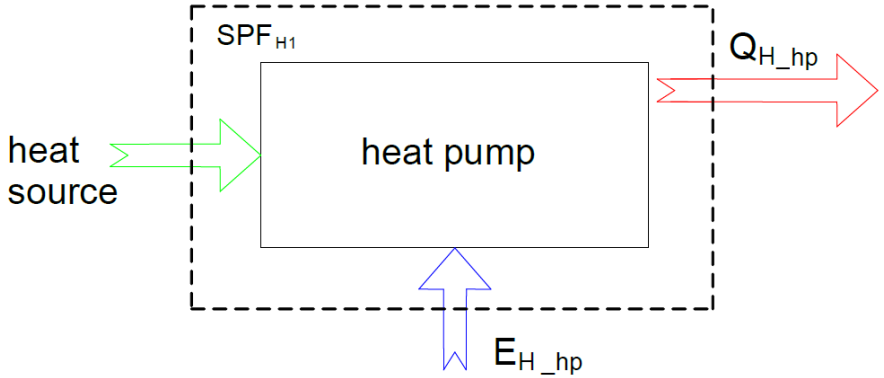
$$SPF_{C2} = \frac{Q_C}{E_{CU} + E_{S\_pump}}$$



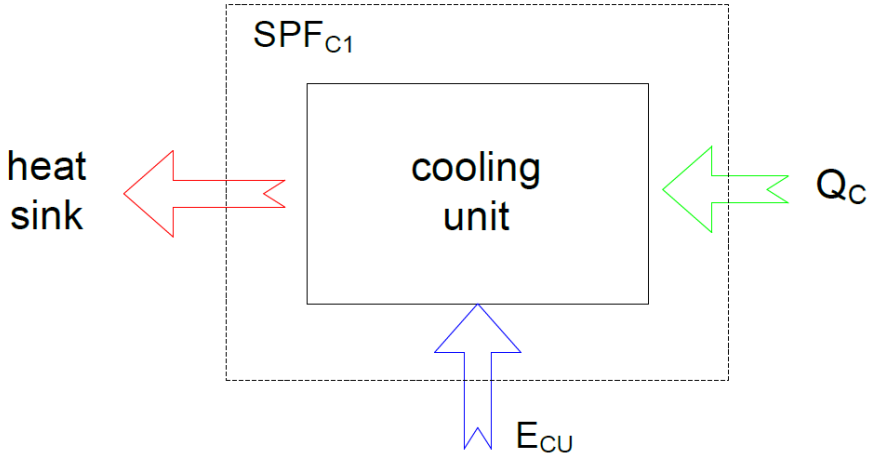
(SEPEMO build.)

For heat pump only: SPF_{H1} vs. SPF_{C1} (COP)

$$SPF_{H1} = \frac{Q_{H\_hp}}{E_{H\_hp}}$$



$$SPF_{C1} = \frac{Q_C}{E_{CU}}$$



(SEPEMO build.)

Energy production vs. Energy saving

- Geothermal energy utilization or production
  - $G_H = Q_H * (1-1/SPF_{H1})$
  - Concept of gross production
  - Coincides with WGC estimation
  - For cooling, $G_C = Q_C * (1-1/SPF_{C1})$: cooling energy with help of ground

- Energy saving or in the context of CO_2 emission reduction
  - We must consider electricity to run circulation pump: concept of net production
  - Coincides with E_{RES} of EU Directive 2009/28/EC
  - $E_H = Q_H * (1-1/SPF_{H2})$
  - $E_C = Q_C * (1-1/SPF_{C2})$

$\Rightarrow$ Now, the issue is how to estimate Q and SPF as accurate as possible

How to estimate energy production

- Direct calculation with measured data
  - Accurate estimation of thermal energy produced
  - Practically impossible to apply to all installations

- Estimates based on rated capacity of GSHP, COP (or SPF) and representative capacity factor
  - Practical way of estimating energy production
  - Very difficult to assign representative values of capacity factor according to use type
  - Electricity consumption must be considered because thermal output of GSHP is driven by electricity as well
  - Note: COP (or SPF_{C1}) for cooling is different from that of heating (SPF_{H1}) as capacity is

