Using Models and Control for Balancing the Fluctuating Wind and Solar Power

WP3 Flexibility Meeting

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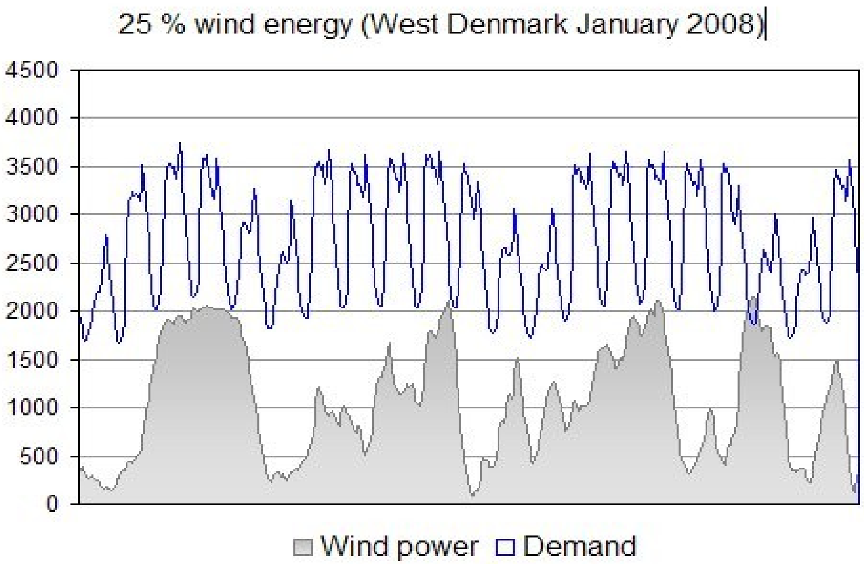
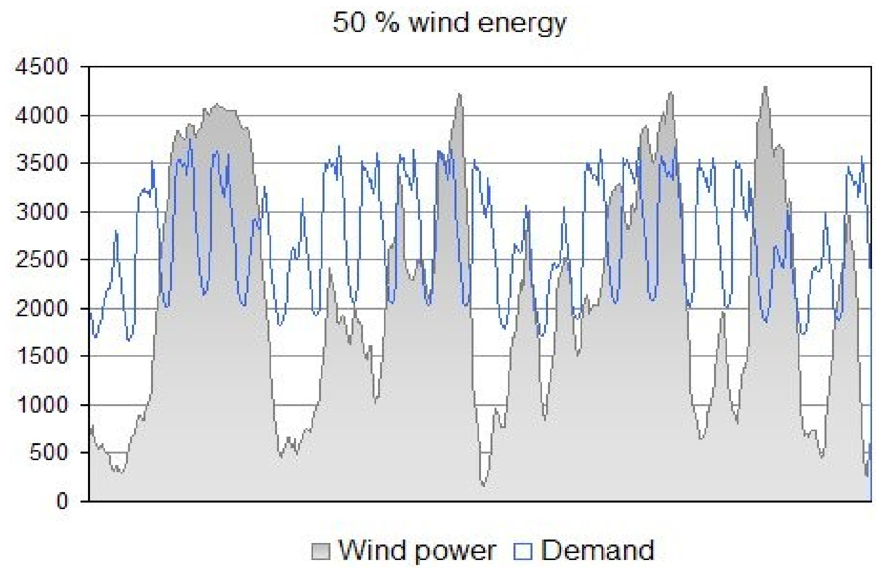
The Danish Wind Power Case

.... balancing of the power system



Wind power covers the entire demand of electricity in 200 hours (West DK)

