4DH
4th Generation District Heating Technologies and Systems

Aggregation of flexible domestic heat pumps for the provision of reserve in power systems

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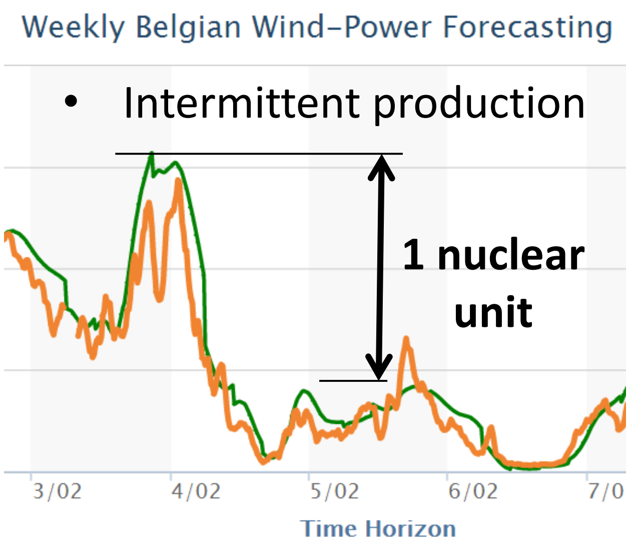
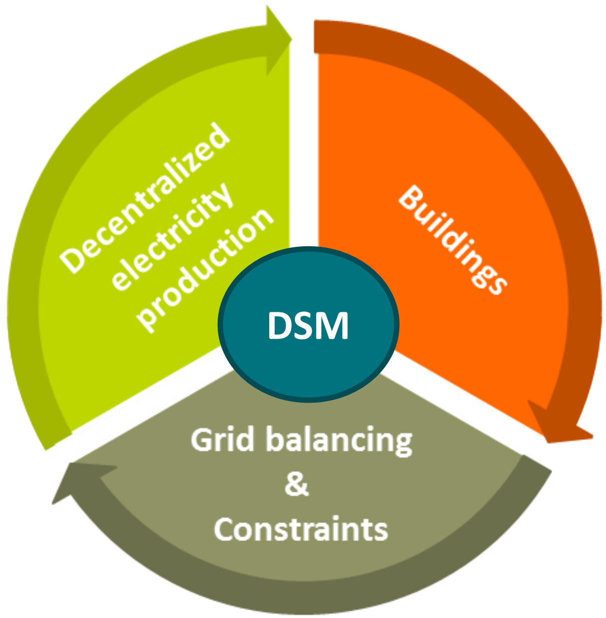
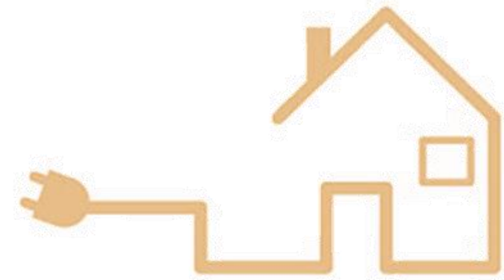
Introduction

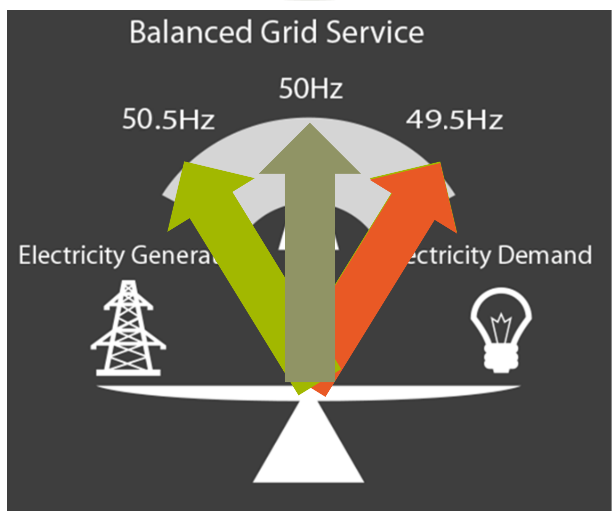


- Intermittent production

(Source: Elia)







Electrification

- Heat pumps
- Electric vehicles
- Batteries

DSM = incentives to modify consumers' demand profiles
$\Rightarrow$ **Demand response**

Introduction

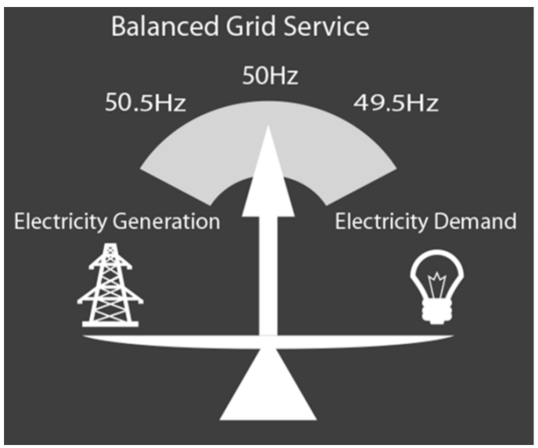
Grid balancing

Day - 1 | Day

Prediction:
If $\sum$ power injections $\neq \sum$ power intakes
$\Rightarrow$ Imbalance

Prediction uncertainty

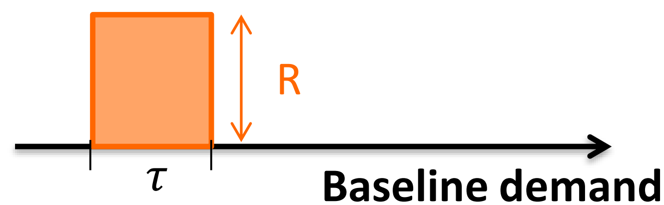
$\Rightarrow$ System Imbalance



→ Ancillary services →

Provision of power reserve

Power modulation

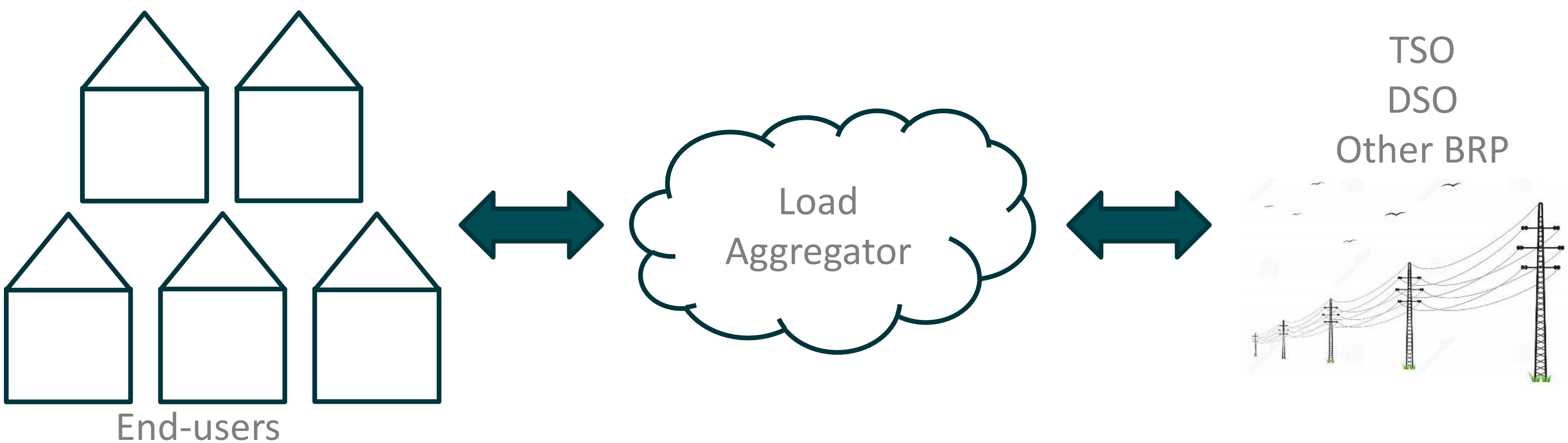


$\Rightarrow$ With 40000 heat pumps, how much **reserve** can we provide?
$\Rightarrow$ Reservation **cost**?