Direct Calculation

- Heat extracted from ground

$$Q_H = \int \dot{m}_H \times (T_{out} - T_{in}) \times C_p dt$$

- Heat rejected into ground

$$Q_C = \int \dot{m}_C \times (T_{in} - T_{out}) \times C_p dt$$

- in WGC report (heating only)
  - Annual Energy Use (TJ/yr) = Ave. flow rate in loop (kg/sec) × [inlet temp. (°C) – outlet temp (°C)] × 0.1319
  - cf> 4,184 × 3600 × 24 × 365 × 10^{-12} = 0.1319

  ⇒ This is only an approximate way since heating (and/or cooling) load changes according to season: difficult to get average flow rate

Possible (or practical) estimates

- Heat extracted from ground (usually in TJ/yr)

$$Q_H = C_p \sum_{m=1}^{12} \dot{m}_{H,ave}(m) \times \Delta T_{H,ave}(m) \times t_H(m) \times 10^{-12}$$

$$\cong Q_{rated,H} \frac{COP_H - 1}{COP_H} \sum_{m=1}^{12} L_{f,H}(m) \times hr_H(m) \times 10^{-9}$$

Equivalent full load hours/yr in WGC

- Cold energy with help of ground (TJ/yr)

$$Q_C \cong Q_{rated,C} \frac{COP_C - 1}{COP_C} \sum_{m=1}^{12} L_{f,C}(m) \times hr_C(m) \times 10^{-9}$$

$t(m)$: operating period (in seconds)
$hr(m)$: operating period (in hours)
Q_{rated} : rated capacity (in kJ/hr)
L_f : load factor

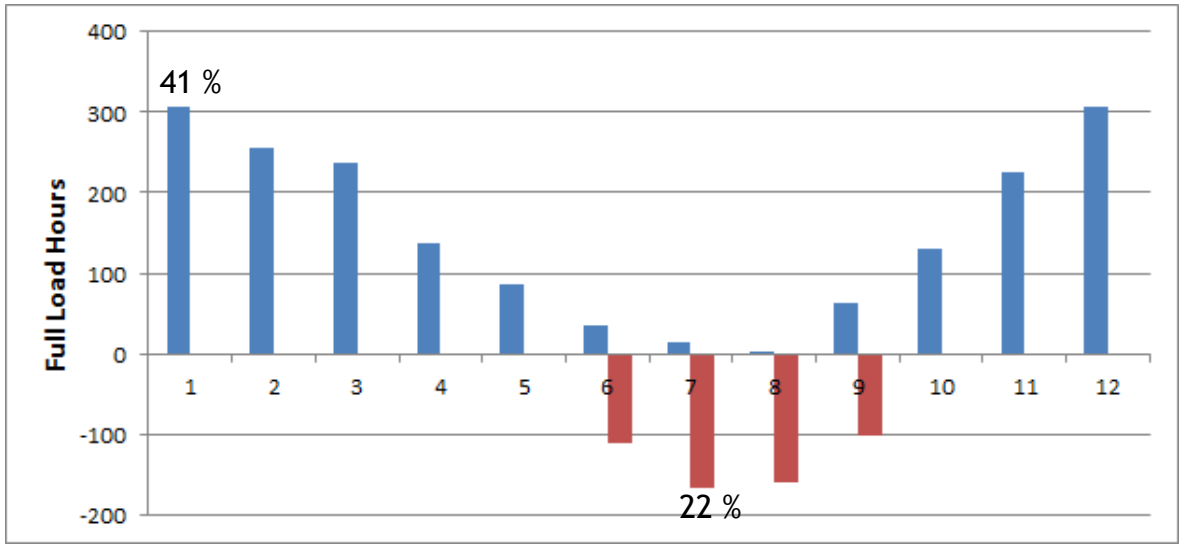
Note: Q_{rated} and *COP's* are accredited values by manufacturer or Energy Authority
(However, we still don't know COP_{net} or $SPF_{H2/C2}$)

Load factor?

