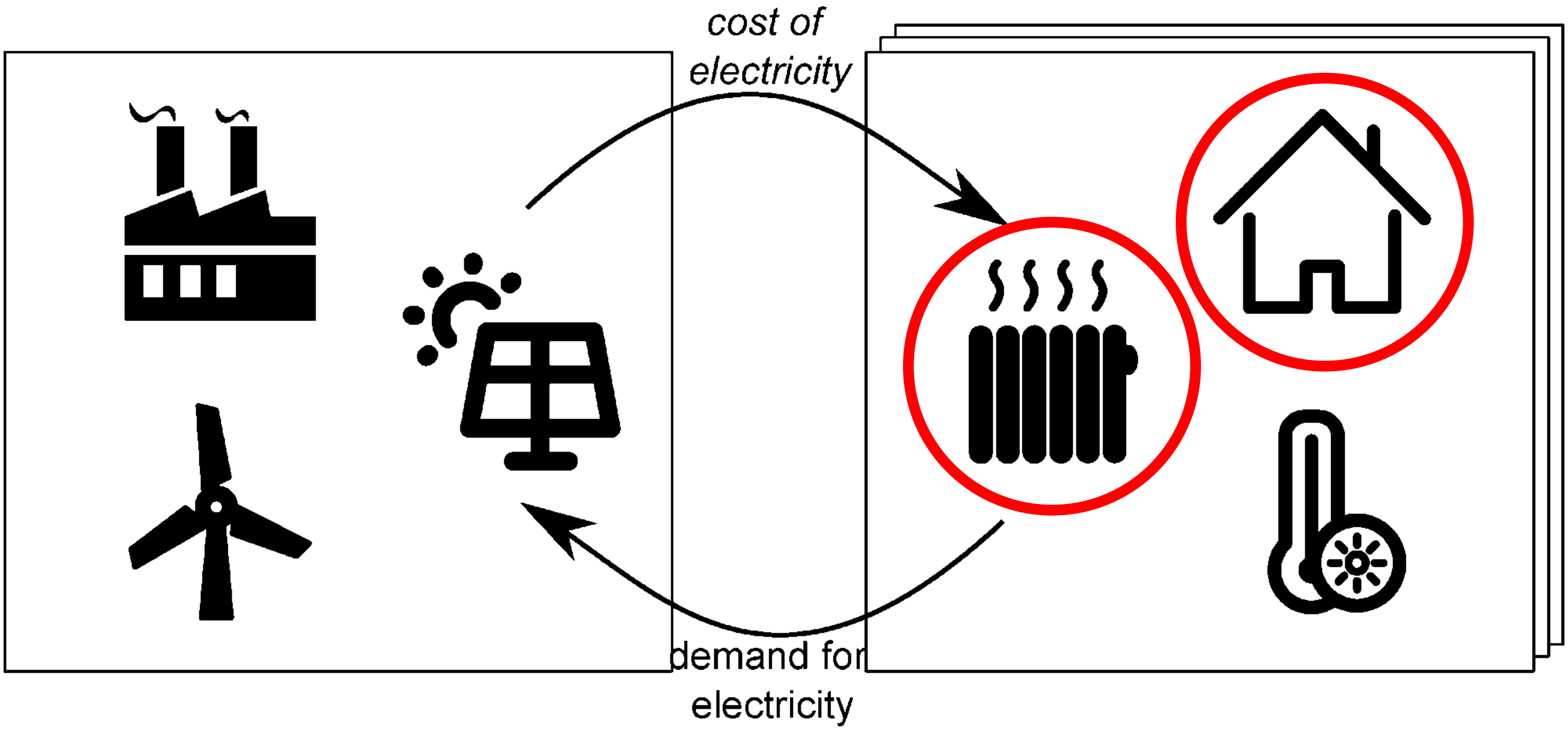
Integrated modeling of active demand response with electro-thermal systems

Dieter Patteeuw, Kenneth Bruninx, Alessia Arteconi, Erik Delarue, William D'haeseleer and Lieve Helsen

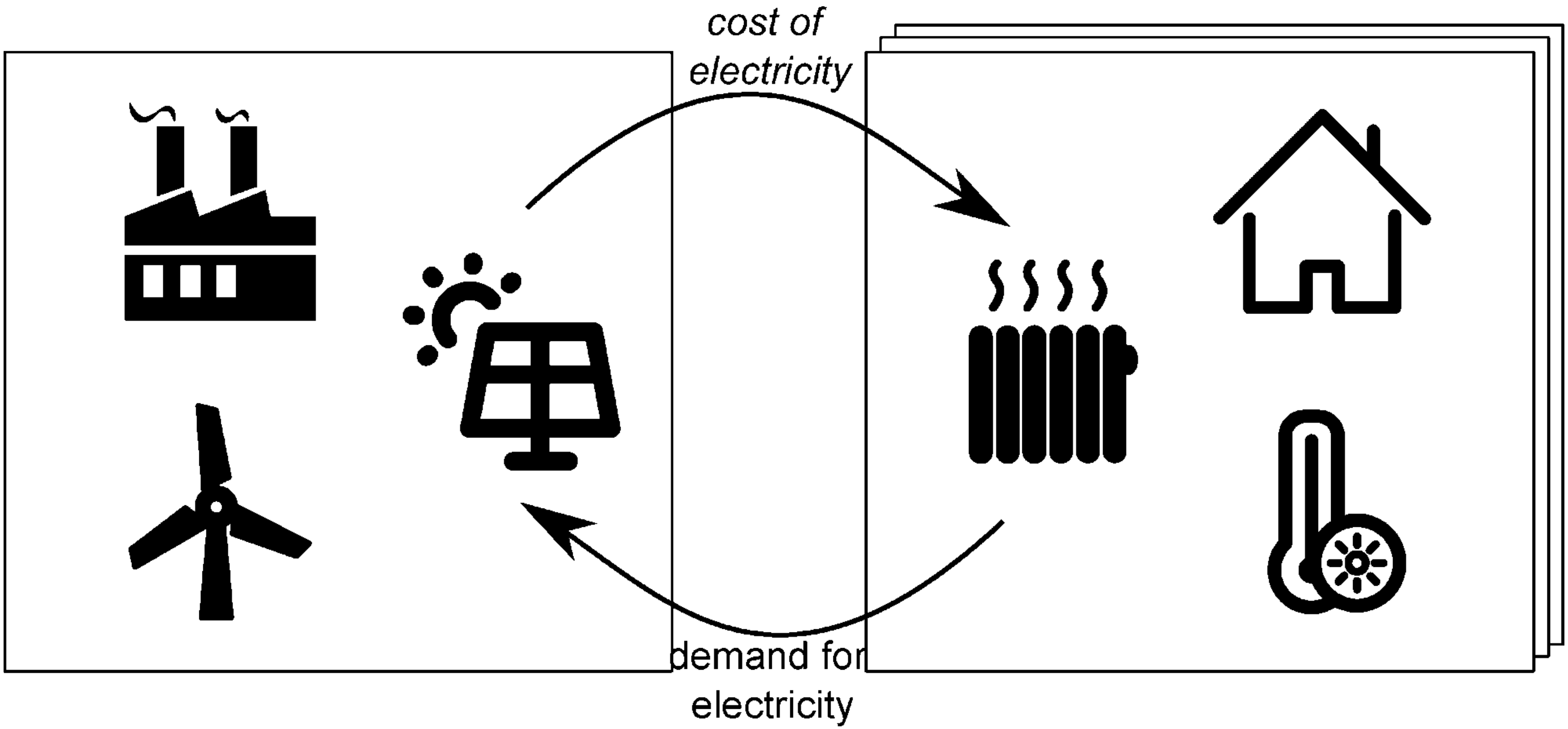
Scope & motivation



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 Conclusion

Outline

2 **Modeling challenges & issues**

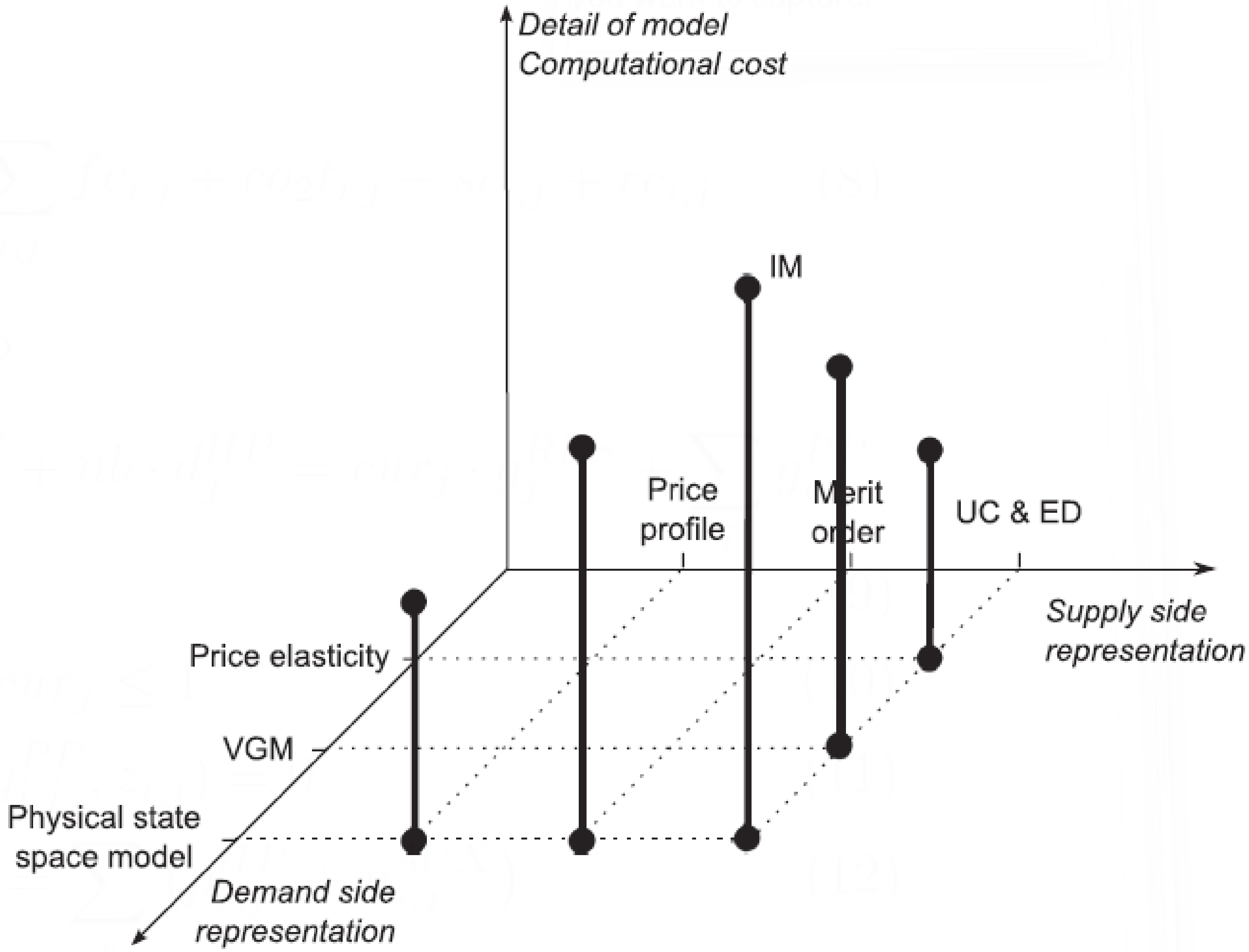
Modeling approaches in the scientific literature

Integrated model & its added value

Based on:

