STORM
Testing and evaluation of the STORM controller in two demonstration sites

Ed Smulders, Tijs van Oevelen, Christian Johansson, Dirk Vanhoudt
SES conference, September 11th, Copenhagen

Powered by

Aalborg University
reINVEST
sEEnergies
Fonden Energi- & Miljødata
Innovation Fund Denmark
STORM
Testing and evaluation of the STORM controller in two demonstration sites

Ed Smulders, Tijs van Oevelen, Christian Johansson, Dirk Vanhoudt
SES conference, September 11th, Copenhagen
STORM project – general info

Self-organizing Thermal Operational Resource Management.

- **Aim:**
  Developing, Demonstrating and performance Assessing of a generic intelligent self-learning DHC network controller

- **Research period:**
  March 2015 => March 2019
STORM control features

1. Peak Shaving (PS)
   • Reduction of running hours of expensive and fossil fuel consuming peak boilers
   • System capacity improvement

2. Market Interaction (MI)
   • Optimizing operation of CHP-plants or heat pumps with respect to fluctuating electricity prices

3. Cell Balancing (CB)
   • Aligning heat and cold demands and/or production, stimulating self-consumption, integrating excess energy.

Offset of outdoor temperature

Demo sites:
• Rottne-Sweden
• Heerlen-The Netherlands
Demo site Rottne, Sweden

- 3rd generation DH
- 175 consumers
- 2 wood chips boilers (1.5 + 1.2 MW) + biofuel peak boiler (3 MW)
- Design temperature 90-60°C
- Testing:
  - Peak Shaving
    - eliminate the operation of the expensive peak boiler
  - Market Interaction
    - Focus on earnings:
      - Avoiding high costs
      - Premier low costs
Demo site Mijnwater Heerlen, The Netherlands

- 4th generation DHC system
- 200,000 m2 connected
- Very low temperatures (28°C – 16°C)
- Simultaneous provision of heating + cooling
- Exchanging energy (prosuming)
- Underground storage in abandoned mines

**Testing:**
- Cell Balancing
  - balancing of heat/cold producers and consumers
- Peak shaving
  - Strive for an average consumption
Peak shaving – Evaluation methodology

• **Approach: Comparison of heat load patterns between**
  - Reference heat load model (historic data without STORM)
  - Results during testing period

• **Hourly data profiles:**
  - Heat load of the total network
  - Heat load of the controllable part
  - Outdoor temperature

• **Test period Rottne:**
  - March 2018 - January 2019 (excl. summer months with low loads)

• **Evaluation criterion:**
  - Peak heat production energy
  - Part of the heat load above 2.5 MW
Peak shaving – Reference heat load modeling

Approach:
• Look-up table with outdoor temperature and hour of the day as input variables
• Filled using historic reference data: July 2015 – January 2019 (excl. control actions)
• Recorded statistics: average, minimum, maximum, count, standard deviation
• Average heat load is used to model the reference behavior

Validation:
MAE: 79.5 kW
MAE: 7.9 h
Peak shaving - Example

- Demo-site Rottne, December 2018
- Comparison of heat load profiles:

![Graph showing heat load profiles for total network and controllable part.](image-url)
Peak shaving - Example

- Demo-site Rottne, December 2018
- Comparison of load-duration curves:

  ![Graphs showing load-duration curves for total network and controllable part, with arrows indicating heat load moved from peak boiler to baseload boiler.](image-url)
Peak shaving – Summary of results

- Demo-site Rottne, March 2018 - January 2019

Impact of STORM controller on heat load and peak production in Rottne

Month | Heat load, MWh
--- | ---
Mar-18 | +13.2
Apr-18 | +12.1
Nov-18 | -23.4
Dec-18 | +18.8
Jan-19 | +48.4

Legend:
- Controlled buildings (ref)
- Controlled buildings (test)
- Total production (ref)
- Total production (test)
- Peak production (ref)
- Peak production (test)
Peak shaving - Conclusions

• Peak shaving
  • Tested in Rottne (March 2018 to January 2019)
  • Test results compared with the behavior of a validated historical reference model

• Disturbances:
  • Weather
  • User behavior
    • Increase in uncontrollable heat load
    • One customer that connected more buildings without notice

• Reduced peak heat production:
  • -3.1% to -12.7% (excluding Jan. ’19)
  • -1.3% controllable part consumption
Market Interaction - Strategy

1. Combined Heat & Power (CHP):
   - Charging and discharging
   - Forecast of spot-prices for electricity
   - Focus on earnings:
     • increase heat demand (charge) during times of high spot-prices
     • decrease heat demand (discharge) during low spot-prices.

