ICTP

International Geothermal Association

Consiglio Nazionale delle Ricerche

International Union of Geodesy and Geophysics
IUGG
UGGI
Union Géodésique et Géophysique Internationale

International School on

'Geothermal Development'

December 7 - 12, 2015
(Miramare, Trieste, Italy)

DIRECT USES/HEAT PUMPS

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Unione Geotermica Italiana

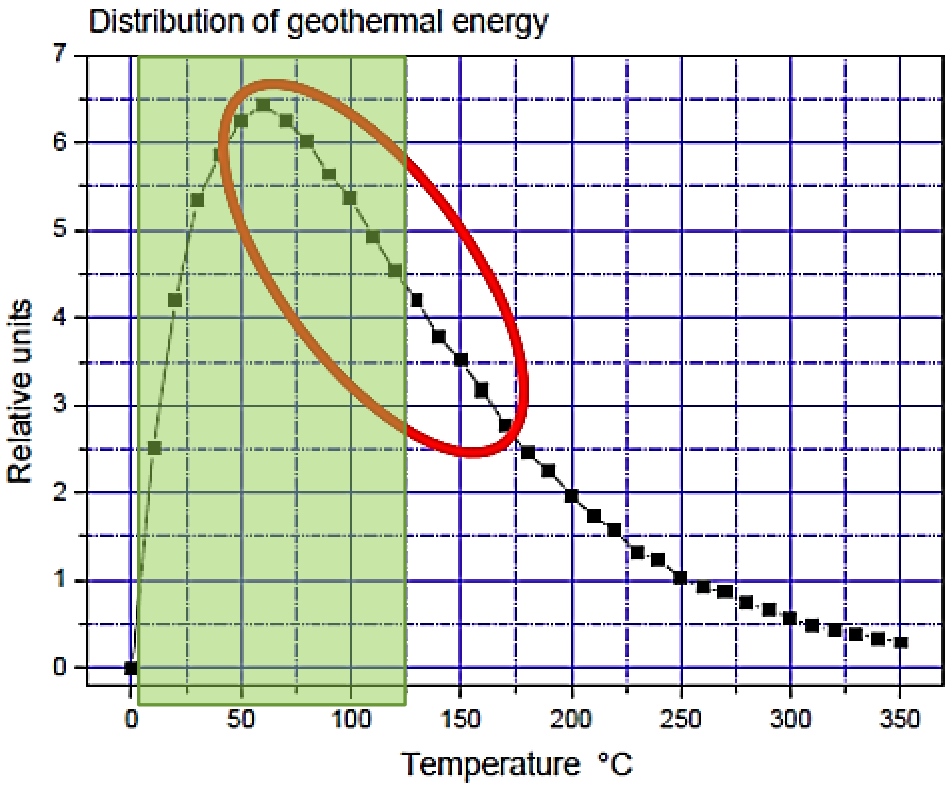
SUMMARY

1. Direct uses: brief introduction and statistical data
2. Traditional/handbook design approach
3. Advanced/optimized design
4. Examples of optimized design systems
5. Investment assessment of direct uses systems

MAIN TOPICS

1. Direct uses equipment, layouts, examples
2. Heat exchangers and hydraulic pumps
3. Cost-benefit optimization
4. Performance simulation
5. Economic and main financial indexes

DIRECT USES OF GEOTHERMAL ENERGY

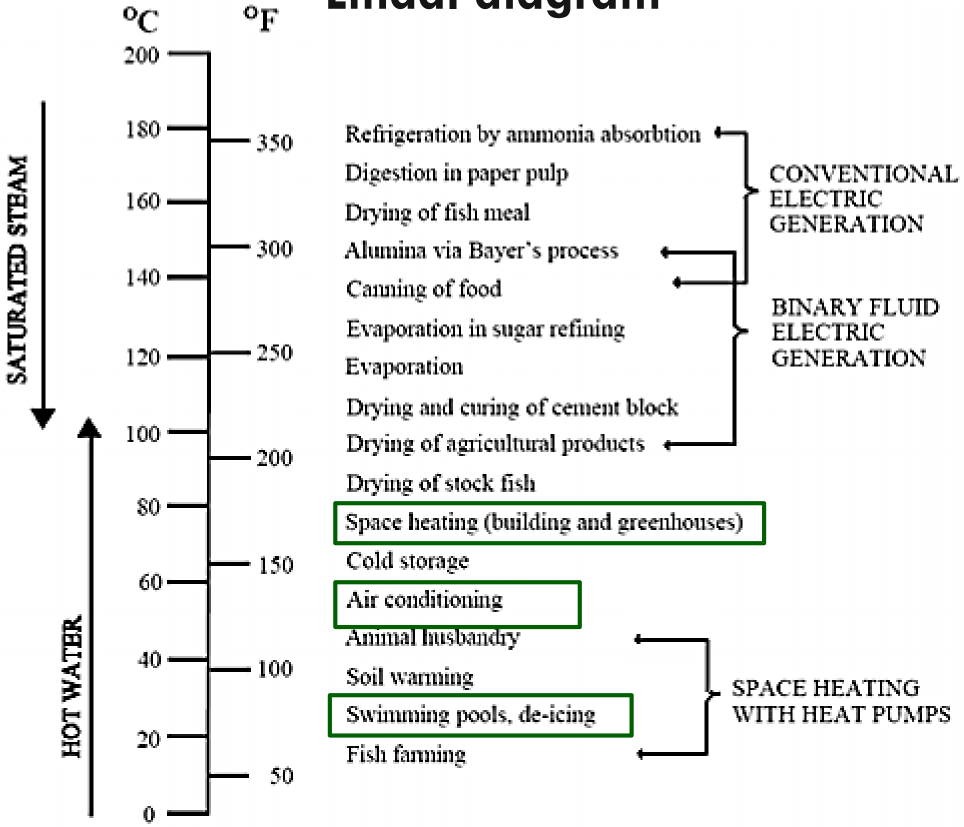


The figure shows worldwide distribution of geothermal energy as function of the resources temperature
(Stefansson, 2005)

More than 70 % of the geothermal resources available in the World are estimated to be water dominated fields at a temperature lower than150 ◦C

DIRECT USES OF GEOTHERMAL ENERGY

Lindal diagram



Heating loads correspond to more than 40% of global final energy consumption

Direct uses of geothermal energy have a notable potential in terms of:

- Fields of application (Lindal diagram)
- Worldwide expansion potential
- Energy saving
- Environmental benefit

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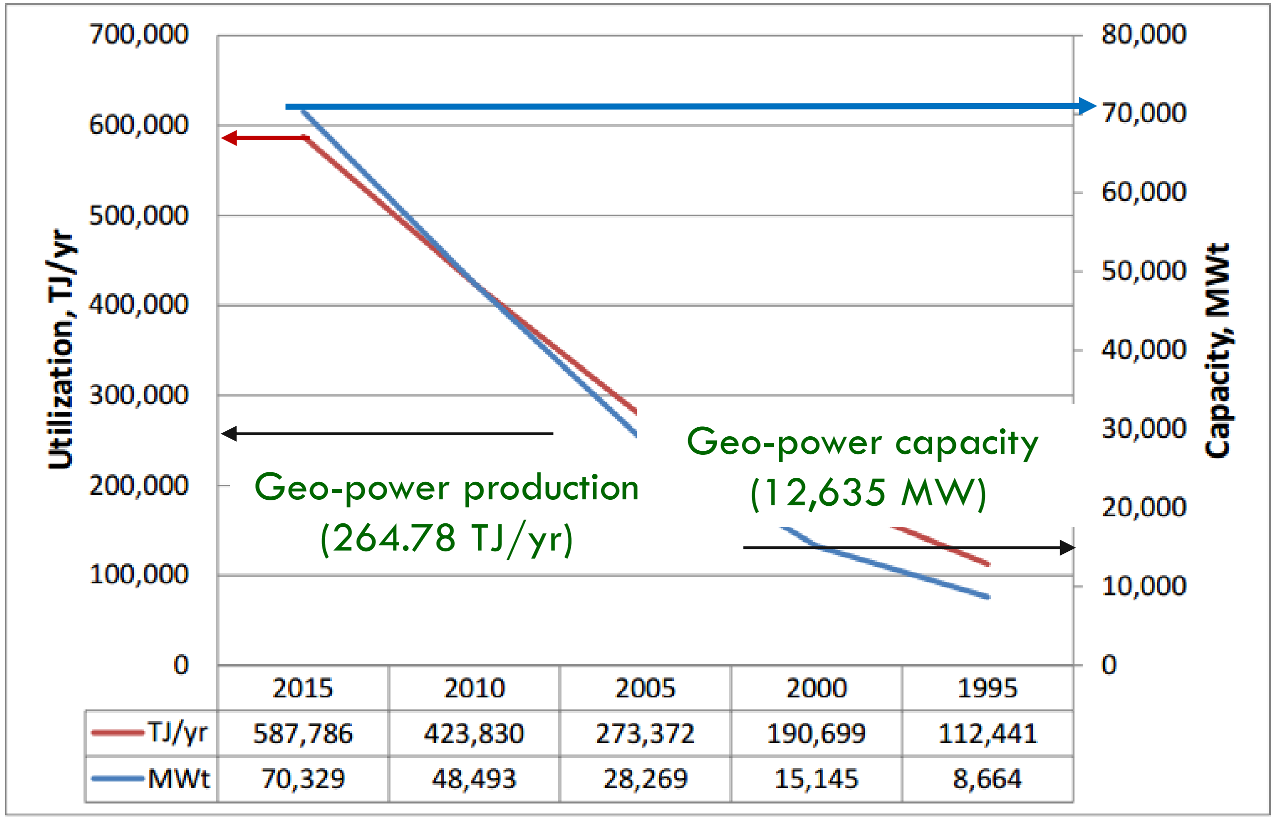
DIRECT USES OF GEOTHERMAL ENERGY

Worldwide geothermal energy statistics



Geo-power production (264.78 TJ/yr)

Geo-power capacity (12,635 MW)

	2015	2010	2005	2000	1995
TJ/yr	587,786	423,830	273,372	190,699	112,441
MWt	70,329	48,493	28,269	15,145	8,664

Data from (Bertani,2015) & (Lund&Boyd,2015)

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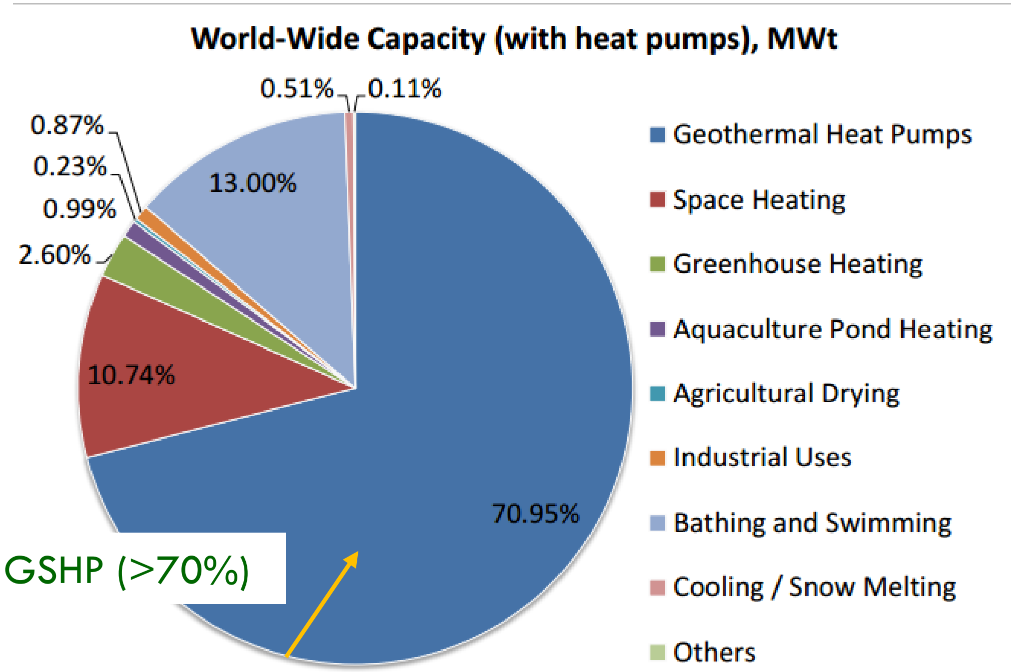
DIRECT USES OF GEOTHERMAL ENERGY

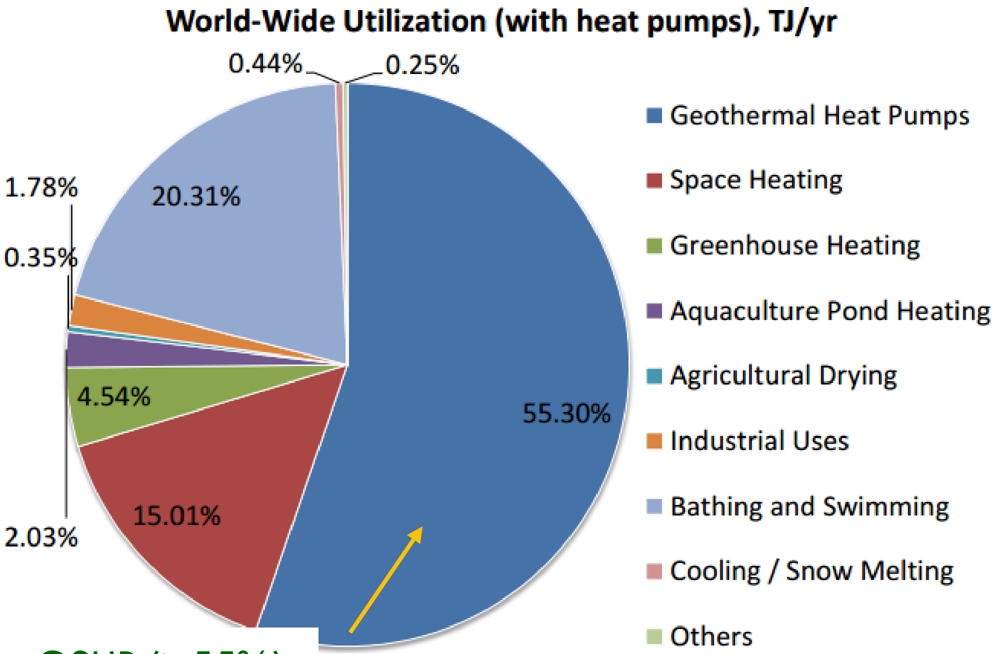
Geothermal direct applications worldwide in 2015 (Lund&Boyd,2015)

Capacity

Energy



GSHP (>70%)



GSHP (>55%)

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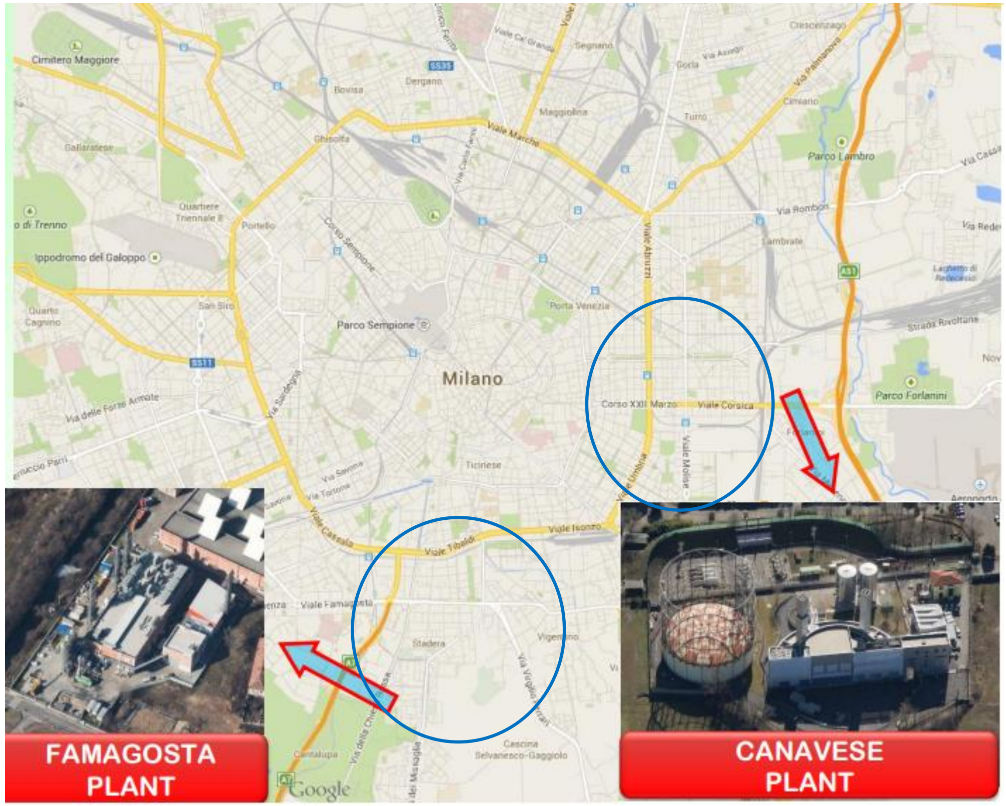
DIRECT USES OF GEOTHERMAL ENERGY

