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Performance analysis of heat pumps utilizing different low temperature heat sources to supply district heating

3rd international Conference on Smart Energy Systems and
4th Generation District Heating

12.-13. September 2017, Copenhagen

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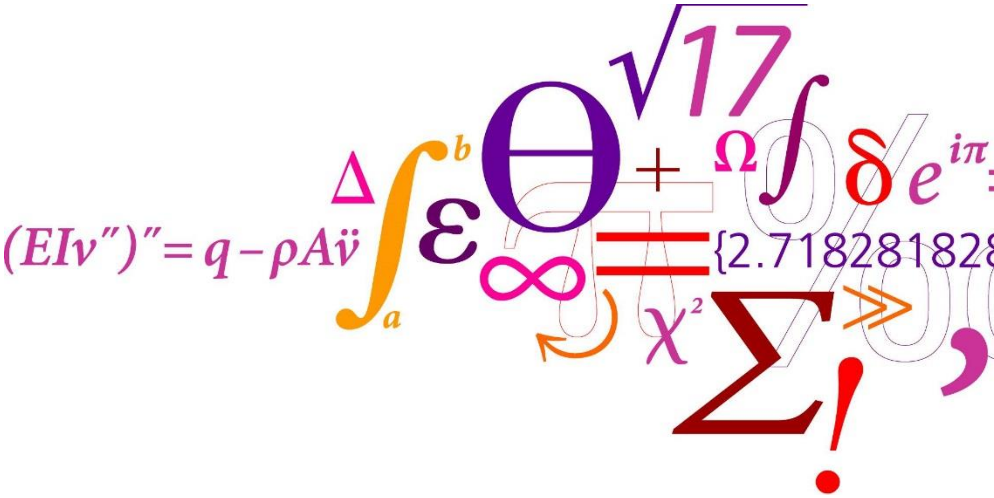
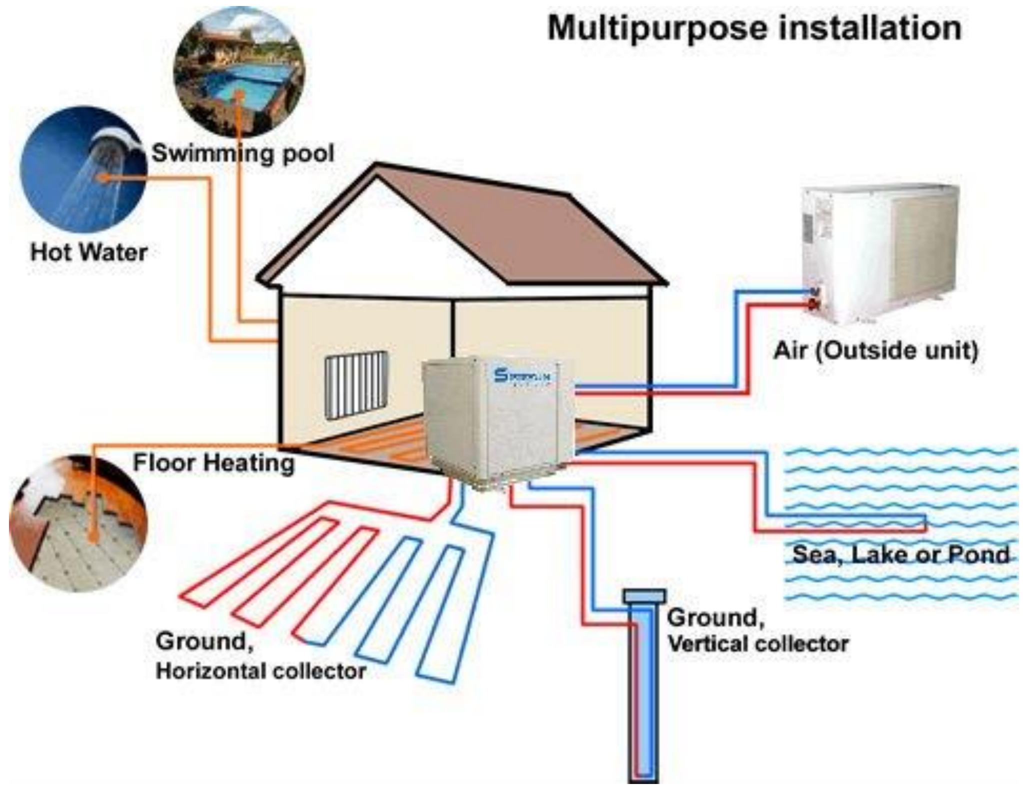


DTU Mechanical Engineering
Department of Mechanical Engineering

Agenda

I. Introduction
  – Motivation
II. Method
  – Model development
  – Key parameters
  – Case description
III. Results
  – Comparison of scenarios
IV. Discussion
  – Model limitations
V. Conclusion

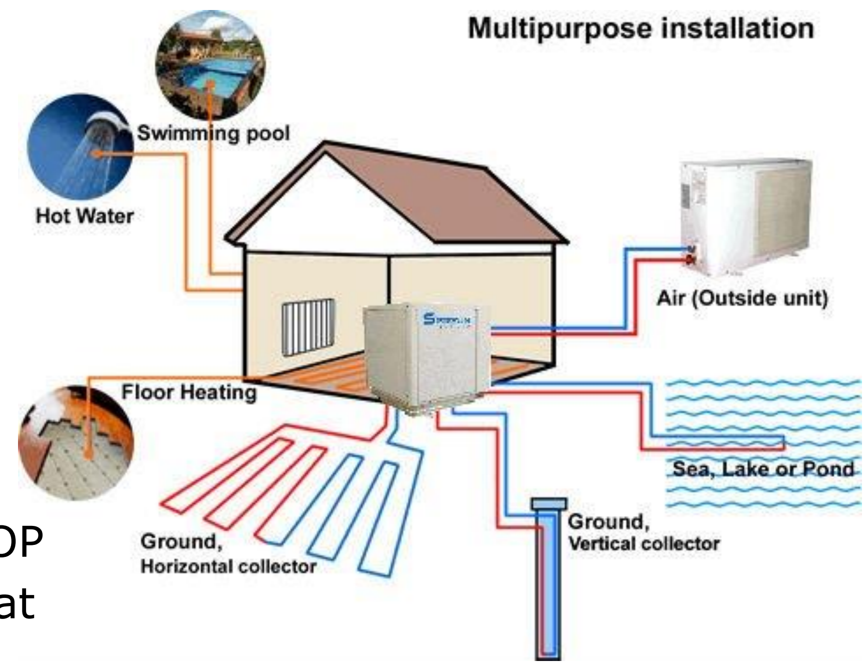


Source: http://www.heatpumpcritique.com/

I. Introduction

- Energy planning:
  - Constant COP of heat pumps (HP)
- Different heat sources:
  - Seawater, lakes, rivers
  - Air, solar energy
  - Groundwater, geothermal energy
  - Sewage water, waste heat
- Varying temperatures:
  - Influence COP