Introduction

Load aggregator

- gathers, pools and trades the flexibility of consumers
  - **Residential houses with heat pumps**
- to offer services to other market actors
  - Congestion
  - **Balancing**



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- **Conclusions**

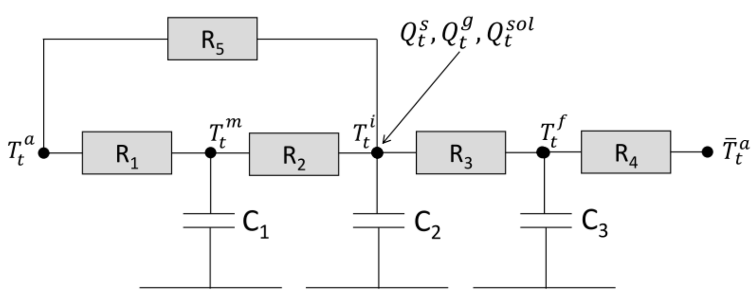
Modeling framework

Buildings

Detailed building models
- Modelica (Dymola)

System Identification

Reduced-order models
- Grey-box models



RC network

$$\boldsymbol{x}_{t+1} = \boldsymbol{A}\boldsymbol{x}_t + \boldsymbol{B}\boldsymbol{u}_t$$
$$y_t = \boldsymbol{C}\boldsymbol{x}_t + \boldsymbol{D}\boldsymbol{u}_t$$

where

- $\boldsymbol{x}$ is the vector of state variables
$\Rightarrow$ temperature nodes

- y is the zone temperature

- $\boldsymbol{u}$ gathers model inputs (heat input, internal heat gains, weather data,…)

- $\boldsymbol{A}, \boldsymbol{B} = f(C_i, R_i)$

$$\Rightarrow \min RMSE(y) = \sqrt{\frac{1}{n}\sum_t (y_t - T_t^z)^2}$$

Zone temperature

Modeling framework

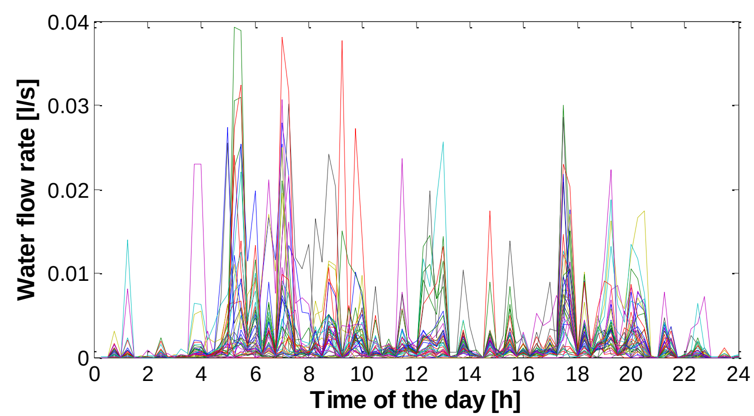
Systems

Heat pump / 	Empirical modeling of steady-state performance: $COP = f\left(T^{su}, T^{amb}, PLR\right)$ for space-heating and DHW production (manufacturer data)
Water tanks 	One-node water tank models: $\frac{CdT}{dt} = Q^{h} - AU(T - T^{surr}) - \dot{m}c_{w}(T - T^{w,mains})$

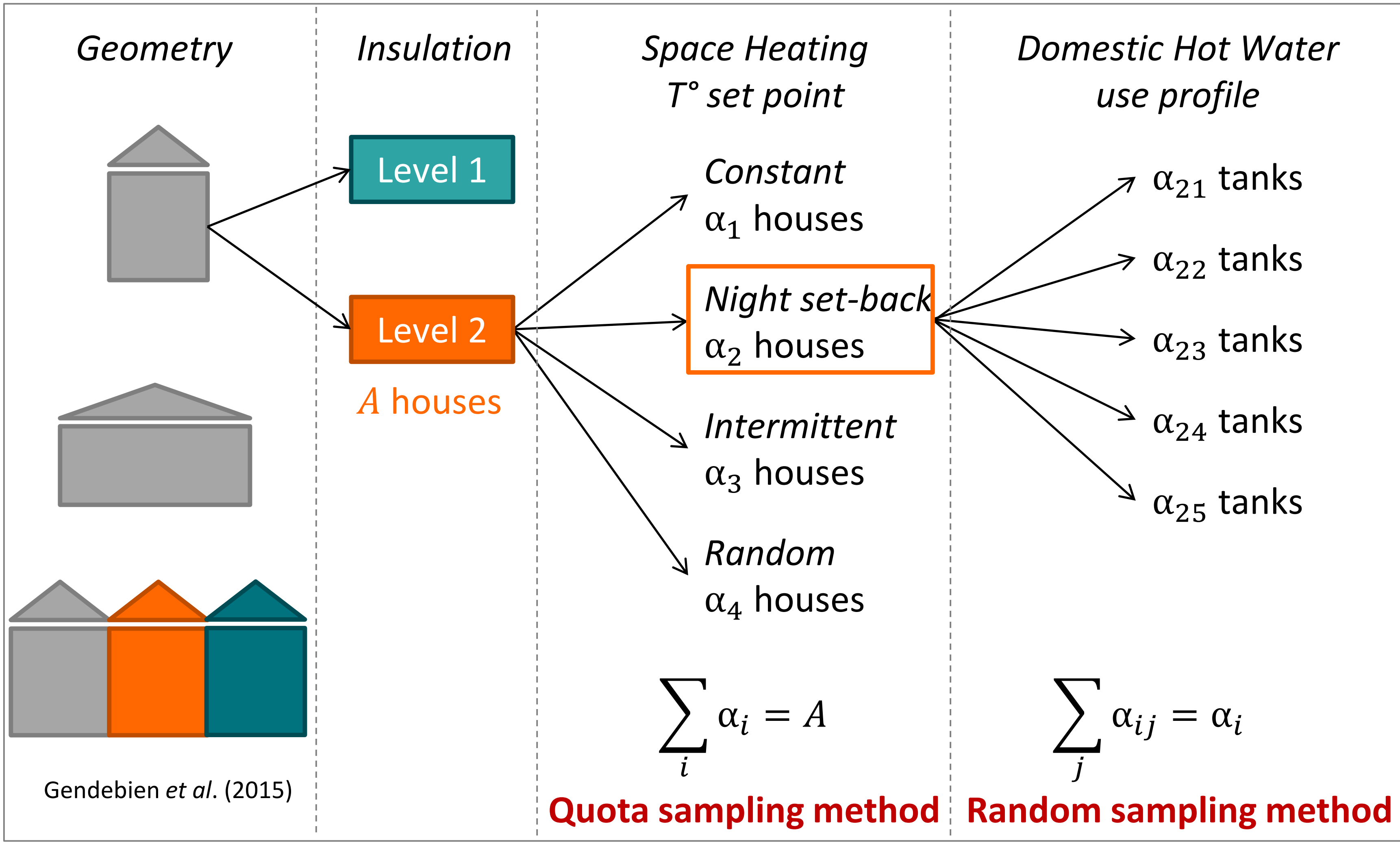
Occupants-related profiles

- Appliances and lighting use profiles
- Domestic hot water consumption profiles
- Zone temperature set point profiles

