HEAT PUMP INTEGRATION IN DISTRICT HEATING SYSTEMS
Opportunities and Barriers

Roman Geyer
Seminar at the University of Geneva
Thursday, 28th November 2019 | 17:15 – 18:30
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- General overview
- Basics of DH and HP
- Hydraulic integration options
- Barriers / challenges
- Possible solutions and opportunities
- Success factors
- Monitoring and Optimization
- Developments / Project Highlights
- Closing
- Discussion
SEMINARS ON ENERGY CHALLENGES

- Energy demand in Switzerland
- District heating (DH) potential
- Renewable heat integration in DH
- Low temperature DH in Geneva
- Heat pump integration in district heating systems: Opportunities and Barriers
- Role of combined heat and power in the energy transition

https://www.unige.ch/sysener/fr/colconf/seminaires/
bmvit

Austria’s largest RTO

1.370 employees
8 Centers

Infrastructure Systems
Next Generation Solutions
System Competence
Applied Research

Federation of Austrian Industries
(through VFFI)

4 Subsidiary Enterprises
LKR, NES, SL, Profactor 51%

Tomorrow Today

162.9 m EUR total revenue

as of YE 2018
INTERNATIONAL ENERGY AGENCY (IEA)

- Founded in 1974 by 16 industrial nations to combat the oil crisis (IEA has strategic oil reserves)

- Goal: To guarantee reliable, cost-effective and clean energy

- Current: 30 Member States

- Important publications:
  - Key Energy Statistics
  - World Energy Outlook ("Bible of the Energy sector")

- Cooperation platform in the field of research, development, market launch and application of energy technologies
IEA HPT ANNEX 47

Heat Pumps in District Heating and Cooling systems

- International project team:
  - Task 1. Market and energy reduction potential
  - Task 2. Description of existing DHC systems and demonstration and R&D projects with HPs
  - Task 3. Review the different concepts/solutions
  - Task 4. Implementation barriers, possibilities and solutions

[Table]

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https://heatpumpingtechnologies.org/annex47/publications/
DH IN EU-27

Cities with district heating networks in the EU27 by number of inhabitants (only cities with >5000 inhabitants are shown).

2188 cities with 2445 DH networks are shown

Source: Heatroadmap Europe; Halmstad & Aalborg Universities 2013
INSTALLED HP CAPACITIES
Survey EHPA (European Heat Pump Association)

1,422 MW\text{th}
57 HP plants
112 HP \to \bar{\Omega} 12.7 \text{MW}_{\text{th}}/\text{HP}

COP
Average: 3.74
RL increase: 5.4 – 6.5
LT-DH: 5.5
Absorption-HP: 1.4 – 1.7

Refrigerants
R134a most frequent (~ 70 %)
NH\textsubscript{3} promising
CO\textsubscript{2} Further development needed
DH IN SWITZERLAND AT A GLANCE

9% of residential heat demand covered by DH

7.7 TWh DH generation in 2017 (CH: 85 TWh total head demand)

17 TWh potential for DH

2-3 TWh potential for HPs in DHN

1,000 [-] DH networks (of which 600 has biomass as main energy carrier)

32% based on waste incineration (wood 30%, gas 23%)

Sources:
BASICS OF DISTRICT HEATING AND HEAT PUMPS

Functional principle district heating
Why to lower temperatures?
Influences of reduced temperatures
Example: CHP (Back pressure)
Motivation for HP integration
(Central) Heat generators produce hot water

(Central) Pumps ensure heat distribution in the network

Heat is distributed by a supply line which supplies the consumers with hot water

Cooled water is returned through the return line to the heat generator(s), where it is heated again
WHY TO LOWER TEMPERATURES?

Supply and return temperature

Outdoor temperature

Min. requirements DHW preparation

Optimum temperature level of the alternative heat source

ΔT

Fossil heat source

Alternative heat source

ΔT

Fossil heat source

Alternative heat source

Source: AIT
INFLUENCES OF REDUCED TEMPERATURES

Generation
Higher fuel utilization, Higher electricity yield in CHPs, Better economic efficiency, Reduction of emissions (CO$_2$, ...), Better integration of alternative energy producers (heat pumps, waste heat, ...), etc.

Grid
Higher transmission capacities, reduction of heat losses, reduction of mass flow and thus of pumping costs, smaller pipe dimensions for new buildings, etc.

