Overcoming heat source limitations for heat pumps in the larger capacity range

Séminaire Energîe-Environnement
Univ. de Genève, Oct. 3, 2024

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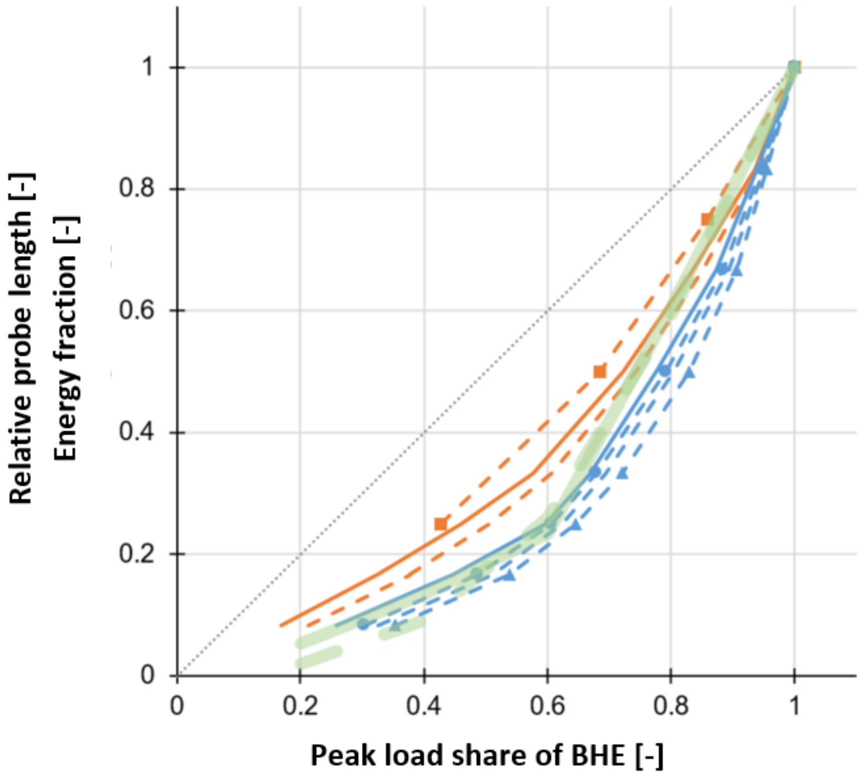
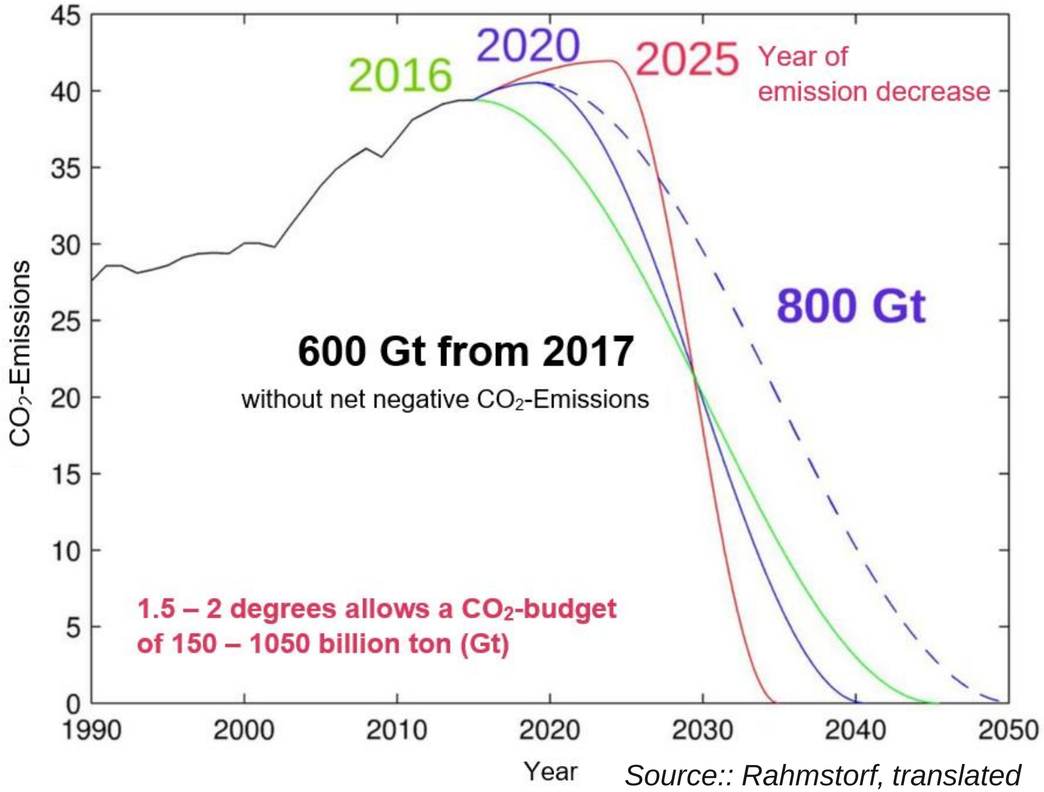
Outline of the presentation

- Motivation multi-source system investigation
- Strategies and boundary conditions
- Results on Peak load strategy
- Results on Regeneration strategy
- Summary and Take home messages
- Outlook on follow-on activities
- Discussion



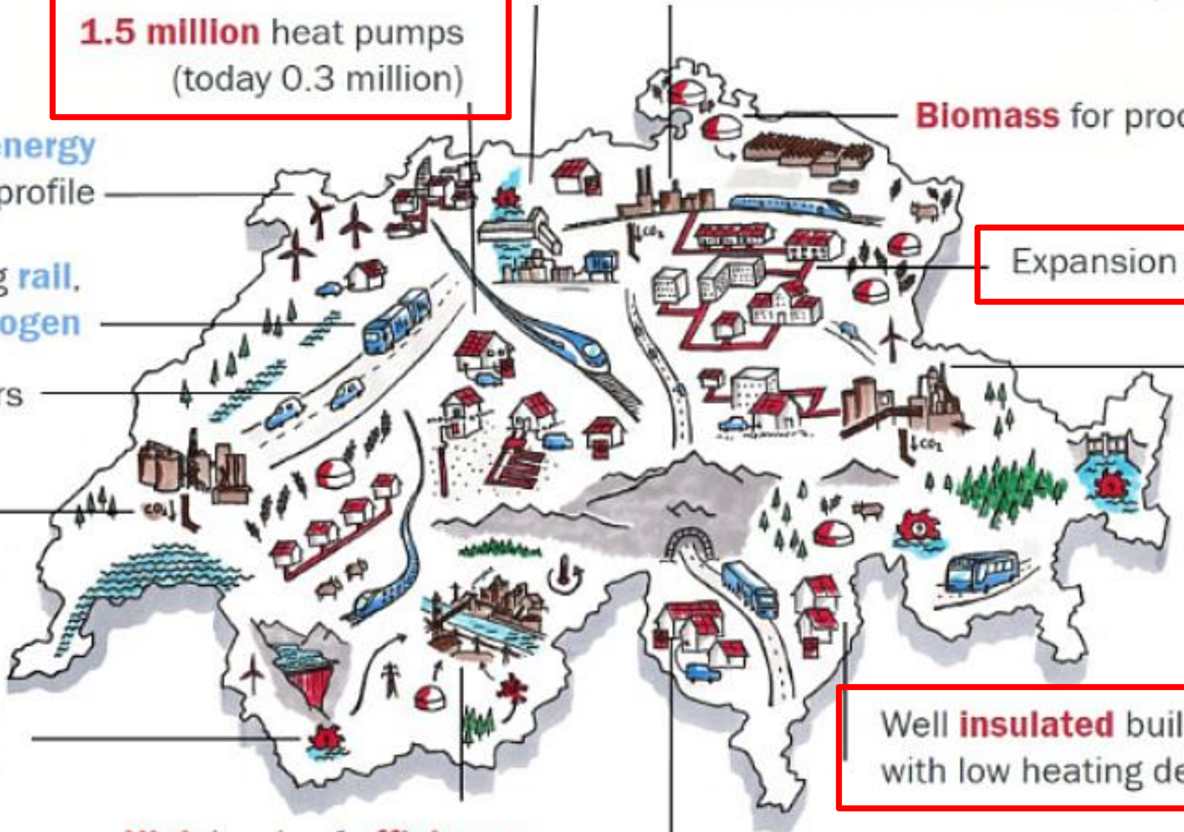
Introduction

- Phase-out of fossil fuel boilers by heat pumps (HP) enables rapid and massive CO_2-reductions
- HP are seen as future heating systems in many scenarios around the world
- Massive HP implementation also needs high quality heat sources
- In particular in retrofit applications limitations of the heat sources can be a major obstacle, especially for higher capacities
- Integration of multiple heat sources can overcome or at least mitigate limitations of individual heat sources
- Synergies among heat sources can also increase performance and cost-effectiveness



