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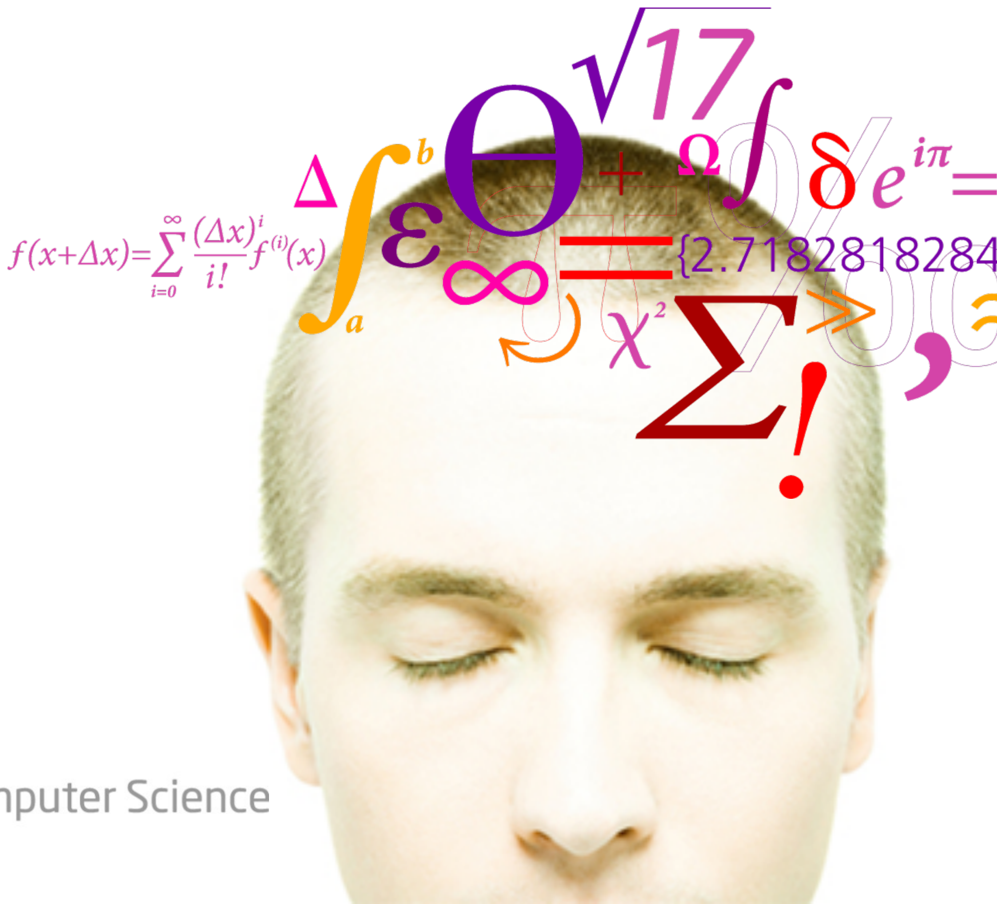
Price Responsive Predictive Control of heat pumps in a family house



Jacopo Parvizi

Consortium Meeting
26-05-2015

DTU Compute
Department of Applied Mathematics and Computer Science

Outline

- **Price responsive units**
- **Test Facility**
- **System's Architecture**
  - Components
  - Communication
- **Models**
- **Controller**
- **Results of experiments**

Why Price Responsive Units?

- The basic motivation of applying the Economic Model Predictive Control framework, in energy efficient buildings, is to have the ability to compute optimal control actions incorporating weather and consumption forecasts.

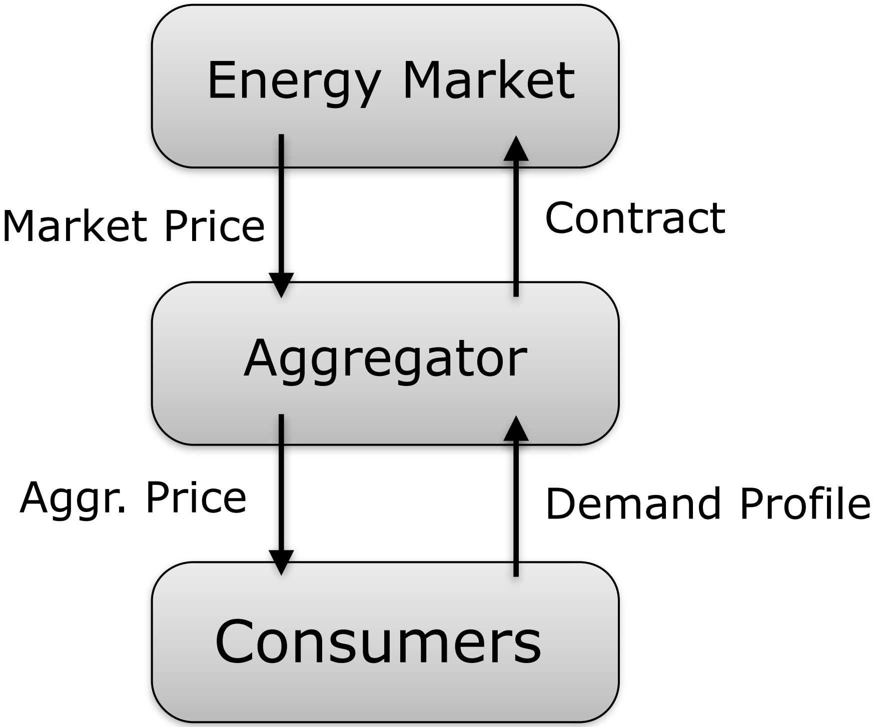
- Wind power uncertainty can be managed at a lower cost by adjusting electricity consumption in case of wind forecast errors, which is another way in which demand response facilitates the integration of intermittent renewables.