⇒ **Stochastic profiles**



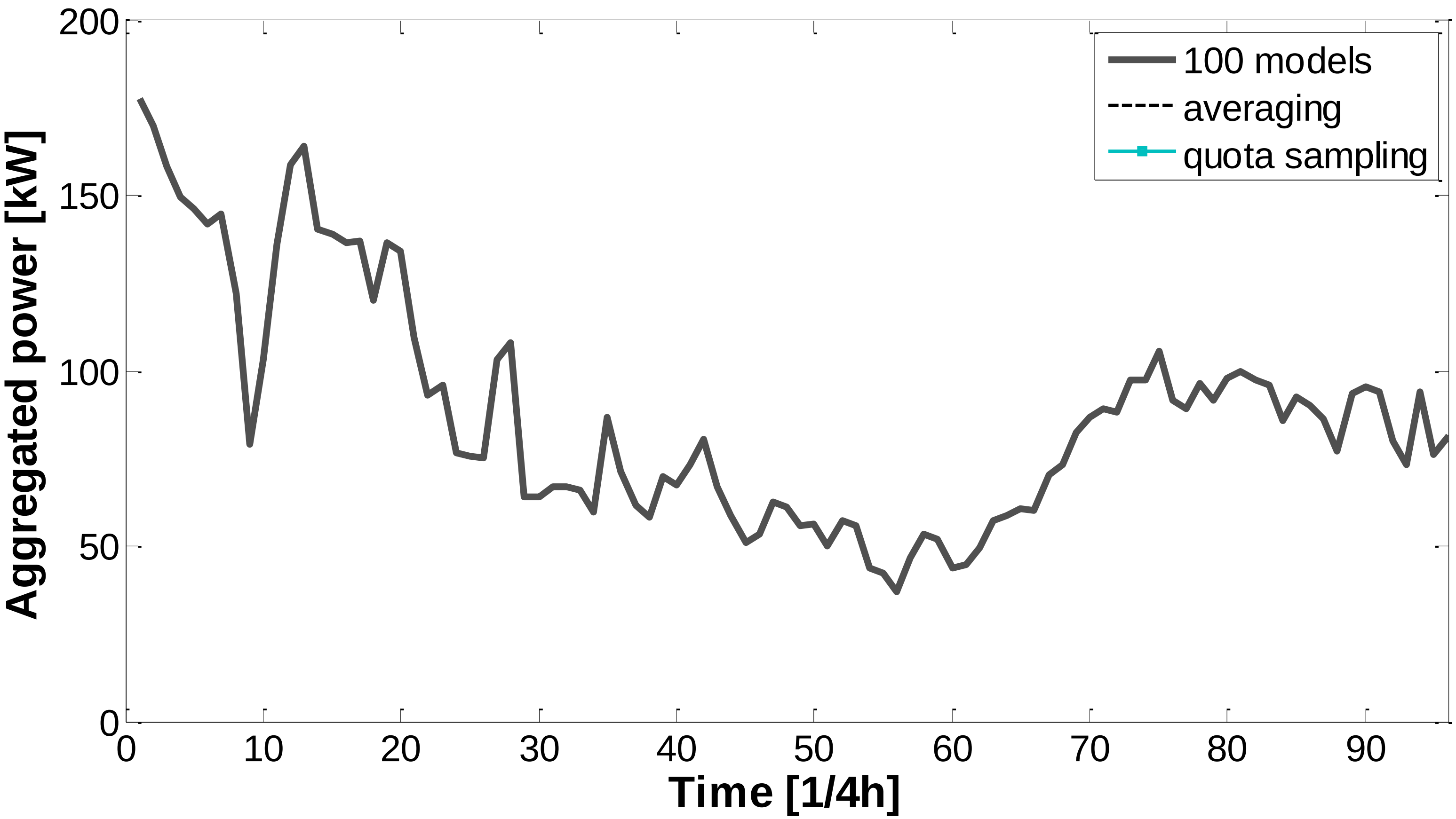
Load aggregation method



Automated generation of 40 aggregated models

Load aggregation method

- Space-heating demand
  - Example: aggregation of 100 houses



Load aggregation method

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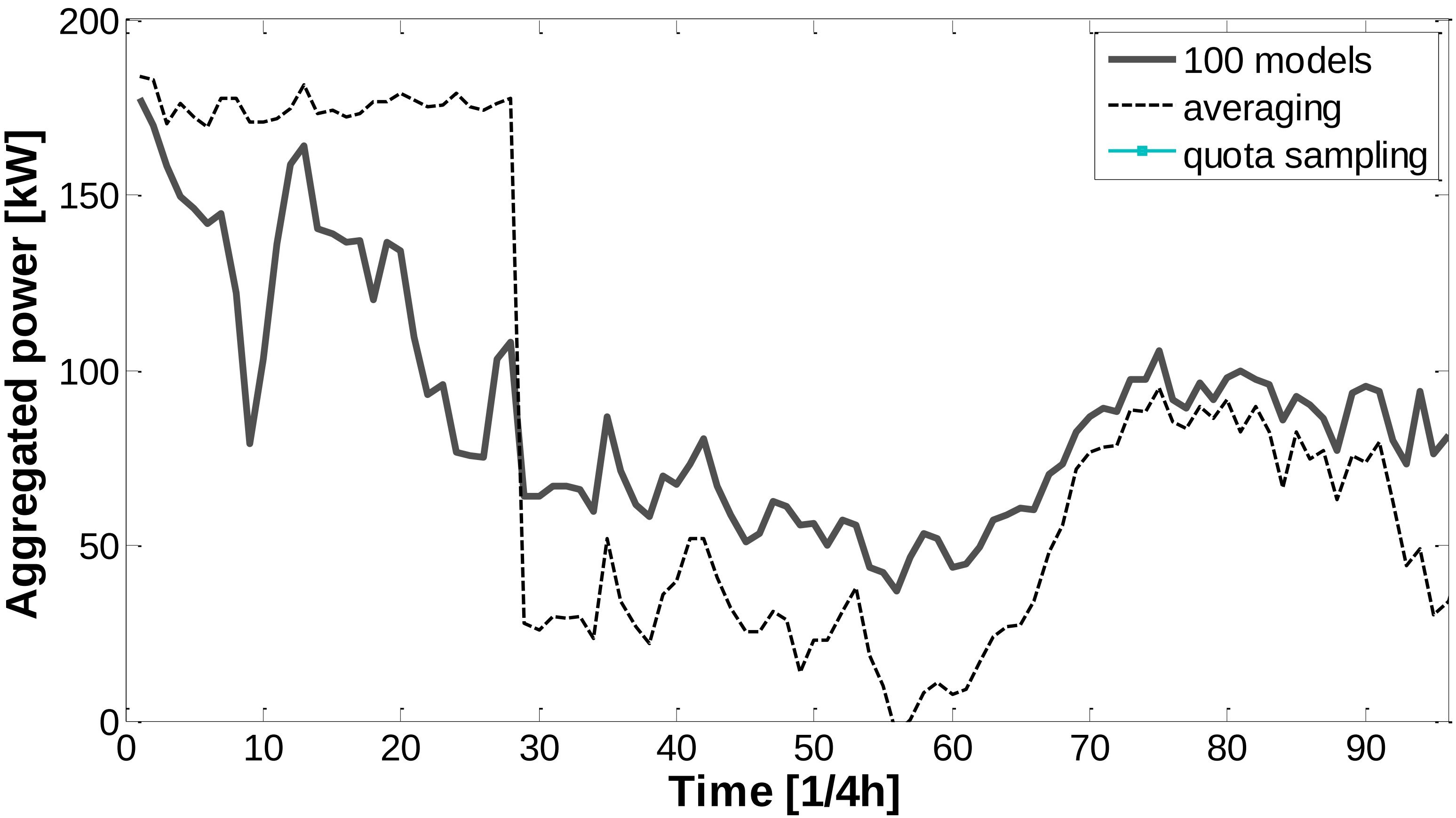