- How to get highest COP?
  - Investigating hourly variations in COP
  - Comparing scenarios with single heat sources and a combination of those



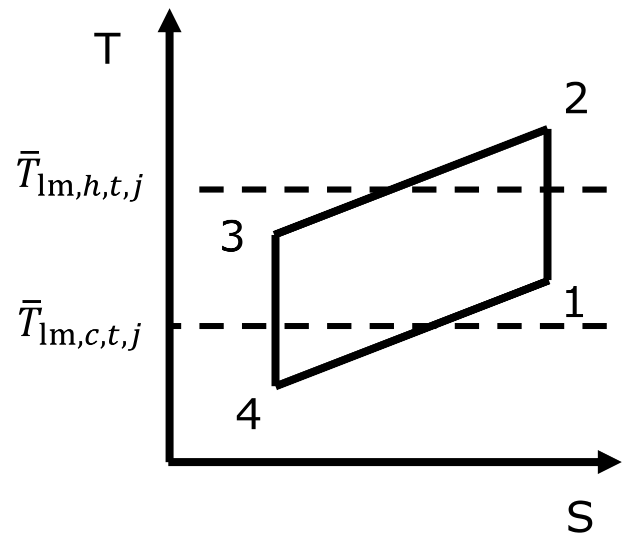
II. Model

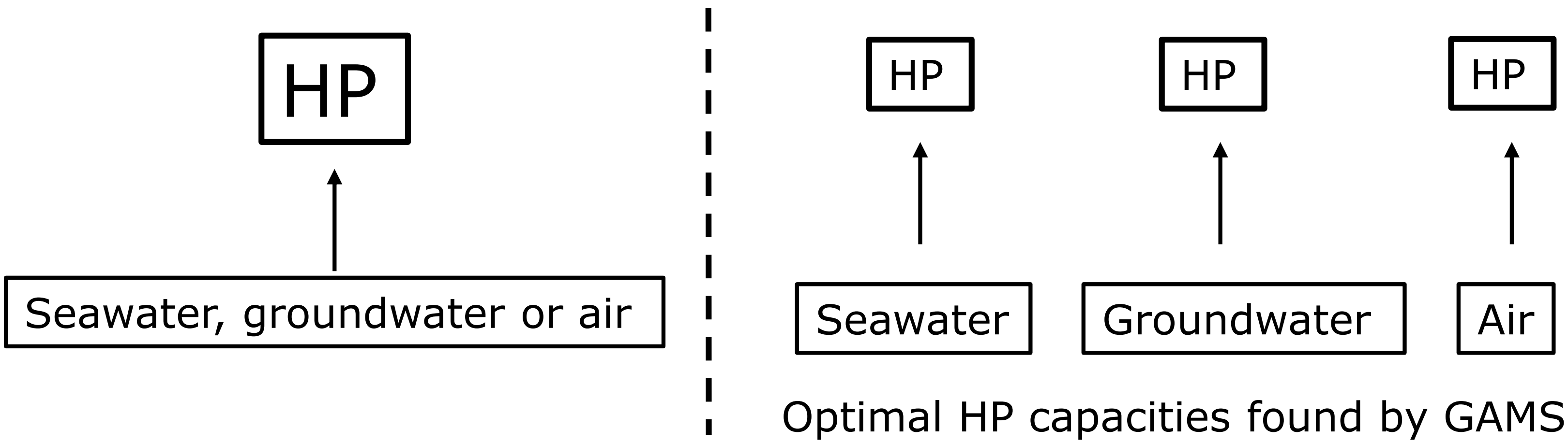
- GAMS
- Linear programming
- Lorenz cycle for COP:

$$\mathrm{COP}_{\mathrm{HP},t,j} = \eta_L \mathrm{COP}_{\mathrm{HP},L,t,j} = \eta_L \frac{\bar{T}_{\mathrm{lm},h,t,j}}{\bar{T}_{\mathrm{lm},h,t,j} - \bar{T}_{\mathrm{lm},c,t,j}}$$

  η_L: Lorenz efficiency

- Comparison of 3 heat sources in 4 scenarios





Optimal HP capacities found by GAMS

II. Key parameters

- Annual mean COP:

$$\mathrm{COP}_{\mathrm{avg}} = \frac{1}{n} \sum_{t=1}^{n=8760} \mathrm{COP}_{\mathrm{HP},t}$$

- Weighted annual system COP:

$$\mathrm{COP}_{\mathrm{Sys}} = \frac{\dot{Q}_{\mathrm{sink},sys,tot}}{P_{\mathrm{sink},sys,tot}}$$

- Full load hours [h]:

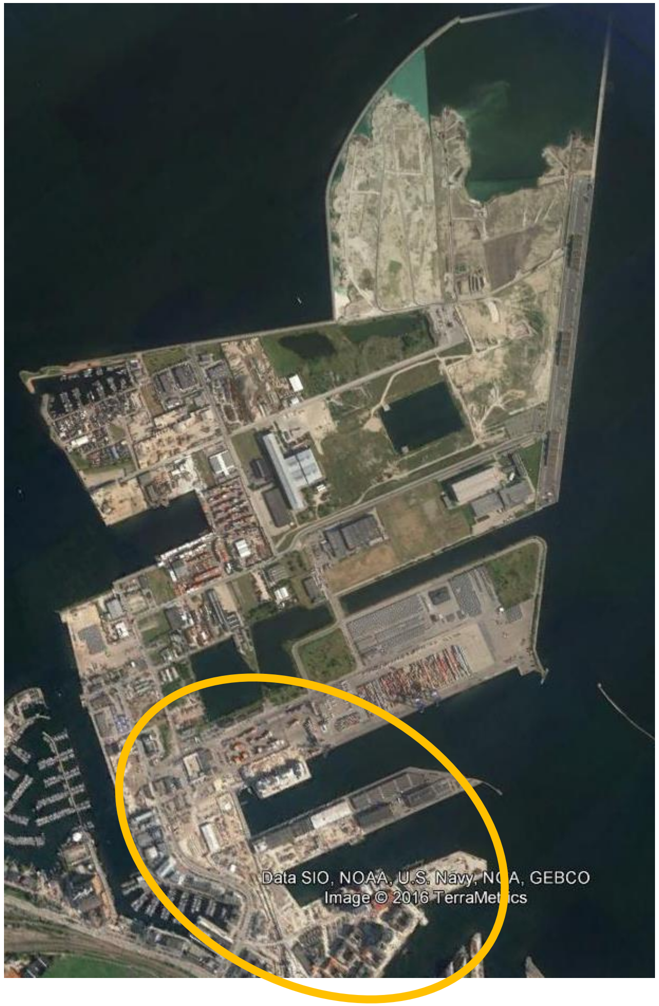
$$\mathrm{FLH}_{j} = \sum_{t=1}^{n=8760} \frac{\dot{Q}_{\mathrm{sink},t,j}}{\dot{Q}_{\mathrm{sink},d,j}}$$

II. Case description: Nordhavn

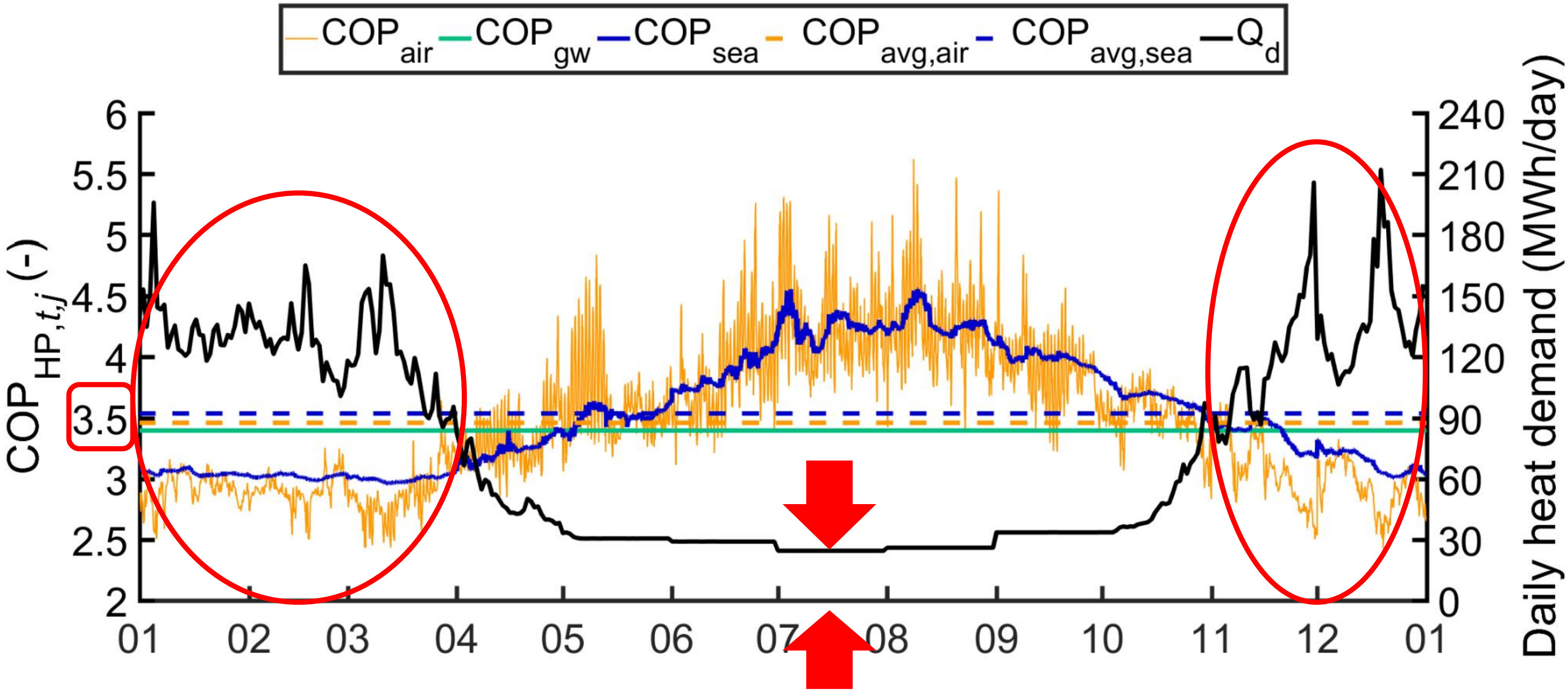
- Large development district in Europe
- www.energylabnordhavn.dk

- For this study:
  - Inner Nordhavn: 670,000 m²
  - New residential buildings
  - Space heating: 18 kWh/m²/yr
  - Domestic hot water: 16 kWh/m²/yr
  - Peak demand: 12.4 MWh/h

- 2 cases:
  - *No base load (& Base load)*
    - Total capacity: 80% of peak demand
    - 15 MWh storage
    - Peak boiler when needed



