Heat pumps for district heating and industry in Denmark
Status, perspectives and ongoing developments
28.08.2019 – ICR Montreal – Workshop on industrial HPs
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Agenda

• Danish energy system and political targets
• Status
  • Overview of industrial heat pump installations
  • Heat pumps in district heating
  • Heat pumps in industrial applications
• Perspectives and ongoing developments
  • Potential of industrial heat pumps in the Danish industry
  • Improving the operation of large-scale heat pumps
  • Exploiting flexibility of large-scale heat pumps
• Conclusions
Energy system and political targets

Political treaties and strategies:

• Energy-Strategy (adopted in 2011)
  • By 2050:
    • Independent of fossil fuels

• Energy-Agreement (adopted in 2018)
  • By 2030:
    • 40 % Reduction in GHG emissions
    • 55 % Renewables
    • 33 % Increase in energy efficiency
    • < 10 % fossil fuels in district heating

• Plans for Copenhagen:
  • Carbon neutral by 2025
  • 300 MW heat supply to DH by HPs

Energy system:

• High share of renewables in electricity production:
  • 2017: 65 %
  • Increased share of biomass during last years

• High share of district heating in heat supply:
  • Approximately 65 % of households

→ High potential impact for heat pumps
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Overview of industrial HP installations

Survey for IEA HPT Annex 48:

- Industrial energy recovery: 22, 19 MW
- District Heating: 47, 100 MW

Installed capacity by refrigerants:
- R717: 93%
- R717+R7: 18%
- R744: 2%
- Hydrocarbons: 2%
- Others: 1%
Overview of industrial HP installations

Number of installations

Installed capacity, kW

District Heating  Industry

0 kW  100 kW  250 kW  500 kW  750 kW  1 MW  2.5 MW  5 MW
100 kW  250 kW  500 kW  750 kW  1 MW  2.5 MW  5 MW

0 kW  100 kW  250 kW  500 kW  750 kW  1 MW  2.5 MW  5 MW  10 MW
0 kW  100 kW  250 kW  500 kW  750 kW  1 MW  2.5 MW  5 MW  10 MW
Economic boundary conditions

Electricity for production

Electricity for space heating

- Transmission & Distribution
- Electricity Price
- PSO
- Taxation production use
- Taxation heat use
Economic boundary conditions

Natural gas for production

Natural gas for space heating

- Transmission & Distribution
- Natural Gas Price
- Taxation, energy, production use
- Taxation, environment
- Taxation, energy, other purpose
- Taxation, environment
Economic boundary conditions

Cost Ratio between Electricity and Natural gas

- Electricity/ Natural gas (Process)
- Electricity/ Natural gas (Heating)
Heat pumps in district heating

- Situation is understood by all involved parties
- Solutions are becoming standardized
- Different tools for planning support available
  - Planning guidelines, incl. all required information
  - Structured overview with possible scenarios
  - Catalogue with inspiration and best case examples
  - Calculation tools
- Heat pumps are becoming preferred solution
- Focus of developments shifts to:
  - Operational issues
  - Integration into smart grids
  - Upscaling of technology
Industrial applications: CP Kelco

Key figures:
- High System COP (>> 18.5)
- Maximum DH supply 8.7 MW
- Average DH supply 6.9 MW
- Covering the heating demand in the Køge region approx. 5-6 month per year

General aspects:
- No “main-business” for customer
- Large variety of boundary conditions
- Extensive process integration
- Secondary benefits (e.g., reduced cooling load, no exhaust gases, …)
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Potential of HPs in the Danish industry

- Mapping of excess heat and heat demand for various industrial processes
- Integration of HPs using Lorenz efficiency
Potential of HPs in the Danish industry

- Mapping of excess heat and heat demand for various industrial processes
- Integration of HPs using Lorenz efficiency

![Diagram showing Potential of HPs in the Danish industry](image)

- **Source**
- **Sink**

<table>
<thead>
<tr>
<th>Excess heat [PJ]</th>
<th>Electricity [PJ]</th>
<th>Median COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>2</td>
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<td>6</td>
<td>8</td>
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</table>

Maximum heat pump supply temperature [°C]

Energy use [PJ]

Average COP [-]
Potential of HPs in the Danish industry

Excess heat source

- 15 °C
- 30 °C
- 40 °C
- 45 °C
- 50 °C
- 60 °C
- 70 °C
- 80 °C
- 90 °C
- 100 °C
- 110 °C
- 120 °C
- 130 °C
- 150 °C
- 200 °C
- 225 °C
- 250 °C
- 350 °C

Excess heat [GWh/year]

0.1 kW-1 kW 1 kW-10 kW 10 kW-100 kW 0.5 MW-1 MW 1 MW-10 MW 10 MW-50 MW > 50 MW

Oil
Food
Wood
Chemical
Building
Metal
Potential of HPs in the Danish industry

- Excess heat source

- Excess heat source
Improving the operation of large-scale HPs

- Demonstration plant for
  - Analysis of heat sources (Sewage water and seawater)
  - Testing new method of optimizing COP
  - Testing new method for monitoring operation