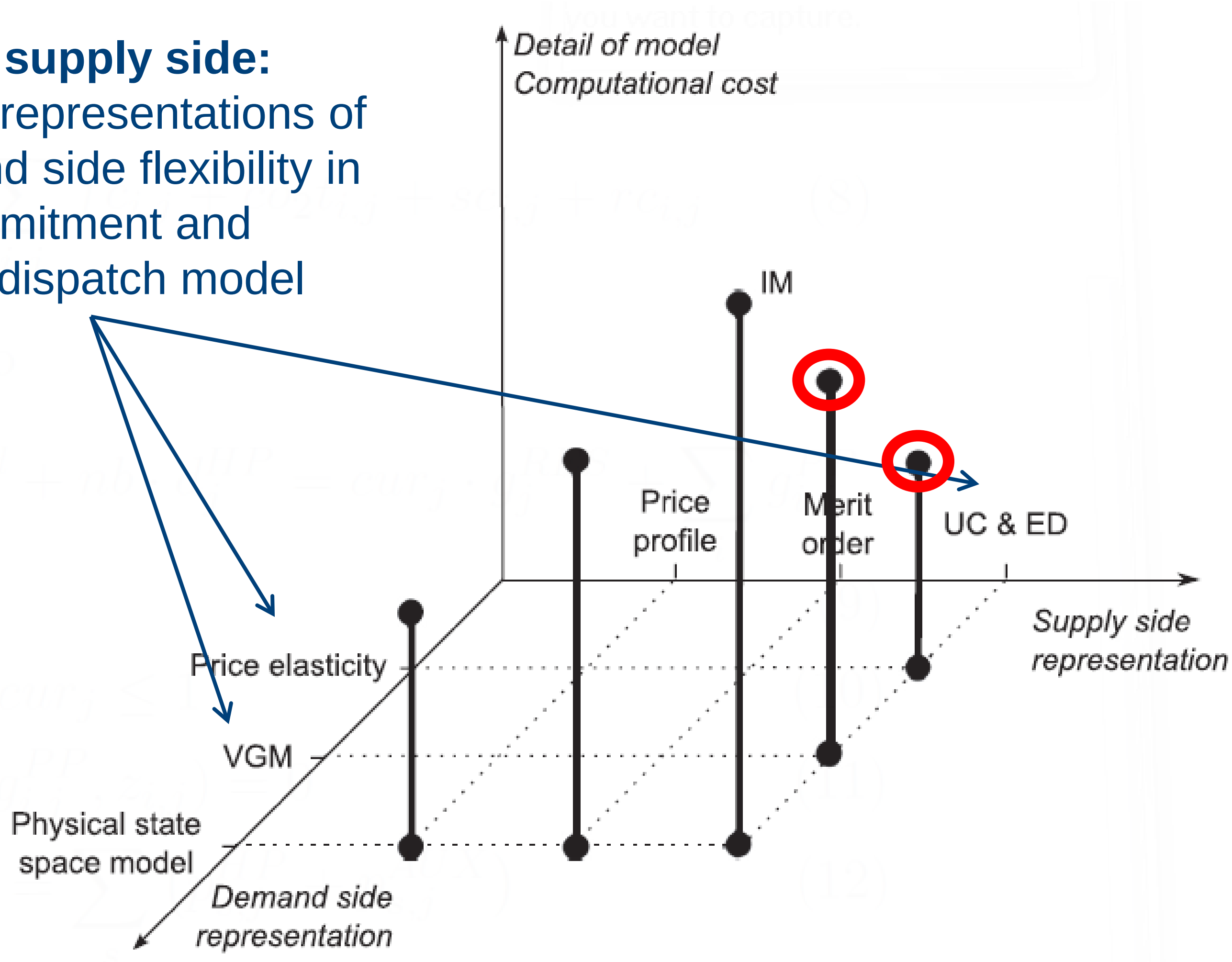
Patteeuw et al. "Integrated modeling of active demand response with electric heating systems coupled to thermal energy storage systems," Applied Energy 151, pp. 306-319, 2015.

