Model Predictive Control of Heat Supply to Greenhouses

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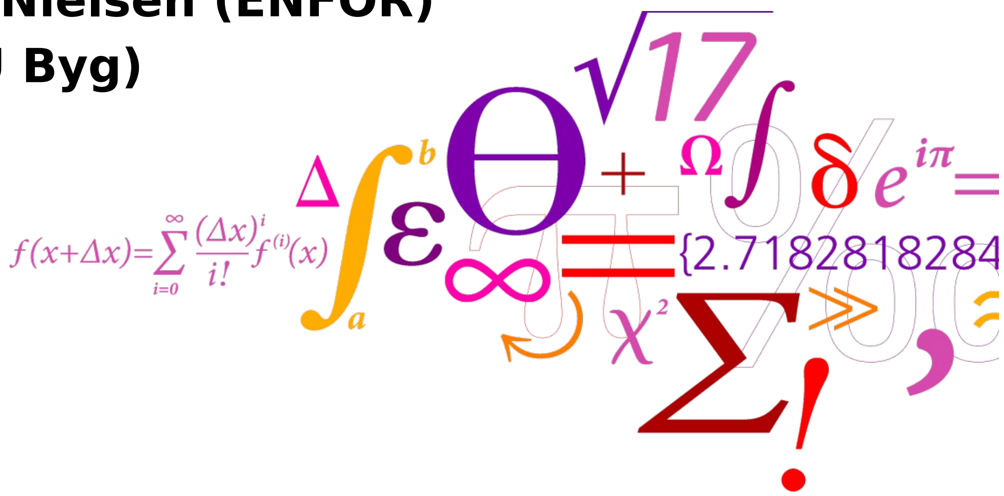

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Outline

- Model for Greenhouses
- Online Predictions
- Model Predictive Control
- Simulation vs. Prediction based Control
- Flexibility in DH Systems

Models for Greenhouses

Lumped models

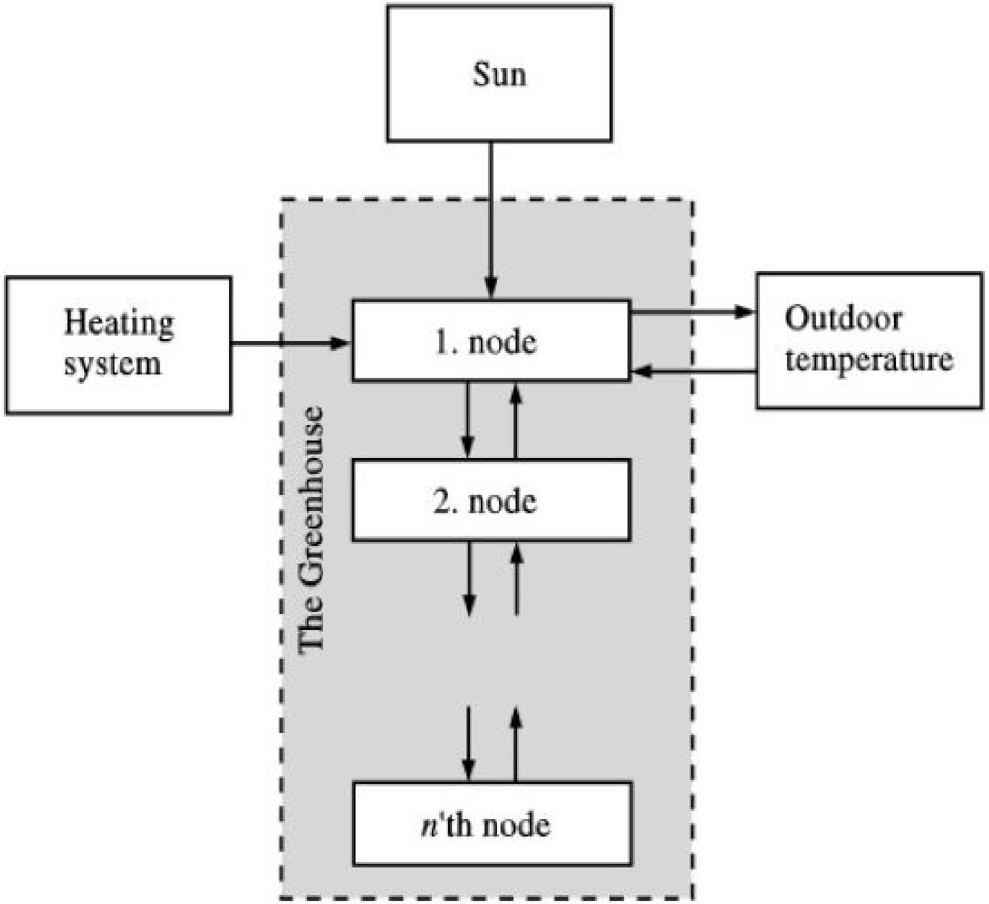


Fig. 1. Serial energy fluxes in a greenhouse with n nodes. Each node is assumed to be spatially uniform with a constant temperature and heat capacity

Model selection

Table 1
Statistic of the models considered

Model no.	*No. of nodes*	*No. of parameter*	$\log(L)$	*SBC*
1	1	6	22 058	− 44 055
2	2	10	34 680	− 69 258
3	3	14	34 833	− 69 523
4	4	16	34 836	− 69 509
5	4	18	34 851	− 69 519

L = likelihood function; SBC = Schwartz's Bayesian Criterion.

