# 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

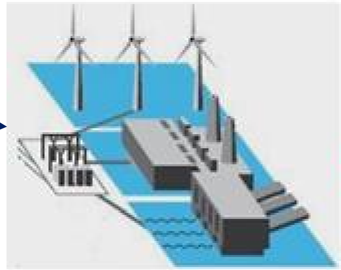
# Background:

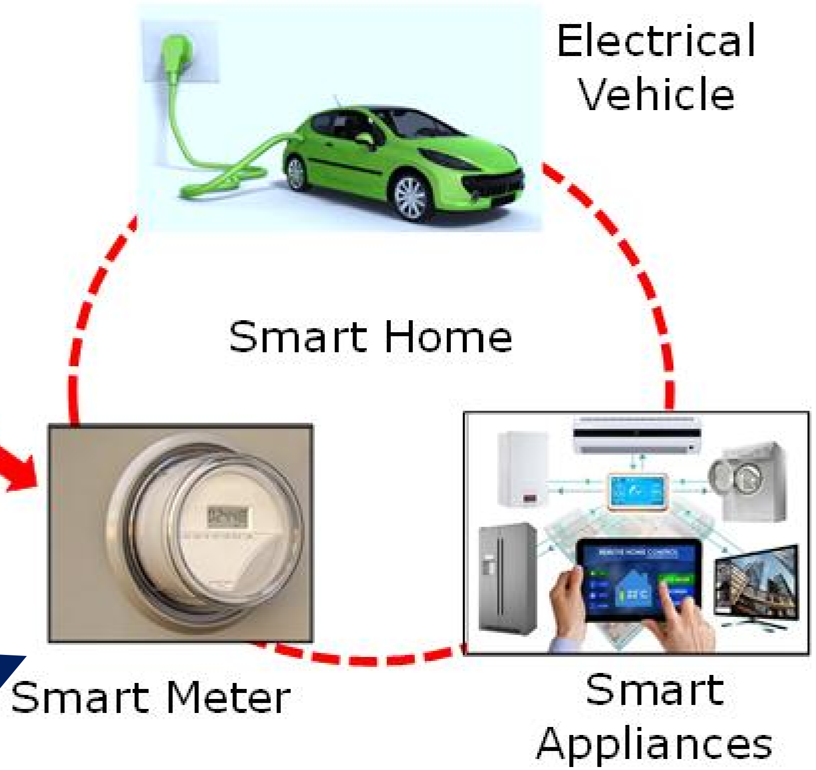
## Building as the basic brick

# Context and challenges: From the generation to the consumption side

**Renewables:**

- Low carbon
- Cheap
- **Inflexible**
- **Uncertain**






**Smart buildings:**

- Flexible
- Controllable
- **Small and complex**

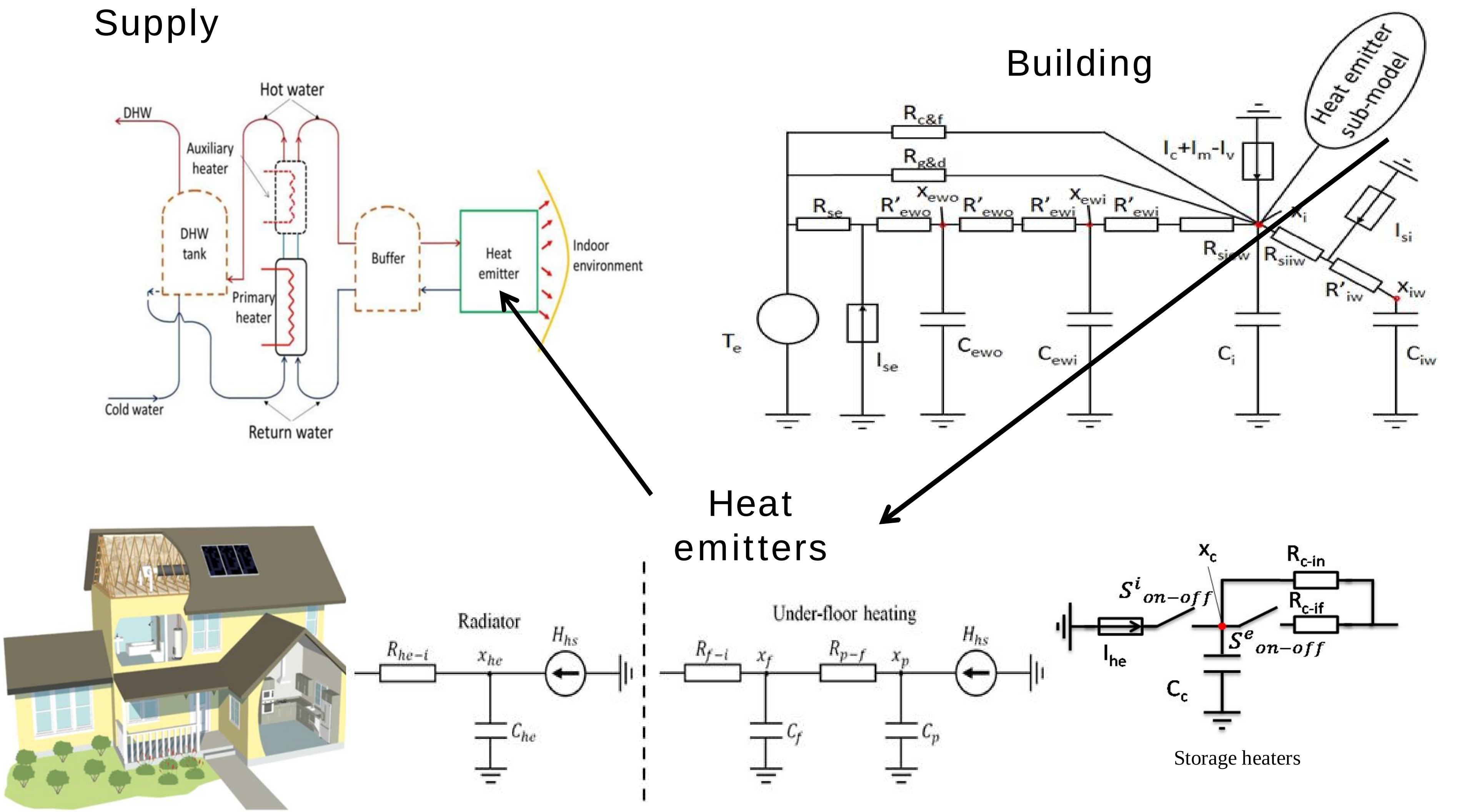
