CITIES

Center for

IT-Intelligent Energy Systems in Cities

WP 5 – Forecasting and Control

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DTU Compute

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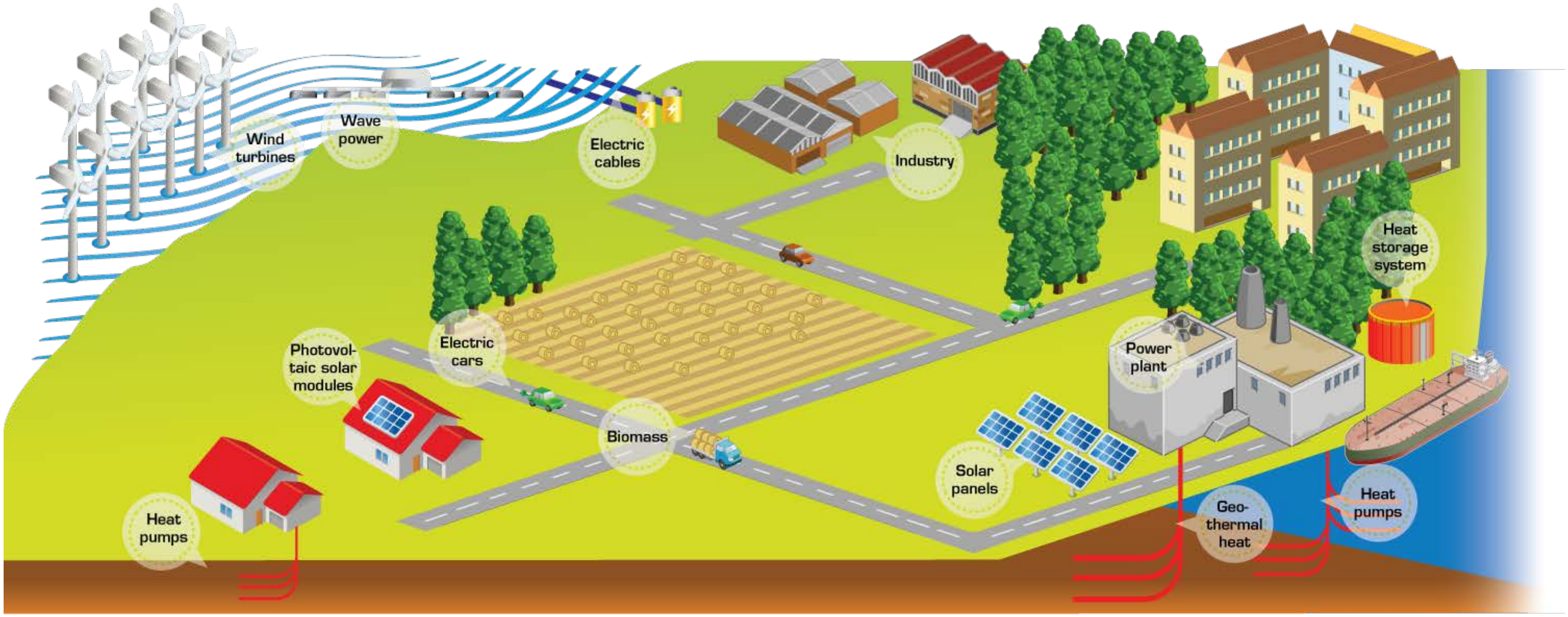
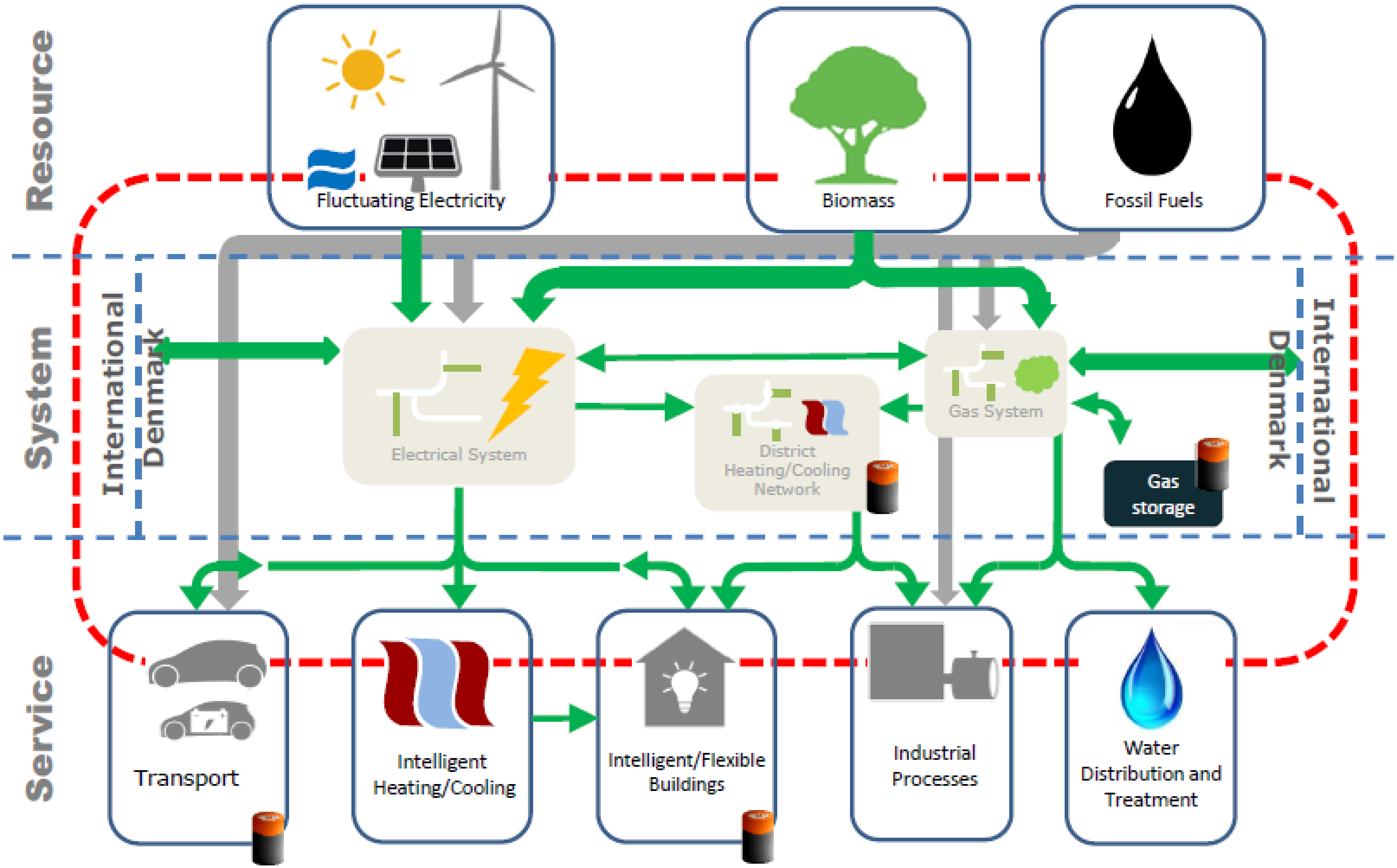
Smart Energy Systems