- Project investment:
  - Overall: 110 Mio. Dkk (≈ 15 Mio. €)
  - Funding: 23 Mio. Dkk (≈ 3 Mio. €)

<table>
<thead>
<tr>
<th></th>
<th>Seawater</th>
<th>Sewage water</th>
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<tr>
<td>Source</td>
<td></td>
<td></td>
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<tr>
<td>Temperatures</td>
<td>4 °C → 0.5 °C</td>
<td>10 °C → 4 °C</td>
</tr>
<tr>
<td>Heatflow</td>
<td>3672 kW</td>
<td>3732 kW</td>
</tr>
<tr>
<td>Sink</td>
<td></td>
<td></td>
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<tr>
<td>Temperatures</td>
<td>50 °C → 80 °C</td>
<td></td>
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<tr>
<td>Heatflow</td>
<td>5194 kW</td>
<td>5177 kW</td>
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<tr>
<td>Power</td>
<td>1635 kW</td>
<td>1552 kW</td>
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<tr>
<td>COP&lt;sub&gt;h&lt;/sub&gt;</td>
<td>3.2</td>
<td>3.3</td>
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Flexible operation of heat pumps

Energylab Nordhavn: Smart City Lab

http://www.energylabnordhavn.com/
Flexible operation of heat pumps

• W. Meesenburg et al. 2019 ‘Design considerations for dynamically operated large-scale ammonia heat pumps’ (Presentation in ‘Dynamics and Control’ at 13.30-15:10)
Conclusions

• Ongoing transition of the Danish Energy system → HPs are playing a key role
• High share of renewables in electricity production → high potential for electrification of heat supply
• District heating:
  • HPs are (becoming) an established solution and the preferred choice
  • Good knowledge base for HPs in DH available
  • Increasing number of installations noticeable
• Industrial applications:
  • Higher diversity in boundary conditions and large effort for integration
  • More challenging economic conditions
• R&D Focus shifts to operating issues, upscaling & integration benefits
Sustainable District heating from Seawater, sewage water and Windpower

SVAF SYDHAVNEN
Demonstration plant (funded)
- Heat supply: 5.0 MW
- Power consumption: 1.5 MW
- Heat Source: Seawater, Sewage (clean)

Forward: 80 °C
Return: 80 °C

1. Seawater inlet at Sjællandbroen
2. SVAF Heat Pump cools seawater and sewage water in two serially connected units and supplies heat at 80 °C
3. Heat is distributed to Copenhagen’s DH consumers
Best Case I: SVAF Heat Pump
Best Case II: CP Kelco

Background:
• CP Kelco produces ingredients for the food sector → High cooling loads
• 2014: Energy symbiosis of VEKS (Utility company), CP Kelco, Sun Chemical, Fef Chemicals and Junckers
• Expansion of DH network to Køge region

Key factors for project realization:
• Expansion of DH network
• Availability of excess heat
• Strong interest from CP Kelco and VEKS
• Energy saving subsidy
• Government support
• Availability of similar business cases
# Best Case II: CP Kelco

## Technology

<table>
<thead>
<tr>
<th>System level</th>
<th>Production level</th>
<th>District heating</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy symbiosis Køge</td>
<td>Integration with existing system</td>
<td>Expansion of network</td>
<td>Heat pump</td>
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<tr>
<td>Cooling towers</td>
<td>HX redesign</td>
<td>Demand (temperature and loads)</td>
<td>Heat storage</td>
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<tr>
<td>Heat recovery system</td>
<td>Piping</td>
<td>Ownership</td>
<td>HX equipment</td>
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<tr>
<td>Buffer systems</td>
<td>Securing redundancy</td>
<td>Agreement between VEKS and CP Kelco</td>
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<tr>
<td>System efficiency</td>
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## Partners

### Authorities
- Municipality
- Applications for dispensation and construction
- Danish Working Environment Authority

### Client (CP Kelco)
- In house engineering
- Maintenance
- Production
- Procurement
- Management
- EHS

### District heating
- Management
- In house engineering
- Subcontractors

### Suppliers
- Mechanical
- Electrical
- Building
- Civil
- HEAT PUMP
Best Case II: CP Kelco

**Key figures:**

- System COP > 80
- After system design
- Maximum district heating effect 8.7 MW (Business case 5 MW)
- Averages district heating effect 6.9 MW
- Expected district heating production of 55 GWh (Business case 40 GWh)
- Covering the heating demand in the Køge region approx. 5-6 month per year
Potential of HPs in the Danish industry

![Diagram showing energy use, maximum heat pump supply temperature, and average COP vs. excess heat and electricity.]

- Excess heat [PJ]
- Electricity [PJ]
- Median COP
- 1./ 3. Quartile

Energy use [PJ]

Maximum heat pump supply temperature [°C]

Average COP [-]

$T_{Process}$

$T_{WH}$

Sink

Source
Potential of HPs in the Danish industry

- Excess heat [PJ]
- Electricity [PJ]
- Median COP
- 1./ 3. Quartile

Graph showing the relationship between maximum heat pump supply temperature and energy use, with a focus on the potential of heat pumps in the Danish industry.