**Future systems:**

- **Classical de-coupling of energy vectors is ineficient**

# Challenges at the building level

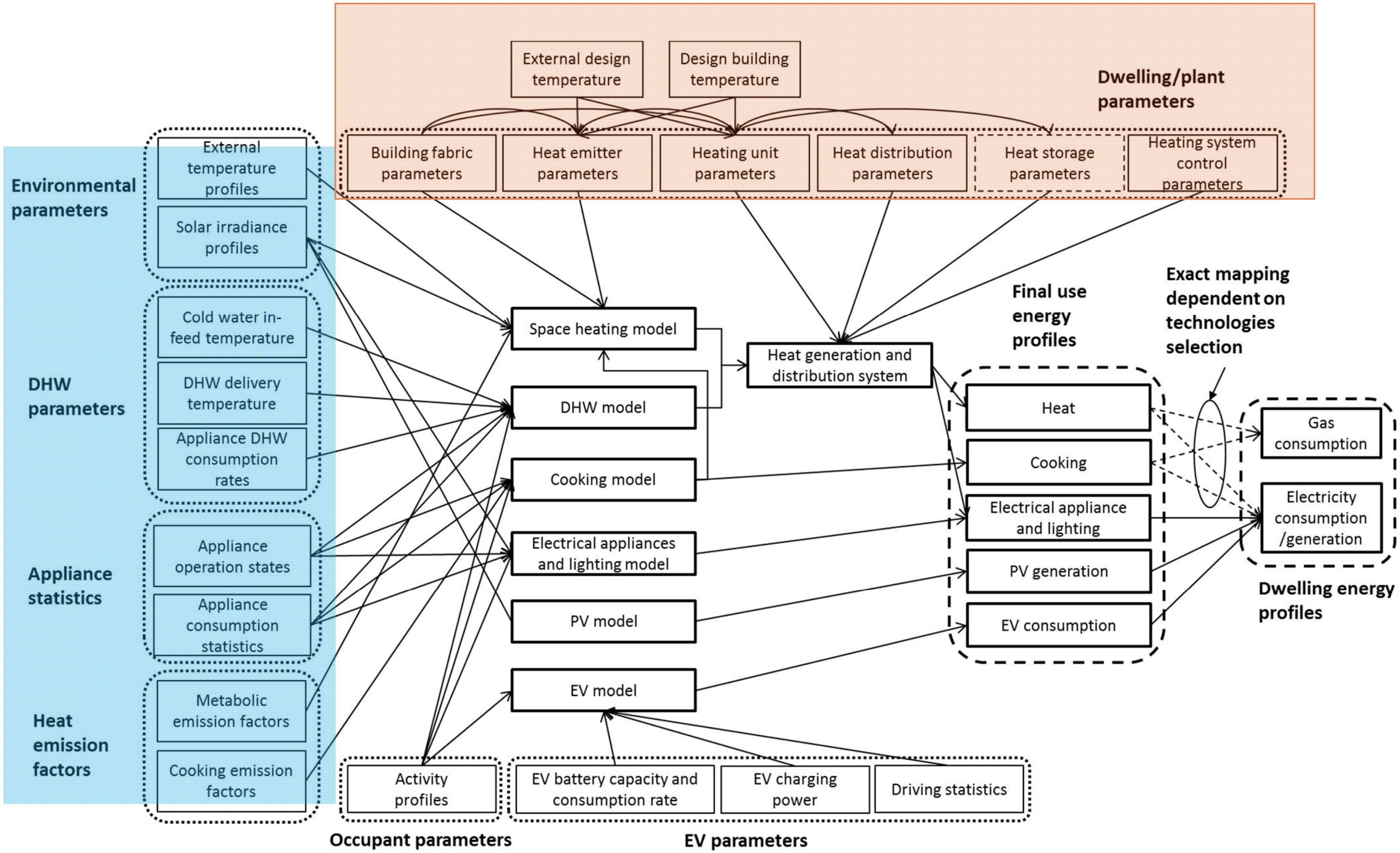
- Need for understanding multi-energy consumption in buildings
  - Future low-carbon technologies
    - Heating (various heat pumps, microCHP, storage)
    - Solar
    - EV
  - Capturing **diversity** across *dimensions*
    - House type and physical characteristics
    - Insulation level
    - Use of 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