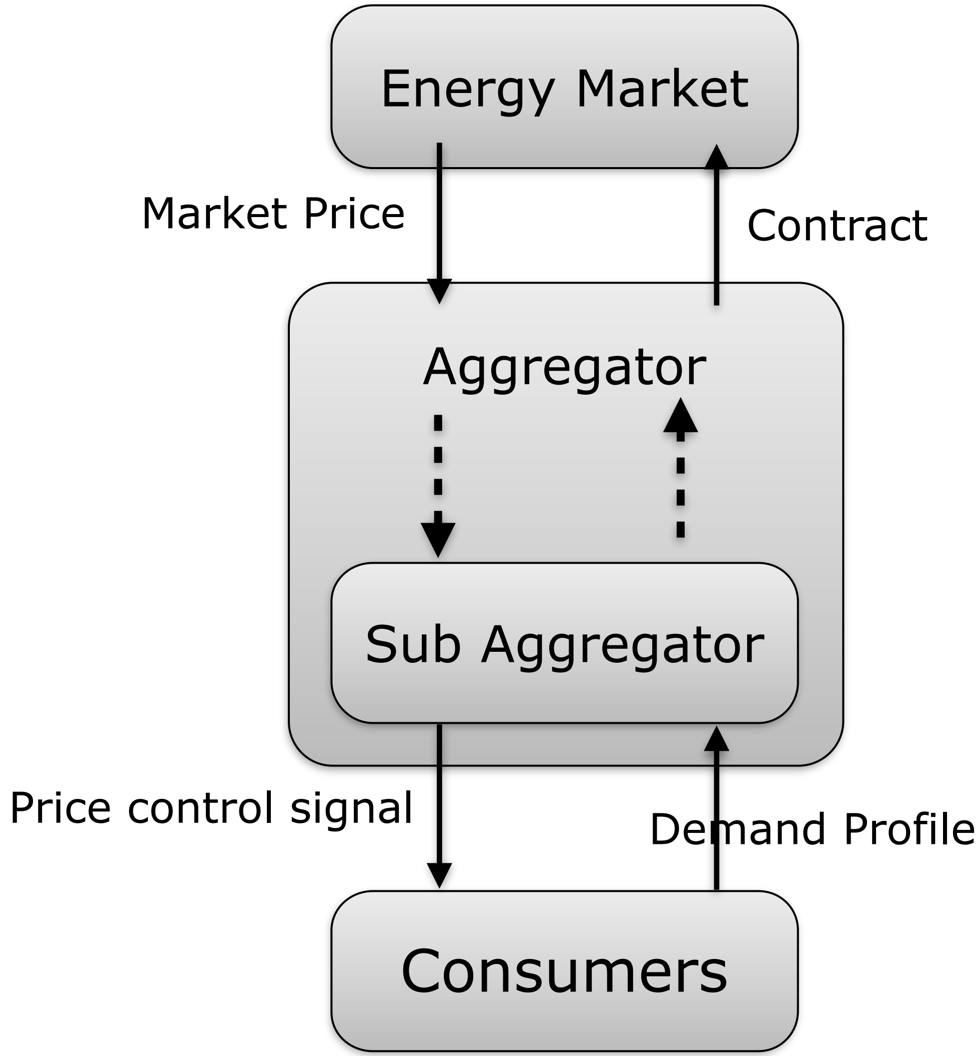
- The short-term supply and demand are balanced during periods of high penetration of renewable energy.

- This new control scheme started flourishing in power systems applications related with Smart Grids, but it is at his infant stage.

- The focus of this work was on the implementation of an EMPC controller to reduce the energy costs in a residential family house.

Energy Markets for Price Responsive Units





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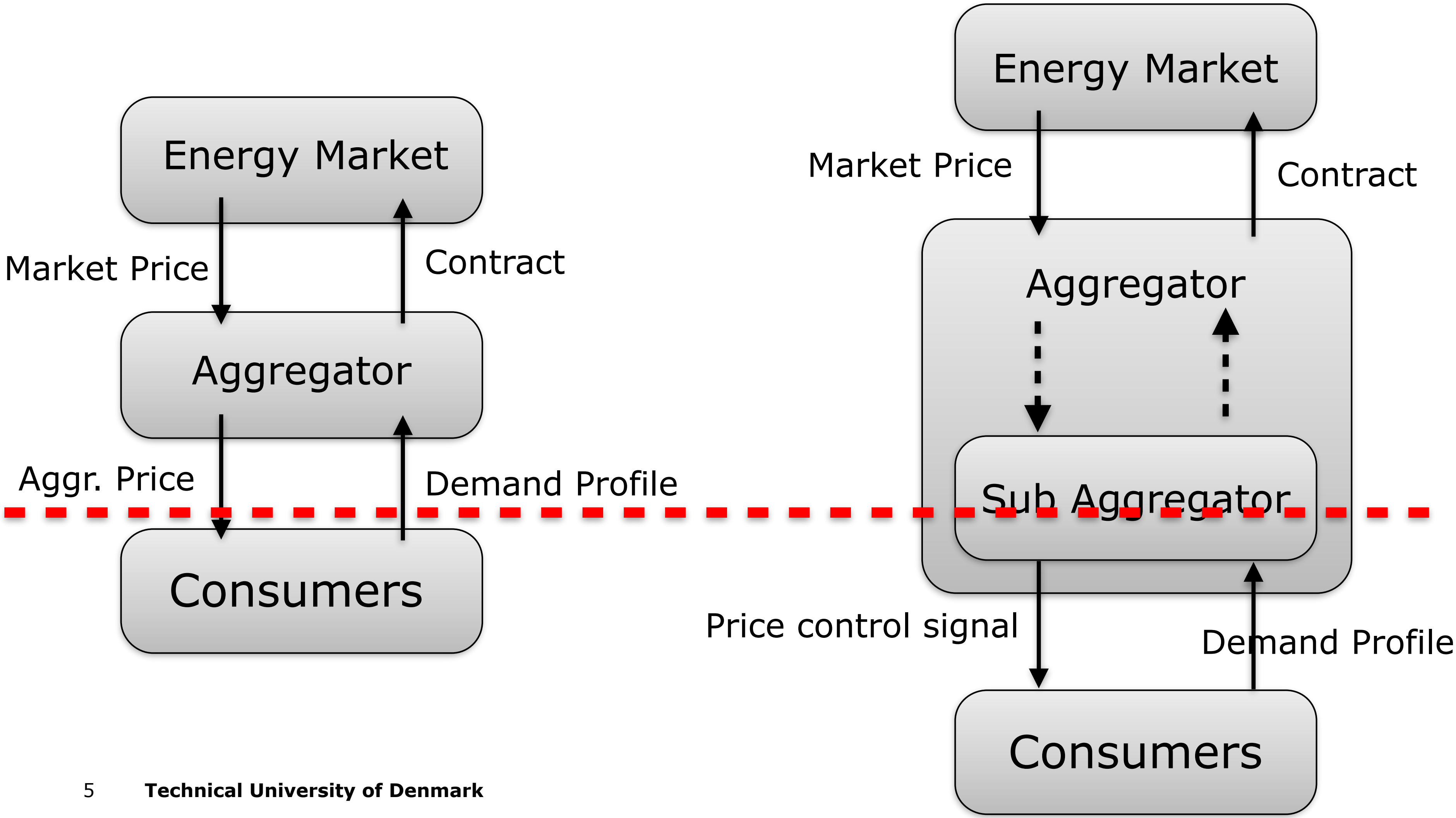
Energy Markets for Price Responsive Units