Source:: Rahmstorf, translated

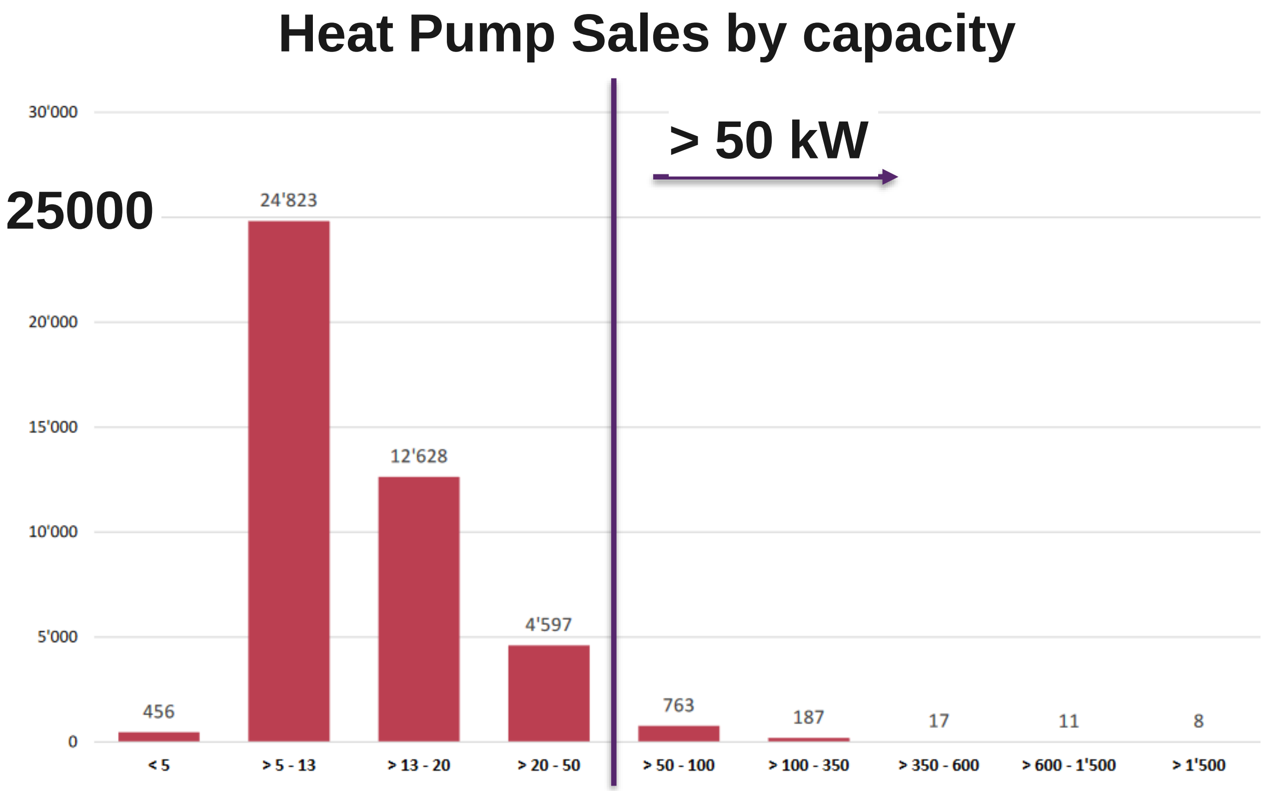
Objectives for a climate-neutral Switzerland by 2050



Graphics: Dina Tschumi; Prognos AG

Objectives

- Identification of favourable heat source integration in the higher capacity range (> 50 kW)
- Investigation of integration, design and control of the heat sources
- Evaluation of the energy and economic performance
- Recommendations for favourable heat source integration
- Primary scope are residential buildings and space heating/DHW operation



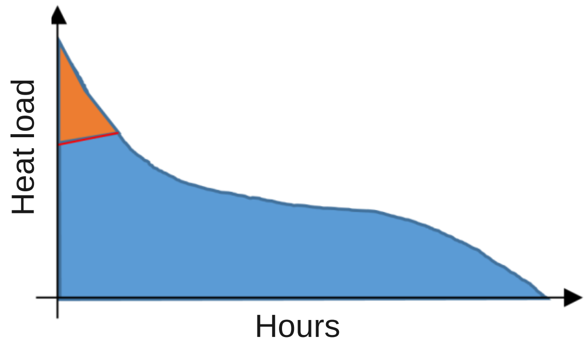
Source:: FWS, 2024

Methodology

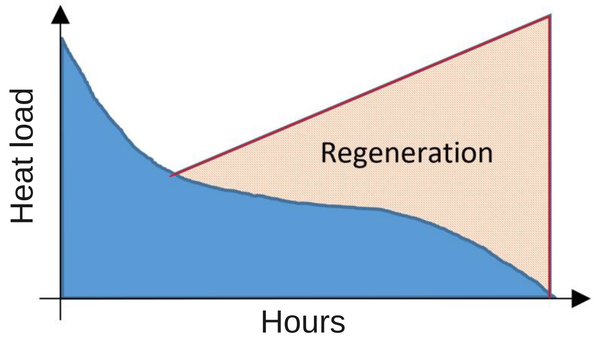
- Investigations by simulation for heat load of 60 kW – 240 kW
  - **Existing building,** space heating (SH) 160 kWh/(m^2yr)
    80% SH, 20% domestic hot water (DHW)
    Radiator emission system, design supply temperature 55 °C
  - **New building,** SH 15 kWh/(m^2yr)
    33% SH, 66% DHW
    Floor heating, design supply temperature 35 °C
- DHW temperature 55 °C,
  tapping energy acc. to SIA 2024 plus 50% losses
- Weather data Zurich SMA normal / cold year
- Thermal conductivity ground 2.4 W/(mK) and grouting 2 W/(mK) which are typical values for the Swiss middleland
- **Design to minimum probe length acc. to SIA 384/6:2021 "no undercut of average fluid temperature below -1.5 °C after 50 yrs". e.g. inlet -3 °C / outlet 0 °C**

Investigated strategies

- **Primary objective: Overcome limitations of individual heat sources by multiple sources**
  - Limitations due to noise in case of outdoor air source,
    space and depths restrictions for borehole heat exchangers
- **Strategy Peak load coverage**
  - Design of both sources can be reduced
    (e.g. design to 50% of heat source capacity at design heat load)
  - Efficiency improvement compared to air-source only



- **Strategy Regeneration**
  - Less ground probes and lower spacing in the ground probe field possible
  - Also direct use of regeneration source possible
  - Cost benefits due to smaller borehole field design



