How heat pumps work: criteria for heat sources evaluation

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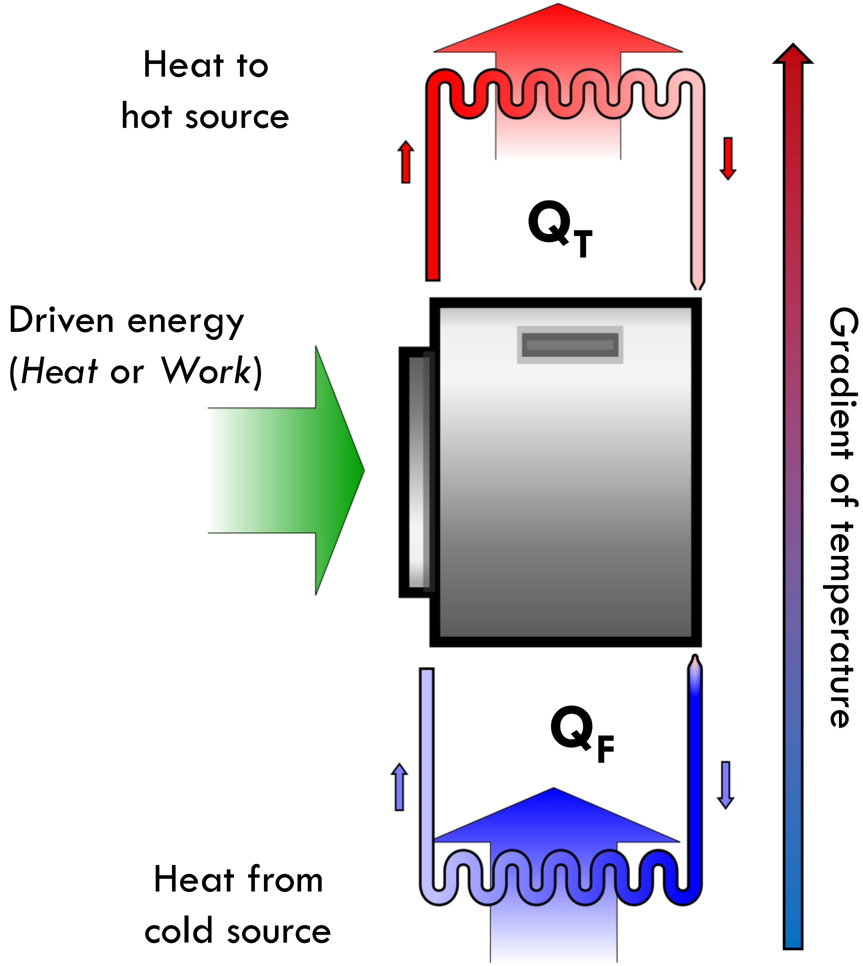
XIV Int. Conference on Science, Arts and Culture. Veli Lošinj, 2014.

Heat pumps: basic theory



- ✓ **What is an heat pump?**

  Heat pumps is a device able to transfer heat from a cold source to an hot source, against the natural direction of flow. To do that, driven energy is required (heat or work)

- ✓ **Coefficient of performance**

- Heating mode

$$COP = \frac{Q_T}{Q_T - Q_F}$$

- Cooling mode

$$EER = \frac{Q_F}{Q_T - Q_F}$$

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Heat pumps: basic theory

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Table 1. Energetic indexes for electrically-driven heat pumps.

NAME	DEFINITION	TIPICAL VALUES
COP/EER	Useful **thermal power** divided by **power input**	3.5 ÷ 5 / 2.5 ÷ 3.5
<COP> / <EER> Average COP/EER	Useful **thermal energy** divided by **total energy** input. The coefficient refers to a **specified time interval.**	3 ÷ 4 / 2.5 ÷ 3
SCOP / SEER Seasonal COP/EER	Useful **thermal energy** divided by **energy input**. The coefficient refers to the **entire heating/cooling season.**	3 ÷ 4 / 2 ÷ 3
PER Primary Energy Ratio	Useful **thermal energy** during a season divided by **primary energy input**	1.2 ÷ 1.6 / 0.8 ÷ 1.2

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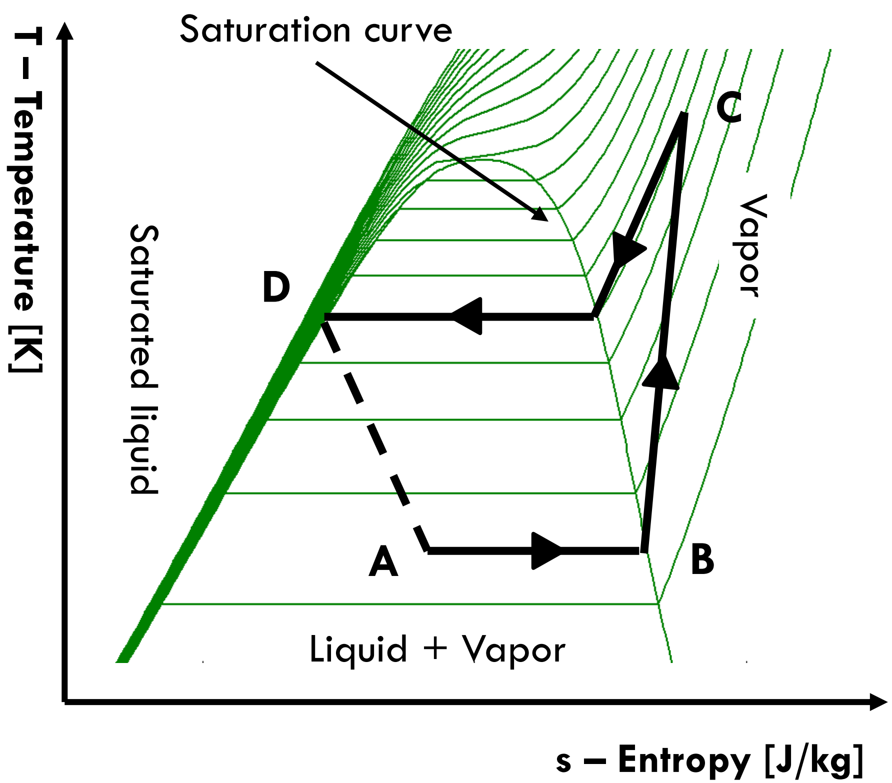
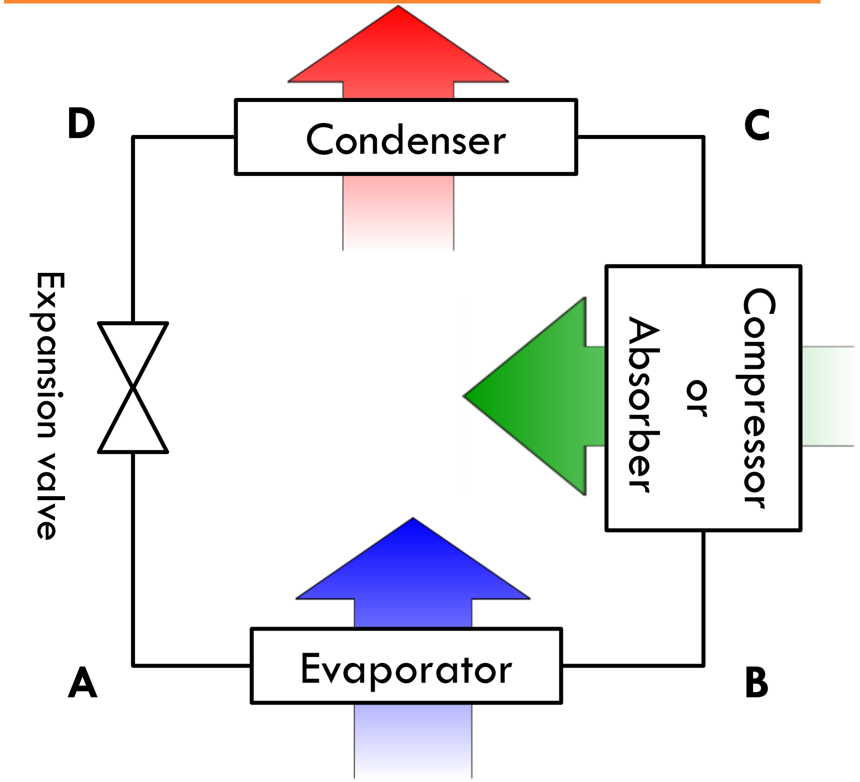
Heat pumps: basic theory