Modeling challenges & issues

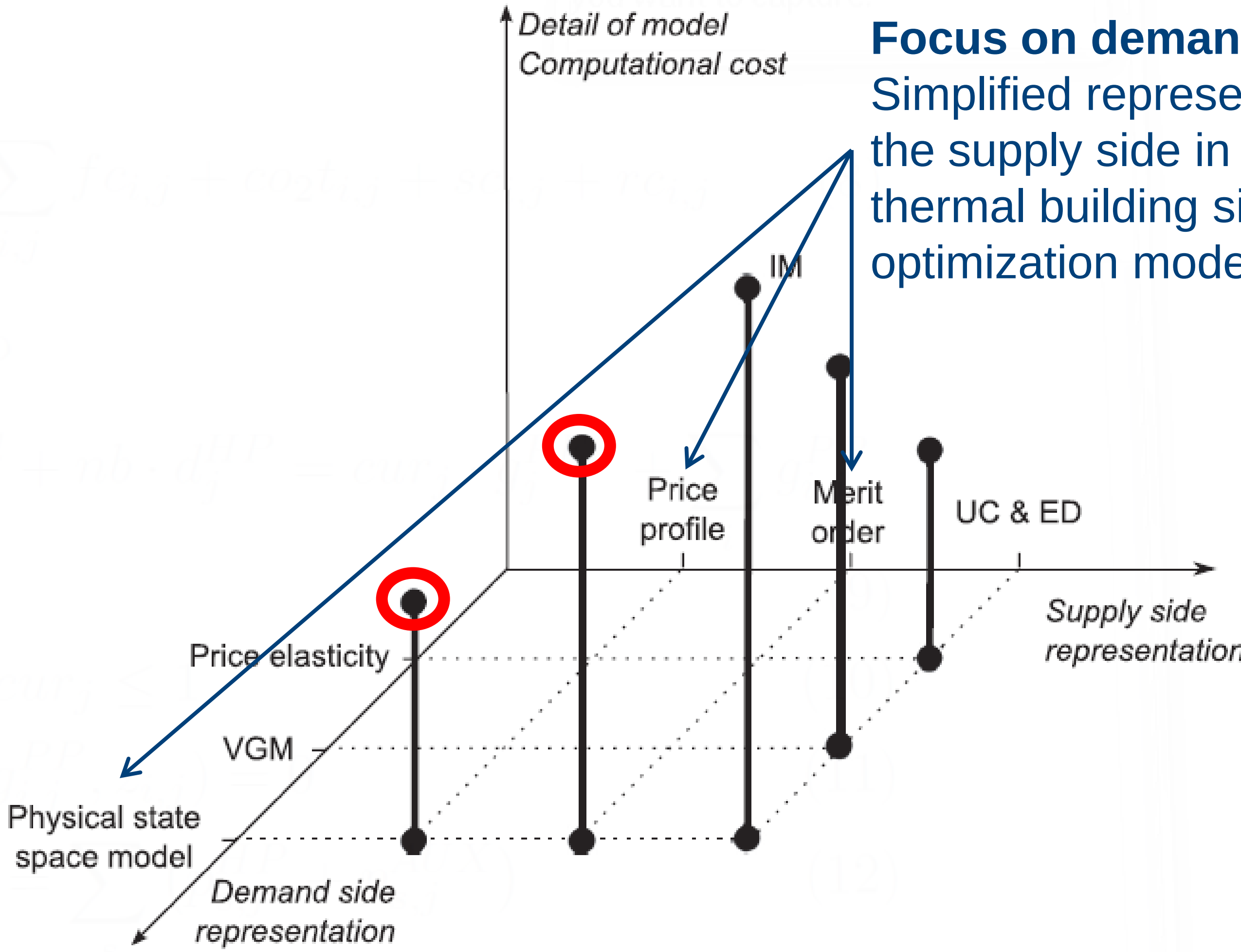


Modeling challenges & issues

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



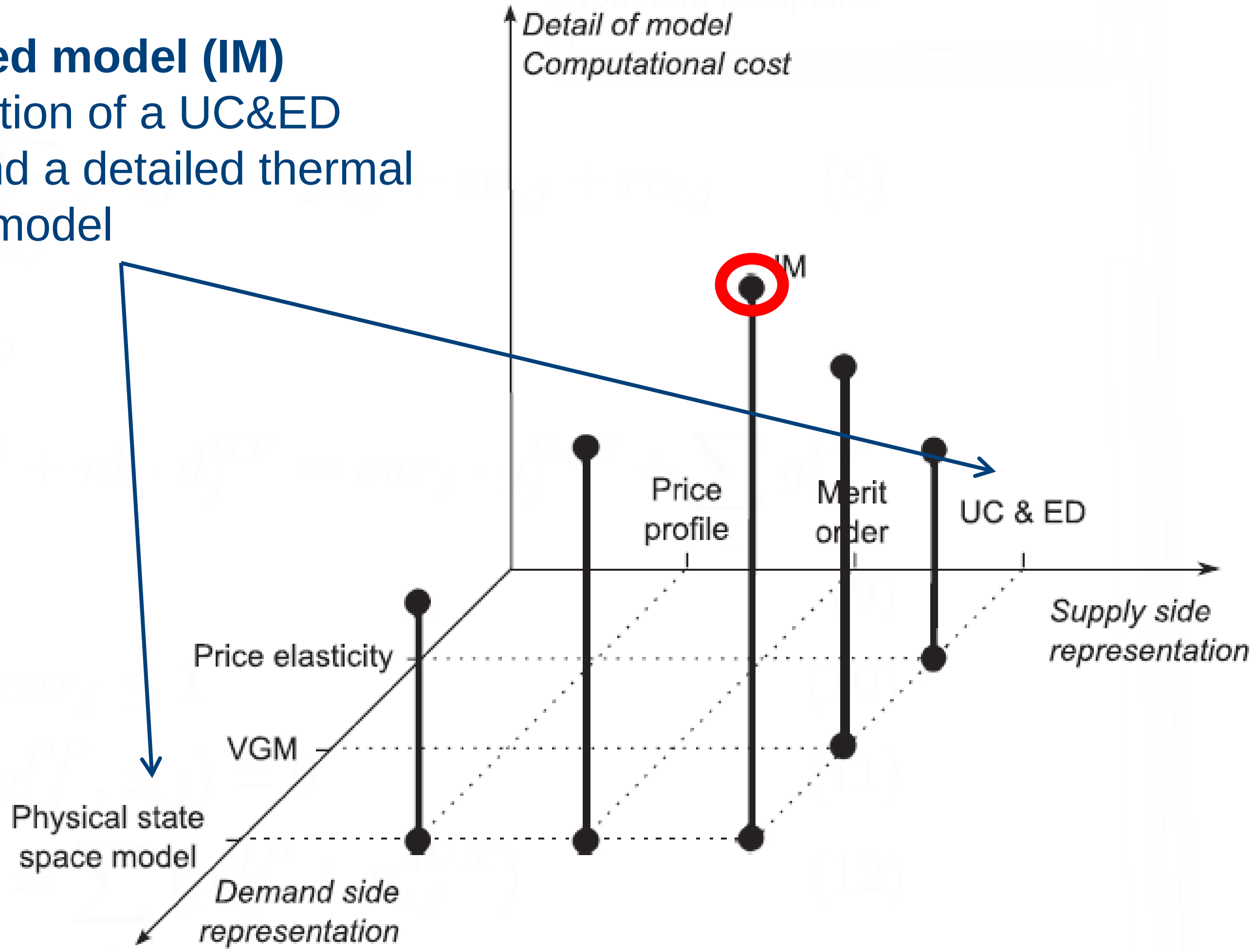
Modeling challenges & issues



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

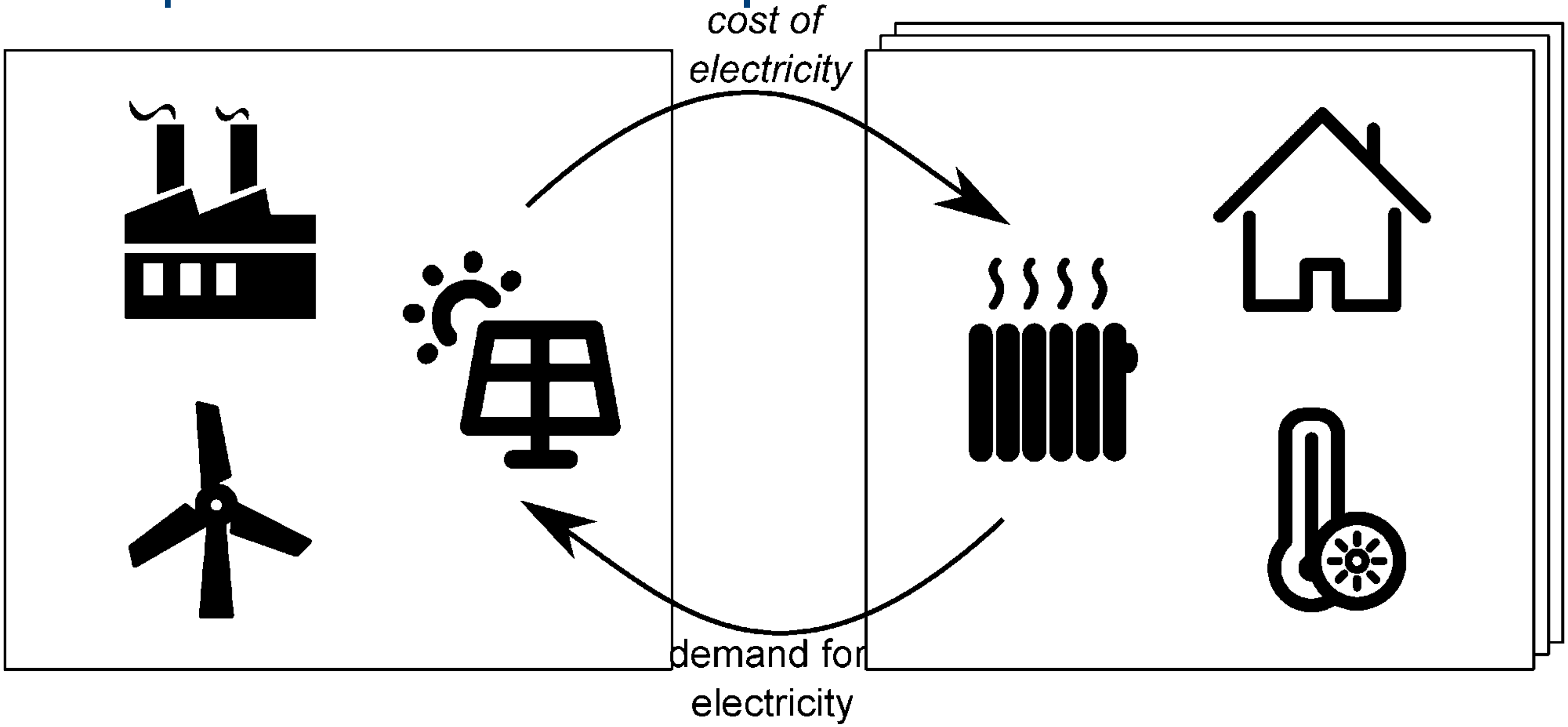
Modeling challenges & issues

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



An integrated model

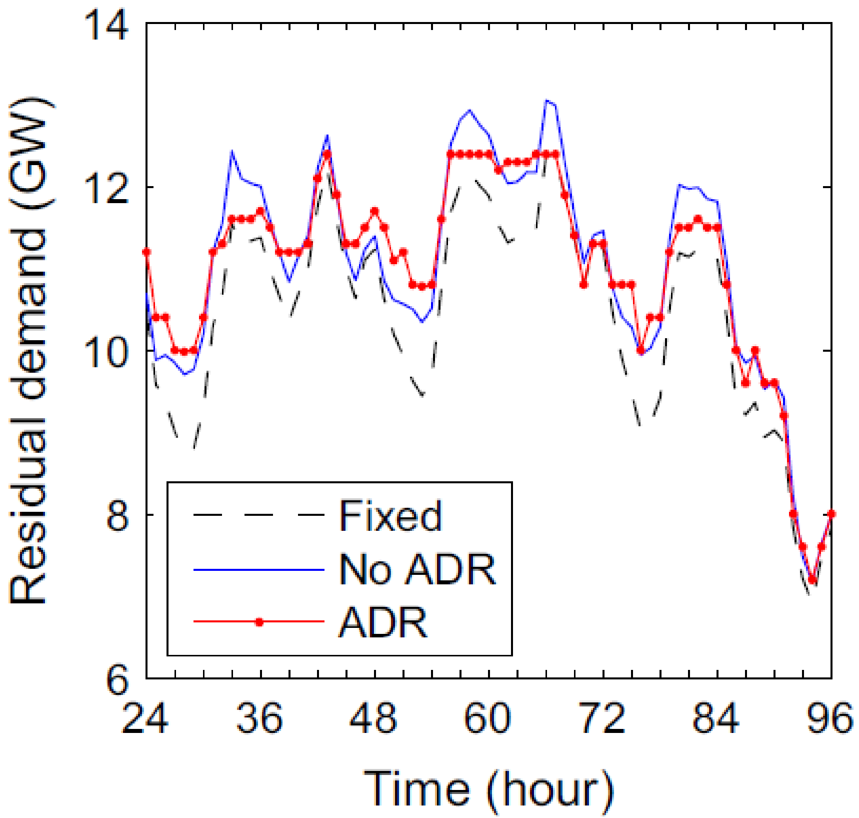
Joint optimization: minimize total operational cost

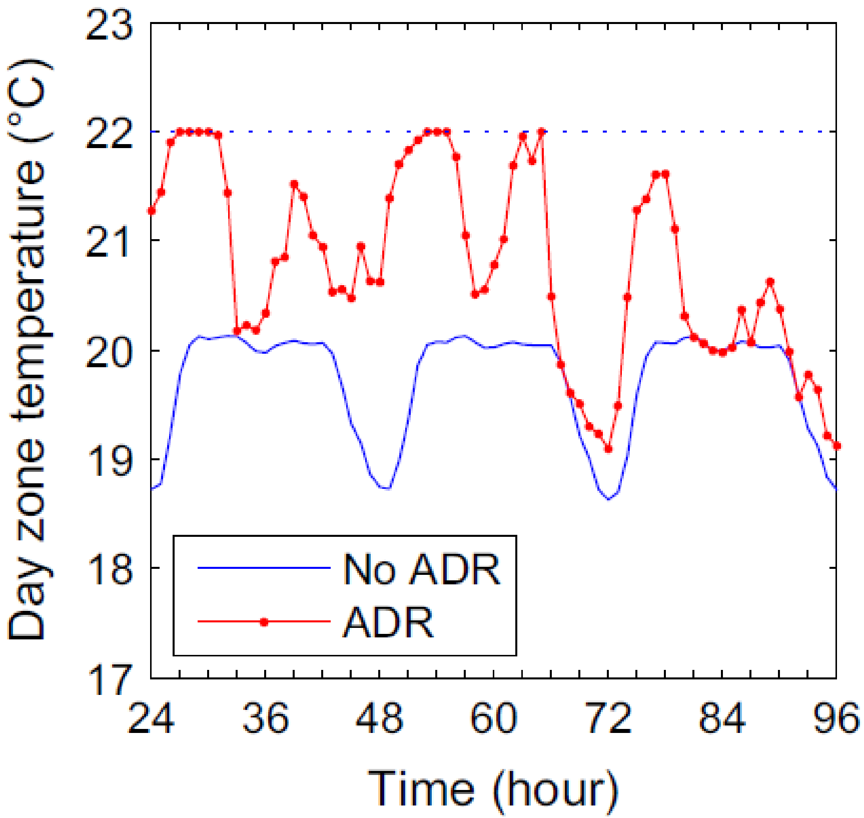


UC & ED model, considering set of power plants, RES-based generation and a fixed demand profile (MILP)

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

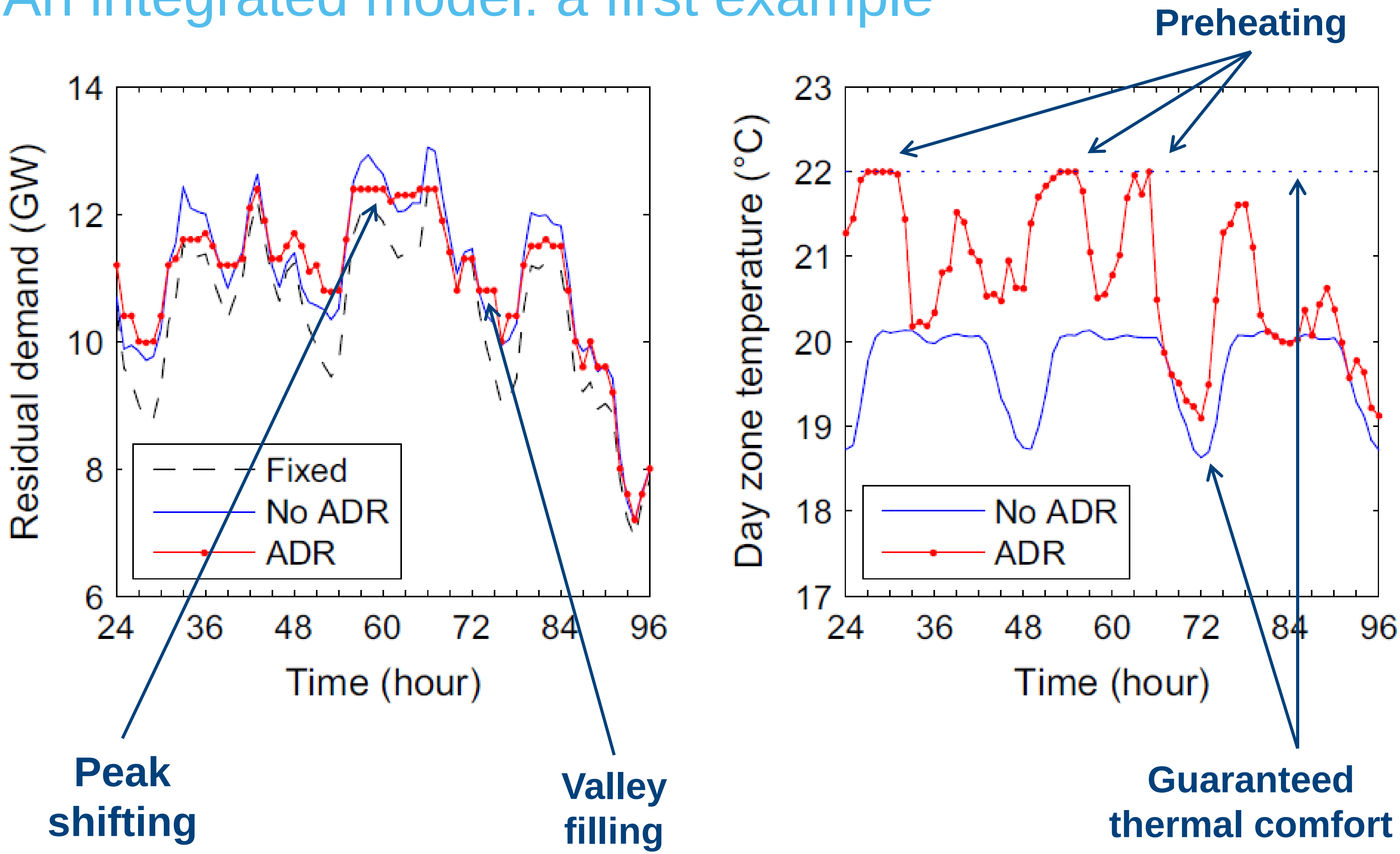
An integrated model: a first example



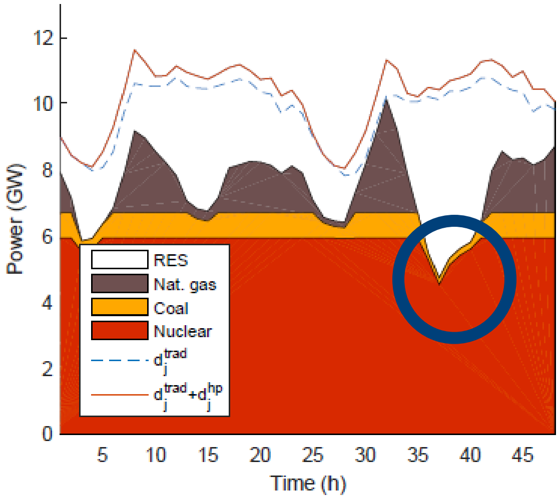


- Power system inspired on possible future setting of BE power system;
- 250,000 heat pumps;
- Building properties represented via an ‘average’ building (detached dwelling);
- 52 user behavior profiles.