Customers
Ecological and economical operation, optimal design and construction of the plants, economical DHW preparation (hygienically perfect and with low return temperatures), etc.
EXAMPLE: CHP (BACK PRESSURE)

Cycle 1:
\[ T_{\text{cond}} = 128 \, ^\circ\text{C} \quad | \quad p_{\text{cond}} = 2.5 \, \text{bar} \]

Cycle 2:
\[ T_{\text{cond}} = 29 \, ^\circ\text{C} \quad | \quad p_{\text{cond}} = 0.04 \, \text{bar} \]

Source: AIT
FIRST ASSESSMENTS

Thermal input
(+0.20 %/K)

Thermal output DH
(constant)

Electricity
(+0.88 %/K)

El. efficiency
(+0.56 %/K)

Source: AIT
MOTIVATION FOR HP INTEGRATION

The motivation to use HPs in DHC can be divided into the following areas:

- **usage / capture** of low temperature alternative heat sources
- **enabler** for other alternative energy sources
- link to **power** grid (balance of energy domains)
- **reduction** of the network temperatures
- increasing transport **capacities** by using the return line as a source
HYDRAULIC INTEGRATION OPTIONS FOR HEAT PUMPS IN DH NETWORKS

External
Internal
Supply line
Return line
Transport capacity
Sub networks
“EXTERNAL” HEAT SOURCES

- Environmental heat
  - Sea, Lake, Groundwater

- Industrial processes
  - Steel & iron and foundries
  - Pulp & paper
  - Food producers
  - Data centers
  - Drying processes (e.g. laundries), etc.

- Existing infrastructure
  - Other alternative energy producers (e.g. flue gas)
  - Sewers
  - Tunnel systems
General hydraulic feed-in options

**From return to supply**
- Pump needed ($\Delta p$: SL-RL)
- "Classical" heat generator integration
- No influence on return temperature

**From return to return**
- no (or small) Pump needed
- Best efficiency for heat generator
- Return temperature increases

**From supply to supply**
- no (or small) Pump needed
- Lower efficiency for heat generator
- Max. temperature after feed-in
INTEGRATION OF HP WITH EXTERNAL HEAT SOURCE IN THE DH SUPPLY LINE

- Parallel (a) or serial (b) integration

- Integration into supply line: high temperature requirements for the heat pump

- Requirements for special Refrigerants

- Pro: Temperature boost happens close to the consumer
INTEGRATION OF HP WITH EXTERNAL HEAT SOURCE IN THE DH RETURN LINE

• Integration into return line: lower temperature of the return line → higher efficiency of the heat pump

• BUT: higher return temperatures on existing heat generators
INTEGRATION OF HP WITH INTERNAL HEAT SOURCE IN THE DH SUPPLY LINE

• Note: No additional renewable energy source is brought to the DH-network by the HP (except using renewable electricity)

• Add on: return temperature reduced → additional possibility for (alternative) energy sources e.g. flue gas condensation or solar thermal
INTEGRATION OF HP WITH INTERNAL HEAT SOURCE IN THE DH RETURN LINE

• Note: No additional renewable energy source is brought to the DH-network by the HP (except using renewable electricity)

• Just return line integration leads to higher efficiency of the heat pump

• Easier integration of low-grade waste heat
INTEGRATION OF HP WITH INTERNAL HEAT SOURCE TO INCREASE TRANSPORT CAPACITY

• Booster: Increasing transport capacity / temperature in secondary networks

• Add on: supplying remote areas and prevent bottlenecks
INTEGRATION OF HP WITH **INTERNAL HEAT SOURCE** TO SUPPLY **SUB NETWORKS**

- Supplying sub networks
- Add on: e.g. coupling 3GDH with 4GDH (low temperature networks)
BARRIERS / CHALLENGES
Social-, economical- and technical barriers
CHALLENGES WE HAVE TO FACE

Customers
- Prosumer
- Citizens' power stations
- Service orientation and comfort (cooling requirements)
- New business and tariff models
- Supply security
- …

Market
- High volatility, pooling of flexibilities/balancing energy markets
- Copper plate or electric fences? (e.g. electricity price zone DE/AT)
- Energy price developments (oil, gas, …)
- …

Society & Politics
- Demographic developments
- Decarbonization / COP21
- Energy efficiency act
- …

Technology & Innovation
- Digitization & Smart Home
- Energy efficiency & storage
- Electric mobility
- …
BARRIERS