Thermodynamic reference cycle



Components diagram



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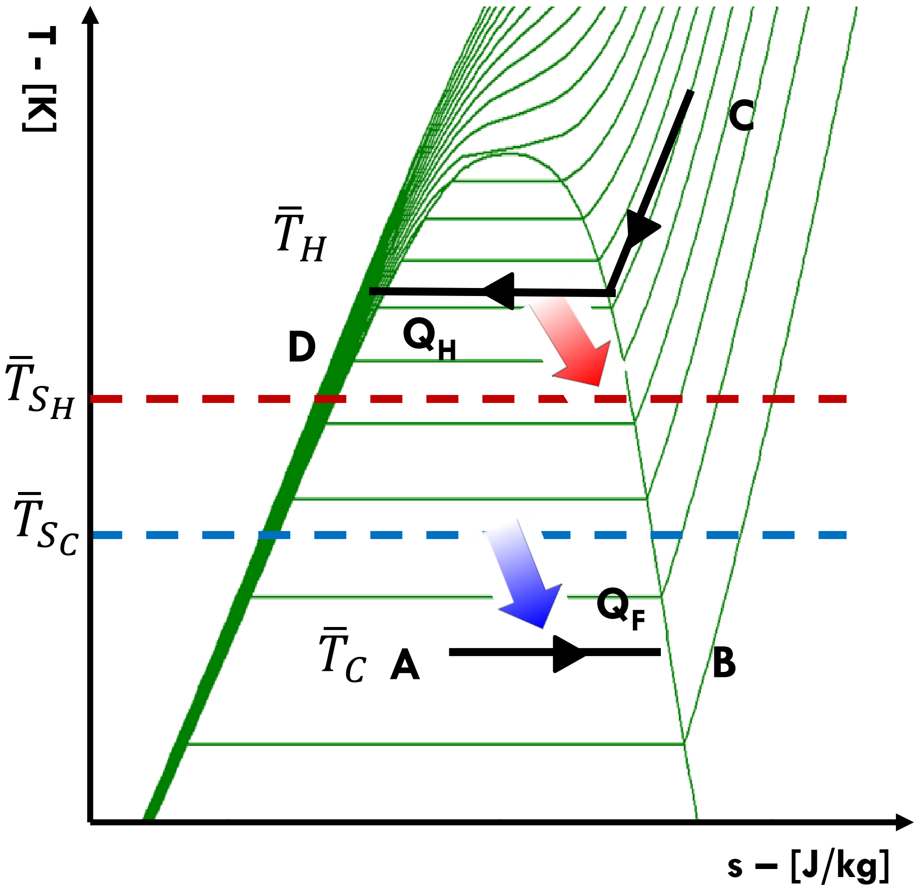
Reference cycle vs. real systems

Thermal sources VS. operating fluid



- ✓ HP efficiency depends on condensing/evaporation temperatures (not sources)

$$\bar{T}_{S_H} < \bar{T}_{f_H}$$
$$\bar{T}_{S_C} < \bar{T}_{f_C}$$

$\bar{T}_S$ -> thermal source

$\bar{T}_f$ -> operating fluid

$$COP(T_s) > COP(T_f)$$

- ✓ HP efficiency is strongly affected by components performance

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Reference cycle vs. real systems

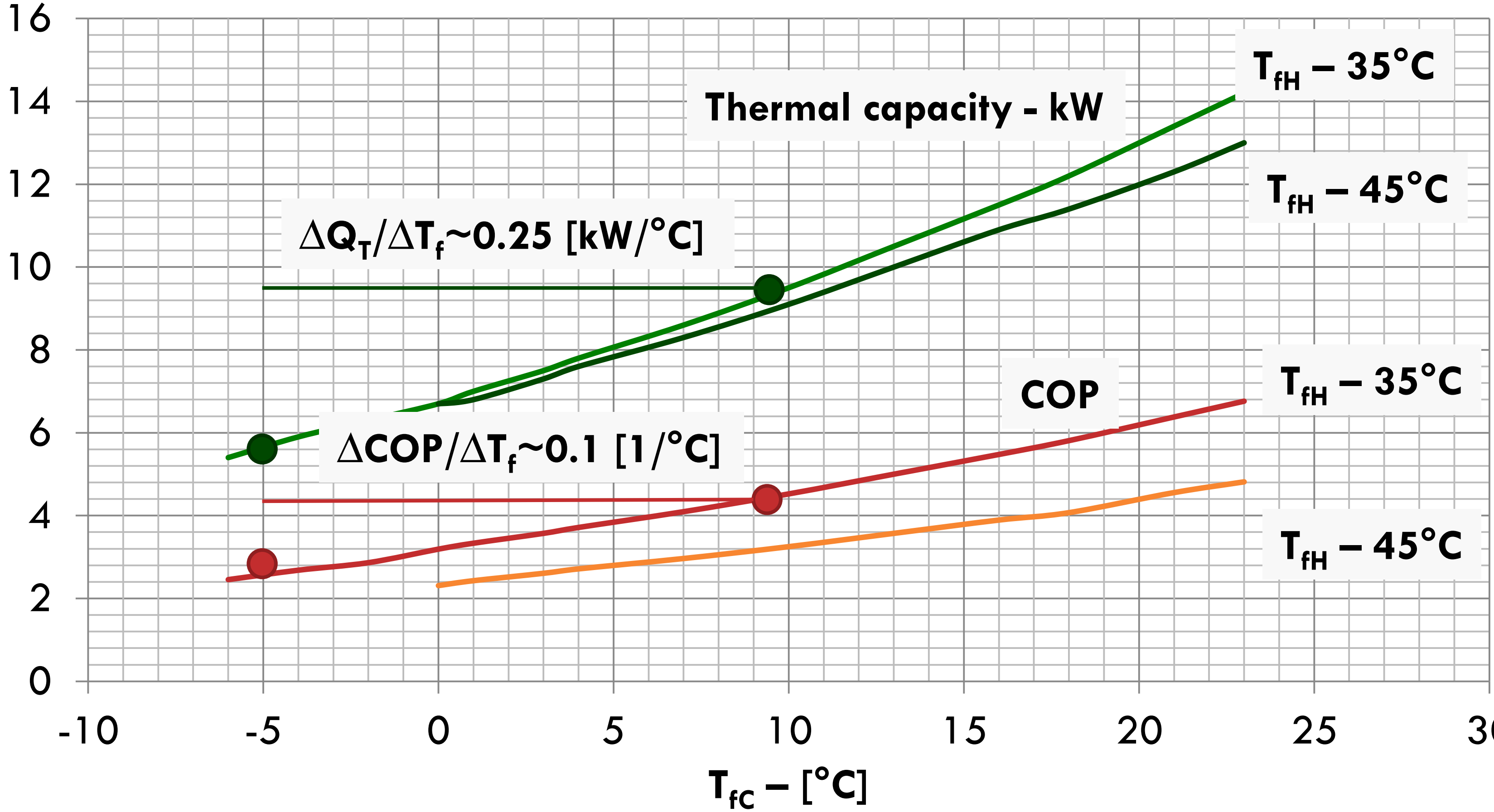
Effects of the variation of evaporation/condensing temperatures

Nominal data refer to standard rating condition of thermal sources (e.g. UNI EN 14511-2:2013)

Nominal performances	
Heating capacity – kW	15.1
Total power input – kW	3.6
COP (only compressor)	4.2