- For higher capacity the strategies can also be combined

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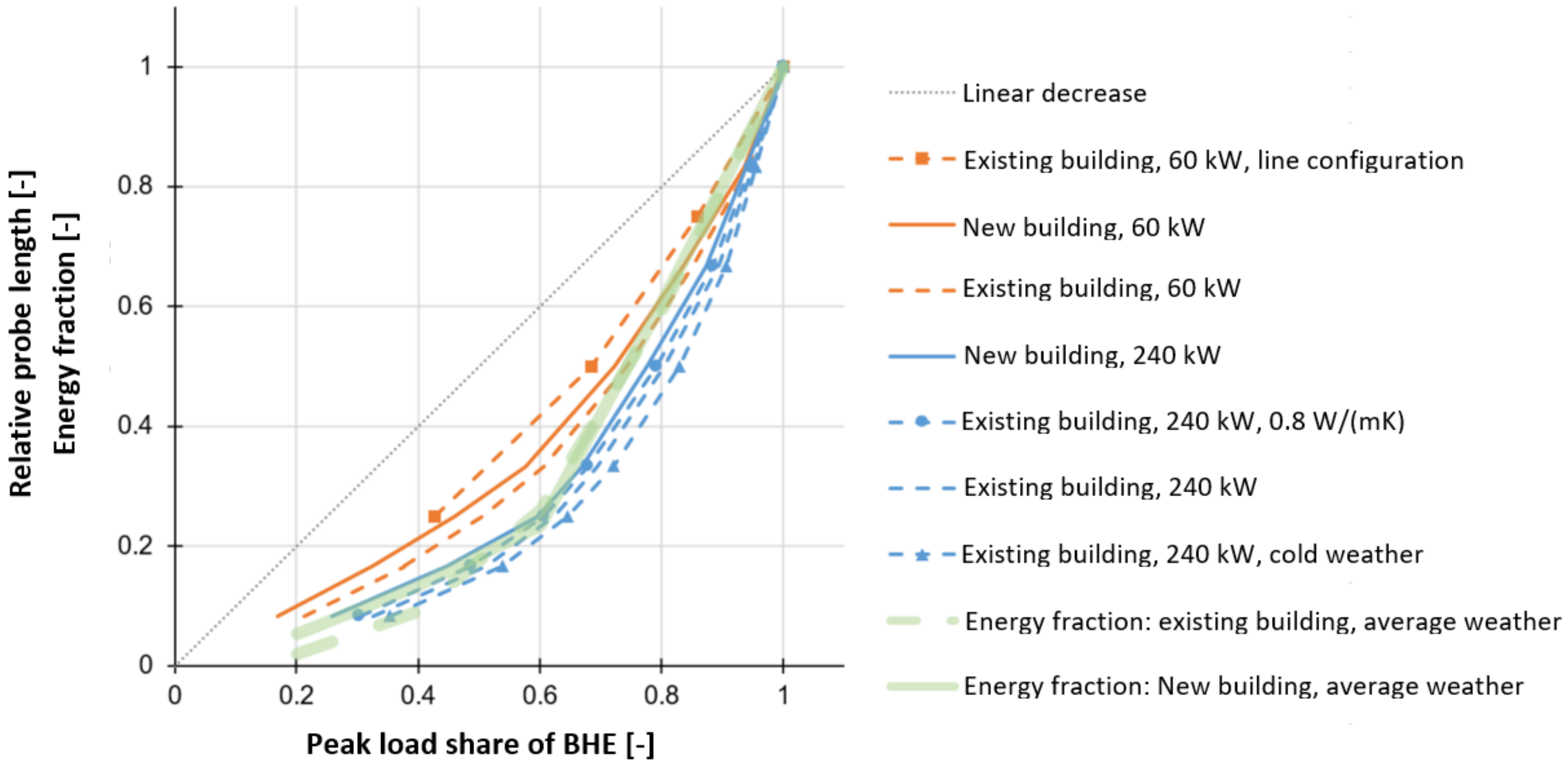
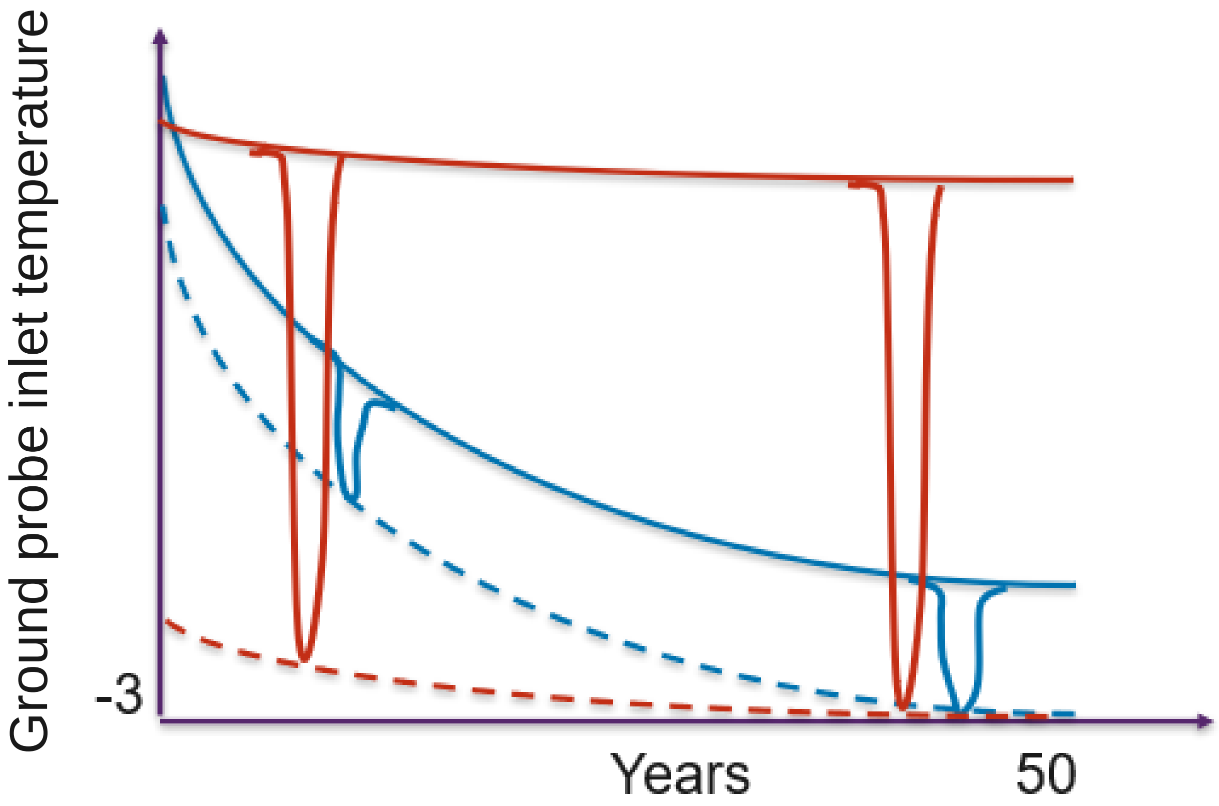
Results peak load coverage

- Disproportional savings of ground probe length
- Approximation by energy fraction
- High impact: Field effect
  - System size
  - Compactness of probe field
- Lower impact
  - Properties grouting
  - Weather profile
  - Existing building or new building (DHW-tapping profile)



Temperature development

- For ground source-only design:
  slow and asymptotic decrease of ground temperature
- For peak load operation, steep decrease of the probe temperature at peak load operation
- Due to short term extraction limited to the peak load hours, recovery of temperatures during the year
- Slower decrease of minimum temperatures over the design period of 50 years.