Social
- Lack of confidence
- Policy
  - (Funding other technologies but not HPs)
- Lack of knowledge
  - (Integration, operation, …)
- Fossil fuel subsidies
  - (do not help …)
- Energy prices
  - (gas, el., …)
- Spatial planning
  - (usually ignorant to available heat sources)

Technical
- Availability of technical requirements
- Availability of heat sources
  - (location, temperature, …)
- Availability of HP-products

Economical
- Investment costs
  - (HP in combination with DHC)
- System change
  - (technology, distribution system, …)
- Shifting policy
  - (long-term strategies needed)
POSSIBLE SOLUTIONS AND OPPORTUNITIES

Holistic heat supply strategies
Sector coupling/ hybrid energy systems
Business models
POSSIBLE SOLUTIONS

Social
- Energy policy/planning
- Local involvement
- Education & Instruction (technology related)
- System thinking (closing energy cycles)
- Phase-out of fossil fuel (reduction of CO₂-emissions)
- Circular energy economy (proper system design)
- Reduction of emissions (air pollution, …)

Technical
- Guidelines / Descriptions (how to use … / install HPs)
- Capacity expansion
- Fair pricing (internalization)
- Heating & Cooling (both at same time)
- Higher efficiency (CHP, network, …)
- Standardization (R&D, solutions, interface)
- Reduction of losses (generation, network, …)

Economical
- Flexibility (balancing markets)
HOLISTIC HEAT SUPPLY STRATEGIES

1. Assessment of boundary conditions
   a) Decision on the evaluation criteria and the time horizon
   b) Status-Quo evaluation and scenarios (heat demand...)
   c) Analyses of regulations, subsidies, political targets, energy market (especially electricity price forecast)

2. Development of technology scenarios
   a) Characteristics of relevant technologies/potential of alternative heat sources
   b) Assessment of levelized heat generation costs,
   c) Development of heat supply portfolio
   d) Sensitivity analyses

3. Decision on the final concept
   a) Selection of different variants (supply/network)
   b) SWOT-Analysis
   c) Multi-Criteria evaluation
   d) Transition strategy & action plan for the selected variant
The use of HPs in times of favorable electricity prices can increase the:

- **share** of renewable energy sources and the **security of supply** in the heating grid and

- technical **capacity** and **own consumption** in areas with a high degree of local electricity production from PV and wind energy

- **services** for power grid / energy markets

**BUT:** high **complexity** and **very dynamic behavior**

BUSINESS MODELS

Innovative approaches are needed

- Digitization
- Regionality
- Fuel substitution
- Specific services
- System optimization
- Flexible tariff models
- Holistic system concept
- Financing and contracting
- Waste heat / cooling energy
- Set up “heat stock exchange”
- Reduction of system temperatures

Source: AIT
SUCCESS FACTORS
WHAT DO WE NEED?

• Strong partners: companies, institutes, start-ups, etc.

• Projects: demo, best practice, experiences, motivation

• Learning by doing: requires pioneers who are willing to "pay its dues"

• Energy spatial planning: localizing waste heat, avoiding double infrastructure

• Standardized solutions: R&D, degression of costs, economy of scale

• Price signals: to the use of fossil fuels, reduce the burden from tax and levy on clean energy
MONITORING AND OPTIMIZATION

District Boost:
Application of heat pumps in the district heating network of Vienna
PILOT PLANT – DISTRICT HEATING NETWORK VIENNA

- Heat generation: ~ 6 TWh/a
- Primary net ≈ 560 km
- Secondary net ≈ 630 km
- $T_{\text{supply \ prim.}}$ 80 – 150 °C
- $T_{\text{supply \ sec.}}$ 63 – 90 °C

Source: B. Windholz et al., Application of heat pumps in the district heating network of Vienna, Smart Energy Systems and 4th Generation District Heating, 2017
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Dimensioning
Capacity and efficiency vary within operating range
→ choose most important operating points well
→ consider most unfavorable operating points

Hydraulics and general concept is good
Thermal storage allows for
• long operating times at full load and thereby high efficiency
• potentially cheaper HP due to lower peak capacity

Further optimization possible
To control faster and more accurate
→ adapt control parameters of mixing valve
To avoid starts (transient operation) and partial load
→ adapt storage management and hysteresis of capacity slide

Monitoring and optimizing is always good
→ especially in the first months after commissioning

Measured heat output was around 23% below the manufacturer specifications!
→ Leakage identified
→ Amount of refrigerant was to little