Sector of application	Capacity MW_{th}			Energy TJ/yr		
	TOTAL	GSHP	DHs	TOTAL	GSHP	DHs
Space heating	725	550	78	4 607	3 211	683
Thermal balneology	421	-	-	3 698	-	-
Agriculture uses	69	14	-	725	82	-
Fish farming	122	-	-	1 927	-	-
Industrial process heat + minor uses	18	4	-	108	25	-
TOTAL	**1,355**	**568**	**92**	**11,065**	**3,318**	-

Development of the different sectors of direct uses in Italy (2010-2014)

DIRECT USES OF GEOTHERMAL ENERGY

District Heating Systems (Milan, IT)



Operative parameters:

Technologies: CHP + GSHP + Boilers

GSHPs heating capacity: 2 x15.5 MW

Heat source: groundwater

Groundwater operative Temp (in/out): 15-7.6 °C

Aquifer depth: 12-35 and 7-8 m

Groundwater flow: 1,150 m3/h

End-user loop temperature (in/out): 65.0 / 90.0 °C

Heating water flow: 546 m3 /h

Operating since: 2009 and 2012

DIRECT USES OF GEOTHERMAL ENERGY

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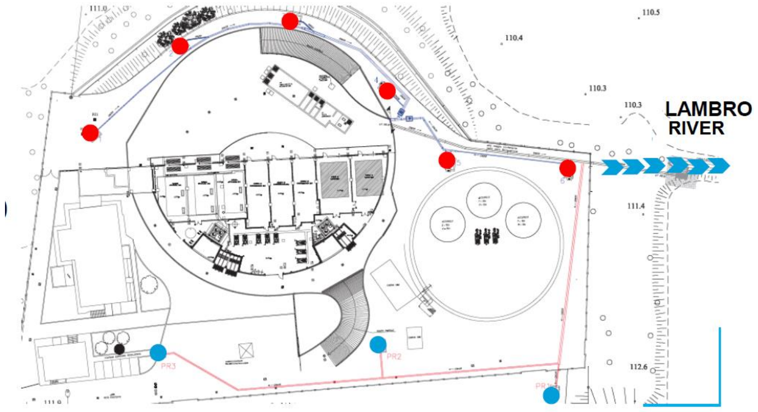
DIRECT USES OF GEOTHERMAL ENERGY

Canavese wells



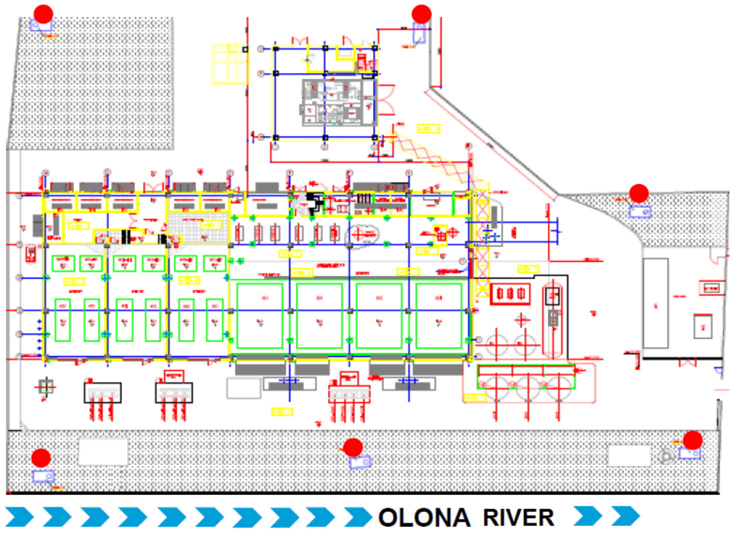
● Production wells

● Injection wells

Aquifer depth: 12-35 m

Nominal flow rate: 1000 m3/h

Famagosta wells



Aquifer depth: 7-8 m

Nominal flow rate: 1000 m3/h

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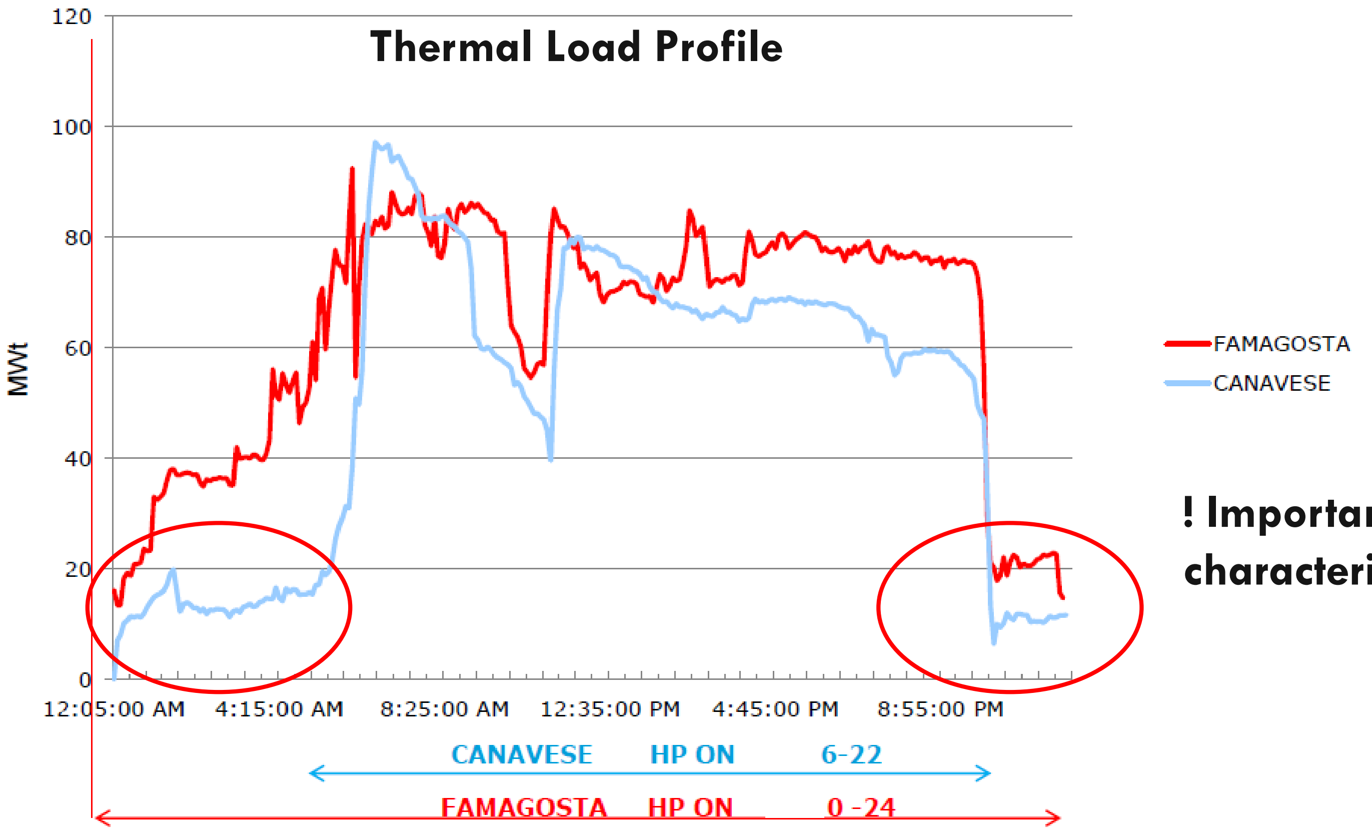
DIRECT USES OF GEOTHERMAL ENERGY



! Importance of equipment characteristics (ON/OFF units)

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DIRECT USES OF GEOTHERMAL ENERGY

[GWh]	2011	2012	2013
Total heat delivered by TLR	732.529	756.823 (+ 3%)	839.786 (+11%)
Heat delivered by GWHPs (Reference point #2)	48.392	56.559 (+ 17%)	61.538 (+ 9%)
Seasonal COP	2.64	2.64	2.65
Geothermal Energy use	30.061	35.135 (+ 17%)	38.316 (+ 9%)

! Importance of end-user loop temperature

- The evolution of the geothermal energy use is related to the load profile

DIRECT USES OF GEOTHERMAL ENERGY

District Heating Systems (Ferrara, IT)

Operative parameters:

Total capacity: 155 MW_{th}

Geothermal capacity: 14 MW_{th}

Operating temperature of the DH: 90 – 60 °C

Temperature of the geothermal fluid: 100-90 °C

DH length: ~56 km

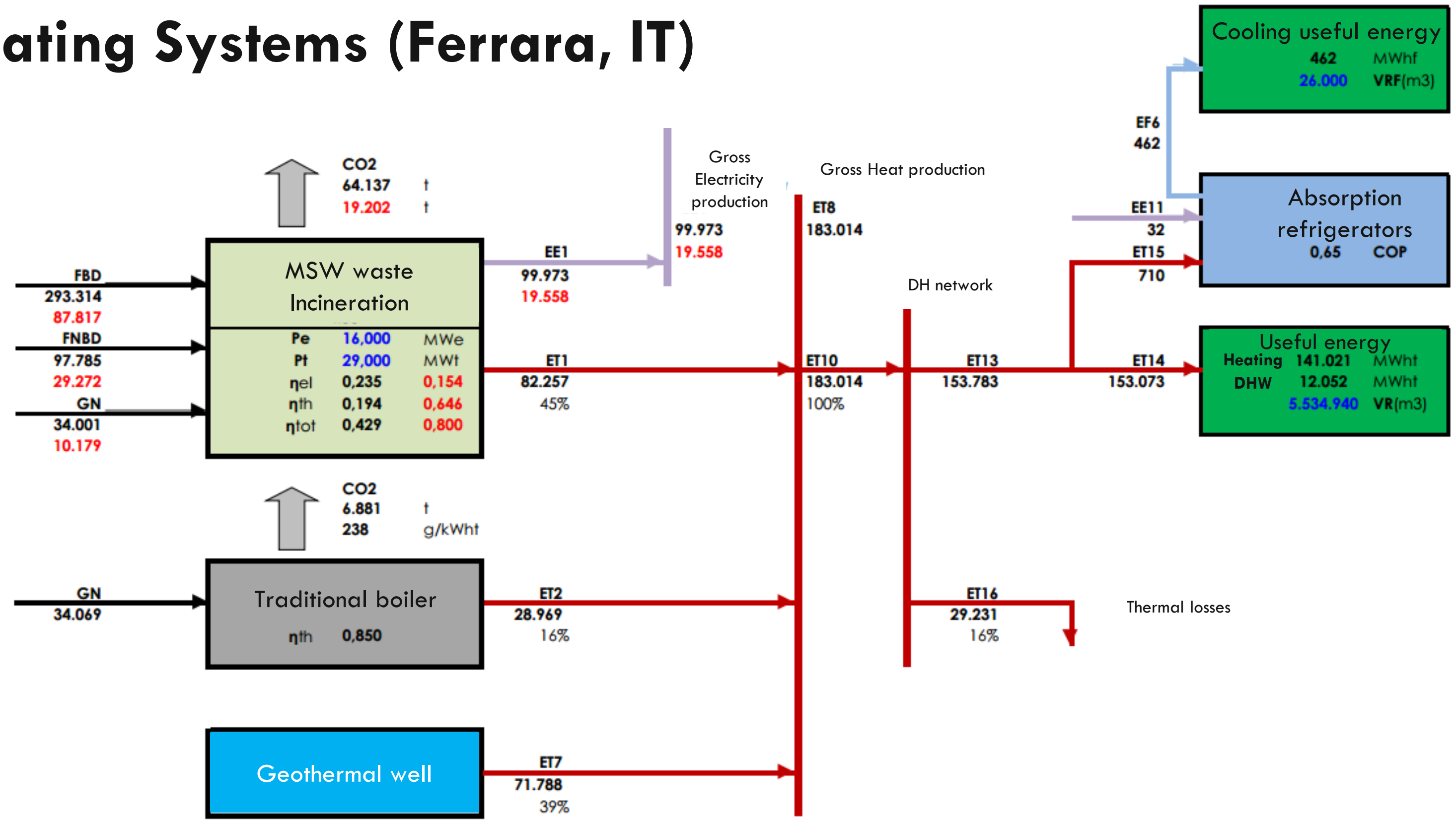
Total heated volumetry: 5.5 x 106 m3

Total thermal energy delivered to final users: >150 GWh/y ≈ 540 TJ/y

Total geothermal energy delivered:
72 GWh/260 TJ/y (gross) 60 GWh/216 TJ/y (net)

DIRECT USES OF GEOTHERMAL ENERGY

District Heating Systems (Ferrara, IT)



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DIRECT USES OF GEOTHERMAL ENERGY

Geothermal greenhouse (Piancastagnaio, IT)

The largest Italian and European greenhouse compound fed by geothermal energy is located in Mt. Amiata region, downstream of Enel's power plants.

Core business is tropical ornamental plants.

The main operation data in 2012 were as follows:

- Surface area: 230,000 m2
- Capacity installed: 35 MWth
- Geo-energy used : 450 TJ/y

DIRECT USES OF GEOTHERMAL ENERGY

	Euganean district *Veneto*	**Ischia** *Campania*
Total users [10^6 people]	3.5	1
Water used [m^3x10^6]	28	8
Water temperature [°C]	38-75	45-100
Energy used [TJ/yr]	1 200	350

	Montecatini Terme *Tuscany*	**Terme dei Papi** *Latium*
Total users [10^6 people]	1.6	1
Water used [m^3x10^6]	3.2	6
Water temperature [°C]	30	49-58
Energy used [TJ/yr]	90	240

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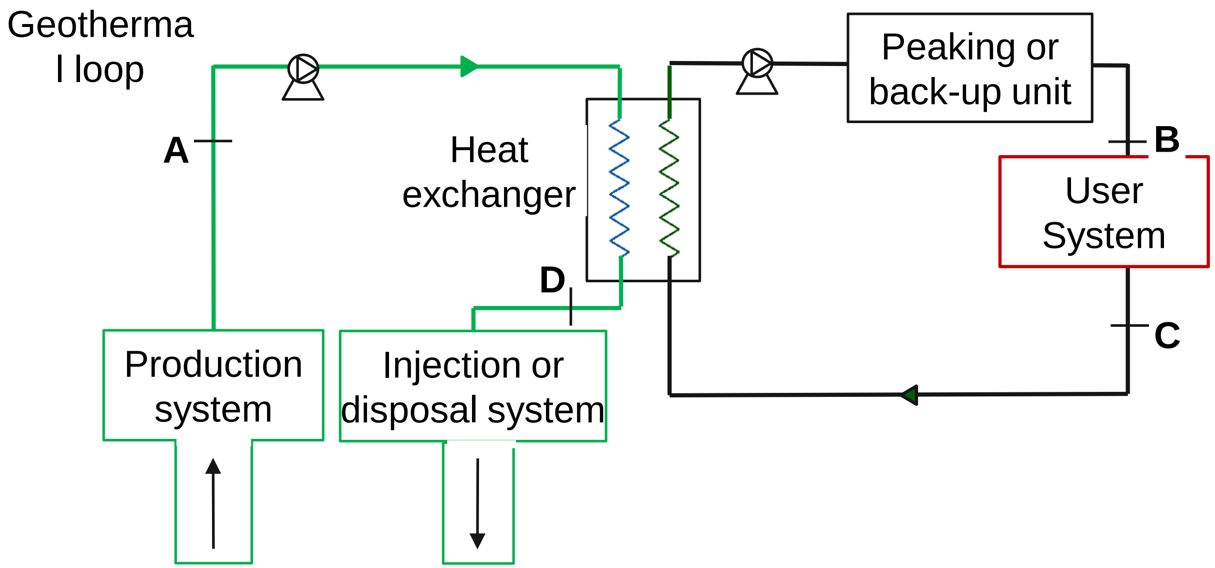
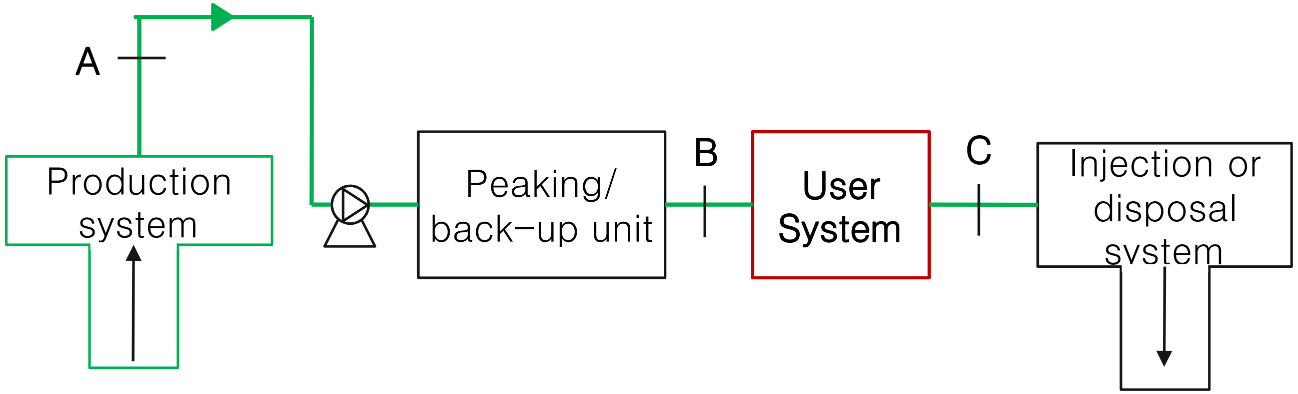
DIRECT USES OF GEOTHERMAL ENERGY



