KU Leuven/EnergyVille
Energy Systems Modeling

Integrated modeling of active demand response with electric heating systems

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EERA JP ESI SP1/2 – DTU, November 2016

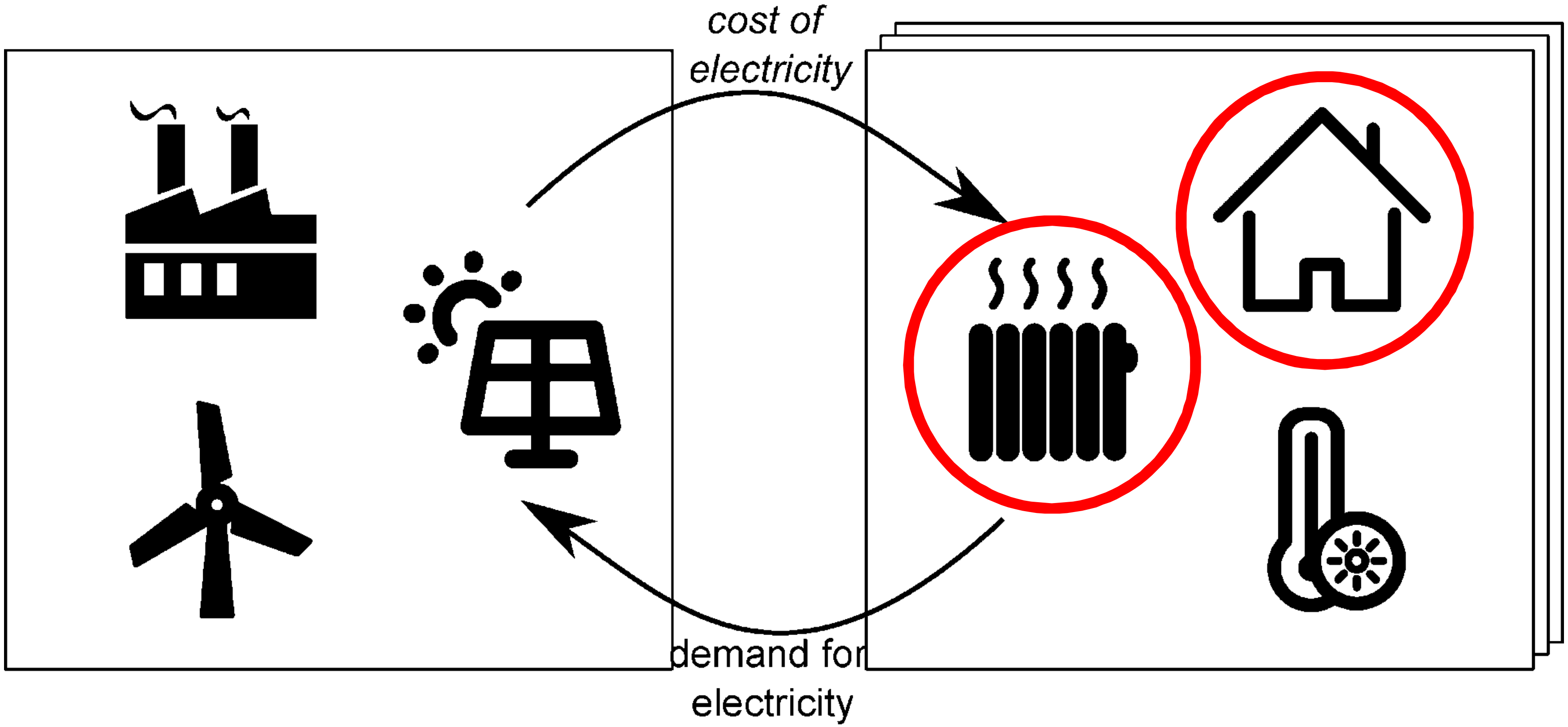
Electricity generation system operation and planning

Electricity generation system operation and planning

- LUSYM framework
  - Operational model
    - Mixed-integer programming for unit commitment
    - Unpredictability: forecast errors, reserve sizing/allocation/activation
    - Link to other energy carriers such as heat and natural gas
    - New technologies: e.g., CCS, active grid elements, power-to-gas

  → Expansion planning models - TIMES framework
    - Improve operational representation and technical detail
    - Uncertainty and market elements

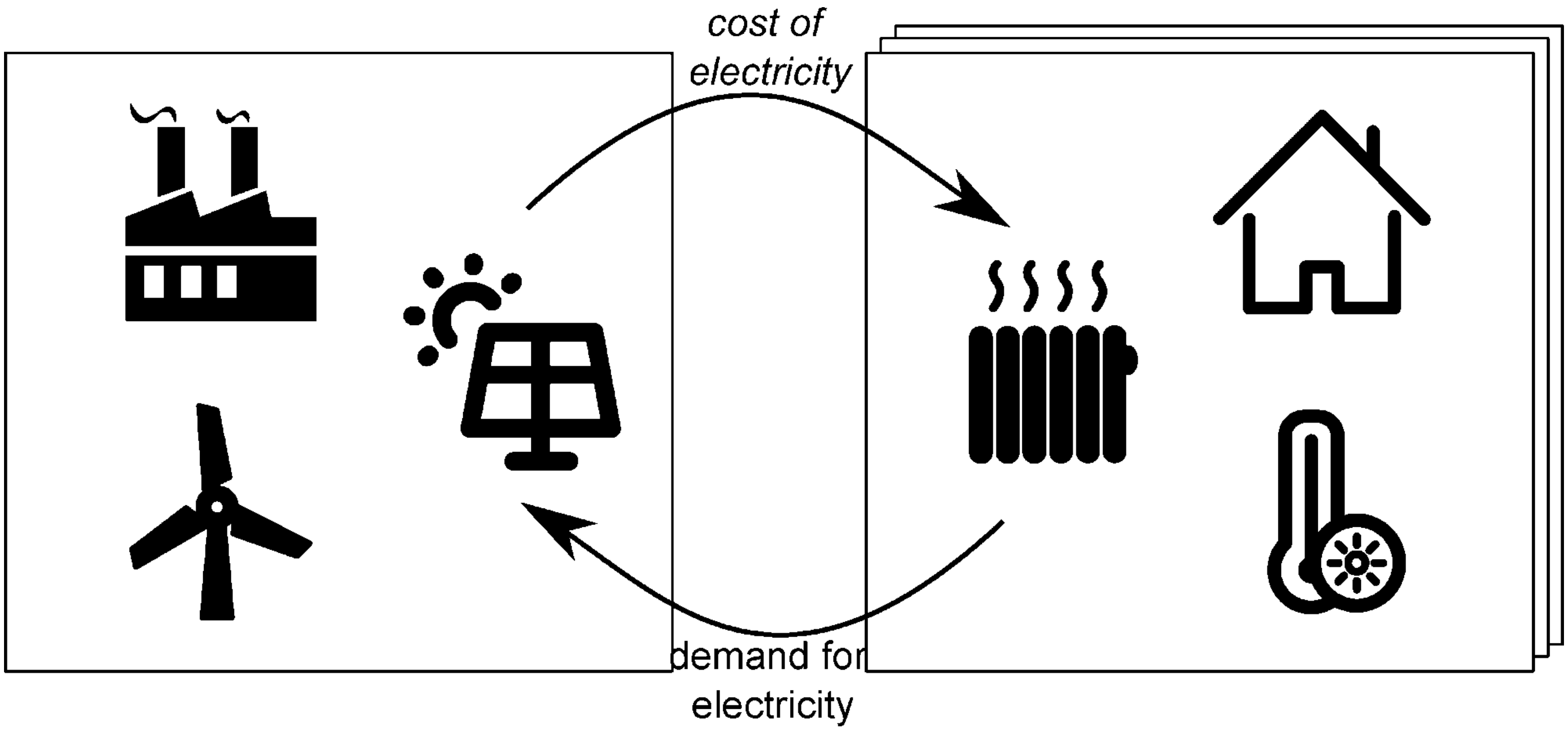
Scope & motivation



Conventional & stochastic RES-based electricity generation

Thermal inertia allows decoupling the electrical demand and the thermal demand without loss of comfort

Modeling challenges & issues



Complex interactions between demand and supply: how do you capture this in an operational model?