Source: B. Windholz et al., Application of heat pumps in the district heating network of Vienna, Smart Energy Systems and 4th Generation District Heating, 2017
CONSIDERATION OF EFFICIENCY WHEN SELECTING THE HEAT SOURCE

• Ratio electricity / heat price:
  • 20ct / 8ct = 2.5
  • SPF >> 2.5

Recommendations
• low network temperatures and/or high heat source temperatures
• SPF > 3.5 ... 4.0

Source: Schmidt R-R, et.al.: D2.2 Einspeiseprofile, NextGenerationHeat, AIT, 2014
EUROPEAN GOOD PRACTICE EXAMPLES

Selected examples

• Mäntsälä (FI): HP for district heating;
  Source: Waste heat data center; 4 HPs; COP: 3.4; Q_H: 3.6 MW

• Mänttä-Vilppula (FI): „steam-temperature“ HP of up to 120 °C;
  Source: Return line DH; 1 HP; COP: 2.0; Q_H: 158 kW

• Stockholm (SE): HP for district heating;
  Source: Sea water; 6 HPs; Q_H: 180 MW

• Drammen (NO): world’s largest low GWP (NH₃ (R717)) refrigerant heat pump in DH;
  Source: Fjord water; 3 HPs; COP: 3; Q_H: 13.2 MW

• Oslo, Sandvika (NO): HP for district heating and cooling;
  Source: Sewage (direct extraction); 3 HPs; Q_H: 21 MW; Q_C: 14 MW

• Oslo, Fornebu/Rolfsbukta (NO): first HP-plant using HFO-1234ze (tetrafluoropropene);
  Source: Fjord water; 2 HPs; COP: 4.4; Q_H: 16 MW; Q_C: 20 MW

• Lausanne (CH): heat pump built in 1985;
  Source: Lake Leman; 2 HPs; COP: 4.8; Q_H: 4.5 MW
Vienna
Largest heat pump in Central Europe

Environmentally friendly DH
25,000 households

40,000 tons CO₂ savings annually

40 MW Thermal output

6 → 95 °C
Using cooling water of power plants

15 m€ Total investment

https://blog.wienenergie.at/2019/03/großes-staenchen-für-mitteleuropas-stärkste-grosswärme-pumpe-in-wien/
Burgenland is the region with the highest wind energy supply in Austria (The Parndorfer Platte is one of the windiest inland regions in Europe)

Neusiedl am See is a preferred living space with increasing heat demand

Installation of a high-performance HP with a direct line to the transformer station

- **winter**: flue gas condensation from the biomass boiler to supply water with 40 °C in a cold storage tank. The cold storage tank is the energy source for the water/water (W/W) heat pump → raising the temperature level to 85 °C.

- **summer**: biomass boiler is shut down. The cold storage tank is filled with air/water (A/W) heat pump. W/W heat pumps are operated as in winter.

Due to a storage of 300 m³ the DH can supply for 10 hours

In case if a wind slack, a battery storage will enable the heat pumps to be operated for a short time and then shut down in a controlled manner

HPs: Saving of **1.250 MWh/a natural gas** and thus a **CO₂ reduction** of **300 t/a** and reduced biomass consumption by 1,200 t biomass (≈ 80 truckloads → 9 t/a CO₂)
POWER2HEAT – SECTOR COUPLING PROJECT IN NEUSIEDL AM SEE (AT)

17 Wind turbines

transformer station

Direct line

Savings through HPs:
• 1.250 MWh/a natural gas (\(\triangleq\) CO\(_2\) reduction of 300 t/a)
• reduced biomass consumption by 1,200 t biomass (\(\triangleq\) 80 truckloads \(\rightarrow\) 9 t/a CO\(_2\))

Battery

Flue gas condensation

A/W HP

W/W HP

DH Neusiedl am See

Source: https://www.imh.at/fileadmin/user_upload/Bilder/extras/waermepumpenkonzept_neusiedlamsee_2018_09_1920x1080px.png
**fit4power2heat**

- Austrian biomass district heating network settings:
  - 2,377 biomass heat plants (2,153 MW\textsubscript{th} and 6.1 TWh/\textsubscript{a})
  - 128 biomass CHP plants (311 MW\textsubscript{el}; 2.3 TWh\textsubscript{el}/\textsubscript{a}; 3.4 TWh\textsubscript{th}/\textsubscript{a})
  - old heat plants operating with low efficiency
  - highly replicable business case
- Power to heat solutions:
  - heat pumps support both electricity and DH networks

Sources:
fit4power2heat

Project concept

- Integration of heat pumps in rural district heating networks
- Development of feasible use cases and potential business models

- Synergies between heat and electricity market
- Participation in the electricity markets:
  - Day-ahead SPOT market
  - Balancing markets (secondary and tertiary)
- Heat pump pooling over several heating networks

Outcomes
The integration of heat pumps in rural district heating networks is technically and economically feasible.