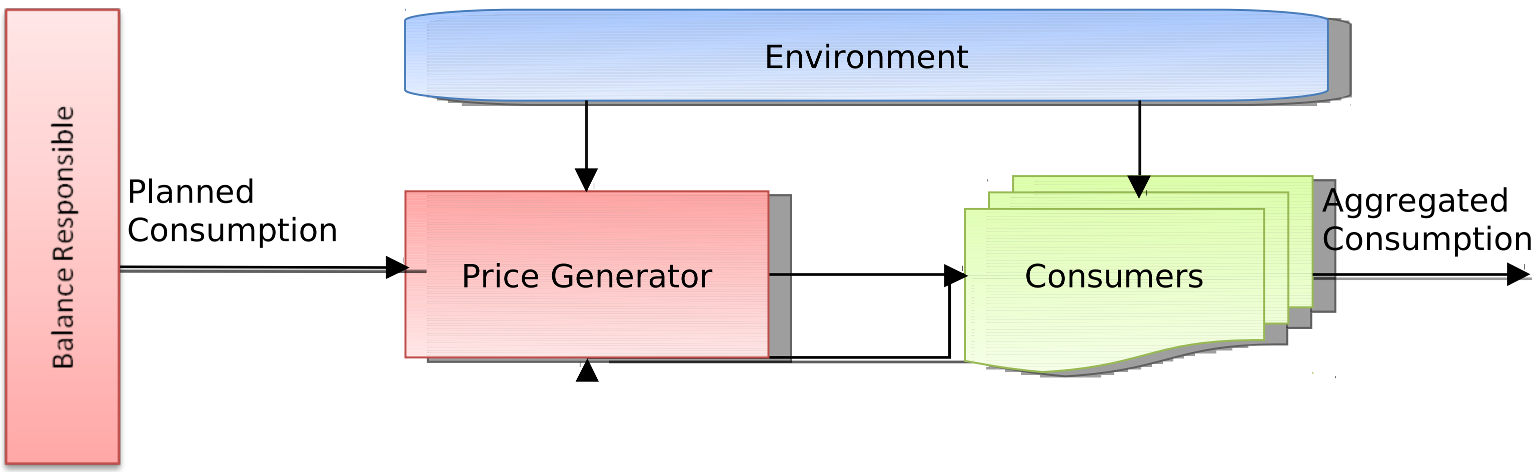


In the future wind power will exceed demand in more than 1,000 hours


50,0
49,9
50,1
49,8
Hz
50,2

Concept

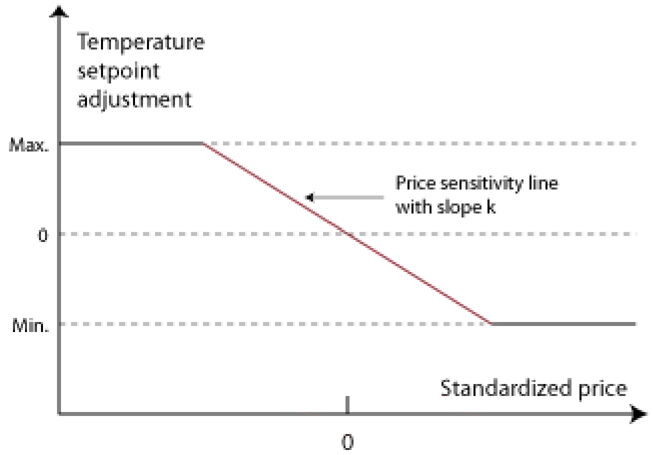
Indirect control of the aggregated consumption

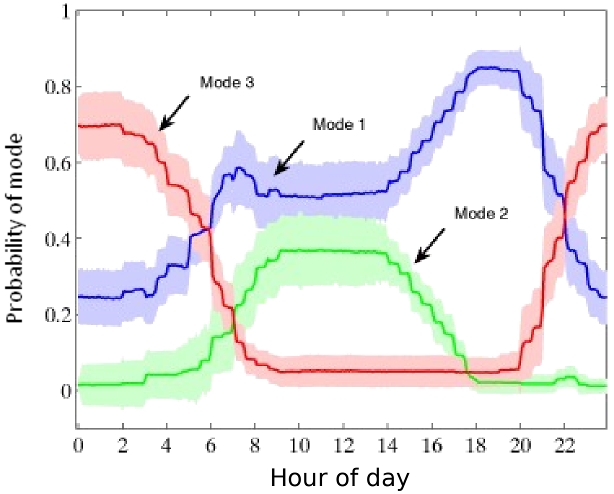


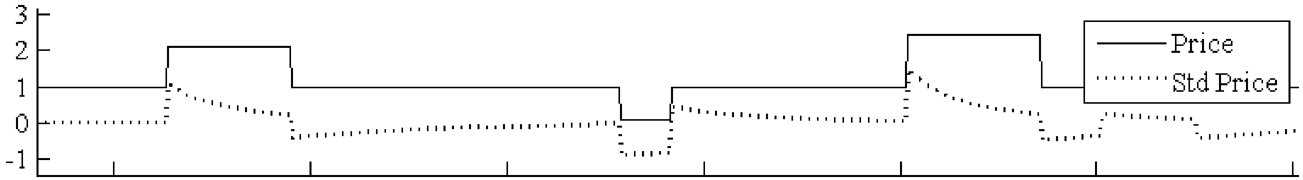
1. **Collect** data from experiments and simulations
2. **Identify** the consumption response to price using **only external variables**
3. **Control** the aggregated consumption by sending out a price signal

Price responsivity

Flexibility is activated by adjusting the temperature reference (setpoint)





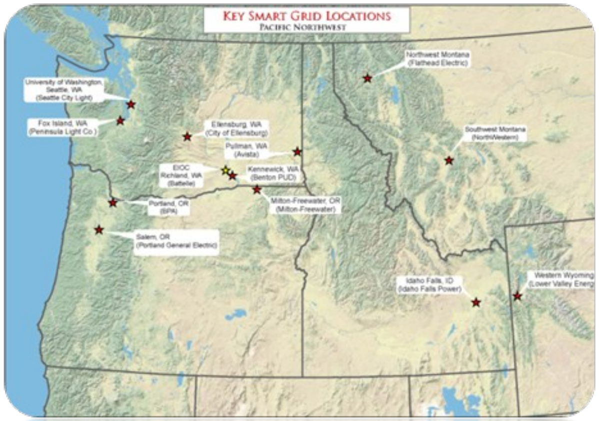


- **Standardized price** is the % of change from a price reference, computed as a mean of past prices with exponentially decaying weights.
- **Occupancy mode** contains a price sensitivity with its related comfort boundaries. 3 different modes of the household are identified (work, home, night)

Step 1:

