Intelligent and Integrated Energy Systems

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http://www.citiesinnovation.org

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Control of Power Consumption Using Thermal Inertia (DR)

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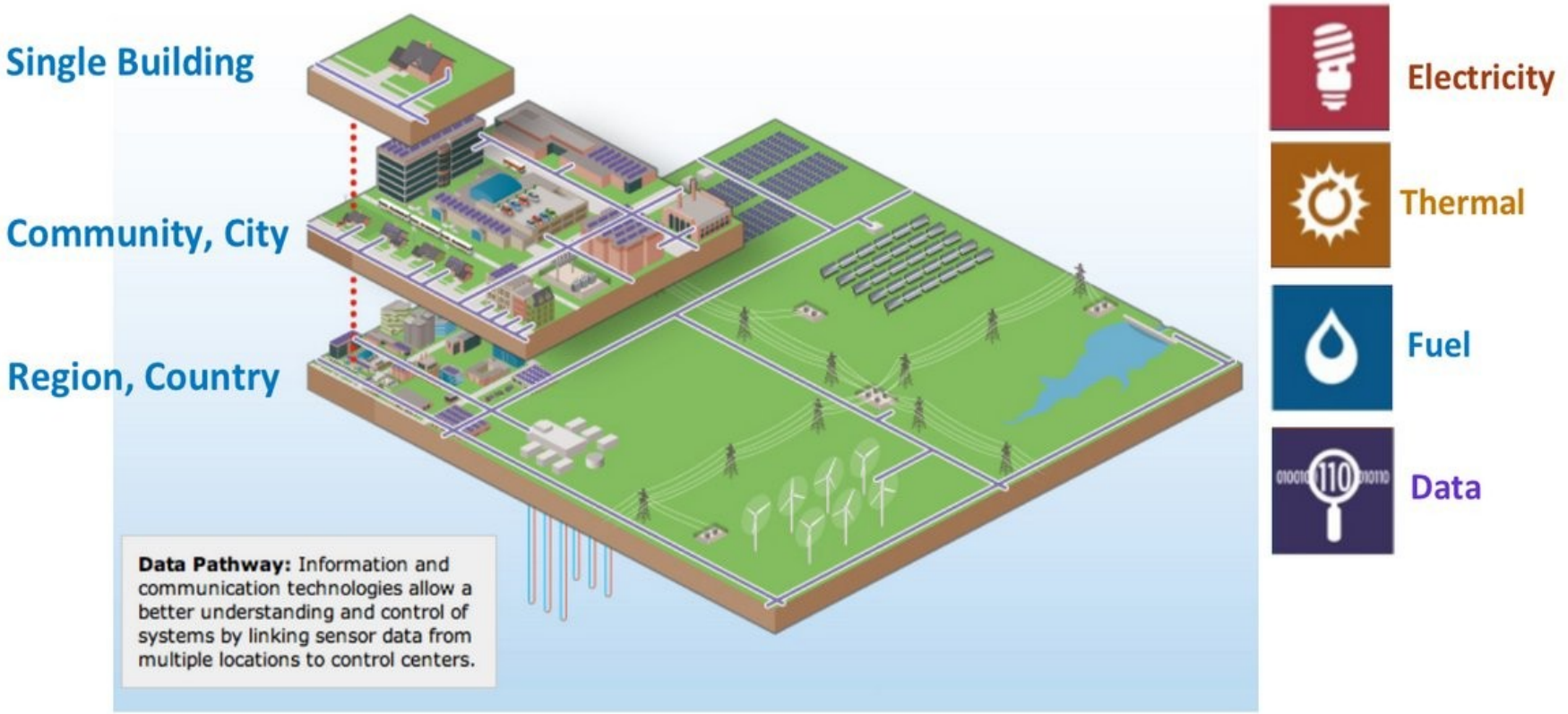
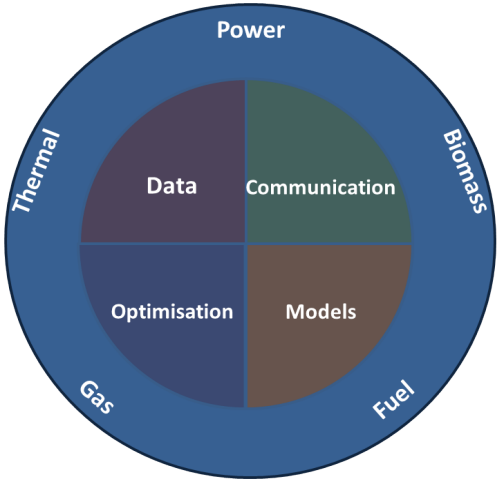
Energy Systems Integration

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



Energy Systems Integration

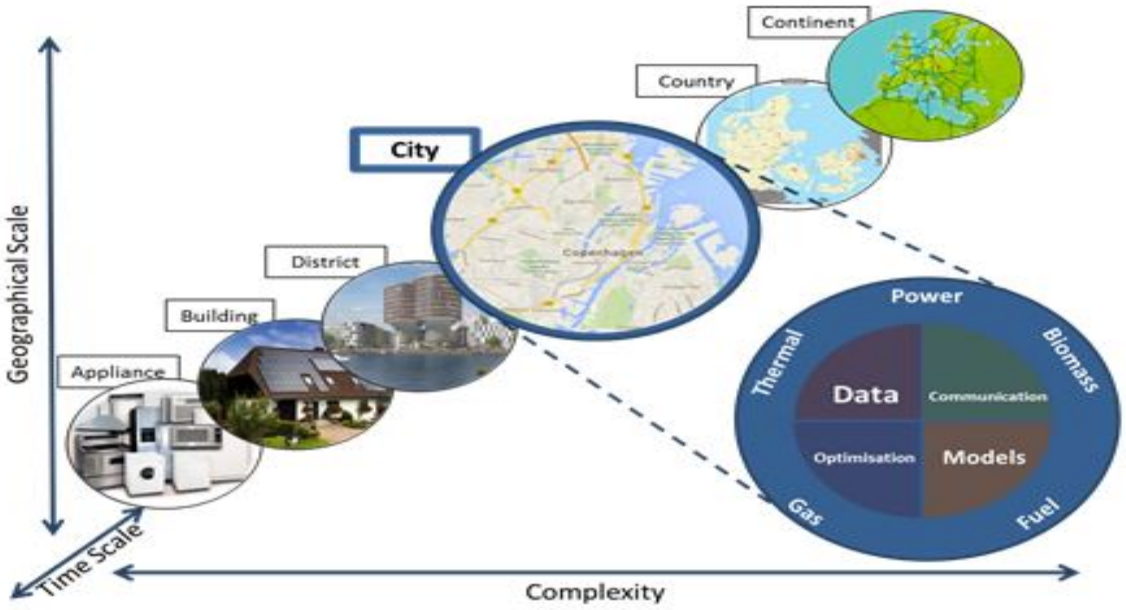


The **central hypothesis** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) using grey-box models we can balance very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

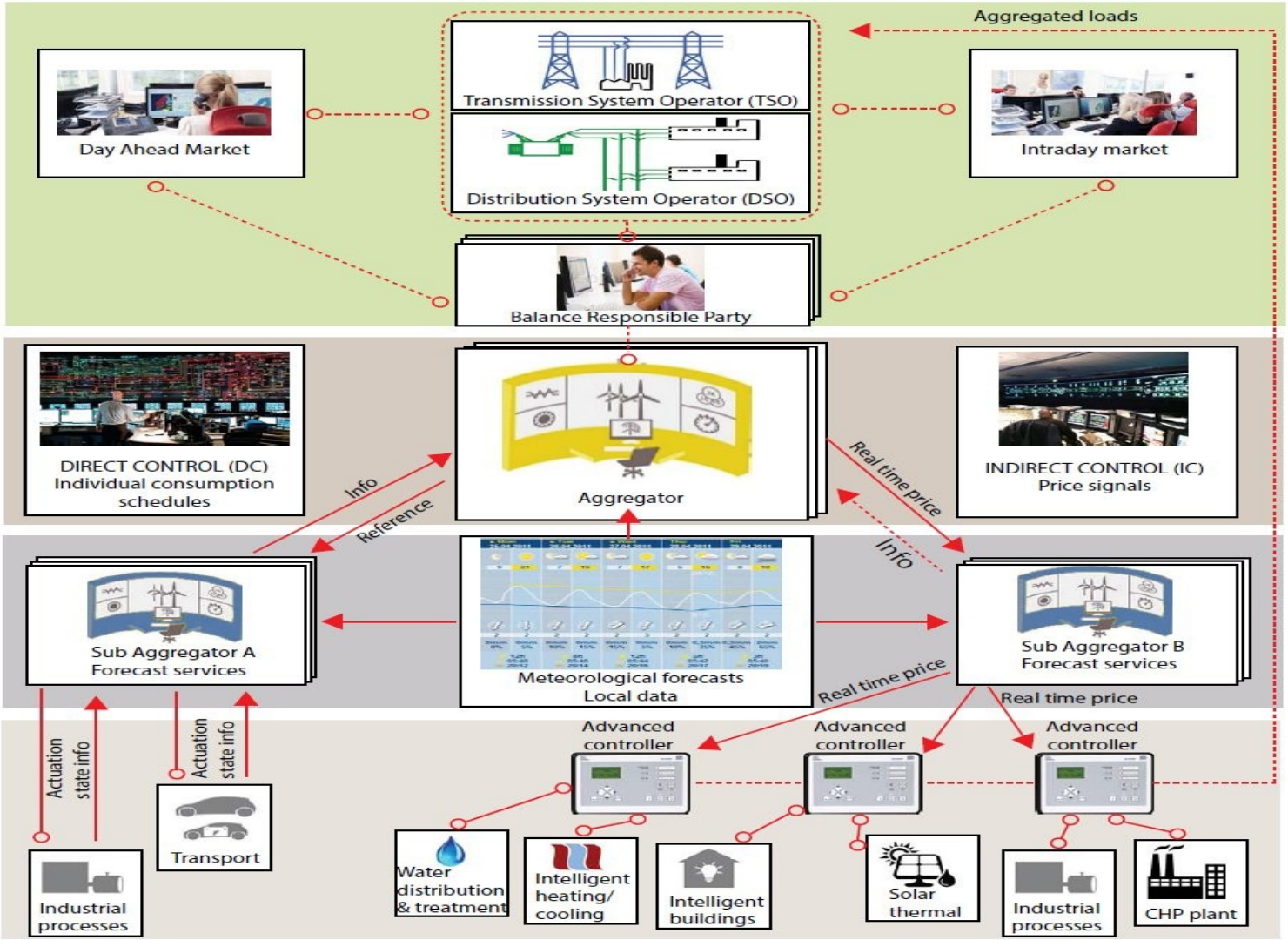
Intelligent integration will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.