Direct use system with heat exchanger



Direct use without heat exchanger (e.g. balneology applications)

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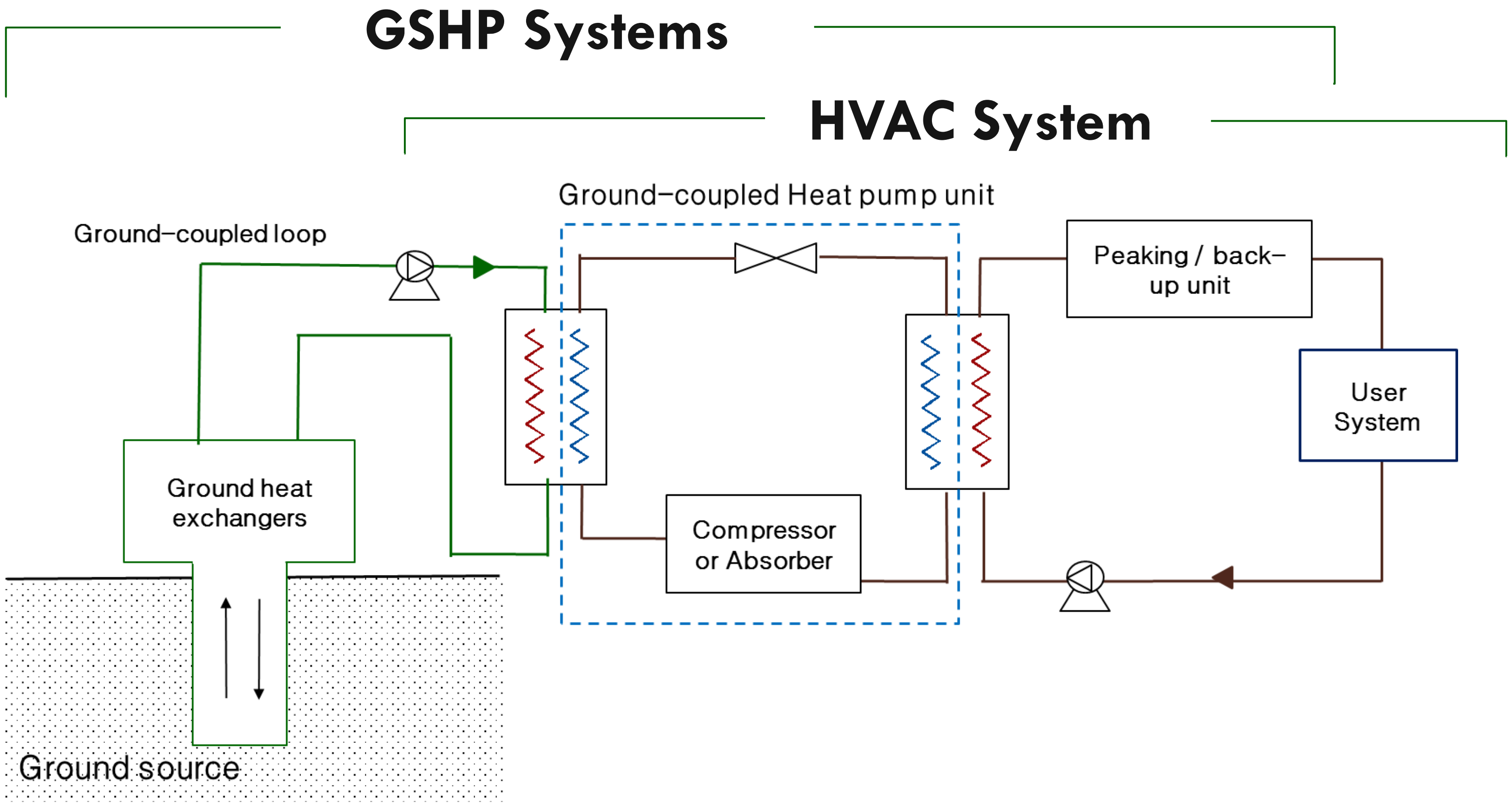
DIRECT USES OF GEOTHERMAL ENERGY

GSHPs: equipment layout



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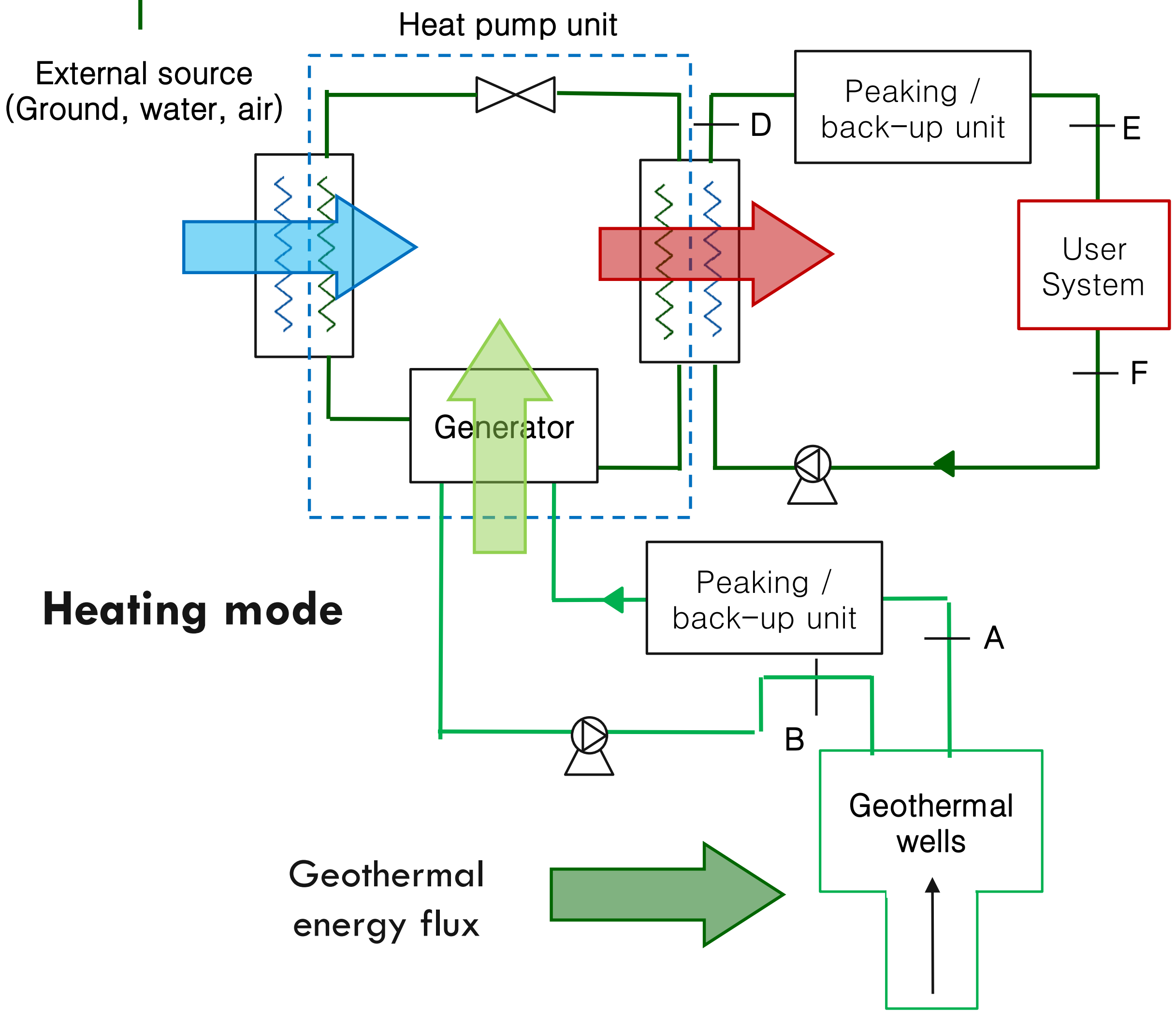
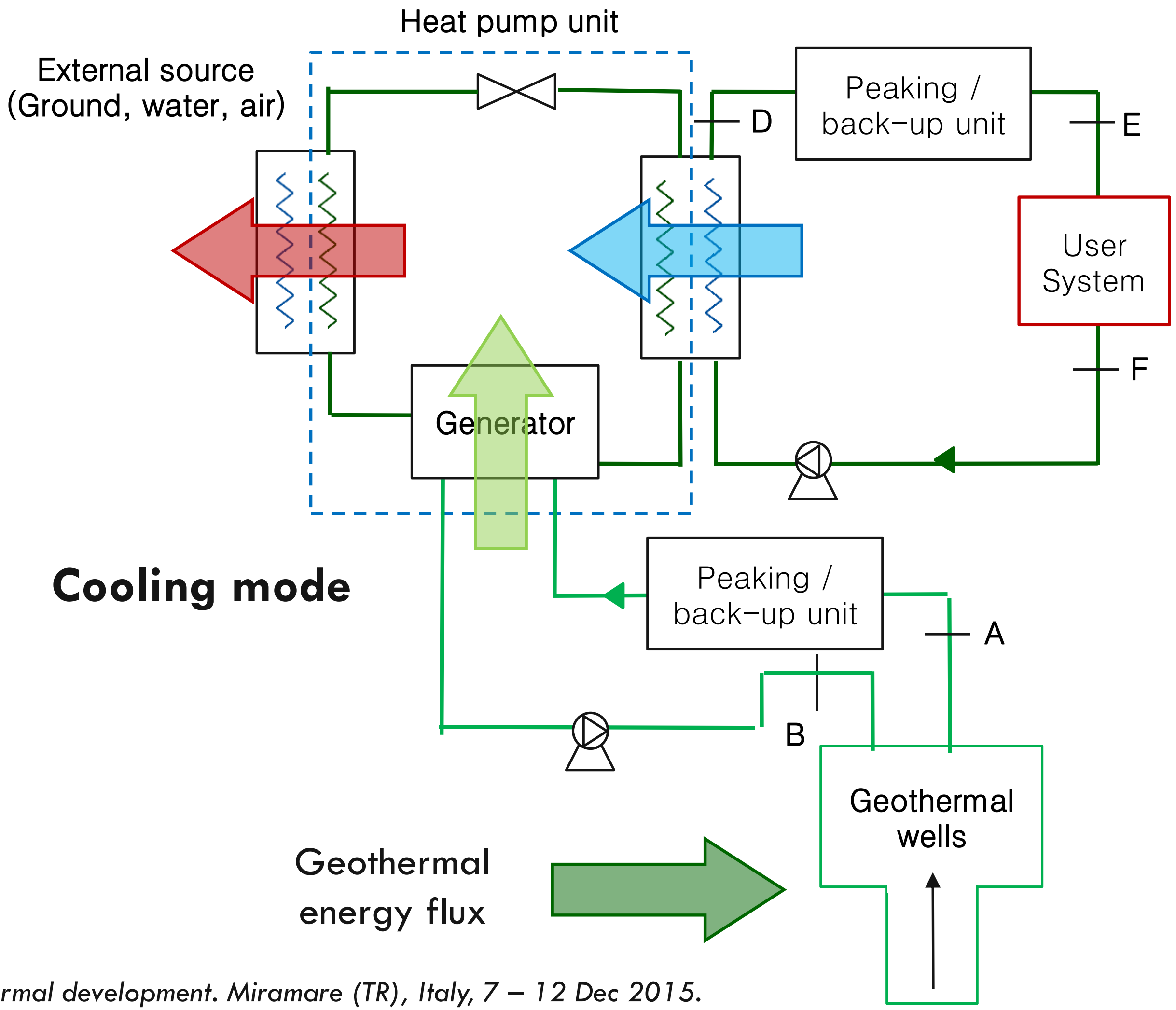
Heating mode



Cooling mode



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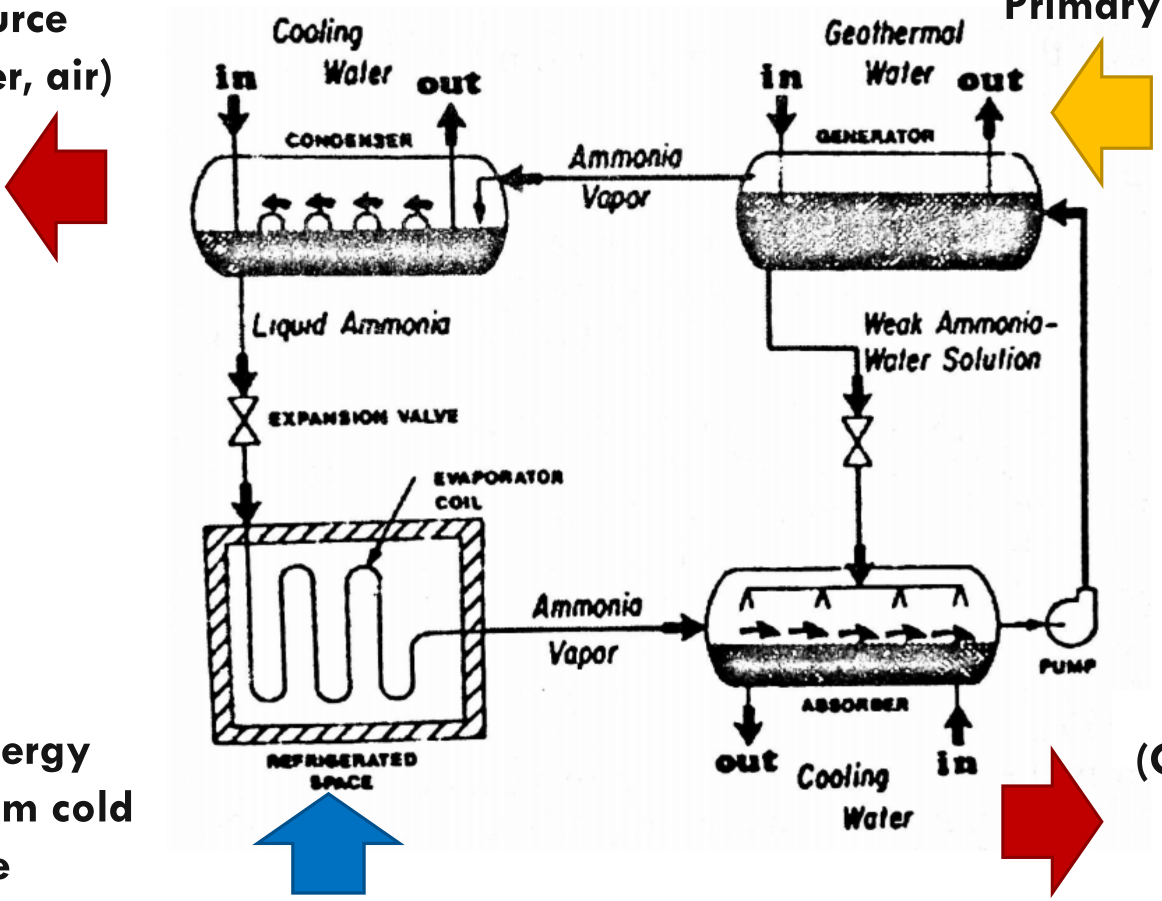
DIRECT USES OF GEOTHERMAL ENERGY



External source
(Ground, water, air)

Primary Energy

Usefull energy removed from cold source

External source
(Ground, water, air)