Outline

1 Scope & motivation

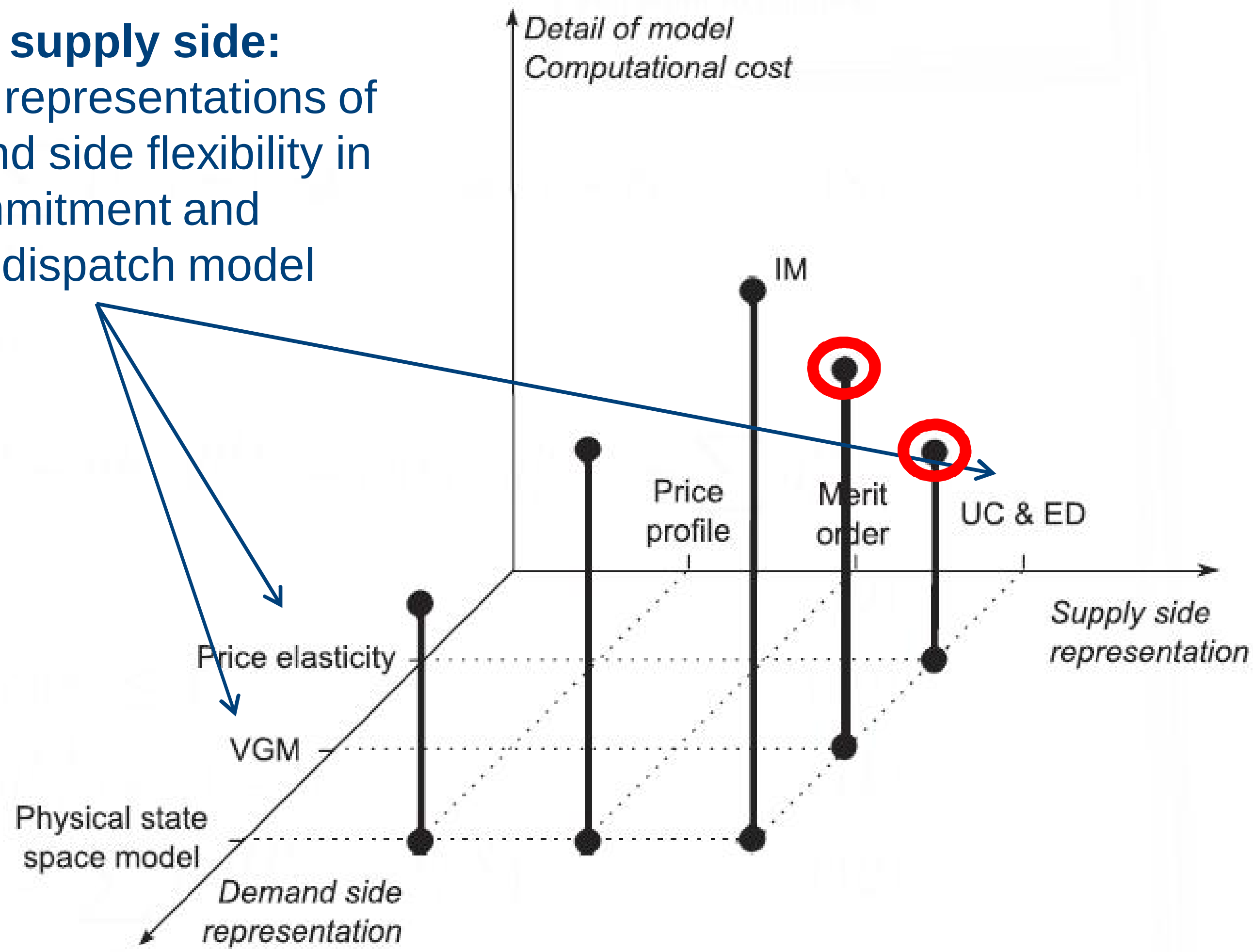
2 Modeling challenges & issues
Modeling approaches in the scientific literature
Integrated model & its added value

3 Applications

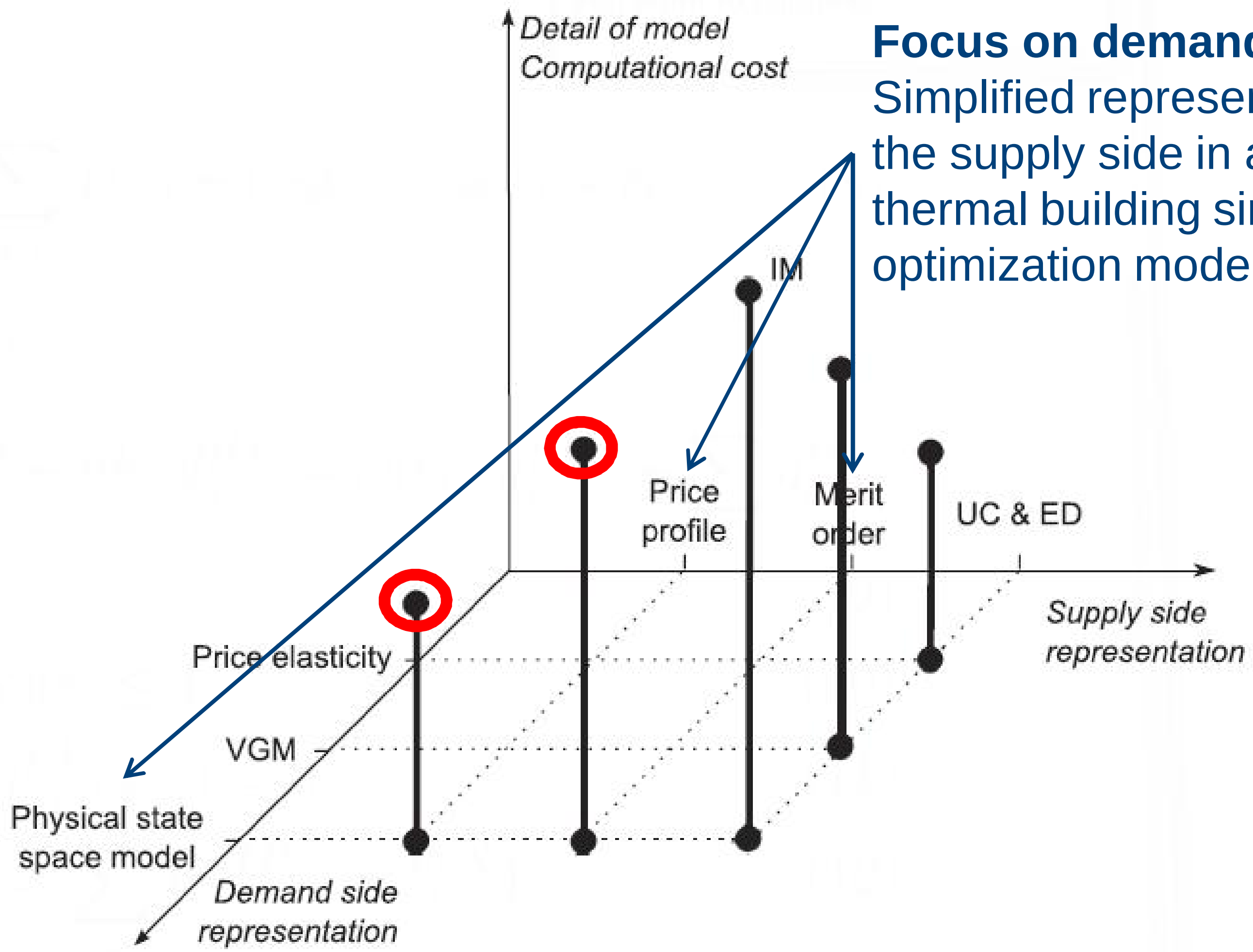
4 Conclusions and future work

Modeling challenges & issues

Focus on supply side:
Simplified representations of the demand side flexibility in a unit commitment and economic dispatch model



