The Importance of ICT Technologies in the Overall Energy Transition

Henrik Madsen

Applied Mathematics and Computer Science, DTU

http://www.smart-cities-centre.org

http://www.henrikmadsen.org

CITIES
Centre for IT Intelligent Energy Systems

Challenges

Preparatory study on Smart Appliances

European Commission

Ecodesign Preparatory Study performed for the European Commission

Welcome | Project summary | Planning & Meetings | Documents | Register for website | Register for meeting | Contact & Consortium

Home > Project summary

Project Summary

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) has analysed the technical, economic, market and societal aspects with a view to a broad introduction of smart appliances and to develop adequate policy approaches supporting such uptake.

The study deals with Task 1 to 7 of the Methodology for Energy related products (MEErP) as follows:

- Scope, standards and legislation (Task 1, Chapter 1);
- Market analysis (Task 2, Chapter 2);
- User analysis (Task 3, Chapter 3);
- Technical analysis (Task 4, Chapter 4);
- Definition of Base Cases (Task 5, Chapter 5);
- Design options (Task 6, Chapter 6);
- Policy and Scenario analysis (Task 7, Chapter 7).

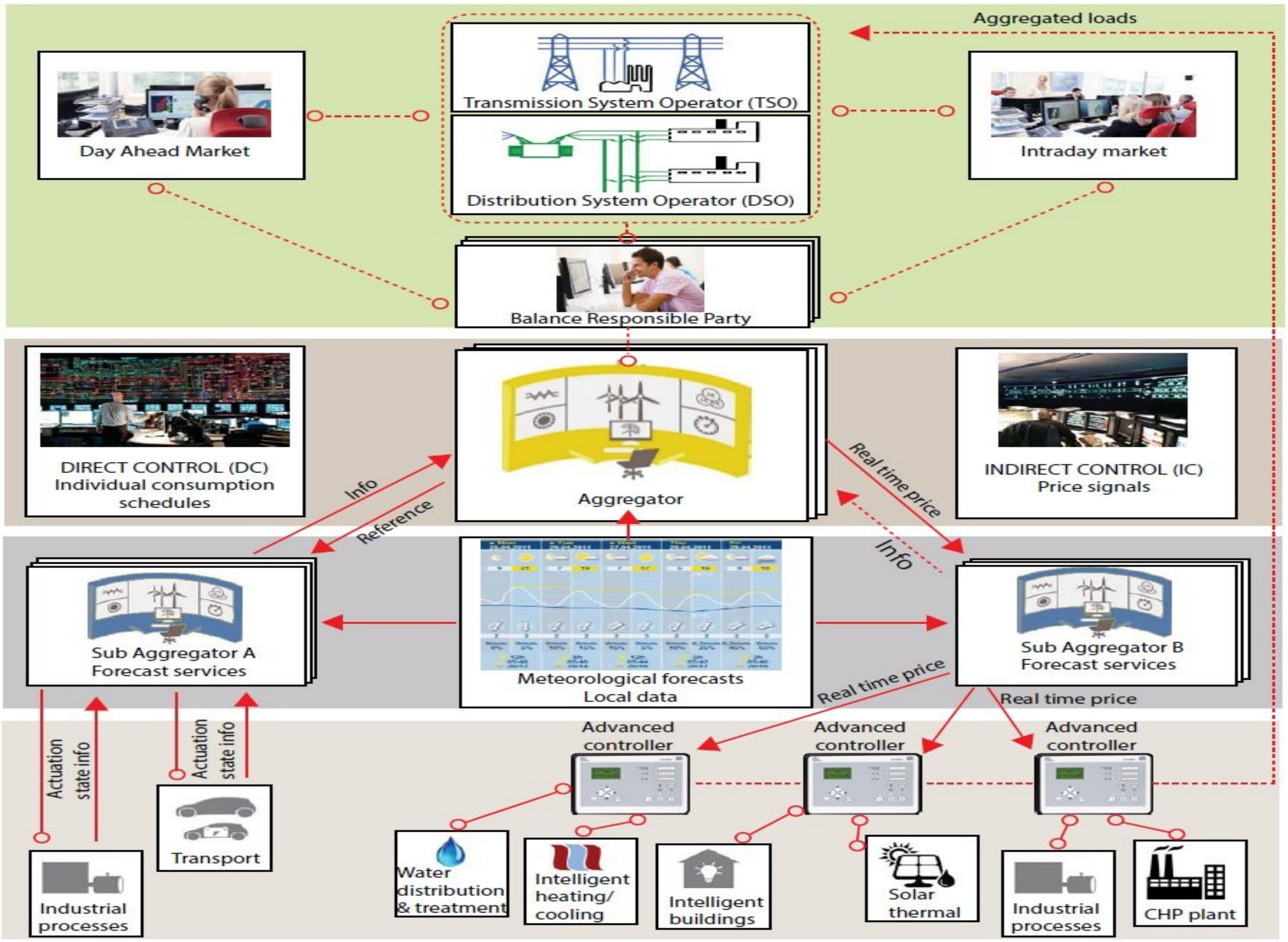
An executive summary of the project results can be downloaded here.