Lumped models for greenhouses
Conclusions – so far

A lumped parameter models with 3 nodes is adequate for describing the heat dynamics of the greenhouse

The solar radiation enters the first node in the model

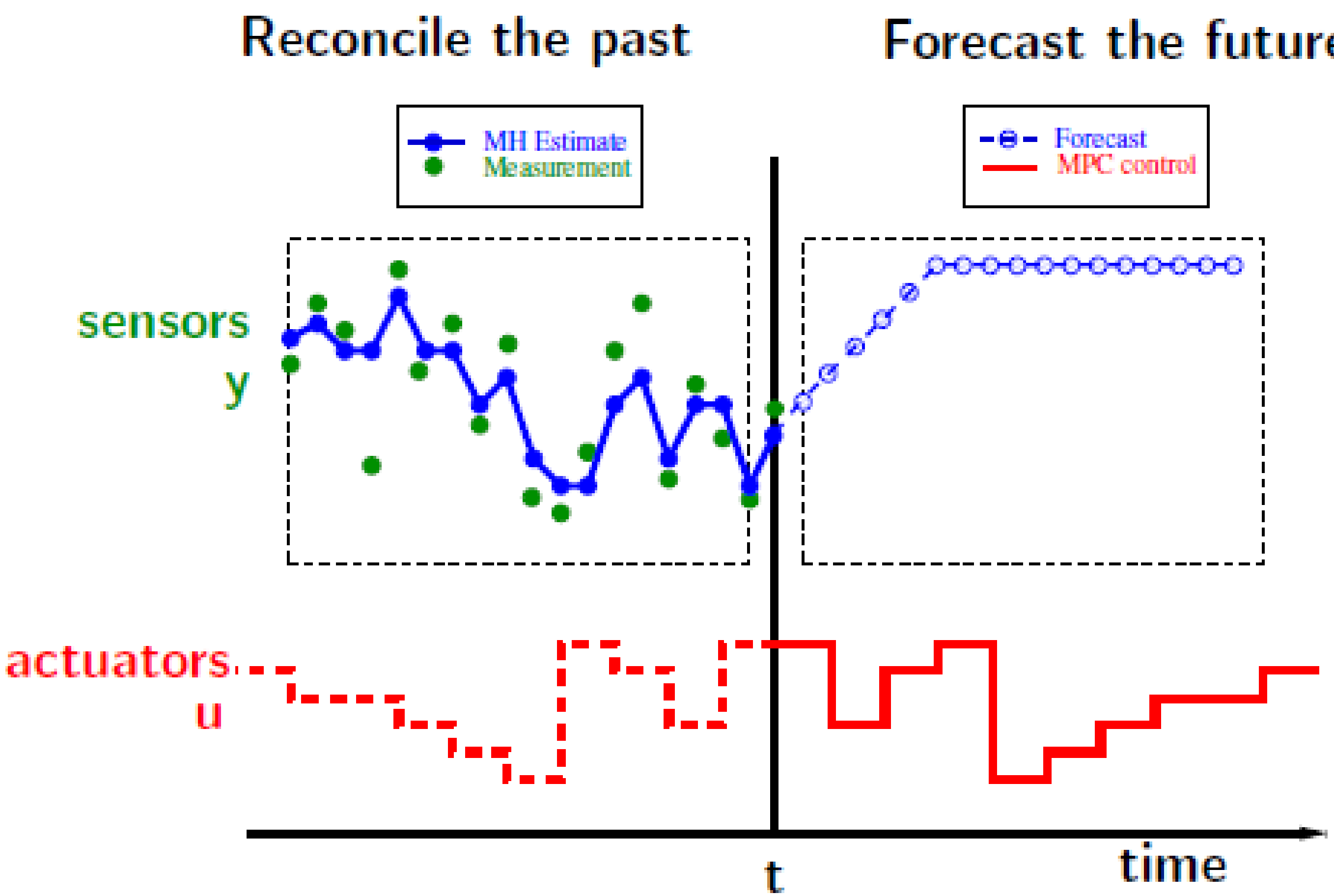
This node seems to represent the air temperature and 'outer' surfaces of other objects in the greenhouse

The next node interacts with the air temperature and represents the plants, the soil in the pots, the inner part of the bench and a few centimeters of the ground