Test Facility

Test Facility

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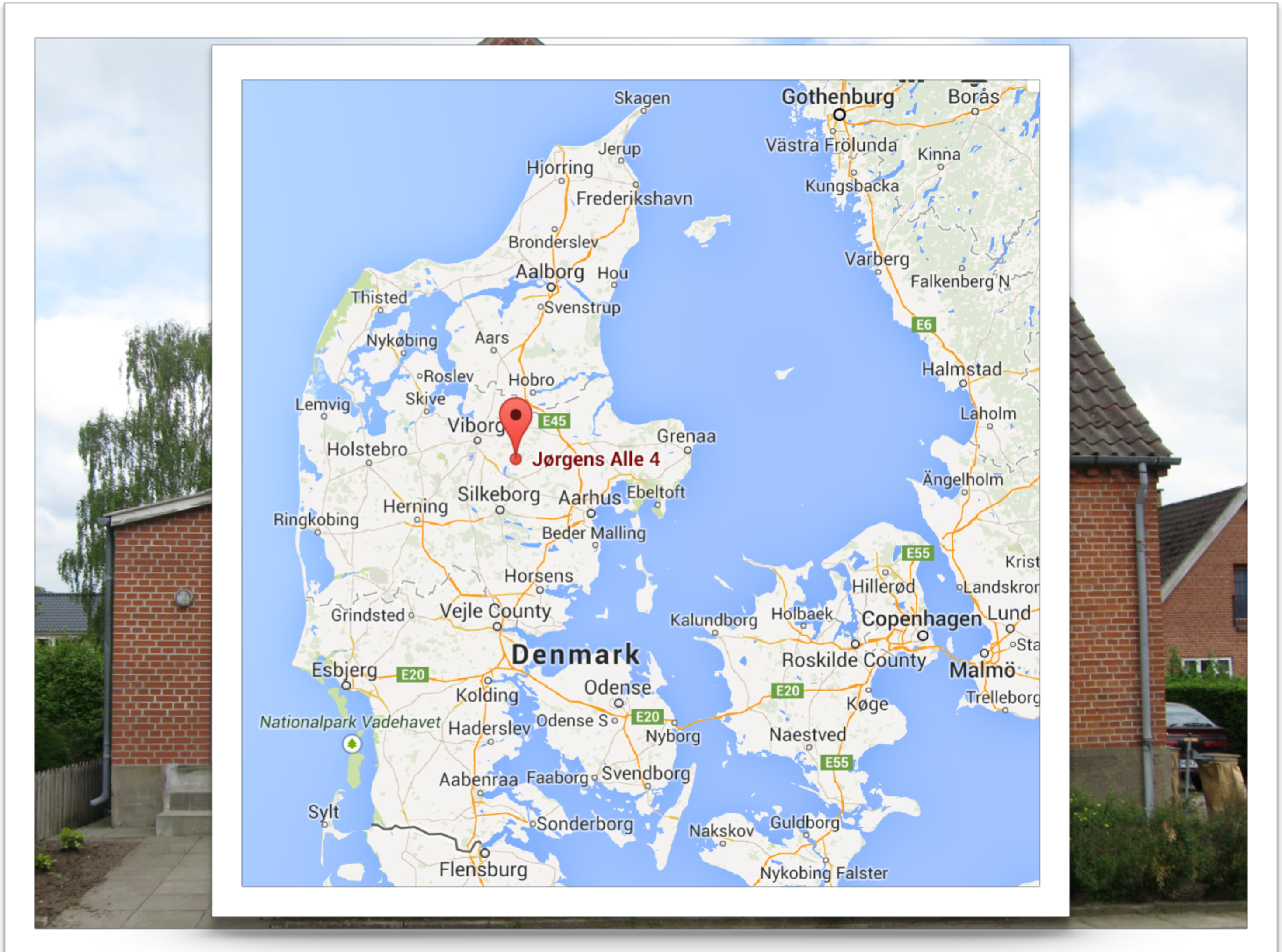