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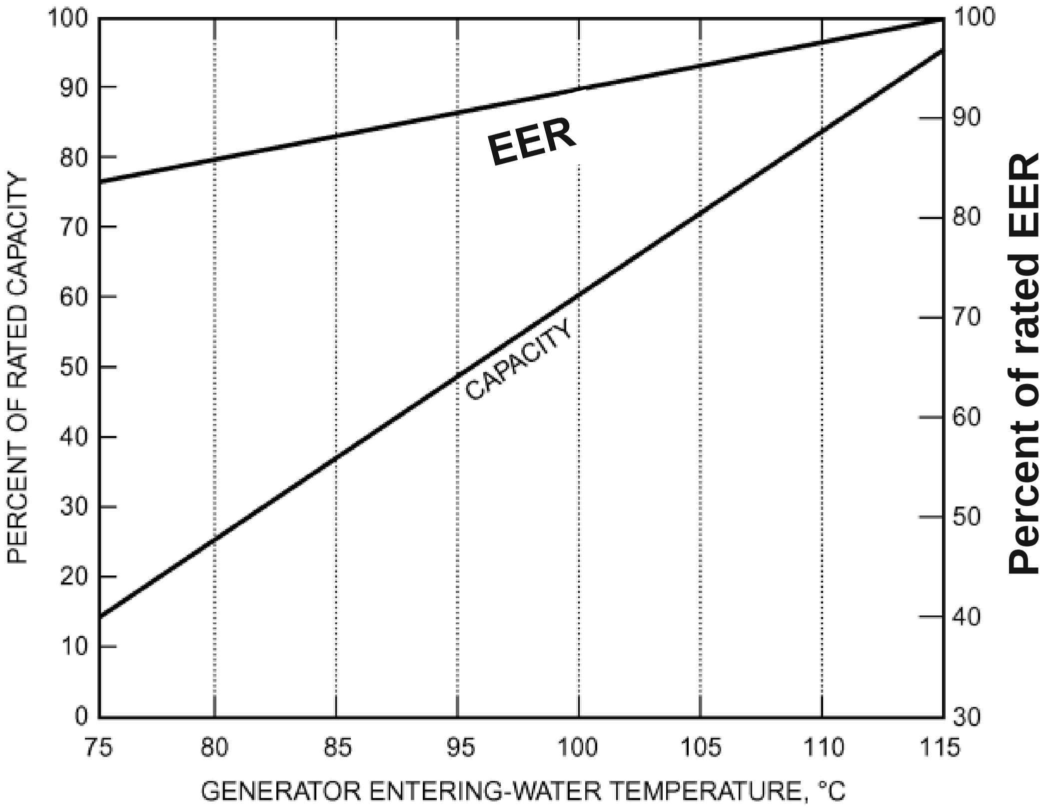
DIRECT USES OF GEOTHERMAL ENERGY



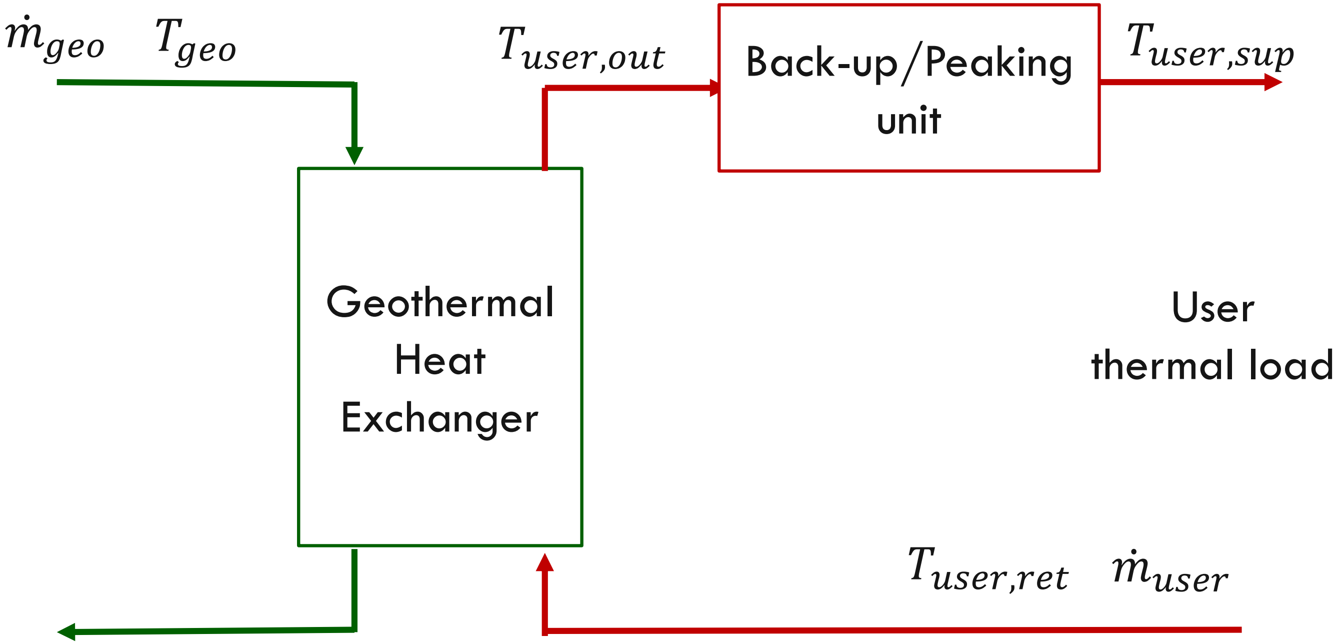
Typical Lithium Bromide Absorption Chiller Performance Versus Temperature

!PER of Absorption Chillers ≈ 0.6
!PER of vapor-compression unit ≈ 1.4 – 1.8

!EER of Absorption Chillers ≈ 0.6
!EER of vapor-compression unit ≈ 3.5 – 5.5

! Thermal energy cost should be ~6 time ess than electricity costs

DIRECT USES OF GEOTHERMAL ENERGY



! Rough analysis / ! First-order evaluation

$c_{f,bk}$ - \$/kWh	Unitary costs of standard fuel (avoided energy consumption)
L – kWh	Annual energy demand
$\dot{m}_{geo}$, T_{geo}	Geo-resource characteristics
$T_{user,ret}$	Operational return temperature from user loop
ϵ	Geo Hex effectiveness

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INVESTMENT ASSESSMENT OF DIRECT USES SYSTEMS

A

B

C

$$T_{geo} > T_{user,ret}$$

A – Radiators

$$T_{user,ret} \approx 50 - 70\ °C$$

B – Fancoils

$$T_{user,ret} \approx 30 - 40\ °C$$

C – Radiant floor

$$T_{user,ret} \approx 20 - 30\ °C$$

DIRECT USES OF GEOTHERMAL ENERGY

Heat exchanger basic theory

Capacity rate ratio:

$$C^* = \frac{C_{\min}}{C_{\max}} \qquad (0 \leq C^* \leq 1)$$

Exchanger heat transfer effectiveness:

$$\epsilon = \frac{q}{q_{\max}} \qquad (0 \leq \epsilon \leq 1)$$

$$q_{\max} = C_c(T_1 - t_1) \qquad (C_c < C_h)$$

$$q_{\max} = C_h(T_1 - t_1) \qquad (C_h < C_c)$$

DIRECT USES OF GEOTHERMAL ENERGY

Heat exchanger basic theory

Number of transfer units:

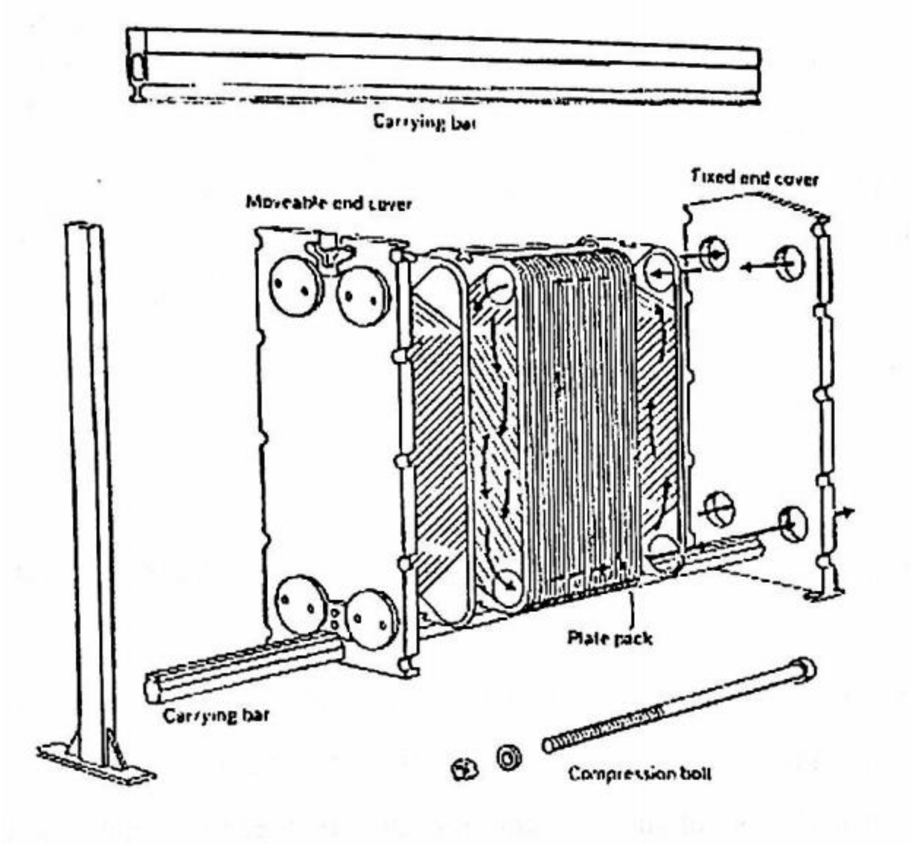
$$N_{\mathrm{tu}} \equiv \frac{US}{C_{\min}} = \frac{1}{C_{\min}} \int_S U\,dS$$

Actual heat transfer performances

$$\epsilon = \frac{q}{q_{\max}} = \frac{C_h(T_2 - T_1)}{C_{\min}(T_1 - t_1)} = \frac{C_c(t_2 - t_1)}{C_{\min}(T_1 - t_1)} \qquad \epsilon = f\,(C^*, N_{\mathrm{tu}}, \text{flow arrangement})$$

DIRECT USES OF GEOTHERMAL ENERGY

PLATE AND FRAME HEAT EXCHANGERS



(Yesin, 1997)

Advantages:

Low space requirede («performance density»): 100-200 m^2/m^3
Low temperature approach: 1-2 K
High overall heat tranfer coefficient: **3000-8000 W/(m2 K)**
Low corrosion rate: <0.05 mm/yr

General disadvantages :

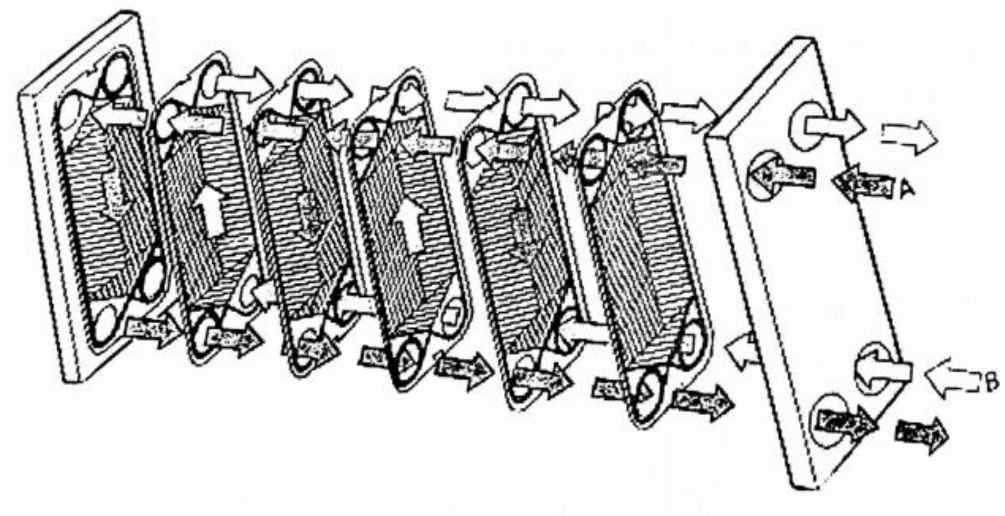
Work pressure: < 25 bar
Work temperature: < 200 °C

! Suitable solution for geothermal applications

DIRECT USES OF GEOTHERMAL ENERGY

PLATE AND FRAME HEAT EXCHANGERS

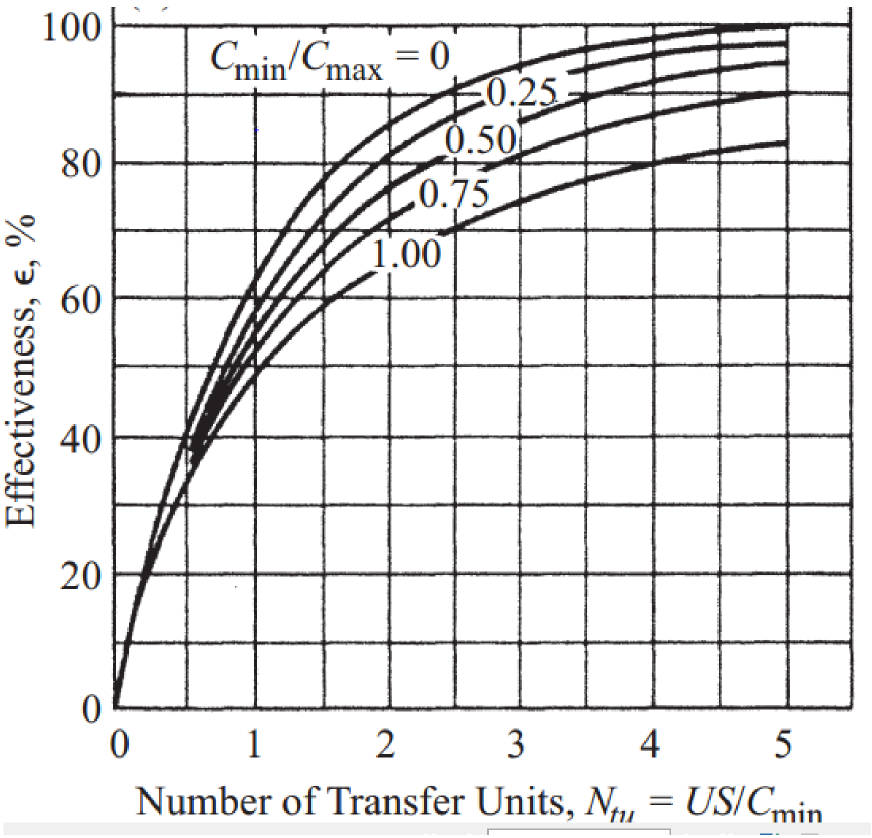
(Yesin, 1997)



Indicative data:

Frame Material: Carbon Steel
Bolt Material: High tensile steel
Heating Surface Area: 0.1-2200 m2
Number of Plates: 30 – 500
Fluid Flow Rates: 4-3600 m3/h
Diameter of Connections: 12-500 mm
Plate Thickness: 0.5 - 1.2 mm
Overall Heat Transfer Coefficient: 3000 - 7000 W/m/K
NTU: 0.3 – 4
Pressure drop: 30 kPa per NTU

DIRECT USES OF GEOTHERMAL ENERGY



Costs:

An example of a typical correlation between HE cost and HE surface:

$$C = 401\ A^{0.4887} \quad \text{stainless steel}$$
$$C = 612\ A^{0.4631} \quad \text{titanium}$$

C - $

(Haslego&Polley, 2002)

A – Surface ft^2

Optimal design criterion

According to heat transfer physics, large **heat transfer surfaces** result in better **performances** (till saturation), but also additional **installation and operative costs** (head losses)

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DIRECT USES OF GEOTHERMAL ENERGY

Pump power

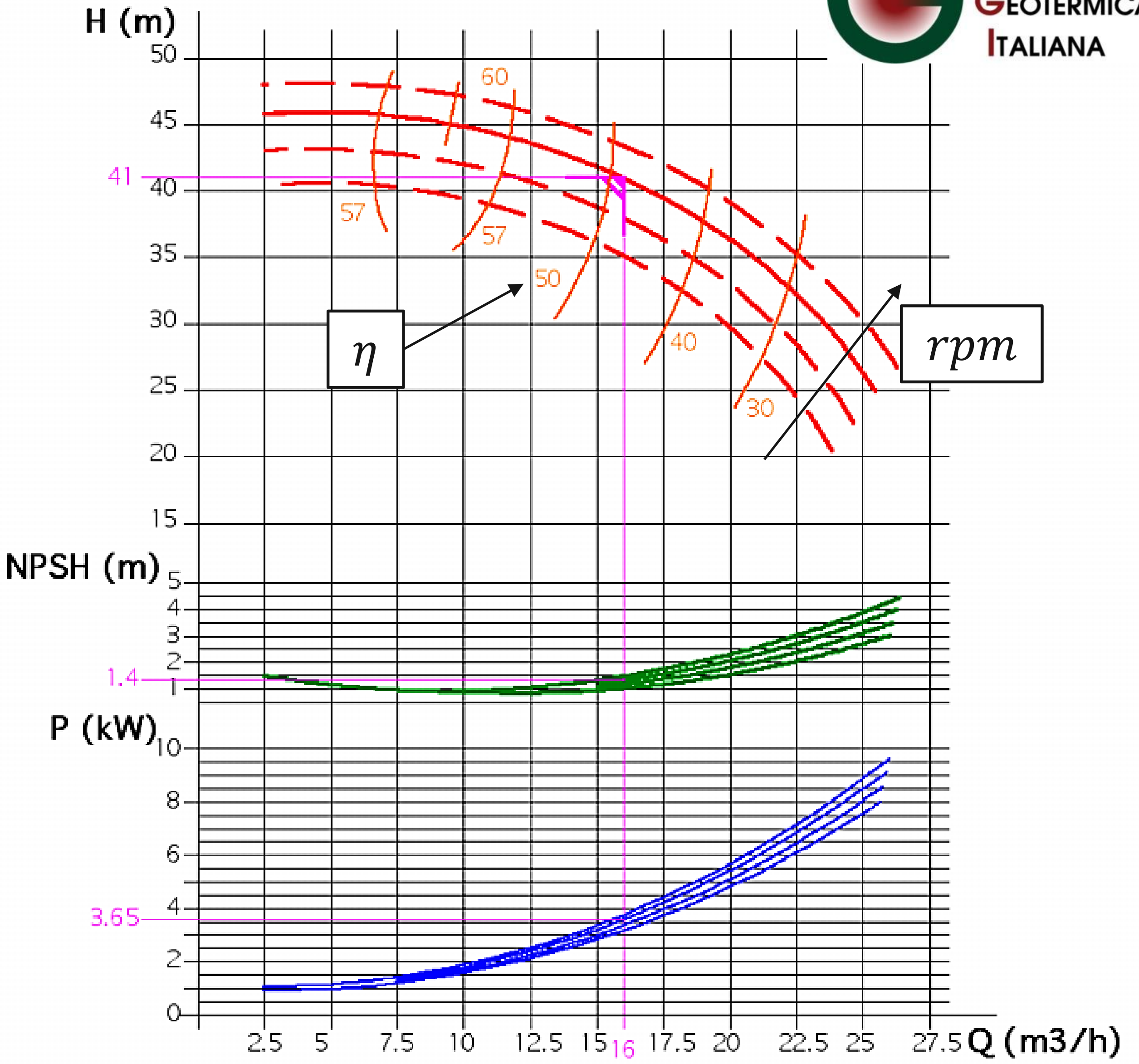
Hydraulic power

$$W_{id} = \rho \dot{Q} H\, g = \left[\frac{\text{kg}}{\text{m}^3}\right]\left[\frac{\text{m}^3}{\text{s}}\right][\text{m}]\left[\frac{\text{m}}{\text{s}^2}\right] = [\text{W}]$$