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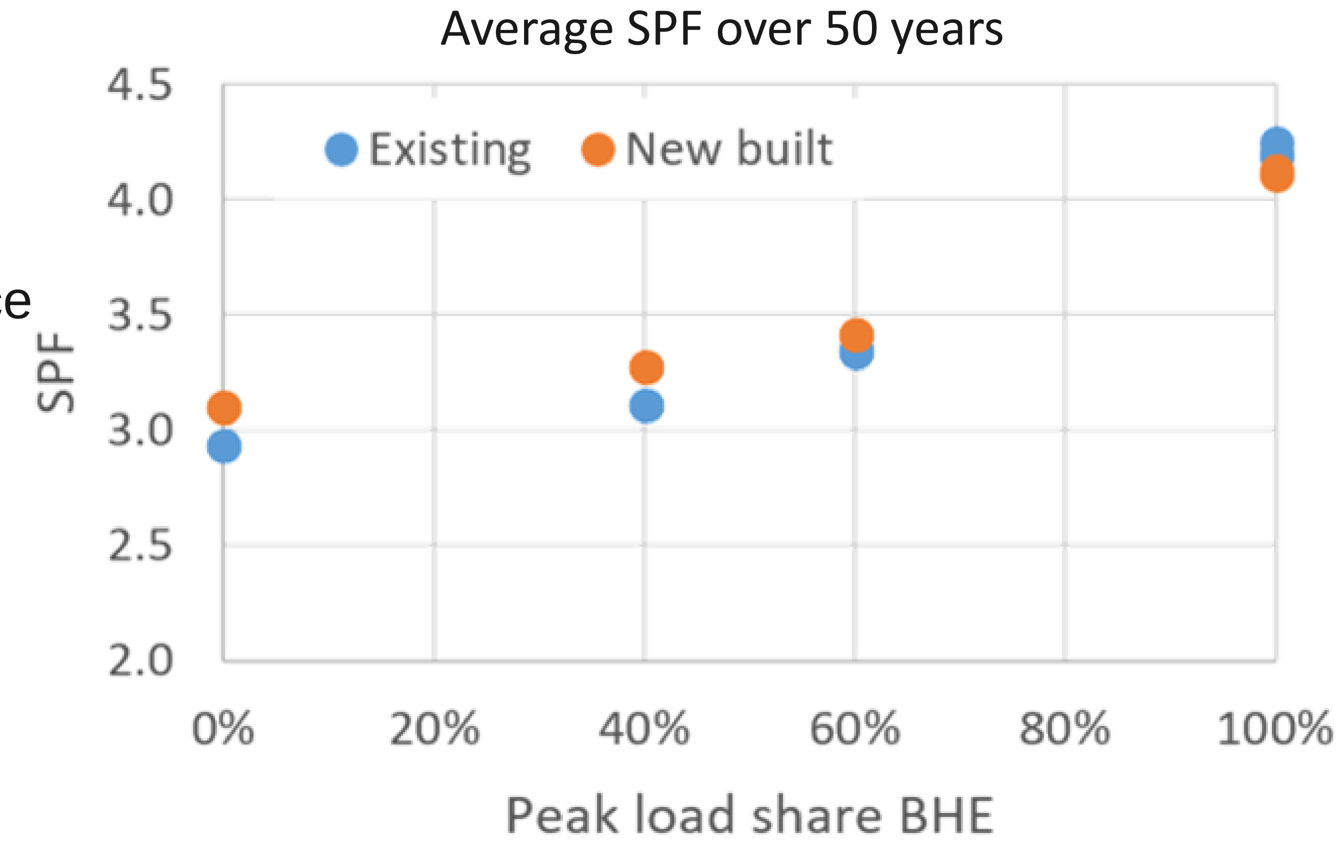
System performance

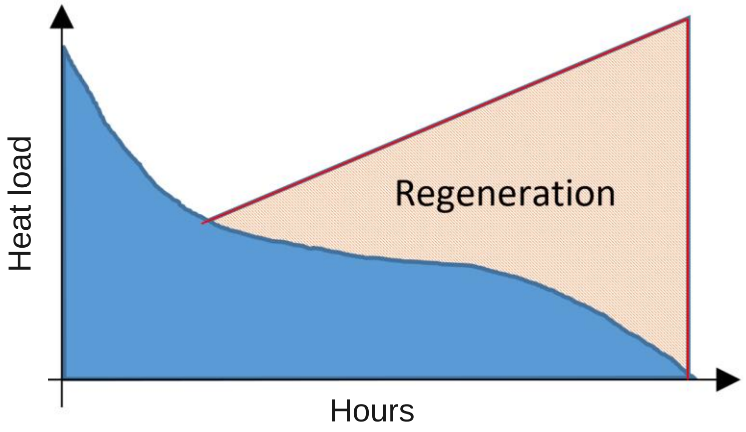
- Seasonal Performance Factor (SPF) increasing with Borehole Heat Exchanger (BHE) fraction
- Existing vs. new built: hardly any difference
- 100% BHE-System:
  - SPF 4.9 in the first year
  - SPF 4.0 in the last year
- Peak load system:
  - SPF relatively constant over 50 years



Cost comparison

- **Peak load coverage can be cost-competitive**
- In midsize and larger systems cost benefits
- With additional cooling also for smaller systems (not depicted)
- To mitigate limitations moderate extra cost tolerable
- Fossil bivalent systems do not have cost benefits (at prices as of June 2022)

Strategy Regeneration



- **Overcome limitations of ground heat source**
  - Space/depths limitation by a lower number of ground probes with regeneration
  - Regeneration source can also be applied as direct heat source => further reduction of use of ground heat source
- **Assumed efficiency benefits,** e.g. by the use of the heat source with better temperature level
- **Assumed cost benefits,** e.g. by savings of investment cost for the ground probes to refund the regeneration source
- **Investigations (with focus on economy)**
  - How can regeneration overcome limitations of the ground source?
  - What regeneration sources are favourable?
  - When is it worthwhile/necessary to regenerate?
  - How much should be regenerated?

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Regeneration sources

- **Solar Regeneration (PV/T, uncovered selective collector (USC))**
  - Well introduced
  - Experience with design, implementation and cost
  - Different suppliers

  + architectural integration, acceptance

  - limited for retrofit (roof size and condition, orientation)

- **Air heat exchanger (AHX)**
  - Less projects, less experience
  - Product variety by industry applications
  - Acceptance? (noise issues, architectural integration)
  - Less space requirement → benefit retrofitting

- **Other possible regeneration sources:**
  - Ground water, river/lake water, district heat, waste heat