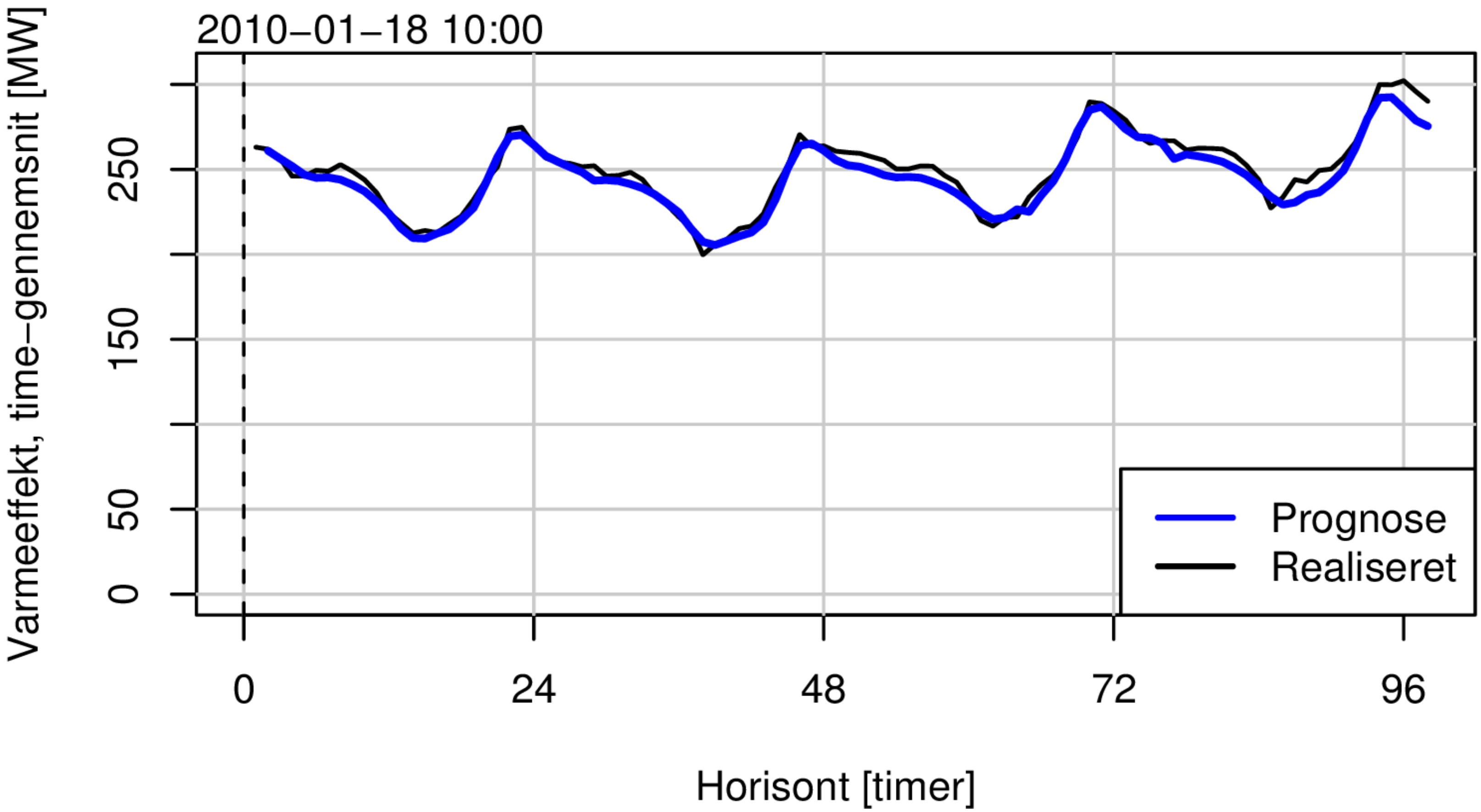
- The third node represents the deeper part of the soil
- Nonlinear models taking the wind speed and humidity into account must be formulated