Secondary fluid (Evaporator): Inlet 10°C / Outlet 7°C
Secondary fluid (Condenser): Inlet 30°C / Outlet 35°C

Reference cycle vs. real systems



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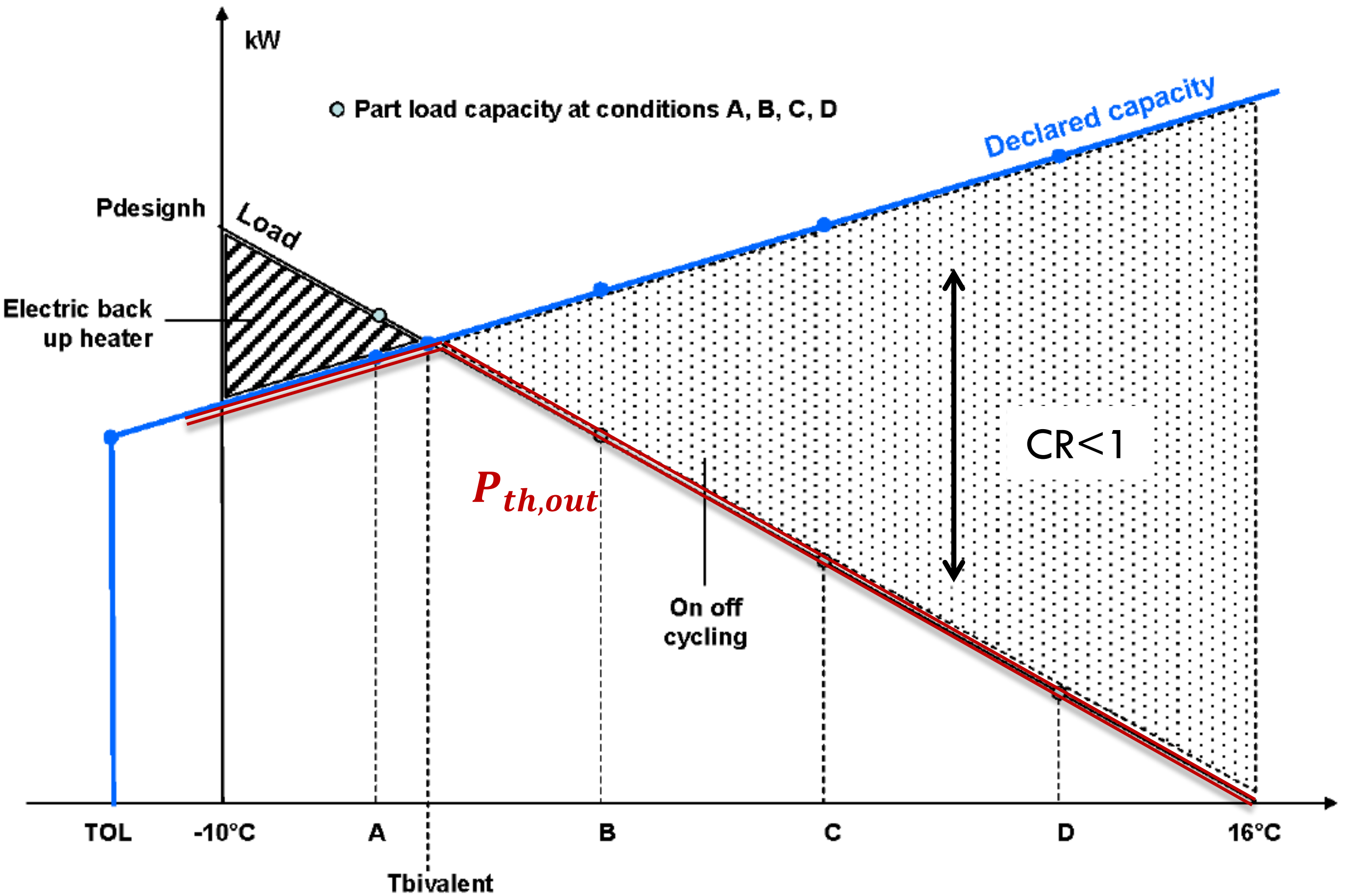
Reference cycle vs. real systems



Reference cycle vs. real systems

Effects of the capacity ratio

$$CR = \frac{\dot{Q}_u}{\dot{Q}_{DC}}$$

where:

- $\dot{Q}_u$ is the useful thermal power delivered by the HP;
- $\dot{Q}_{\mathrm{DC}}$ is the maximum capacity of the HP unit, when operating at the temperatures of the thermal sources.

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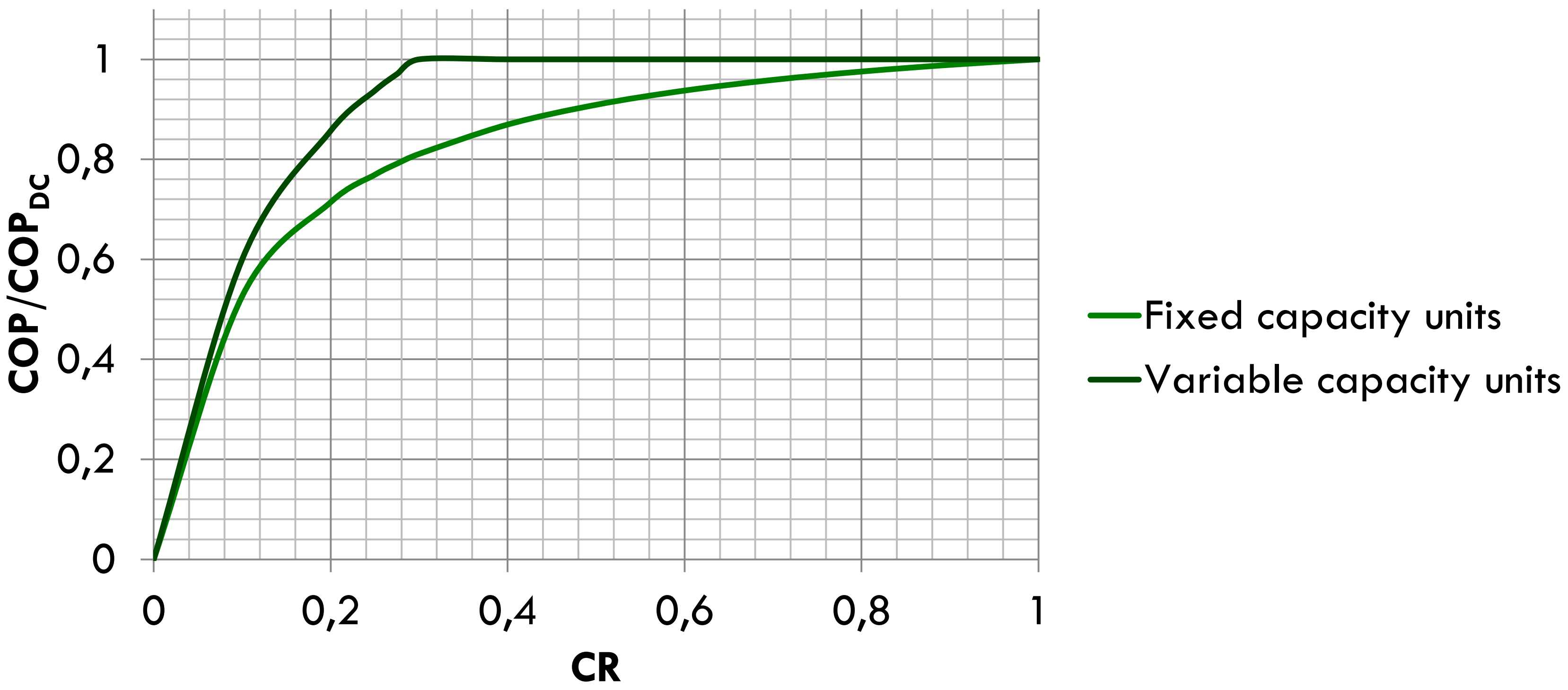
Reference cycle vs. real systems