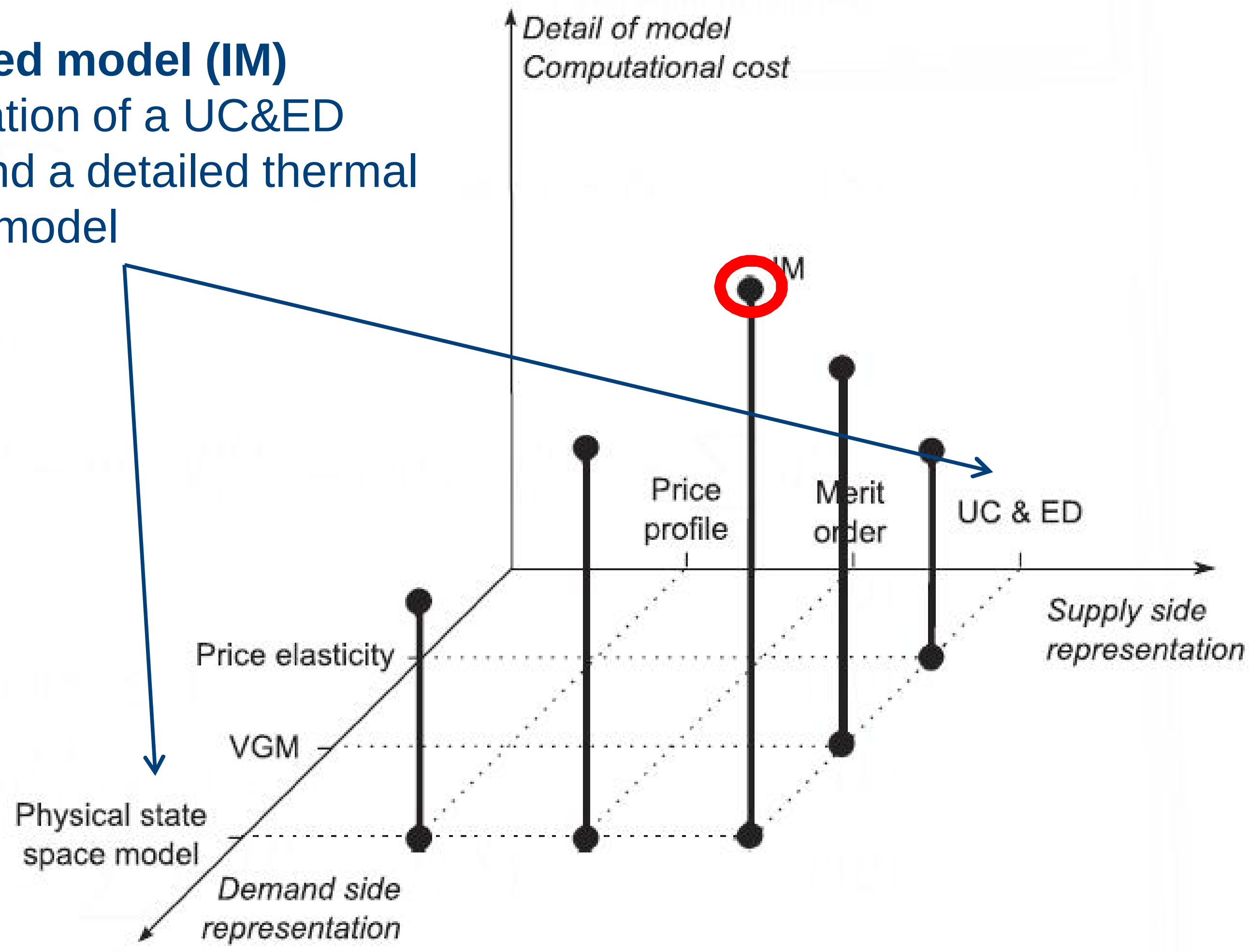
Modeling challenges & issues



Focus on demand side:
Simplified representations of the supply side in a detailed thermal building simulation or optimization model

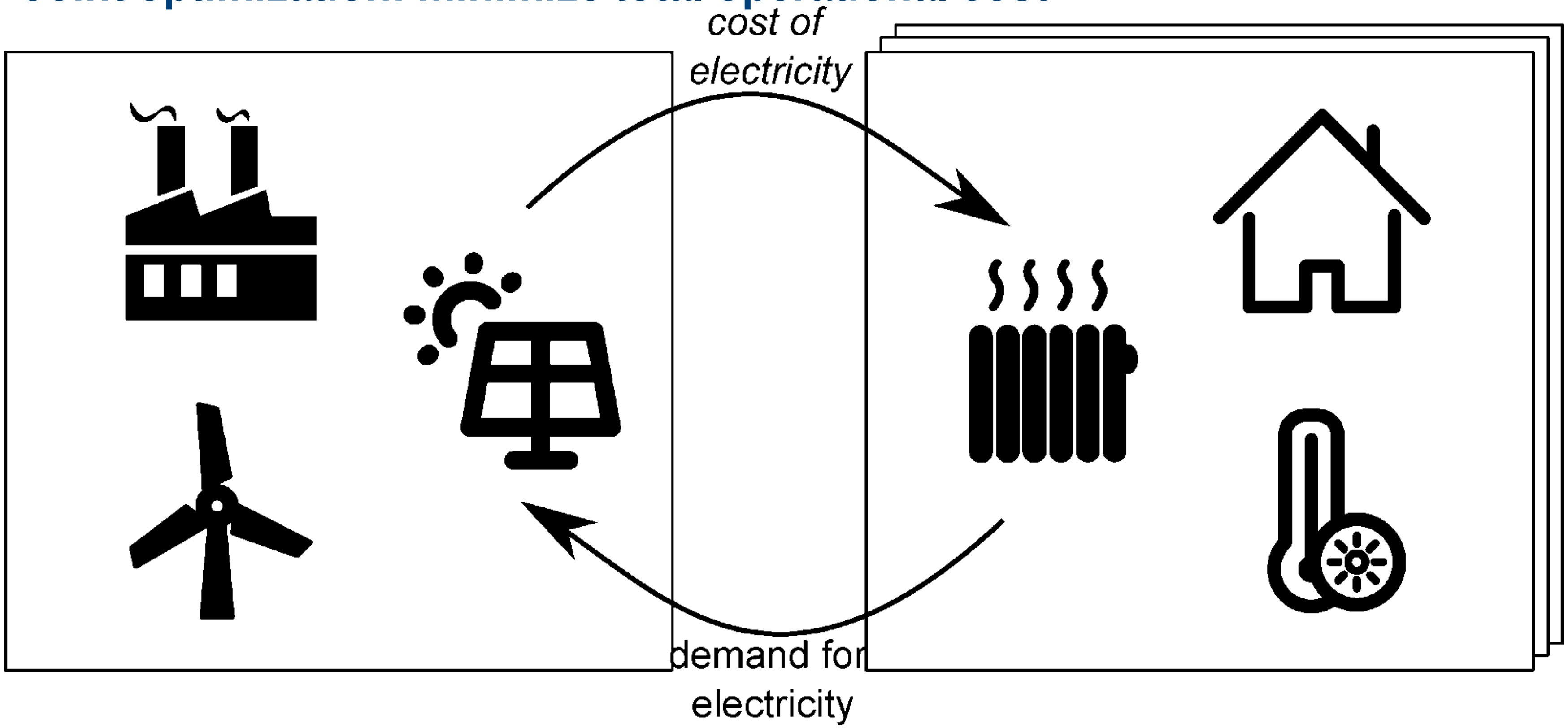
Modeling challenges & issues

Integrated model (IM)
Combination of a UC&ED model and a detailed thermal building model



An integrated model

Joint optimization: minimize total operational cost

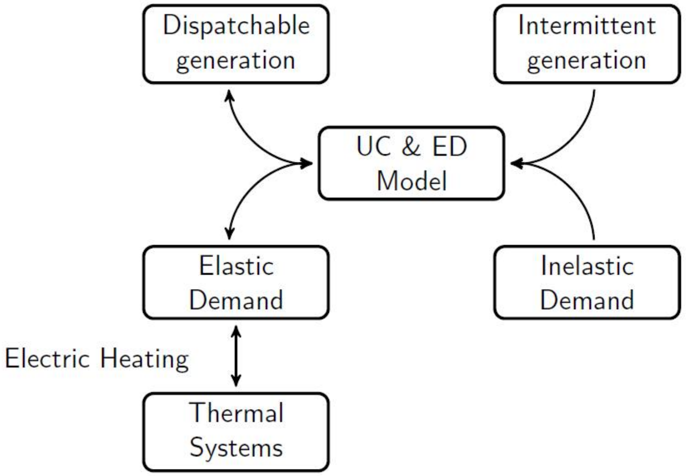


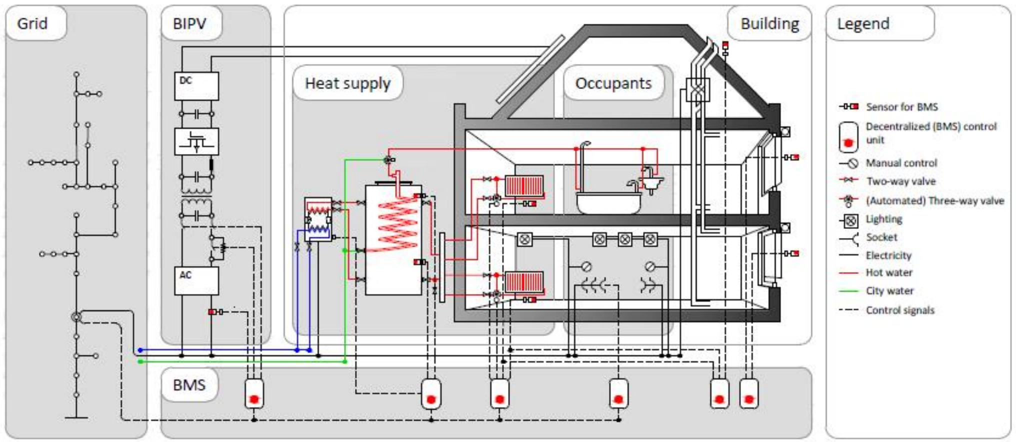
UC & ED model, considering set of power plants, RES-based generation and a fixed demand profile (MILP)