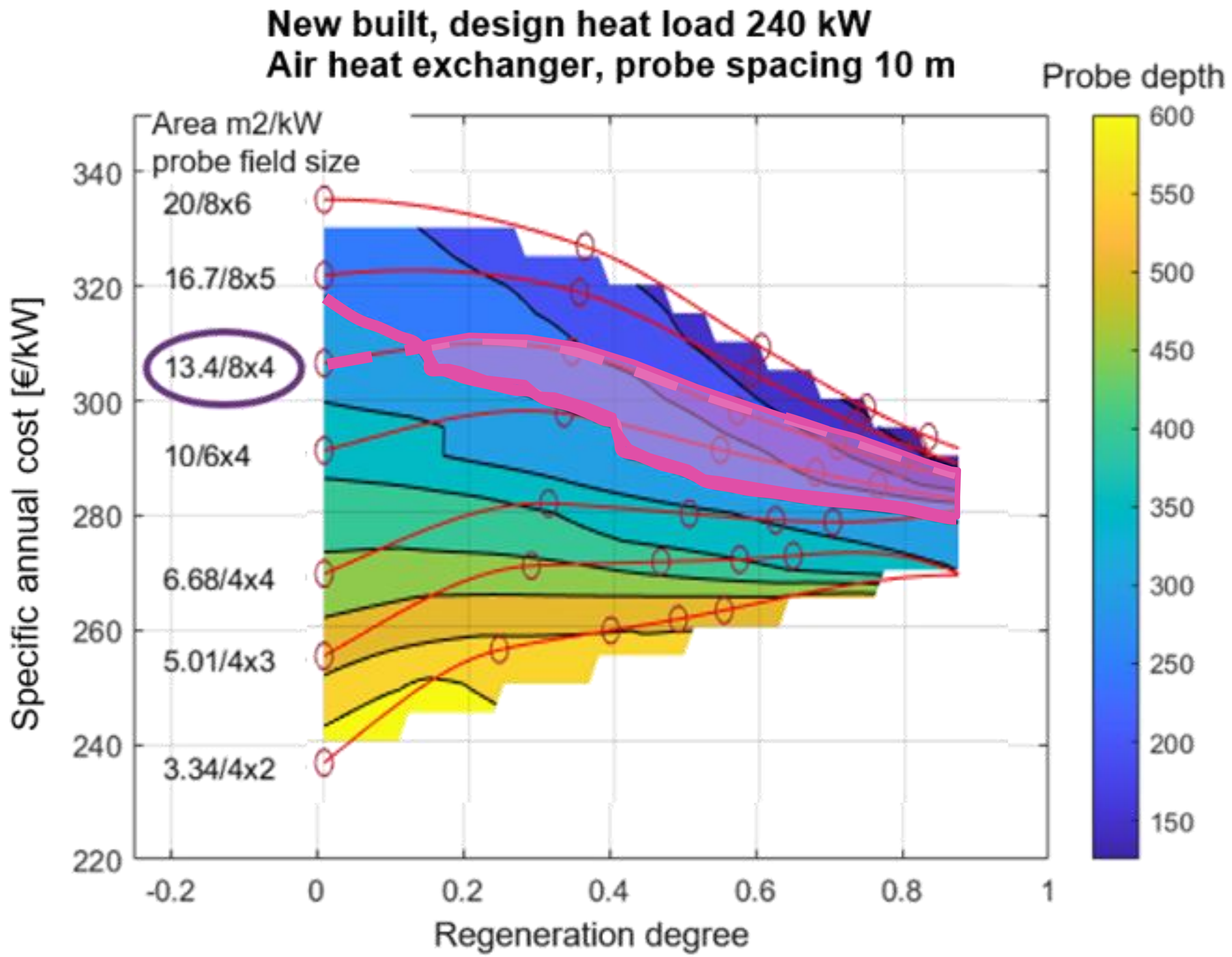
Depiction of cost effective design

- **Case study:**
  - Heat load 240 kW
  - Bore field area 3200 m² (13.4 m²/kW)
    → Max. 32 probes at 10 m spacing
  - Depth limitation at ca. 300 m

    → without regeneration not possible
    (at minimum about 15% regeneration)

    → min. cost at 60-80% regeneration rate

    → specific annual cost 270 €/kW



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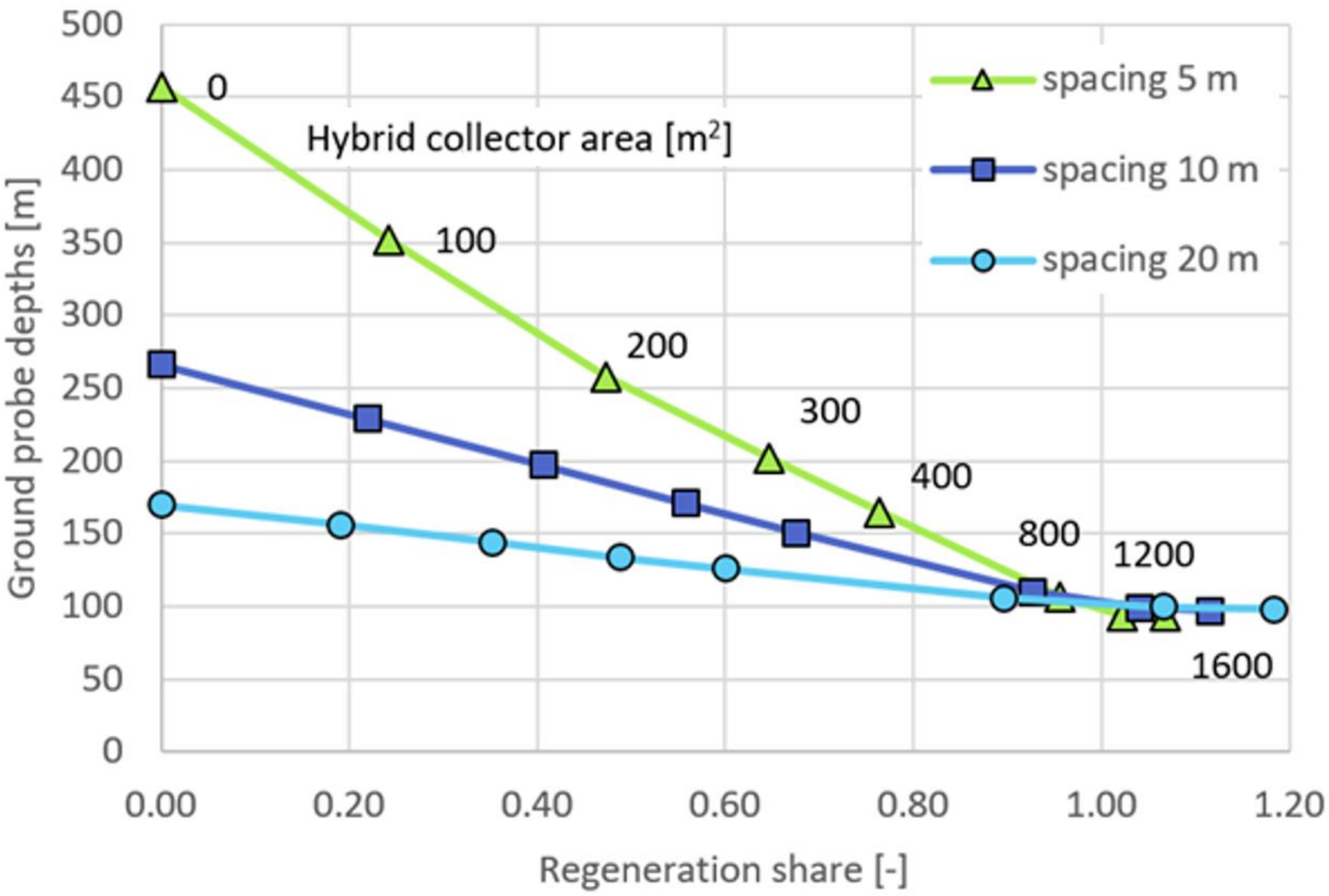
Overcoming depth and space limitations

- **Borehole depth can be reduced**
  - By larger spacing (no space limits)
  - By regeneration (add. space limits)

- **Additional space limitations**
  - can be overcome by closer spacing
  - But requires higher regeneration shares
  - However, regeneration is more effective at closer probe spacing
  - Synergies by use of regeneration source e.g. for DHW production