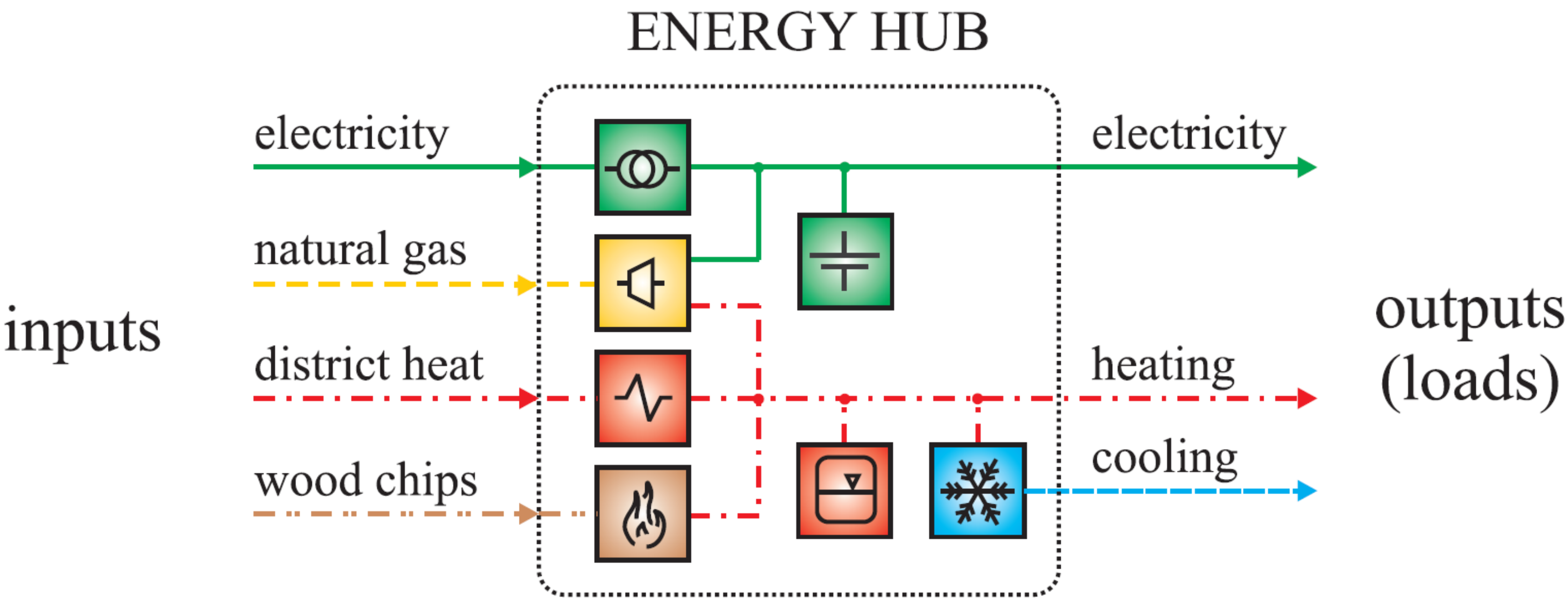


- Thermal Storage
  - Heating of floors etc
  - Heating of water accumulation tanks
  - Refrigeration Systems
- Power / Heat Producers
  - Wind Turbines
  - Photovoltaic Solar Modules
  - Solar Panels
  - CHP Plants
  - Fuel Cells