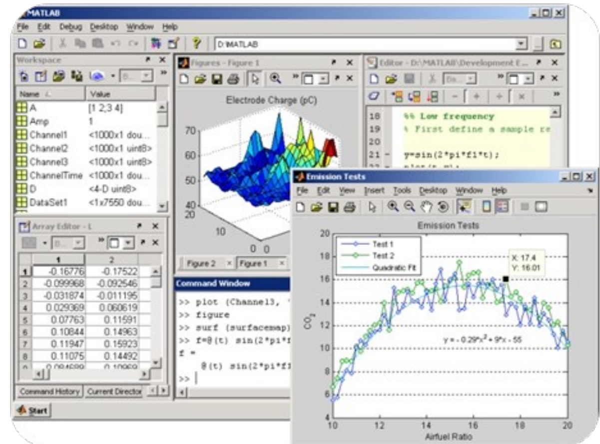
Collect data

Two data sources



Olympic Pensinsula project

- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption



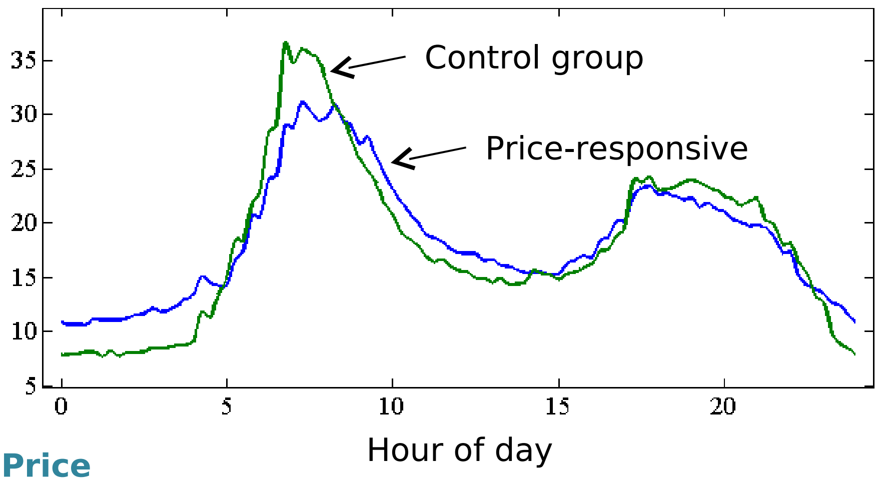
Simulation framework

- Modular design
- Runge-Kutta solver (diff. equations)
- Scalable (linear computation time)
- Variable sampling rate
- Open source (?)

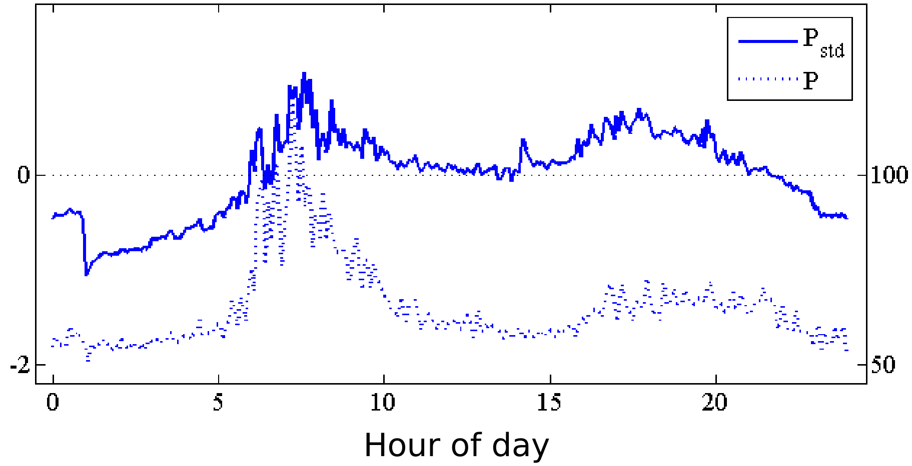
Olympic Peninsula project

- Price-responsive and control group available for comparison
- Access to aggregated variables
  (mean, min, max and variance)
- Prices are the result of intersecting demand/supply curves in a shadow market
- Main flexibility source is heating/cooling