III. COP and heat demand



III. Key parameters

1 MW/7 MW/2 MW

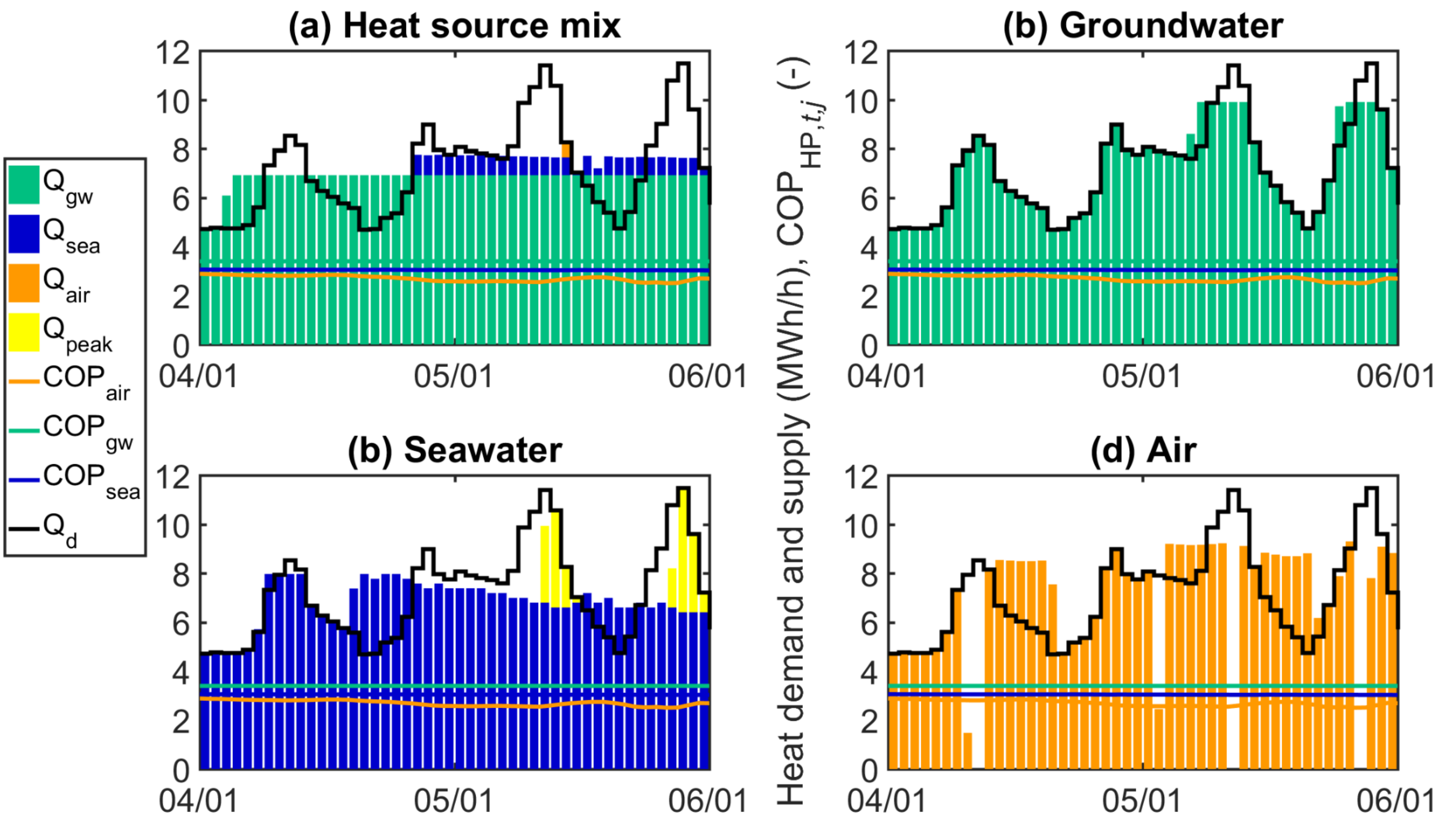
Parameters	Unit	Seawater		Groundwater		Air		Heat source mix: Sea/GW/Air
				no base load case				Shares: 9%/56%/15%
Average COP_{avg}	(-)	3.54	>	3.40	<	3.46	-10%	3.43
Weighted COP_{Sys}	(-)	2.90	<	3.40	>	3.12		3.50
Full load hours HP	(h)	2576		2704		2710		3214/2893/1736