N. Good, L. Zhang, A. Navarro Espinosa, and P. Mancarella, High resolution modelling of multi-energy demand profiles, Applied Energy, Volume 137, 1 January 2015, Pages 193–210, 2014

# Building energy consumption model

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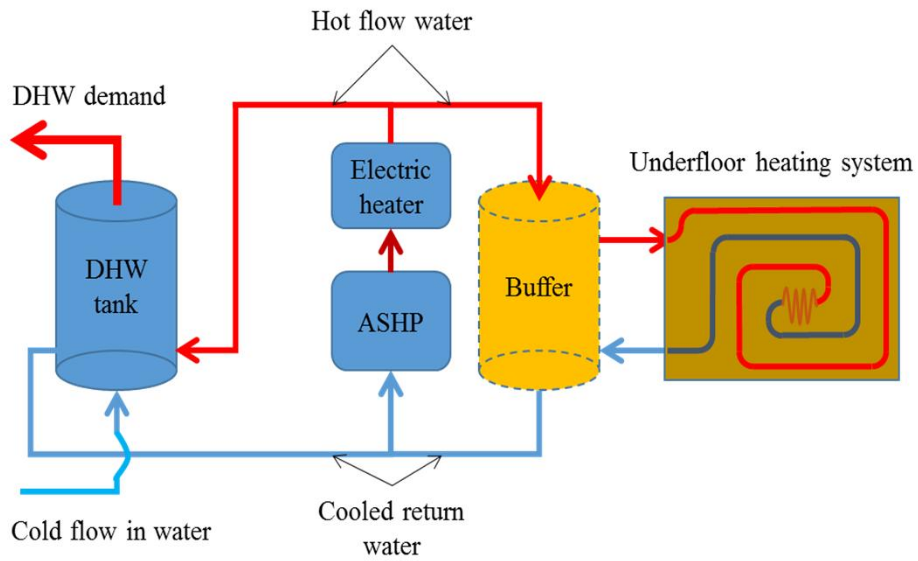
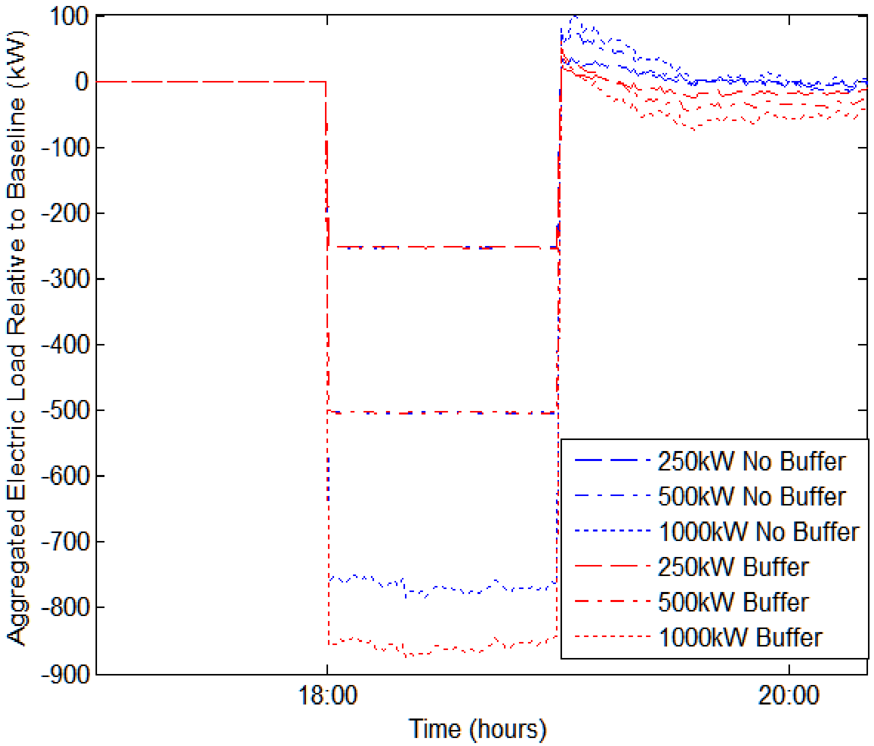
# Example: DR considering 300l Buffer tank