DR-adherent demand model: RC network (thermal dynamics building), linear heat pump model, user behavior & external gains(LP)

An integrated model

Joint optimization: minimize total operational cost





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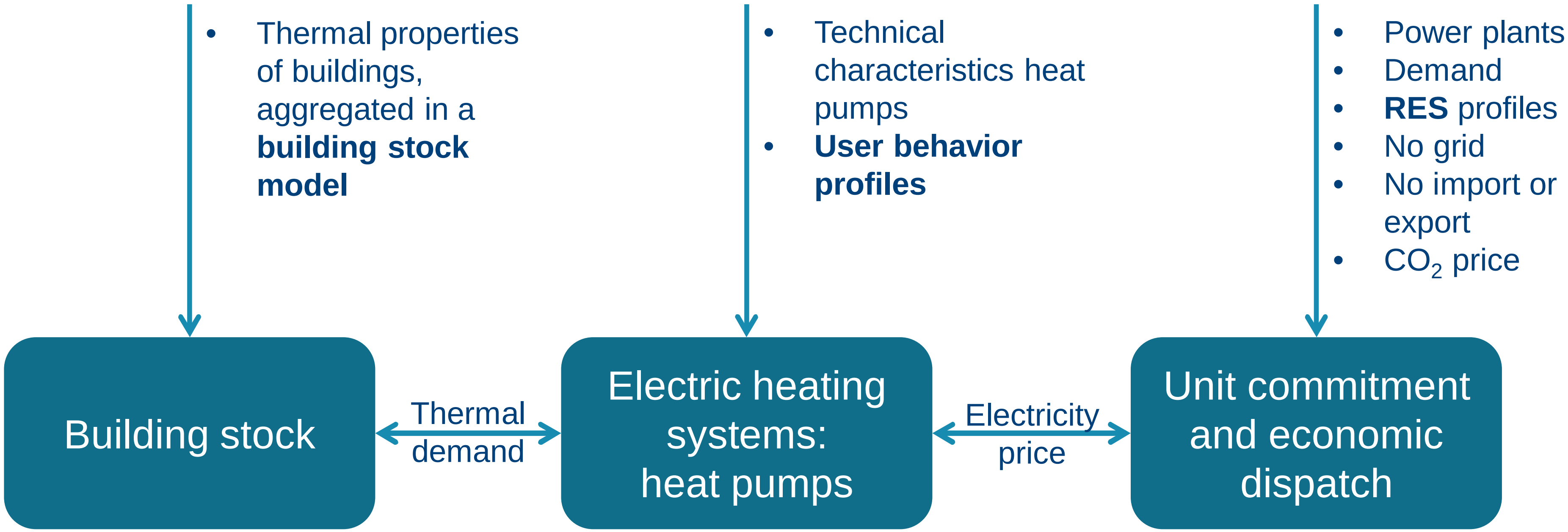
An integrated model

Joint optimization: minimize total operational cost



Linear state-space model

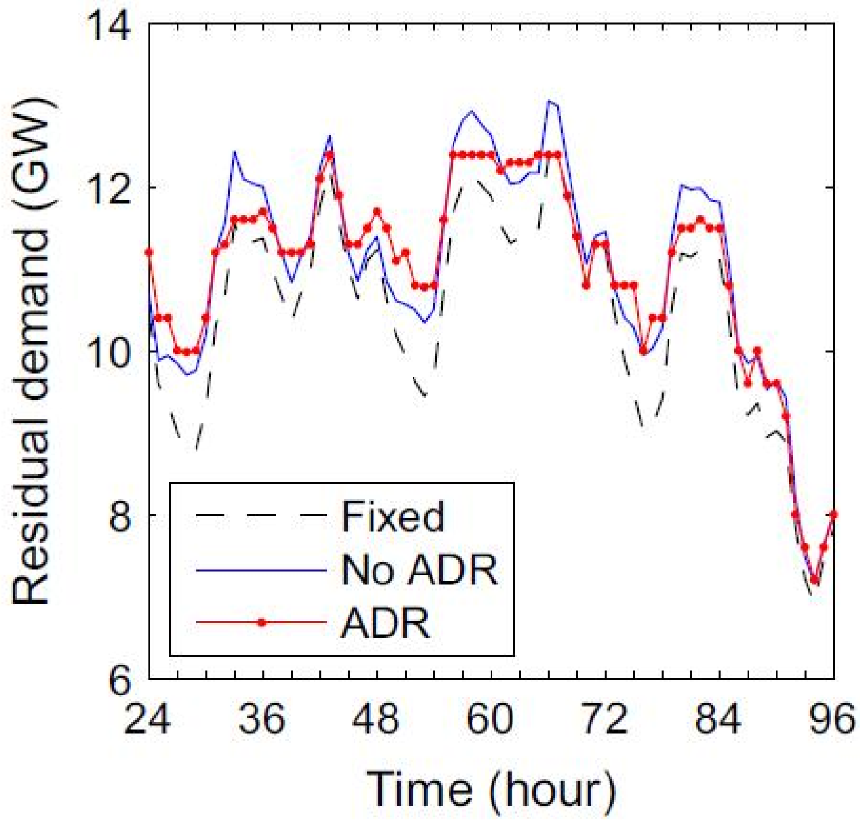
Different building types

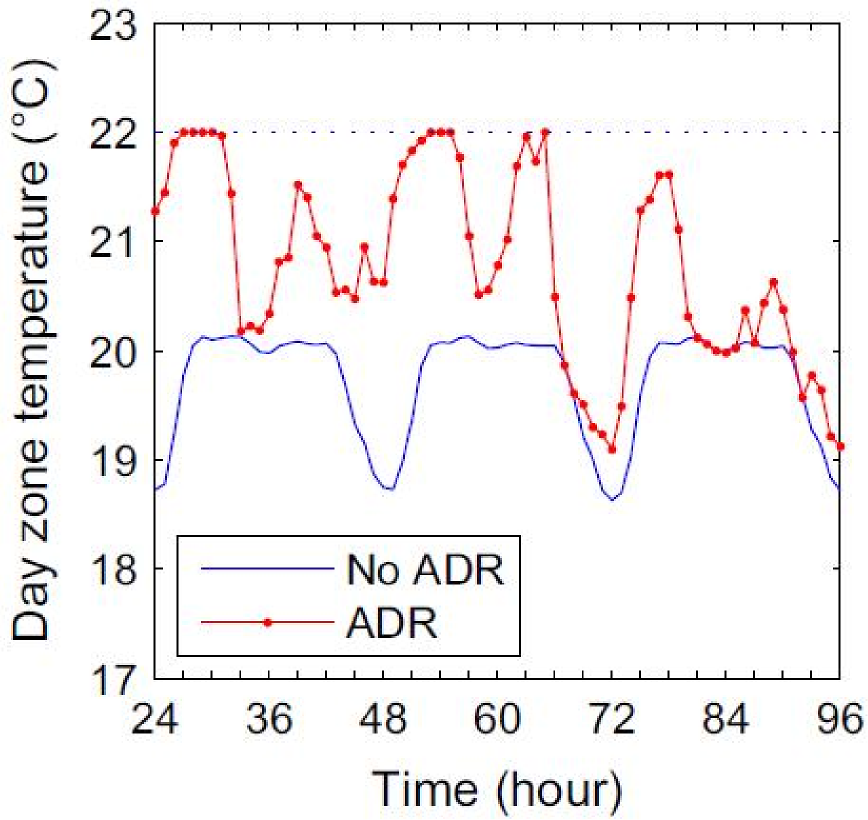
Linear technical model

Different user behaviour types

Mixed integer linear programming model

An integrated model: a first example





- Power system inspired on possible future setting of BE power system;
- 250,000 heat pumps;
- 52 user behavior profiles.