Throughout the study, new relevant aspects have come up which will be covered in a second phase of the Preparatory Study:

- Chargers for electric cars: technical potential and other relevant issues in the context of demand response.
- The modelling done in the framework of MEErP Task 6 and 7 will be updated with PRIMES data that recently became available, and with the EEA-countries.
- The development and assessment of policy options that were identified in the study will be further elaborated and deepened.

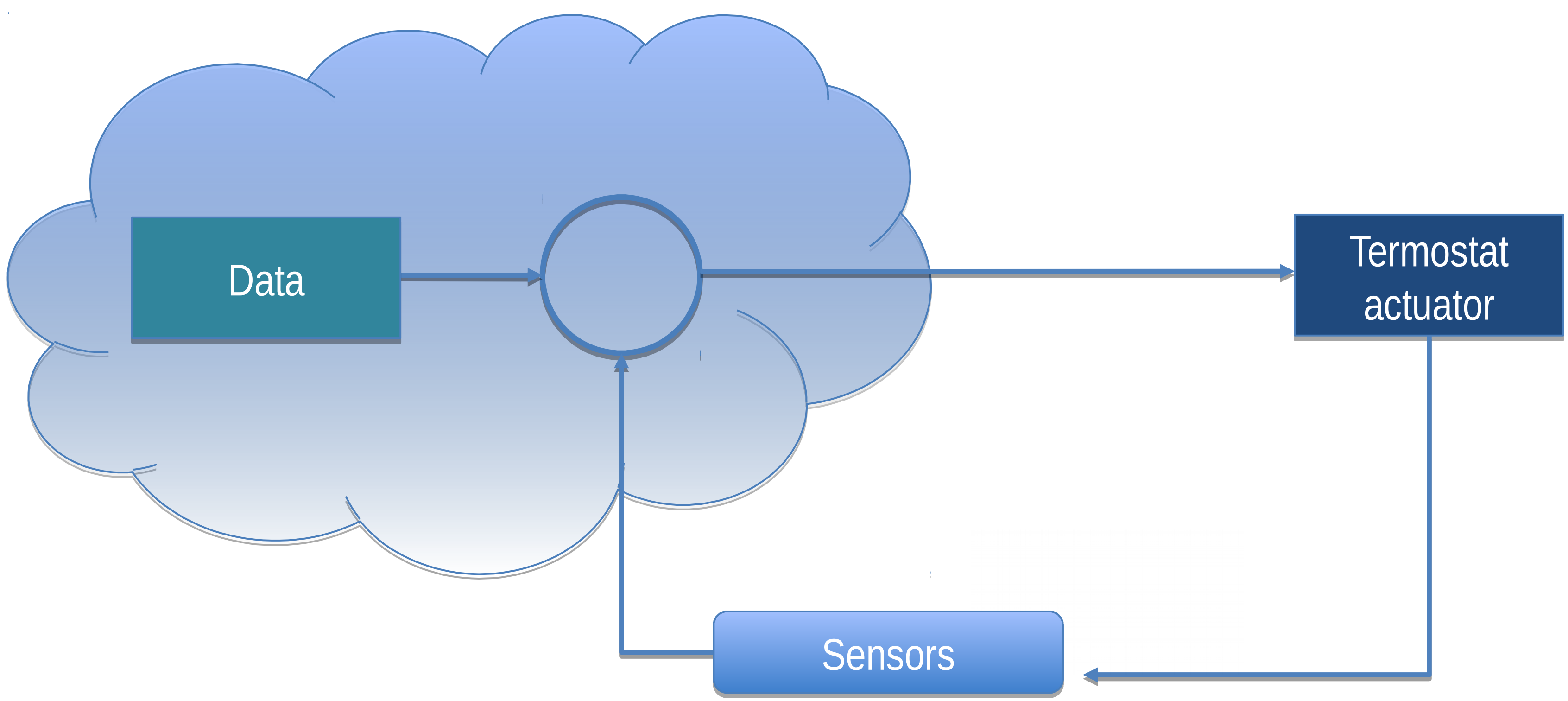
Conclusion: Almost no flexibility ?!