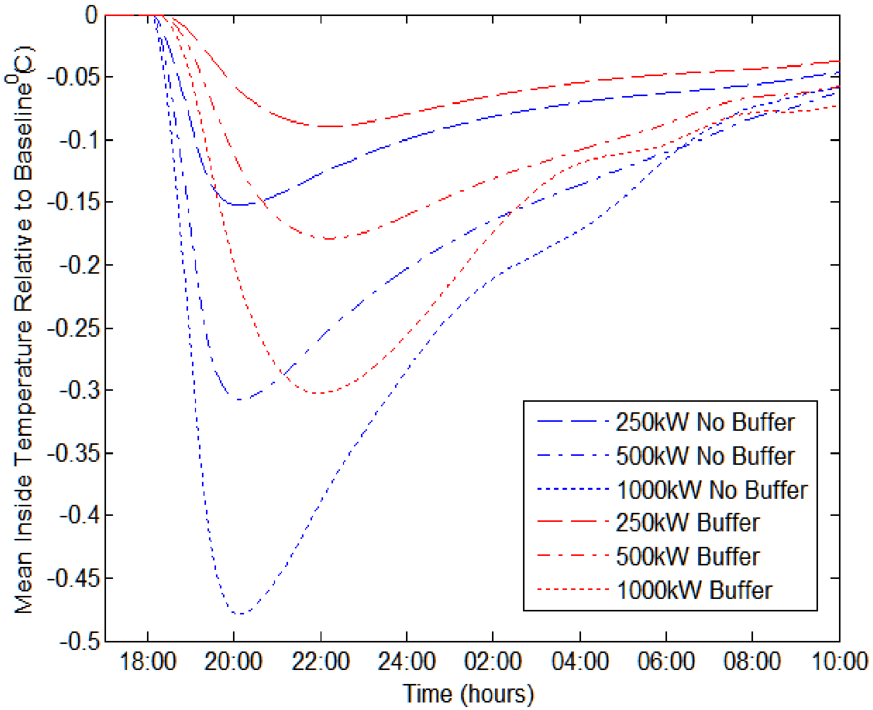
- *Dwelling*: Semi-detached house
- *Heating unit*: Air source heat pump
- *Number of dwellings*: 500
- *DR period*: 18:00-19:00
- *Emitter*: Underfloor heating unit
- *Insulation level*: modern (built between 1944-1984)
- *Space heating buffer options*: 0/150/300/600 litres
- *Weather*: Cold Winter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