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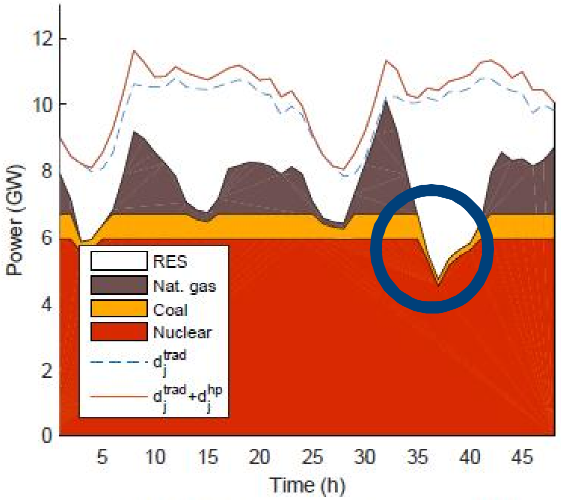
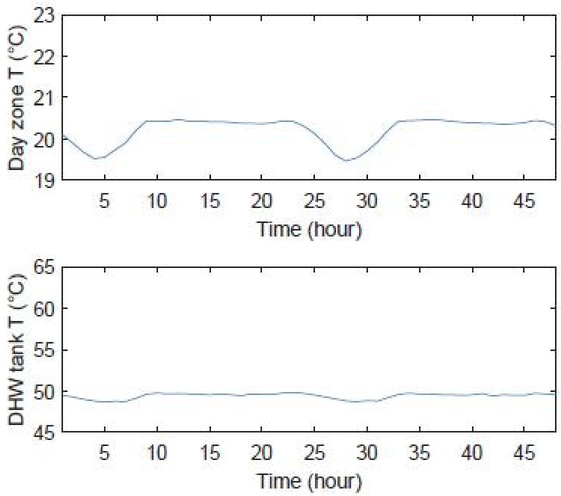
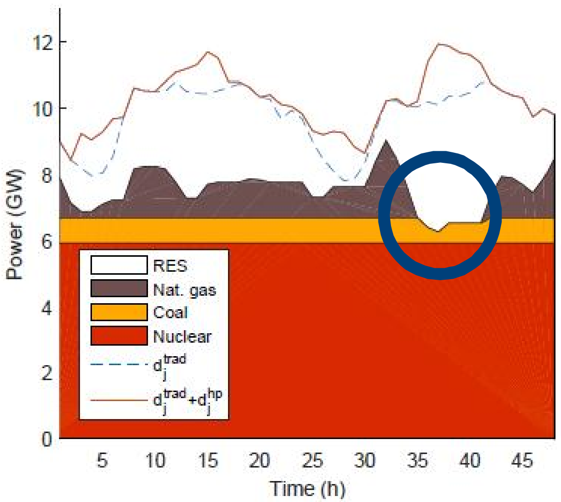
An integrated model: a second example