COP penalization factor depending on control type (UNI EN 14825:2012)



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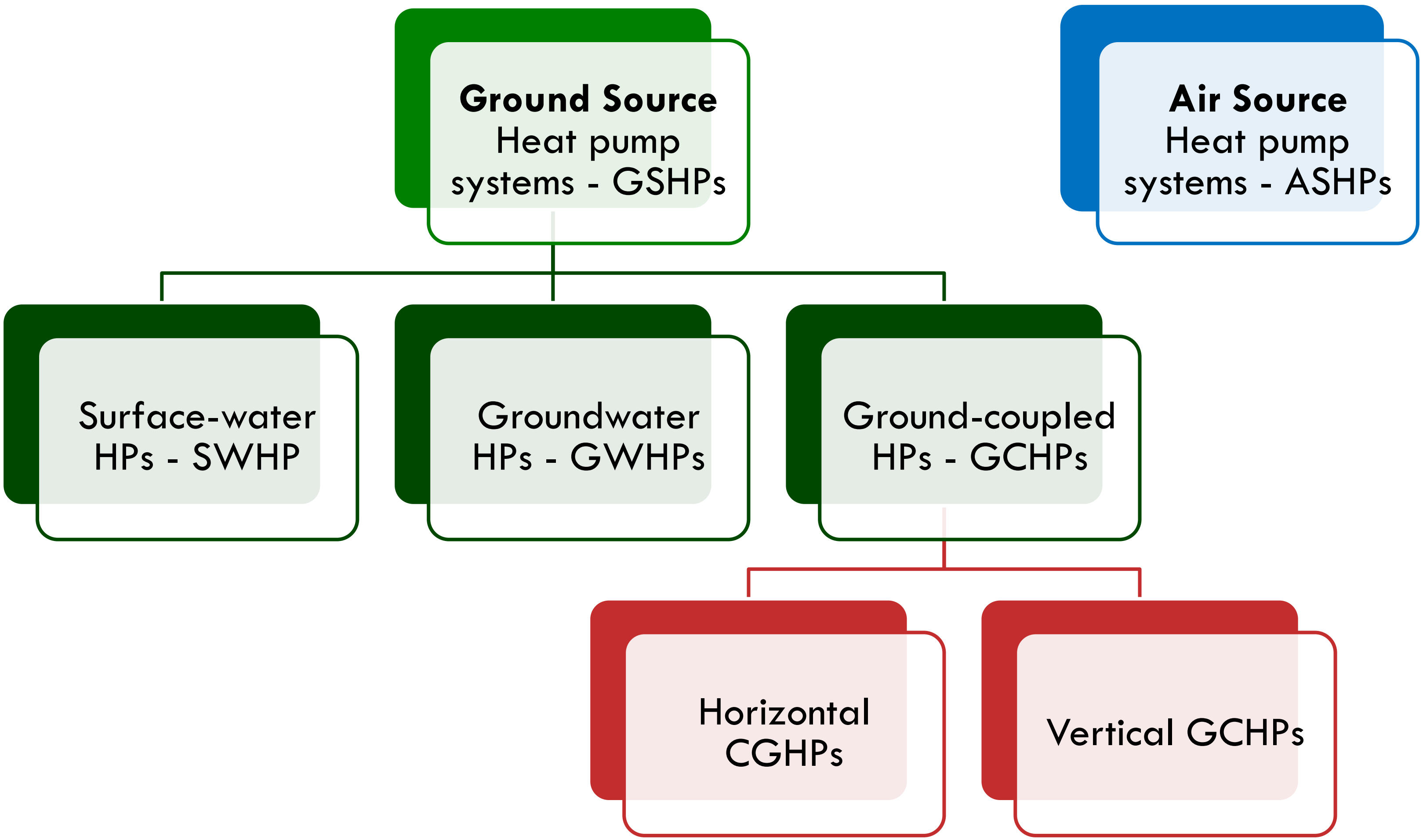
Classification and Terminology



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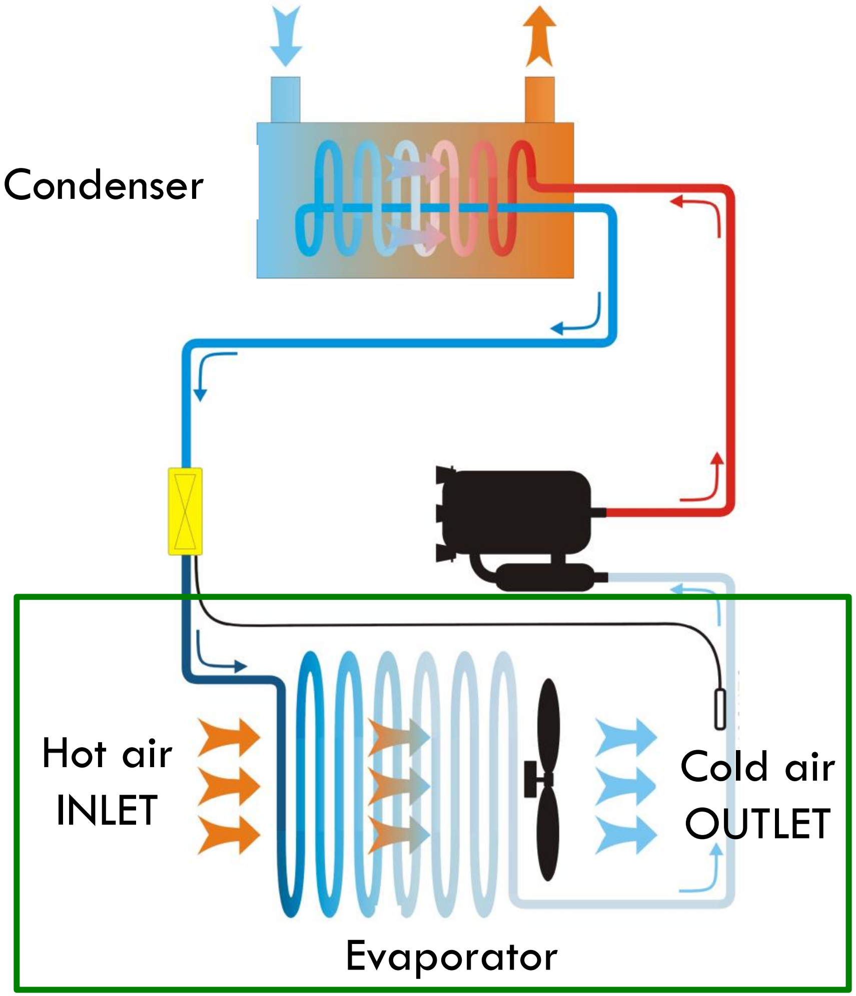
Air Source HPs