# Example: DR considering 300l Buffer tank

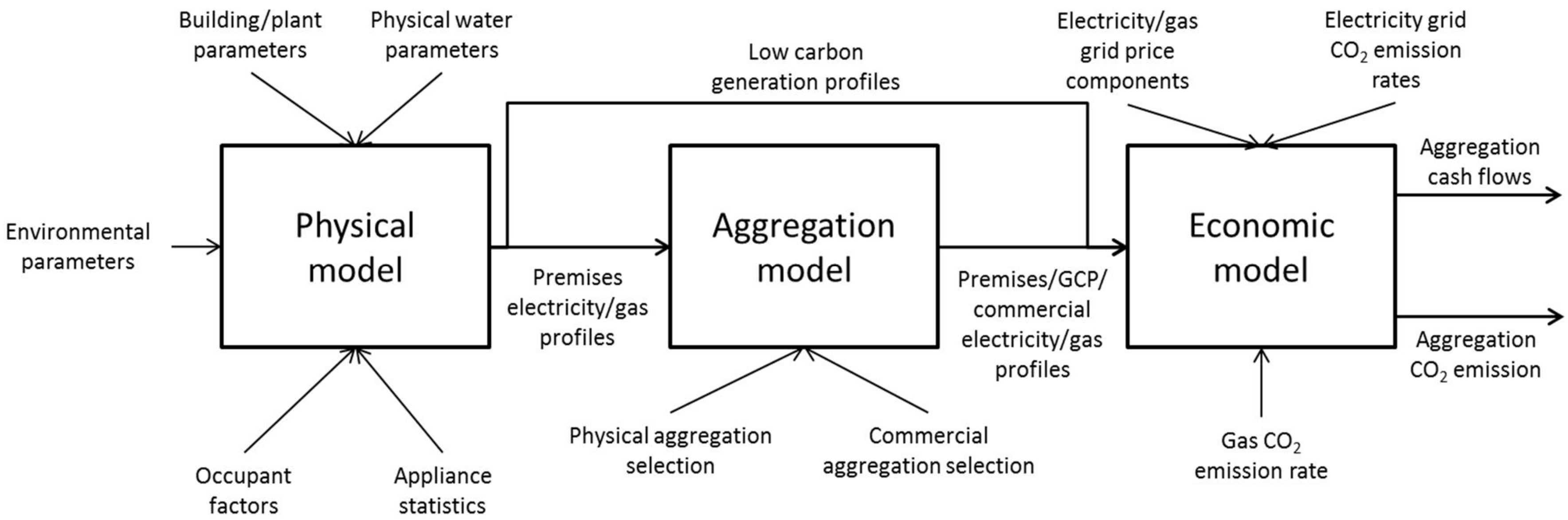



Demand profile




Temperature profile

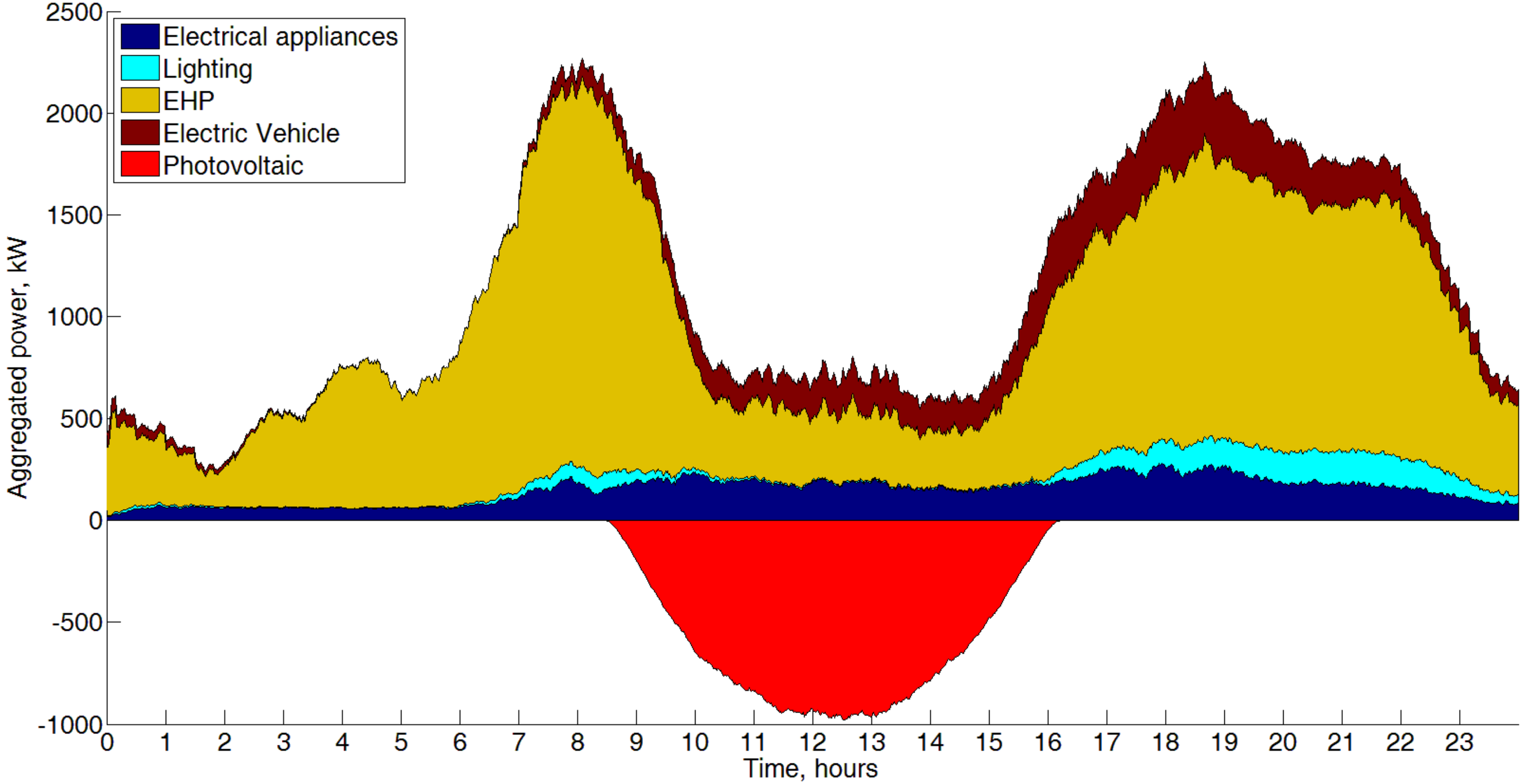
# Technical and economic aggregation




N. Good, E.A. Martinez-Cesena, L. Zhang, and P. Mancarella, Techno-economic assessment and business case modelling of low carbon technologies in distributed multi-energy systems, *Applied Energy, Special Issue on Integrated Energy Systems, Accepted for publication, 2016*

# 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?

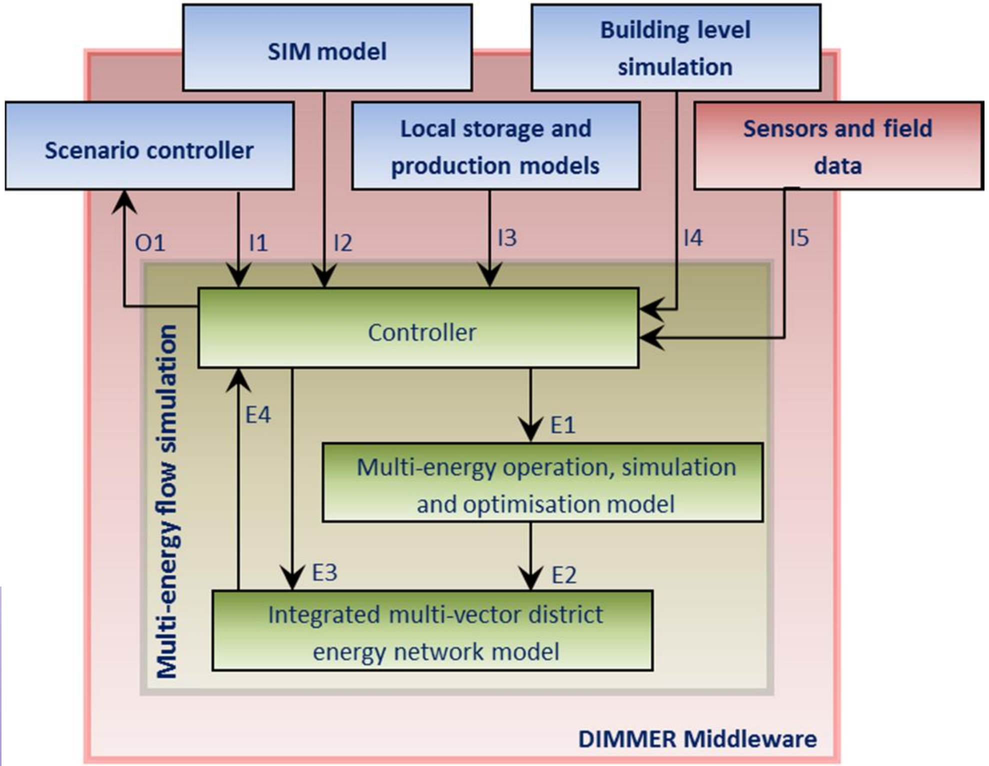
- Reduce total energy consumption
- Actuate only in target “low efficiency” buildings
- Minimise exports to the network