Temporal and Spatial Scales

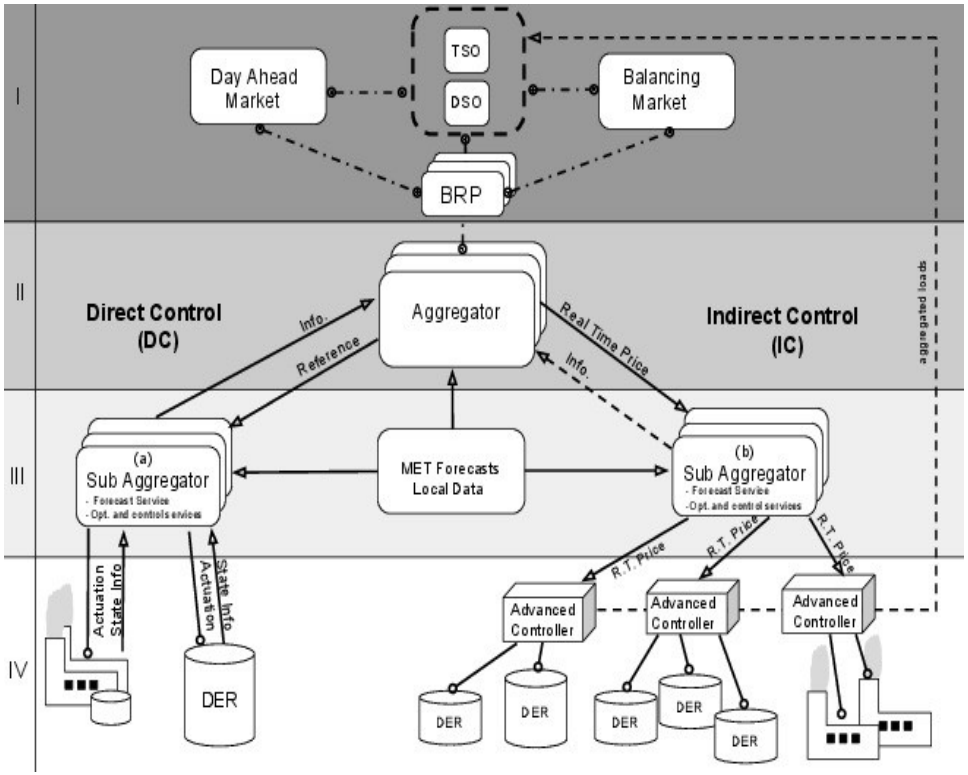
The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems*** at **all scales**.



Smart-Energy OS



Control and Optimization



Day Ahead:

Stoch. Programming based on eg. Scenarios

Cost: Related to the market (one or two levels)

Direct Control:

Actuator: **Power**

Two-way communication

Models for DERs are needed

Constraints for the DERs (calls for state est.)

Contracts are complicated

Indirect Control:

Actuator: **Price**

Cost: E-MPC at **low (DER) level**, One-way communication

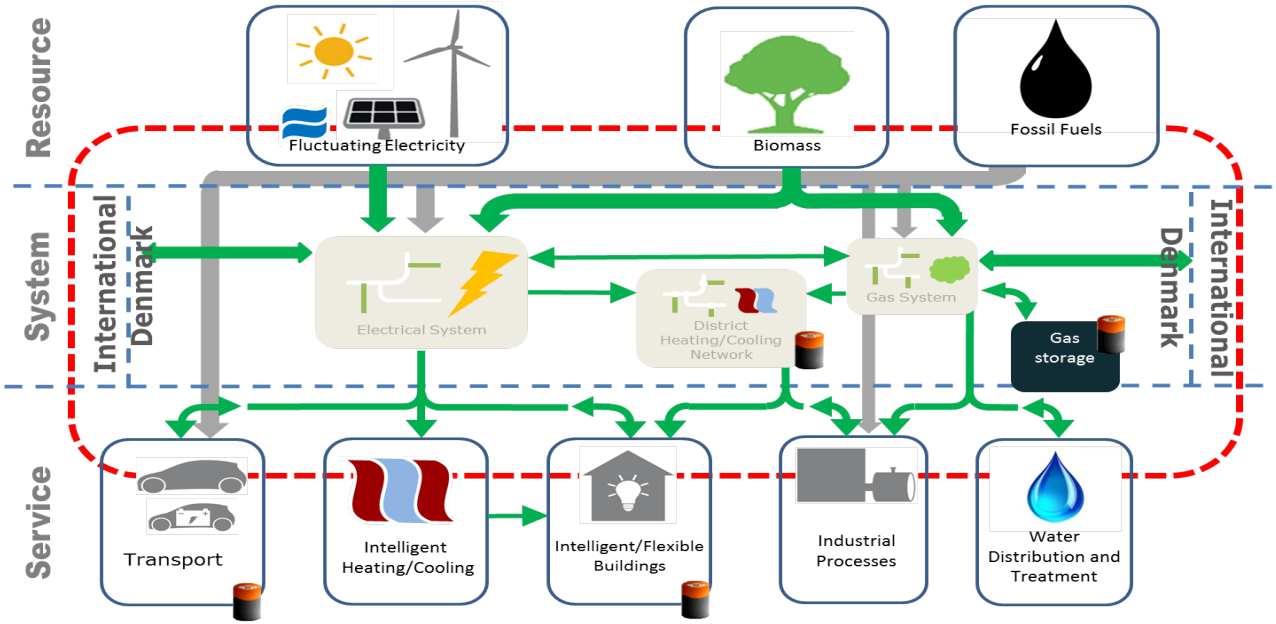
Models for DERs are not needed

Simple 'contracts'

In New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

Models for systems of systems

Intelligent systems integration using **data and ICT solutions** are based on **grey-box models** **for real-time operation of flexible energy systems**



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Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available on GitHub.

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R . The software is available on GitHub.

Latest news

Summer School at DTU, Lyngby, Denmark – July 4th-8th 2016

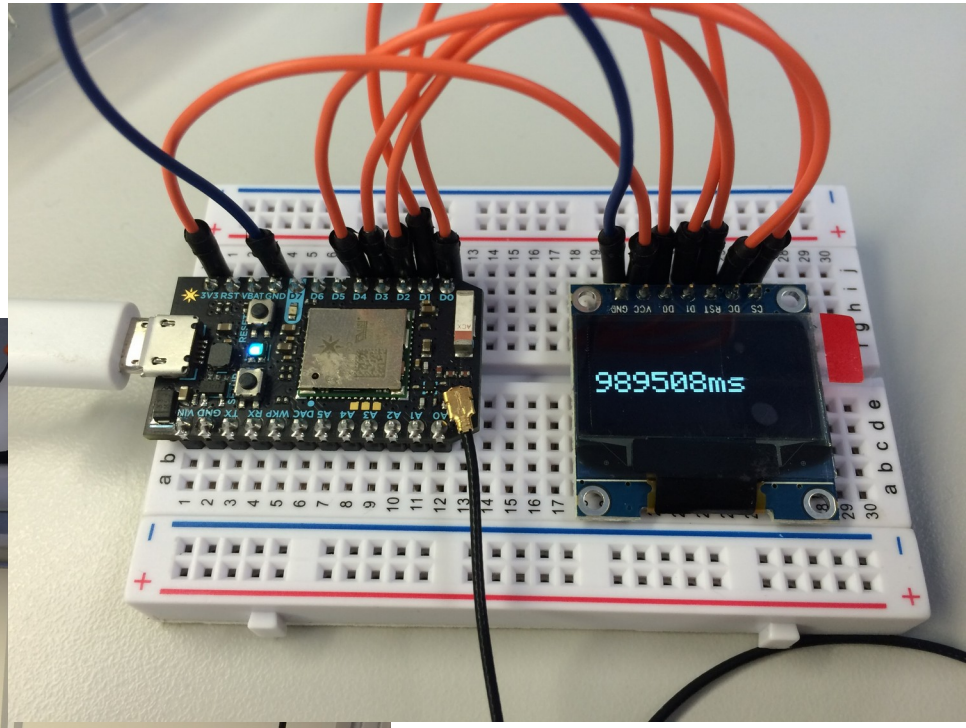
Summer School – Granada, Spain, June 19th-24th 2016