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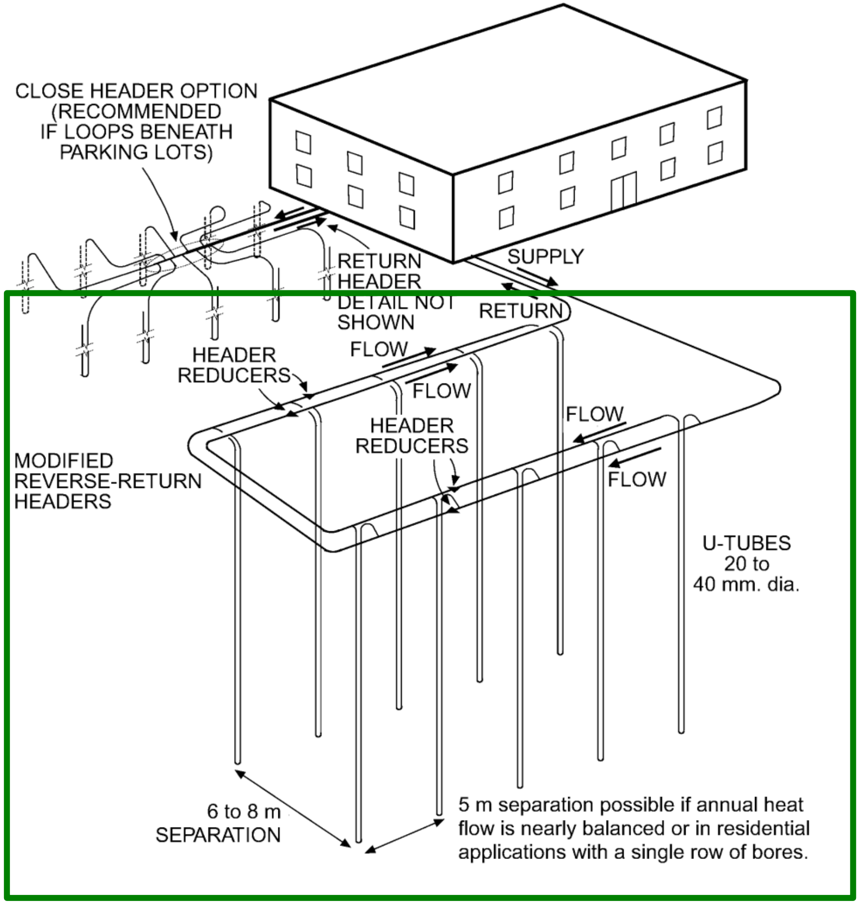
Vertical GCHPs



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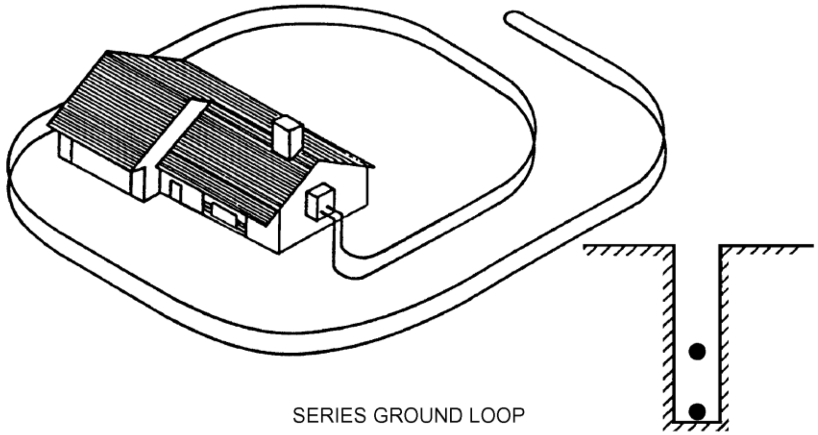
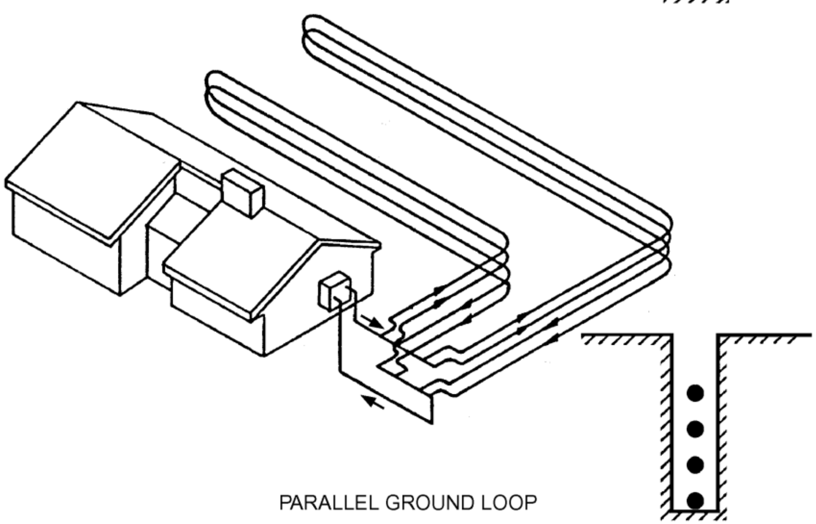
Horizontal GCHPs





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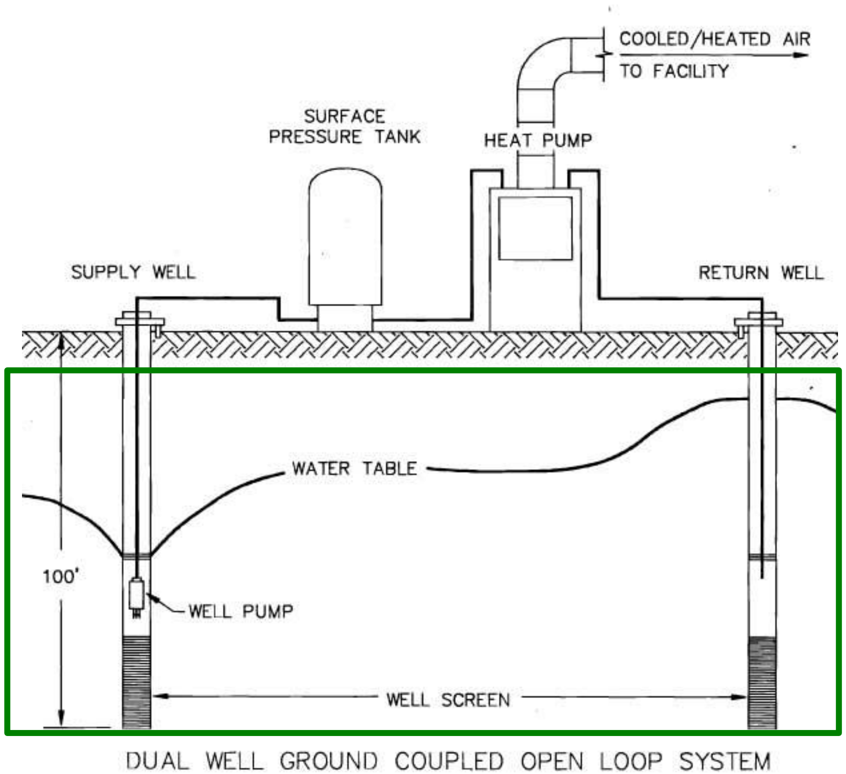
Groundwater HPs



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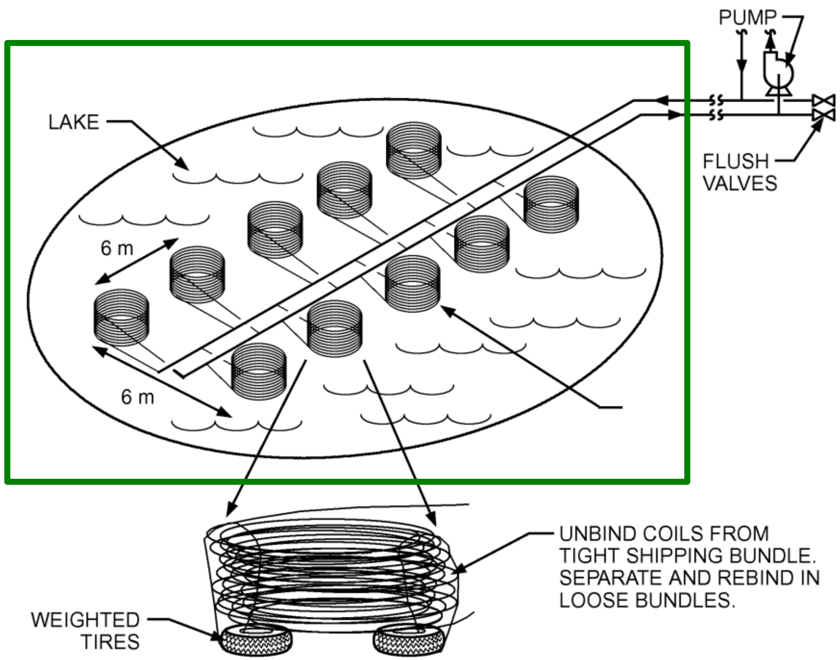
Surface-Water HPs



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Which source should I use?