- 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




Source: N. Good, E. A. Martínez Ceseña , X. Liu and P. Mancarella, “A business case modelling framework for smart multi-energy districts,” in CIRED 2016

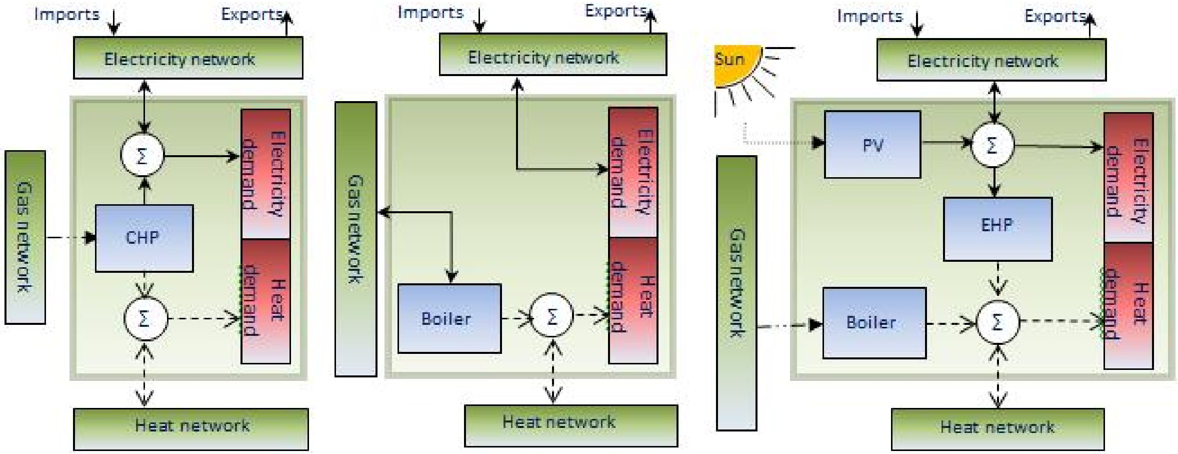
# District perspective: Challenges

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

| Global node numbering | Type | Gas to electricity | Gas to heat | Electricity to heat |
|---|---|---|---|---|
| 1 | CHP (large scale) | $H_g\eta_{ge}^1$ | $H_g\eta_{gh}^1$ | |
| 2 | CHP (building 1) | $H_g\eta_{ge}^2$ | $H_g\eta_{gh}^2$ | |
| 3 | Gas generator (building 2) | $H_g\eta_{ge}^3$ | | |
| 4 | Heat pump (building 3) | | | $\eta_{eh}^4$ |
| 5 | Electric heater (building 4) | | | $\eta_{eh}^5$ |
| 6 | Gas boiler (building 5) | | $H_g\eta_{gh}^6$ | |
| 7 | CHP (building 6) | $H_g\eta_{ge}^7$ | $H_g\eta_{gh}^7$ | |
| 8 | CHP (building 7) | $H_g\eta_{ge}^8$ | $H_g\eta_{gh}^8$ | |
| 9 | Heat pump (building 8) | | | $\eta_{eh}^9$ |
| 10 | Heat pump (building 9) | | | $\eta_{eh}^{10}$ |
| 11 | Gas boiler (building 10) | | $H_g\eta_{gh}^{11}$ | |

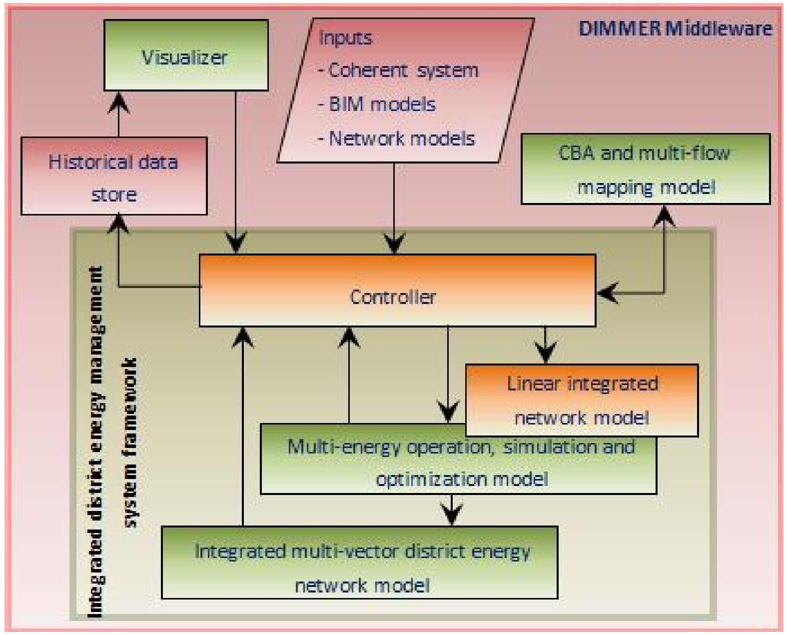
Source: X. Liu and P. Mancarella. Modelling, assessment and Sankey diagrams of integrated electricity-heat-gas networks in multi-vector district energy systems. Applied Energy, 2016