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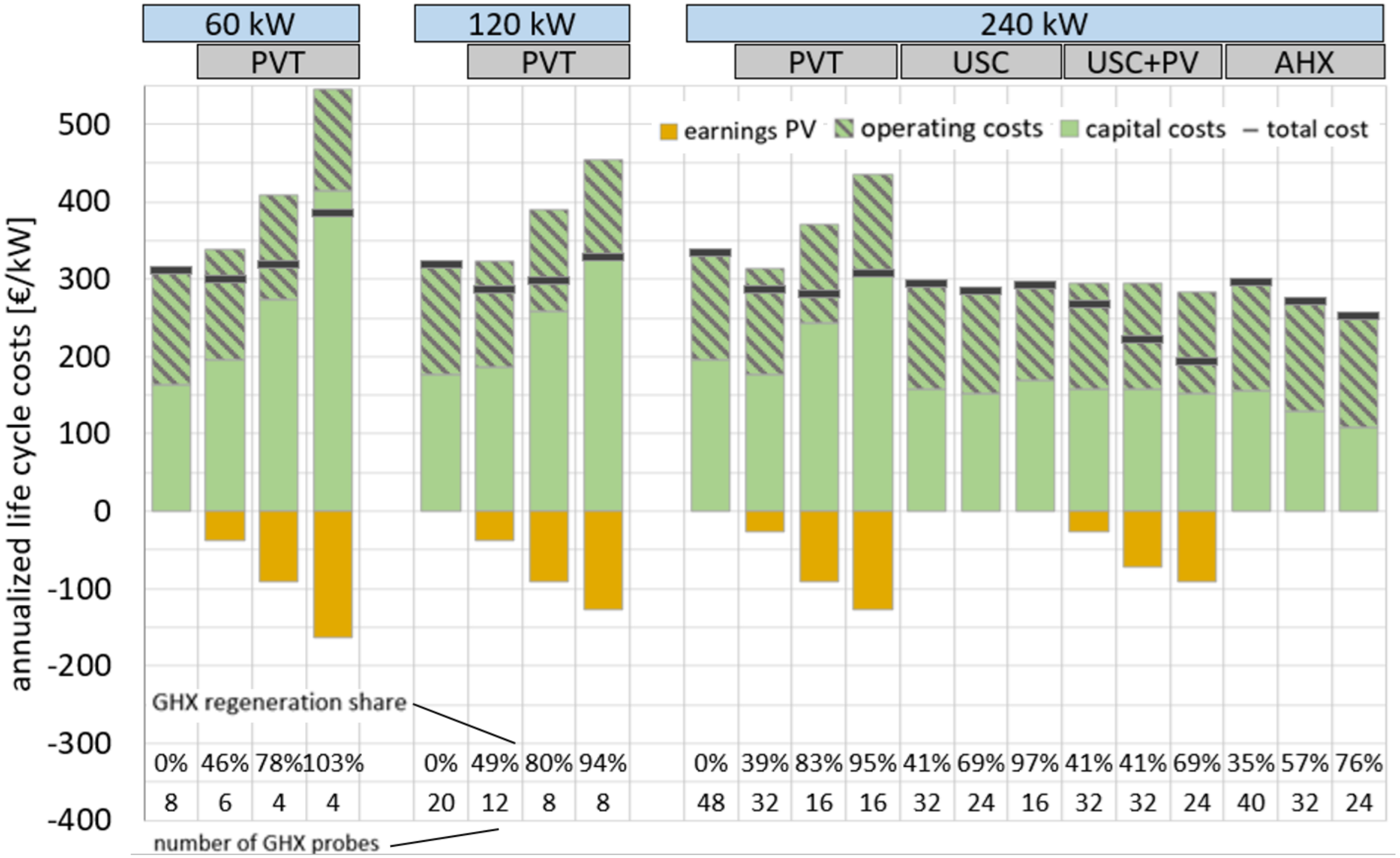
Cost comparison regeneration

- **Design with regeneration**
  - By regeneration also total borehole length can be reduced
  - Cost savings by reduced borehole field size
- **Cost evaluation**
  - **At smaller capacities** Regeneration effect limited, i.e. refunding only for small regeneration source design
  - **At larger capacities** Regeneration can yield cost benefits also at larger regeneration shares
  - **Cost of regeneration source** can be overcompensated by savings in the borehole field
  - **Cost effective regeneration share** in the range of 40% – 80%



Take home messages

- **Interesting potential for different integration strategies**
  - Peak load coverage, regeneration
  - Also combination of strategies possible (e.g. at higher capacities)
- **Source limitations of individual heat sources can be overcome**
  - Enables the application of heat pumps with higher capacity in monovalent operation
  - In particular interesting for existing buildings and retrofit projects, where heat source limitations may be a major obstacle
- **Cost reduction potentials by synergies of heat sources**
  - Integration of multiple heat sources can be more cost-effective than individual heat sources
  - Multiple source integration can thus also be interesting without limitations
- **Efficiency potentials by synergies of heat sources**
  - Use of best source temperatures, better temperatures by regeneration, etc. can also increase the efficiency

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P&D project boiler replacement

- **P&D of boiler replacement in two multi-family houses**
  - Replacement boiler of 200 kW in two multi-family houses (ca. 4200 m^2)
  - Original concept:
    - Ground probe field at 300 m with regeneration by air-source
    - Space restriction due to steep surrounding, after first drilling additionally depth restriction to 120 m due to artesic water
- **Present concept for P&D project/Monitoring**
  - Larger air heat exchanger and ground as peak load coverage
  - Combination peak load coverage with regeneration
  - Replacement of boiler with two indoor installed propane heat pumps

source: Lägern-Wohnen

P&D project boiler replacement

- **Objectives P&D and Monitoring**
  - Real performance of combination of peak load and regeneration strategy
  - Validation of simulation results and models by monitoring data
  - Extended design and control recommendations for multi-source integration
  - Improved design and control of multi-source systems
  - Behaviour of indoor placed propane heat pumps in retrofitting application
- **State**
  - Drilling of ground probes in November 2023
  - Installation of heat pumps planned for December 2023, but delayed to February 2024
  - Commissioning has taken place end of February 2024
  - Verification of measurement system
  - Some data of regeneration operation of the first summer

source: Lägern-Wohnen

Simulations: ground temperatures

- 175 kW heat capacity of the heat pumps

- BHX only source: 14 probes at 400 m
- → depth of boreholes !!

- BHX only source: 14 probes at 300 m, regenerated

→ depth of boreholes !!