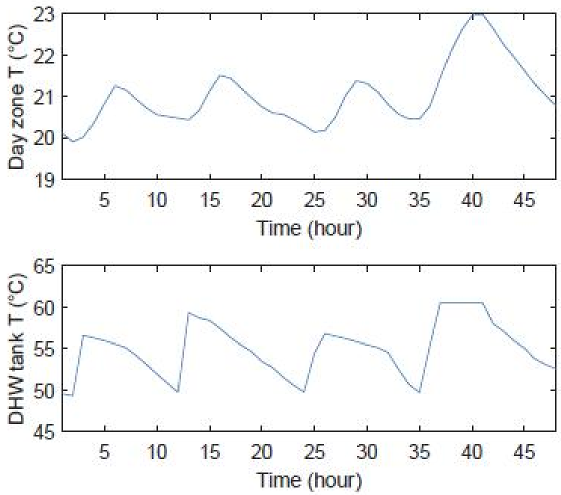
(a) Electricity generation, no DR



(b) Mean temperatures, no DR



(c) Electricity generation, with DR

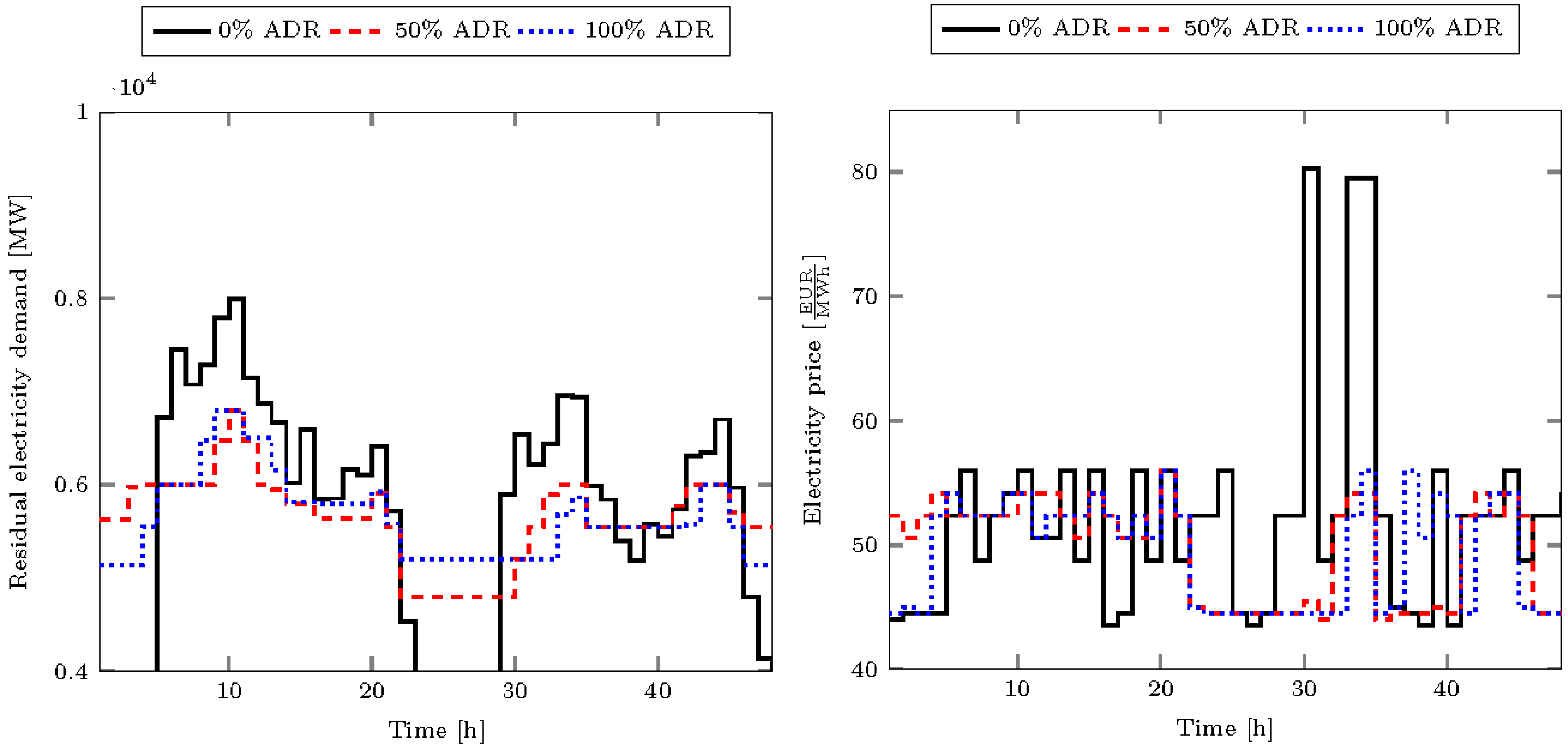


(d) Mean temperatures, with DR

<u>Case study:</u>

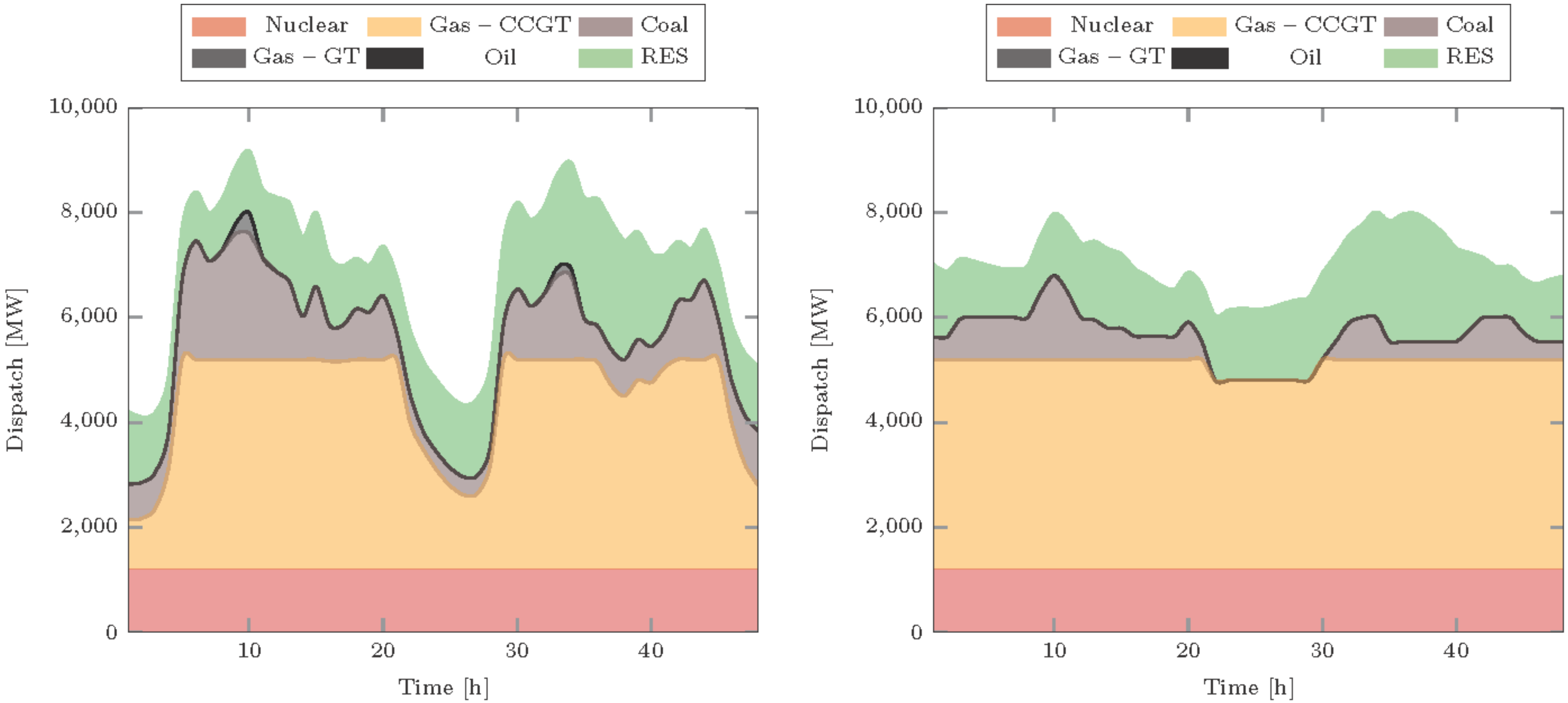
- Power system inspired on possible future setting of BE power system;
- 250,000 heat pumps;
- Building properties represented via an ‘average’ building (detached dwelling);
- 52 user behavior profiles.

An integrated model: a third example



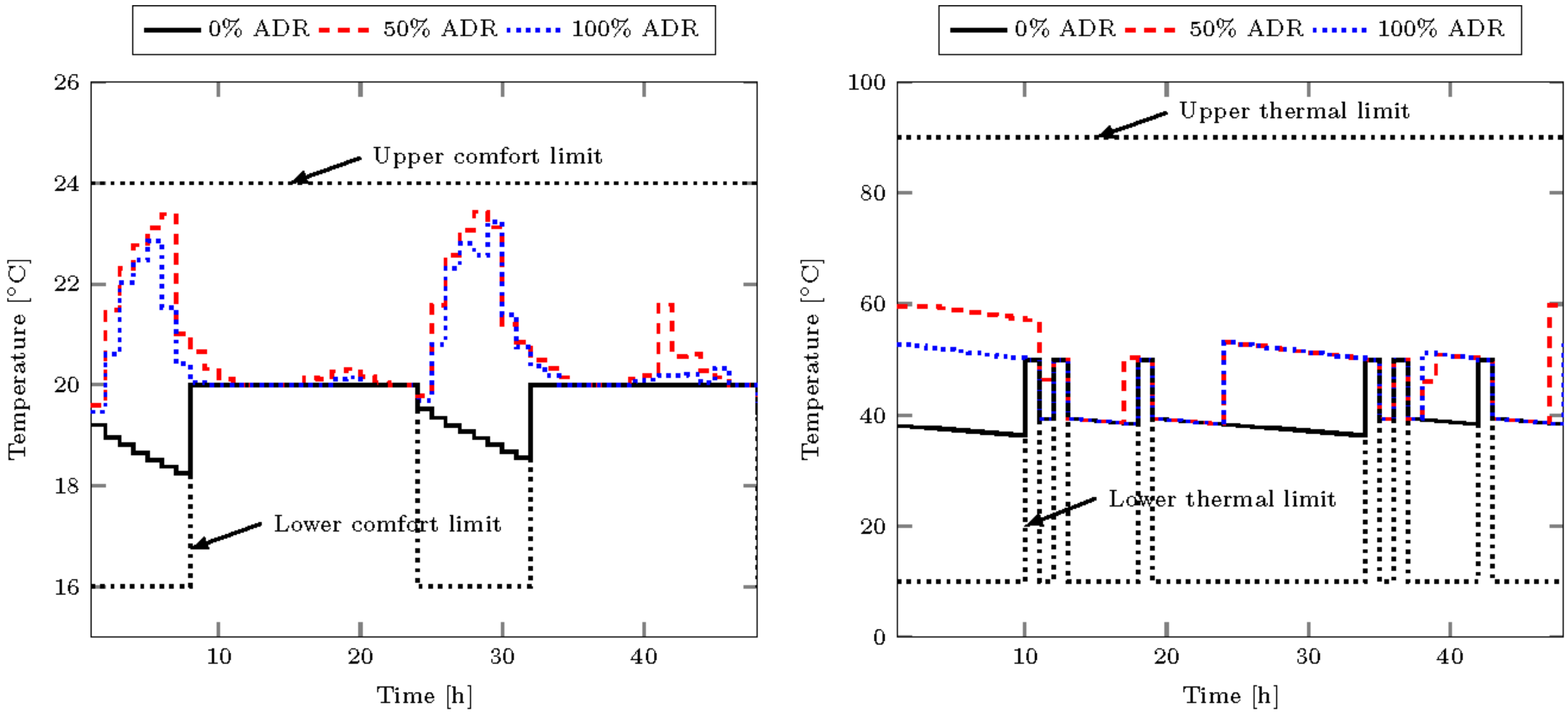
The residual electricity demand (left) and electricity price (right) in three cases of ADR participation (0%, 50%, 100%).

An integrated model: a third example



Output of the committed power plants in case of 0% (left) and 50% (right) ADR participation.

