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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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:
  \[
  \text{COP}_{\text{HP},t,j} = \eta_L \text{COP}_{\text{HP},L,t,j} = \eta_L \frac{\bar{T}_{\text{Im},h,t,j}}{\bar{T}_{\text{Im},c,t,j}}
  \]
  \[
  \eta_L : \text{Lorenz efficiency}
  \]
- Comparison of 3 heat sources in 4 scenarios

Seawater, groundwater or air

Optimal HP capacities found by GAMS

Seawater
Groundwater
Air
II. Key parameters

• Annual mean COP:

\[
\text{COP}_{\text{avg}} = \frac{1}{n} \sum_{t=1}^{n=8760} \text{COP}_{\text{HP},t}
\]

• Weighted annual system COP:

\[
\text{COP}_{\text{sys}} = \frac{\dot{Q}_{\text{sink,sys,tot}}}{P_{\text{sink,sys,tot}}}
\]

• Full load hours [h]:

\[
\text{FLH}_j = \sum_{t=1}^{n=8760} \frac{\dot{Q}_{\text{sink},t,j}}{\dot{Q}_{\text{sink,d},j}}
\]
II. Case description: Nordhavn

- Large development district in Europe
- [www.energylabnordhavn.dk](http://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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Seawater</th>
<th>Groundwater</th>
<th>Air</th>
<th>Heat source mix: Sea/GW/Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>no base load case</td>
<td>Shares: 9%/56%/15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average COP(_{avg})</td>
<td>(-)</td>
<td>3.54</td>
<td>&gt;</td>
<td>3.46</td>
<td>-10%</td>
</tr>
<tr>
<td>Weighted COP(_{Sys})</td>
<td>(-)</td>
<td>2.90</td>
<td>&lt;</td>
<td>3.12</td>
<td>-18%</td>
</tr>
<tr>
<td>Full load hours HP</td>
<td>(h)</td>
<td>2576</td>
<td>2704</td>
<td>2710</td>
<td>3214/2893/1736</td>
</tr>
</tbody>
</table>

- 1 MW/7 MW/2 MW

- COP:+3%
- 7 MW peak boiler capacity

7 MW peak boiler capacity
III. Winter: no base load case

(a) Heat source mix

(b) Groundwater

(c) Seawater

(d) Air

Heat demand and supply (MW/h), COP $\text{HP,}_{I,I}$
III. Summer: *no base load case*
III. Variation of heat source capacity shares

no base load case

![Graph showing COPsys vs Share of groundwater (%) for different heat source shares.](image)

- Sea
- GW
- Air
- 0% Air
- 5% Air
- 10% Air
- 15% Air
- 20% Air
- Optimum

- 45% < GW > 65%
- 0% < Air > 20%
- 0% < Sea > 20%
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

![Graph showing available heat source capacities](image)
III. Winter: *base load case*

(a) Heat source mix

(b) Groundwater

(c) Seawater

(d) Air
III. Summer: base load case
III. Variation of heat source capacity shares

*base load case*

![Graph showing variation of heat source capacity shares](image)

GW > 35%
## III. Key parameters

<table>
<thead>
<tr>
<th>Parameters</th>
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<th>Seawater</th>
<th>Groundwater</th>
<th>Air</th>
<th>All heat sources: Sea/GW/Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>base load case</strong></td>
</tr>
<tr>
<td>Average COP&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>(-)</td>
<td>3.54</td>
<td>3.40</td>
<td>3.46</td>
<td>3.43</td>
</tr>
<tr>
<td>Weighted COP&lt;sub&gt;HP,w&lt;/sub&gt;</td>
<td>(-)</td>
<td>3.10</td>
<td>3.40</td>
<td>2.90</td>
<td>3.40</td>
</tr>
<tr>
<td>Weighted COP&lt;sub&gt;Sys&lt;/sub&gt;</td>
<td>(-)</td>
<td>5.28</td>
<td>6.02</td>
<td>5.38</td>
<td>6.03</td>
</tr>
<tr>
<td>Full load hours HP</td>
<td>(h)</td>
<td>1358</td>
<td>1414</td>
<td>1417</td>
<td>446/1668/0</td>
</tr>
</tbody>
</table>

|                          |      |          |             |     | **no base load case**        |
| Average COP<sub>avg</sub> | (-)  | 3.54     | 3.40        | 3.46| 3.43                         |
| Weighted COP<sub>HP,w</sub> | (-)  | 3.27     | 3.40        | 3.12| 3.50                         |
| Weighted COP<sub>Sys</sub> | (-)  | 2.90     | 3.40        | 3.12| 3.50                         |
| Full load hours HP       | (h)  | 2576     | 2704        | 2710| 3214/2893/1736               |

- **COP:** +3%
- **FLH for no base case:** 90% higher
- **7 MW peak boiler capacity:** -18%