Forecasting and Control

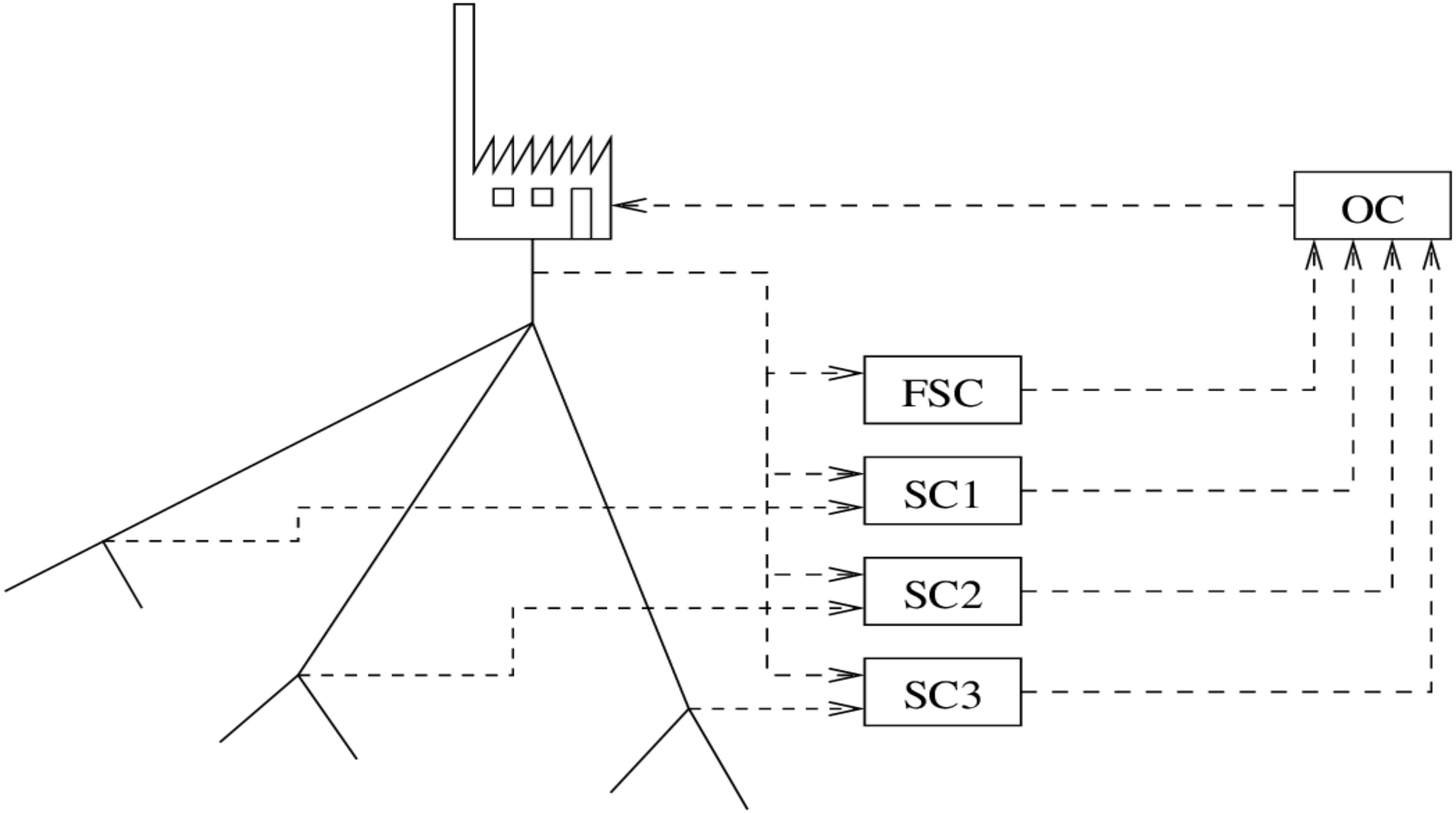
Predictive Control



Heat load – 96 hour forecasts (Sønderborg DH system)