Consumption



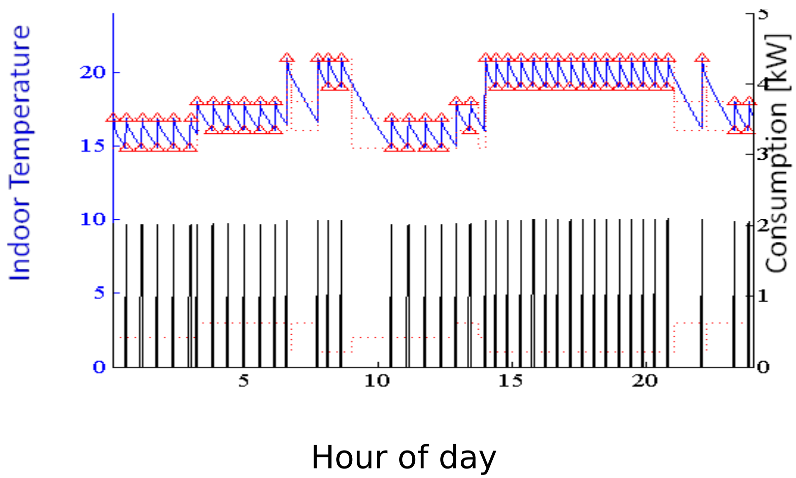
Price

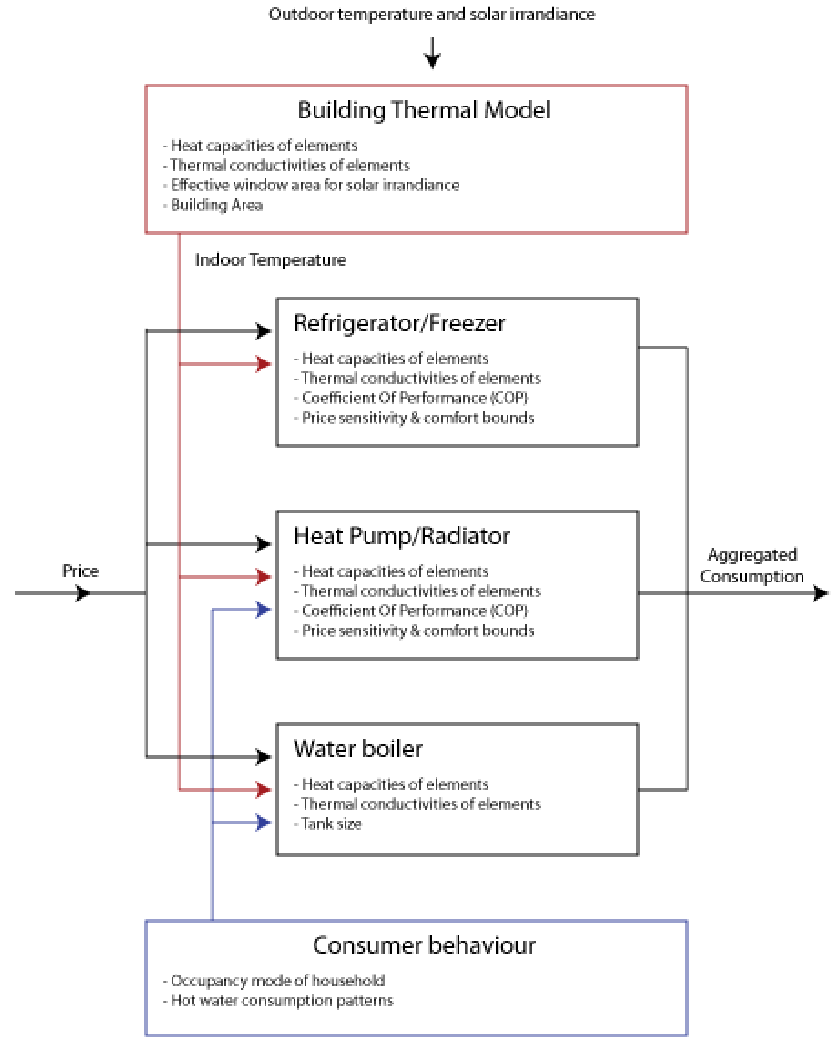


Simulation framework

- Occupancy modes are extracted
from the *Olympic Peninsula* project

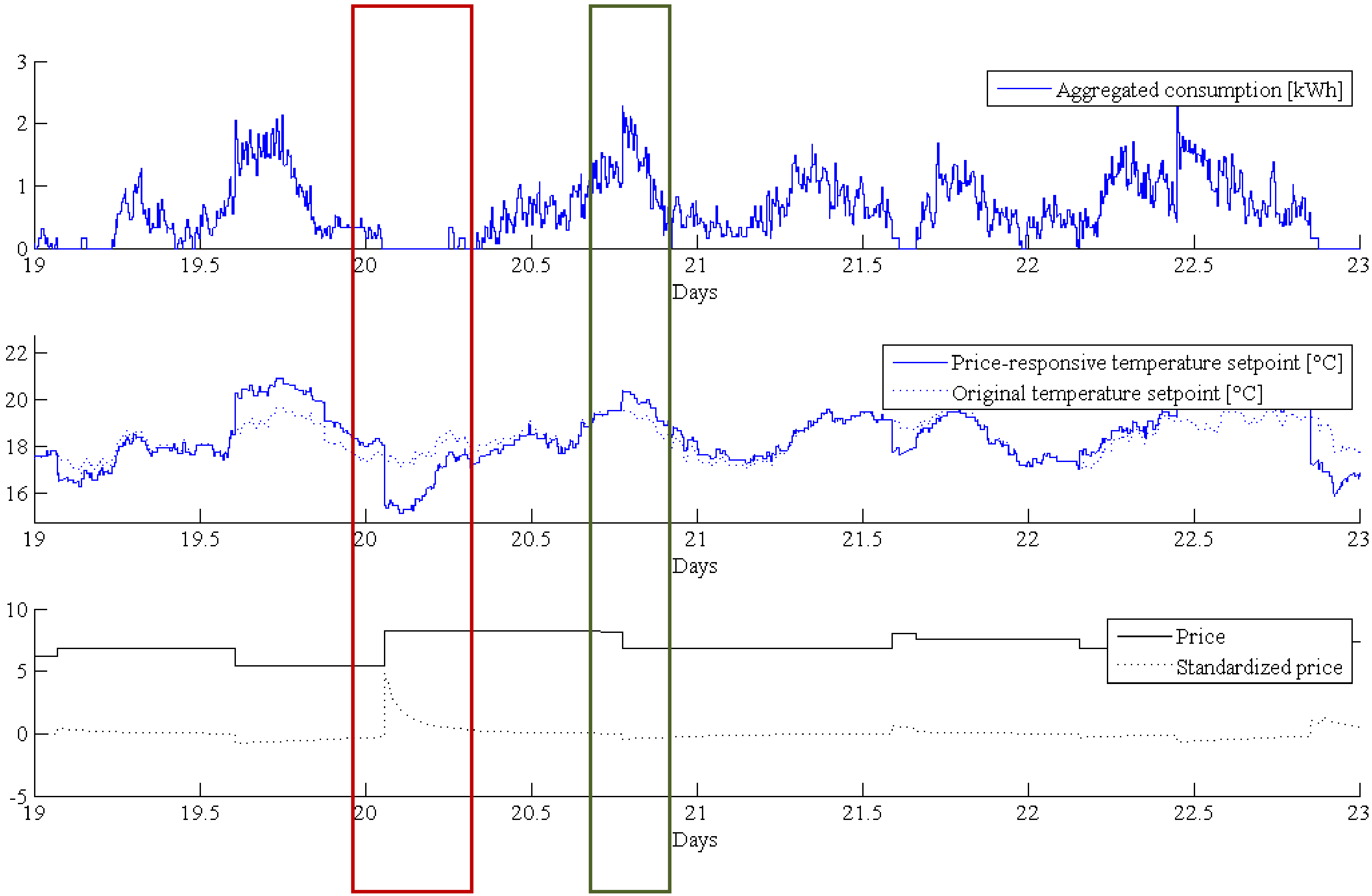
- Building and appliance parameters are randomized based on public statistics





Aggregation (over 20 houses)