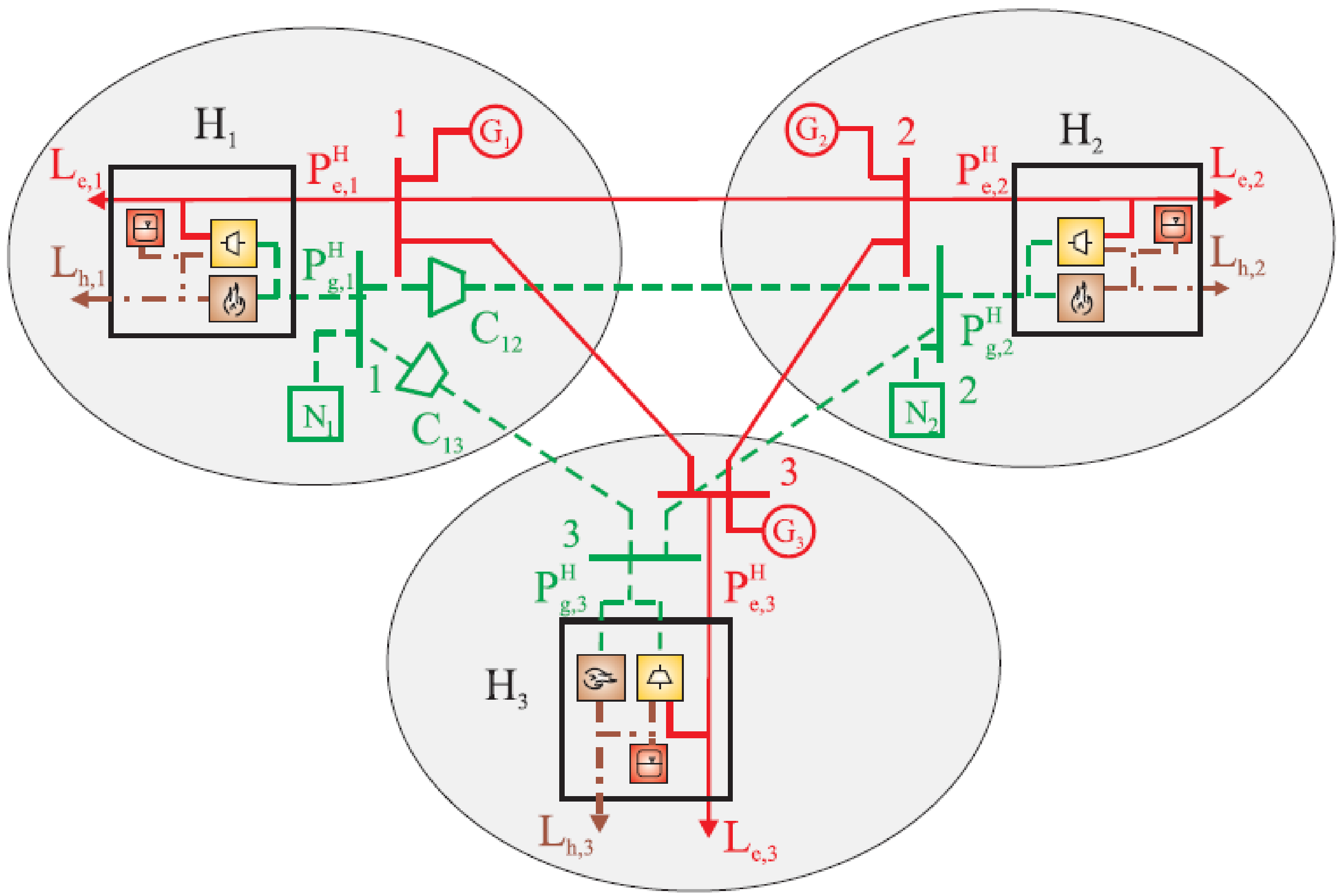
Connected Energy Systems



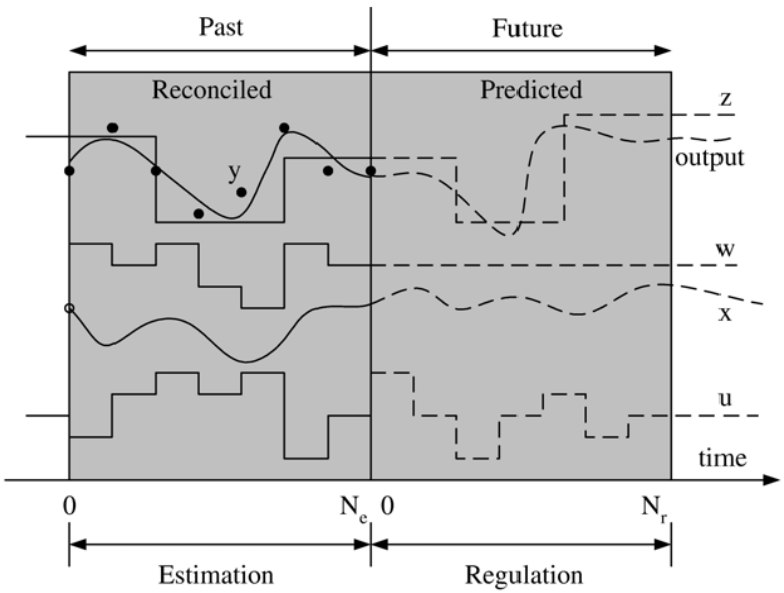
Electricity & Heating / Cooling

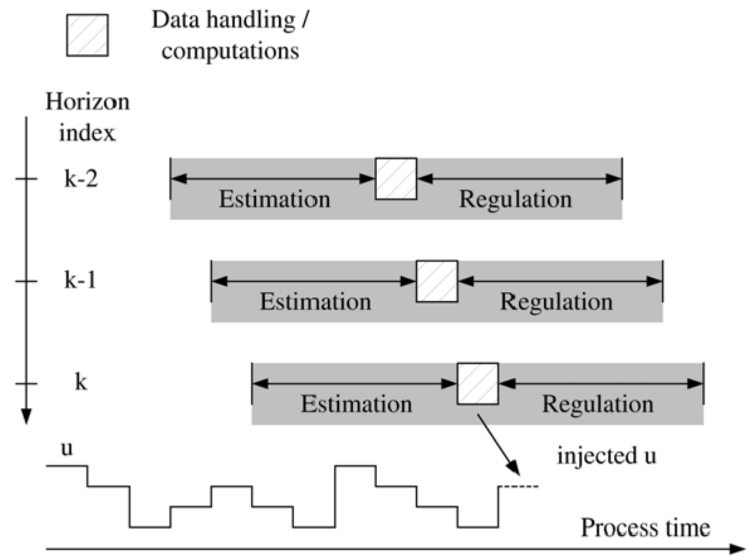


Multiple Connected Energy Hubs



Model Predictive Control





$$
\begin{aligned}
\min_{\{u_k, x_{k+1}\}_{k=0}^{N-1}} \quad & \phi = \phi(\{u_k, x_{k+1}\}_{k=0}^{N-1}; x_0, \theta) \\
s.t. \quad & x_{k+1} = F_k(x_k, u_k, \theta) \qquad k = 0, 1, \ldots, N-1 \\
& u_k \in \mathcal{U}
\end{aligned}
$$

Economic MPC
Mathematical Optimization

The portfolio power generation problem can be stated as

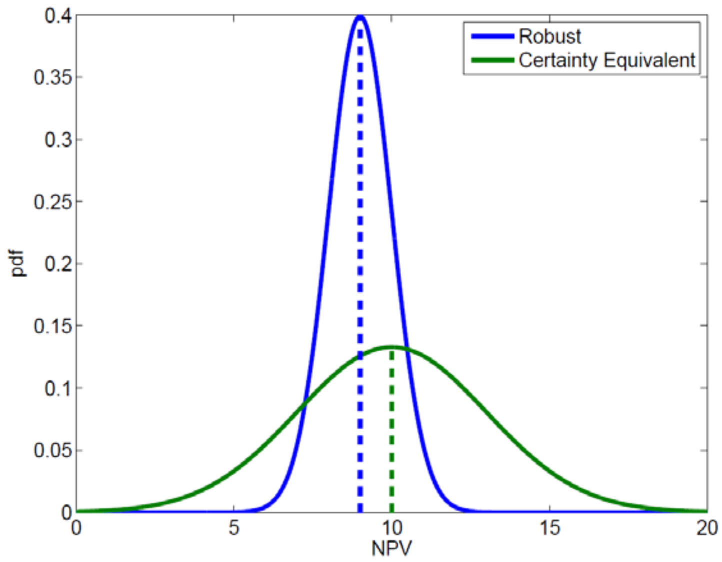
$$\min_{\{u_k\}_{k=0}^{N-1}} \quad \phi = \sum_{k=0}^{N-1} c' u_k$$