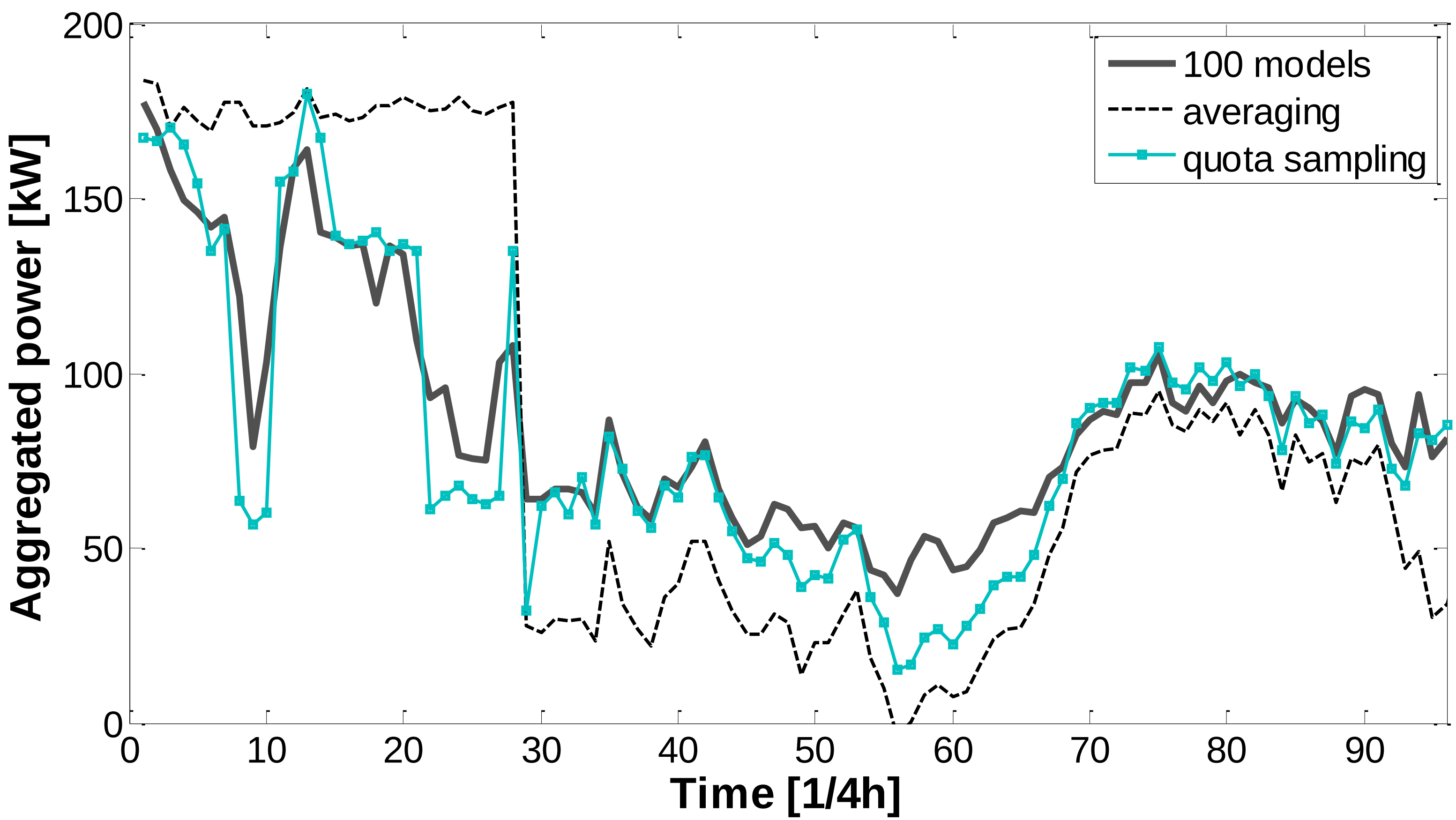


With one aggregated model – error = **37%**

Load aggregation method

- Space-heating demand
  - Example: aggregation of 100 houses



With four aggregated model – error = **12%**

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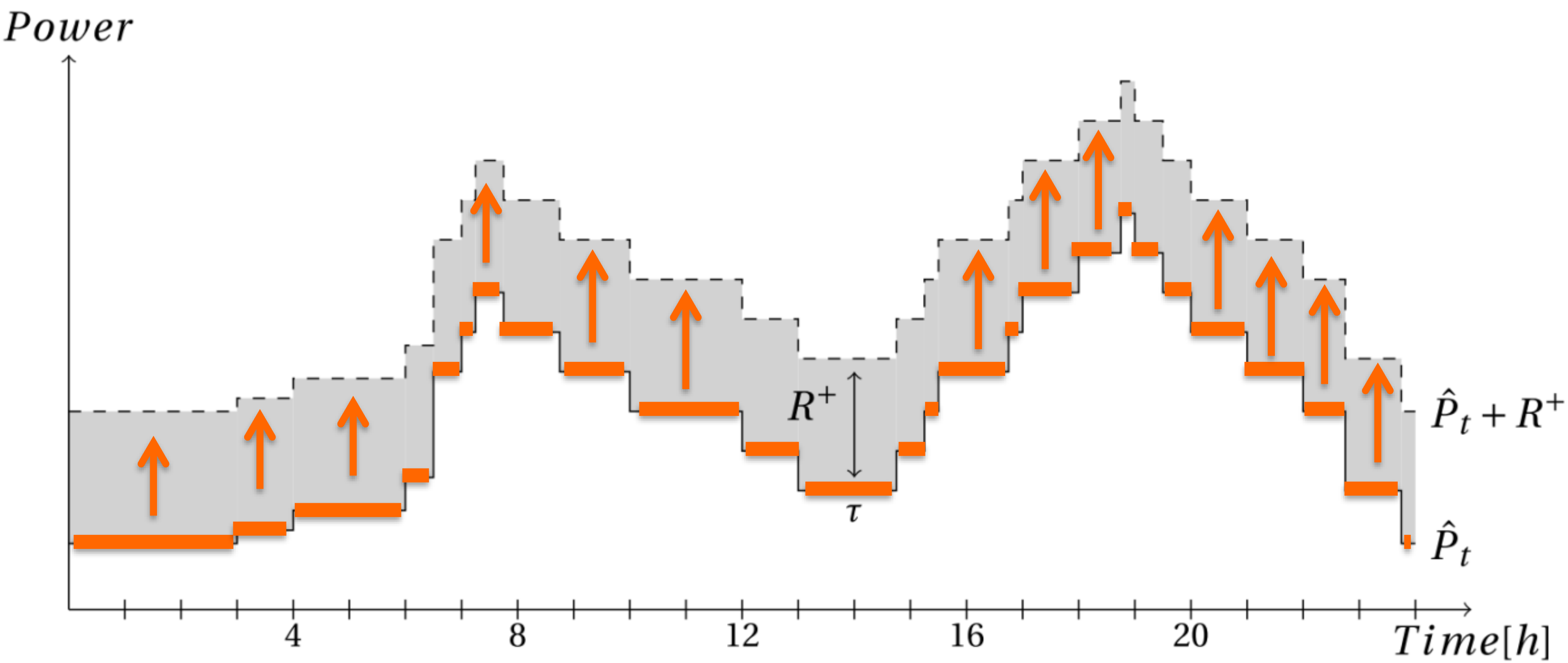
  - Bases of allocation costs
  - Results for year 2012
- **Conclusions**