An integrated model: a third example

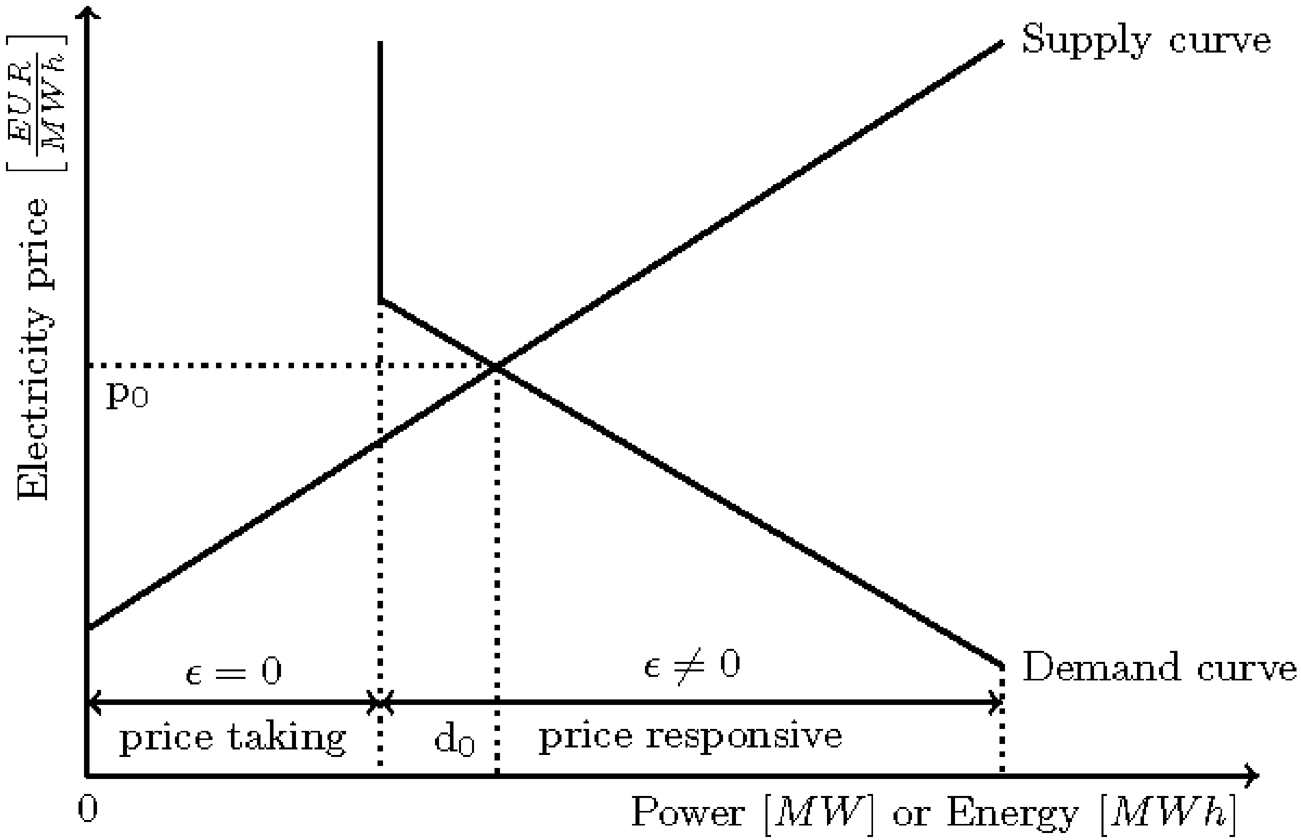


Building indoor temperature (left) and DHW temperature (right) over the two simulated days under different ADR participation.

An integrated model: added value

1 w.r.t to price-elasticity models

Supply side focus



$$\epsilon_{u,k} = \frac{\delta d_u}{\delta p_k} \cdot \frac{p_{0,k}}{d_{0,u}}$$

p_k The price of electrical energy in hour k

d_u The demand for electrical energy in hour u

Schematic representation of the partly elastic, partly inelastic demand.
The intersection of the demand and supply curves yields the anchor points (index 0) for the elasticity calculation.

An integrated model: added value

2 w.r.t to virtual generator models

Supply side focus

- Schedule and dispatch an equivalent generator or energy storage system with a negative output;
- This virtual generator or energy storage system is governed by

$$E_t = E_{t-1} - \Delta T \cdot \dot{L}_t - \Delta T \cdot \dot{D}_t + \Delta T \cdot \dot{I}_t + \Delta T \cdot \dot{G}_t$$

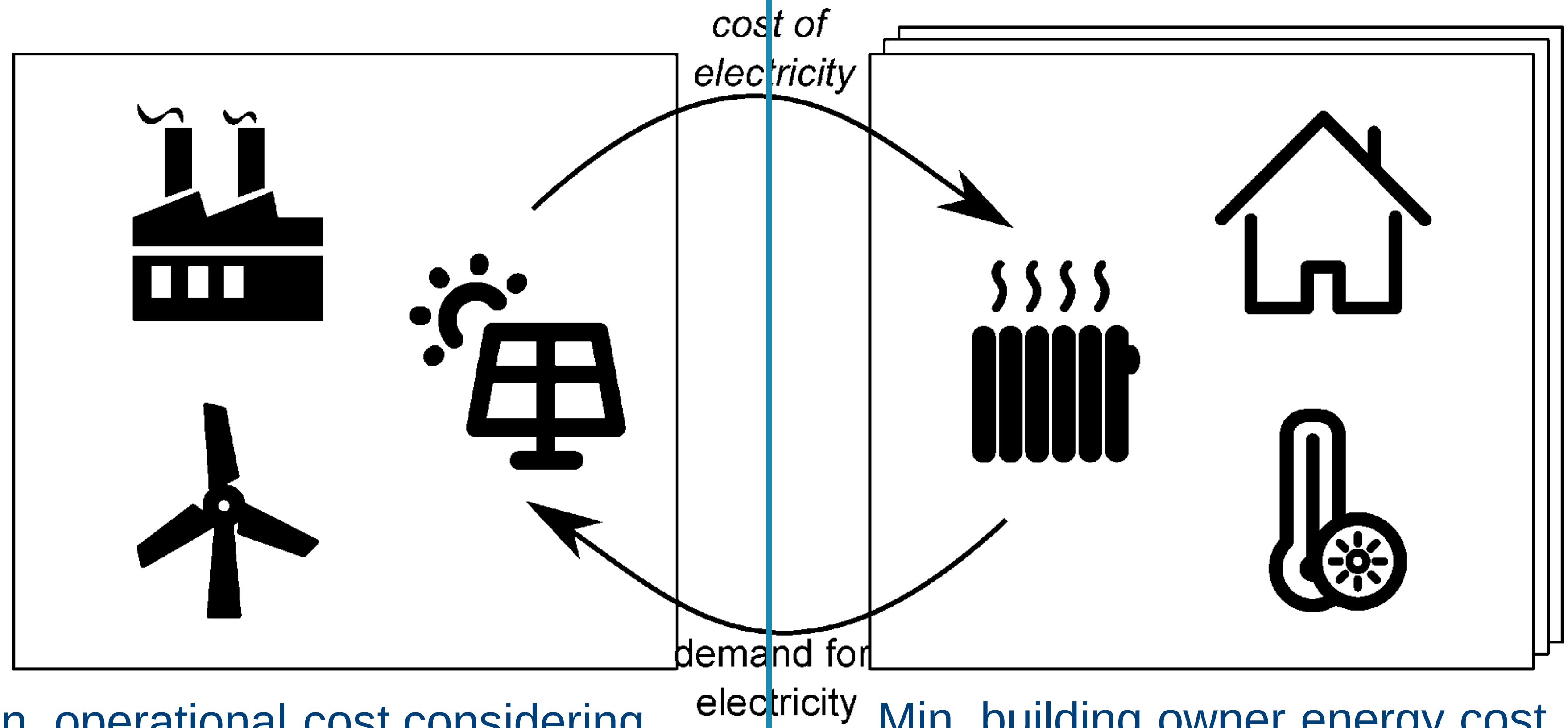
- E_t: Energy content
- $\dot{L}_t$: Loss term, related to efficiency of storage
- $\dot{D}_t$: Demand, e.g. for thermal energy services
- $\dot{I}_t$: Stored energy
- $\dot{G}_t$: Gains

- Efficiency, gains and demand for thermal services are difficult to predict ex-ante and highly dependent on user behavior and boundary conditions (e.g. external temperature)