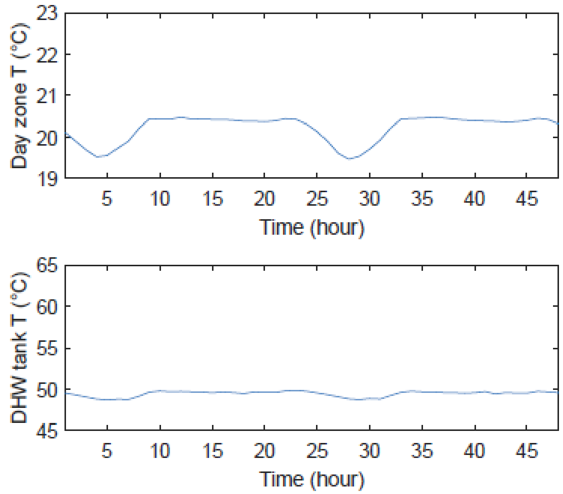
An integrated model: a first example



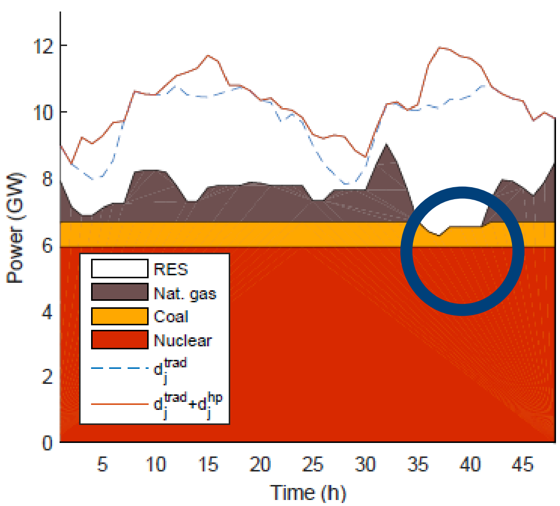
An integrated model: a second example



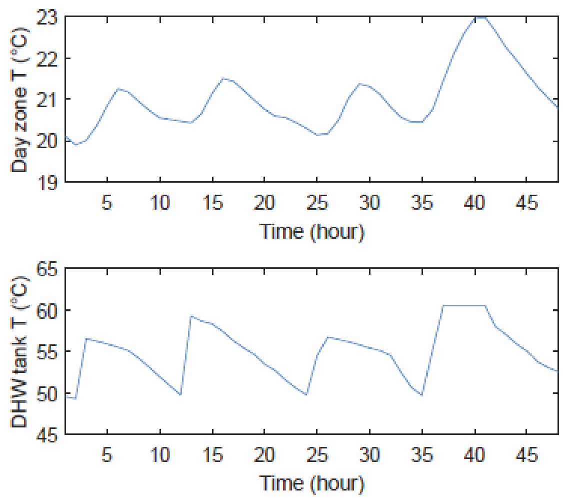
(a) Electricity generation, no DR



(b) Mean temperatures, no DR



(c) Electricity generation, with DR

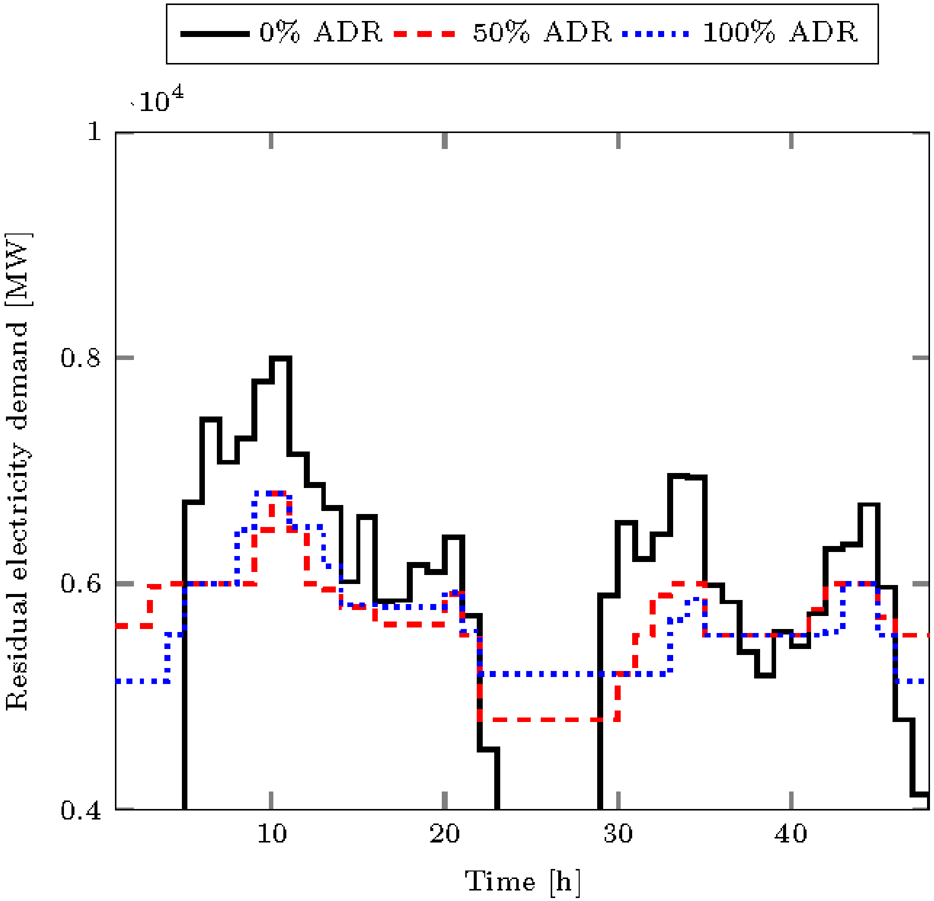


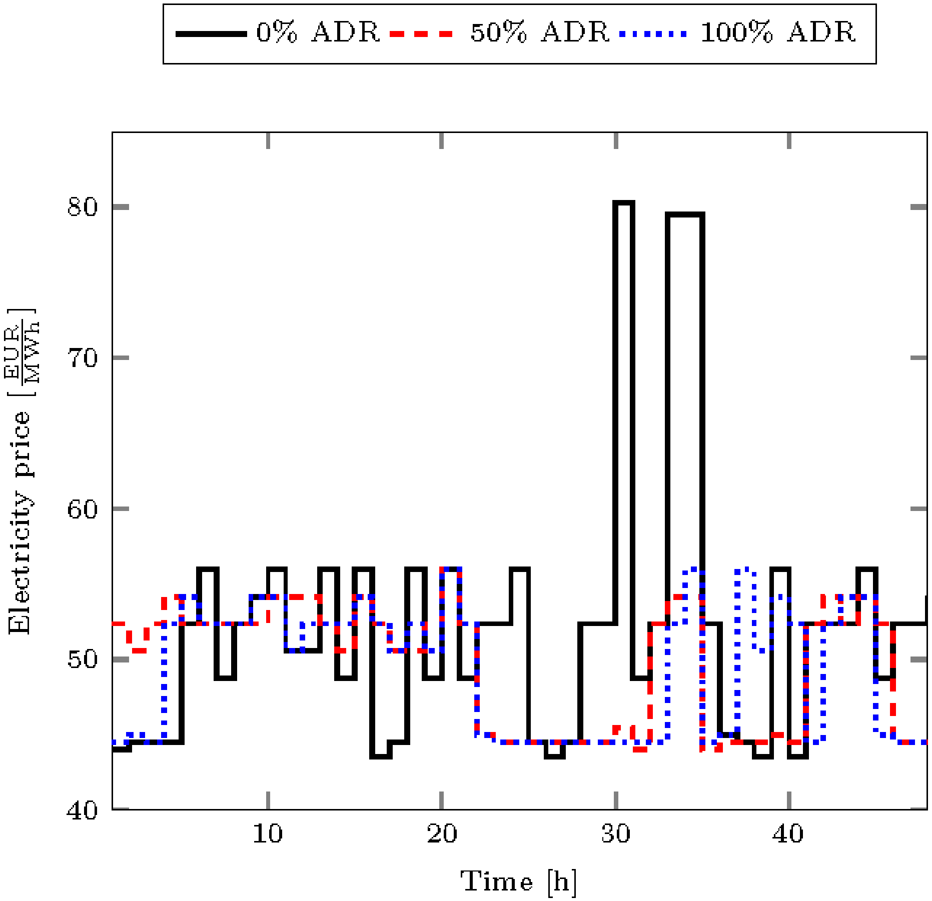
(d) Mean temperatures, with DR

<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.

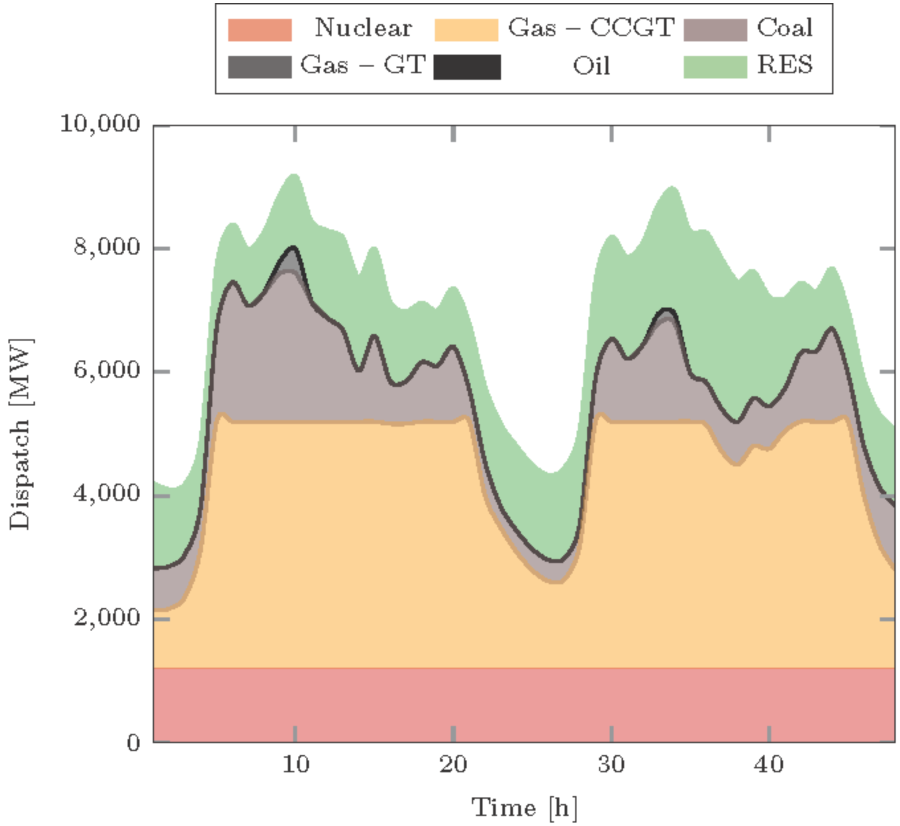
An integrated model: a third example

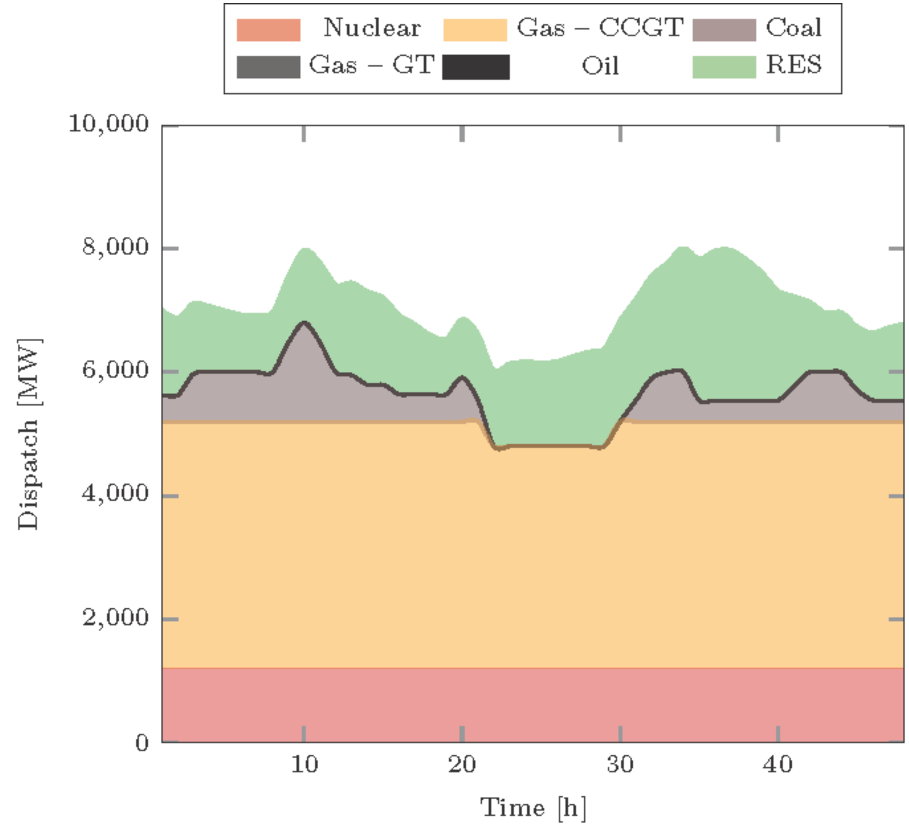




The residual electricity demand (left) and electricity price (right) in three cases of ADR participation (0%, 50%, 100%).