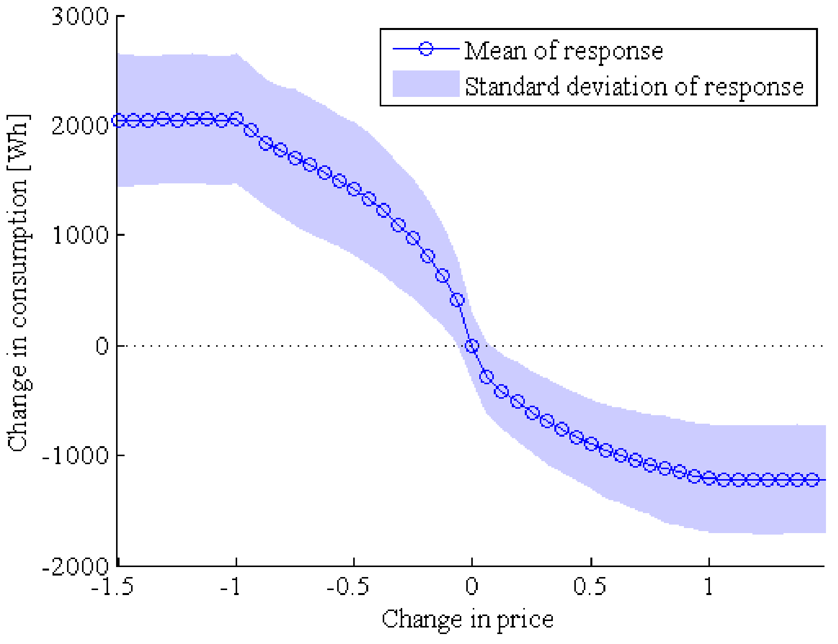
Simulated data (sampling time: 5 min)

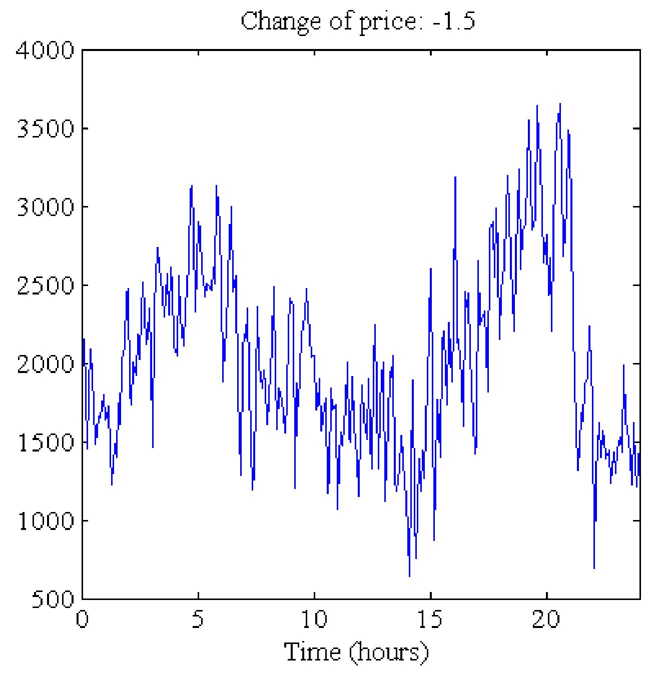


Step 2:

Identify price response

Instant response



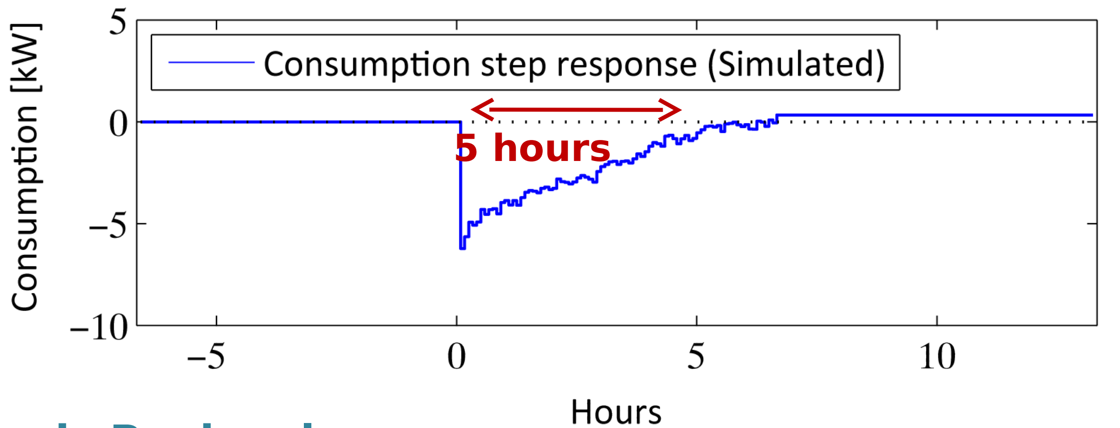


- The price response saturates for extreme prices
- The impact of a price change varies over one day