Smart-Energy OS

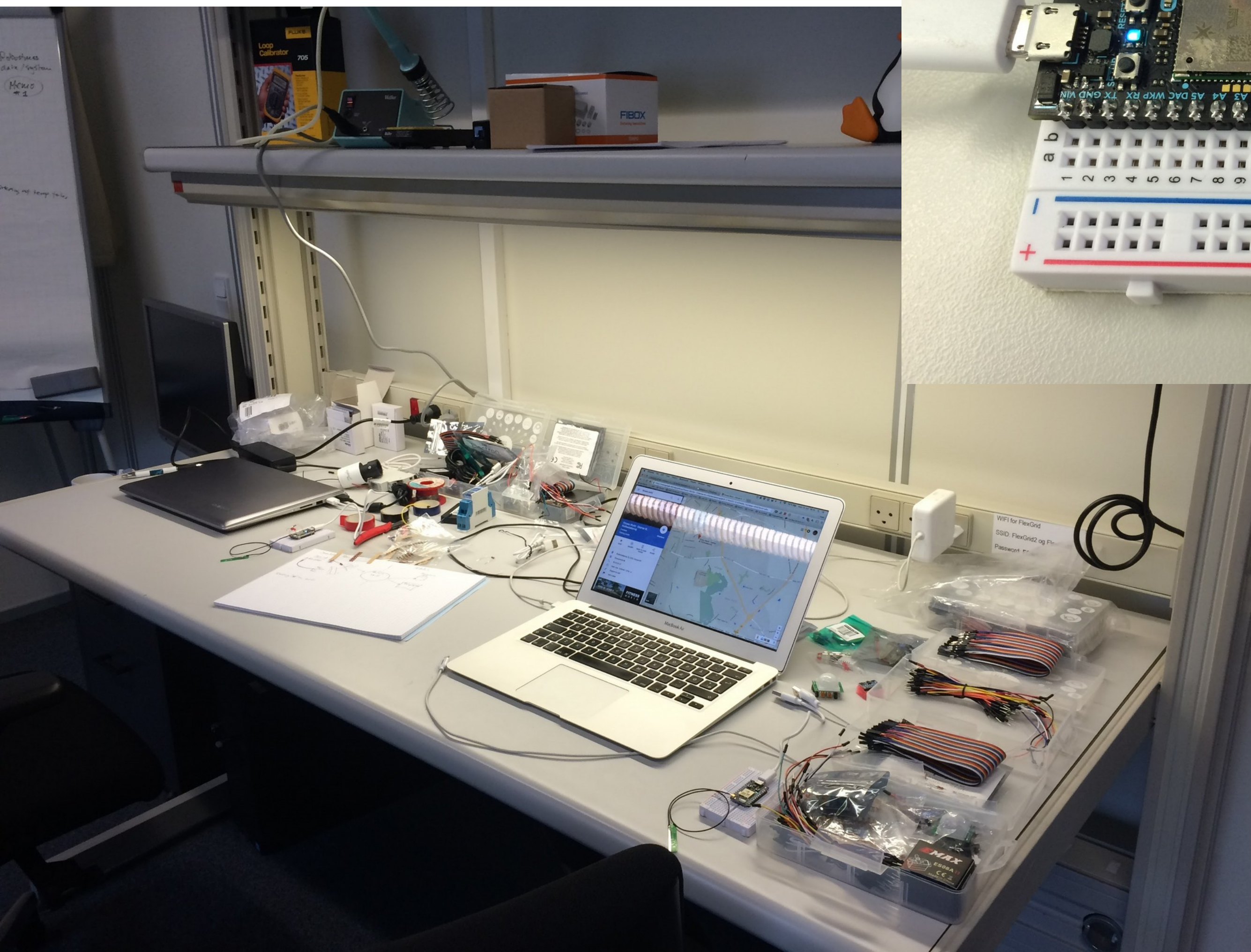