Reduction of heat generation costs
• Some scenarios show up heat generation cost reduction up to 15 % (12,600 €/year).
• Most attractive case: combination of day-ahead spot and secondary market

• Capacity increase in the district heating network
• Prolongation of the lifetime of the existing old boilers

FUTURE MARKET: DISTRICT COOLING

- Europe < 50% of all office space air-conditioned (USA, Japan ~ 80%)
- FR: largest district cooling market in Europe
- Possibility to increase efficiency (Trigeneration | CCHP)

Europe (survey)
- 22 HP systems for heating and cooling purposes
- Showcase plants:
  - Helsinki (Kari Vala), Oslo (Sandvika), Stockholm (Nimrod)

[District cooling in international comparison graph]

HIGH TEMPERATURE HEAT PUMP (HT-HP)

• Project DryFiciency (12 partners)

• Horizon2020 Innovation project for Waste Heat Utilization in Industrial Drying Processes

• Drying: 12 - 25% of industrial energy consumption
  • Goal: up to 80% energy saving

• Demonstration of two HT-HP (400 kW) up to 160 °C
  • Agrana
  • Wienerberger

http://dry-f.eu/
https://www.ehpa.org/fileadmin/red/03._Media/03.02_Studies_and_reports/Large_heat_pumps_in_Europe_MDN_II_final4_small.pdf
Hydrogen needed in steel & iron production → waste heat from electrolysis for DH

Possible supply by heat pumps

Source: R. Geyer et al., IndustRiES – Energieinfrastruktur für 100% Erneuerbare Energie in der Industrie, 2019
Is there a progress?
Is there a progress?

Updated values for:
- AT (x14)
- CH (x20)

**CONCLUSIONS**

- **Heat pumps** can make a significant **contribution** to the **decarbonization** of the heat supply (simultaneous decarbonization of the electricity supply).
- HPs are "**enablers**" for other alternative energy sources (geothermal, solar thermal, waste heat, etc.).
- HP **potential** depends on **economic** and **political framework** (but also on DH grid type, generation mix and other local conditions).
- **New business models** and **application** possibilities are required / support HP integration (e.g. sector coupling, energy markets, pooling, heating & cooling, flexible tariffs, etc.).

**Looking ahead:**
- **Positive** signs for **heat pumps** in **DHC networks** (remarkable developments in recent years; e.g. Austria, Switzerland).
KEY MESSAGES FOR DEEP DECARBONIZATION

- High temperature Heat pumps
- Lower system temperatures in District Heating networks
- Price signals
ANNOUNCEMENT

https://map.geo.admin.ch/ → category «Energy» → «thermal networks»

Source: https://s.geo.admin.ch/82d8014435 as of December, 18th 2019
THANK YOU!

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November 28th, 2019

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http://heatpumpingtechnologies.org/annex47/
https://map.geo.admin.ch/
https://www.unige.ch/sysener/fr/colconf/seminaires/
IndustRiES (Study how to supply the Austrian Industry by RES)
IEA HPT Annex 48 – Task 1 Report: Case Studies of Industrial Heat Pumps in Switzerland
ANNEX
**ABSORPTION HEAT EXCHANGER**

- Reduction of the return temperature
- Capacity increase of the existing network

ECOP – ROTATION HEAT PUMP

- Joule-Process
- High-Temperature 100-150 °C
- High COPs fluctuating input and output temperatures

Source: Erste Testergebnisse der ECOP Rotationswärmepumpe, 5FWKForum, B. Adler, ecop Technologies GmbH, https://www.ecop.at
STRATEGIC DEVELOPMENT OF HEAT PRODUCTION

• Utilization of latent heat within flue gas (waste incineration power plant) through a high temperature heat pump (estimated capacity: 16 MW\textsubscript{th})

• GeoTief Wien
  • Research project analysing the geothermal potential in eastern Vienna
  • 3D-seismic measurements in 2018 (October to end of November) in an area of about 180 km\textsuperscript{2}
  • Analysing the data until 2020