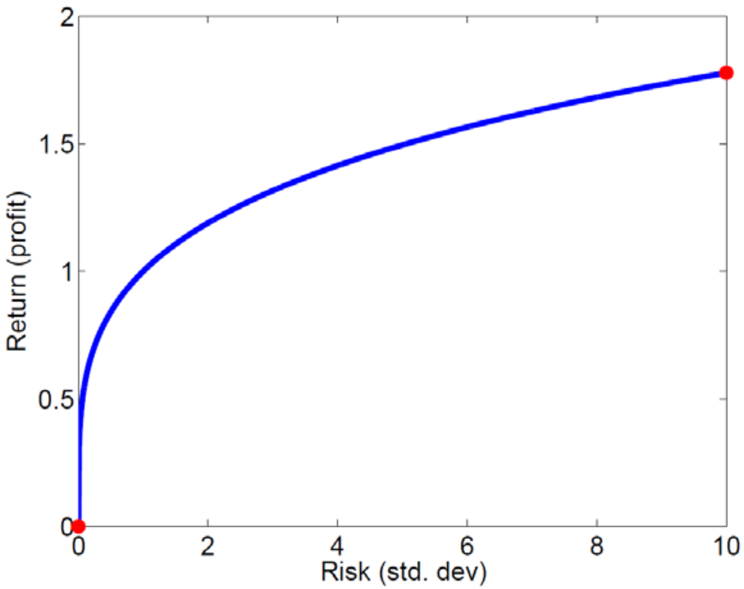
$$\begin{aligned}
s.t. \quad & x_{k+1} = Ax_k + Bu_k + Ed_k && k = 0, 1, \ldots, N-1 \\
& y_k = Cx_k && k = 1, 2, \ldots, N \\
& u_{\min} \leq u_k \leq u_{\max} && k = 0, 1, \ldots, N-1 \\
& \Delta u_{\min} \leq \Delta u_k \leq \Delta u_{\max} && k = 0, 1, \ldots, N-1 \\
& y_k \geq r_k && k = 1, 2, \ldots, N
\end{aligned}$$

The parameters for this problem are

- Initial state, x_0, and previous decision, u_{-1}
- Predicted loads on non-controllable generators (e.g. wind speed on wind turbines): $\{d_k\}_{k=0}^{N-1}$
- Predicted power demand: $\{r_k\}_{k=1}^{N}$

Economic MPC for Uncertain Systems





$$\max_{x \in \mathbb{R}^n} \quad \psi(x) = \alpha \overbrace{E_\theta \left\{ R(x,\theta) \right\}}^{\text{Mean profit}} - (1-\alpha) \overbrace{V_\theta \left\{ R(x,\theta) \right\}}^{\text{Profit variance}}$$

Bi-Criterion Economic MPC

$$
\begin{aligned}
\min_{\{u_k, x_{k+1}\}_{k=0}^{N-1}} \quad & \phi = \phi(\{u_k, x_{k+1}\}_{k=0}^{N-1}; x_0, \theta) \\
s.t. \quad & x_{k+1} = F_k(x_k, u_k, \theta) \qquad k = 0, 1, \dots, N-1 \\
& u_k \in \mathcal{U}
\end{aligned}
$$

Least Squares Objective

$$
\phi_{\text{reg}} = \frac{1}{2} \left(\sum_{k=0}^{N-1} \|x_k(\theta) - \bar{x}_k\|_Q^2 + \|u_k(\theta) - \bar{u}_k\|_R^2 \right) + \frac{1}{2} \|x_N(\theta) - \bar{x}_N\|_P^2
$$

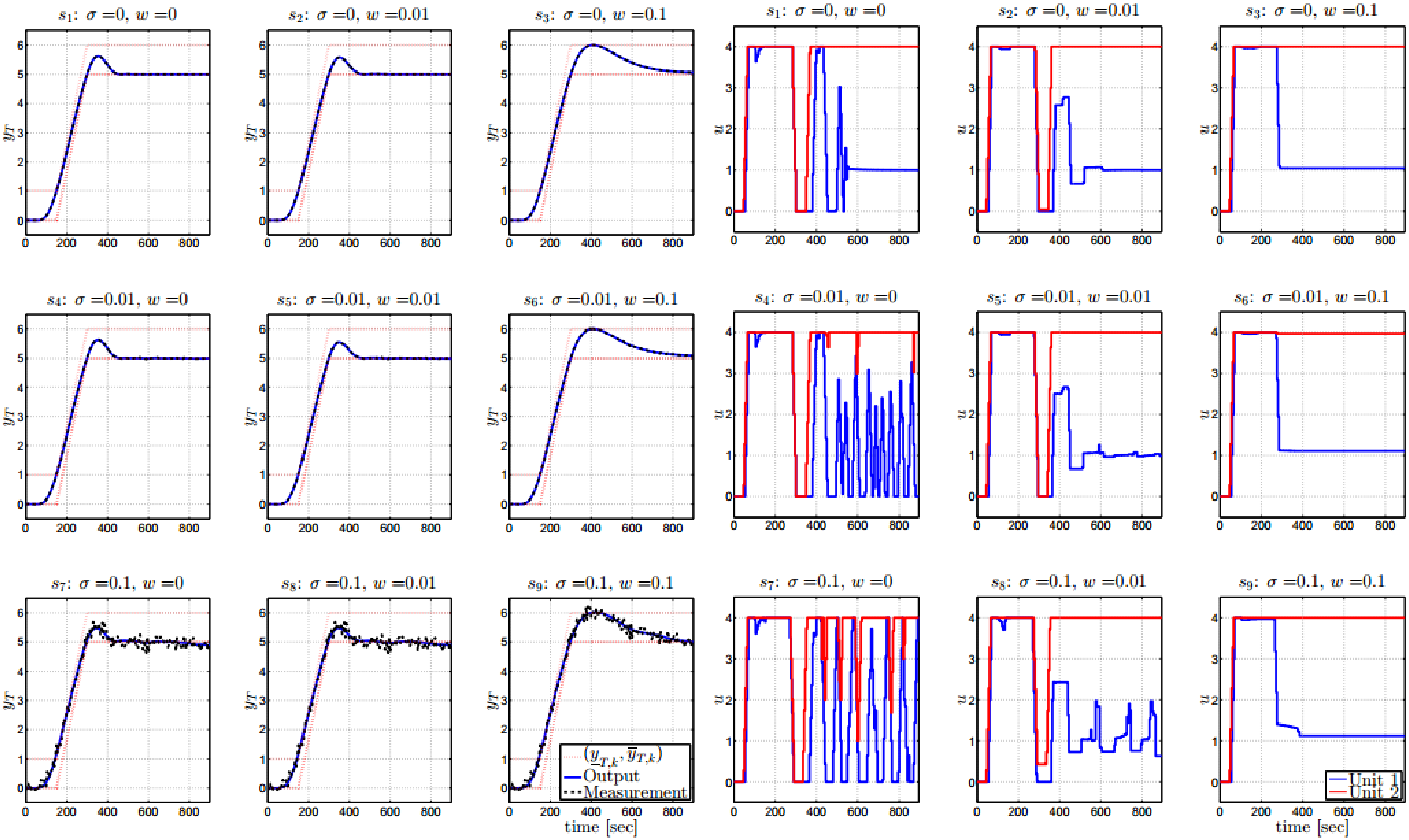
Economic Objective - cost, profit, ...

$$
\phi_{\text{eco}} = \sum_{k=0}^{N-1} l_k(x_k, u_k, \theta) + l_N(x_N, \theta)
$$