Electric input power

$$W_{in} = \frac{W_{id}}{\eta}$$

Indicative η values	W_{in} - kW	η
Circulator pumps	<0.1	0.1-0.25
	0.1 – 0.5	0.2 – 0.4
	0.5 – 2.5	0.3 – 0.5
Electro-mechanic pumps	<1.5	0.3-0.6
	1.5-7.5	0.35 – 0.75
	7.5 - 45	0.4 – 0.75



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DIRECT USES OF GEOTHERMAL ENERGY

High levels of exploitation result in an excessive alteration of the ground temperature resulting in GHP efficiency decrease
(i.e. high operative costs)

Large heat transfer surfaces are required to minimize the impact of heat removal/injection from the source
(i.e. high installation costs)

Low levels of exploitation do not take advantage of a favorable thermal source, reducing overall system efficiency (i.e. high operative costs)

TRADITIONAL/HANDBOOK DESIGN PROCEDURE

$$\boxed{CR = \frac{Useful\ energy}{Nominal\ capacity} \propto \frac{Energy\ (Economic)\ savings}{Instalation\ costs}}$$

Primary energy savings

Thermal load is delivered with lower primary energy consumption than alternative technologies

Back-ups and auxiliaries performances should be considered

Main parameters affecting direct geothermal applications performances are:

- Temperature of geothermal fluid
- Pumpung energy
- Temperature of the ground source and end-user loop
- Capacity ratio (i.e. thermal load evolution)

Economic profitability

Installation costs:

- Equipment retail and drilling costs

Operative costs:

- Energy savings
- Prices/Fares of electricity and natural gas

Other non-technical parameters:

- Inflation of energy prices
- Evolution of retail prices (i.e. market situation)
- Operators fees
- Possible financial incentives

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TRADITIONAL/HANDBOOK DESIGN PROCEDURE

1. **Building thermal load analysis:** peak loads and energy needs
2. **Characterization of the ground source:** Thermal Response Test, pumping test
3. **Sizing of the heat generation system:** primary heat exchanger, ground-coupled heat pump(s) and back-up(s) generators
4. **Design of the ground-coupled system:** ground heat exchangers, ground-coupled loop, pumping devices

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TRADITIONAL/HANDBOOK DESIGN PROCEDURE

TRADITIONAL/HANDBOOK DESIGN PROCEDURE FOR GSHPs

1. Calculate reference cooling and heating loads, and estimate off-peak loads;
2. Evaluate annual heat extraction from and rejection to the ground through an estimation of seasonal COP, seasonal EER, and equivalent full load hour in cooling and heating mode
3. Select operative temperatures of the circulating fluid within the BHEs
4. Select ground-coupled heat pump(s) according to a proper share of cooling and/or heating loads
5. Design pipework apparatus aiming at minimizing duct costs and hydraulic losses
6. Conduct site survey to determine ground thermal properties and drilling conditions
7. Determine and evaluate possible BHE field arrangements that are likely to be optimum for the specific building and site (bore depth, separation distance, completion methods, annulus grout/fill, and header arrangements);
8. Determine ground heat exchanger dimensions;
9. Iterate and optimize to evaluate alternative operative temperatures, flow rates, BHEs arrangement, etc;
10. Design end user-loop
11. Select auxiliaries (e.g. pumps). If pumping energy exceeds 8 % of the total system demand different loop layouts should be investigated.

TRADITIONAL/HANDBOOK DESIGN PROCEDURE

ASHRAE method

ASHRAE method is the worldwide reference methodology for BHEs sizing (*ASHRAE 2011*)

ASHRAE method uses two similar equations to evaluate the necessary BHE depth in heating and cooling mode. The final borehole size corresponds to the larger one.

$$H_{BHE,H} = \frac{\dot{Q}_a R_{g,a} + \left(\dot{Q}_{lh} - \dot{W}_h\right)\left(R_b + PLF_m R_{g,m} + R_{g,d} F_{sc}\right)}{T_g^0 - \frac{T_{w,in} + T_{w,out}}{2} - T_p}$$

$$H_{BHE,C} = \frac{\dot{Q}_a R_{g,a} + \left(\dot{Q}_{lc} - \dot{W}_c\right)\left(R_b + PLF_m R_{g,m} + R_{g,d} F_{sc}\right)}{T_g^0 - \frac{T_{w,in} + T_{w,out}}{2} - T_p}$$

TRADITIONAL/HANDBOOK DESIGN PROCEDURE

(UNI, 2012)

Horizontal GCHPs

$$L_{h,p} = \frac{\dot{Q}_{g,h_D} \times (R_p + R_g \times P_m \times S_m \times F_h)}{\theta_{g,L} - \left(\frac{\theta_{wi} + \theta_{wo}}{2}\right)_{h_D}}$$

$$L_{c,p} = \frac{\dot{Q}_{g,c_D} \times (R_p + R_g \times P_m \times S_m \times F_c)}{\theta_{g,H} - \left(\frac{\theta_{wi} + \theta_{wo}}{2}\right)_{c_D}}$$

Rp: ducts thermal resistance

Rg: effective ground thermal resistance

Pm: correction factor due to pipe diameter

Sm: correction factor due to trenches distance

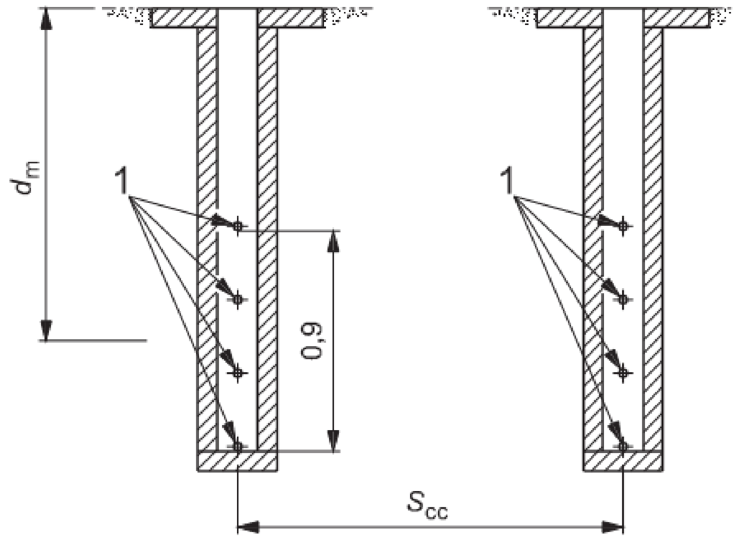
Fh,c: Part load factor during the design month

TRADITIONAL/HANDBOOK DESIGN PROCEDURE

Thermal conductivity	Ground resistance	# trenches	S_m			
λ_g	R_g		(S_{cc}) (m)			
W/(m K)	(m K)/W		3,35	2,74	2,13	1,52
0,35	4,22	2	1,01	1,03	1,07	1,15
		4	1,02	1,05	1,11	1,24
		6	1,02	1,05	1,12	1,27
0,87	1,89	2	1,04	1,07	1,12	1,21
		4	1,06	1,11	1,2	1,38
		6	1,06	1,12	1,23	1,44
1,30	1,31	2	1,05	1,09	1,15	1,23
		4	1,08	1,14	1,24	1,43
		6	1,09	1,15	1,27	1,5
1,73	1,00	2	1,06	1,1	1,16	1,25
		4	1,1	1,17	1,27	1,47
		6	1,12	1,18	1,31	1,55
2,42	0,73	2	1,07	1,11	1,17	1,26
		4	1,11	1,18	1,3	1,5
		6	1,13	1,2	1,35	1,6

(UNI, 2012)

1 Pipes
dm≈2 m (indicative)



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TRADITIONAL/HANDBOOK DESIGN PROCEDURE

Groundwater wells - TRADEOFF

An open-loop system design focuses on well pumping power and heat pump/heat transfer performances

As groundwater flow increases, more favorable average temperatures occur within the heat exchanger (i.e. reduced temperature drop)

As groundwater flow increases, pump power requirements increase.

At some point, additional increases in groundwater flow result in a greater increase in well pump power than the resulting heat pump efficiency decreases

The key strategy in open-loop system design is identifying the point of maximum system performance with respect to heat pump and well pump power requirements.

TRADITIONAL/HANDBOOK DESIGN PROCEDURE

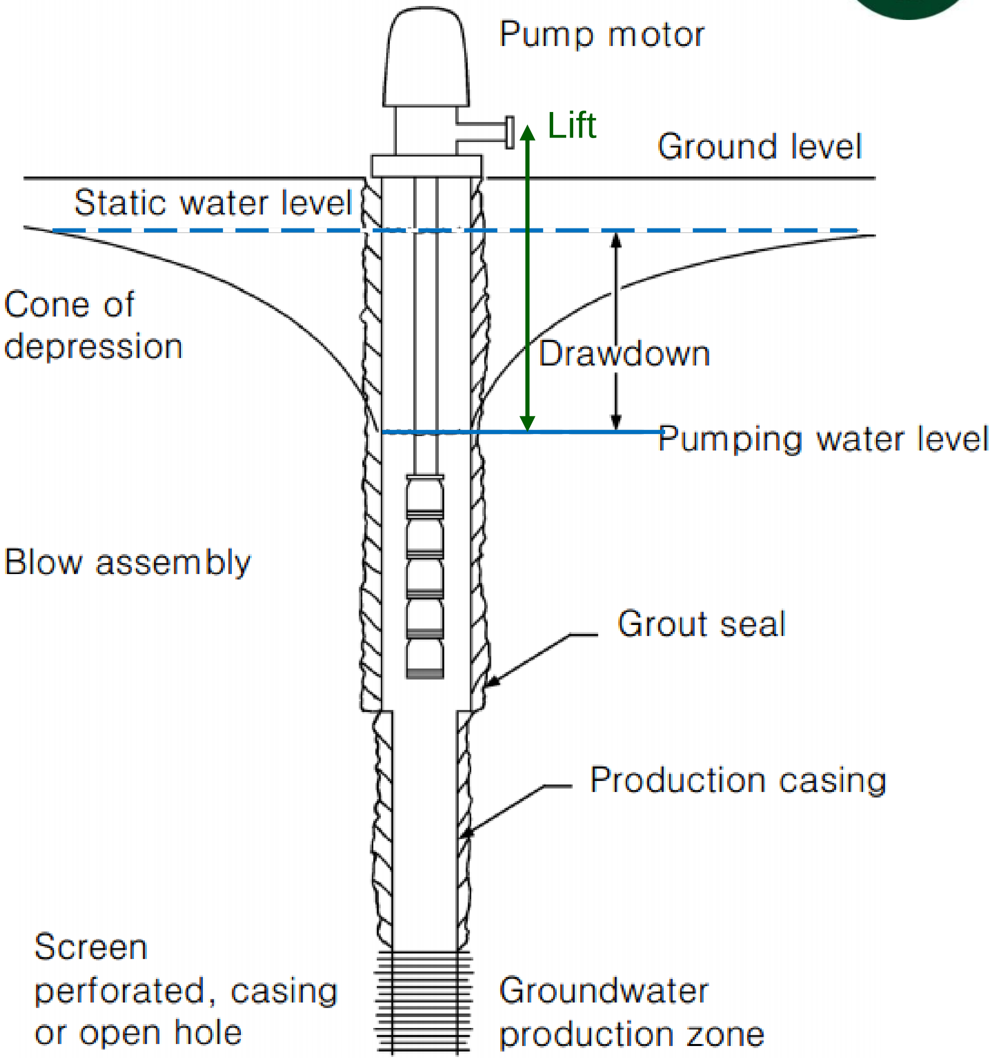
Static water level (SWL) is the level that exists under static (non-pumping) conditions

Pumping water level (PWL) is the level that exists under specific pumping conditions. It depends on pumping flow rates, well, and aquifer characteristics.

Drawdown (s_w) is the difference between the SWL and the PWL.

The *specific capacity* of a well is given by the pumping rate per meter of drawdown, l s^{-1} m−1

Total pump head is composed of four primary components: **lift**, column friction, surface requirements, and injection head due to aquifer conditions and water quality.



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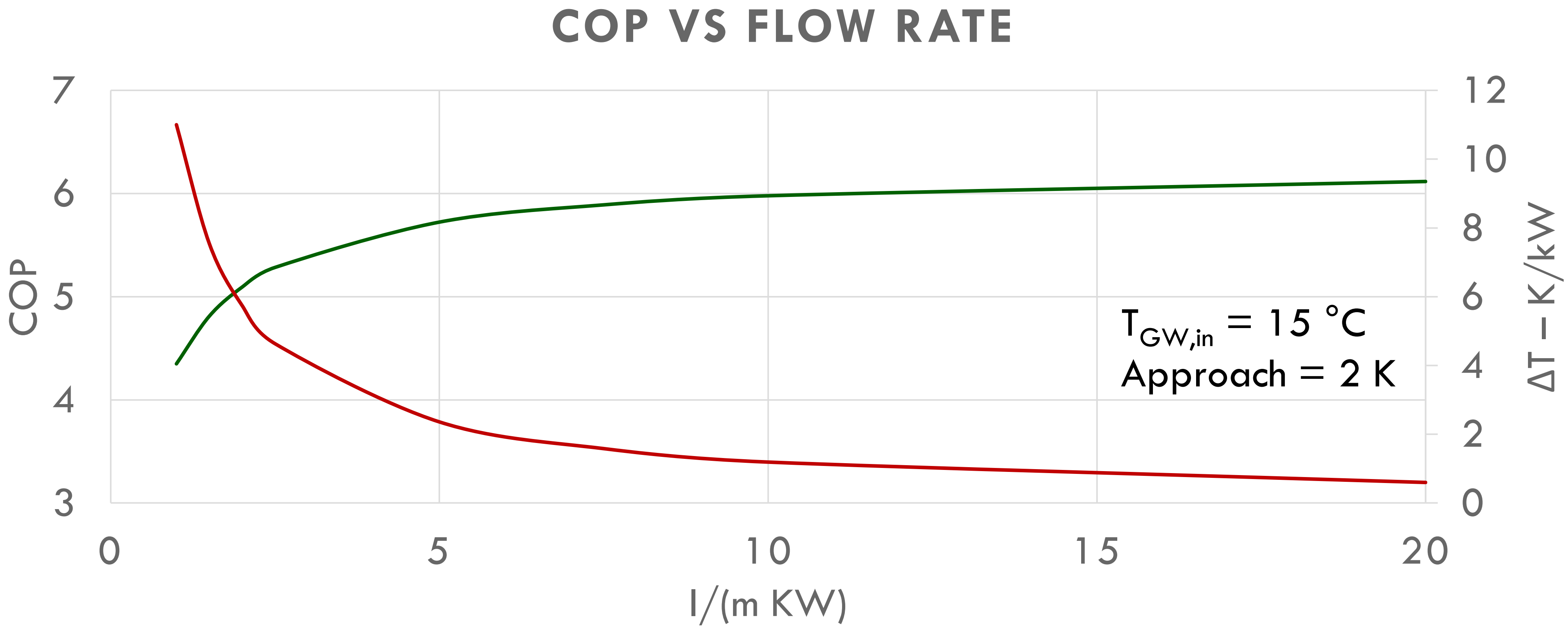
TRADITIONAL/HANDBOOK DESIGN PROCEDURE



