Extending a building-scale optimisation model to low-temperature district heating systems

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Literature overview and objective

**DH Network optimisation**
- Möller & Nielsen (2014)
- Möller & Lund (2010)
- Nielsen (2014)
- Delangle et al. (2017)
- Unternährer et al. (2017)

**Decentralized building supply**
- Akbari, Jolai & Ghaderi (2016)
- Omu, Choudhary & Boies (2013)
- (Baetens et al. 2012)
- Coninck et al. (2014)
- Mehleri et al. (2013); (2012)

**Centralized district supply**
- Yang, Zhang & Xiao (2015)
- Orehounig, Evins & Dorer (2015)
- Walker et al. (2017)
- Wu et al. (2018)

**Objective:** Comparison of centralized and decentralized energy supply systems in urban areas with different residential areas

Study considers all three aspects
General approach to model extension

- Existing building-level MILP model extended to include heating grid
- Directional graph
- Building and heat generation plant shown as nodes
- Forward and return flow shown in the model
- Grid topology represented in the model by matrices
Dimensioning options for pipelines

- Each section is allocated a pipe diameter
- Available pipe diameters are linked to various properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Data origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner radius</td>
<td>Exogenous</td>
</tr>
<tr>
<td>External radius</td>
<td>Exogenous</td>
</tr>
<tr>
<td>Thermal conductivity of the insulation</td>
<td>Exogenous</td>
</tr>
<tr>
<td>Max. heat flow</td>
<td>Endogenous</td>
</tr>
<tr>
<td>Max. volume flow</td>
<td>Endogenous</td>
</tr>
<tr>
<td>Max. &amp; average flow velocity</td>
<td>Exogenous</td>
</tr>
<tr>
<td>Material and installation costs</td>
<td>Exogenous</td>
</tr>
<tr>
<td>Heat losses</td>
<td>Endogenous</td>
</tr>
<tr>
<td>Pressure losses</td>
<td>Endogenous</td>
</tr>
</tbody>
</table>
Calculation of heat losses

\[ \text{loss}_{\text{Heat},l}^{\text{max},R} = \text{Surf}_{R,l} \times \Delta T_L \times U_R \]

**Relevant Surface**

- **Difference in temperature**
- **Heat transfer coefficient**

- Installation distance & overlap height the same for all pipe diameters

\[ \text{surf}_R = 2 \times \pi \times l_R \times r_{RU_R} = \frac{\Delta T_L}{T_{VL} + T_{RL} - T_{Bo}} \left( \frac{1}{r_R \ln \left( \frac{r_A}{r_R} \right) + \frac{r_R^2}{\lambda_{Bo} \ln \left( \frac{4(h_\bar{U} + r_A)}{r_A} \right) + \frac{r_R}{\lambda_{Bo} \ln \left( \frac{2(h_\bar{U} + r_A)}{a + 2r_A} \right)^2 + 1}^{0.5}} \right) \]
Pipe diameters are defined on the basis of various restrictions
Description of the model extension

• Determination of the critical path in the model
• Determine maximum case for critical path
  – Maximum distance
  – Smallest pipe radii
  – Maximum case is subdivided for selection of head differences
• Consideration of the efficiencies in the model
Validation

• Modifications of the model:

<table>
<thead>
<tr>
<th>Properties of the network</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Location</td>
<td>Böblingen, Germany</td>
</tr>
<tr>
<td>Length</td>
<td>2062 m</td>
</tr>
<tr>
<td>Connected houses</td>
<td>63</td>
</tr>
</tbody>
</table>
# Validation results

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<tr>
<th>Comparison point</th>
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<th>Existing network</th>
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<tbody>
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<td>Annual heat losses</td>
<td>7.11%</td>
<td>25%</td>
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- Use of smaller pipe diameters in the model
- Lower flow temperature in the model
- Better insulation in the model
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<tr>
<td>Deviation of the installed boiler capacity</td>
<td>Model 30 % lower</td>
<td></td>
</tr>
<tr>
<td>Deviation of the installed pump capacity</td>
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- Differences in the heat demand of the networks (lower peak load in the model)
- Reduced heat losses mean that less heat generally has to be generated
- Perfect foresight of the model
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<td>Deviation of the annual heat production</td>
<td>Model 21% lower</td>
<td></td>
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</tbody>
</table>
Validation results: heat flow

Wärmefluss im Netz für Wintertag mit maximalem Bedarf
(Validierungsnetz)

Zeit [h]

kWh

Wämeverluste
Mindestfluss
Speicheranteil im Netz
Gesamter Wärmefluss
Quartierswärmebedarf
Wärmeleistung des Kessels

00:00:00 01:00:00 02:00:00 03:00:00 04:00:00 05:00:00 06:00:00 07:00:00 08:00:00 09:00:00 10:00:00 11:00:00 12:00:00 13:00:00 14:00:00 15:00:00 16:00:00 17:00:00 18:00:00 19:00:00 20:00:00 21:00:00 22:00:00 23:00:00
Validation results: pump
Discussion

• Question of over-specification...
• Assuming not over-specified:
  – Runtime reduction by e.g. decomposition methods
  – Increase the temporal scope of the model
    - currently only 8 days
  – Consider more technologies
  – Better pump linearization through SOS2-Constraints
  – Consider more realistic plant operating times
  – Possibility to allocate individual capacities to the houses
Summary and Conclusions

• MILP model for DH network layout and operation, given demand sinks and network topology
• Possible to model and compare centralized and decentralized systems (not shown here)
• Validation shows deviations from empirical data are plausible and system operation is realistic
• Further work should improve the pump and plant operation, e.g. part load efficiencies and ramp rates
Thank you for your attention!