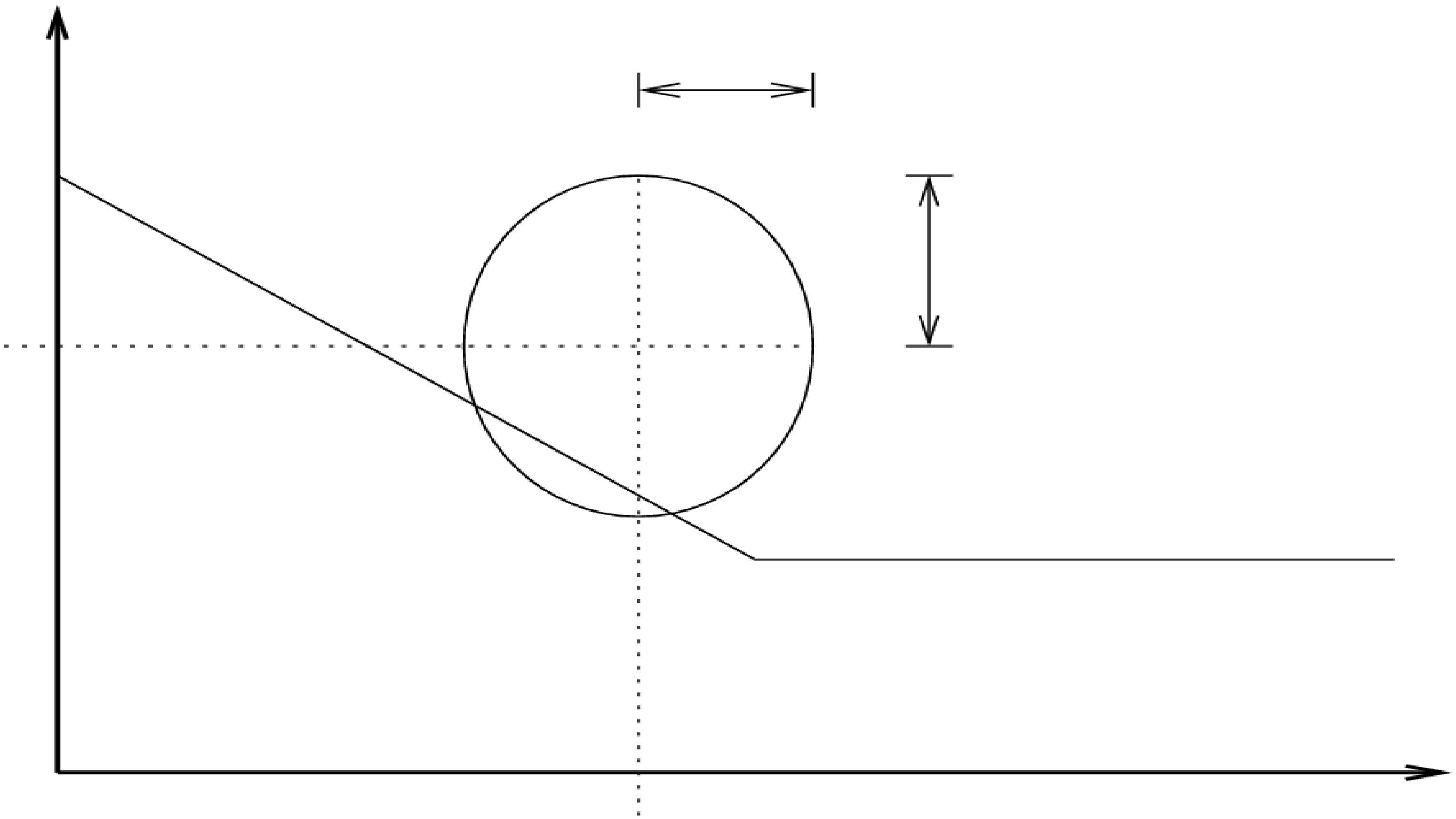


Stoch. Models for the DH Network (simplified)



Set-point selection
Use of uncertainties

User supply temperature



Ambient air temperature

Optimal Control

Let us define the following optimal control problem:

$$\min_{u_k} J(\Gamma_k, \Lambda_k, \omega_k; k, u_k)$$

$$= E_k[(y_k - y_k^0)^T \Gamma_k (y_k - y_k^0)$$

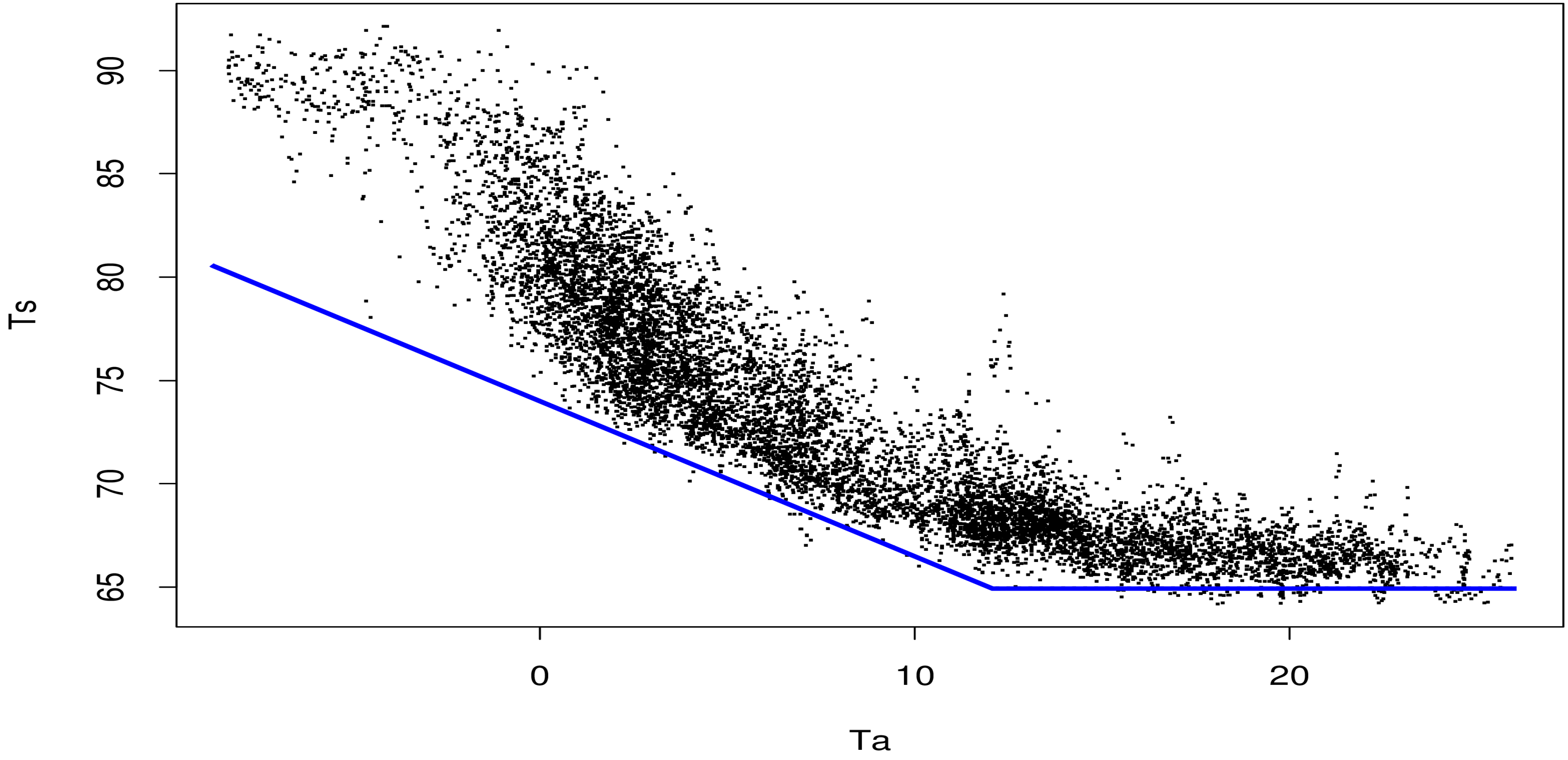
$$+ u_k^T \Lambda_k u_k + 2\omega_k^T u_k] \; ,$$