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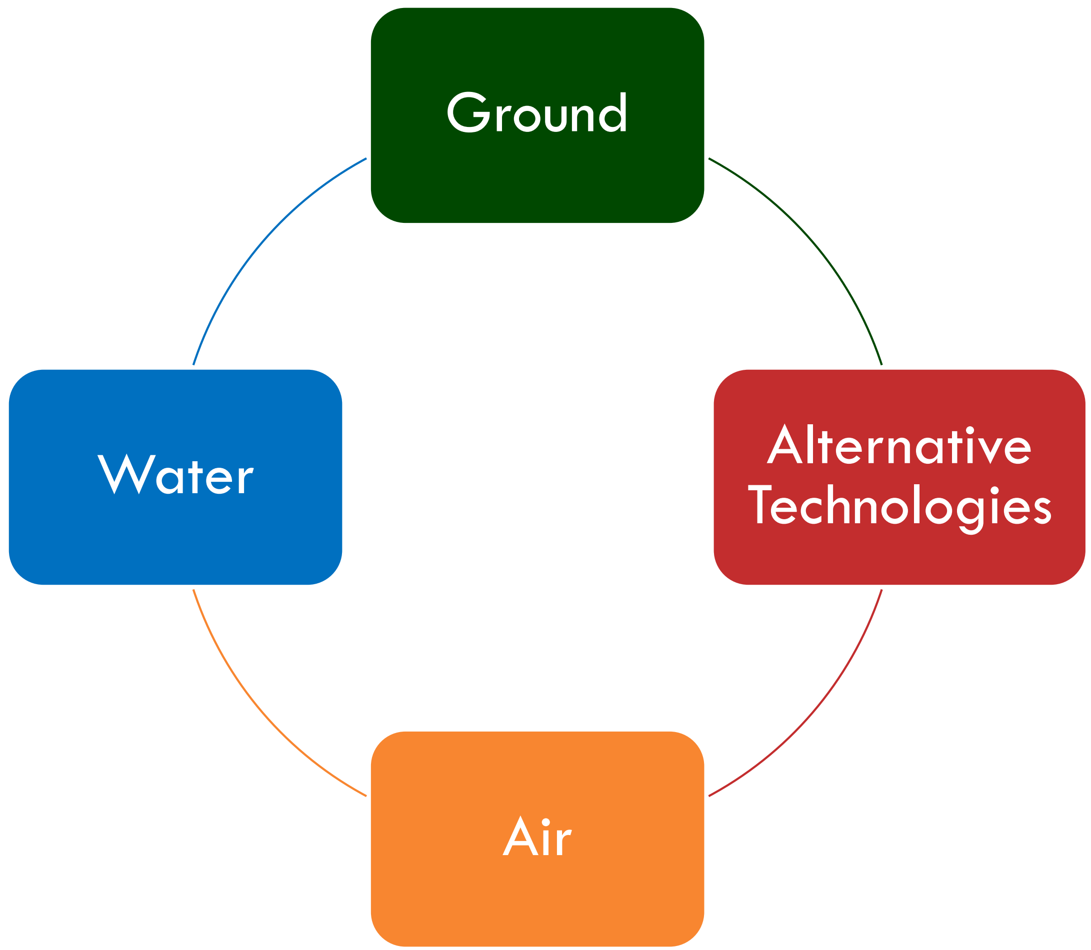

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Qualitative comparison

	Suitability	Availability	Installation Cost	O&M Cost	Temperature
ASHPs	GOOD	EXCELLENT	LOW	MODERATE	VARIABLE
Vertical GCHPs	MODERATE	GOOD / EXCELLENT	HIGH	MODERATE	GOOD
Horizontal GCHPs	MODERATE	MODERATE/ GOOD	MODERATE	MODERATE	GOOD / EXCELLENT
GWHPs	GOOD	GOOD	MODERATE	MODERATE/ HIGH	GOOD / EXCELLENT
SWHPs	GOOD	MODERATE	MODERATE	MODERATE/ HIGH	GOOD

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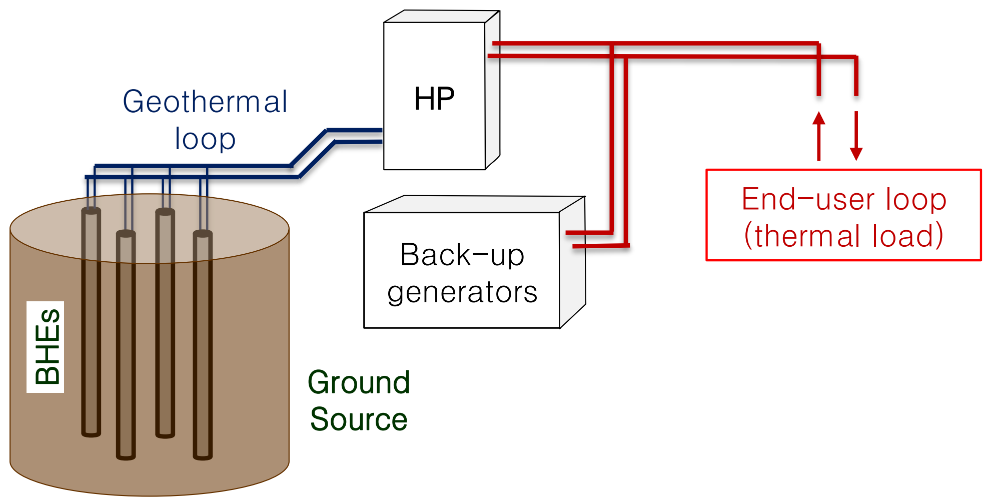
Real systems layout



Ground	Ground Heat Exchangers (GHEx)	Geothermal loop	HP equipment	Back-up generators	End user loop
Thermophysical properties	Number, depth, diameter, arrangement	Flow rate and operating temperature	Capacity, Type, Control	Capacity, efficiency	Puffer and thermal loads (power and energy)

GSHP Systems

HVAC Systems

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What determines a proper work by GSHPs?

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Primary ENERGY savings

- ✓ Share of loads delivered with a SCOP/SEER higher than alternative technologies
  - **Operating Temperature** at the evaporator/condenser
    - Thermal sources
    - Heat transfer apparatus
  - **Capacity ratio**
    - HP sizing and control
    - Thermal load pattern

Economy

- ✓ Capacity ratio

$$CR \propto \frac{Energy\ savings}{Initial\ Costs}$$

- Initial costs
  - HP capacity + GHEXs
- Total energy savings
  - (HP + Back-up)
- Prices/Fares of electricity and natural gas

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What should be the goal?

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- ✓ **What is the goal?**
  - Maximize benefit-cost ratio (energy/economy) of overall system (GSHP & Back-up generators)
  - Evaluate the optimal fraction of building load *(energy!)* delivered by GSHPs.
  - Nominal capacity of GSHP system is a variable and not the final result
- ✓ **What are the main design variables?**
  - HP capacity & GHEXs (depth, number, arrangement…)
  - Management strategy during operation time.
- ✓ **What should be avoided?**
  - Rough & hasty approach to design process
  - No consideration on the management of system during operation time.