- 14 x 120 m peak load, progressive control
- with regeneration

  w/o regeneration

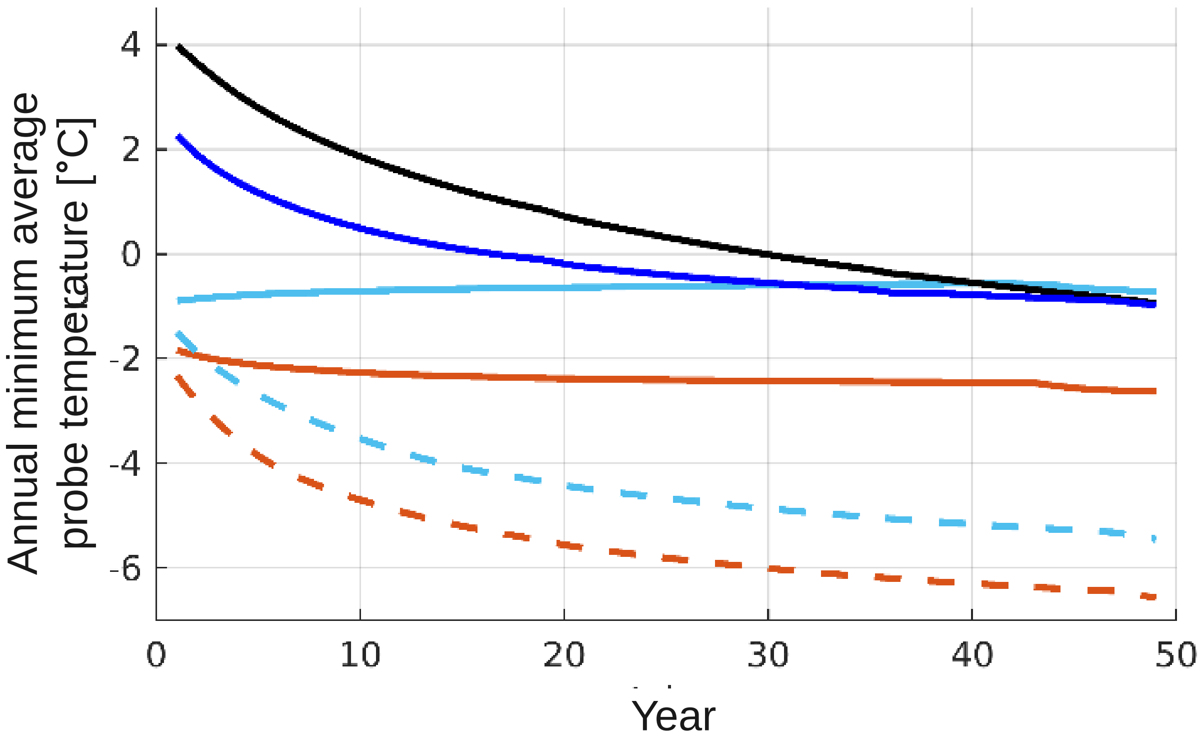
  → subcooling of the ground

- 14 x 120 m peak load, conservative control

  with regeneration

  w/o regeneration

  → possible with regeneration



Realised BHX: 16 probes at 100 m

Outline Papieri District

Background

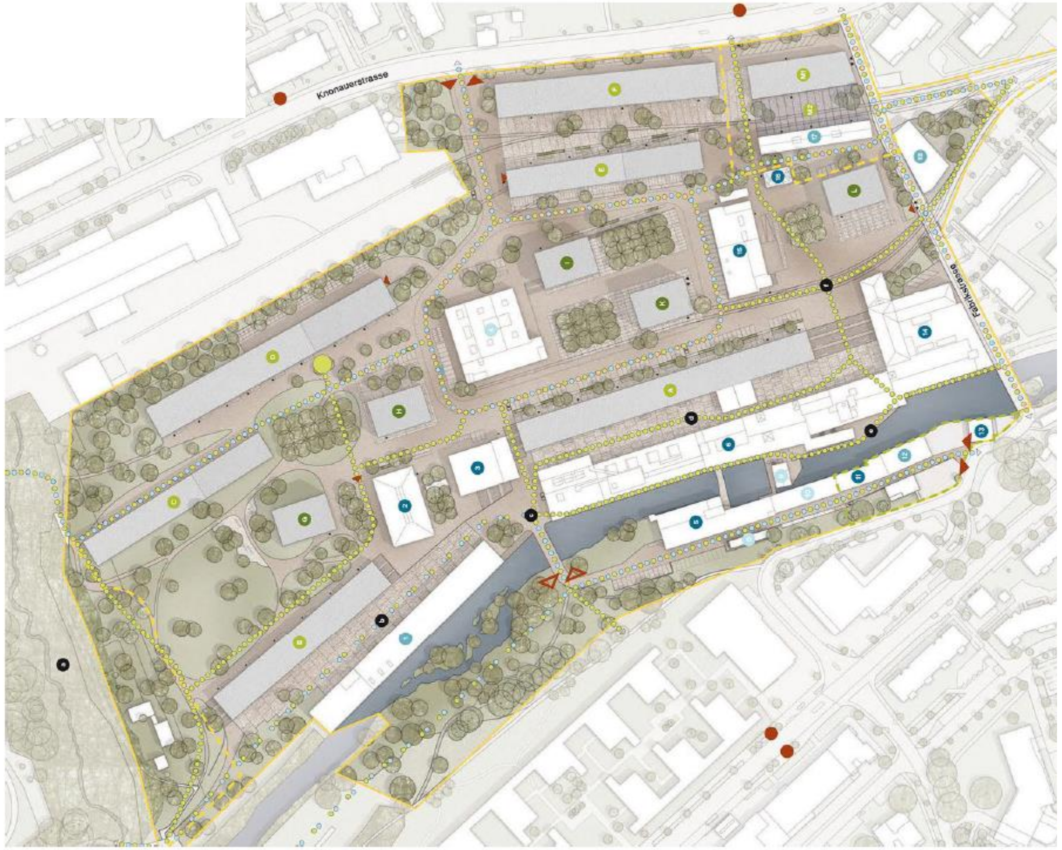
- Rebuilding of an old industrial district of a paper factory

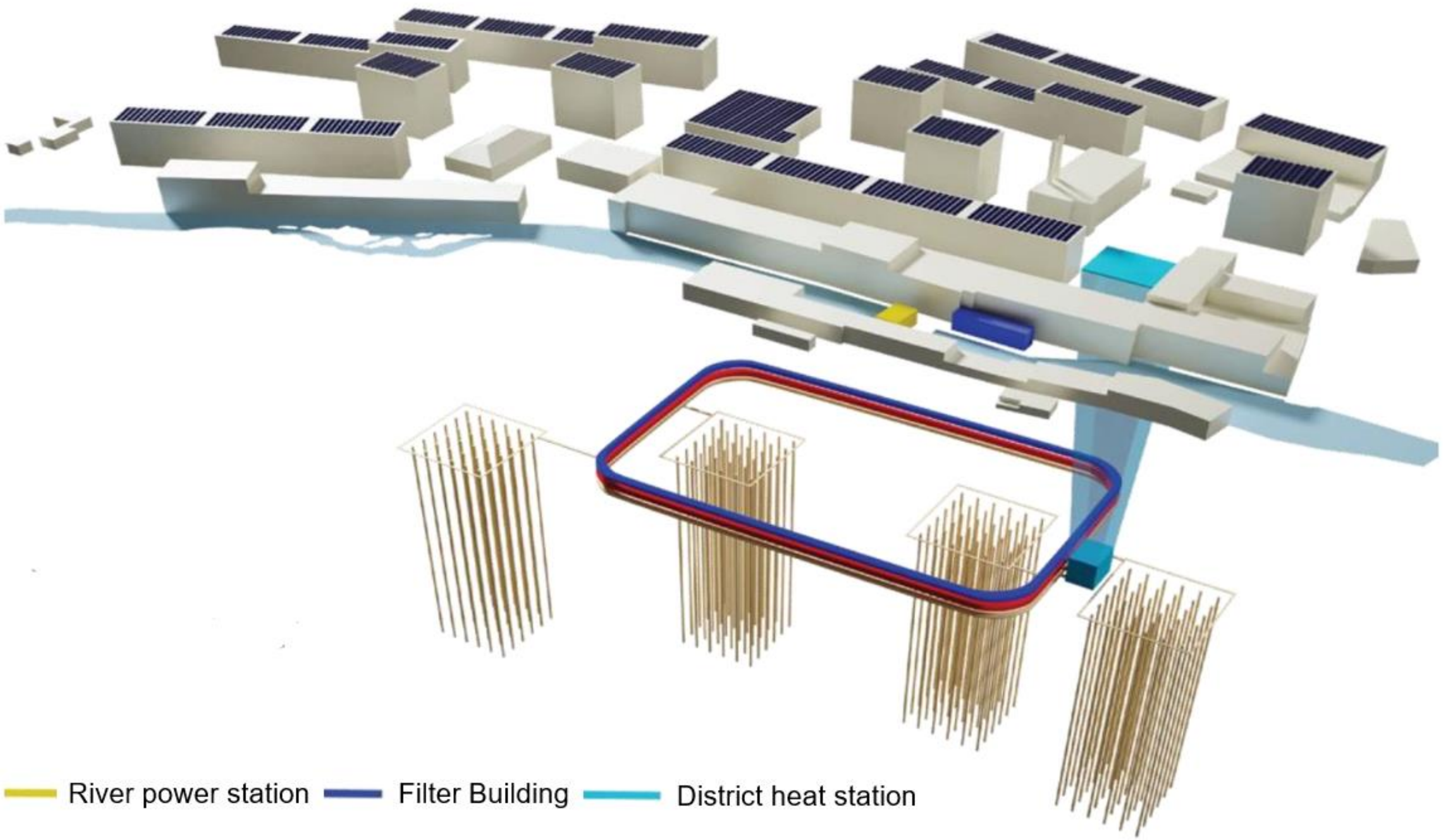
Development

- First buildings commissioned in the end of 2022
- Monitoring started in summer 2023
- Extension of district until 2032 by yearly 100 flats and 2000 m^2 office/retail space
- Extension of the space heating and cooling system
  - Currently 192 ground probes installed
  - Currently HP capacity of 2 MW installed

Follow-on activities – Papieri Cham

Papieri District





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Papieri District – Energy concept

- **River (Lorze)**
  River power station and thermal energy source
- **Energy management**
  Energy management of electricity use for enhanced self-consumption and reduced grid interaction
- **Heat pumps**
  Centralised heat pumps with natural refrigerant ammonia

- **Thermal grid**
  Integrated space heating and cooling
- **Electricity generation**
  6500 m^2 PV systems on new buildings
- **Geothermal heat source/sink**
  Central borehole field with 192 ground probes of 320 m depth