2. Heat Pumps (HP):
   - Focus on costs:
     • avoiding high costs and premier low costs.

   - Ensuring no overall increase of energy usage for customers
Market Interaction - Charging

Group of buildings

![Graph of Group of buildings]

Individual building

![Graph of Individual building]
Market Interaction - Results and Conclusions

Average results:
- number of control actions for charging

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>805</td>
<td>1176</td>
<td>371</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>700</td>
<td>1080</td>
<td>380</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>582</td>
<td>1141</td>
<td>559</td>
<td>49</td>
</tr>
</tbody>
</table>

- discharging has been tested extensively through peak load management

Conclusions:
- MI has the ability to charge and discharge (depending on requested behaviour)
- Results of charging are in line with the results of discharging
- maximum impact of 50% of the instantaneous demand.
- Impact on short-term demand ranges between 30–50% on individual building level.
- zero-sum functionality achieved in Rottne 5.8%.
- MI is a powerful control strategy
- several commercial spin-off projects based on STORM technology
Cell Balancing - Strategy
The outdoor temperature offset was:
- Not used to influence the indoor energy demand, but:
  - Used to influence the flow going to the cluster- or customer installations (i.e. implementing PS)
- With less flow, the activity of the HP’s increases, leading to a larger dT, thus to more energy per m3 of water;

- Optimisation process performed over 3*24 hour time horizon (24 hours in the past to 48 hours into the future)
- The process is repeated every hour
Cell Balancing - Performance

ODT_OS = outdoor temperature offset
PS_F = measured flow
PS_F_0 = predicted flow
PS_F_1 = optimised flow
Cell Balancing - Results

- The average dT increased with 3.13°C (cluster A) and 2.55°C (cluster B)
- The average flow could be decreased with 7.5% (cluster A) to 34.1% (cluster B); =PS-potential.
- The capacity of the system (the weighted product of the flows times the increased dT) increased with 36.9% (cluster B) to 49.4% (cluster A); =CB-potential

<table>
<thead>
<tr>
<th>Backbone</th>
<th>Cluster A</th>
<th>Cluster B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference</td>
<td>STORM</td>
</tr>
<tr>
<td>Supply temperature [°C]</td>
<td>20.23</td>
<td>21.26</td>
</tr>
<tr>
<td>Return temperature [°C]</td>
<td>13.9</td>
<td>11.8</td>
</tr>
<tr>
<td>Flow [m³/h]</td>
<td>14.97</td>
<td>13.85</td>
</tr>
<tr>
<td>Capacity [GJ/m³.h]</td>
<td>0.03</td>
<td>0.04</td>
</tr>
</tbody>
</table>

• combining CB and PS leads to system’s **capacity improvement of 52%**
# STORM - Final results

<table>
<thead>
<tr>
<th>Evaluated results of the STORM controller</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak Shaving</strong></td>
</tr>
<tr>
<td>up to 12.75% (Rottne) on peak heat load</td>
</tr>
<tr>
<td>up to 17.3% (Heerlen; median values) on flow</td>
</tr>
<tr>
<td><strong>Market Interaction</strong></td>
</tr>
<tr>
<td>up to 49% influence on instantaneous demand, leading to:</td>
</tr>
<tr>
<td>• 15% reduction on electricity purchase price</td>
</tr>
<tr>
<td>• 6% reduction on electricity procurement costs</td>
</tr>
<tr>
<td><strong>Cell Balancing</strong></td>
</tr>
<tr>
<td>up to 42.1% (Heerlen; median values) capacity improvement through improved energy exchange potential</td>
</tr>
<tr>
<td><strong>Sustainability</strong></td>
</tr>
<tr>
<td>Up to 15% of annual energy savings of connected buildings, especially in combination with the Smart Heat Building service,</td>
</tr>
<tr>
<td>Avoided CO₂ emissions per year:</td>
</tr>
<tr>
<td>• Rottne: another 10,880 tonnes</td>
</tr>
<tr>
<td>• Heerlen: an additional amount of 12,816 tonnes</td>
</tr>
</tbody>
</table>
STORM – Benefits for DHC operators

- **Economical:**
  - Positive annual operating result by:
    - Reduced costs of energy production
    - Reduced costs of electricity purchase
    - connecting more customers to the system
    - installing less capacity
  - Reduced TCO

- **Environmental:**
  - Reduced energy demand
    - Improved energy exchange
    - Integration of excess energy
  - Reduction on GHG emissions

- **Other:**
  - Improved supply security
Questions?
THANK YOU!

Contact:
Ed Smulders
e.smulders@mijnwater.com
Tijs van Oevelen
Tijs.vanoevelen@vito.be

info@storm-dhc.eu
storm-dhc.eu