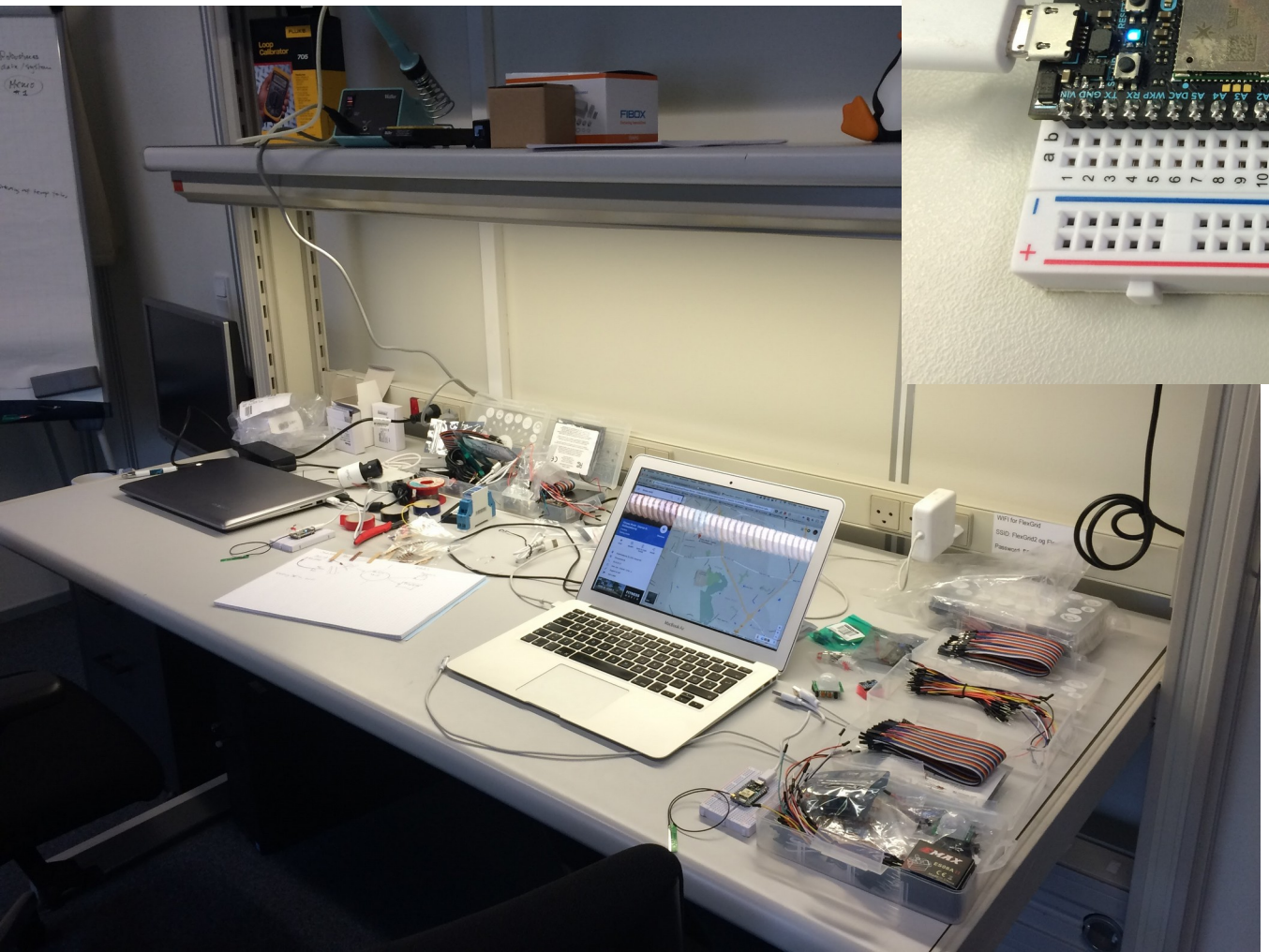
Third general consortium meeting – DTU, May 24th-25th 2016

Smart City Challenge in Copenhagen – April 20th 2016

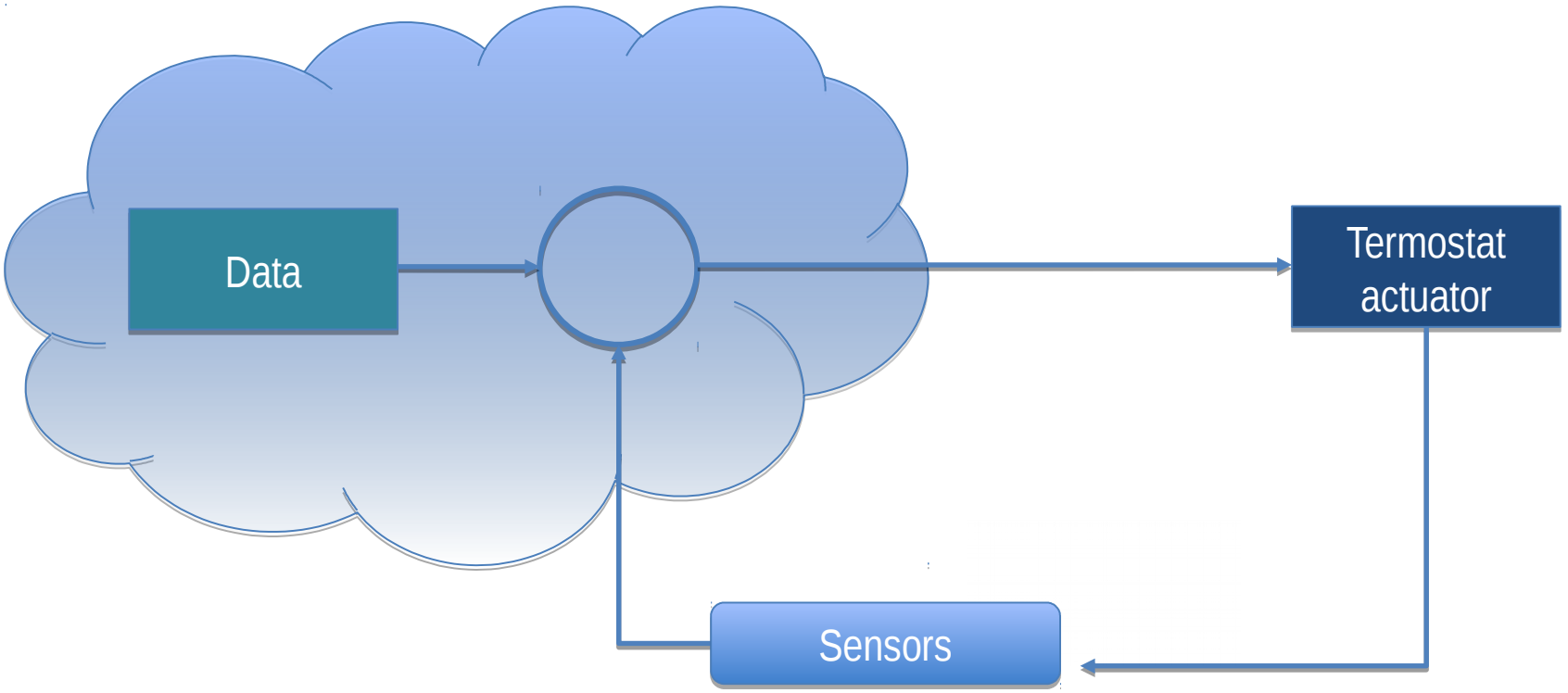
Guest lecture by Pierluigi Mancarella at DTU, April 6th

Lab testing ….