-18%

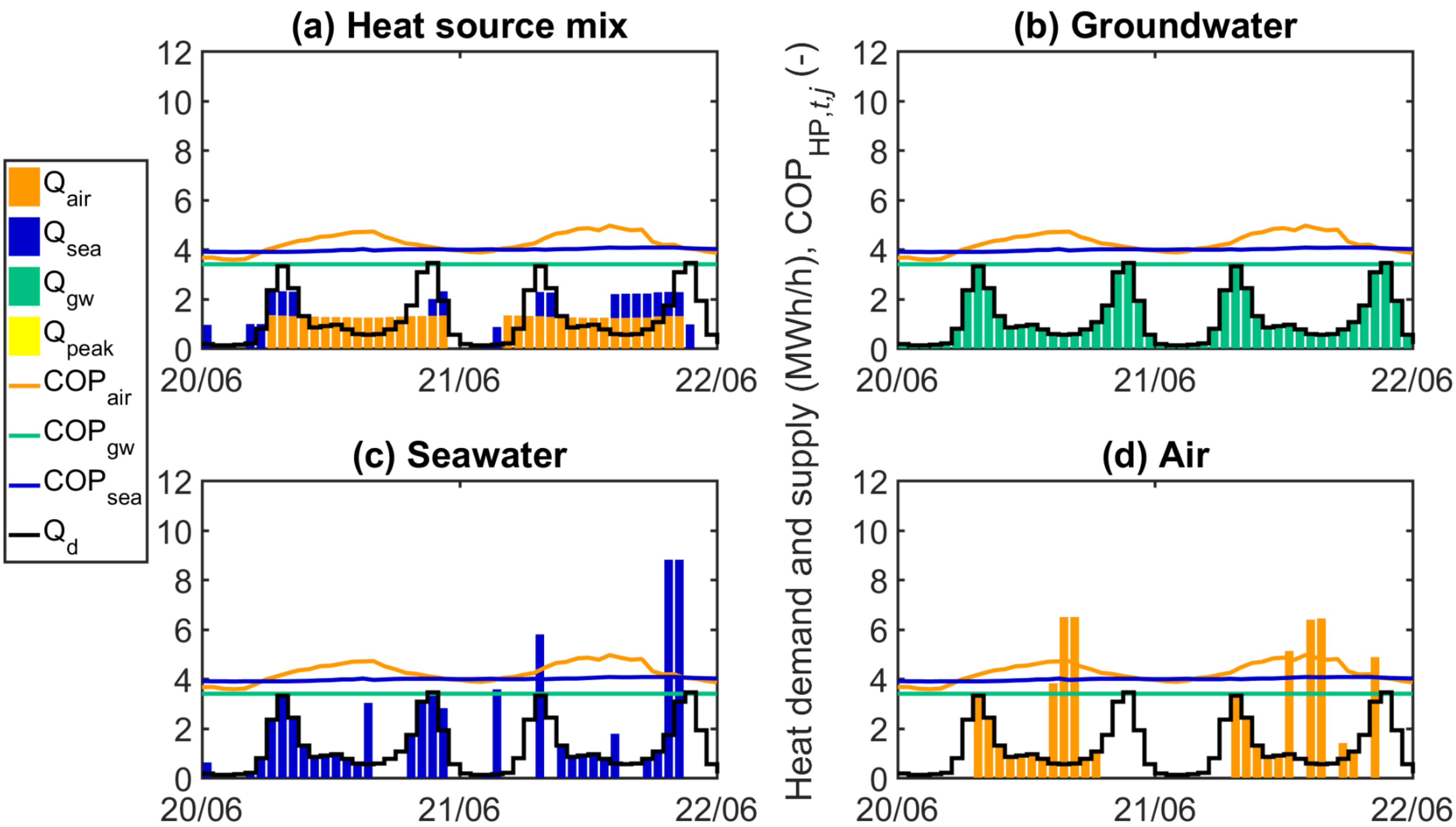
COP:+3%

7 MW peak
boiler capacity

III. Winter: *no base load case*

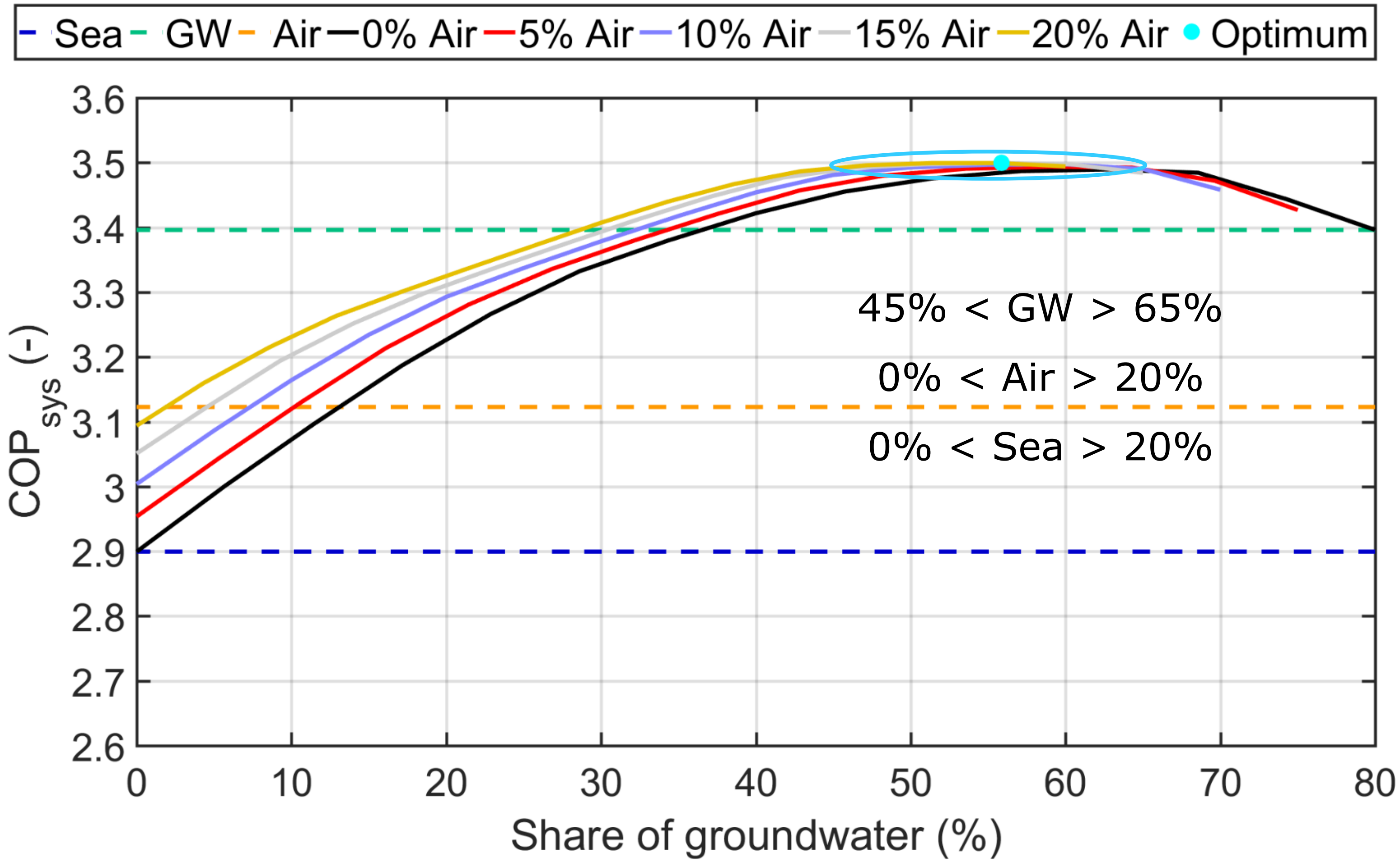


III. Summer: *no base load case*



III. Variation of heat source capacity shares

no base load case



IV. Discussion

Model limitations:

- No auxiliary electricity consumption
- No investment costs
- Constant Lorenz efficiency
- No minimum HP operation level
- Constant electricity price
- Limited to groundwater, seawater and air
- No cooling demand

V. Conclusion

- COP of seawater and air varies a lot
  - Fixed annual COP not recommended without heat demand
  - Weighted COP identified true performance & ranking of heat sources