Bi-criterion (cost and variance)

$$
\phi = \phi(x, u, \theta) = \alpha \phi_{\text{eco}} + (1 - \alpha) \phi_{\text{reg}} \qquad \alpha \in [0,\ 1]
$$

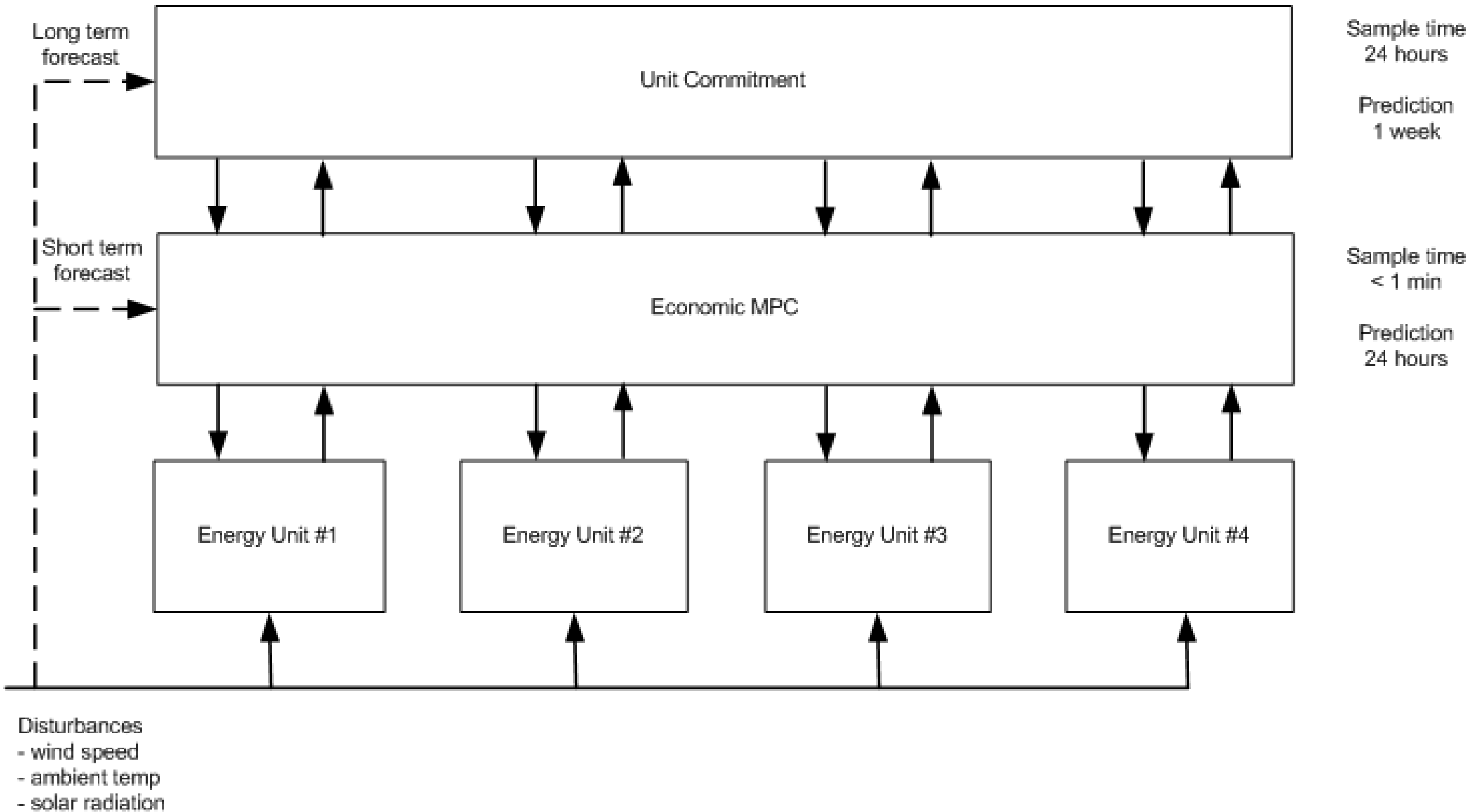
Risk Mitigation (Regularization)



(a) Total power output, y_T.

(b) Inputs (power setpoints), u_1 and u_2, for each power plant.

Hierarchical Control Structure



Case Study

Energy Efficient Refrigeration and Flexible Power Consumption in a Smart Grid

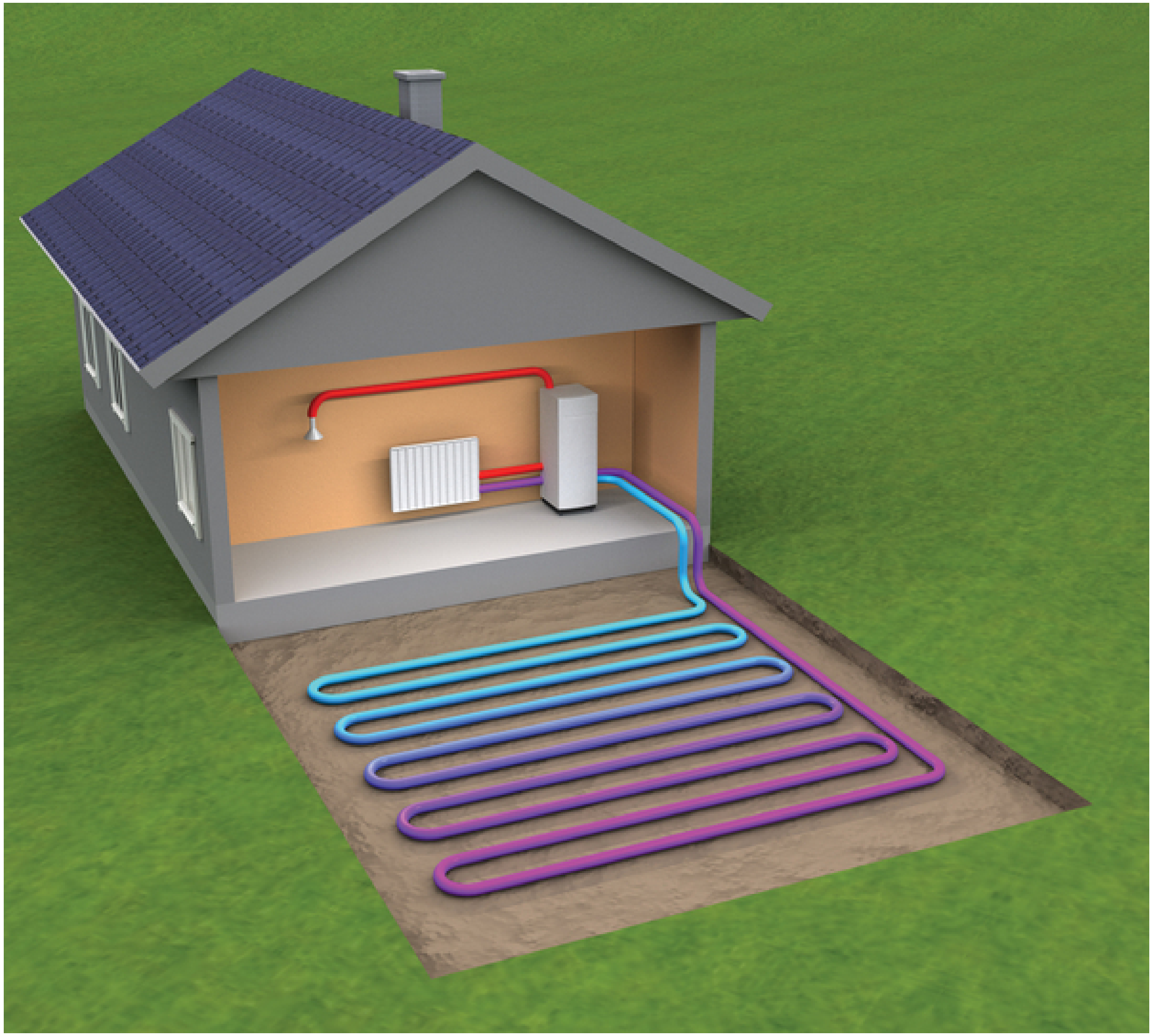
Tobias Gybel Hovgaard, Rasmus Halvgaard, Lars F. S. Larsen and John Bagterp Jørgensen