- Multiple smart buildings now exchange different energy flows




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

# Multi-energy district: Integrated model

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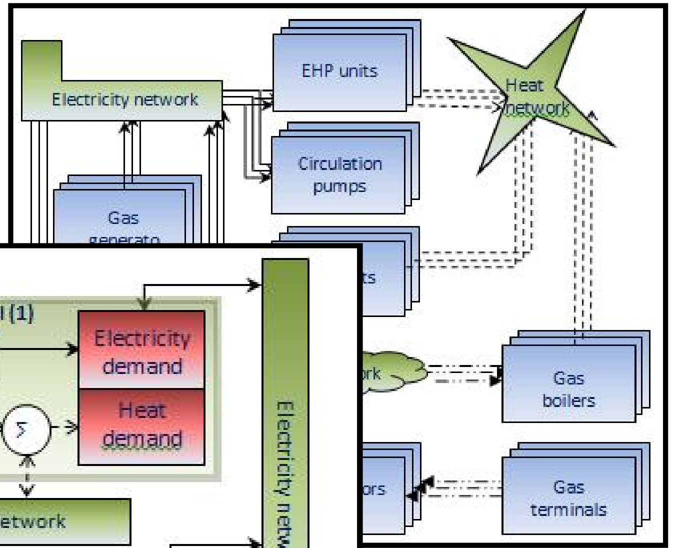


**Networks**

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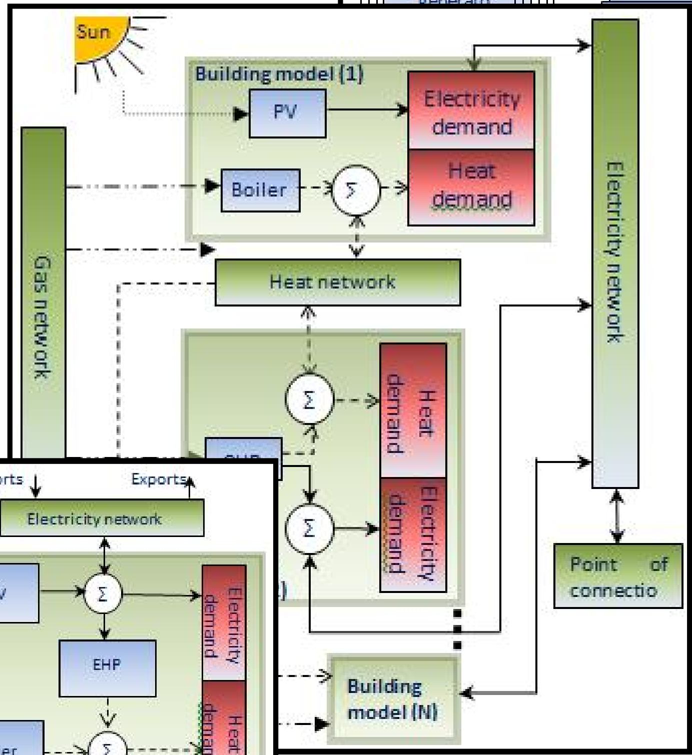


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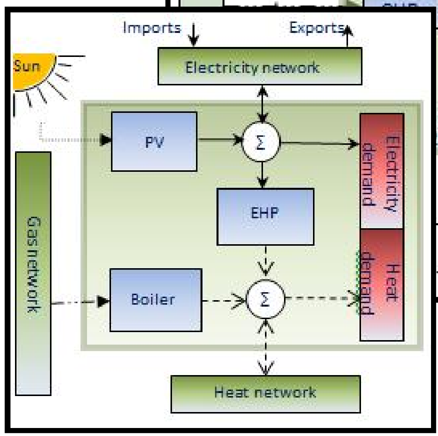