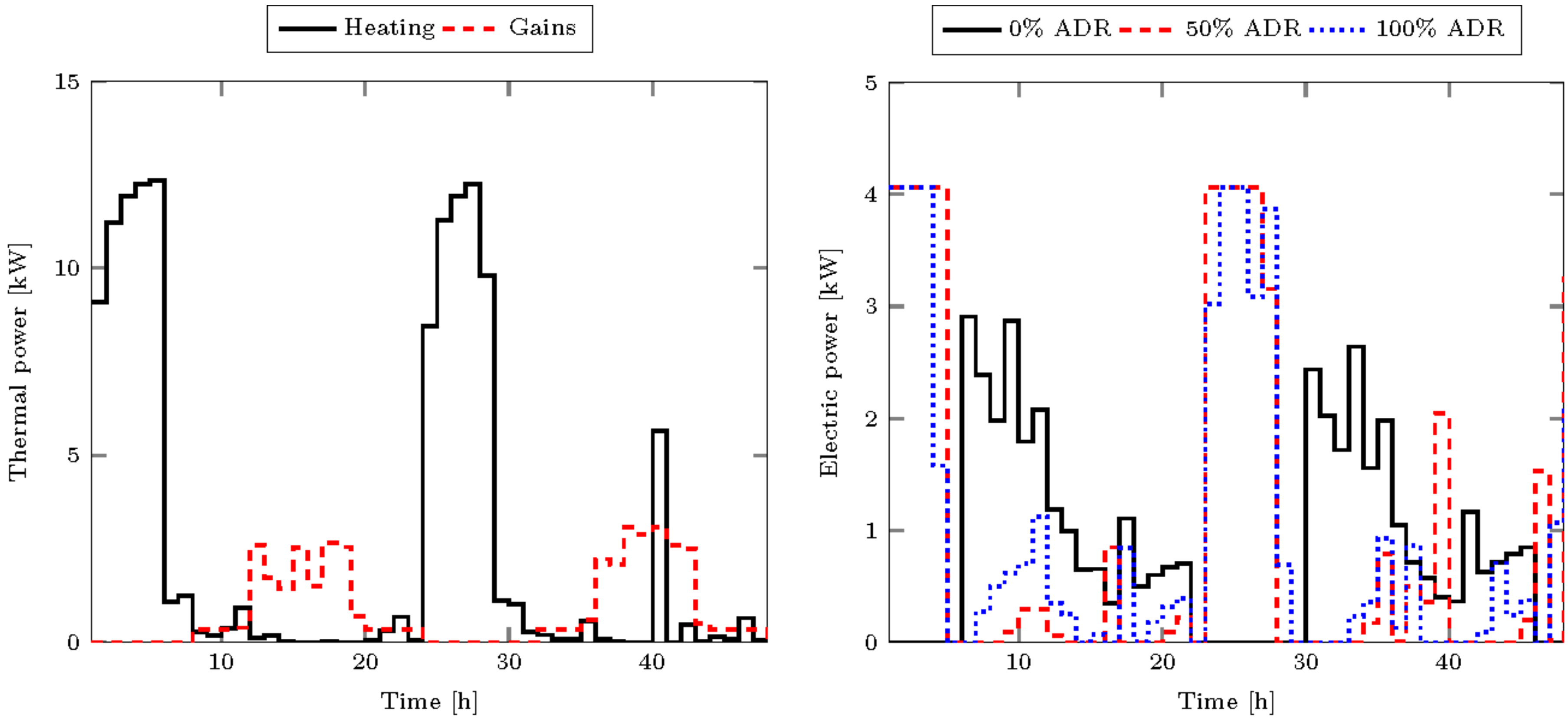
An integrated model: a third example





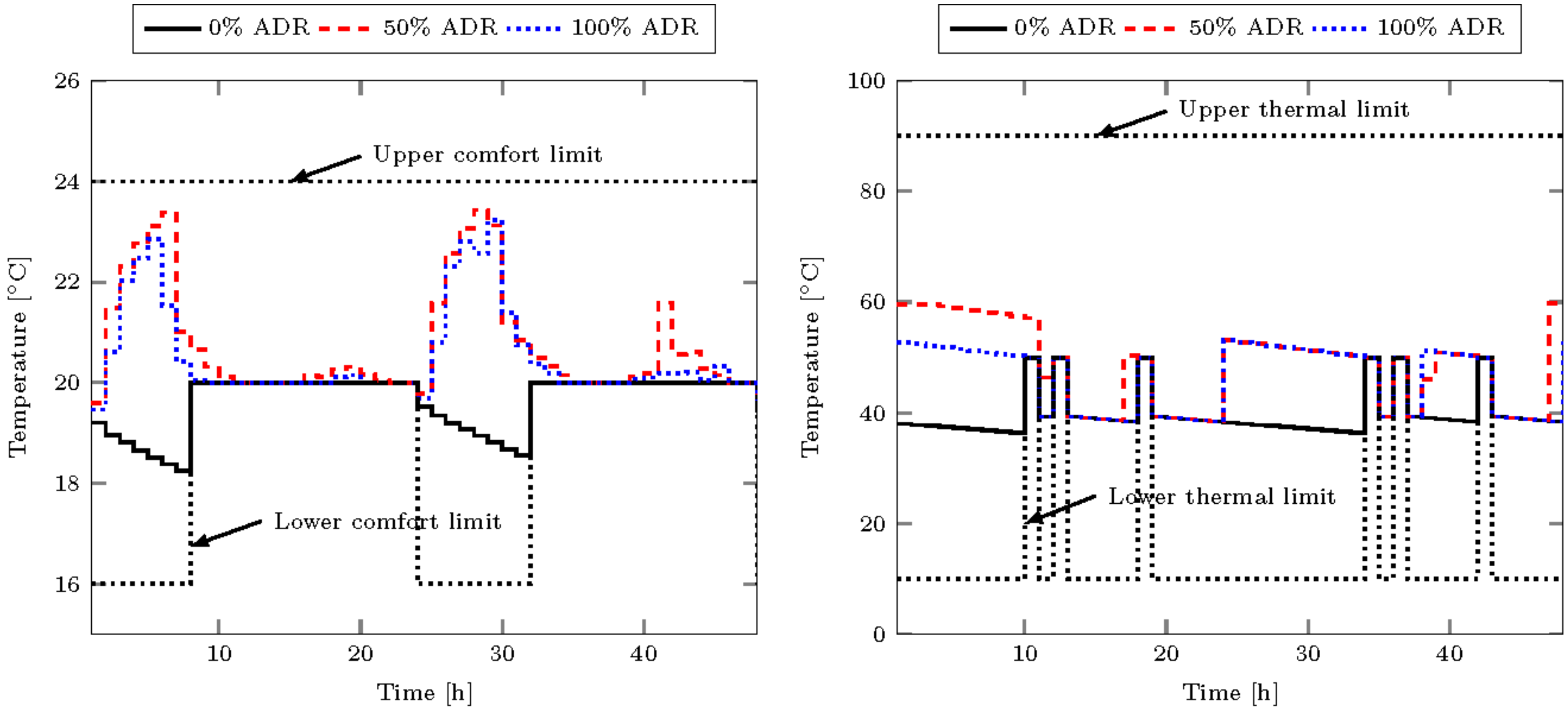
Output of the committed power plants in case of 0% (left) and 50% (right) ADR participation.

An integrated model: a third example



The thermal and electrical power supplied to one of the dwellings on the two simulated days. Left: Breakdown of the thermal power supplied to a building (50% ADR participation. Right: Electricity demand of the heating system of a single building.

An integrated model: a third example



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

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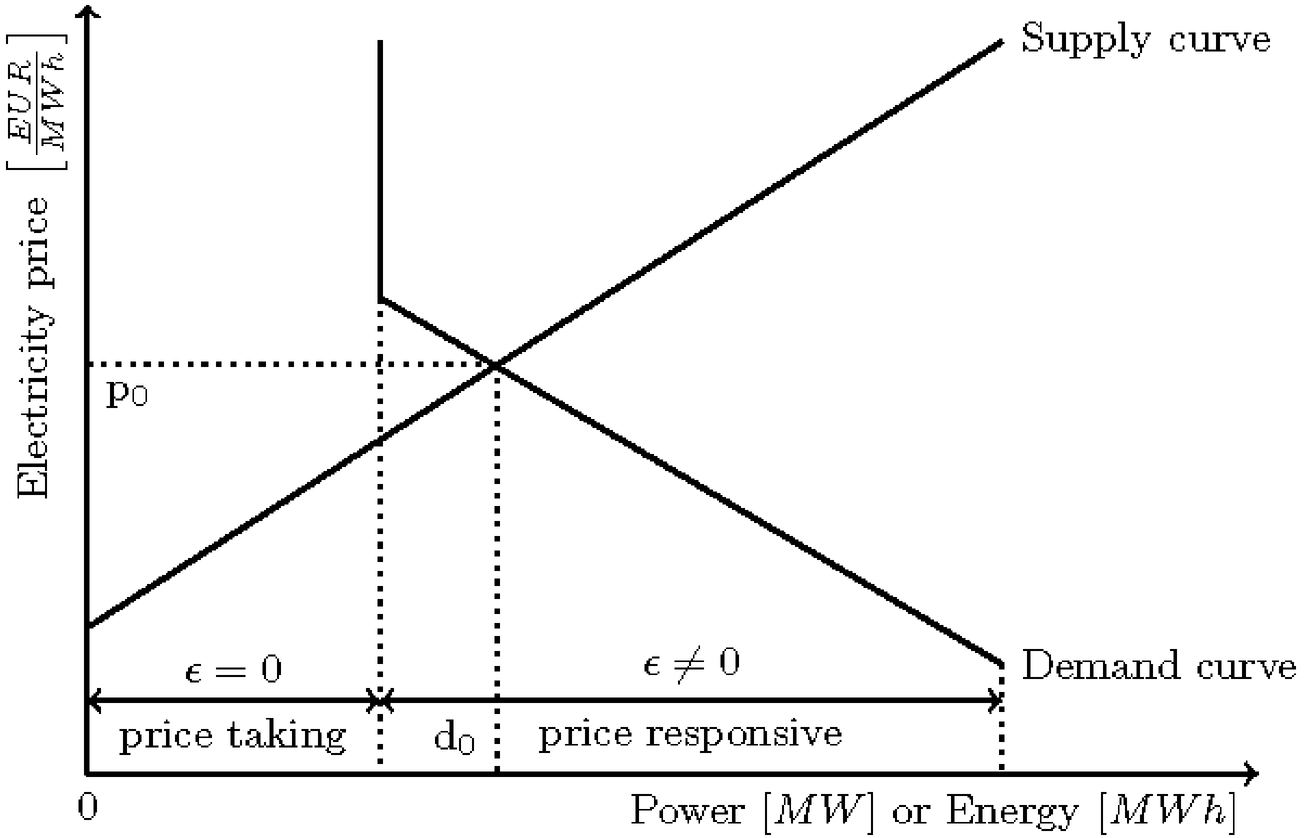
An integrated model: added value

1 w.r.t to price-elasticity models

Supply side focus



$$\varepsilon_{u,k} = \frac{\partial d_u}{\partial p_k} \frac{p_{0,k}}{d_{0,u}}$$

p_k The price of electrical energy in hour k

d_u The demand for electrical energy in hour u

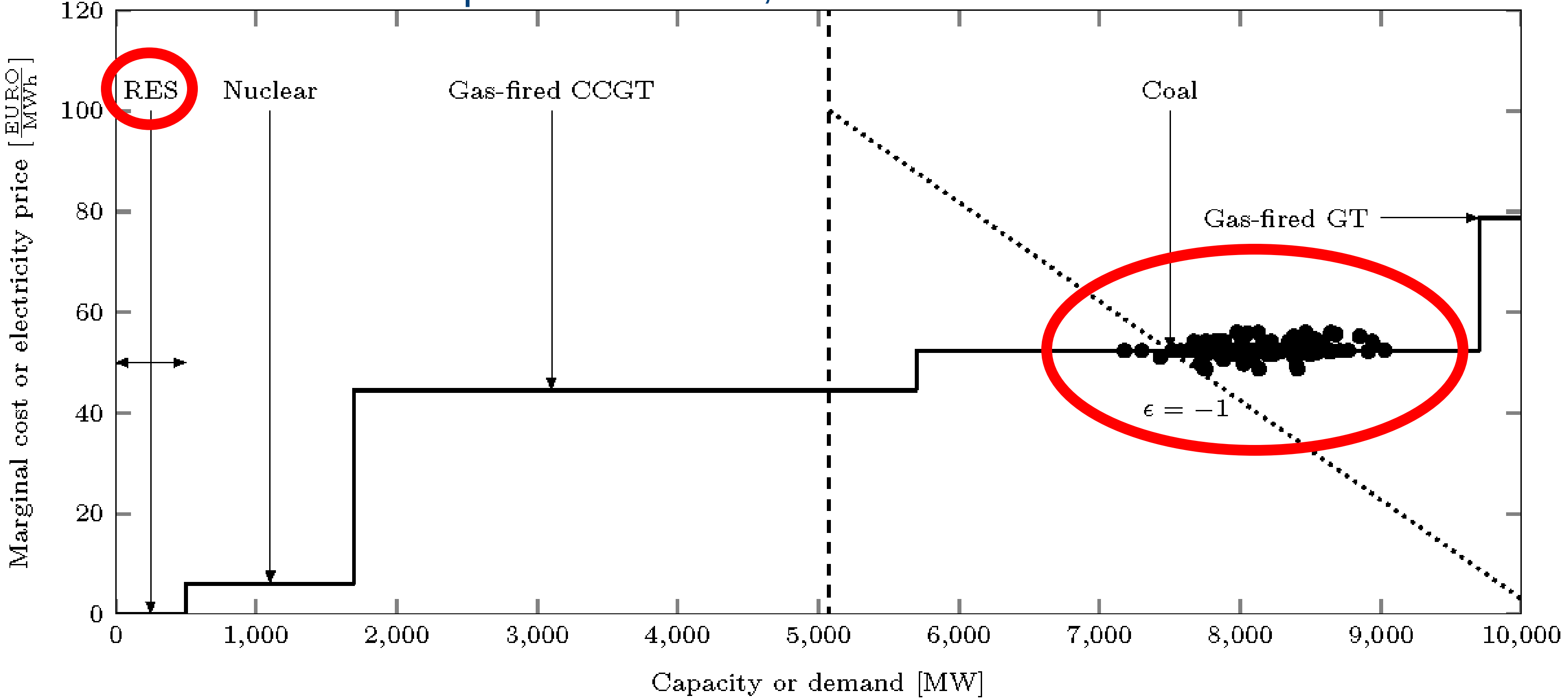
Schematic representation of the partly elastic, partly inelastic demand.
The intersection of the demand and supply curves yields the anchor points (index 0) for the elasticity calculation.