Risø International Energy Conference 2011 Proceedings Page 164

Economic Model Predictive Control for Building Climate Control in a Smart Grid

Rasmus Halvgaard, Niels Kjølstad Poulsen, Henrik Madsen and John Bagterp Jørgensen

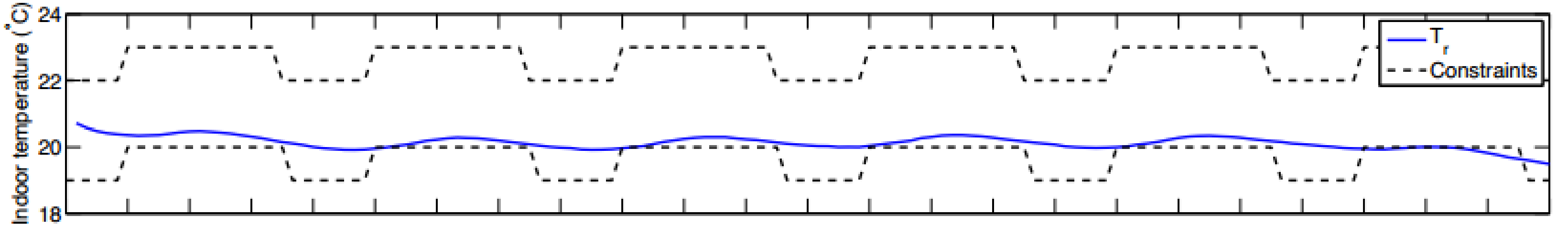
House with Heat Pump



Temperature Control

- Danfoss

- NEST (Google)



Smart Grid Ready Heat Pump

IVT PremiumLine HQ - En smartare värmepump

Framtidssäkrad med Smartgrid.

AWS II – Patentsökt funktion som anpassar varmvattenproduktionen efter behovet.

Lågenergiteknik som kan spara över 2000 kr extra per år.

Vår tystaste bergvärmepump någonsin.

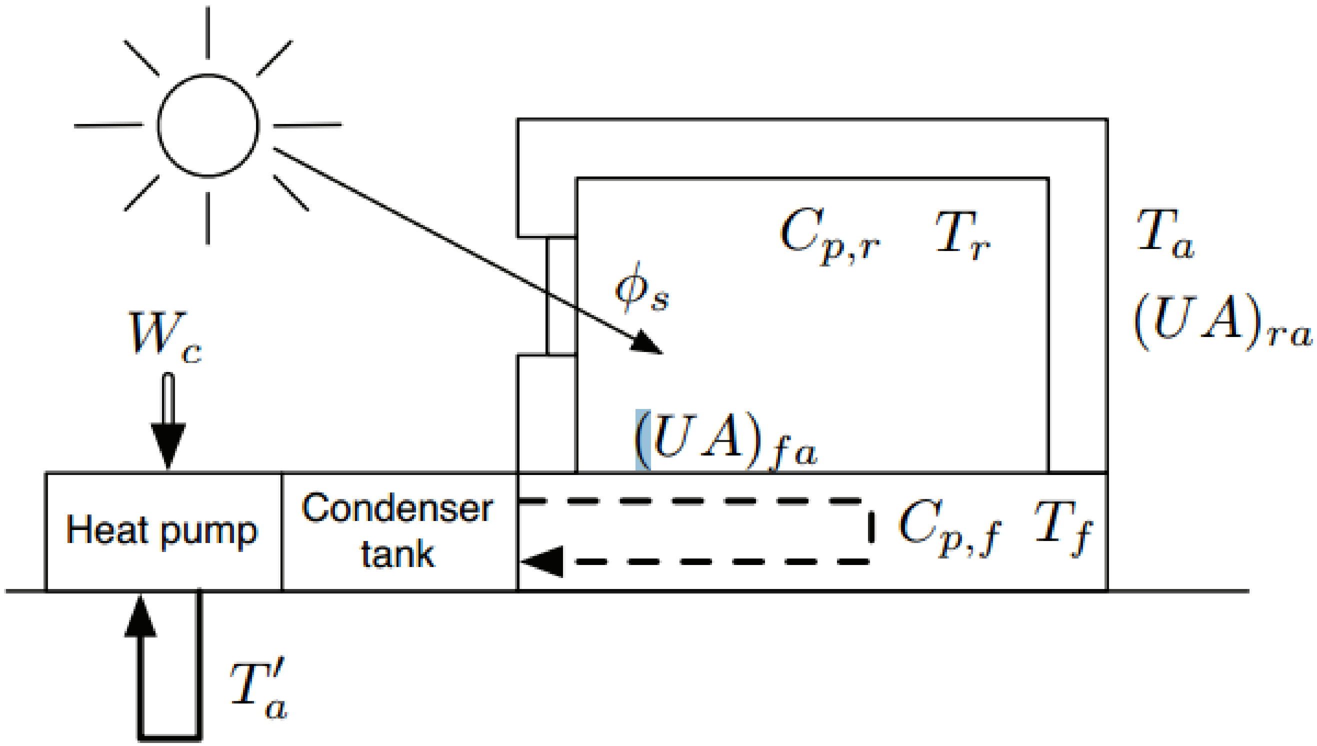
Kvalitets- och miljömärkt med Svanen.