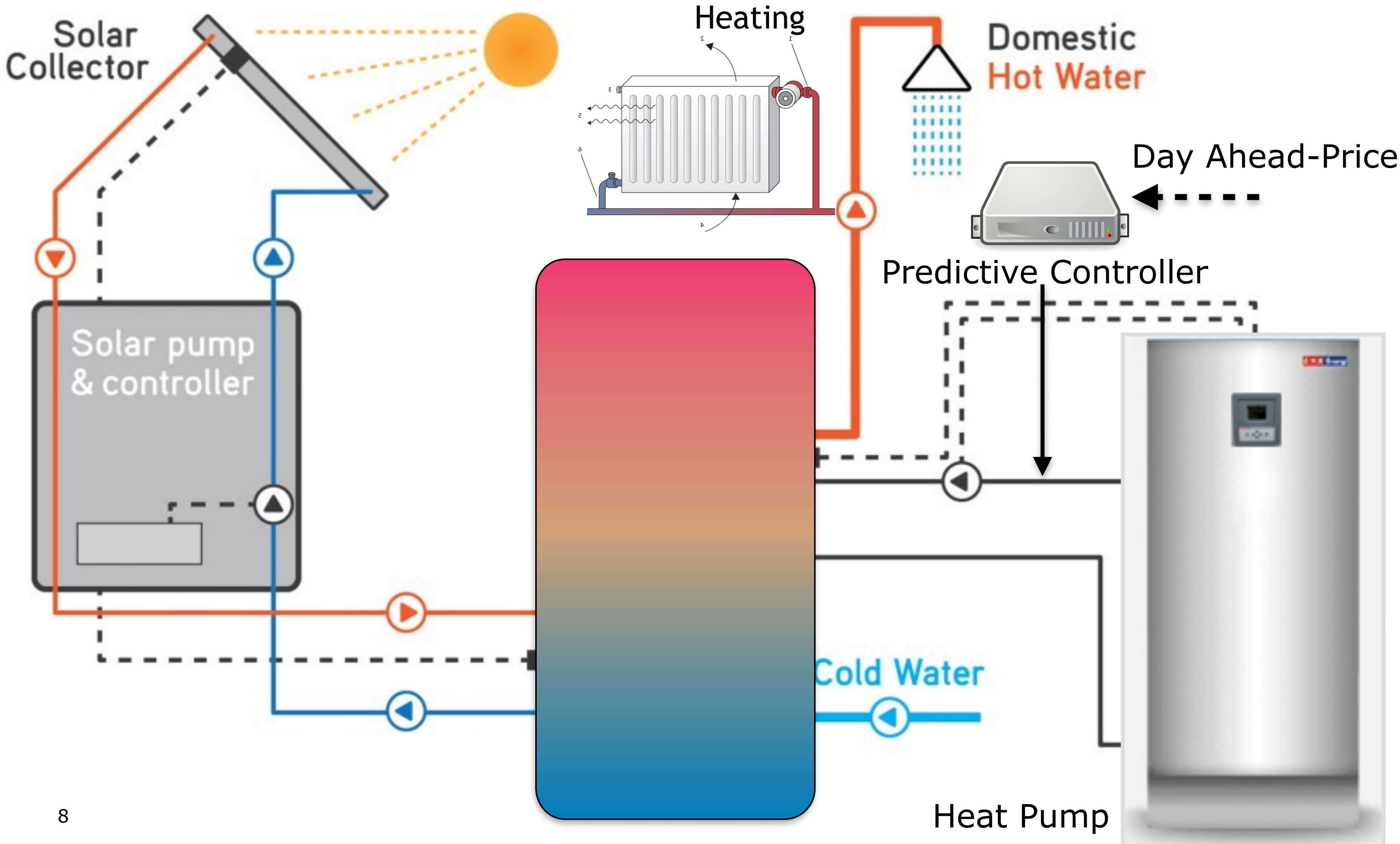
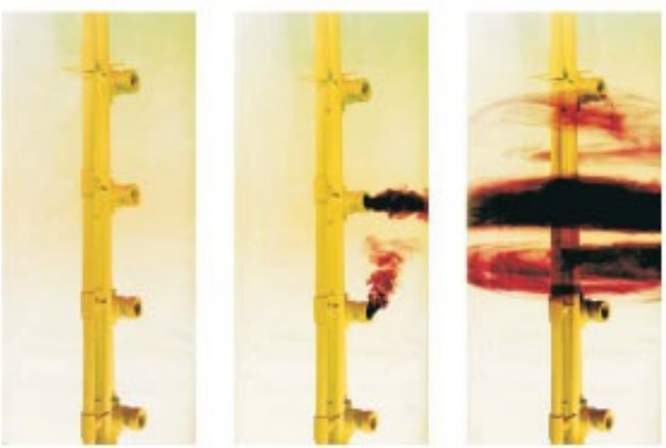