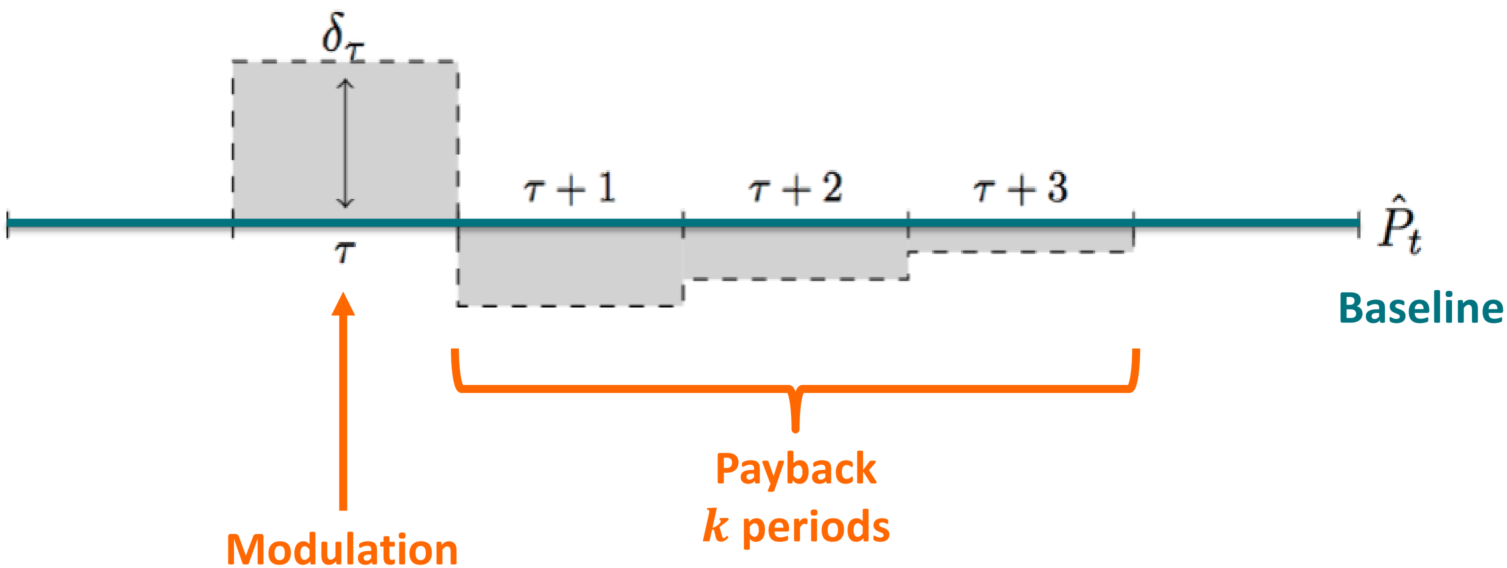
Provision of power reserve

- Problem statement:
  - Objective: pool flexible heat pumps to provide power reserve at every time period of the day



Provision of power reserve

- /!\ **payback period** to allow the system to **return to its baseline** after the power modulation
- At each time step τ:



Provision of power reserve

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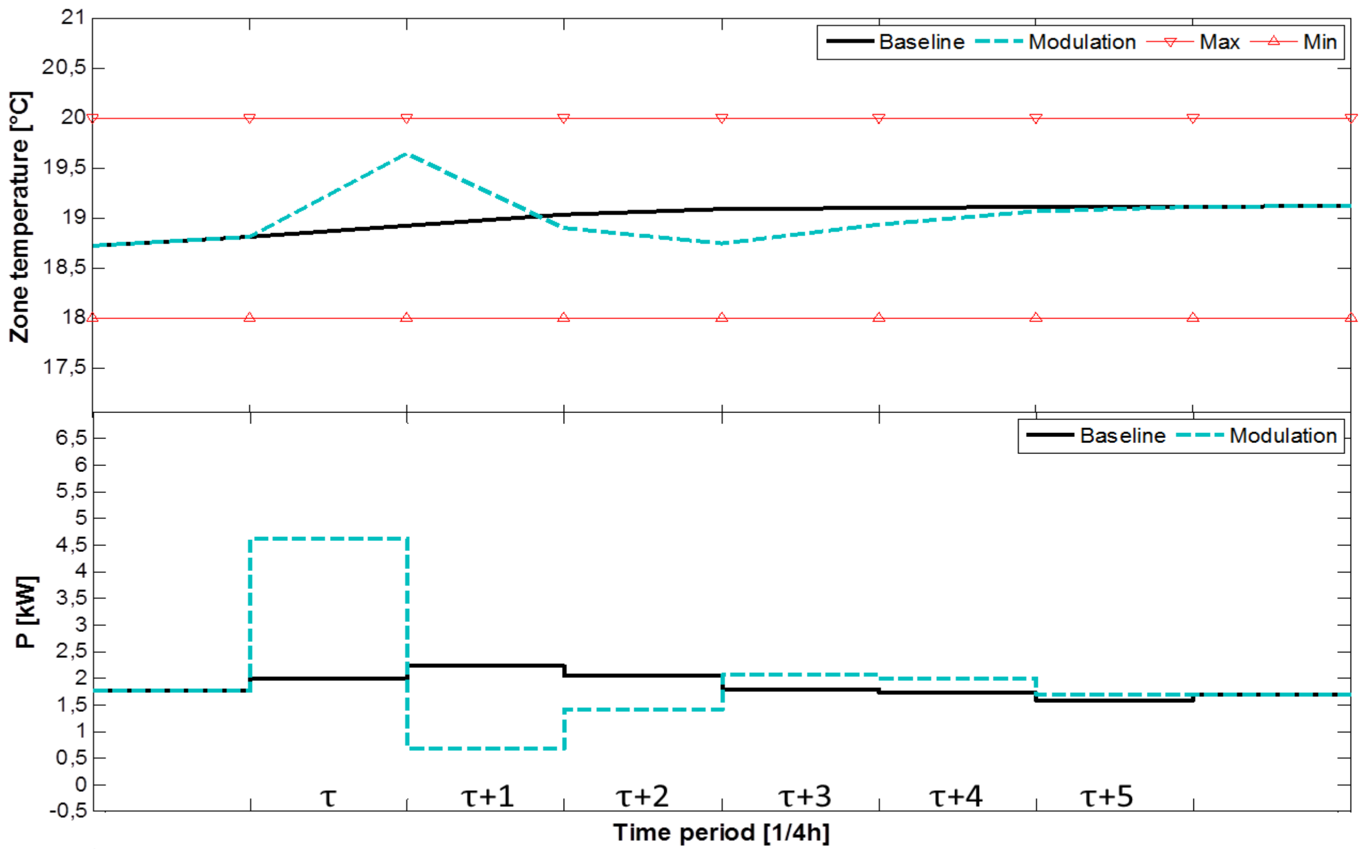


Provision of power reserve

- Problem statement:

CENTRALIZED OPTIMIZATION

minimize electricity costs on day-ahead market

$$\min \sum_{t} \left(\sum_{i}^{\#\,clusters} P_{i,t}\alpha_i \right) \pi_t + \beta \sum_{\tau} \lambda_\tau$$

while providing a defined amount of power reserve:

$$\sum_i^{\#\,clusters} \delta_\tau^i \alpha_i \geq R^+(1 - \lambda_\tau)$$

while ensuring that any activation can be corrected within comfort limits:

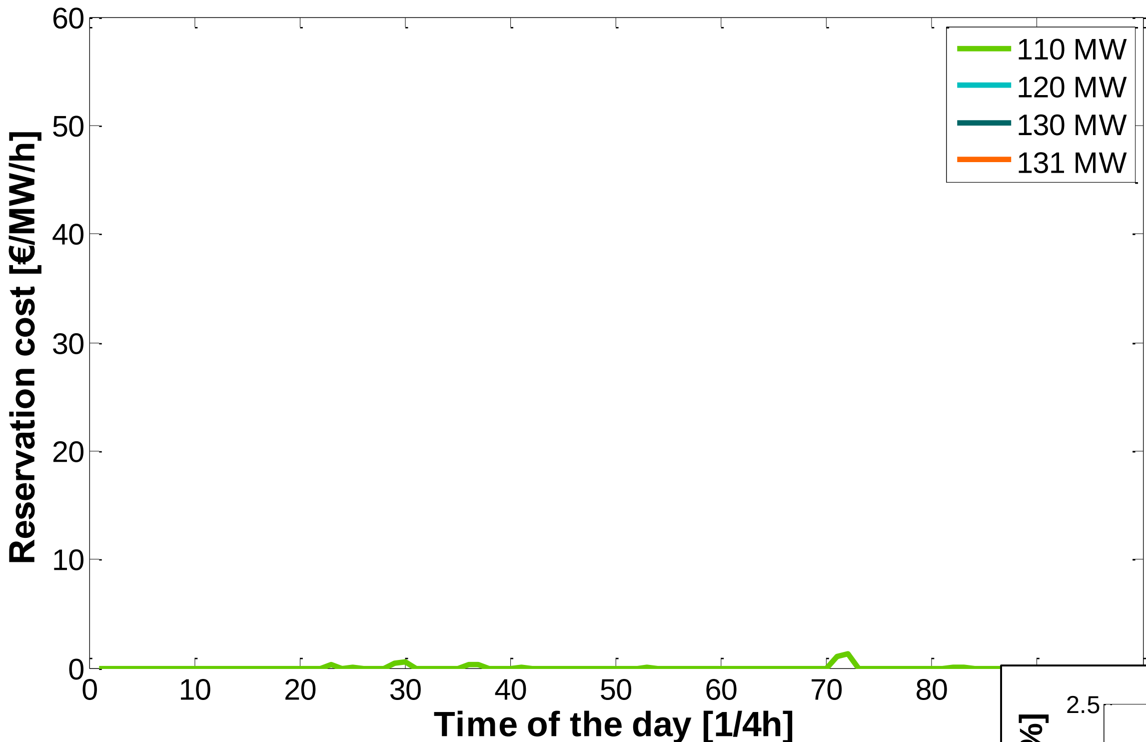
$$-\sigma \leq \hat{\mathbf{x}}_{i,\tau+k+1} - \mathbf{x}_{i,\tau,k+1} \leq \sigma$$

and under thermal comfort, power and energy limitation constraints

Reservation cost = opportunity cost due to the constraint

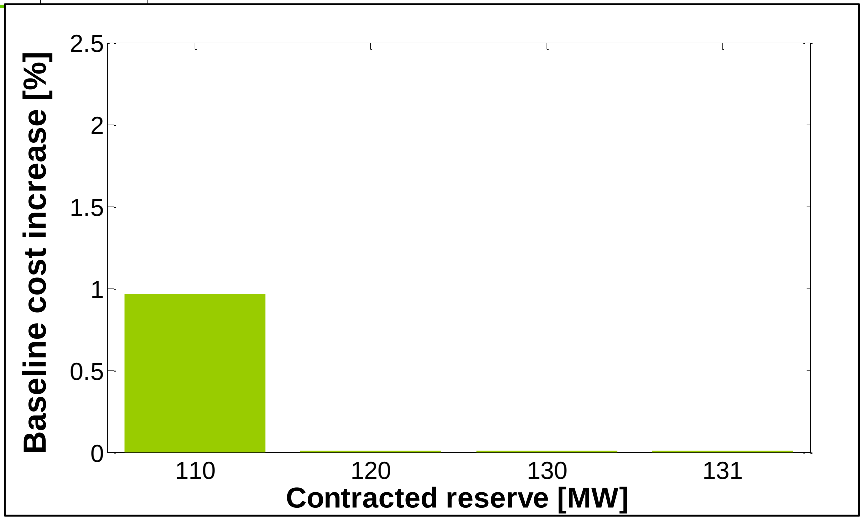
⇒ Given by the **dual value** of the constraint

Bases of reservation costs

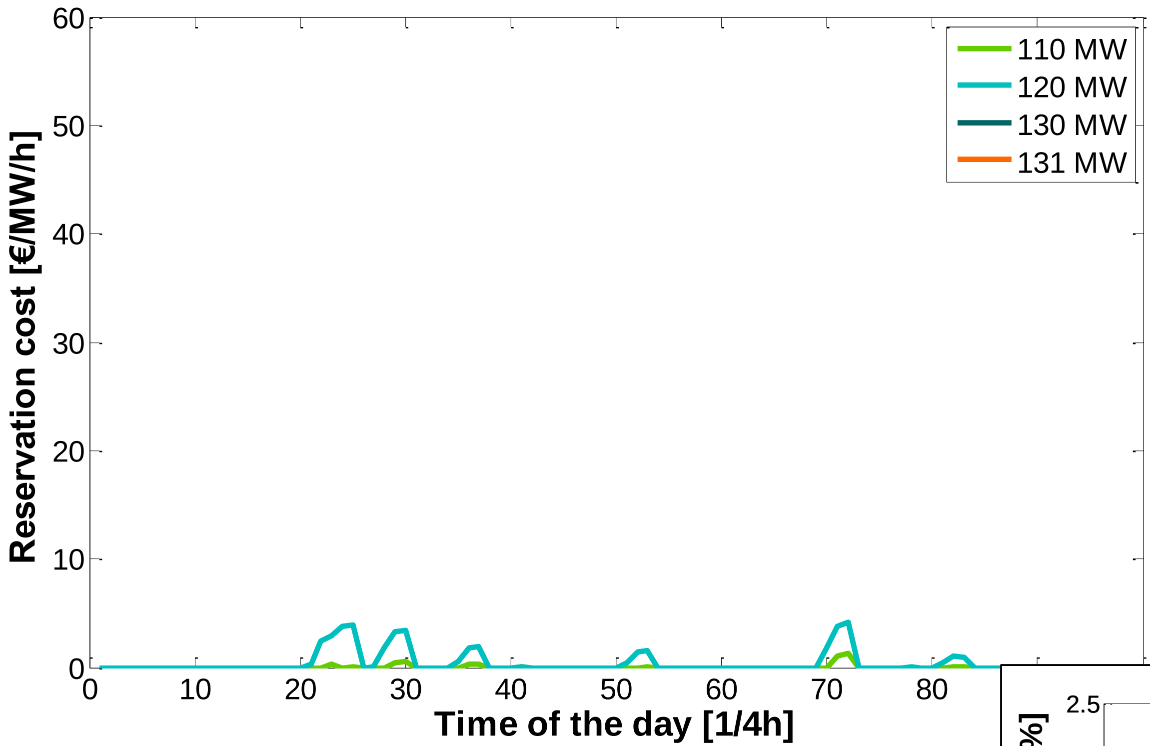


Upward power reservation:

- 40000 identical HP and building geometries
- constant ambient temperature
- constant DA market price



Bases of reservation costs



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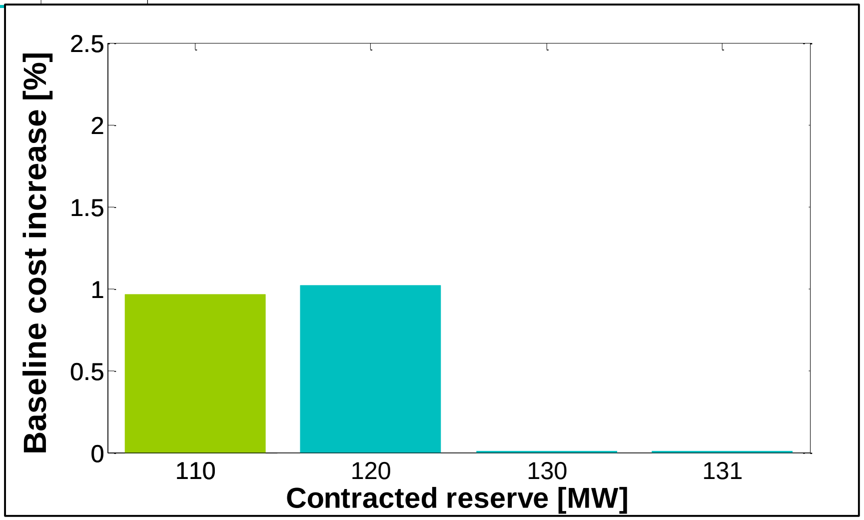
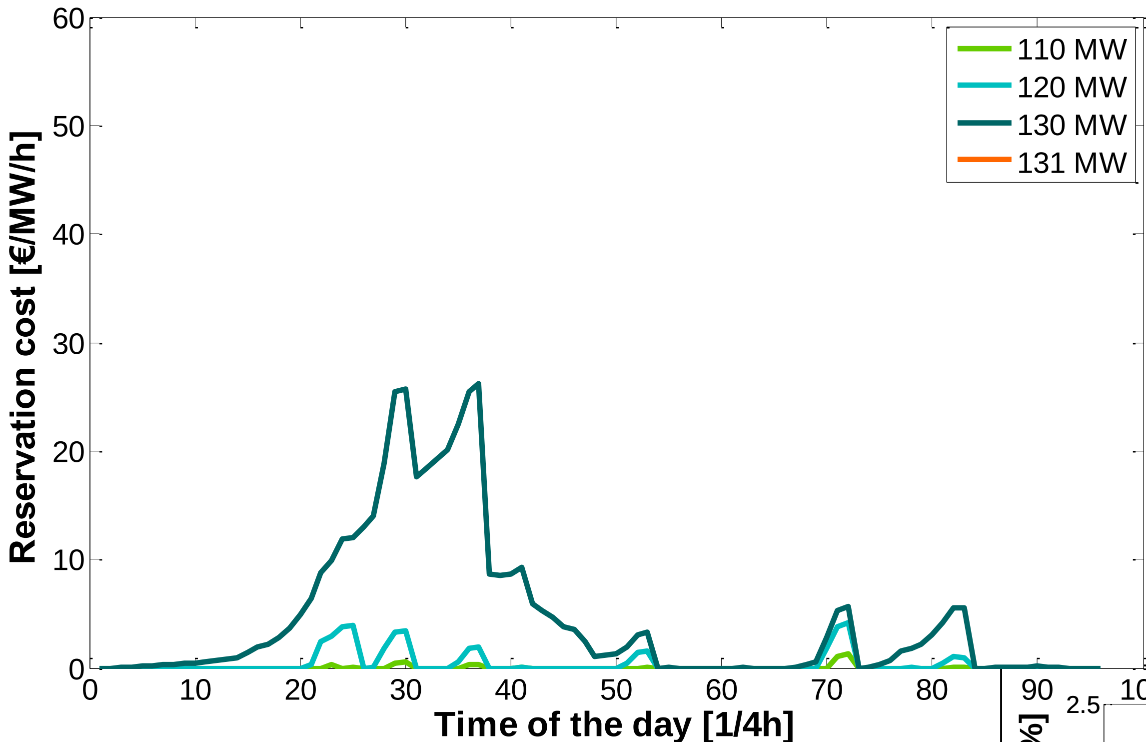


Bases of reservation costs



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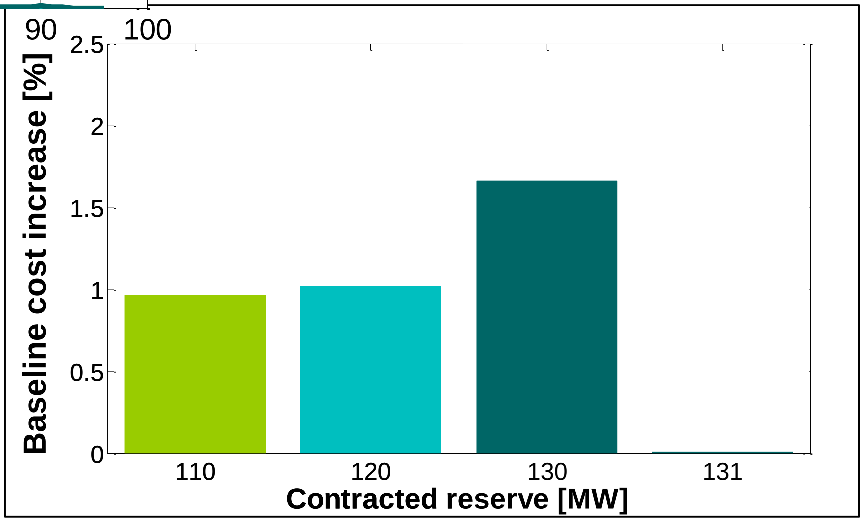
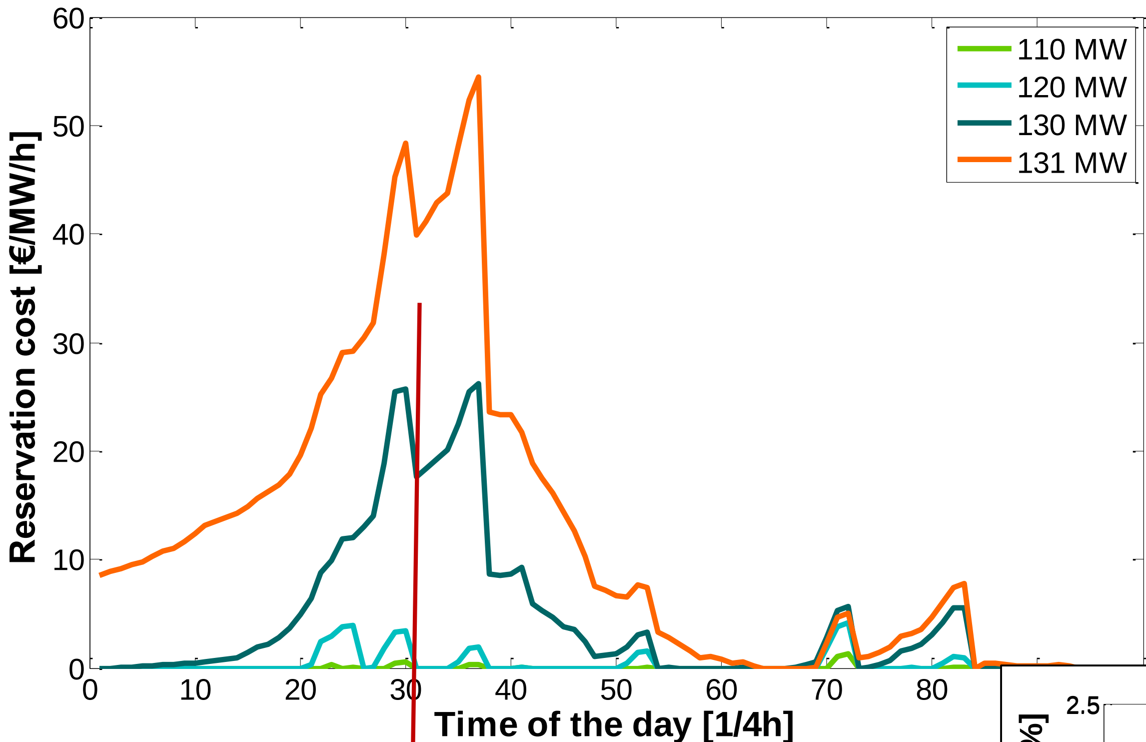