An integrated model: added value

1 w.r.t to price-elasticity models

Supply side focus

Price demand couples for hour 30; RES in hr 30 varies from 346 to 4099 MW



The resulting price-demand couples indicate that the price-responsiveness of thermal systems cannot be captured via an own-price elasticity.

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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

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

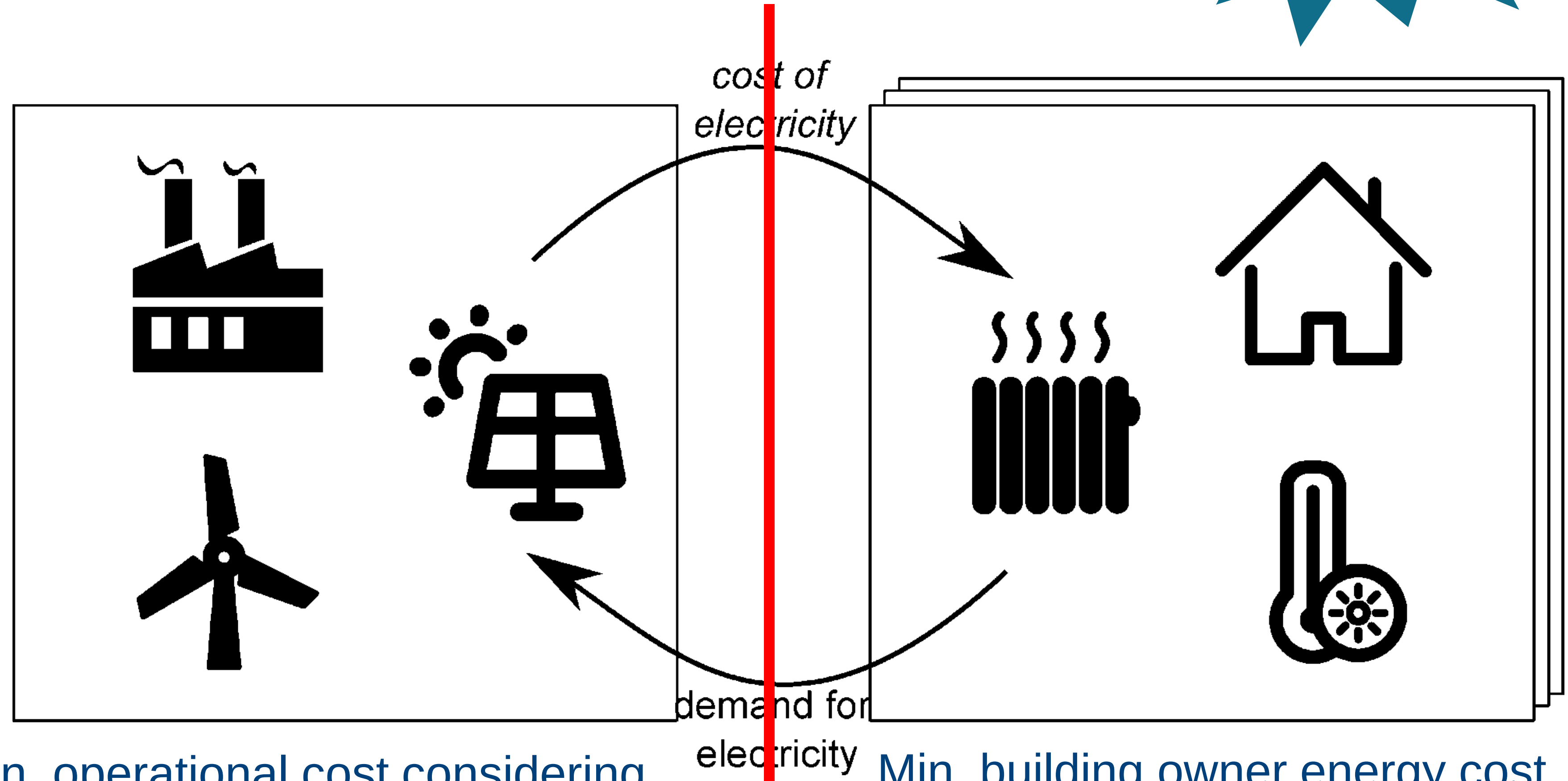
E_t	$\dot{L}_t$	$\dot{D}_t$	$\dot{I}_t$	$\dot{G}_t$
Energy content	Loss term, related to efficiency of storage	Demand, e.g. for thermal energy services	Input power for storage	Gains

- 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



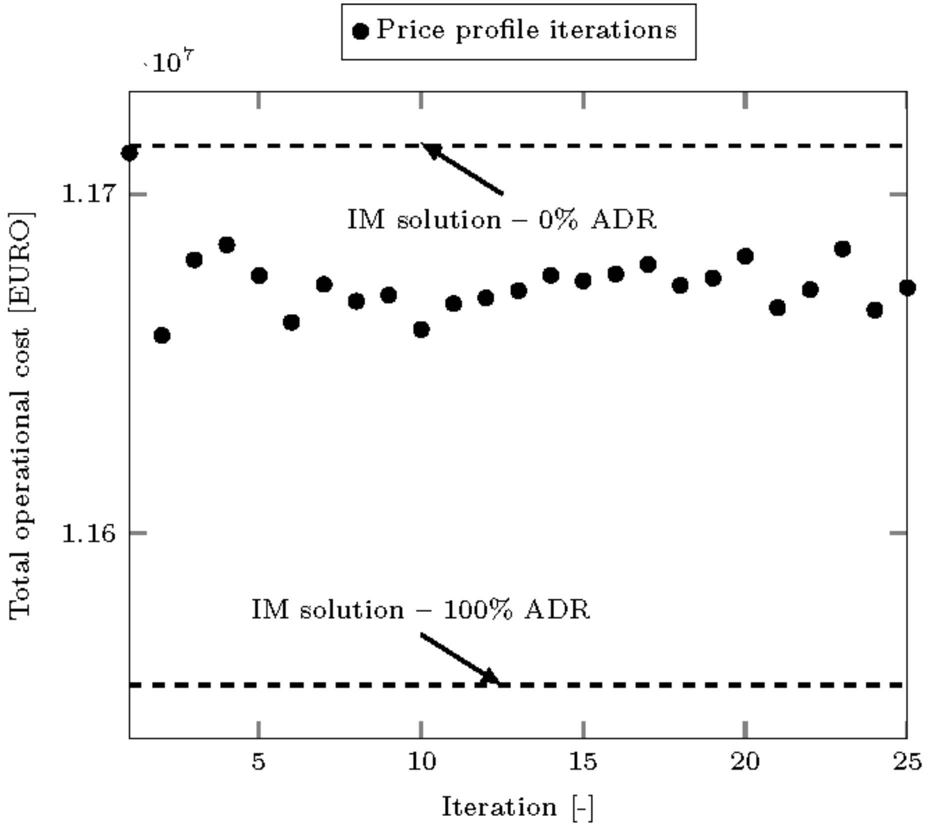
Min. operational cost considering fixed electricity demand

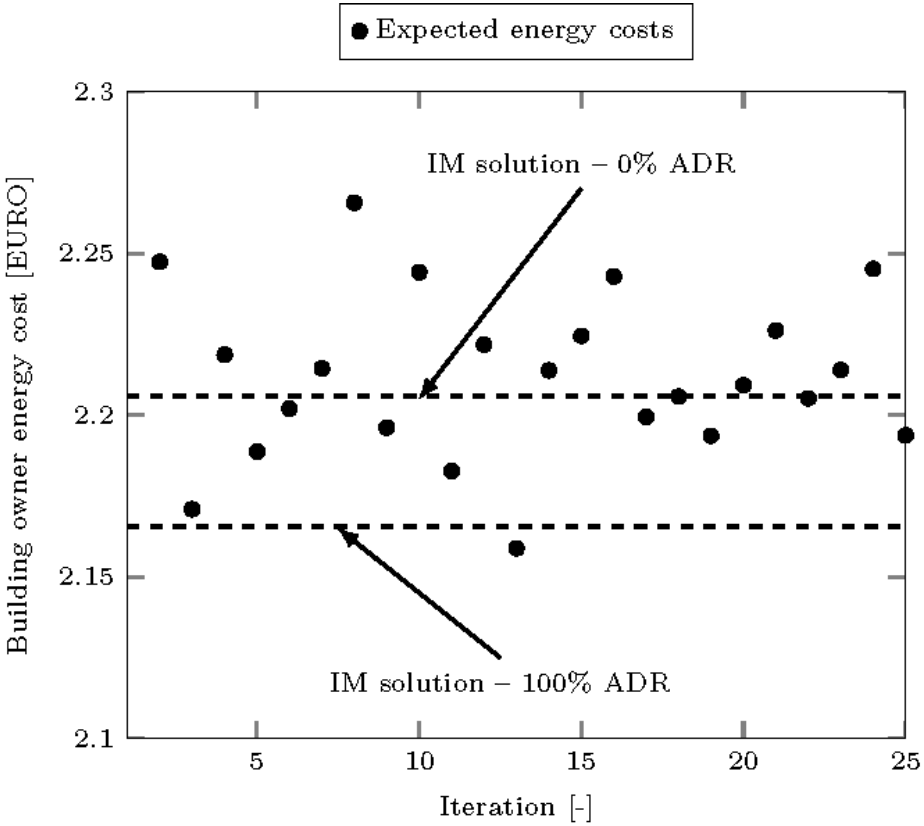
Min. building owner energy cost considering fixed electricity price profile