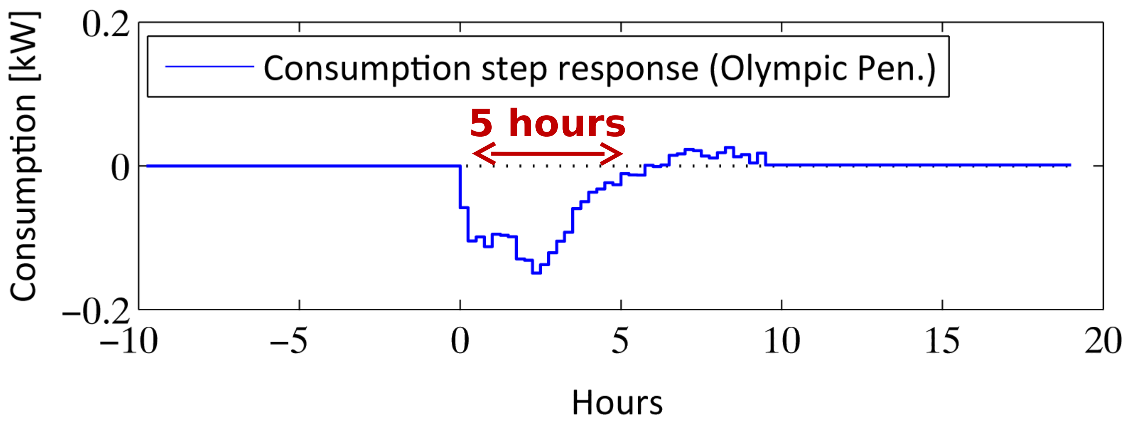
Step response

Model inputs: price, minute of day, outside temperature/dewpoint, sun irrandiance

Simulated



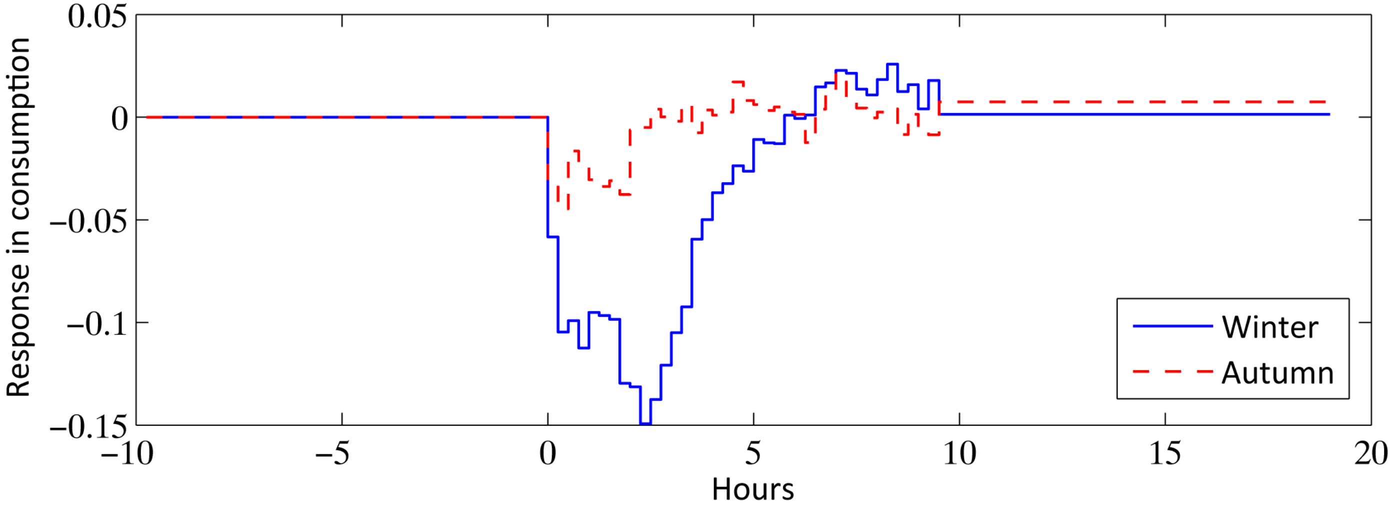
Olympic Peninsula



Step response

Dependency on season

Olympic Peninsula



Step 3:
Control by price

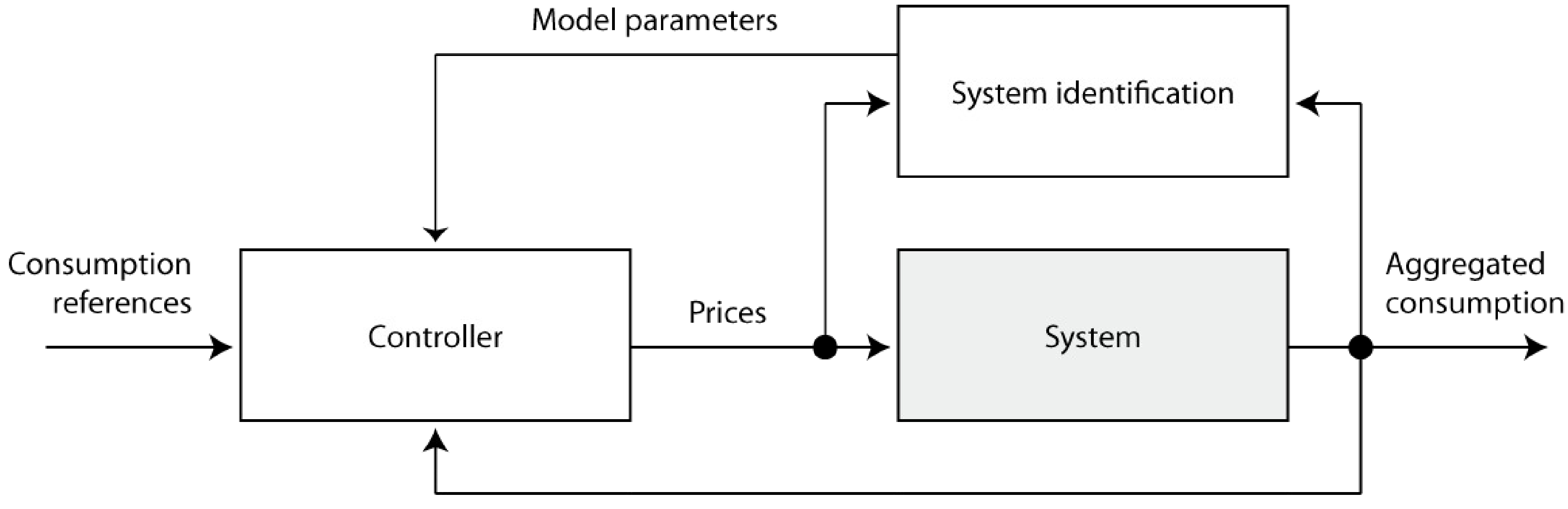
Meibom, P., Baggesen, K.B., Madsen, H., Winther, D.: Energy Comes together in Denmark: *The Key to a Future Fossil-Free Danish Power System*, IEEE Power & Energy Magazine, 11, 46-55, 2013