- High peak unit capacity required for seawater HP

- HPs with combination of heat sources
  - perform better than HP with single heat source
  - utilize heat sources and capacity more effectively

- Recommended range of HP capacities based on peak demand

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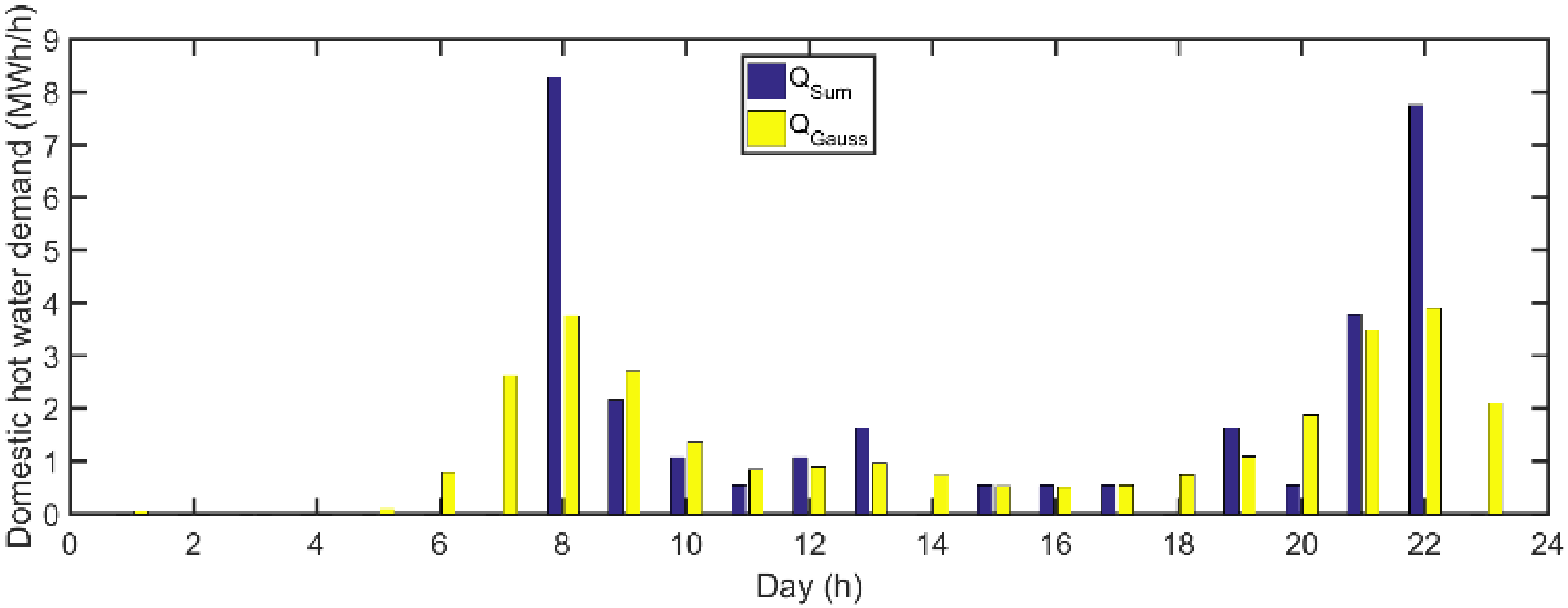
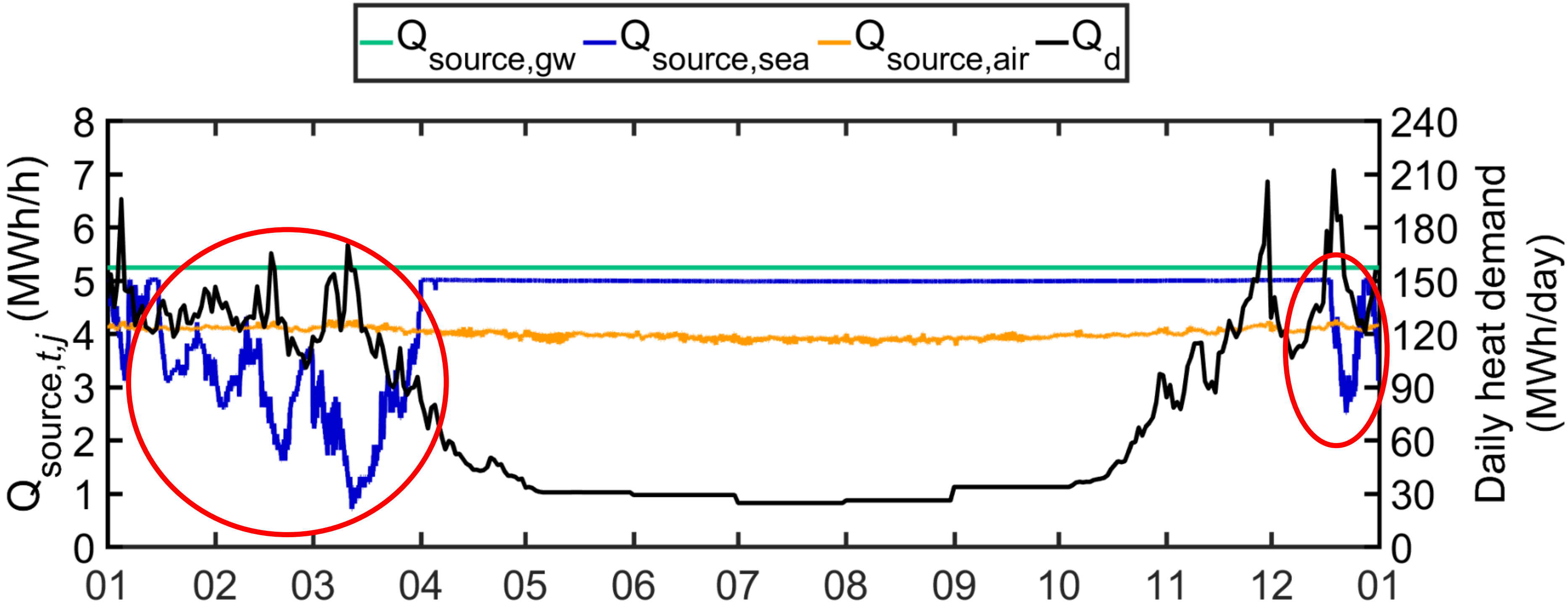
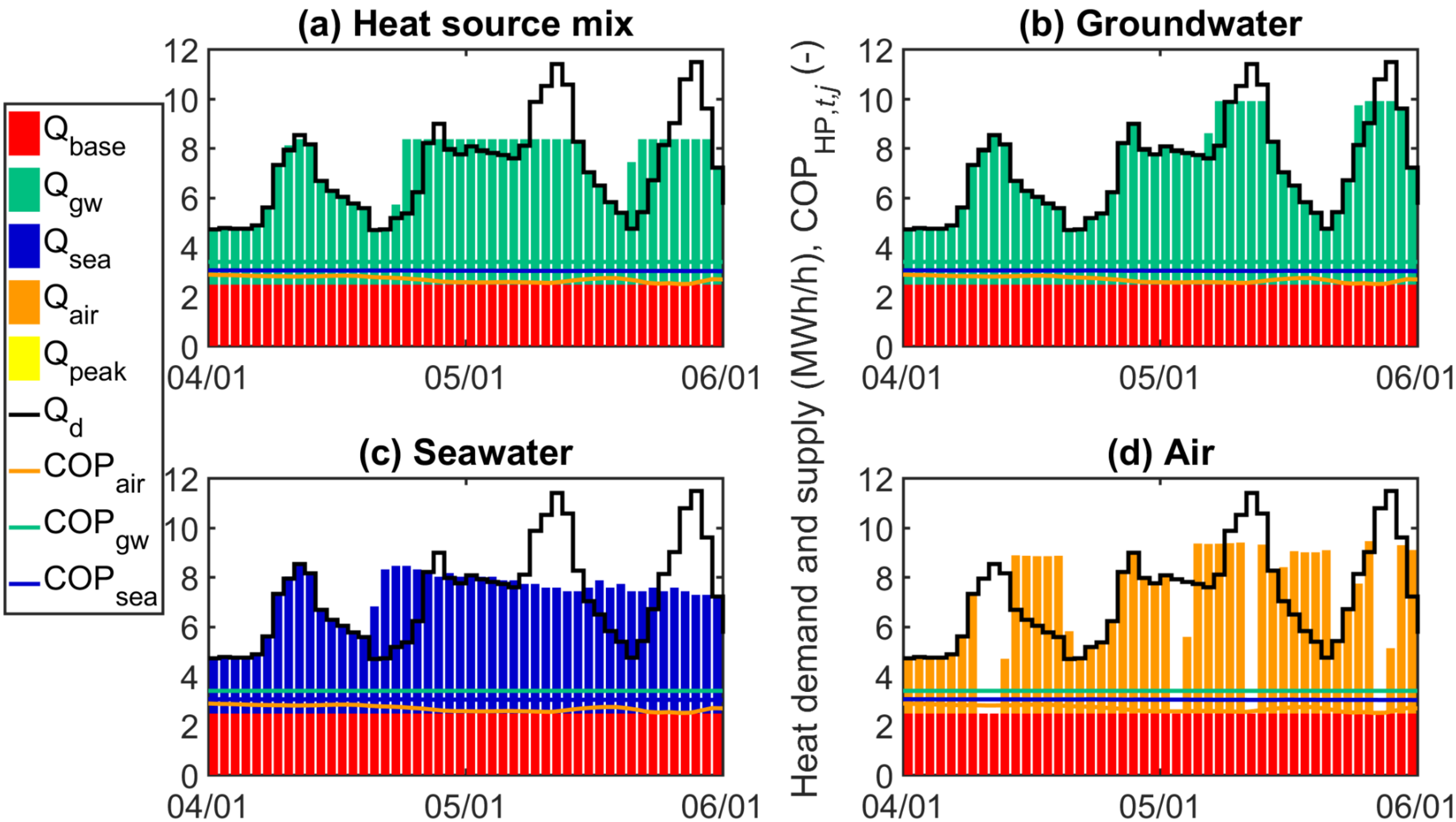
II. DHW + SH demand profile