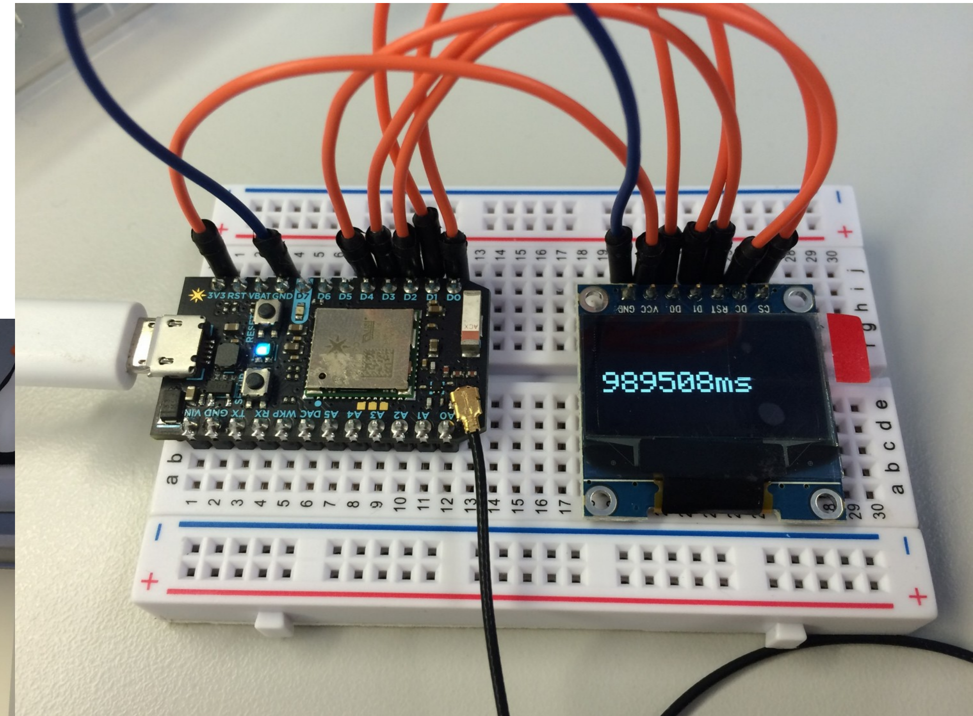
CITIES
Centre for IT Intelligent Energy Systems