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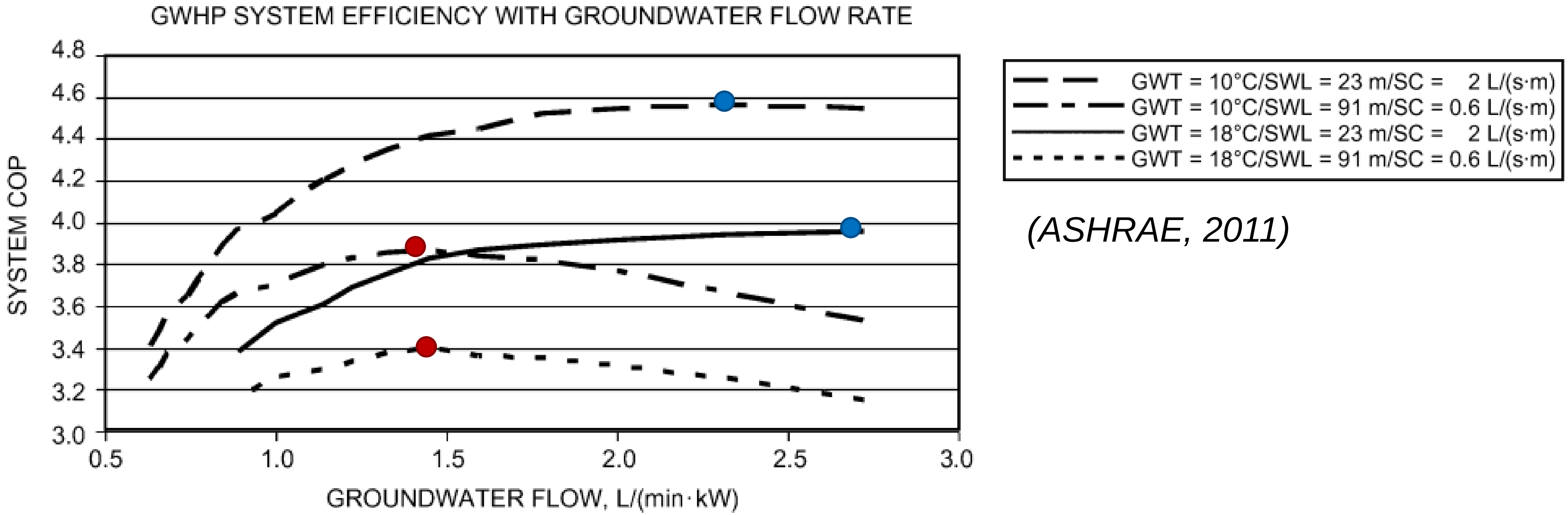


(ASHRAE, 2011)

TRADITIONAL/HANDBOOK DESIGN PROCEDURE

CURRENT DRAWBACKS

- ✓ Probable oversizing due to traditional engineering «precautionary principle»
- ✓ Uncertainty on final operative performances
- ✓ Unfavorable cost-benefit ratio among energy/economic savings and initial investment
- ✓ Several competitor technologies with similar performances, but more established design and installation methodologies
- ✓ Lack of formation and specialization among operators and authorities
- ✓ Lack of communication among operators (geologist, drillers, H&C system designers)
- ✓ Lack of optimized design approach in order to maximize system performances with respect of initial expenditure (CBA approach)

ADVANCED/OPTIMIZED DESIGN

Traditional engineering design process is based on the classical **"precautionary principle"** to ensure the meeting of project specifications.

The latter point is obtained by **oversizing** the main equipment, on the basis of the worse operative situation, and the **installation of additional back-up devices.**

Modern engineering design approach is not aimed only at sizing system components to meet project specifications and constraints, but it seeks the **optimal design and management** strategies in terms of **energetic and economic performances**.

The latter looks for rigorous methods of decision making, such as **optimization methods**, which are based on the **predictions of the operative performances of the future project**.

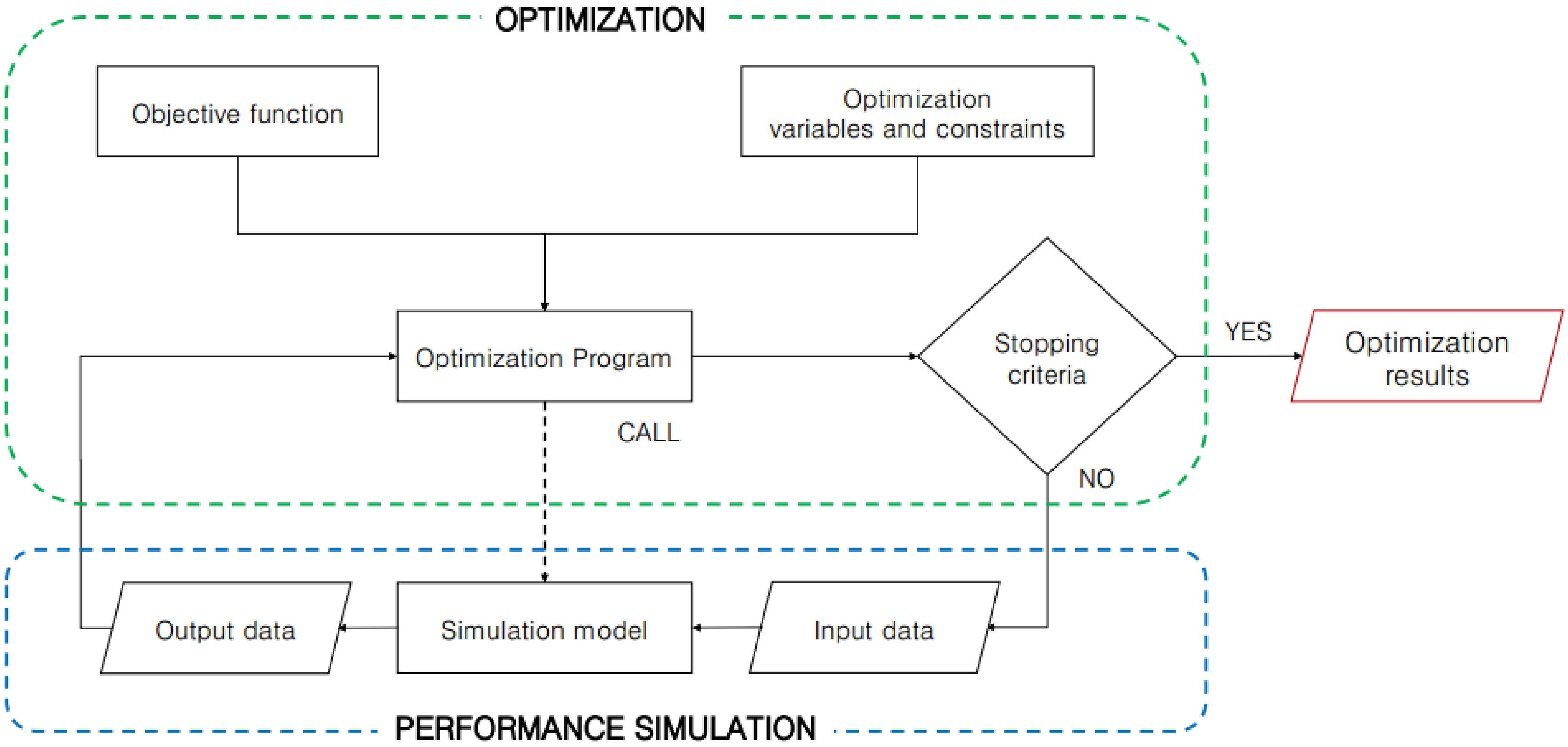
The accurate evaluation of the energy fluxes during the operative period is a mandatory input for any **cost-benefit analysis**.

ADVANCED/OPTIMIZED DESIGN

The **optimal design configuration can be achieved through a holistic simulation** of the overall equipment on the basis of a proper modeling of the physical mechanisms involved and including mutual interactions among different components.

The **design of direct use systems** (GSHPs included) is a paradigmatic case to apply the above-mentioned considerations. Independently from the specific configuration adopted, these systems always require a **proper synergy among "geothermal devices" and back-ups in order to limit installation costs and ensure appropriate economic and energy savings**, together with the sustainable exploitation of the ground source.

ADVANCED/OPTIMIZED DESIGN



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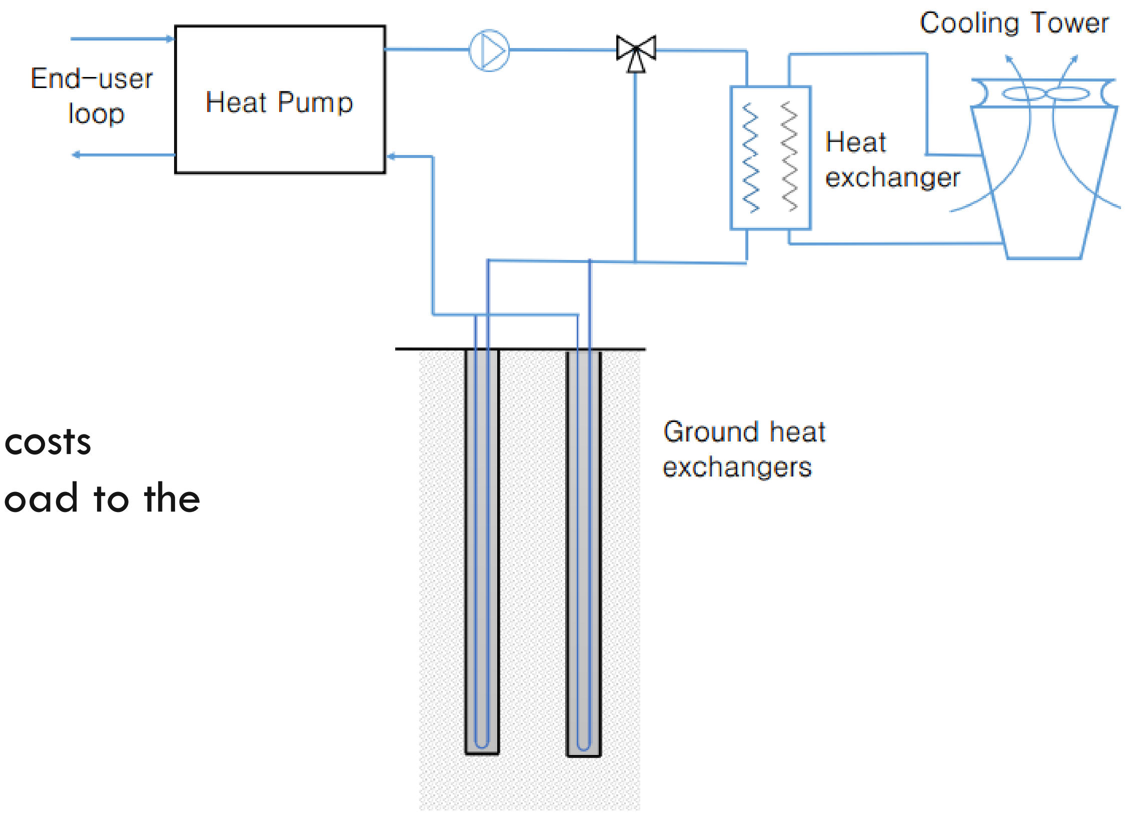
TRADITIONAL/HANDBOOK DESIGN PROCEDURE

Hybrid systems



Potential benefits:

1. Lower installation costs
2. Net-zero energy load to the ground source
3. Peak load

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ADVANCED/OPTIMIZED DESIGN

A simple case study: Heating system made of GSHP and Air-source HP (back-up)

$$COP_{GSHP} = \frac{T_l}{T_l - T_g(t)}\eta^{II}$$

(GSHP unit performance)

$$\left\{\begin{aligned}
&COP_{AHP} = \frac{T_l}{T_l - T_a(t)}\eta^{II} && \text{(Back-up performance)}\\
&L(t) = \max\left[\mathrm{A_l}\cdot\cos(2\pi/\omega_l t)\,;0\right] && \text{(Building thermal load profile)}\\
&T_a(t) = \overline{T_a} - \mathrm{A_a}\cdot\cos(2\pi/\omega_a t) && \text{(External air temperature profile)}\\
&T_g(t) = T_g^0 + \int_0^t W(t-\beta)\frac{d\dot{q}}{dt}(\beta)\,d\beta && \text{(Ground temperature evolution)}\\
&W(t) = \frac{1}{2\pi\lambda_g}\int_{\frac{R_{BHE}}{2\sqrt{\alpha_g t}}}^{+\infty}\frac{e^{-\beta^2}}{\beta}d\beta && \text{(Infinite line source model)}\\
&\dot{q}(t) = \frac{\boxed{p_l}\,L(t)}{N_{BHE}\,H}\left(\frac{COP_{GSHP}(t)-1}{COP_{GSHP}(t)}\right) && \text{(Energy balance of the BHE field)}
\end{aligned}\right.$$

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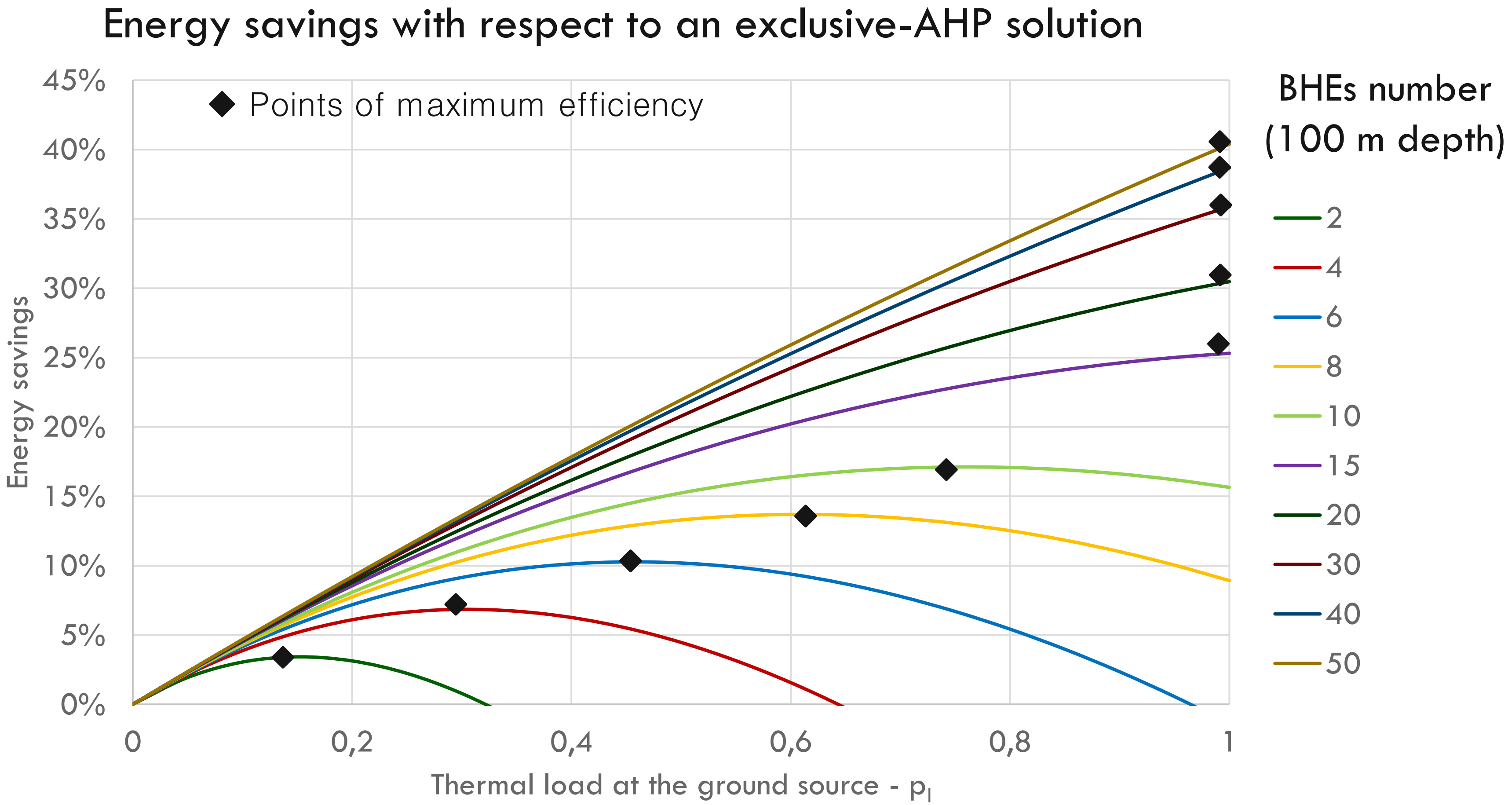
ADVANCED/OPTIMIZED DESIGN