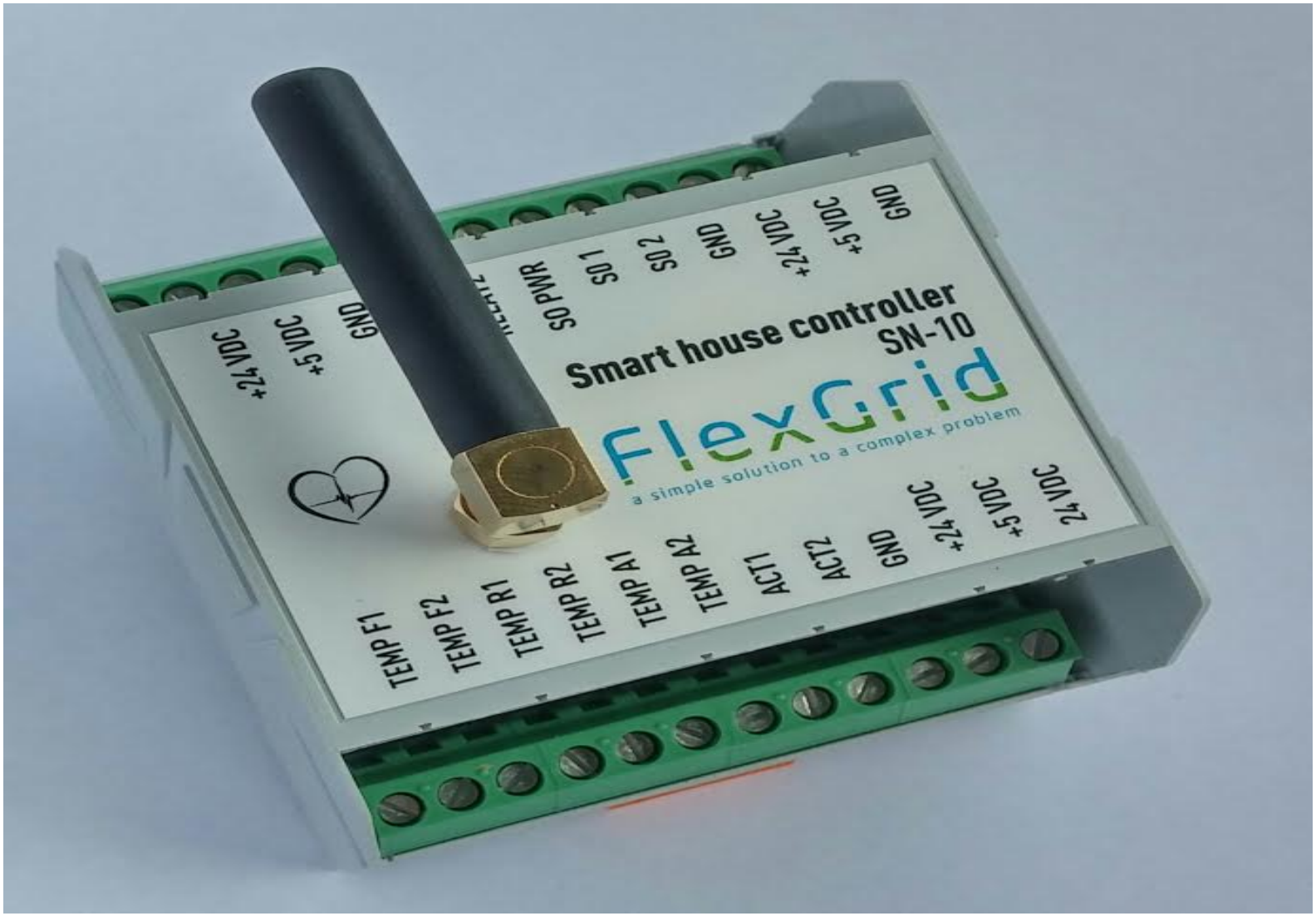




SE-OS
Control loop design – **logical drawing**



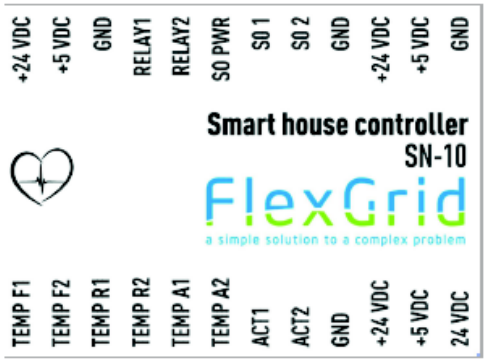
SN-10 Smart House Prototype

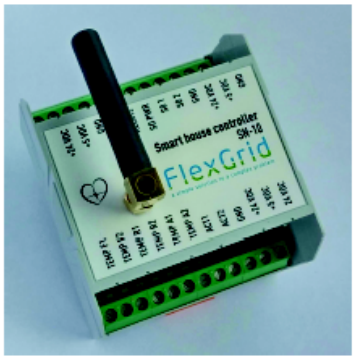


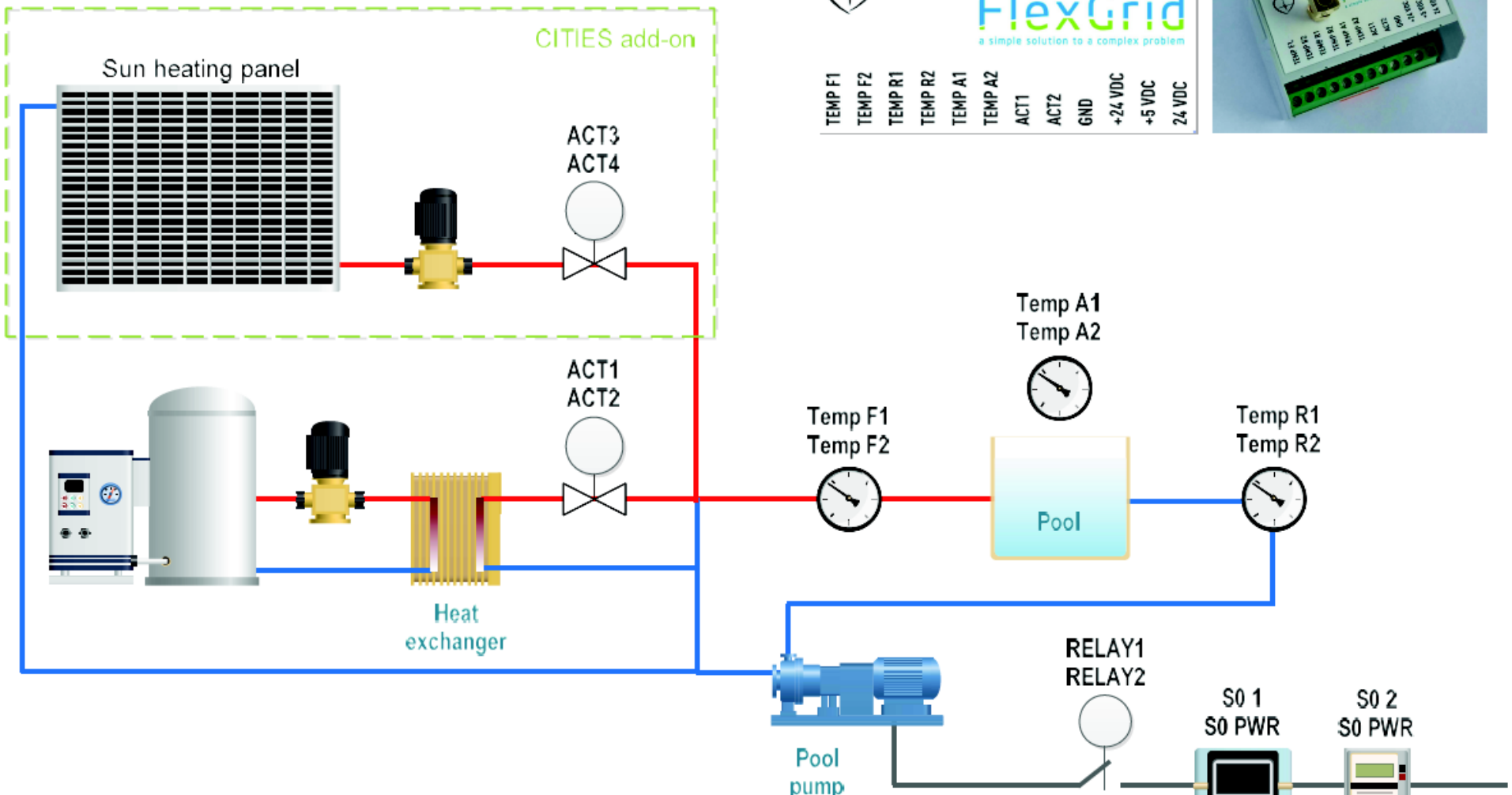
Smart Control of Houses with a Pool

PilotB SN-10 signal overview

revision 1.0 (CITIES add-on)







SE-OS Characteristics

- ‘Bidding – clearing – activation’ at higher levels
- Nested sequence of systems – systems of systems
- Hierarchy of optimization (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud or Fog (IoT, IoS) based solutions – eg. for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, …)
- Allow for new players (specialized aggregators)
- Simple setup for the communication and contracts
- Provides a solution for ancillary services
- Harvest flexibility at all levels