The design process: a cost-benefit optimization

- Energetic systems design (especially GSHPs) consists in a comprehensive procedure aimed at evaluating the performance of the system during its operational life for cost-benefit considerations

- Sizing process, feasibility study, performance analysis should to be considered as the very same activity

- Further details on this design approach can be found in:
  - "Proposal of a Novel Design Procedure for GSHP Systems"
    W. Grassi, P. Conti, D. Testi – EGC2013 proceedings.
  - "A Design Method for Ground Source Heat Pump Systems Based on Optimal Year-Round Performance – Part 1: Model Definition and Discussion", *submitted to Applied Energy.*

Thermal sources assessment operative conditions vs. initial conditions

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- ✓ Collect all possible information about undisturbed/initial state of the external thermal sources
  - **Air (ASHPs):** annual climate;
  - **Water (GWHPs and SWHPs):** Aquifer depth, temperature, pumping test…
  - **Ground (GCHPs):** temperature, thermophysical properties, TRT…
- ✓ Evaluate thermal load profile (second thermal sources)
  - Heat delivery temperature
  - Power and Energy needs
- ✓ **Does GSHP operation alter the thermal sources?**

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Air/water vs. ground

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- ✓ Ground has a huge thermal capacity, governing its temperature evolution
- ✓ Current performance of the GSHP depends on the full history of heat exchanges (sizing and control strategy)
- ✓ Air and water sources are weakly affected by past operation

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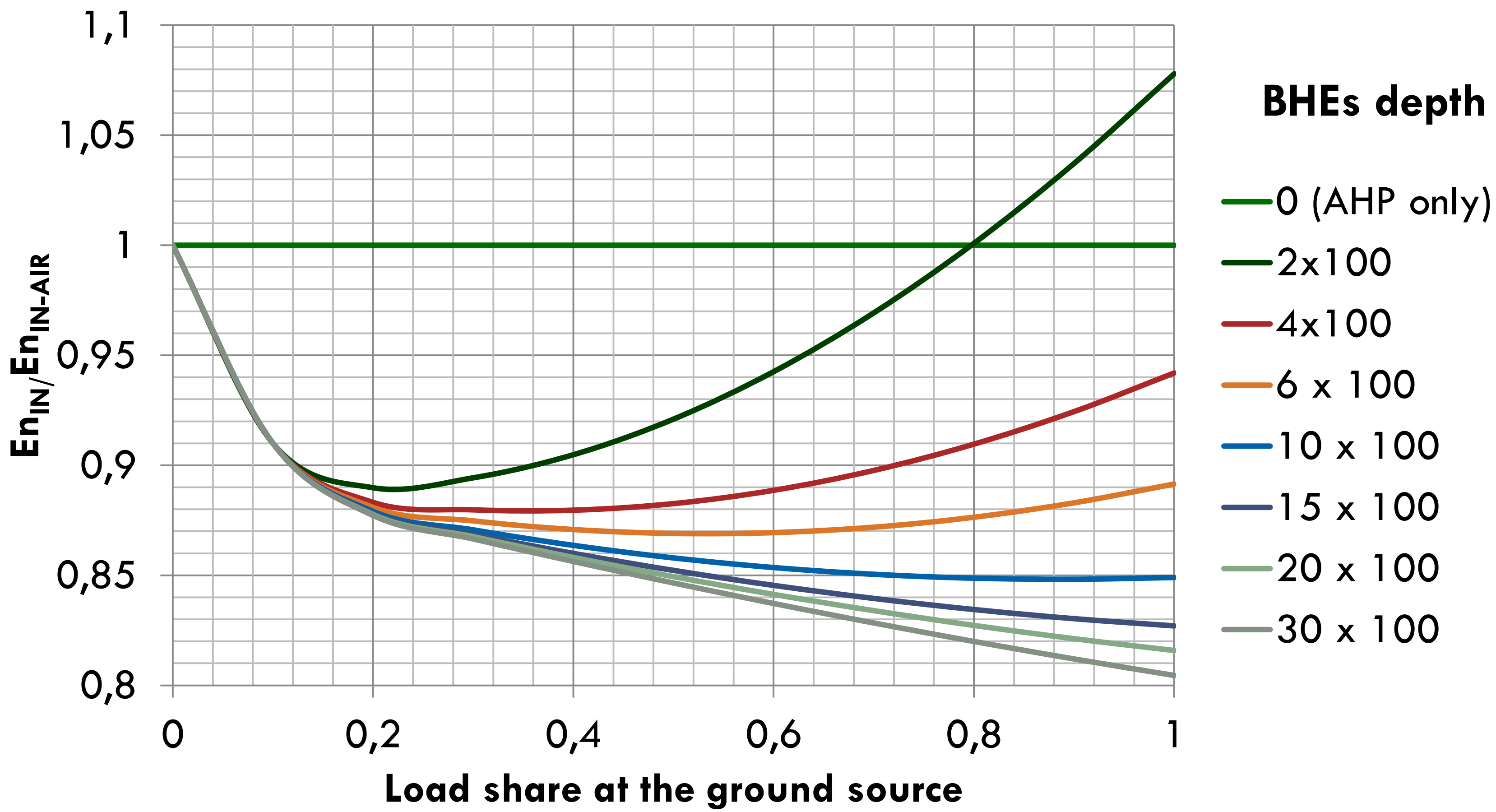
Feasibility of GSHP projects: a case study

We consider **an heating system** made of **a GCHP** and **an ASHP** (as back-up).



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Feasibility of GSHP projects: a case study

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- ✓ Minimum energy consumption corresponds to the optimal synergy between air and ground sources.
- ✓ Energy savings show a saturation trend at elevate BHEs number, hinting an unfavorable benefit-cost ratio for oversized systems.
- ✓ BHEs number and depth have to be chosen seeking the optimal tradeoff among installation costs and corresponding achievable savings.

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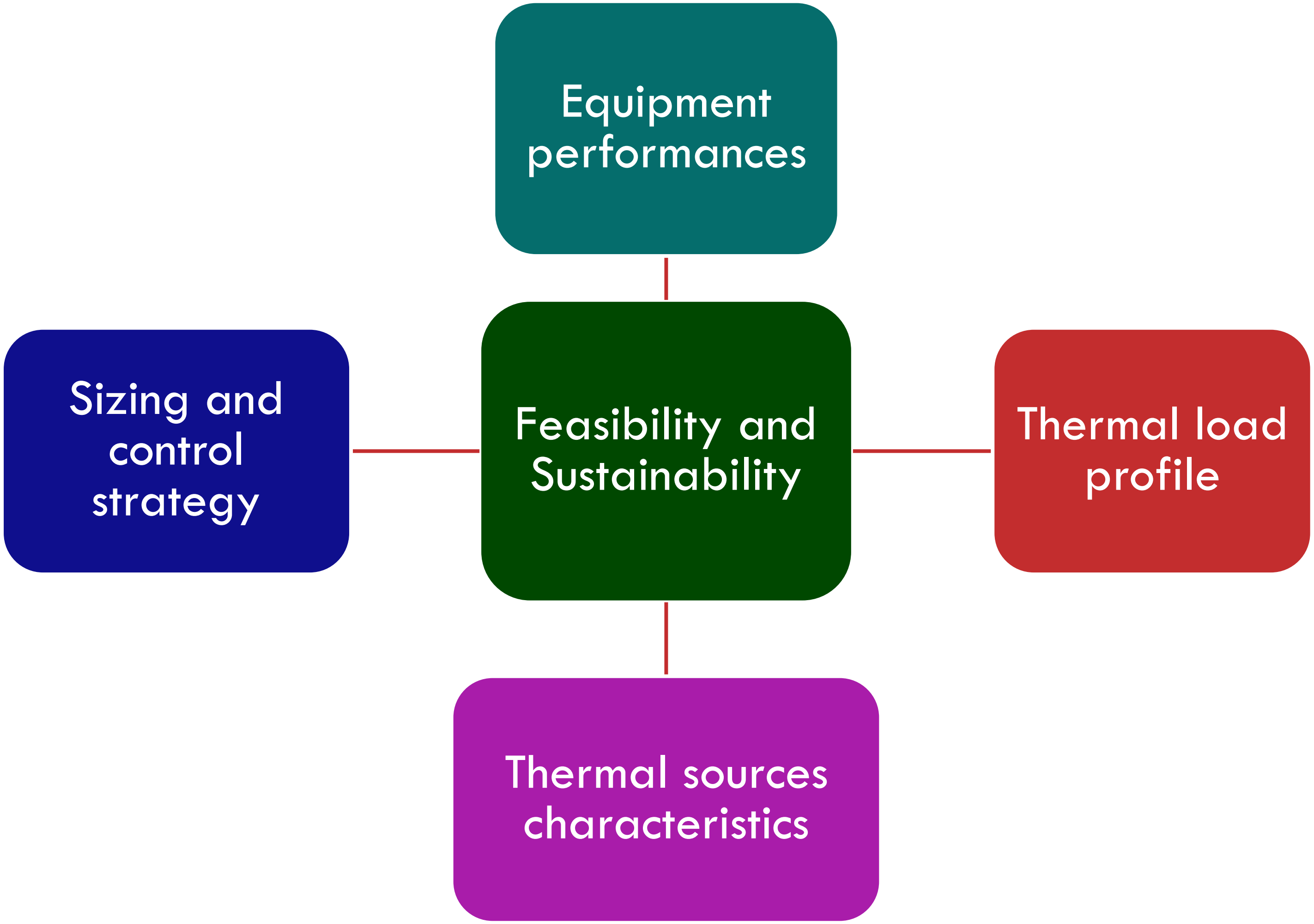
Feasibility of GSHP projects