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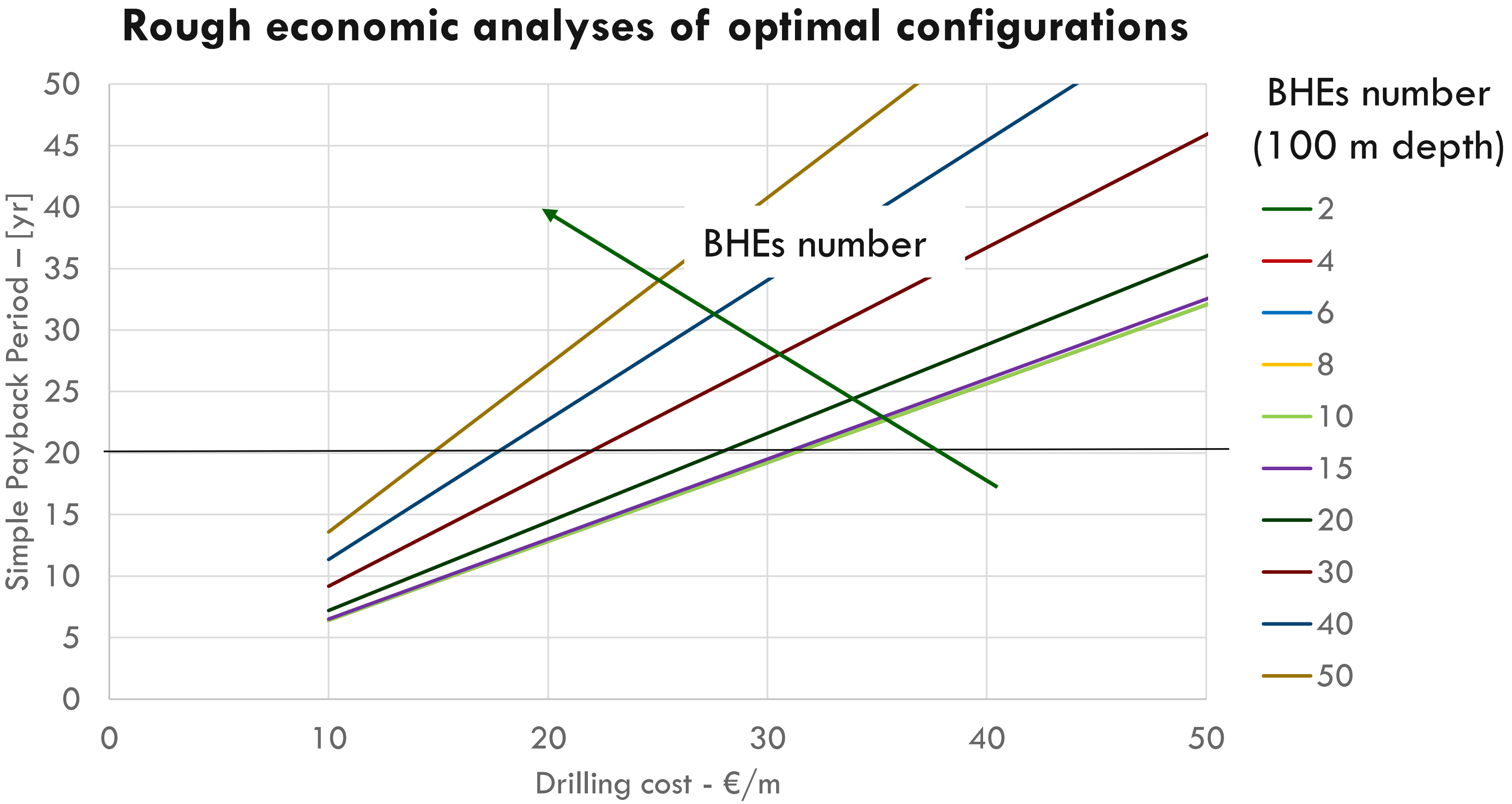

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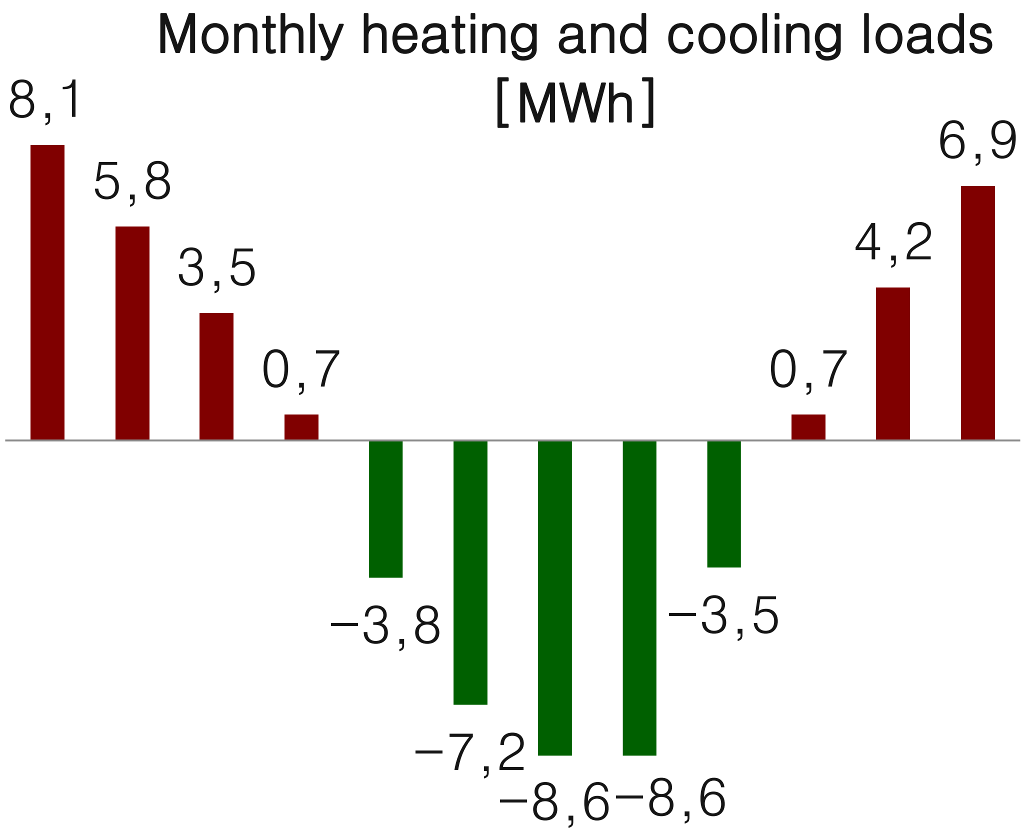
ADVANCED/OPTIMIZED DESIGN

Load profile



Declared Capacities (kW) of the examined heat pumps (EN 14511:2008)

		Conf#1	Conf#2	Conf#3	Conf#4
GHP	Heating DC	35	10.7	12.1	-
	Cooling DC	40.5	12.1	8.88	-
Boiler		-	23.9	23.9	33.5
Air chiller		-	29.1	33.5	44.2

- **CONF#1:** GHP sized on the peak load
- **CONF#2:** GHP sized on the average power demand of the design months
- **CONF#3:** GHP sized on the seasonal average power demand
- **CONF#4:** No GSHP solution

P. Conti: Direct uses/heat pumps . *International school on geothermal development. Miramare (TR), Italy, 7 – 12 Dec 2015.*

ADVANCED/OPTIMIZED DESIGN

Technical parameters

✓Electrically-driven heat pumps

✓Double U-loops arrangement of BHEs

✓Thermo-physical properties

Ground thermal conductivity	1.7 W/(m·K)
Ground thermal diffusivity	0.68 mm^2/s
BHE diameter	15 cm
BHE pipe diameter	2.62-3.2 cm
Spacing between BHEs	8 m
Grouting thermal conductivity	1.7 W/(m·K)
BHE thermal resistance	0.062 m·K/W

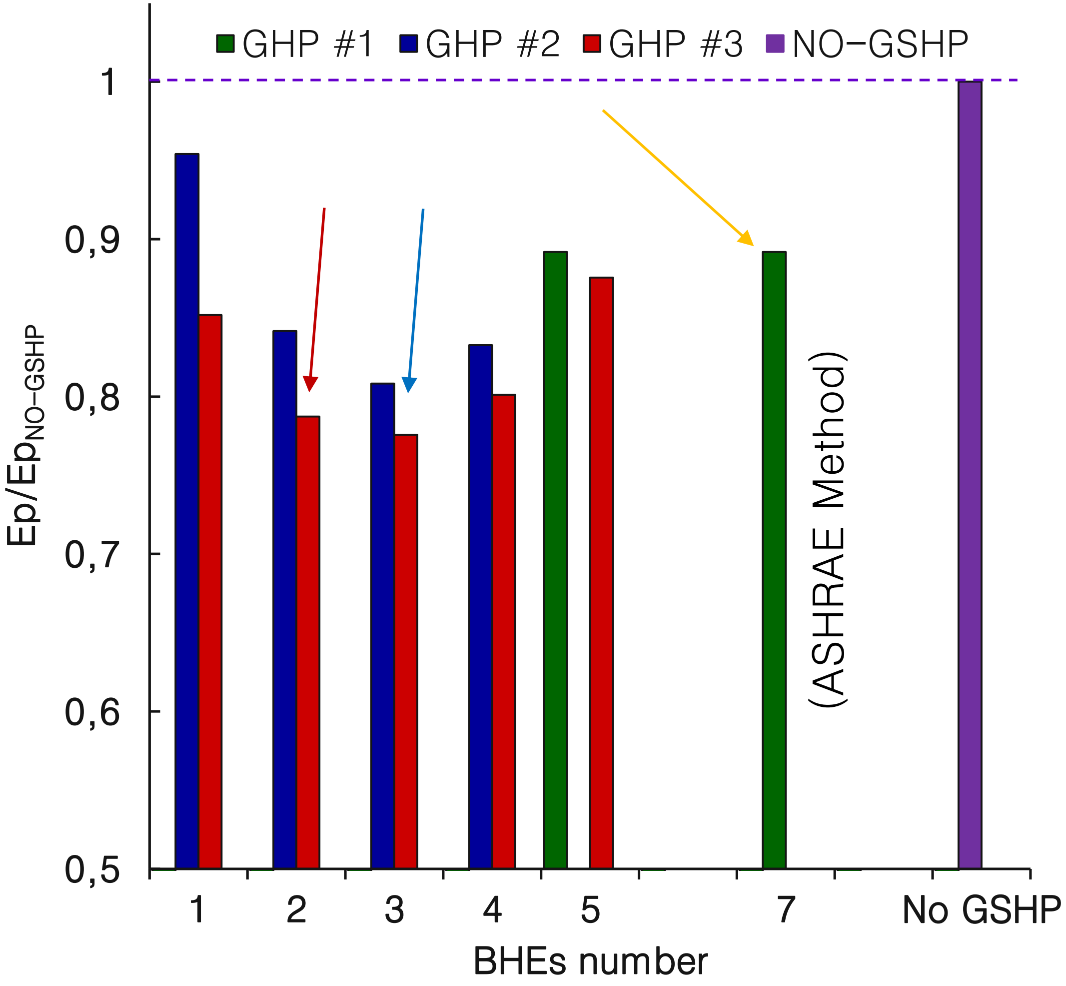
Economic parameters

Energy Fees - €/kWh	
Unit price of electrical energy	0.20
Unit price of natural gas	0.08

Retail prices – k€					
GHP #1	18.5	Boiler #2	4.0	Air unit #2	8.5
GHP #2	5.2	Boiler #3	4.6	Air unit #3	10.0
GHP #3	4.0	Boiler #4	5.0	Air unit #4	14.0

*Prices are purely indicative.

ADVANCED/OPTIMIZED DESIGN



Remarks:

✓Energy savings normalized with respect to NO-GSHP solution (1183 MWh)

✓GHP#1 needs 5 boreholes to cover the building load alone

✓GHP#3 – 3 BHEs is the best configuration, savings ~22.5% of primary energy

✓GHP#3 – 2 BHEs leads to similar savings (~21.5%) with one less BHE

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ADVANCED/OPTIMIZED DESIGN

	GHP#2 – 3 BHEs	GHP#3 – 3 BHEs	GHP#3 – 2 BHEs	GHP#1 – 7 BHEs (ASHRAE)
Total length of BHEs [m]	100 x 3	100 x 3	100 x 2	100 x 7
f_H (heating season)	0.94	0.85	0.65	1
f_C (cooling season)	0.84	0.23	0.23	1
SCOP	3.42	3.46	3.59	2.53
SEER	3.52	3.55	3.50	3.40
CR (winter/summer)	0.39 / 0.65	0.61 / 0.56	0.47 / 0.56	0.14 / 0.24
Condensing boiler efficiency	1.09	1.09	1.09	-
SEER Air chiller	1.88	3.33	3.33	-
CR Air chiller	0.29	0.81	0.81	-
Heat flow per unit length (winter/summer) [W/m]	19.4 / 34.5	17.2/20.6	19.7/31.6	7.3/10.3
Primary energy consumption (after 20 years) [MWh]	956 (-19.2%)	917 (-22.5%)	931 (-21.3%)	1 055 (-10.8%)

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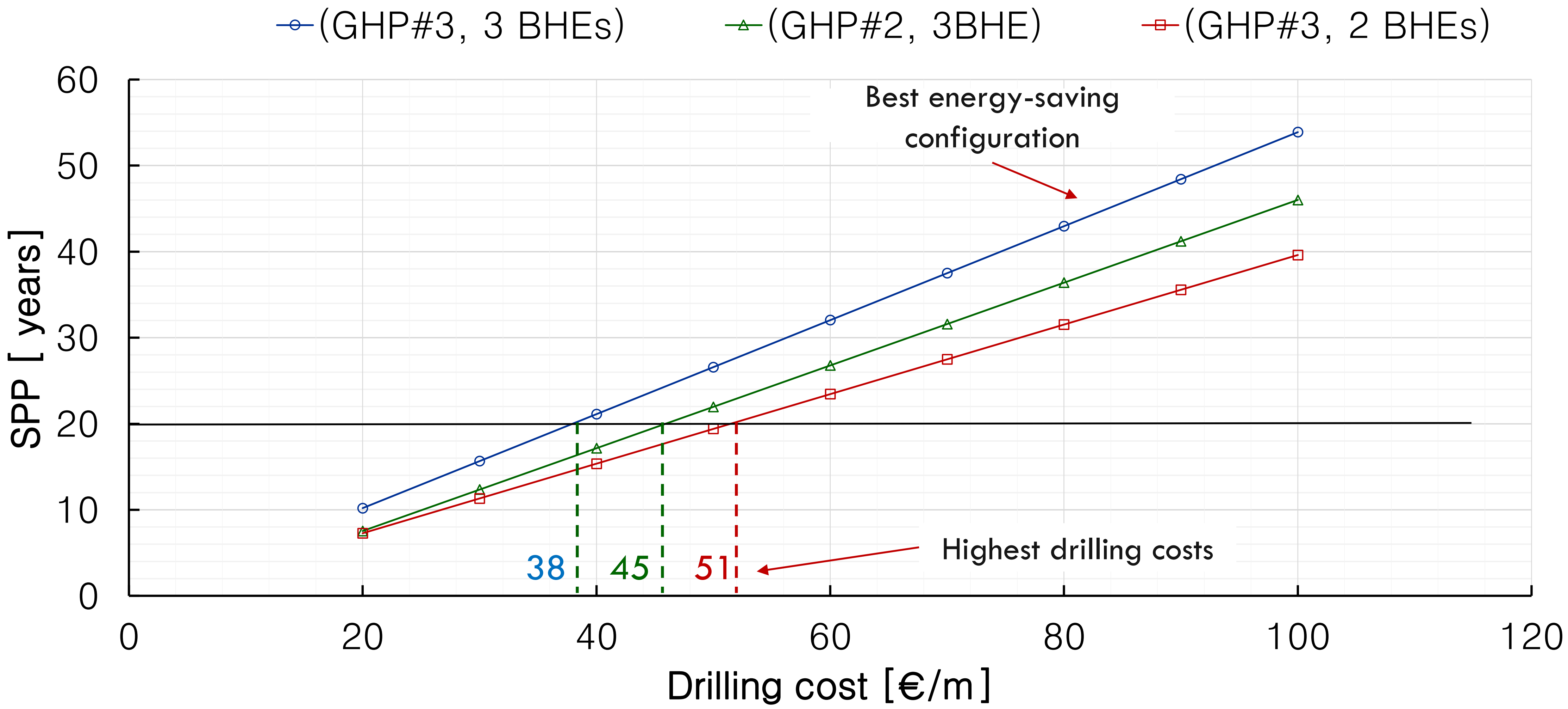
ADVANCED/OPTIMIZED DESIGN



Best energy-saving configuration

Highest drilling costs

ADVANCED/OPTIMIZED DESIGN

	GHP #2 – 3 BHEs			GHP #3 – 3 BHEs			GHP #3 – 2 BHEs		
Drilling cost	SPP	NPV [k€]	PI	SPP	NPV [k€]	PI	SPP	NPV [k€]	PI
20 €/m	8	7.8	0.33	10	5.4	0.22	7	6.3	0.28
40 €/m	17	1.8	0.06	21	<0	<0	15	2.3	0.09
60 €/m	27	<0	<0	32	<0	<0	23	<0	<0
80 €/m	36	<0	<0	43	<0	<0	32	<0	<0
100 €/m	46	<0	<0	54	<0	<0	40	<0	<0