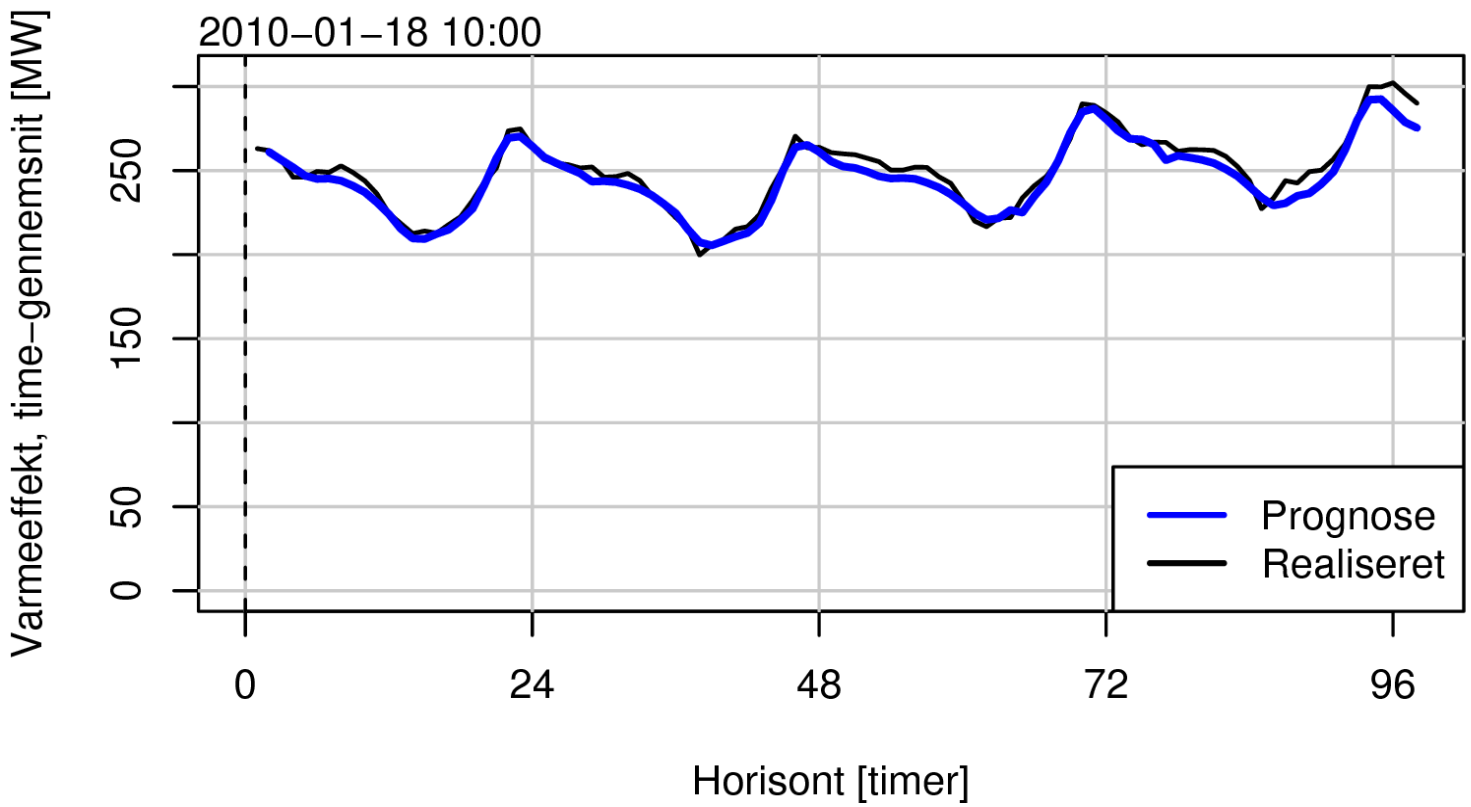
Some DH Related Demo Projects

- Control of WWTP (ED, Kruger, ..)
- Heat pumps (Grundfos, EConGRID, HTF, ..)
- Summerhouses (DC, ENDK, SE, ..)
- Green Houses (NeoGrid, ENFOR, Fj.v. Fyn, ...)
- CHP production opt. (Dong Energy, HOFOR, ...)
- Dynamics Prices in DH systems (EON, EA-E, AVA, Fj.V. Fyn, ...)
- Seasonal Storage Solutions (NREL, Brædstrup,
- Small Area District Heating and Cooling (Rambøll, HOFOR, ..)
- Use of Heat from Supermarkets (Hyllie, HTF, VEKS, ...)
- Use of data from meters (IC-meter, ENFOR, ...)

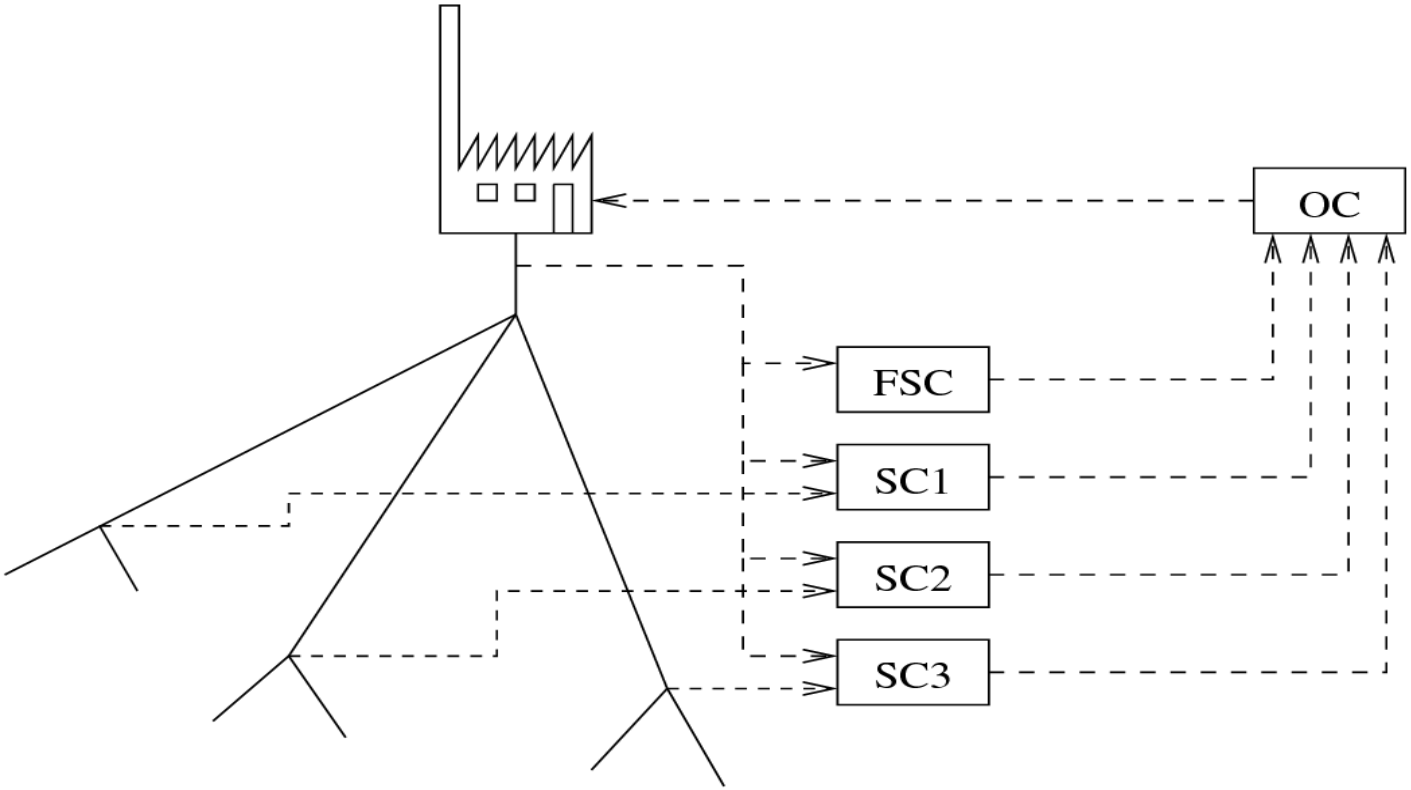
Case study

Models and Control for DH Systems

Heat Load forecasts – up to 96 h ahead



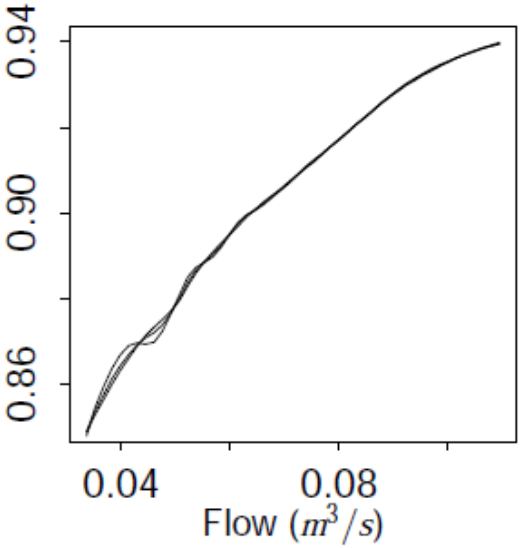
Models and Controllers
(Highly simplified!)



