The role and potential of distributed thermal energy storage systems for active control of district heating networks

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Thermal energy storage in DH networks

• Short and long term energy storage systems
  – Sensible, latent, sorption, thermochemical storage

• Short-term TES in district heating systems:
  – hot water storage tanks
  – phase change materials (PCM)
  – varying temperature in the DH network
  – utilizing building thermal inertia

• Peak heat load reduction measures
  – Demand side measures
  – Tariff model measures
  – Supply side measures
Research question

• The situation:
  – DH network, connecting 100 houses
  – Heat supply by a gas fired CHP, selling electricity (gas boiler for peaks)
• Combination of smart control of the system and integration of storage.
• Which system performs best, i.e. when is the profit of the CHP the highest?
  – No storage
  – Central buffer tank next to the CHP
  – Distributed buffers in the individual houses
  – Thermal mass of the individual houses
**Methodology - 1**

- **Tested configurations:**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Storage tank type?</th>
<th>Smart CHP control?</th>
<th>Smart demand control?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reference</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2. SC, central</td>
<td>Central</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3. SC, distributed</td>
<td>Distributed</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4. SC, no buffer</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

![Diagram of configurations](image)
Methodology - 2

• Necessary components of the simulation
  – District heating pipe model: pseudo-dynamic
    • Flow rate calculation
    • Temperature propagation
  – Building model
    • Lumped capacitance model (3C,5R)
  – Buffer tank model
    • Multinode model
  – CHP and gas boiler model
    • Quasi-static black-box models
Smart control system

- Market-based multi-agent system (MAS)
  - The buildings and the CHP are represented by software agents
  - Every timestep, each agent communicates the supply or demand needs of the device to the market by means of a bid function
  - Then an equilibrium is calculated for priority and power, and communicated to the agents
  - The agents switch the CHP and opens the DH valves
Hardware in the loop simulation

• Lab tests:
  – 96 buildings simulated, 4 present in the lab
  – To validate the simulation models
  – Determination of state of charge storage vessels
  – To check the practical feasibility
Results – 1 - operational behaviour DHN

International Conference on Smart Energy Systems and 4th Generation District Heating, Copenhagen, 25-26 August 2015
Results – 2 - energy consumption

<table>
<thead>
<tr>
<th>configuration</th>
<th>energy consumed</th>
<th>energy produced total</th>
<th>energy produced CHP</th>
<th>energy produced gas boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>no buffers, regular control</td>
<td>70649</td>
<td>79447</td>
<td>58714</td>
<td>20651</td>
</tr>
<tr>
<td>no buffers, active control</td>
<td>73562 (+4.1%)</td>
<td>79600 (+1.9%)</td>
<td>52100 (-11.3%)</td>
<td>27985 (+35.5%)</td>
</tr>
<tr>
<td>distributed buffers, active control</td>
<td>73594 (+4.2%)</td>
<td>80965 (-0.2%)</td>
<td>59177 (+0.8%)</td>
<td>21900 (+6.0%)</td>
</tr>
<tr>
<td>central buffer, active control</td>
<td>70577 (-0.1%)</td>
<td>78741 (-0.9%)</td>
<td>43750 (-25.6%)</td>
<td>35804 (+73.4%)</td>
</tr>
</tbody>
</table>

- Energy consumption higher for DSM cases: more switches DH valves
- Energy production comparable: a bit higher network efficiencies for DSM cases
- Large difference in CHP and gas boiler production: resulting from the choices of the MAS control system
Results – 3 - costs and revenues

- ‘Operational profit’ = revenues of heat + electricity sales – costs for gas
- Smart control: increase of the profit
- ‘Distributed’ and ‘no-buffer’ case perform better than central buffer case: activation of thermal mass buildings
- Hardly any difference between distributed case and no-buffer case: thermal mass of the buildings is way larger than that of the buffers (4165 kWh/K v.s. 39.5 kWh/K)

Assumptions:
- gas price: € 39.9/MWh (mean 2013 in Belgium for small industrial customers)
- heat price: € 54.5/MWh (mean natural gas price for residential customers in 2013 in Belgium)
FP7 E-hub project – overview

• Results achieved in the framework of the FP7 E-hub project (2010 -2014)
• Energy-Hub for residential and commercial districts
  – Ambition: covering up to 100% of the energy demand on district level with renewable energy by overcoming it’s fluctuating character through:
    o conversion and storage of energy
    o load shifting
  – All types of energy flow are considered: heating and cooling, electricity...
    Connecting houses but also EV, commercial buildings or industry
  – e-hub = “a physical cross point, similar to an energy station, in which energy and information streams are interconnected, and where the different forms of energy can be converted into each other and/or can be stored”

• Objective:
  – develop the e-hub as a system,
  – to develop technologies that are necessary to realize the system,
  – to develop business models in order to overcome institutional and financial barriers,
  – and to demonstrate an e-hub in feasibility cases.

• More details: www.e-hub.org
Conclusions and future work

• A controller framework was developed to compare the performance of central and distributed storage in a smart district heating grid.
• The controller is able to shift the demand and the production of heat.
• As a result, the controller is able to increase the profit of a CHP.
• The configuration with distributed buffers performs best, however the difference with the configuration without buffers is very small.
• Using building thermal mass as short-term TES in DH networks:
  – great potential as a cost-effective method for storing heat but ...
  – important is the control of such storage, the type of business model with the DH supplier and the consumers acceptance (indoor temperature).
• Future work:
  – Need for an integrated control of the DH network and the installations.
  – Impact of building thermal mass on system efficiency.
  – Extension to larger non-residential buildings and cooling applications.
• There is potential for thermal energy storage systems in DH network (control!).
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