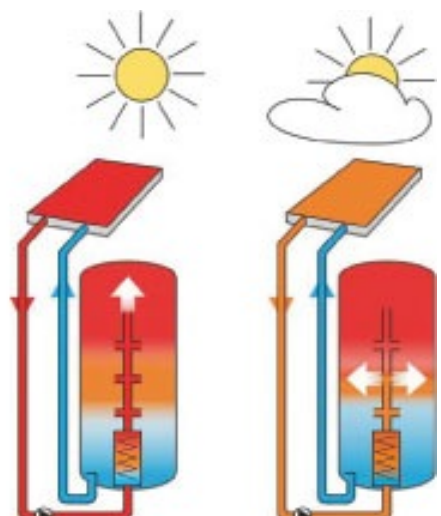
Heating System



Hot Water Tank

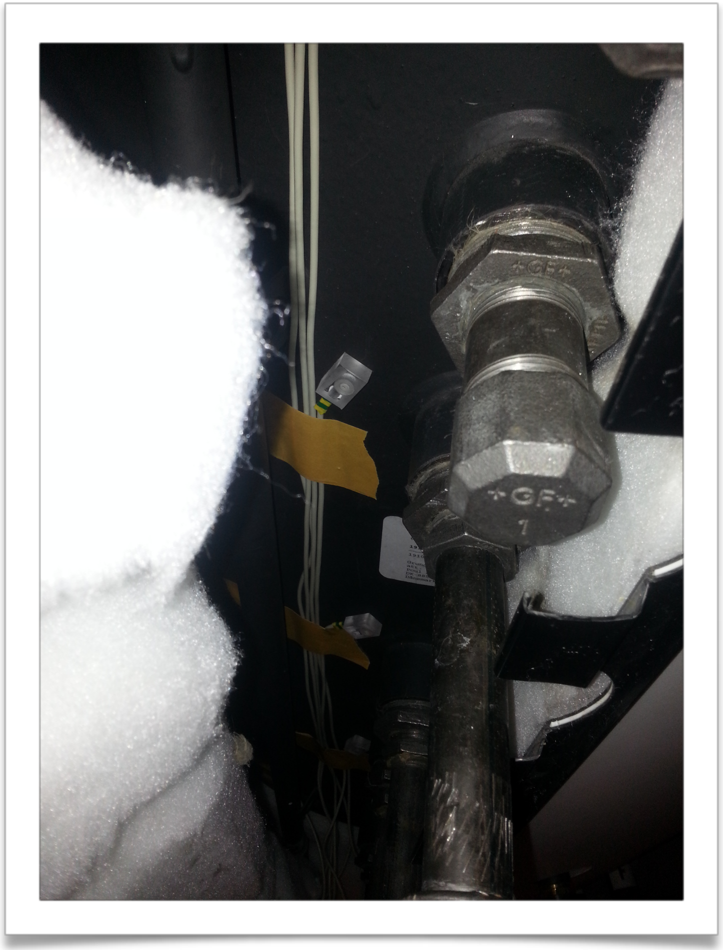
600L Hot Water Tank
- Stratified
- Multiple Connections
- Good with Solar Thermal System





Hot Water Tank - Sensors

- 8 Temperature Sensors are placed equidistantly from each other on the hot water tank



Solar Thermal Collector

- Wall mounted. 7.2 m2
- Approx. 90% effectiveness compared to the optimal tilt

Heat Pump

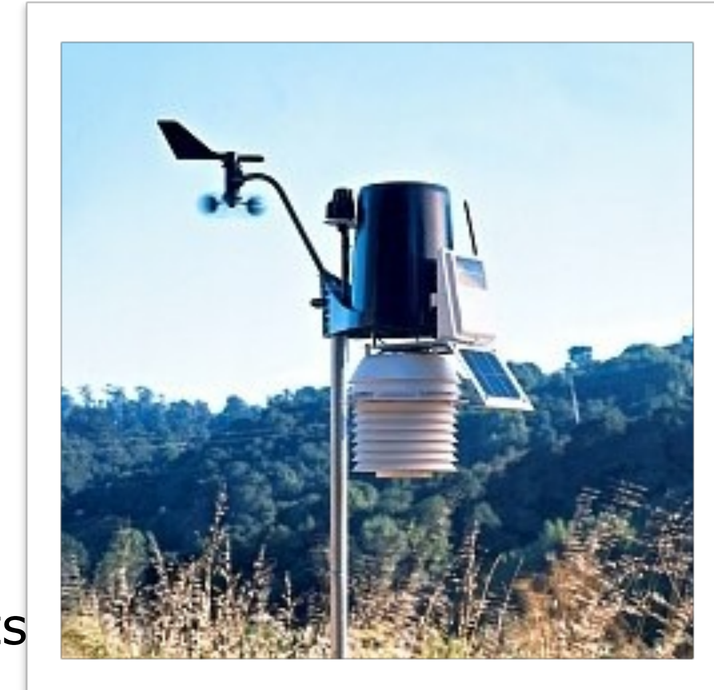
- Delivers from 1.5 to 7 kW
- Variable speed compressor
- Grundfos pumps
- 300m ground pipe

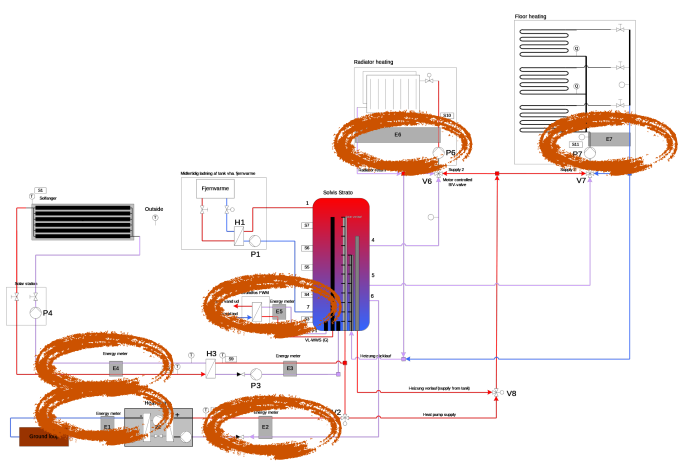
Domestic hot water and district heating

- Sonnenkraft / Grundfos Fresh water module
- District heating connected as backup