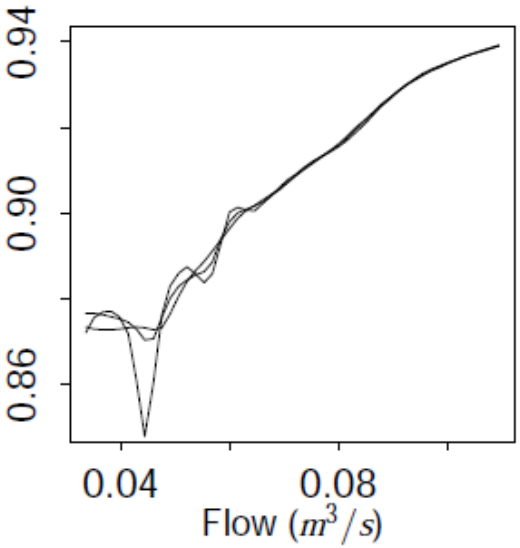
Characteristics

30%, 40%, 50%

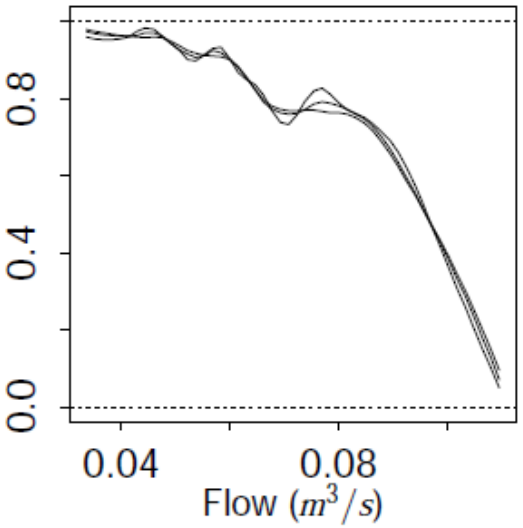
Stationary gain of FIR



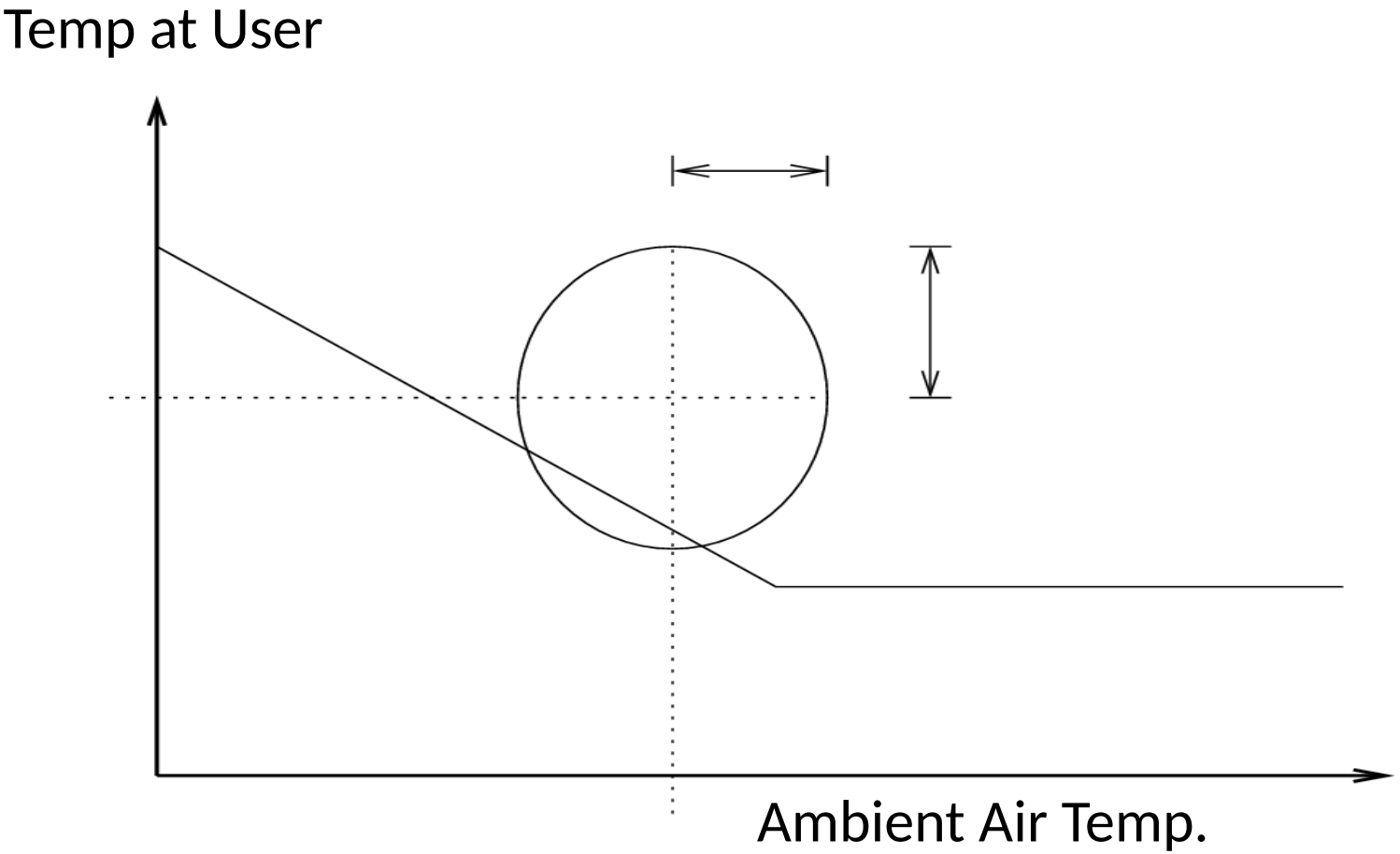
Stationary gain of ARX



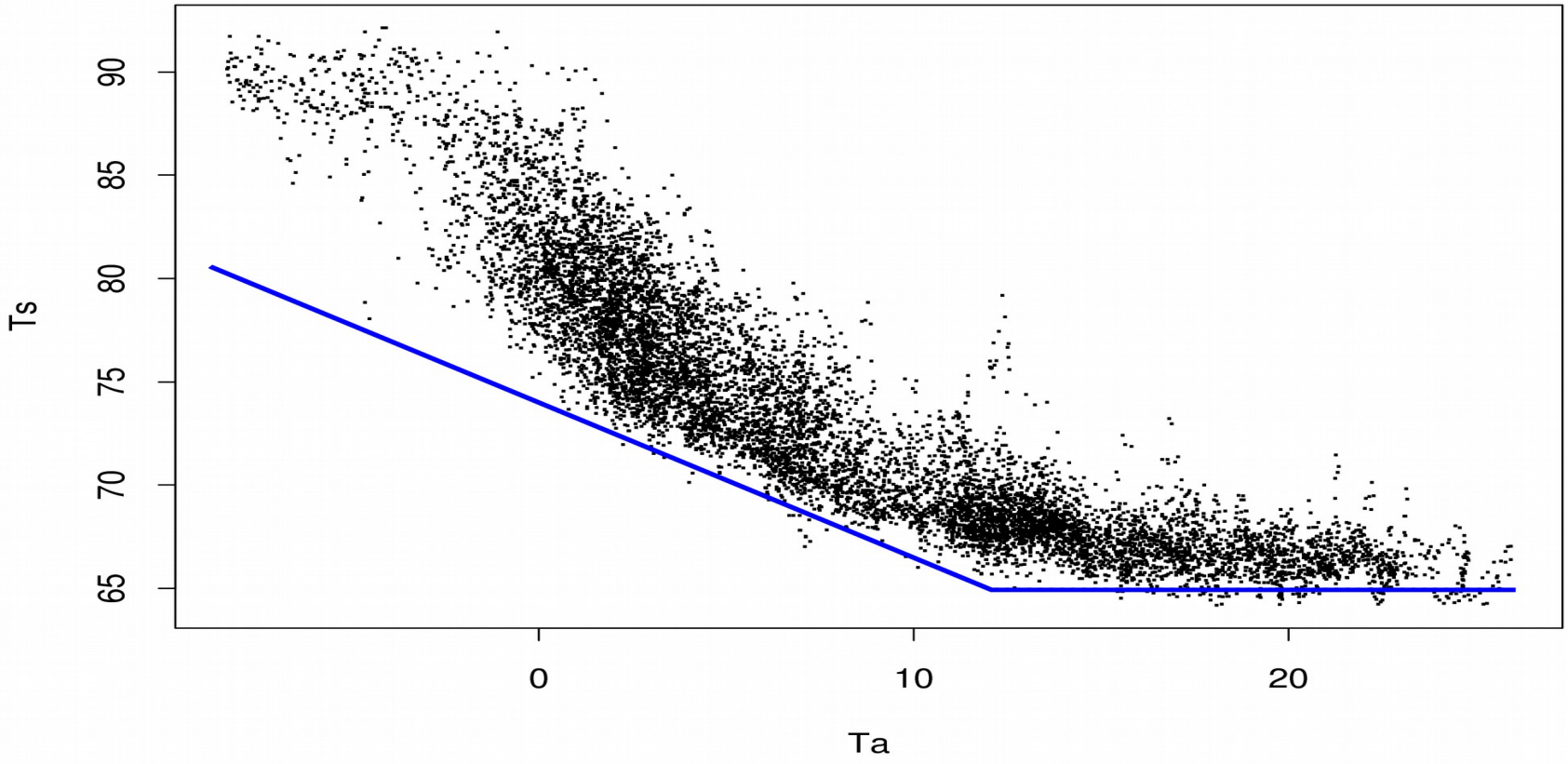
Pole of ARX



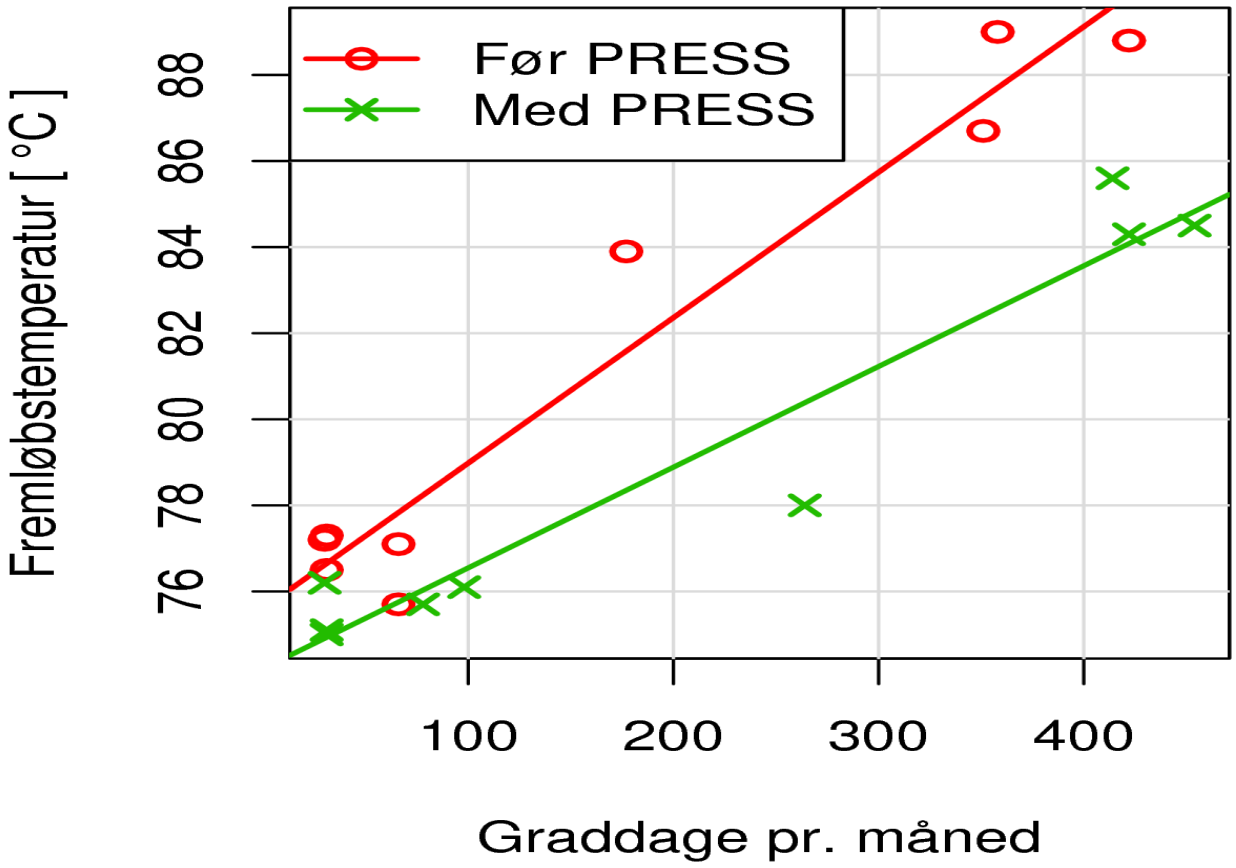
Prob. constraints
Controller set-points



Observed User Temp.



Supply temperature with/without predictive control



Savings
(Reduction of heat loss = 18.3 pct)

	Varmekøb		Elkøb	
	GJ	1000kr	kWh	1000kr
Før PRESS	653,000	30,750	499,000	648
Med PRESS	615,000	28,990	648,000	842
Forskel	37,400	1,760	-149,000	-194

Total besparelse (9 første måneder af normalår): **1,566,000kr**

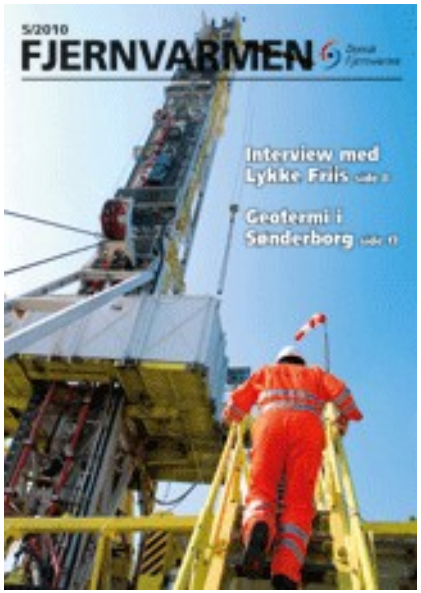
Besparelse for et normalår:

- $12/9 \times$ 1,566,000kr $=$ **2.1 mill.**