If we assuming that the output can be predicted by a piecewise linear model, we obtain easily

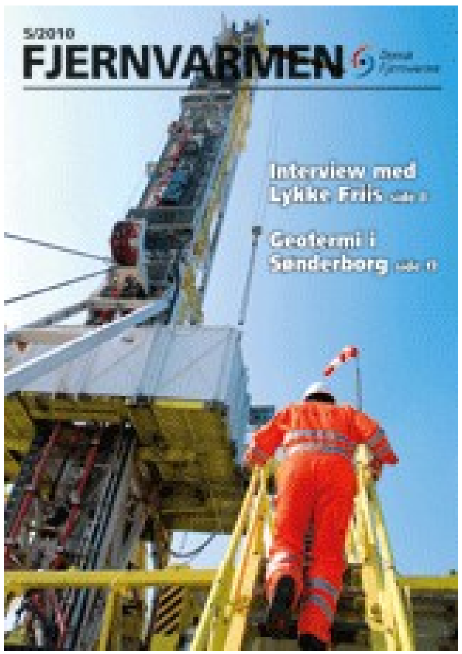
$$u_k = -\left[H_k^T \Gamma_k H_k + \Lambda_k\right]^{-1} \left[H_k^T \Gamma_k^T \beta_k + \omega_k\right] \; .$$

This defines the optimal supply temperature for each of the greenhouses. The resulting supply tempeturature is then found as the maximum of all.

Observed supply temperature



Control of Supply Temperatures



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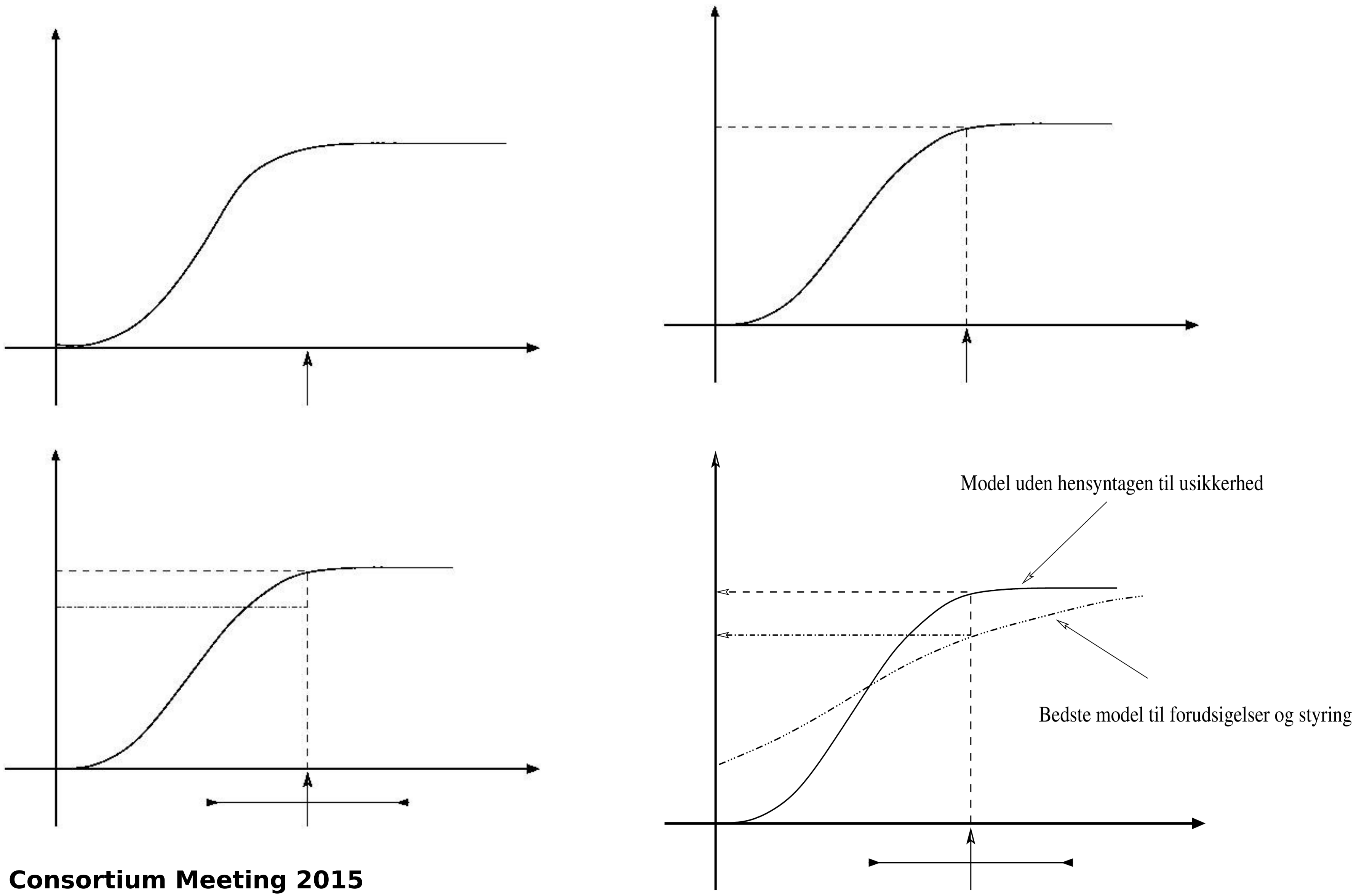
Styring af temperatur rummer kæmpe sparepotentiale