**Building**

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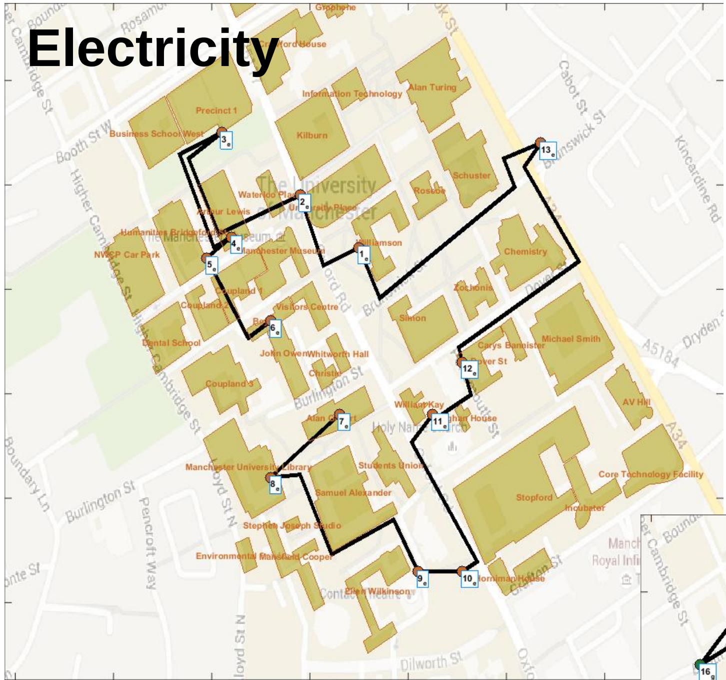
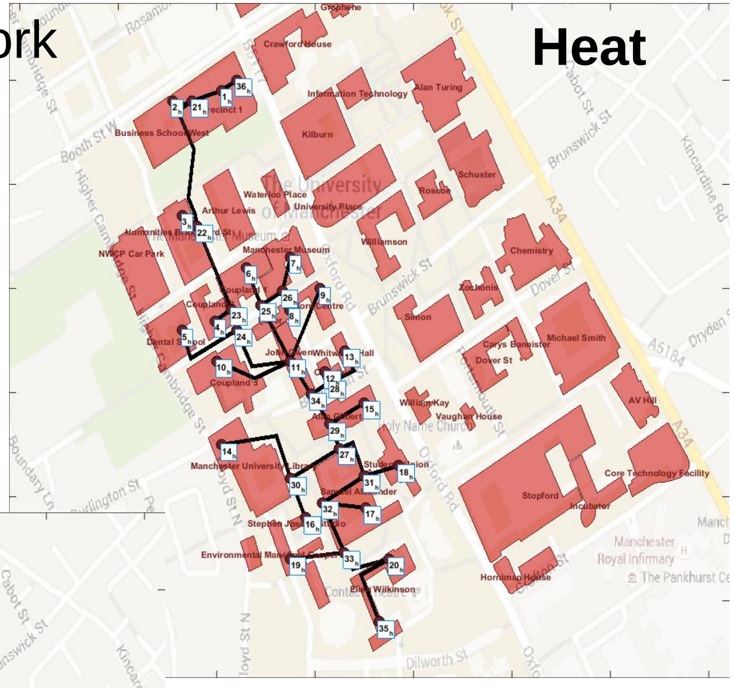
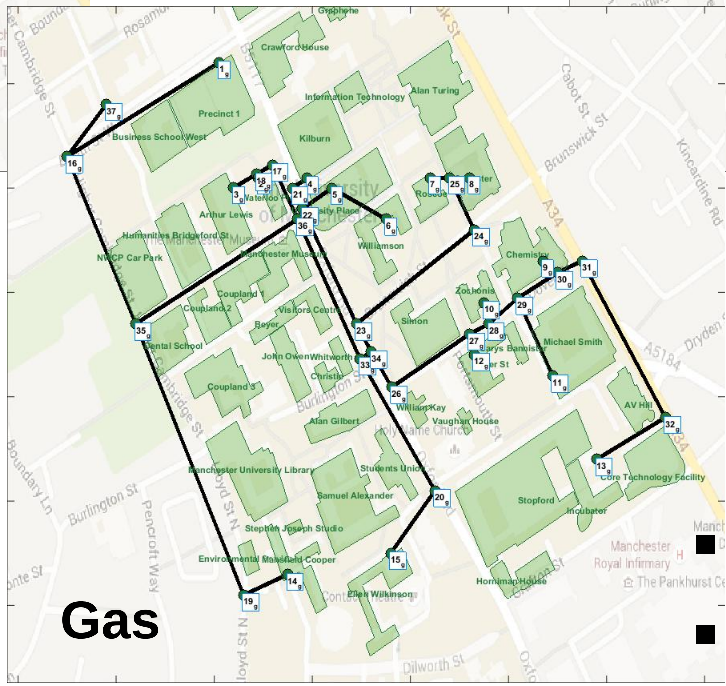
# Case study: The University of Manchester




- 6.6 kV distribution network
- 17 buildings




- 85ºC heat network
- 30 buildings




- Radial gas network
- 28 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%**

| Building | Installed capacity (kW) | | |
|---|---|---|---|
| | PV | EHP | CHP |
| 1 | 85 | 100 | 40 |
| 2 | 150 | 350 | 400 |
| 3 | 50 | 100 | 100 |
| 4 | 55 | 40 | 0 |

| | | | |
|---|---|---|---|
| District | 3495 | 2660 | 2710 |

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

# Case study: The Manchester district

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

| Building | Emissions ($tCO_2$) | | | Costs (£x$10^3$) | | |
|---|---|---|---|---|---|---|
| | Ref. | Opt. Emis. | Opt. Cost. | Ref. | Opt. Emis. | Opt. Cost. |
| 1 | 257 | 173 | 197 | 52 | 102 | 36 |
| 2 | 692 | 638 | 733 | 152 | 188 | 146 |
| 3 | 500 | **518** | 532 | 100 | 167 | 97 |
| 4 | 111 | 104 | 114 | 25 | 87 | 24 |

| | | | | | | |
|---|---|---|---|---|---|---|
| District | 16034 | 14854 | 15478 | 3189 | 4311 | 2863 |

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

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# Thank you

# Any Questions?

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