10 års garanti på kompressorn ingår. För vi chansar aldrig.

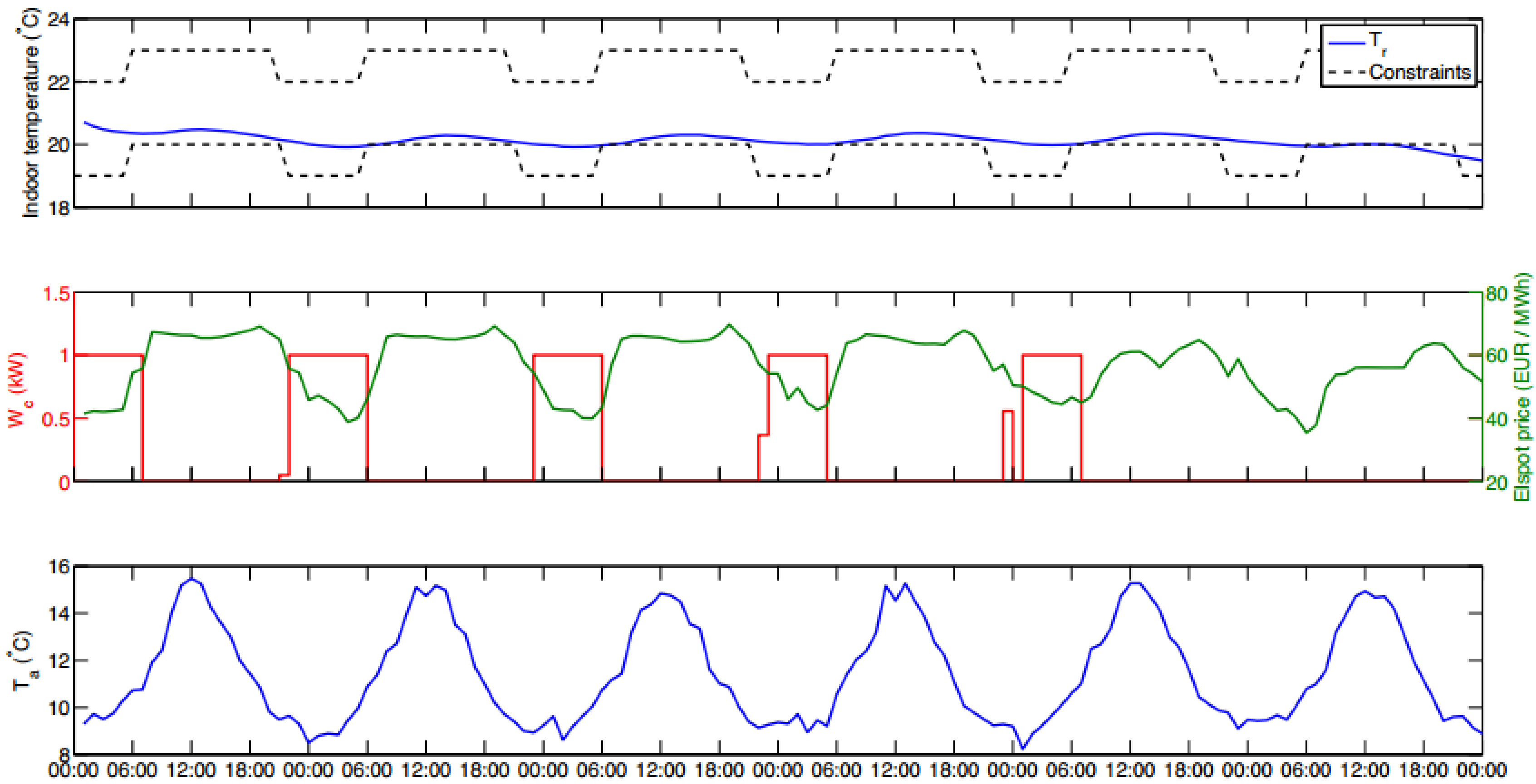
Klicka på symbolerna för att läsa mer.

Med IVT PremiumLine HQ introducerar vi nästa generation av smarta värmepumpar. Styrsystemet är förberett med Smartgrid. Det innebär att värmepumpen kan kopplas direkt mot den nordiska elbörsen, och själv anpassar så att den jobbar hårdast när elpriset är lägst. Den här tekniken sparar både pengar åt dig samtidigt som den bidrar till en jämnare och mer hållbar energianvändning. För att kunna utnyttja funktionen behöver värmesystemet kompletteras med IVT Anywhere samt ett abonnemang som kostar 39 kronor per år – en investering som snabbt sparas in.