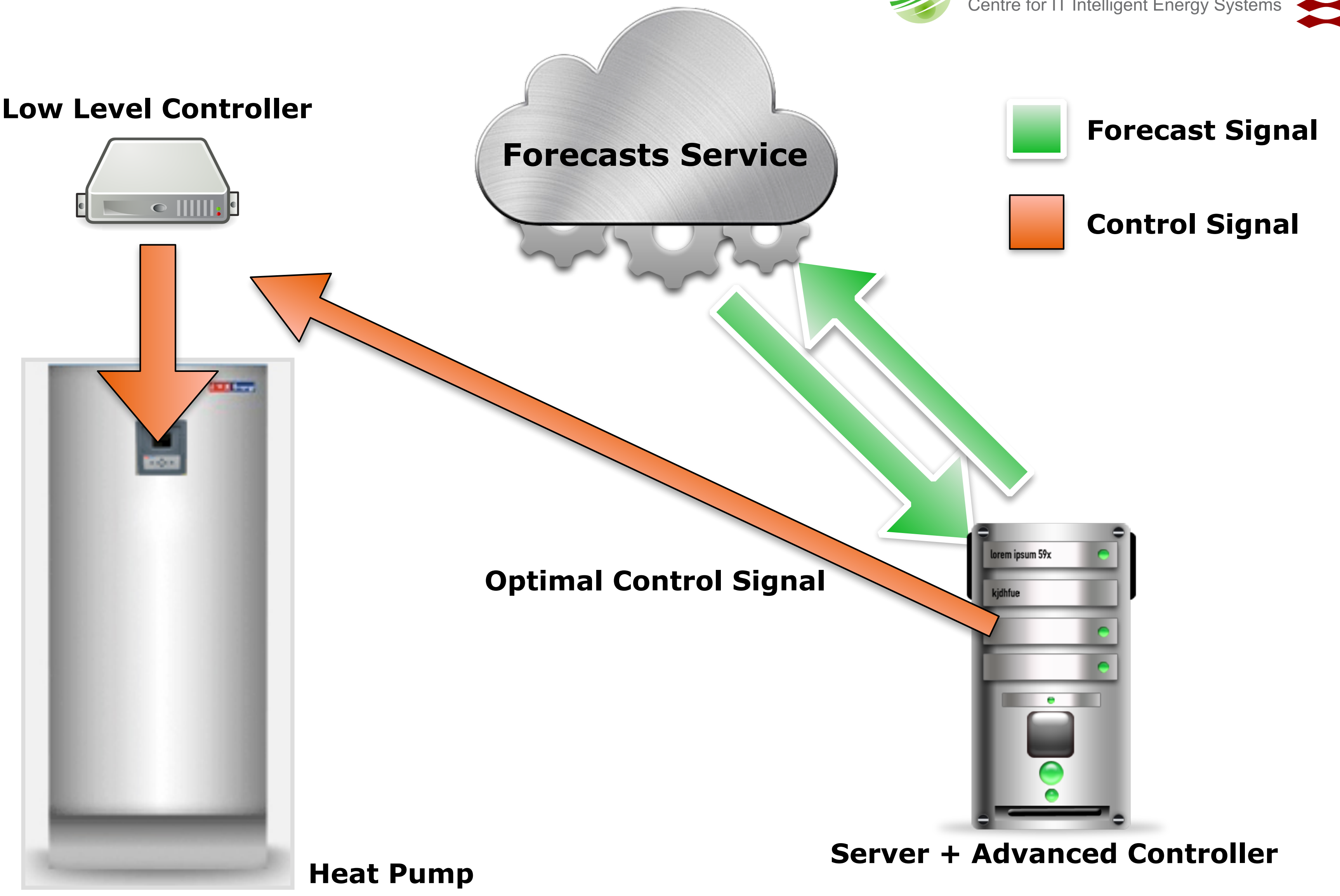
Sensors

- Weather Station
  - Davis Vantage Pro2 Plus
- Heat Meters
  - Kamstrup Multical in water circuits
  - Sontex Multical in brine circuits
- Wireless temp. sensors
  - Room and floor Temps