Conclusions:

- Control using **simulation** gives up to **10 pct** reduction of heat loss.
- Control using **forecasting and measurements** gives up to **20 pct reduction** of heat loss

Models and Optimal Control

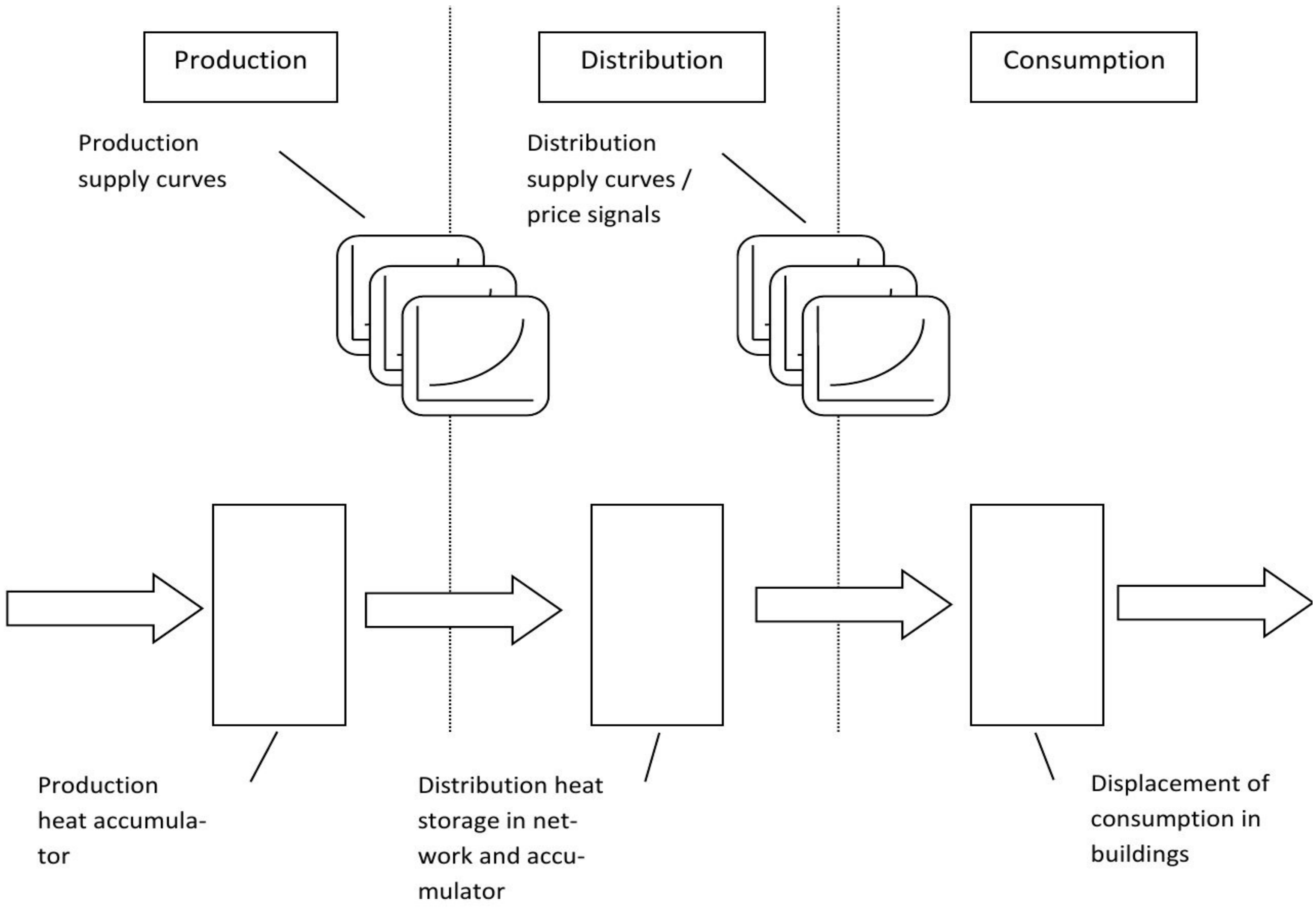


Conclusion on Control

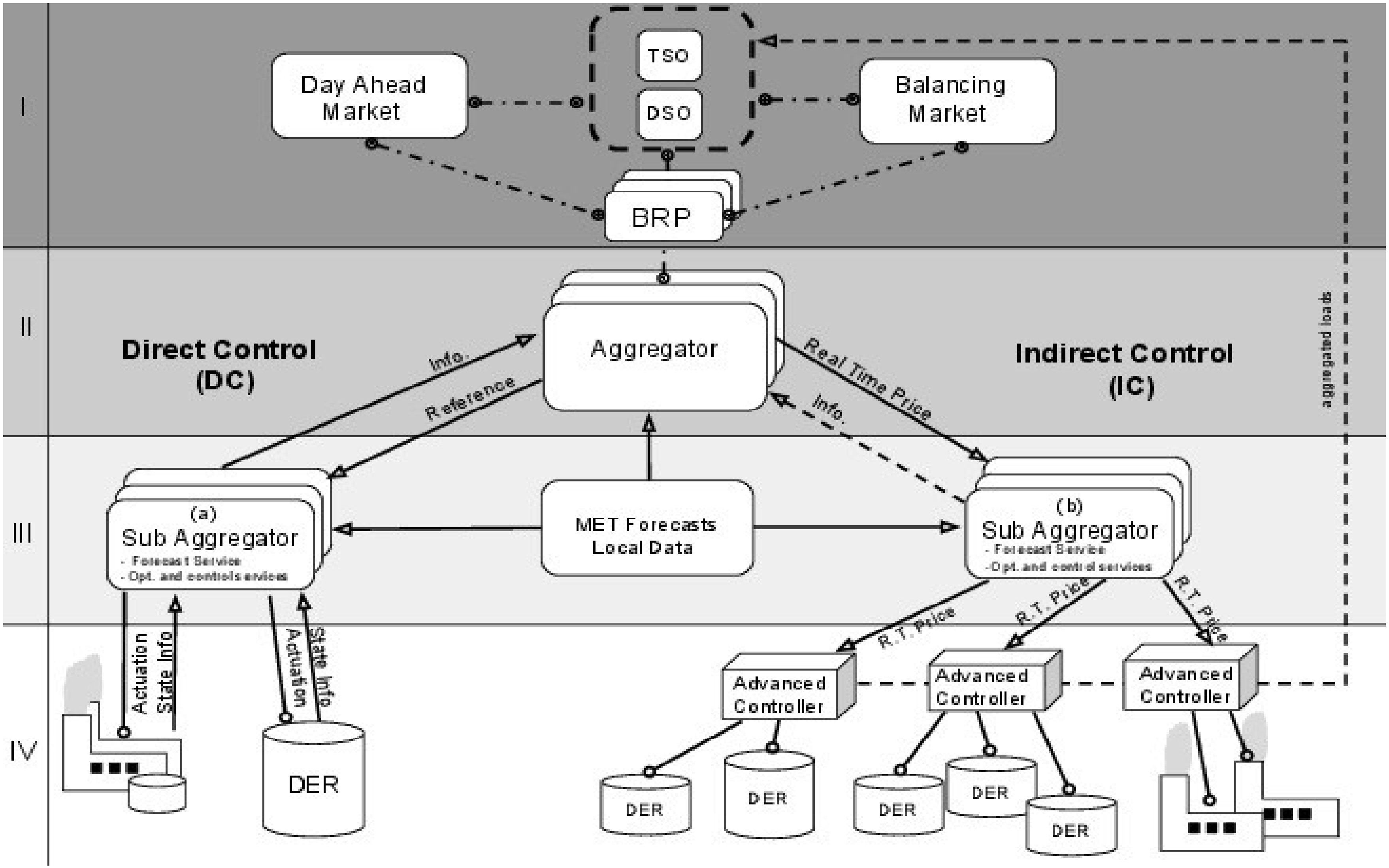
- Use **simulation based control** when:
  - No data is available from the DH net
  - A new layout of the DH system is selected
- Use **prediction based control** when:
  - Data is available online (so they can be used for control and forecasting)
  - Meteorological forecasts are used for improved control
  - For adaptive – self calibrating – control setups

Flexibility in DH systems

Flexibilities in DH Systems



Interface with power system



Summary

Lumped parameter models for greenhouses

Load forecasting in DH systems which takes advantage of Meteorological forecasts

Controllers for minimizing the supply temperature in DH networks

Principles for flexibility in DH systems are described

Interface with power system is outlined

Thanks for your time...