- Imidlertid står jan.–sept. (75% af året) kun for ca. 65% af graddagen i er normalår.
- 1,566,000kr$/0.65 =$ **2.4 mill.**

Which approach to use?

- Use **simulation based** control if:
  - No access to data from the DH network
  - Want an evaluation of new operational scenarios
- Use **prediction based** control if:
  - Access to network data online
  - Want to used meteorological forecasts automatically
  - Want automated update of models

Control of Temperatures in DH Systems



FJERNVARMEN | 5 2010

Styring af temperatur rummer kæmpe sparepotentiale

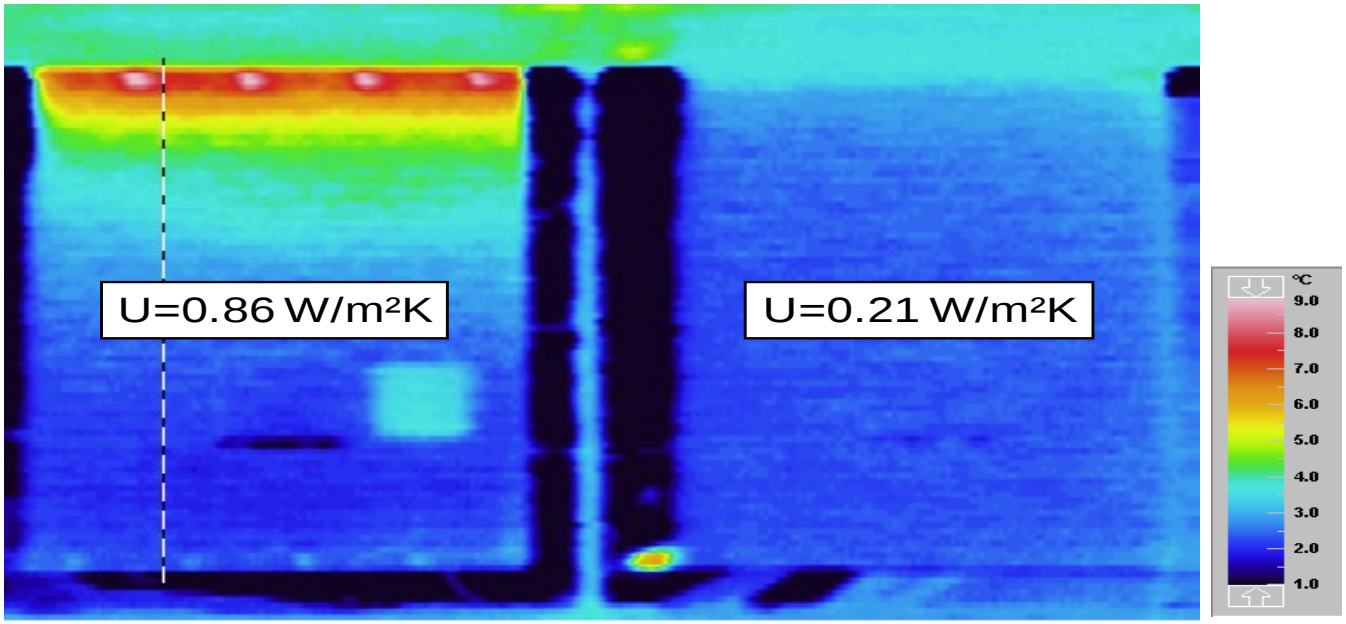
Lesson learned:

- Control using **simulation** of temperature gives **up to 10 pct reduction** of heat loss.
- Control using **data and predictions** gives **up to 20 pct. reduction** of heat loss.