Papieri District - Investigations

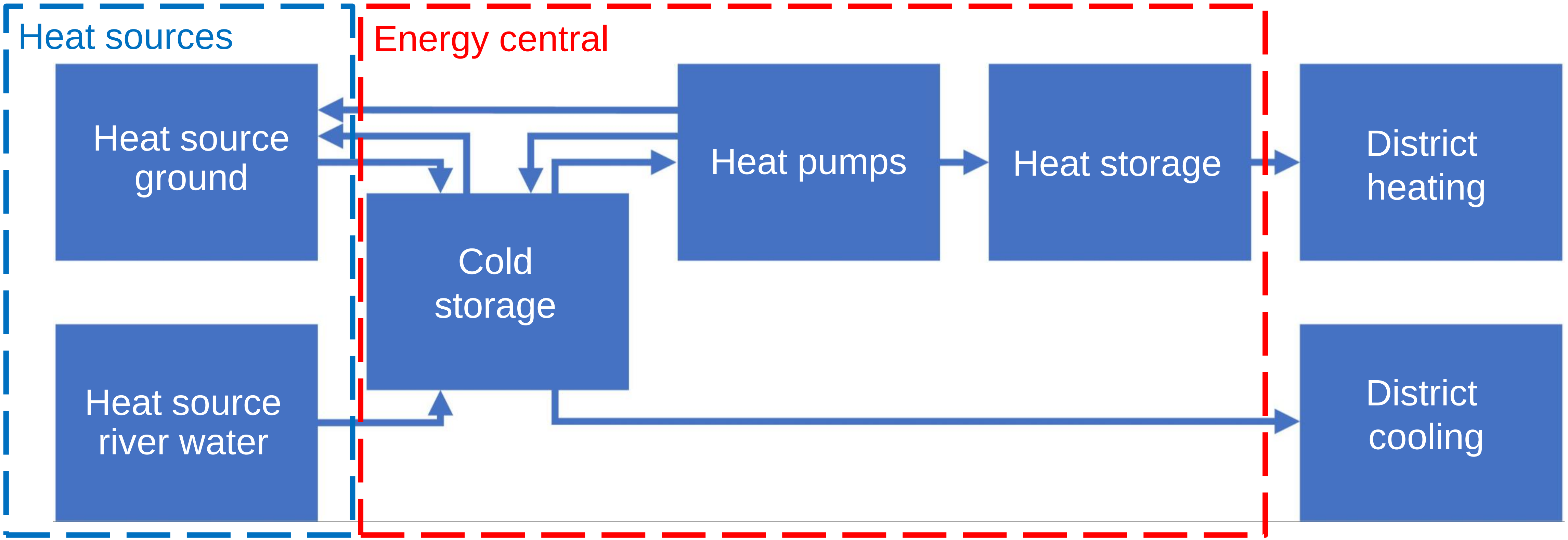
Investigations

- Derivation of KPI to characterise system performance by monitoring data for different operation modes
- Modelling/simulation of core components HP and heat sources
- Identification of the optimisation potentials by monitoring/simulation
- Investigation of source management for free coolng vs. regeneration
- Investigation of dual source operation of ground source and river water, also regarding extension of the district
- Overall evaluation of the district regarding plus energy
- Contribution to IEA HPT Annex 61 on «Heat pumps in Positive Energy Districts»

Papieri District – Heating & cooling system

Sketch heating and cooling concept

- 100% renewable heating and cooling in the district



Upcoming P&D project Multisource

- **Follow-on SFOE project on multi-source integration**
  - Evaluation of different source combination
  - Focus on combinations where vertical boreholes are not possible
  - Simulation work on different source combinations
- **P&D / Monitoring part**
  - Also a P&D part is included in the project
  - Collaboration with «Liegenschaften Zurich» and canton Zurich
  - Idea of combination of surface near ground use in combination with air
  - Validation of simulation results and models by monitoring data

source: A+W

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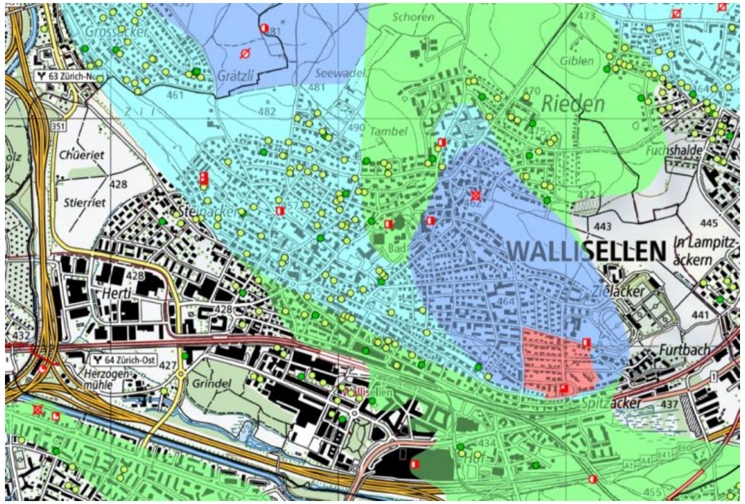
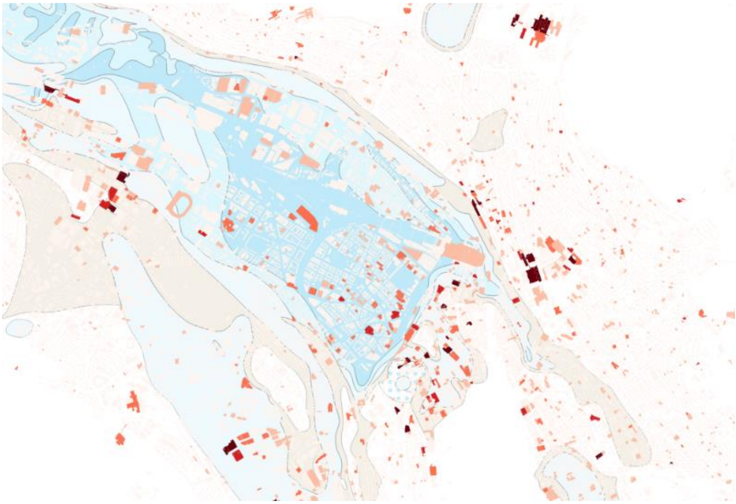
Upcoming project Peak’n’Cool for districts

- **Upcoming SFOE project on Integration of HP in district heating system**
  - Heat pump integration for peak load coverage in District heating systems
  - Decentralised integration of ground source heat pumps at larger users for peak load coverage
  - Additional option for summer cooling operation by ground coupled free-cooling or Heat pump/Chiller
  - Extension of connected buildings possible in case of capacity limitations of the district heating due to peak load coverage by HP
- **Case studies with utilities and City of Zurich**
  - Die Werke Wallisellen, 360° Zürich
  - Case study of City of Zurich on Ground water use
  - SIG as associated partner





Acknowledgment

Results outlined in this presentation have been investigated in the project "HP-source – Integration options for heat sources". The project supervision, support and funding of the Swiss Federal Office of Energy SFOE under the contract SI/502144-01 and the continuation in the P&D project is highly appreciated and acknowledged.

Schweizerische Eidgenossenschaft
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Confederazione Svizzera
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Swiss Federal Office of Energy SFOE

Final report HP-source available for download at
https://www.aramis.admin.ch/Texte/?ProjectID=47519

Thank you for your attention

Cost assumptions for cost comparisons

Parameter	Specific cost/tariff	Variation/remark
Investment cost		
Air-source HP	1700 €/kW	
Ground-source HP	900 €/kW	
Gas boiler system (averaged)	300 €/kW	
Borehole heat exchanger	100 €/m	
Air heat exchanger (60 kW-240 kW)	1500 – 600 €/kW	
PV/T collector	750 €/m2	
Operational cost		
Electricity tariff	0.20 €/kWh	As of June 2022, strongly dependent on market
Gas tariff	0.15 €/kWh	As of June 2022, strongly dependent on market
Feed-in tariff	0.10 €/kWh	Dependent on site
Component lifetime/interest rate		
Ground probes	50 yrs.	
Heating system components	20 yrs.	
Interest rate (real)	1.5%	