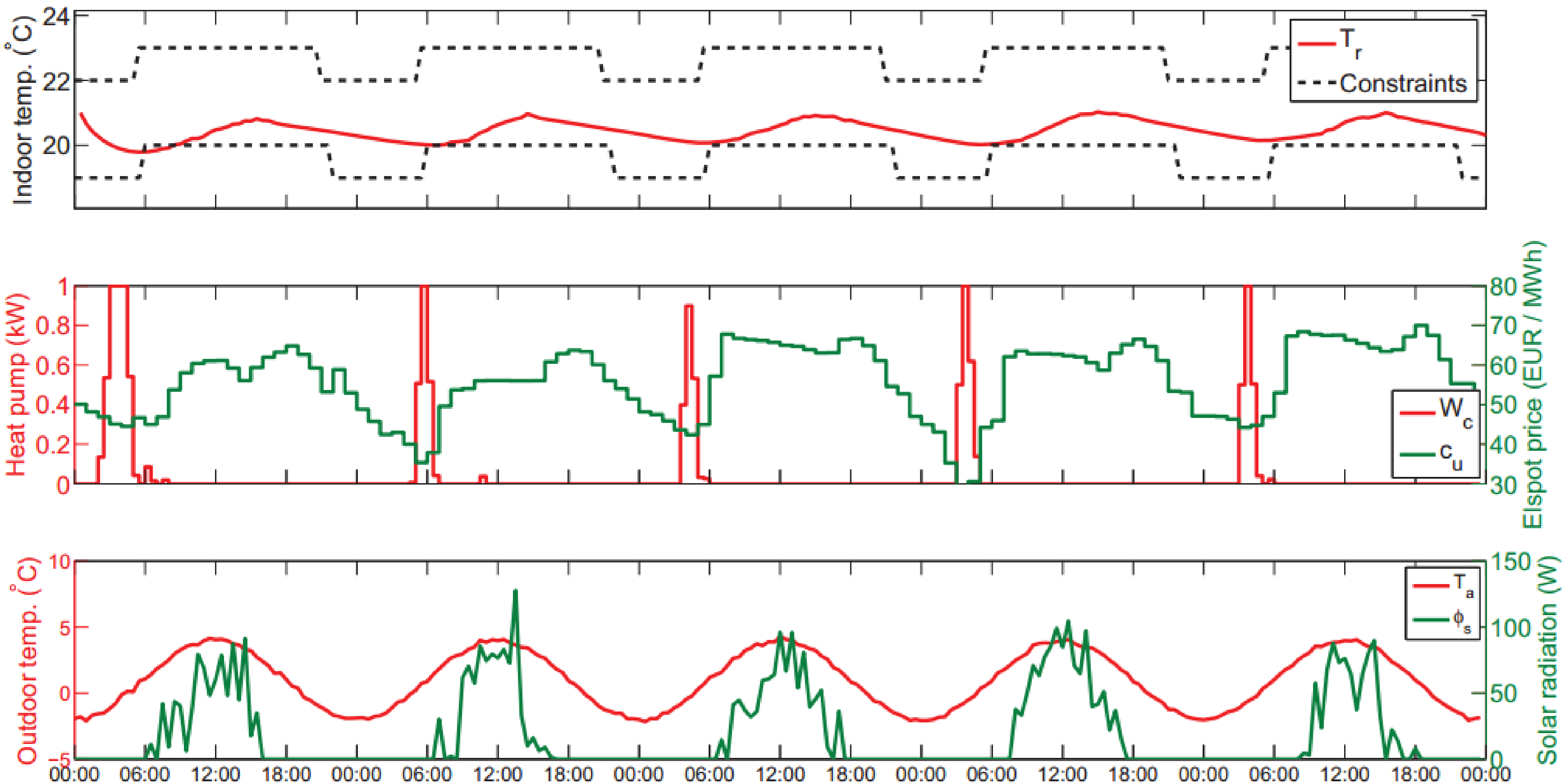
Schematics of House with Heat Pump



Economic MPC for Building Control



Economic MPC for Building Control

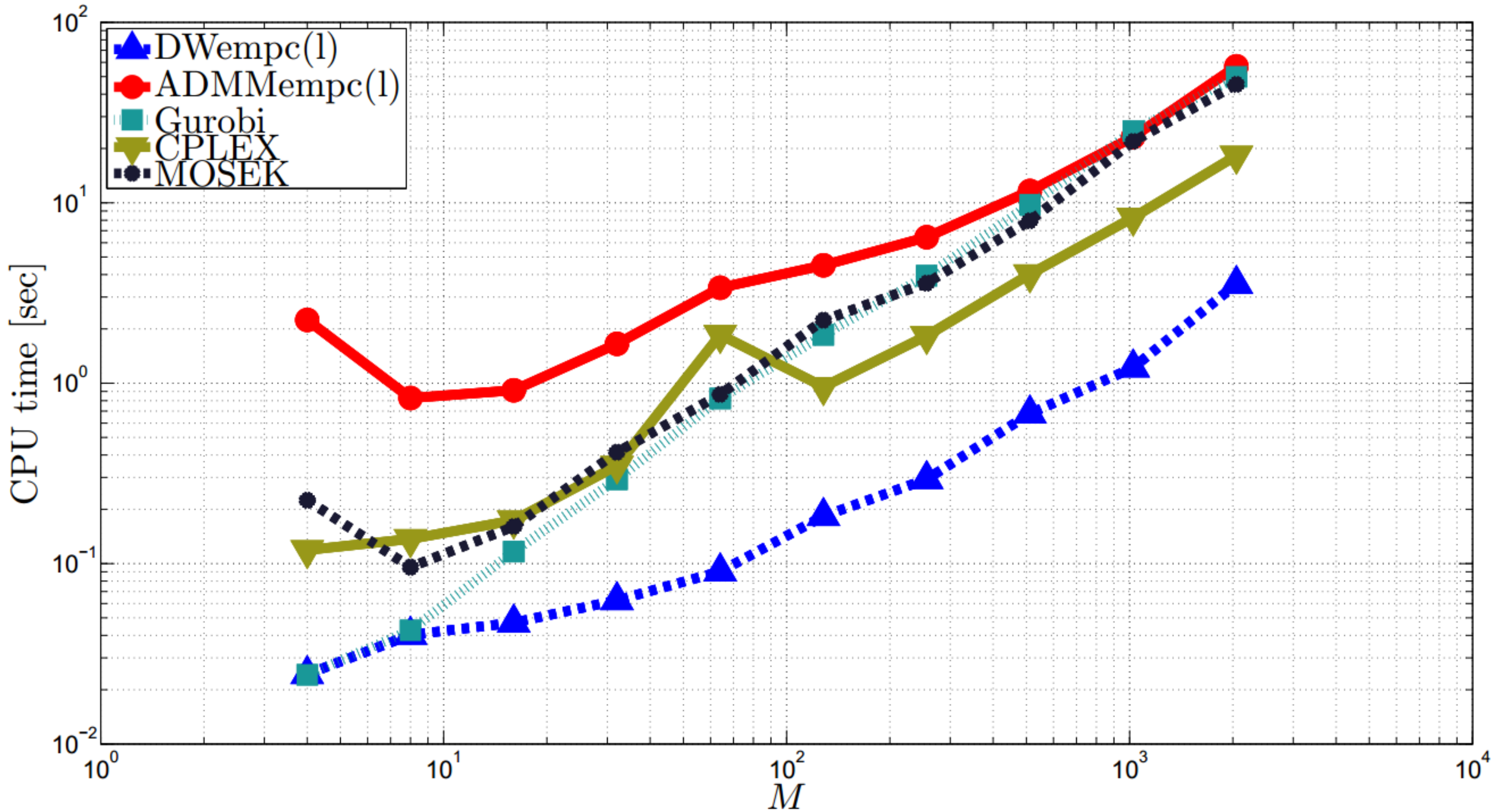


Fast Solver for Direct Control of an Entire City

A Dantzig-Wolfe Decomposition Algorithm for
Linear Economic Model Predictive Control of Dynamically Decoupled Subsystems

L.E. Sokoler[a,b], L. Standardi[a], K. Edlund[b], N.K. Poulsen[a], H. Madsen[a], J.B. Jørgensen[*,a]

[a]*Department of Applied Mathematics and Computer Science, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark*
[b]*DONG Energy, DK-2820 Gentofte, Denmark*



CITIES
WP5 – Forecasting and Control

- WP 5.1
  Statistical Characterization of Resources
- WP 5.2
  Probabilistic forecasts of production and consumption
- WP 5.3
  Direct control
- WP 5.4
  Price Based Control
- WP 5.5
  Operations and Forecast Portal

CITIES
WP 5 Forecast and Control

- 1 Post Doc
  - Forecasting
  - Model different energy components
  - Forecasts with uncertainty

- 1 PhD Student
  - Economic Model Predictive Control
  - Use the uncertainties in the forecast in an intelligent way
  - Large Scale
  - Control of several different energy components