Madsen, H., Parvizi, J., Halvgaard, R., Sokoler, L.E., Jørgensen, J.B., Hansen, L.H., Baggesen, K.B.: *Control of Electricity Loads in Future Electric Energy Systems*, in Handbook of Clean Energy Systems, Wiley, 2015.

Adaptive control setup

As the system changes during time

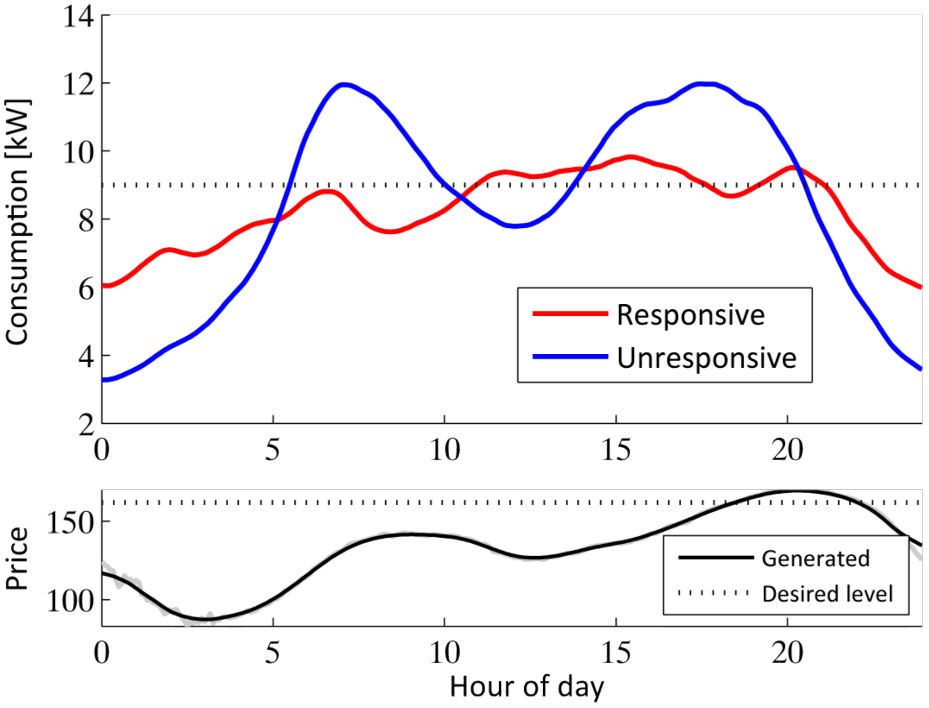
$$\min_{p_{t,1},\ldots,p_{t,k}} \mathbb{E}\left\{\sum_{k=1}^{K} w_{t,k} \left\|\hat{C}_{t,k}\left(p_{t,1},\ldots,p_{t,k},\mathcal{F}_t\right) - C^*_{t,k}\right\|^2 \middle| \mathcal{F}_t\right\}$$