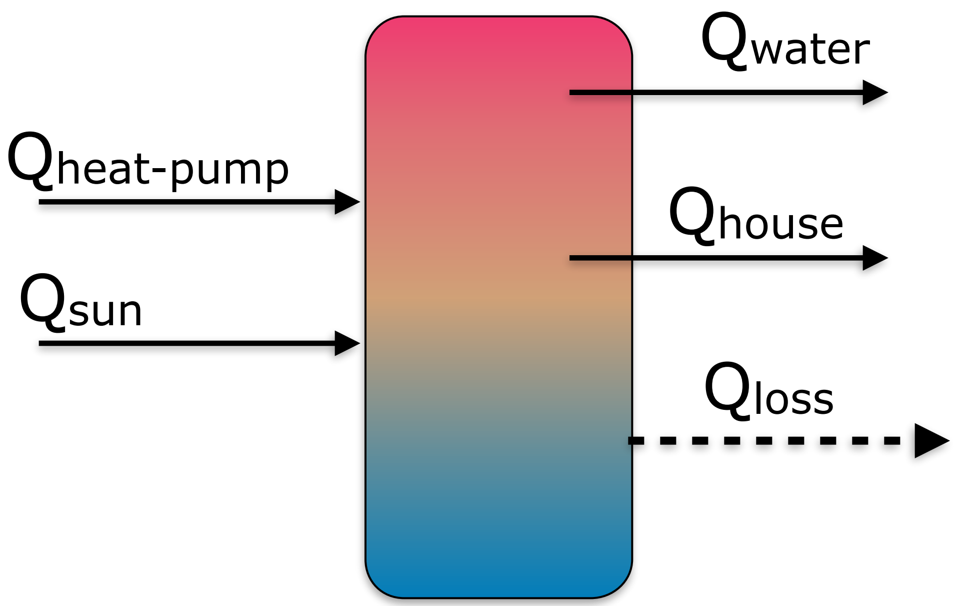


Controller Communication

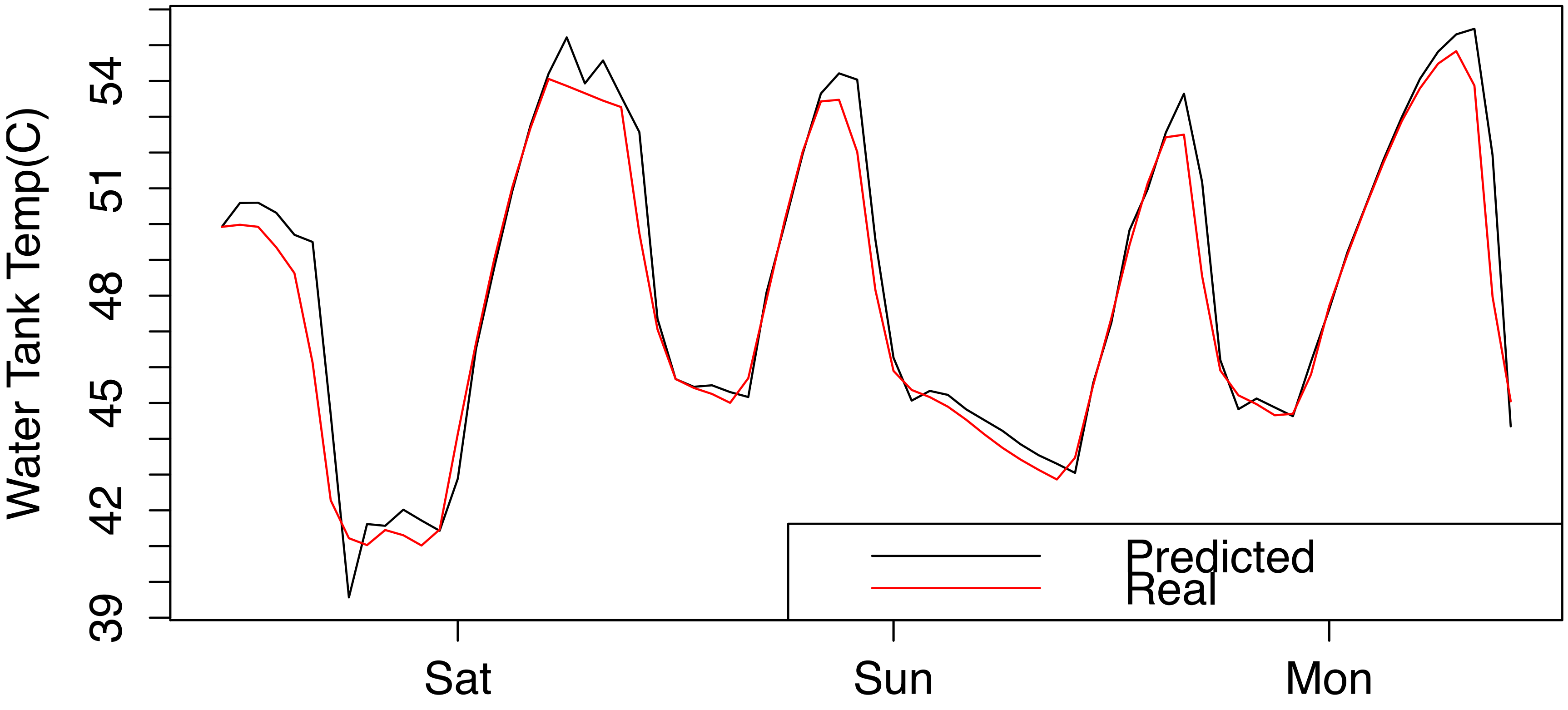


Tank Model

$$C_{tank}\frac{dT_{tank}}{dt} = \frac{1}{R_t}(T_{room} - T_{tank}) + Q_{solar} + Q_{heatPump} - Q_{house} - Q_{tapWater} + \sigma_{E_1}\frac{dW}{dt}$$



Tank Model



Economic MPC

$$\min_{\{u_k\}_{h=0}^{N-1}} \phi = \sum_{h=0}^{N-1} \hat{p}_{k+h|k}^T u_{k+h|k} + \sum_{h=1}^{N} \rho v_{k+h|k}$$

$$\begin{aligned}
\text{s.t.} \quad & x_{k+1+h|k} = A x_{k+h|k} + B u_{k+h|k} + E d_{k+h|k} \\
& y_{k+h|k} = C x_{k+h|k} \\
& u_{min} \leq u_{k+h|k} \leq u_{max} \\
& \Delta u_{min} \leq \Delta u_{k+h|k} \leq \Delta u_{max} \\
& y_{k+h|k} + v_{k+h|k} \geq z_{k+h|k}^{min} \\
& y_{k+h|k} - v_{k+h|k} \leq z_{k+h|k}^{max} \\
& v_{k+h|k} \geq 0
\end{aligned}$$

$k \in \{0, 1, \ldots, N\}$. $T_s = 1$ h

- Output and state $y = x = T_{tank}$
- Disturbances $d = [\hat{Q}_{sun}, \hat{Q}_{house}]$
- Electricity price p