An integrated model: added value

3 w.r.t to price profile representations

Demand side focus





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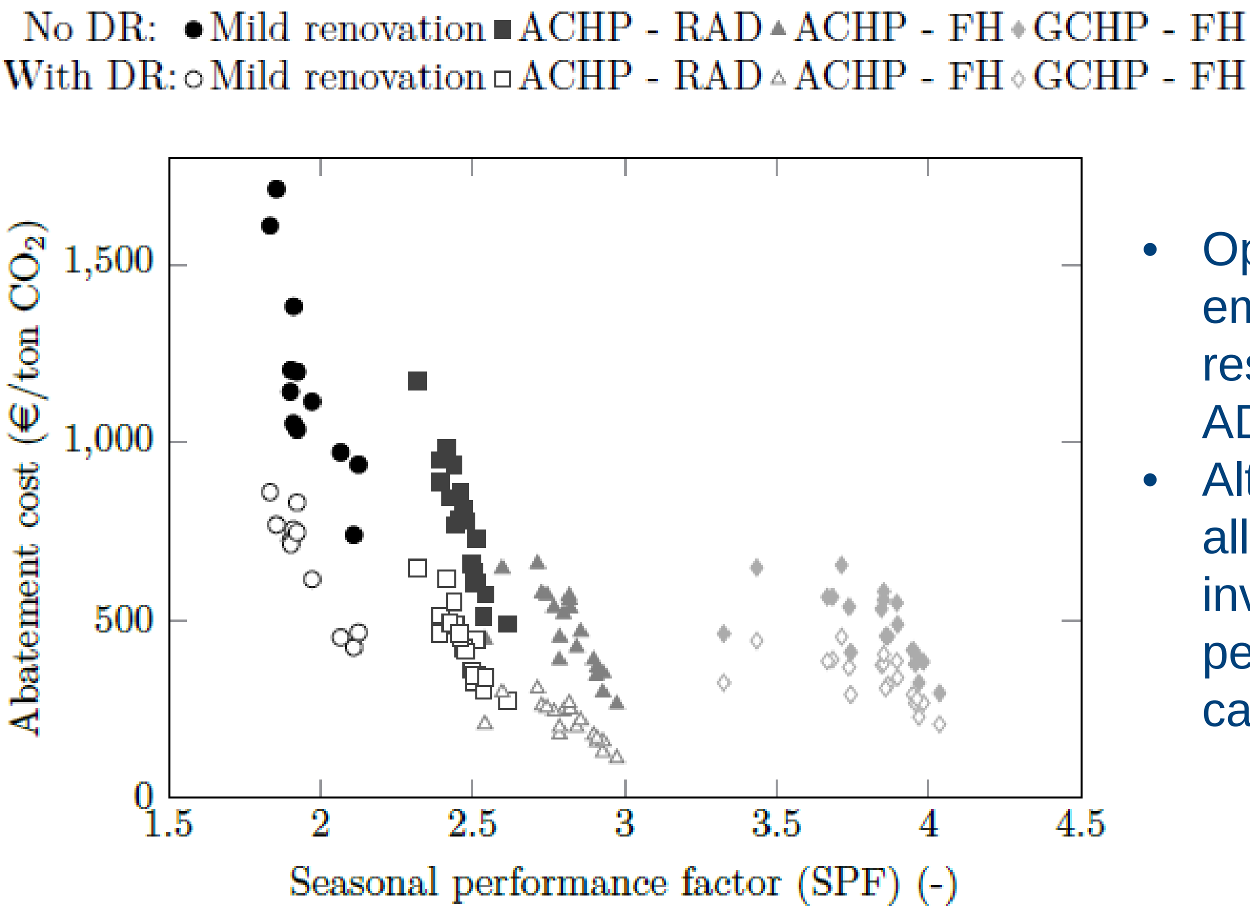
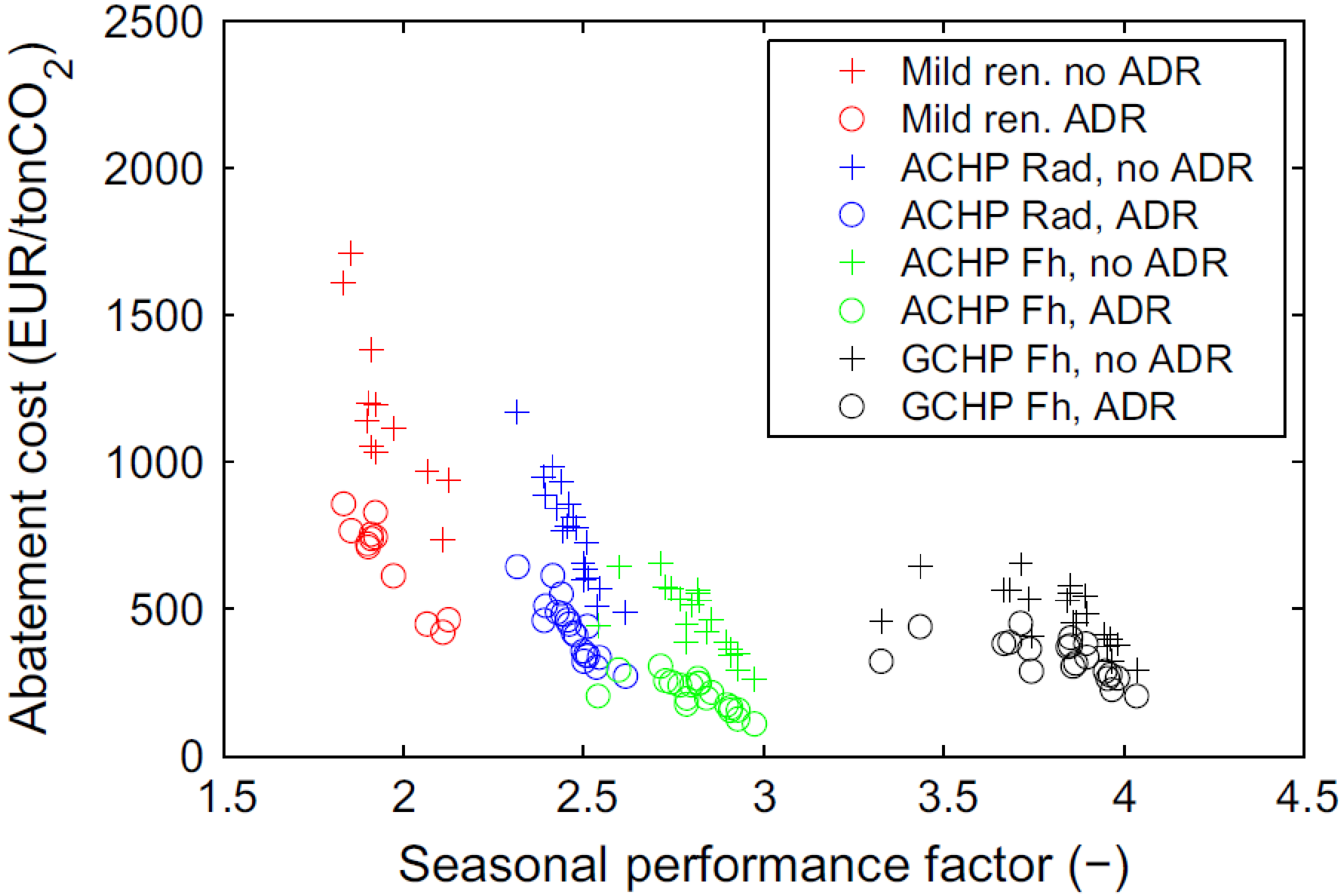
CO_2 abatement cost of DR-adherent heat pumps



- Operational cost and CO_2 emission reduction resulting from deployment ADR based on IM
- Alternative use of IM allows estimating avoided investment in additional peak power plant capacity (next slide)

From: Patteeuw et al. "CO_2-abatement cost of residential heat pumps with Active Demand Response: demand-and supply-side effects.“ Applied Energy 156, pp. 490-501, 2015.

CO_2 abatement cost of DR-adherent heat pumps



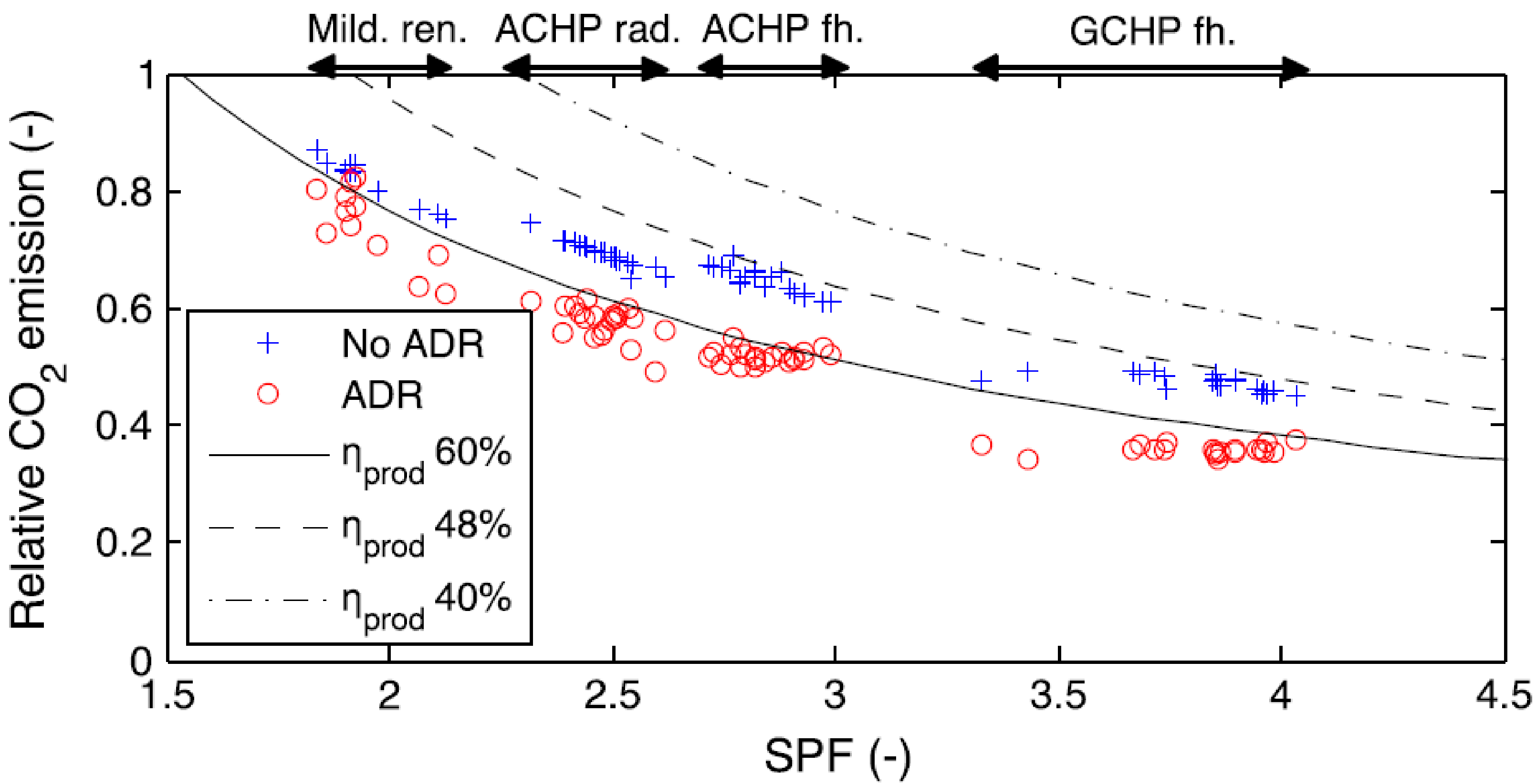
Operational cost and CO_2 emission reduction resulting from deployment ADR based on IM

Alternative use of IM allows estimating avoided investment in additional peak power plant capacity (next slide)

From: Patteeuw et al. "CO_2-abatement cost of residential heat pumps with Active Demand Response: demand-and supply-side effects." Applied Energy 156, pp. 490-501, 2015.

CO_2 emission savings of DR-adherent heat pumps

- Operational CO_2 emission reduction resulting from ADR based on IM
- Reference: standard condensing gas boiler