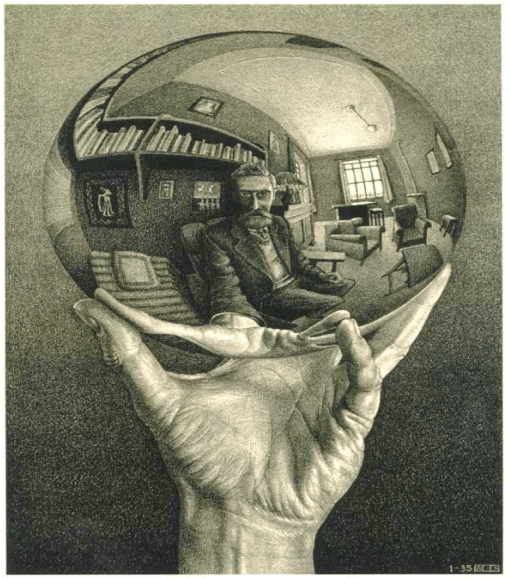
Case study

Modelling the thermal characteristics of a small office building

Example



Characterization using Data from Smart Meters



- Energy labelling
- Estimation of UA and gA values
- Estimation of energy signature
- Estimation of dynamic characteristics
- Estimation of time constants

Results

	UA W/°C	σ_{UA}	gA^{max} W	wA_E^{max} W/°C	wA_S^{max} W/°C	wA_W^{max} W/°C	T_i °C	σ_{T_i}
4218598	211.8	10.4	597.0	11.0	3.3	8.9	23.6	1.1
4381449	228.2	12.6	1012.3	29.8	42.8	39.7	19.4	1.0
4711160	155.4	6.3	518.8	14.5	4.4	9.1	22.5	0.9
4836681	155.3	8.1	591.0	39.5	28.0	21.4	23.5	1.1
4836722	236.0	17.7	1578.3	4.3	3.3	18.9	23.5	1.6
4986050	159.6	10.7	715.7	10.2	7.5	7.2	20.8	1.4
5069878	144.8	10.4	87.6	3.7	1.6	17.3	21.8	1.5
5069913	207.8	9.0	962.5	3.7	8.6	10.6	22.6	0.9
5107720	189.4	15.4	657.7	41.4	29.4	16.5	21.0	1.6
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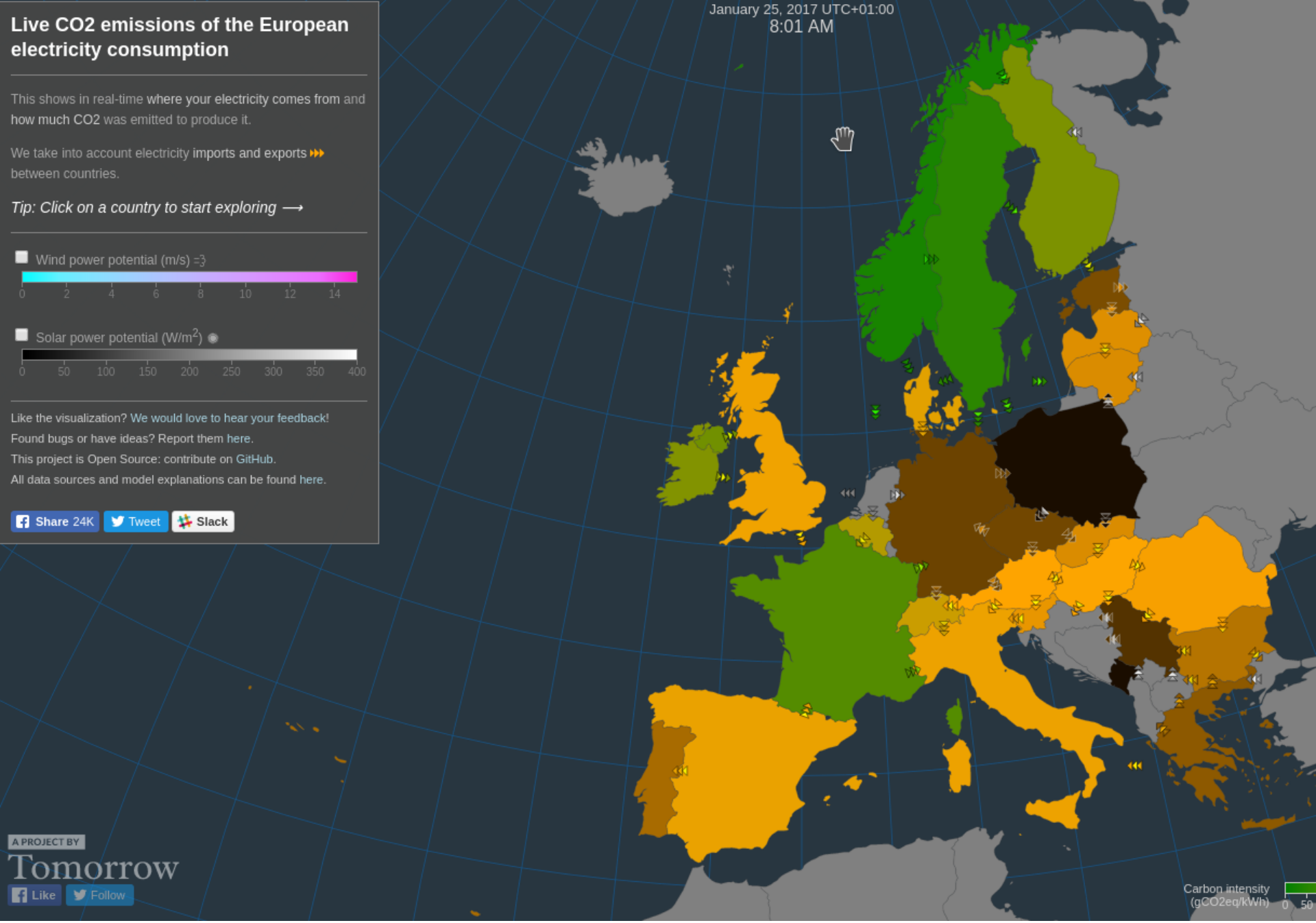
Perspectives for using data from Smart Meters

- Reliable Energy Signature.
- Energy Labelling
- Time Constants (eg for night set-back)
- Proposals for Energy Savings:
  - Replace the windows?
  - Put more insulation on the roof?
  - Is the house too untight?
  - .....
- Optimized Control
- Integration of Solar and Wind Power using DSM

Further Aspects



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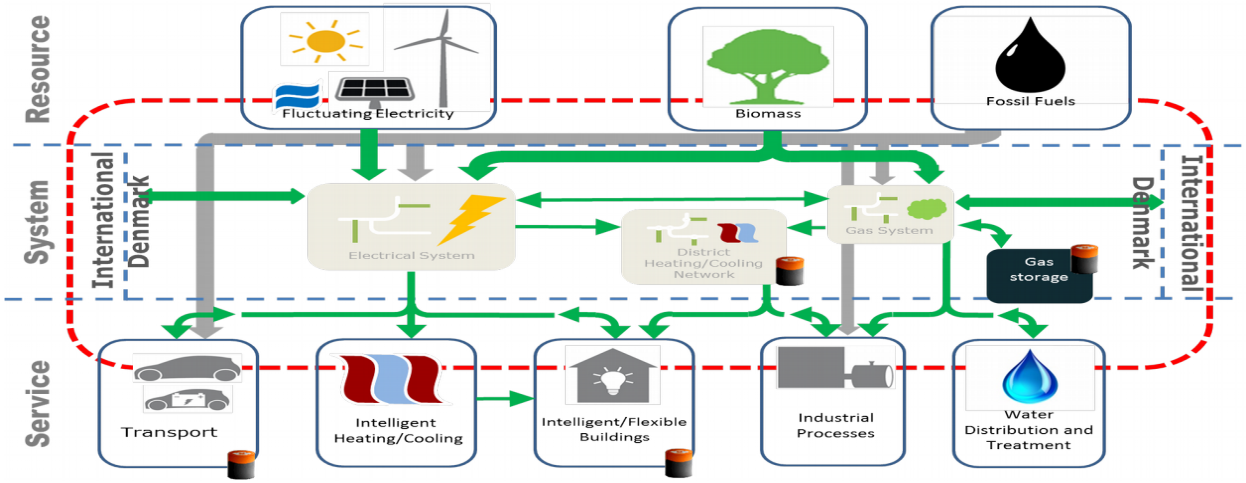
HEATMAN – NIRAS, TREFOR, Grunfos, Danfoss, DTU, March 2017

(Virtual) Storage Solutions



- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - DH systems with thermal solar collectors can often provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions

Summary

- A Smart-Energy OS for harvesting the flexibility of future intelligent and integrated energy systems has been described
- **Modelling:** Toolbox – CTSM-R - for combined physical and statistical modelling (**grey-box modelling**)
- **Control:** Toolbox – MPC-R - for Model Predictive Control
- Two models for ***characterizing the flexibility*** have been suggested and demonstrated:
  - **Dynamic models** (used for E-MPC based on prices / indirect control)
  - **Saturation curves** (used for market bidding / direct control)

For more information …

See for instance

www.smart-cities-centre.org

…or contact

- Henrik Madsen (DTU Compute)

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Acknowledgement - DSF 1305-00027B