- Actual load ÷ rated capacity (Q_{rated})
  - Can be estimated hourly values according to usage
  - Between 0 (no usage) and 1.0 (full load)
  - Hardly exceeds 0.9
  - Can be averaged over the month ⇒ monthly load factor L_f
- Useful to estimating capacity factor
  - Capacity factor: full load hours in year ÷ (24 × 365)
  - $CF = \Sigma(L_f \times hr) \ / \ (24 \times 365)$
  - CF is assumed to be 0.25 (= 2,200 full load hours) for residence builing in WGC report (heating only)
- Load factor significantly varies not only to season but also to usage (building type or crop type in greenhouse and so on,,,)

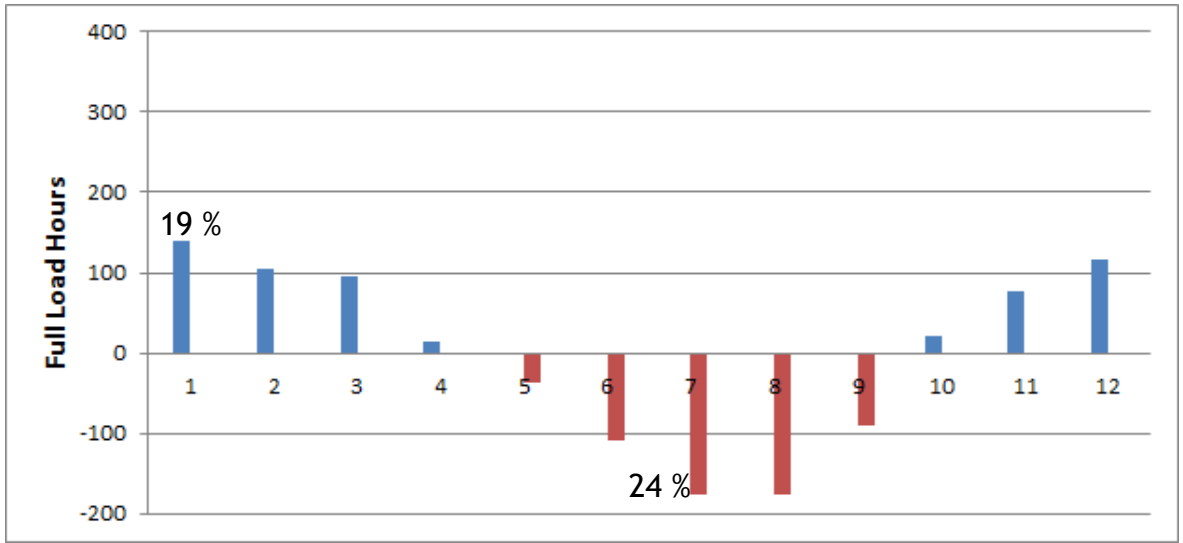
Load factor into full load hours:
An example in Korea

Residence Building (Apartment):
1,800 hrs for heating
540 hrs for cooling
⇒ CF = 0.27
(can be higher if we account for DHW or individual houses)



Office Building (City Hall):
570 hrs for heating
590 hrs for cooling
⇒ CF = 0.13
(10 hr/day, 21.5 day/m)

cf> 24×30 = 720



Example of Switzerland (1/2)