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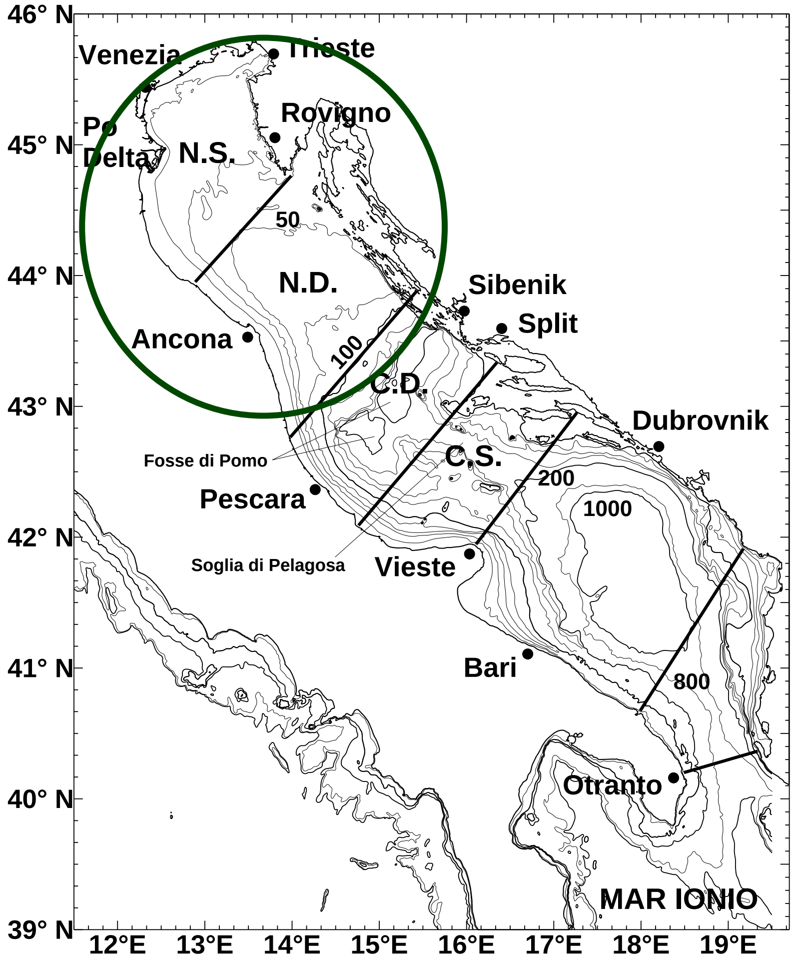
Seawater as thermal source



Preliminary considerations

- ✓ Seawater temperature is less variable than air one
- ✓ Seawater temperature is weakly affected by HPs operation
- ✓ Maintenance required
- ✓ Feasibility study required (always!)

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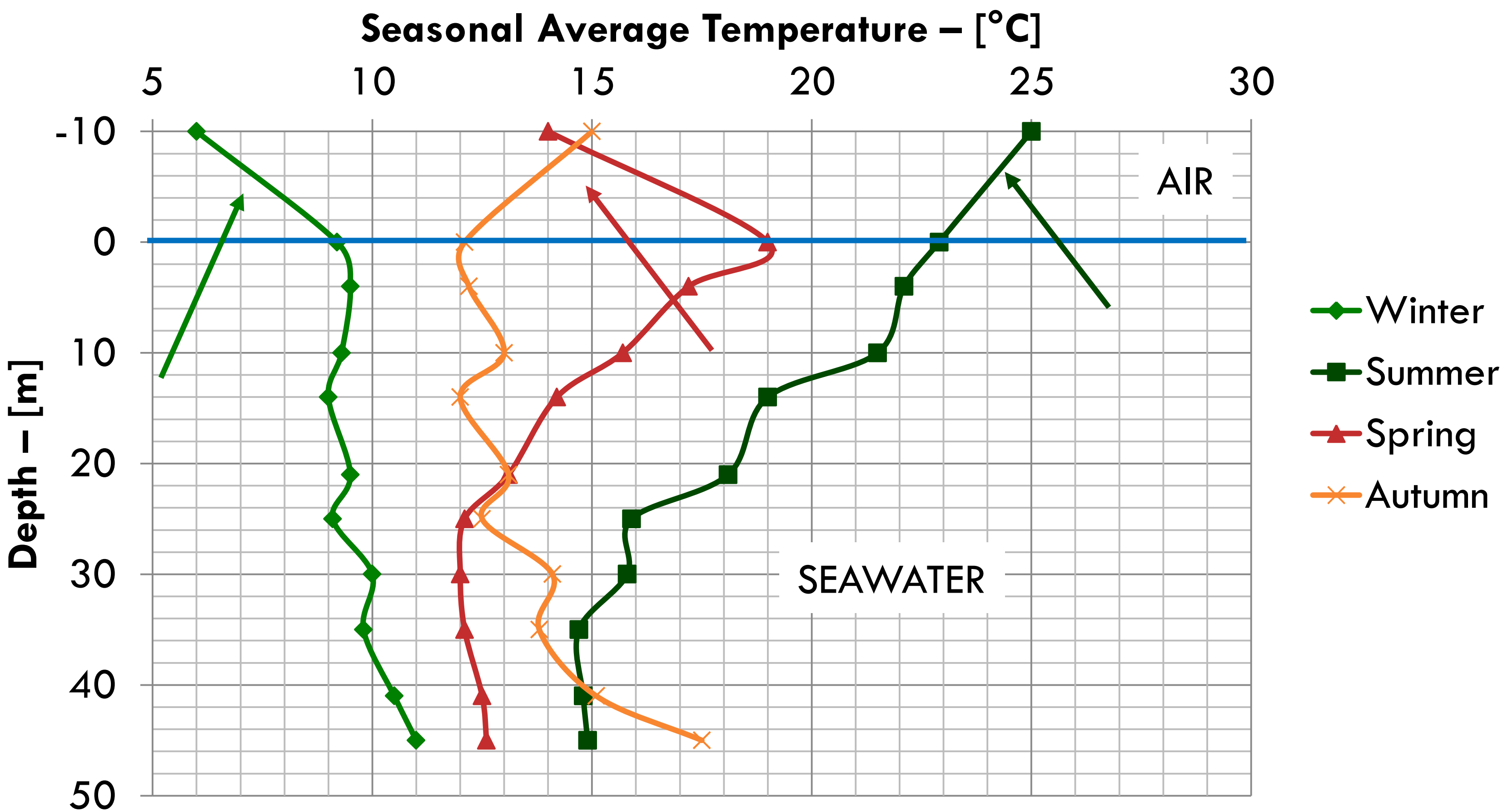
Seawater as thermal source



Data from: UNI 10349:1994 and ISMAR (CNR)

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Thanks for your attention!

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