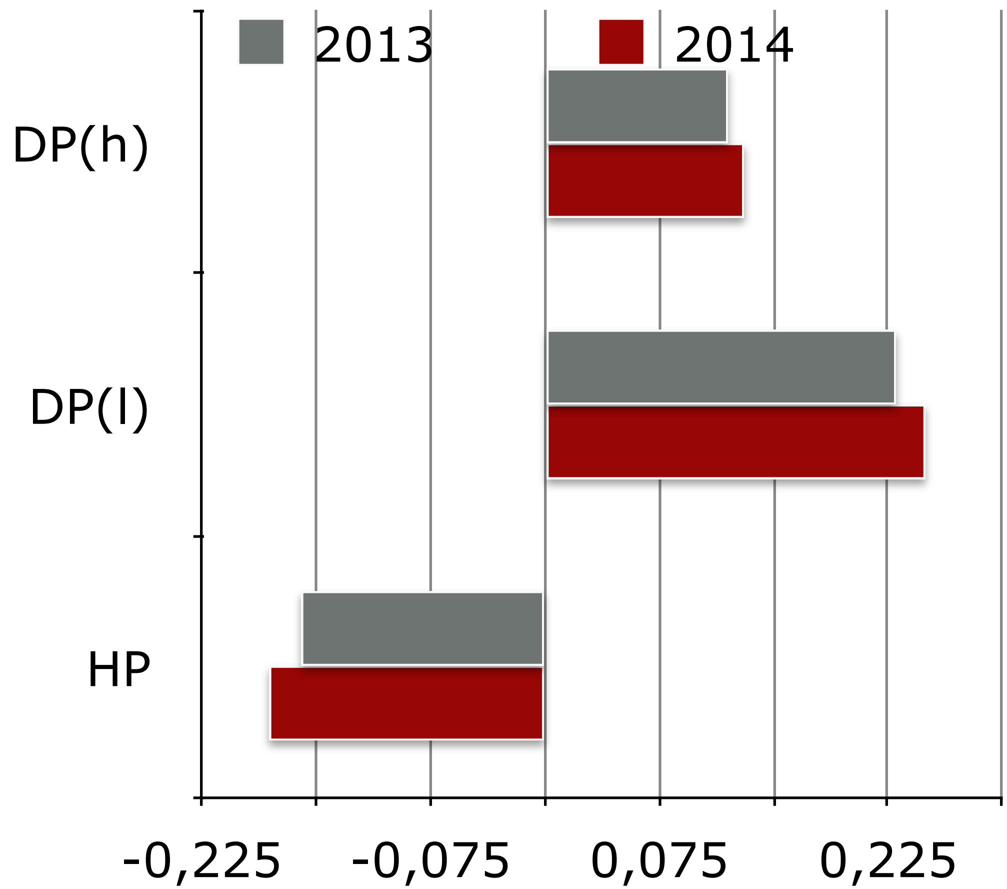
Advanced Controller

Results - Economic Savings Against Flat Tariff

» Dynamic Price (high penalty)

» Dynamic Price (low penalty)

» Normal Use Heat Pump

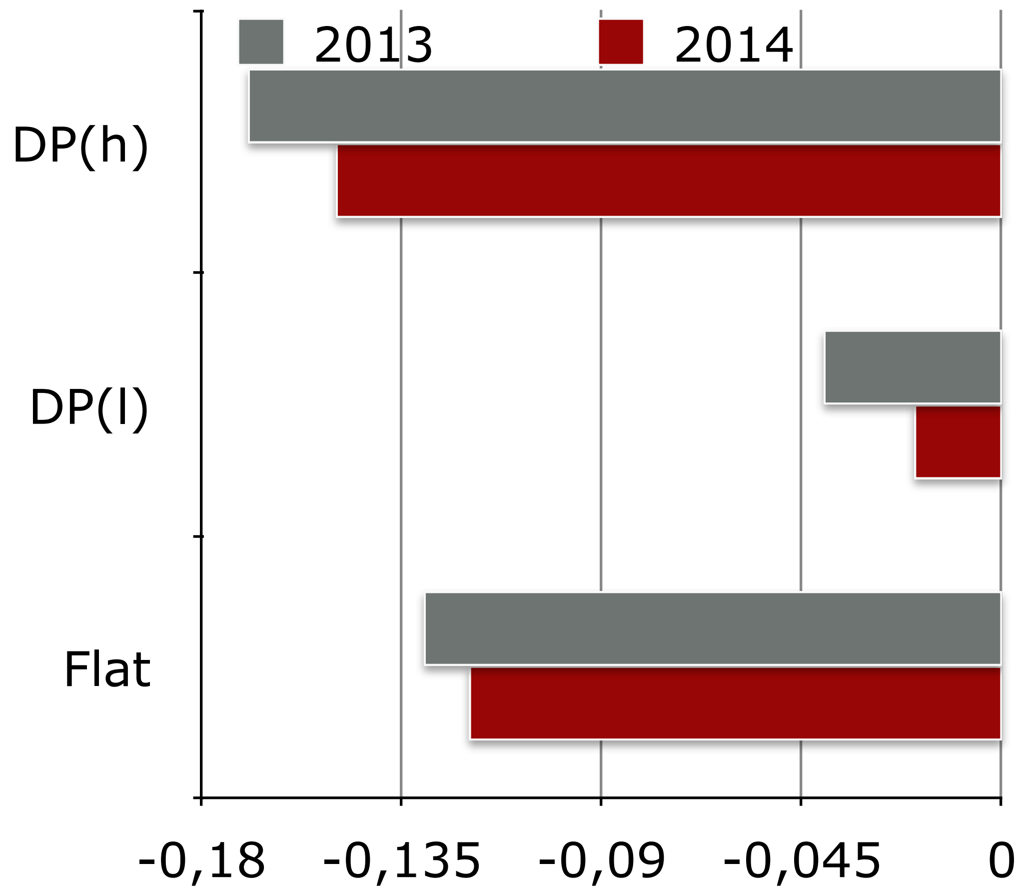


Results - Energy Consumption

» Dynamic Price (high penalty)

» Dynamic Price (low penalty)

» Flat Tariff



Conclusions

» In this experiment we implemented an Economic MPC that takes into account not only the weather predictions. Other energy sources are forecasted providing better performances

» Economic savings are up to 24%

» Prediction horizon doesn't influence the savings due to limited storage capacity

» Missing forecasts must be computed locally

» Houses with higher demand require additional heat sources (e.g electric heater)

» Models and controller parameters need to be automated

Thank you for your attention

Jacopo Parvizi

jacop@dtu.dk

www.imm.dtu.dk/~jacop

Department of Applied Mathematics and Computer Science
Technical University of Denmark