Bases of reservation costs



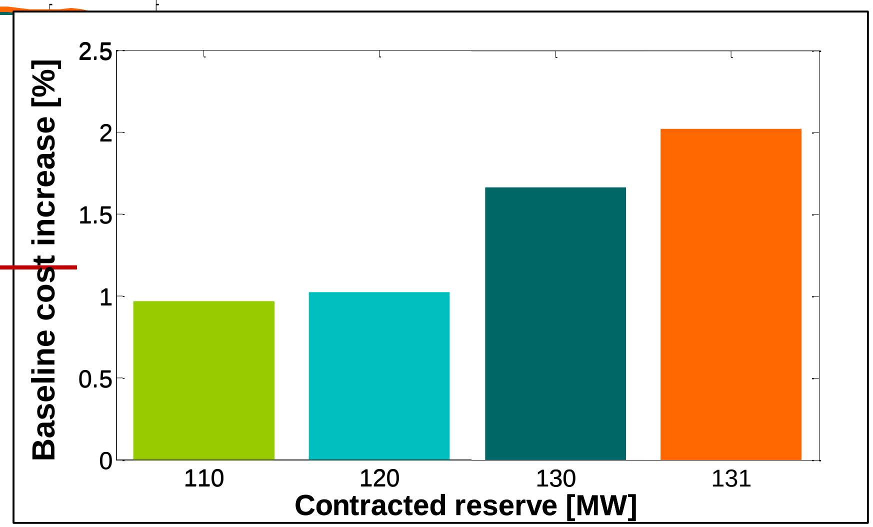
Upward power reservation:

- 40000 identical HP and building geometries
- constant ambient temperature
- constant DA market price

Full-load operation

+

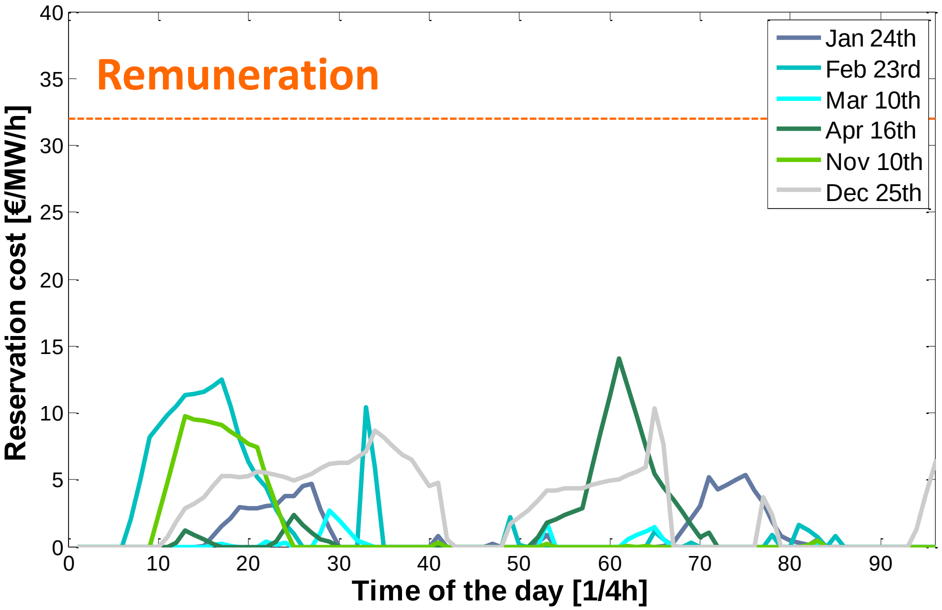
constrained rebound effect



Reservation costs

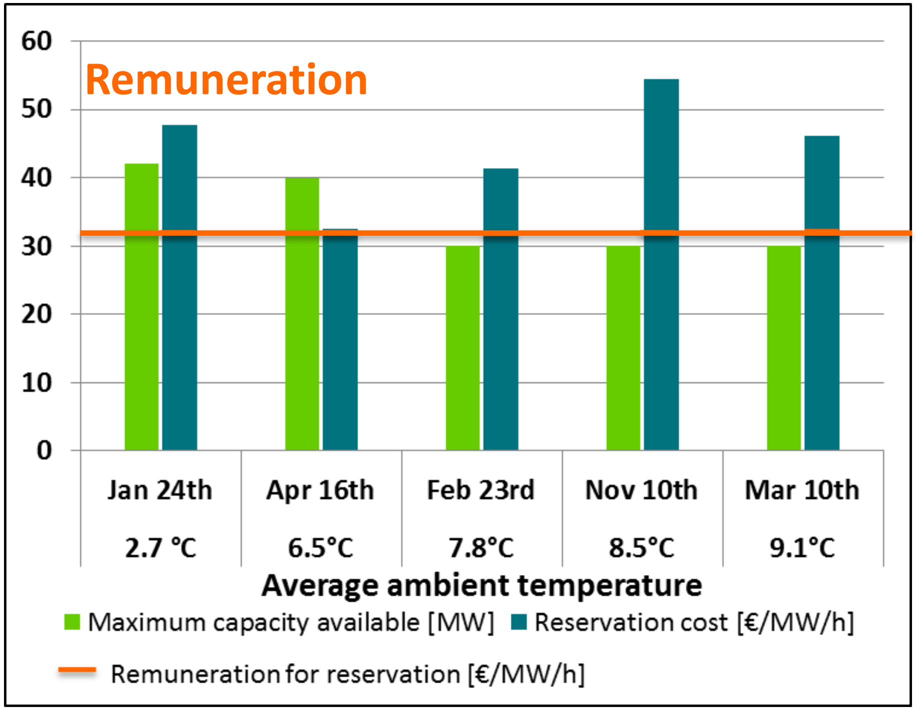
- 40000 heat pumps with two building typologies
- Historical DA market prices for Belgium
- Historical weather conditions

Upward power reservation



100 MW (70% of total reserve)

Downward power reservation



Conclusions

- A method to develop reliable **aggregated models** of residential buildings equipped with heat pumps and water storage with different energy use profiles was presented.
- The method is used to assess the provision of power reserve with such flexible loads:
  - A **combined optimization problem** that aims at the minimization of procurement costs on the day-ahead market while ensuring a certain amount of reserve is proposed.
  - Results show that
    - the provision of upward reserve is limited by the ability of the system to return to its baseline state, and by limited heat pump capacities. The provision of up **to 70% of the current contracted amount of reserve** (140MW) can be achieved with 40000 units during the winter at 44% of the cost.
    - the provision of downward reserve is hampered by **significant overconsumption** and may become non competitive compared to current reserve market prices.

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