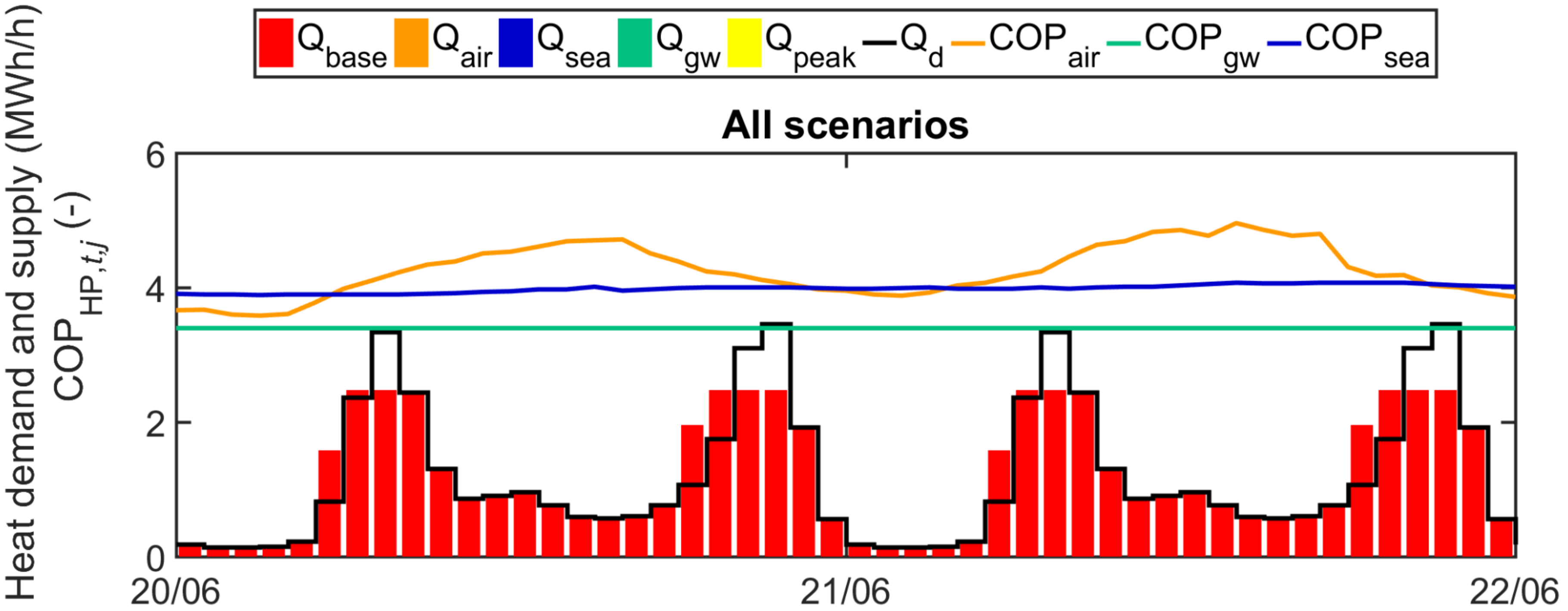
III. Available heat source capacities



III. Winter: *base load case*

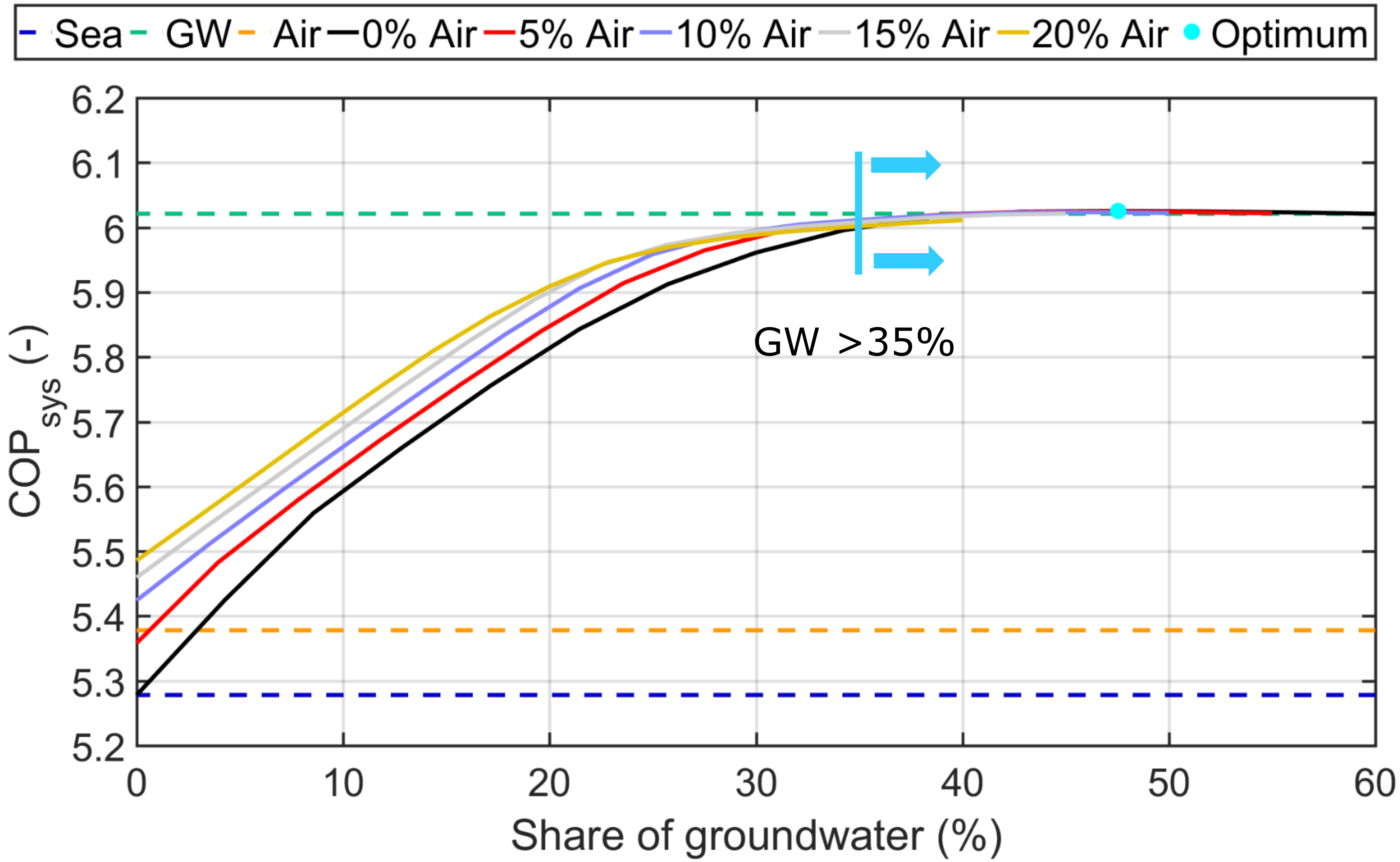


III. Summer: *base load case*



III. Variation of heat source capacity shares

base load case



III. Key parameters

Parameters	Unit	Seawater	Groundwater	Air	All heat sources: Sea/GW/Air
	-12%	*base load case*			Shares: 12%/48%/0.0%
Average COP_{avg}	(-)	3.54	3.40	3.46 -16%	3.43
Weighted $COP_{HP,w}$	(-)	3.10	3.40	2.90	3.40
Weighted COP_{Sys}	(-)	5.28	6.02	5.38	6.03
Full load hours HP	(h)	1358	1414	1417	446/1668/0
		no base load case			Shares: 9%/56%/15%
Average COP_{avg}	(-)	3.54	3.40	3.46 -10%	3.43
Weighted $COP_{HP,w}$	(-)	3.27	3.40	3.12	3.50
Weighted COP_{Sys}	(-)	2.90	3.40	3.12	3.50
Full load hours HP	(h)	2576	2704	2710	3214/2893/1736

-8%

-18%

7 MW peak
boiler capacity

COP:+3%

FLH for no base case 90% higher