Acronyms

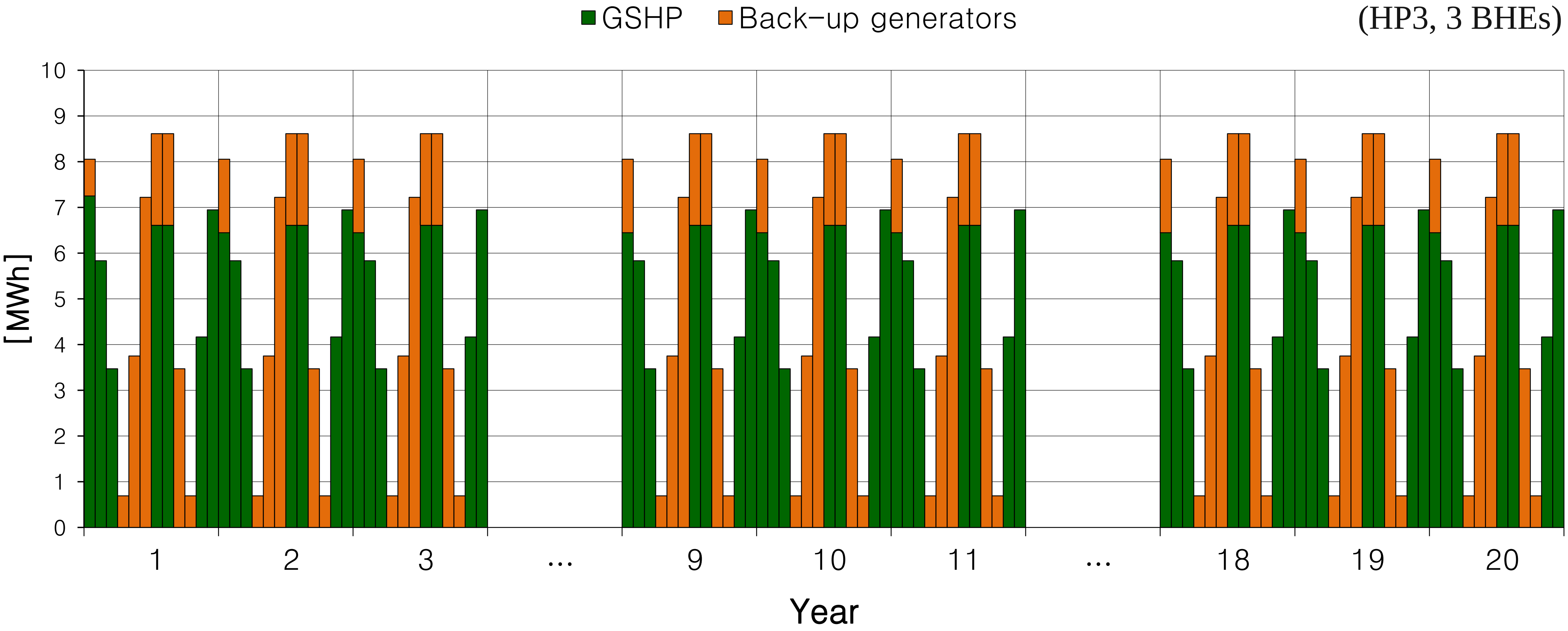
- **SPP:** simple payback period
- **NPV:** net present value after 20 years of operation
- **PI:** performance index after 20 years of operation

Note:

- ✓ The 20-year period corresponds to the assumed operative life of the GHP unit; it does not refer to the overall GSHP system.
- ✓ The BHEs field can still operate, thanks to the optimized sizing and control strategy that ensure the sustainability of the ground source.

ADVANCED/OPTIMIZED DESIGN

(HP3, 3 BHEs)



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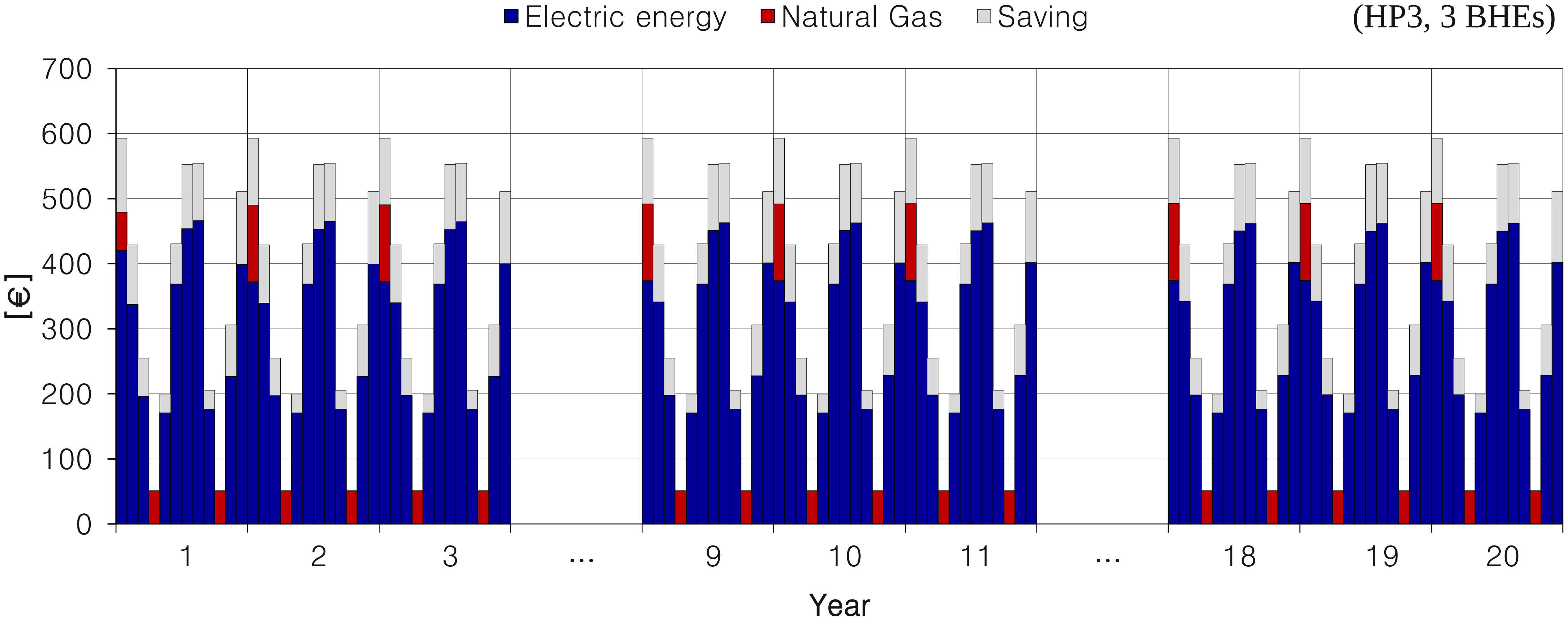
ADVANCED/OPTIMIZED DESIGN

(HP3, 3 BHEs)



(Savings with respect to the «NO-GSHP» solution)

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ADVANCED/OPTIMIZED DESIGN

Economic performance indexes

SPP – Simple payback period (yrs)

PP – Payback period (yrs)

NV – Net value (€)

NPV – Net present value (€)

Profitability indexes – NPV per investment cost

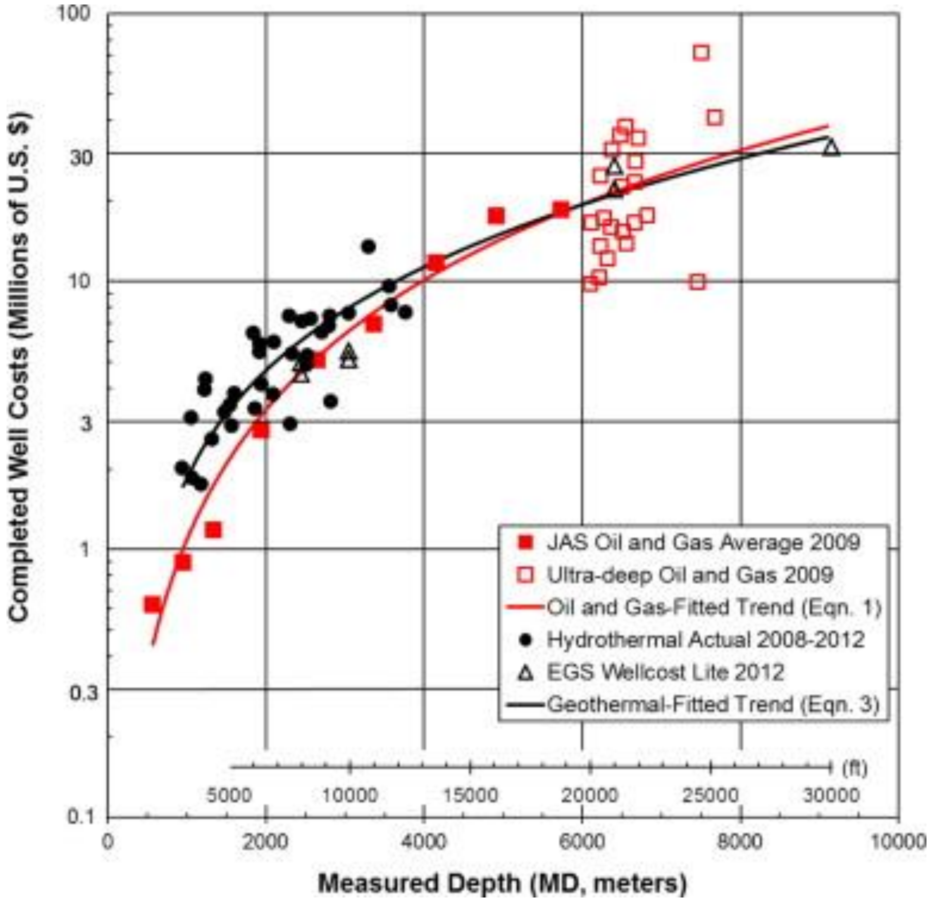
IRR – Internal rate of return

Economic/energetic performace indexes

COSE - Cost of saved energy ($/kWh)

Capital cost of saved energy (kWh/$)

INVESTMENT ASSESSMENT OF DIRECT USES SYSTEMS



Shallow boreholes:

50 – 100 €/m

Geothermal well costs:

$C_{well} = 1.72 \times 10^{-7} (D)^2 + 2.3 \times 10^{-3} - 0.62$

C_{well} - M$

D – m (*Lukawski et al, 2014*)

! Rule of thumb 1 km –> 1 M$

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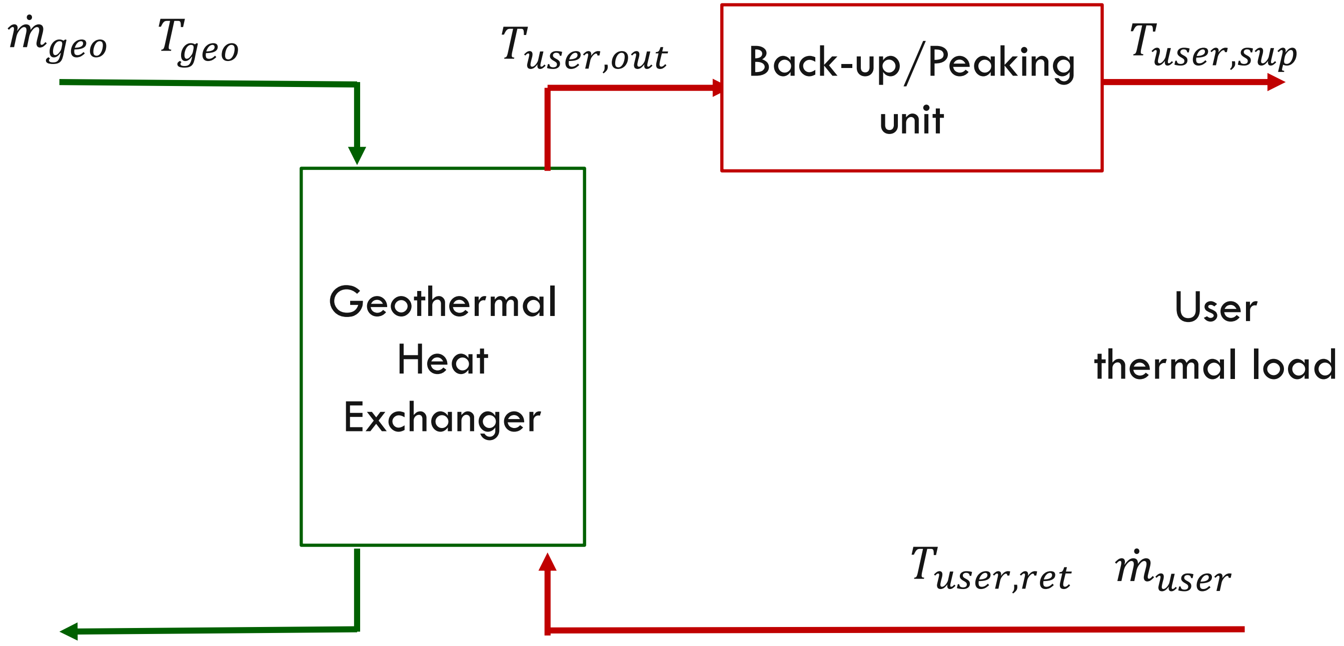
INVESTMENT ASSESSMENT OF DIRECT USES SYSTEMS



! Rough analysis / ! First-order evaluation

$c_{f,bk}$ - \$/kWh	Unitary costs of standard fuel (avoided energy consumption)
L – kWh	Annual energy demand
$\dot m_{geo}$, T_{geo}	Geo-resource characteristics
$T_{user,ret}$	Operational return temperature from user loop
ϵ	Geo Hex effectivness

$$\boxed{\frac{c_{f,bk}\left[L-\dot m_{geo}\; c_{geo}\left(T_{geo}-T_{user,ret}\right)\epsilon(C^*,NTU)\right]-\Delta C_{maint}-\Delta C_{aux}}{C_{well}+C_{GHEx}(\epsilon)+C_{pipeline}}>0}$$

DIRECT USES/HEAT PUMPS

Do less, do it best!!

THANKS FOR YOUR KIND ATTENTION!!!

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DIRECT USES/HEAT PUMPS

References:

R. Bertani, 2015, "Geothermal Power Generation in the World - 2010–2015 Update Report", Proceedings of the World Geothermal Congress, ISBN: 9781877040023, 11 pp.

J. W. Lund, T. Boyd, ”Direct Utilization of Geothermal Energy 2015 Worldwide Review”, , Proceedings of the World Geothermal Congress, ISBN: 9781877040023, 11 pp.

P. Conti, R. Cataldi, 2013, “Energy balance of the Italian hydrothermal spa system”, Proceedings of the European Geothermal Congress, ISBN: 9782805202261, 10 pp.

“Geothermal energy”, in ASHRAE Handbook - HVAC Applications, Atlanta (GA): American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2011, ch. 34, pp. 34.1 –34.4.

J.S. Gudmundsson, 1988, "The elements of direct uses", Geothermics, Vol.17 (1), 119-136.

K. Dimitrov, 1997, Distribution of geothermal fluids, Geothermal District Heating Schemes. ISS 1997 Course TextBook, Editor: K. Dimitrov, Ankara, Turkey.

O. YESIN, 1997, GDHS and heat exchanger design criteria. ISS 1997 Course TextBook, Editor: K. Dimitrov, Ankara, Turkey.

DIRECT USES/HEAT PUMPS

R. Harrison, 1987, Design and performance of direct heat exchange geothermal district heating schemes, Geothermics, Vol. 16 (2), 197-211.

C. Haslego, G. T. Polley, 2002, Compact Heat Exchangers, Part 1: Designing Plate-and-Frame Heat Exchangers, CEP Magazine, Vol. 9, 32-37.

UNI 11466:2012, «Heat pump geothermal systems - design and sizing requirements», Milan (IT).

A. T. Nguyen, S. Reiter, P. Rigo, 2014, "A review on simulation-based optimization methods applied to building performance analysis", Applied Energy, Vol. 113, 1043-1058.

P. Conti, 2015, "A novel evaluation criterion for GSHP systems based on operative performances", IYCE 2015 - Proceedings: 2015 5th International Youth Conference on Energy, art. no. 7180740

P. Conti, W. Grassi, D. Testi, 2015, “Proposal of Technical Guidelines for Optimal Design of Ground-Source Heat Pump Systems”, Proceedings of the World Geothermal Congress, ISBN: 9781877040023, 11 pp.

M. Z. Lukawski, B. J. Anderson, C. Augustine, L. E. Capuano Jr., K. F. Beckers, B. Livesay, J. W. Tester, 2014, "Cost analysis of oil, gas, and geothermal well drilling", Journal of Petroleum Science and Engineering, Vol. 118, 1-14.

W. Grassi, P. Conti, E. Schito, D. Testi, 20155, "On sustainable and efficient design of ground-source heat pump systems", J Phys Conf, Vol. 655, art.no.012003.