Heat Pumps Architecture Optimization For Enhanced Medium Temperature Geothermal Heat Use in District Heating

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Context

• District Heating
  » Urban

• Valorizing low temperature heat sources
  » Why?
  » How?

➢ Heat pumps integration in Geothermal Heat Use
State of the art

Energy integration methods

« Graphical » methods

Energy transfers

- Pinch analysis
- Formulation:
  - Deterministic linear (MILP)
  - Deterministic non linear (MINLP)
- Objective:
  - Mono-objective
  - Multi-objective

Mathematical programming methods

Energy balance equation, economic evaluation

Simulation models

- Precision
- Reliability
- Calculation time

- Robustness
- Global optimum
Key idea / Case study description

- District heating network
- Available géothermal potential

+ Minimization of total exergy consumption
  - Reduced order modeling for conversion technologies
  - MILP in multiperiod

→ Production mix
  - Heat pumps architecture
    (temperature & power)
Pinch imposed between the intermediate fluid $T[k]$, circulating in the network, and the operating flux $T[i]$. 

- Energy balance applied to each interval of temperature $i$ of each hot flow $j$ at a certain period of time $p$.
- Additional cooling and heating powers are considered after the heat integration of fluxes.

Law of mass conservation applied to all the heat capacity flows entering or exiting each node $k$ in the network at a certain period of time $p$.

\[
Debh_{[k+p]} - Debh_{[k,p]} + x_{h_{[k,p]}} = 0
\]

Considered after the heat integration of fluxes:

\[
CP_{C_{[i,j,p]}} \cdot (T_{[i]} - T_{[i+1]}) = \sum_{k=1}^{NS-1} Deb_{f_{[k,i,j,p]}} \cdot (T_{[k]} - T_{[k+1]}) + U_{f_{[i,j,p]}}
\]

(if $T_{[i]} \geq (T_{[k]} + Pinc)$ and $T_{[i+1]} \geq (T_{[k+1]} + Pinc)$)
Heat Pump reduced model

Reduced order modeling of the heat pumps, considering their performance in terms of exergy

- Constraint delimiting the number of HP
- Constraint delimiting the maximal compressor power of HP
- HP’s COP related to the evaporator’s and condenser’s power

\[
COP_{HP[l,m,n,o,p]} = \eta_{HP} \cdot \frac{Ts[l] + Pinc_{cond,HP}}{(Ts[l] + Pinc_{cond,HP}) - (Ts[o] - Pinc_{evap,HP})}
\]

- Compressor’s power connected to evaporator’s and condenser’s power (1st law)
Minimize the net heating and cooling demands.

\[
\text{min} : E_{x_{\text{tot}}} = \sum E_{x_h} + E_{x_c} + E_{x_{HP}}
\]

\[
E_{x_h} = \sum_{i=1}^{NT-1} \sum_{p=1}^{t} U_{h[i,p]} \cdot \text{per}_p \left( 1 - \frac{T_{\text{ref}}}{T_h} \right) \quad T_h > T_{\text{ref}}
\]

\[
E_{x_{HP}} = \sum_{l=1}^{Ns-2} \sum_{m=l+1}^{Ns-1} \sum_{n=m}^{Ns-1} \sum_{o=n+1}^{NS} \sum_{p=1}^{t} P_{\text{comp}[l,m,n,o,p]} \cdot \text{per}_p
\]
Application of methodology
Assumptions

Network heat demand for different ambient temperature intervals (left scale) and temperature occurrences

Network operating conditions and geothermal potential

Maximization of the use of an available geothermal potential
### Reference Case

**Heat Generation Share**

- **Total Heat (MWh):** 117,211
- **Gas Boiler Heat (MWh):** 66,385
- **Geothermal Heat (MWh):** 50,826
- **Geothermal Max Potential (MWh):** 113,880
- **Geothermal Use Rate:** 44.6%
- **Geothermal to Total Ratio:** 43.4%

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**The Network's Configuration for Reference Situation**

![Diagram of network configuration]

- **Boiler**
- **Direct Heat Exchange**
- **Geothermal Energy**
- **Heating Needs**

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*Purdue Conferences*
Heat pumps integration scenarios (1)

Heat load distribution for the first scenario

The operating temperatures at the heat pump’s exchangers for the first scenario

<table>
<thead>
<tr>
<th>Total heat (MWh)</th>
<th>Gas boiler heat (MWh)</th>
<th>Goethermal direct heat (MWh)</th>
<th>Condenser heat (MWh)</th>
<th>Geothermal use rate</th>
<th>Geothermal to total ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>117 211</td>
<td>32 355</td>
<td>50 826</td>
<td>34 030</td>
<td>66.3 %</td>
<td>64.46 %</td>
</tr>
</tbody>
</table>
Heat pumps integration scenarios (1)

Variation of the heat pump’s electrical consumption

Compressor's electrical power

HP’s architecture
- HP placed in parallel
- Operating range between 50 and 100% of nominal

Ambiant temperature (°C)

Electrical power (MW)
Heat load distribution for the second scenario

Architecture for the HP’s integration for the second scenario

<table>
<thead>
<tr>
<th>Total heat (MWh)</th>
<th>Gas boiler heat (MWh)</th>
<th>Goethermal direct heat (MWh)</th>
<th>Condenser heat (MWh)</th>
<th>Geothermal use rate</th>
<th>Geothermal to total ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>117 211</td>
<td>34210</td>
<td>50 826</td>
<td>32 175</td>
<td>66.5 %</td>
<td>64.65 %</td>
</tr>
</tbody>
</table>
## Synthesis of results

### Conclusions

- Increase in the share of geothermal energy used
- Upgrade of geothermal energy
- Share of gas based heat reduced (56.6% to 27.6%)
- Higher seasonal COP with an additional HP

### Further developments

- Detailed design of the heat pumps
- Economical evaluation

### Table: Case Analysis

<table>
<thead>
<tr>
<th>Case</th>
<th>Total heat (MWh)</th>
<th>Gas boiler heat (MWh)</th>
<th>Goethermal heat (MWh)</th>
<th>Condenser’s heat (MWh)</th>
<th>Geothermal use rate</th>
<th>Geothermal to total ratio</th>
<th>COP</th>
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</thead>
<tbody>
<tr>
<td>Reference</td>
<td>117 211</td>
<td>66 385</td>
<td>50 826</td>
<td>-</td>
<td>44.6%</td>
<td>43.4%</td>
<td>-</td>
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<tr>
<td>1 HP</td>
<td>117 211</td>
<td>32 355</td>
<td>50 826</td>
<td>34 030</td>
<td>66.3 %</td>
<td>64.46 %</td>
<td>3.66</td>
</tr>
<tr>
<td>2 HP</td>
<td>117 211</td>
<td>34210</td>
<td>50 826</td>
<td>32 175</td>
<td>66.5 %</td>
<td>64.65 %</td>
<td>4.45</td>
</tr>
</tbody>
</table>
Thank you

Collaborators:

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