Multi-Vector District Energy System Management: Modelling Aspects and Challenges

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Outline

- **Background**: Building as the basic brick
- **Decentralized modelling**: Multi-energy exchanges between systems
Background:

Building as the basic brick
Context and challenges: From the generation to the consumption side

Renewables:
- Low carbon
- Cheap
- Inflexible
- Uncertain

Smart buildings:
- Flexible
- Controllable
- Small and complex

Future systems:
- Classical de-coupling of energy vectors is inefficient
Challenges at the building level

- Need for understanding multi-energy consumption in buildings
  - Future low-carbon technologies
    - Heating (various heat pumps, microCHP, storage)
    - Solar
    - EV
  - Capturing diversity across dimensions
    - House type and physical characteristics
    - Insulation level
    - Use of appliances and heating set points
    - Geographic
    - etc
- Provide high resolution (e.g., 1 minute) to capture physical aspects
- Capturing thermal inertia and comfort level impact
Electro-thermal modelling

Supply

Building

Heat emitters

Building energy consumption model

Example: DR considering 300l Buffer tank

- **Dwelling**: Semi-detached house
- **Heating unit**: Air source heat pump
- **Number of dwellings**: 500
- **DR period**: 18:00-19:00
- **Emitter**: Underfloor heating unit
- **Insulation level**: modern (built between 1944-1984)
- **Space heating buffer options**: 0/150/300/600 litres
- **Weather**: Cold Winter weekday (range from -5.0 to 0.1°C)
Example: DR considering 300l Buffer tank

Demand profile

Temperature profile
Technical and economic aggregation

Example results

Aggregated outputs – Old detached house/4 occupants/ Winter/18°C set point/radiator 500 houses
Decentralized modelling:
Multi-energy exchanges between systems
Buildings or districts: Why model building level interactions?

- What is really more environmentally and economically attractive?

- Reduce total energy consumption
- Actuate only in target “low efficiency” buildings
- Minimise exports to the network

- Lower economic/ carbon intensive consumption
- Actuate in convenient locations directing energy flows to target buildings
- Actively provide demand response
Energy Efficiency Engine

- Solving the problem in an integrated manner is daunting and even computationally infeasible (involving stochastic MINLP problems)

- A methodology that iteratively couples parts of the problem provides a more practical approach

District perspective: Challenges

- The use of multi-energy technologies effectively couples the different networks (e.g., electricity, heat and gas)

<table>
<thead>
<tr>
<th>Global node numbering</th>
<th>Type</th>
<th>Gas to electricity</th>
<th>Gas to heat</th>
<th>Electricity to heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CHP (large scale)</td>
<td>$H_p \eta_{pe}$</td>
<td>$H_p \eta_{ph}$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CHP (building 1)</td>
<td>$H_p \eta_{pe}$</td>
<td>$H_p \eta_{ph}$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Gas generator (building 2)</td>
<td>$H_p \eta_{pe}$</td>
<td>$H_p \eta_{ph}$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Heat pump (building 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Electric heater (building 4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Gas boiler (building 5)</td>
<td>$H_p \eta_{pe}$</td>
<td>$H_p \eta_{ph}$</td>
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</tr>
<tr>
<td>7</td>
<td>CHP (building 6)</td>
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<tr>
<td>8</td>
<td>CHP (building 7)</td>
<td>$H_p \eta_{pe}$</td>
<td>$H_p \eta_{ph}$</td>
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</tr>
<tr>
<td>9</td>
<td>Heat pump (building 8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Heat pump (building 9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Gas boiler (building 10)</td>
<td></td>
<td>$H_p \eta_{ph}$</td>
<td></td>
</tr>
</tbody>
</table>


- Multiple smart buildings now exchange different energy flows

Source: E. A. Martinez Ceseña, and P. Mancarella, “Operational optimization and environmental assessment of integrated district energy systems,” in PSCC 2016,
Multi-energy district: Integrated model

EAMC and PM, "Distribution network support from multi-energy demand side response in smart districts," ISGT Asia 2016.

Building

District

Networks


Case study: The University of Manchester

Electricity
- 85°C heat network
- 30 buildings

Heat
- Radial gas network
- 28 buildings

Gas
- Radial gas network
- 28 buildings

- 6.6 kV distribution network
- 17 buildings
Integrated model: Capabilities (1)

Which factors can be considered?

- Energy profiles: Time series for demand and price data, and so forth
- Existing infrastructure: PV and CHP, among others
- Intelligence levels: Load following or optimal mode
- Aggregation levels: Building or district levels
- Objectives: Costs or CO$_2$ minimisation, among others
Integrated model: Capabilities (2)

- On-off integer constraints for relevant devices
- Non linear electricity/heat curves modelled as MILP constraints
- Inter-temporal constraints for storage devices
- Annual (half-hour resolution) energy and price profiles
- Customisable scenarios to model uncertainty
Case study: The Manchester district

Large scale installation of multi-energy DER to reduce emissions by 30%

<table>
<thead>
<tr>
<th>Building</th>
<th>Installed capacity (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PV</td>
</tr>
<tr>
<td>1</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
</tr>
<tr>
<td><strong>District</strong></td>
<td><strong>3495</strong></td>
</tr>
</tbody>
</table>

Case study: The Manchester district

Flexible operation in heat-following mode (Reference) or to minimise emissions or costs?

<table>
<thead>
<tr>
<th>Building</th>
<th>Emissions (tCO₂)</th>
<th>Costs (£x10³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>257</td>
<td>173</td>
</tr>
<tr>
<td>2</td>
<td>692</td>
<td>638</td>
</tr>
<tr>
<td>3</td>
<td>500</td>
<td>518</td>
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<tr>
<td>4</td>
<td>111</td>
<td>104</td>
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<tr>
<td>District</td>
<td>16034</td>
<td>14854</td>
</tr>
</tbody>
</table>

Source: E. A. Martínez Ceseña, and P. Mancarella, “Operational optimization and environmental assessment of integrated district energy systems,” in PSCC 2016,
Acknowledgment

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Thank you
Any Questions?

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http://www.energy.manchester.ac.uk/research/multi-energy-systems/dimmer/
Selected references

Modelling of residential multi-energy technologies and multi-energy networks

Selected references

Multi-energy systems and distributed multi-generation framework


Selected references

Operational optimization and demand response in multi-energy systems


Selected references

Network planning and reliability assessment


Selected references

Planning under uncertainty of multi-energy systems


Selected references

Business cases of multi-energy systems