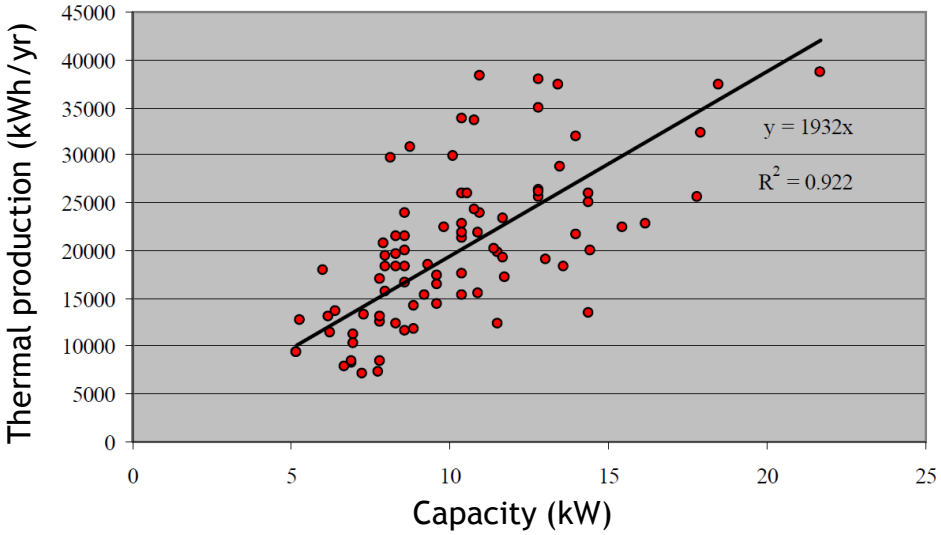
- Consider heating only
- Based on sales data and performance monitoring results:
  - Collect sales data and consider replacement rate
  - Categorize the type (brine/water or water/water) and size (<5 kW, 5-10 kW, 10-20 kW, 20-50 kW, 50-100 kW, 100-300 kW, >300 kW)
  - Apply 'standard running time' (full load hours) for calculating annual thermal production: 1,932 hr/yr for brine/water and 1,634 hr/yr for water/water
  - Apply climate condition with Heating Degree Days
  - Apply annual average SPF (COP=1.194 SPF) to estimating 'pure geothermal contribution'

Ref>

Geowatt AG, "Statistik der geothermischen Nutzung in der Schweiz, Ausgabe 2012"
Basics AG, 2007, "Erweiterung der schweizerischen Elecktrowärmepumpendtatistik"

Example of Switzerland (2/2)

- Discussion
  - Fairly reasonable approach
  - Cooling is not accounted for although they agree on the importance: free cooling must be separately considered
  - ‘Standard running time’ may not be accurate for bigger installation such as in large office building



For brine/water
(Basics, 2007)

Discussion: to make reasonable estimate

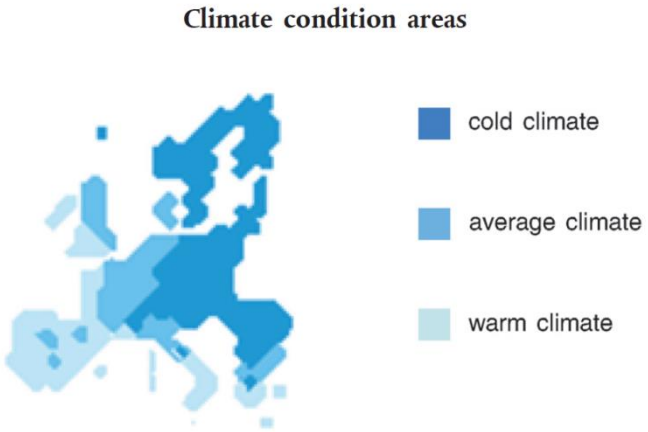
- Accurate statistics on GSHP installation
  - Not only for number of HP and total capacity, but also for category of installation or individual capacity
  - To determine test sites for long-term monitoring at each category (according to capacity or application)

- Monitoring of field data
  - To get representative load profile: separation of heating and cooling is important
  - To estimate representative $SPF_{H1/C1}$ and $SPF_{H2/C2}$

- Set a guideline and update
  - Pursueing comparable statistics to international standards
  - Annual update according to continuous monitoring results

If we don't have sufficient monitoring

- Example from EU Decision 2013/114/EU



	Warm		Average		Cold	
	H_{HP}	SPF_{H2}	H_{HP}	SPF_{H2}	H_{HP}	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

Note: this is for residential houses and cooling is not considered here, yet

What we are doing in IEA Geothermal?

- As a Task under Annex VIII: Direct Use of Geothermal Energy
  - To collect information on statistical methods of each country
  - To compare methods and information level
  - To device a guideline considering each country's available data

- Comparing to other guidelines or standards regarding HP
  - Our focus is not to validate the efficieny of GSHP
  - We try to make a reasonable estimate of GSHP uses in terms of
    - geothermal utilization (source side)
    - environmental benefits (load side)

- Why this is important?
  - To find accurate energy production by GSHP in geothermal utilization and world renewable energy uses
  - Accurate input to RHO (Renewable Heat Obligation)

Thank you for attention!

ありがとう
ございます!