An integrated model: added value

3 w.r.t to price profile representations

Demand side focus



Min. operational cost considering fixed electricity demand

Min. building owner energy cost considering fixed electricity price profile

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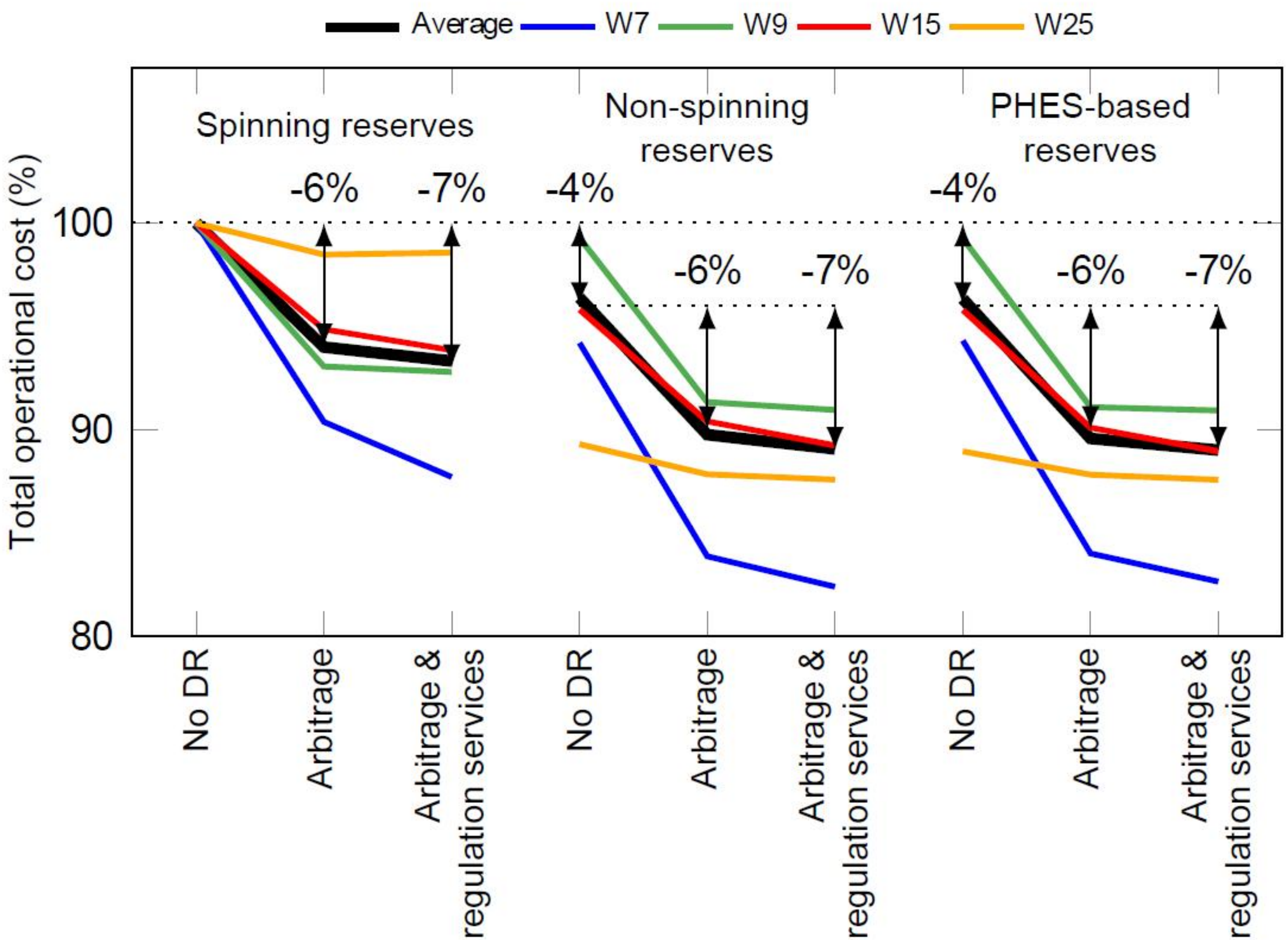
Value of DR-based arbitrage and regulation services



From: K. Bruninx, Improved modeling of unit commitment decisions under uncertainty, PhD thesis, KU Leuven, 2016.

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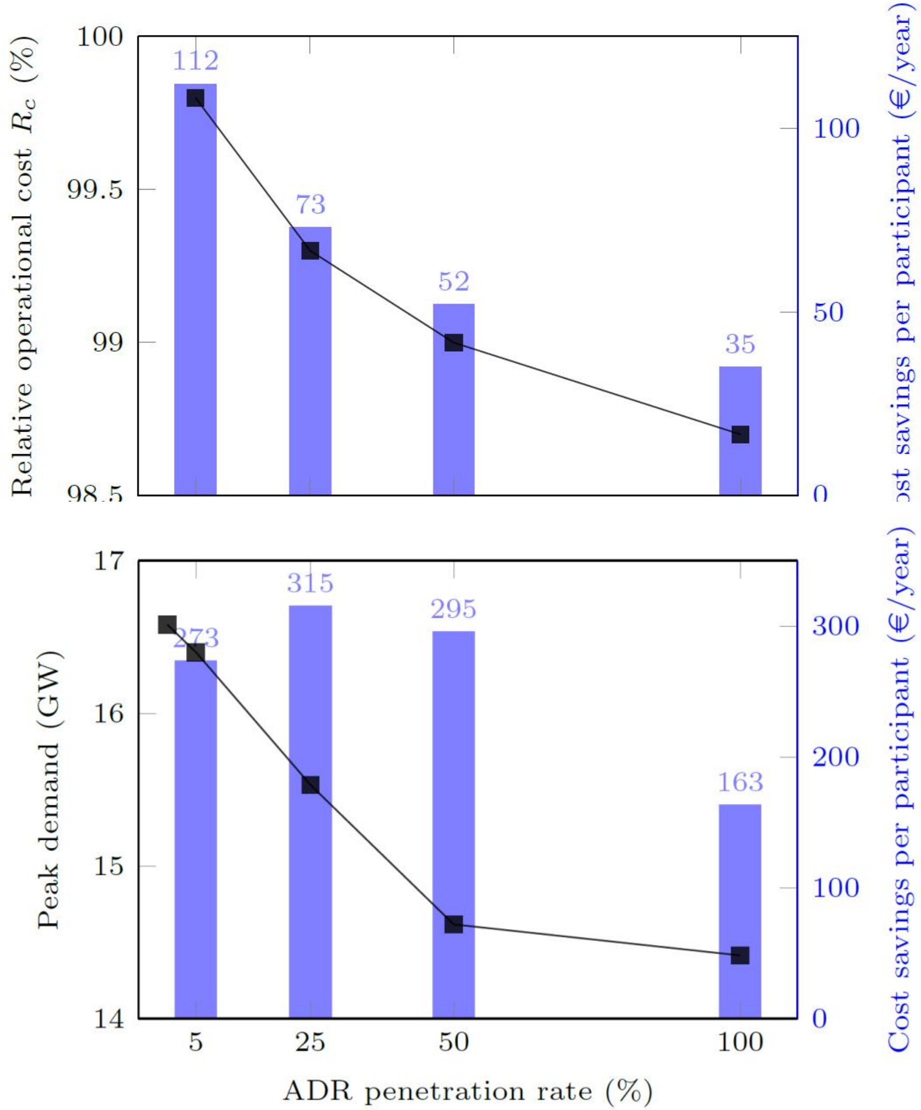
Impact of the market penetration on the value of DR

Decrease in operational cost:

- Operational cost decreases as penetration of ADR increases, but average benefit per consumer decreases.

Deferred investment in additional power plant capacity:

- Deferred investment 'saturates': additional, 'similar' flexibility during critical winter weeks does no longer reduces peak demand.



A. Arteconi et al., Active demand response with electric heating systems: impact of market penetration, Applied Energy, 2016

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Conclusion

1 **Integrated modelling framework**

- Operational demand and supply side model formulated using MILP
- More accurate representation w.r.t. other methods
  - Merit order model provides valuable results at much lower computational cost
- Myriad of applications possible

2 **Demand response with heat pumps**

- Could hold significant environmental and economical advantages: operational cost savings, (additional) peak demand reduction, cost-effective regulation services

3 **Future work**

- Impact on heating system design
- Accounting for limited controllability of DR-adherent heat pumps
- Heterogeneity of DR-loads, user behavior, building types
- Accounting for uncertainty
- Conflicting objectives building owner – system operator
- Long term system adequacy

Further reading

[1] Patteeuw et al., *Integrated modeling of active demand response with electric heating systems coupled to thermal energy storage systems*, Applied Energy 151, pp. 306-319, 2015.

[2] Patteeuw et al., *CO2-abatement cost of residential heat pumps with Active Demand Response: demand-and supply-side effects*, Applied Energy 156, pp. 490-501, 2015.

[3] A. Arteconi et al., *Active demand response with electric heating systems: impact of market penetration*, Accepted for publication in Applied Energy, 2016.

[4] K. Bruninx, E. Delarue (co-supervisor) and W. D'haeseleer (supervisor), *Improved modeling of unit commitment decisions under uncertainty*, PhD thesis, KU Leuven, May 2016.

[5] D. Patteeuw and L. Helsen (supervisor), *Demand response for residential heat pumps in interaction with the electricity generation system*, PhD thesis, KU Leuven, September 2016.

Thank you for your attention!

- EERA JP on Energy Systems Integration
  SP5 “Finance and Regulation”
  - Markets, financing, policies and regulation
  - Closely linked to modeling
  - E.g., interaction effects between polcies, actual beneficiaries of subsidies for distributed generation (e.g. rooftop solar PV)
    - Spillover effects, cross border effects, national versus EU-wide effects

- Interested?
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