Control performance

With a price penality avoiding its divergence

- Considerable reduction in max consumption
- Mean daily consumption shift



Advantages & Further work

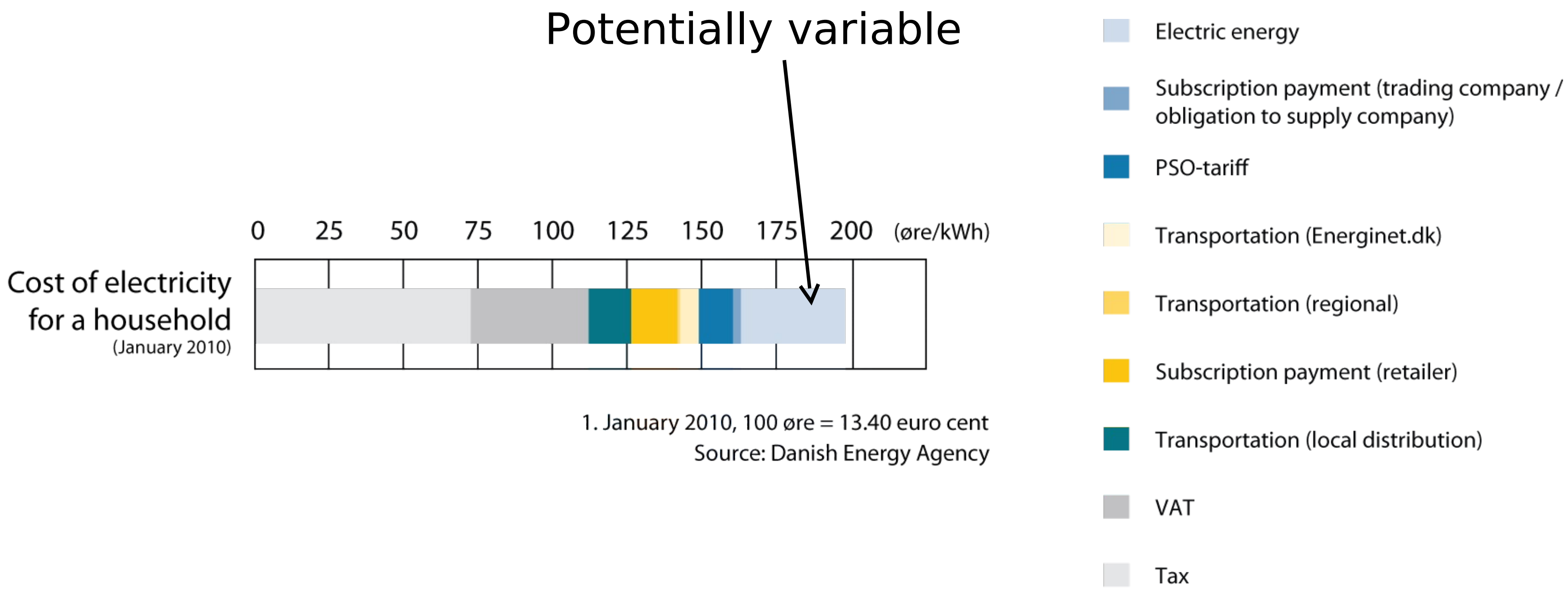
Advantages

- One-way communication is enough
- Increased value for the consumer
- Generalisable to many appliances
- Can be used to manage grid congestion (even locally)

Further work

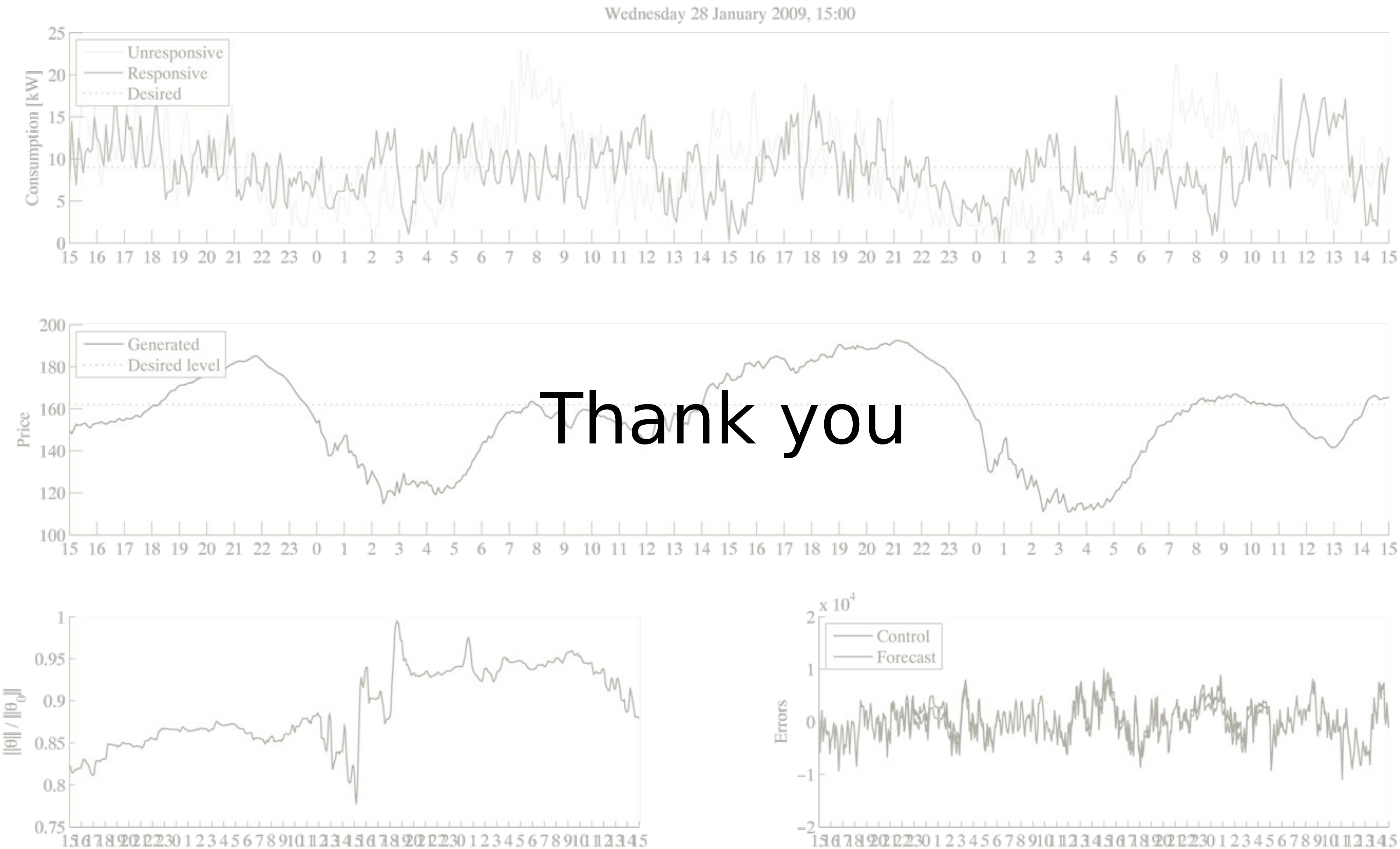
- Test controller on variable reference (e.g. wind production)
- Extend to non-linear price response models
- Incorporate uncertainty into the controller

Electricity price challenge



1. January 2010, 100 øre = 13.40 euro cent
Source: Danish Energy Agency

Thank you


Wednesday 28 January 2009, 15:00
Unresponsive
Responsive
Desired
Consumption [kW]
Generated
Desired level
Price
||θ|| / ||θ0||
x 10^4
Control
Forecast
Errors