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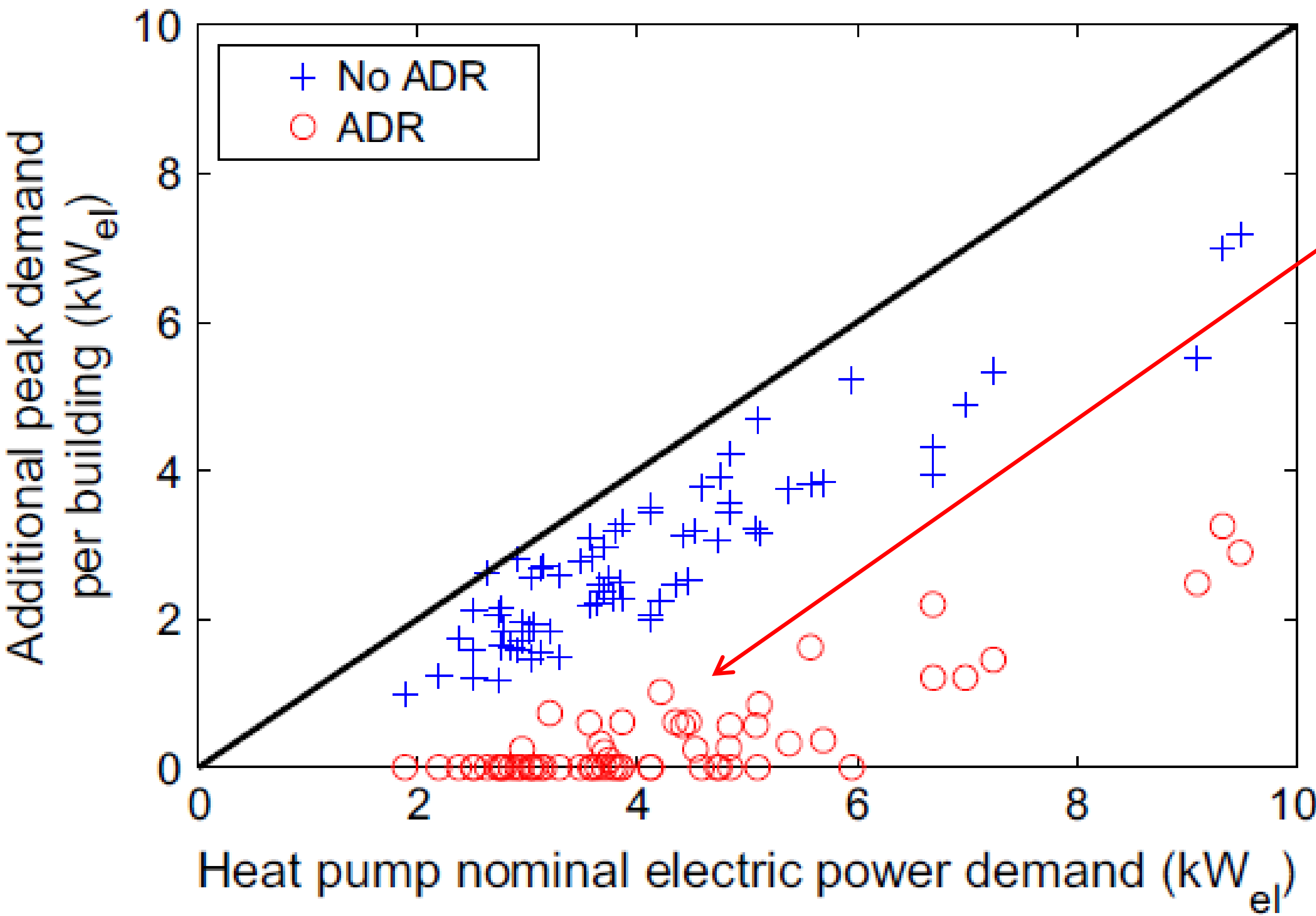
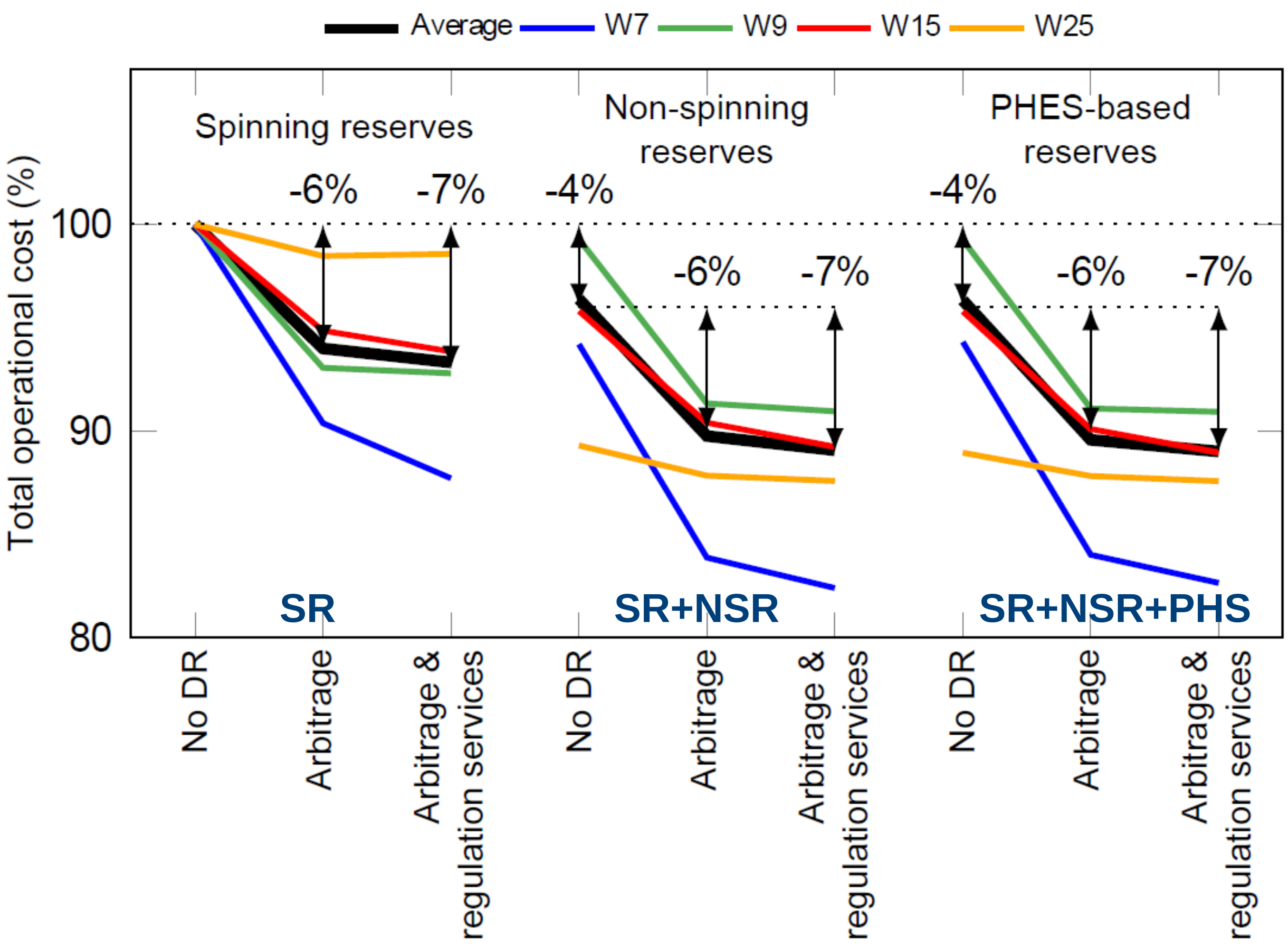
CO_2 abatement cost of DR-adherent heat pumps



Attainable without violating thermal comfort requirements of buidling owners!

From: Patteeuw et al. "CO_2-abatement cost of residential heat pumps with Active Demand Response: demand-and supply-side effects." Applied Energy 156, pp. 490-501, 2015.

Value of DR-based arbitrage and regulation services



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

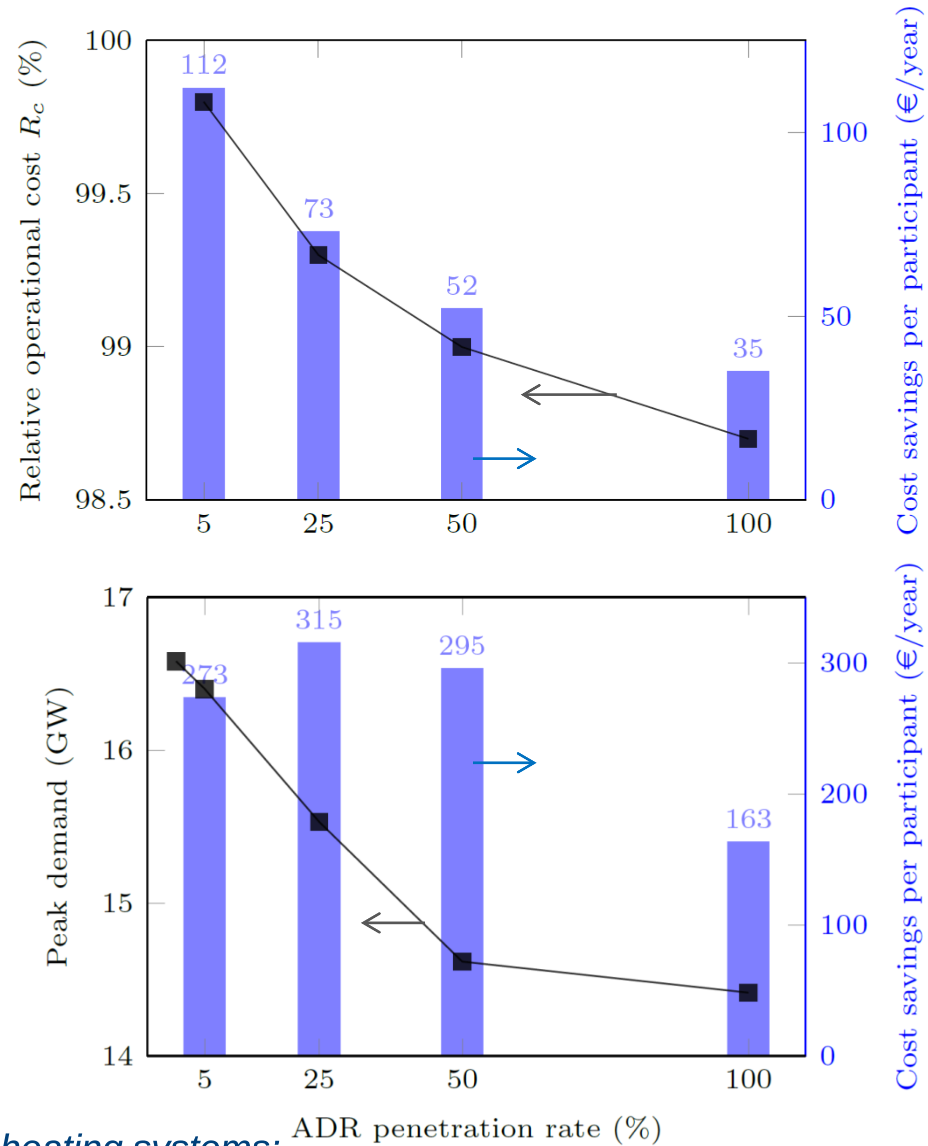
Impact of the market penetration on the value of DR

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 no longer reduces peak demand.



A. Arteconi et al., Active demand response with electric heating systems: impact of market penetration, Applied Energy 177 (2016) 636-648

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Conclusion

1 Integrated modeling framework

- Operational demand and supply side model formulated using MILP
- More accurate representation compared to other methods
- Myriad of applications possible

2 Demand response with heat pumps

- Could lead to significant environmental and economic 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
- Conflicting objectives building owner – system operator

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,* Applied Energy 177, pp. 636-648, 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 (Forthcoming).

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Appendix

Integrated modelling framework (1/3)

Operational MILP combining

- Generation
    - Operational costs
    - Technical constraints
- Demand
    - o Traditional (profile)
    - o Electrical heating
        - Linear model flexibility

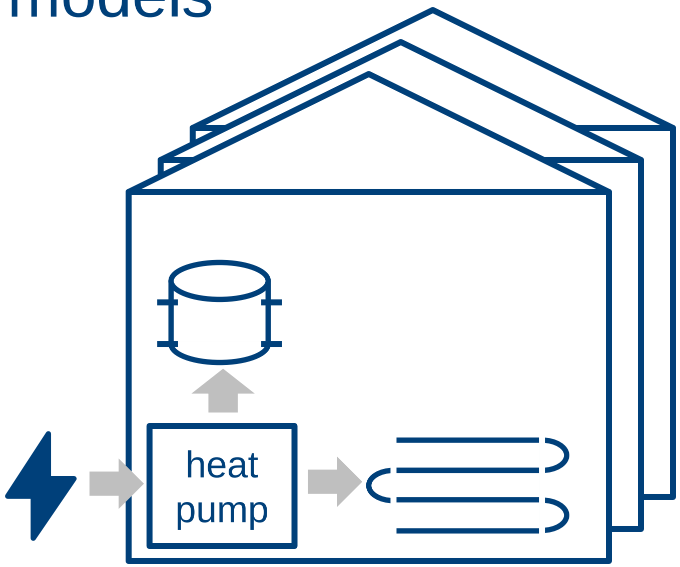
Traditional
unit commitment and
economic dispatch
(MILP)

Explicit model
flexible demand
(LP)

Integrated modelling framework (2/3)

Demand side model (LP)

- Scaled up demand from x building models
- For each building model:
  - Heat pump
    - Linearized: COP, part-load
  - Domestic hot water tank
    - Fully mixed, DHW demand
  - Building
    - Thermal RC network, solar & internal heat gains
    - User behavior



Case study CO2 abatement cost study

- Set-up
  - Belgium 2030
  - Electricity generation
    - No nuclear; 30% wind; 10% PV; CCGTs and OCGTs
  - Building types
    - 6 age classes; 3 typologies; 2 renovation cases
  - Heating system
    - All DHW tank; 3 heat pump cases

- 250,000 heat pumps with or without ADR

Patteeuw, Dieter, et al. "CO2-abatement cost of residential heat pumps with Active Demand Response: demand-and supply-side effects.“ Applied Energy 156 (2015): 490-501.