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

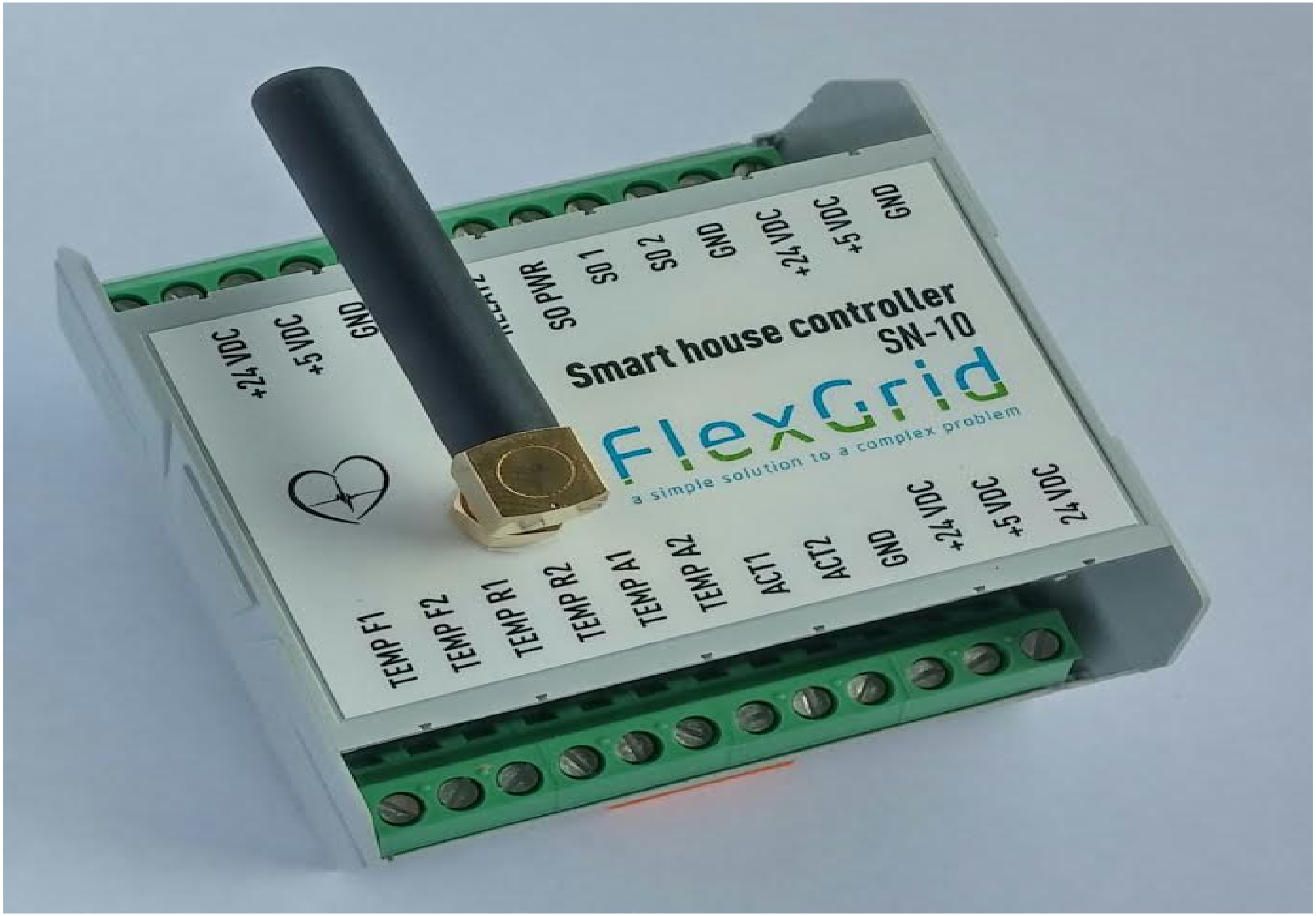


Lab testing ….





SN-10 Smart House Gateway



SE-OS Characteristics

- 'Bidding – clearing – activation' at higher levels
- Nested sequence of systems – systems of systems – models based on **Big Data Analytics**
- Hierarchy of optimization (or control) problems based on **AI technologies**
- Control principles at higher spatial/temporal resolutions
- **Cloud, Fog or Edge Computing** based solutions – eg. for forecasting and control
- Facilitates **Energy Systems Integration** (power, gas, thermal, ...)
- Accelerates the clean energy transition (see later ..)
- Simple setup for the communication and contracts
- Provides **a solution for all ancillary services**
- Harvest flexibility at all levels

Innovation Fund Denmark

DTU

Case study No. 1

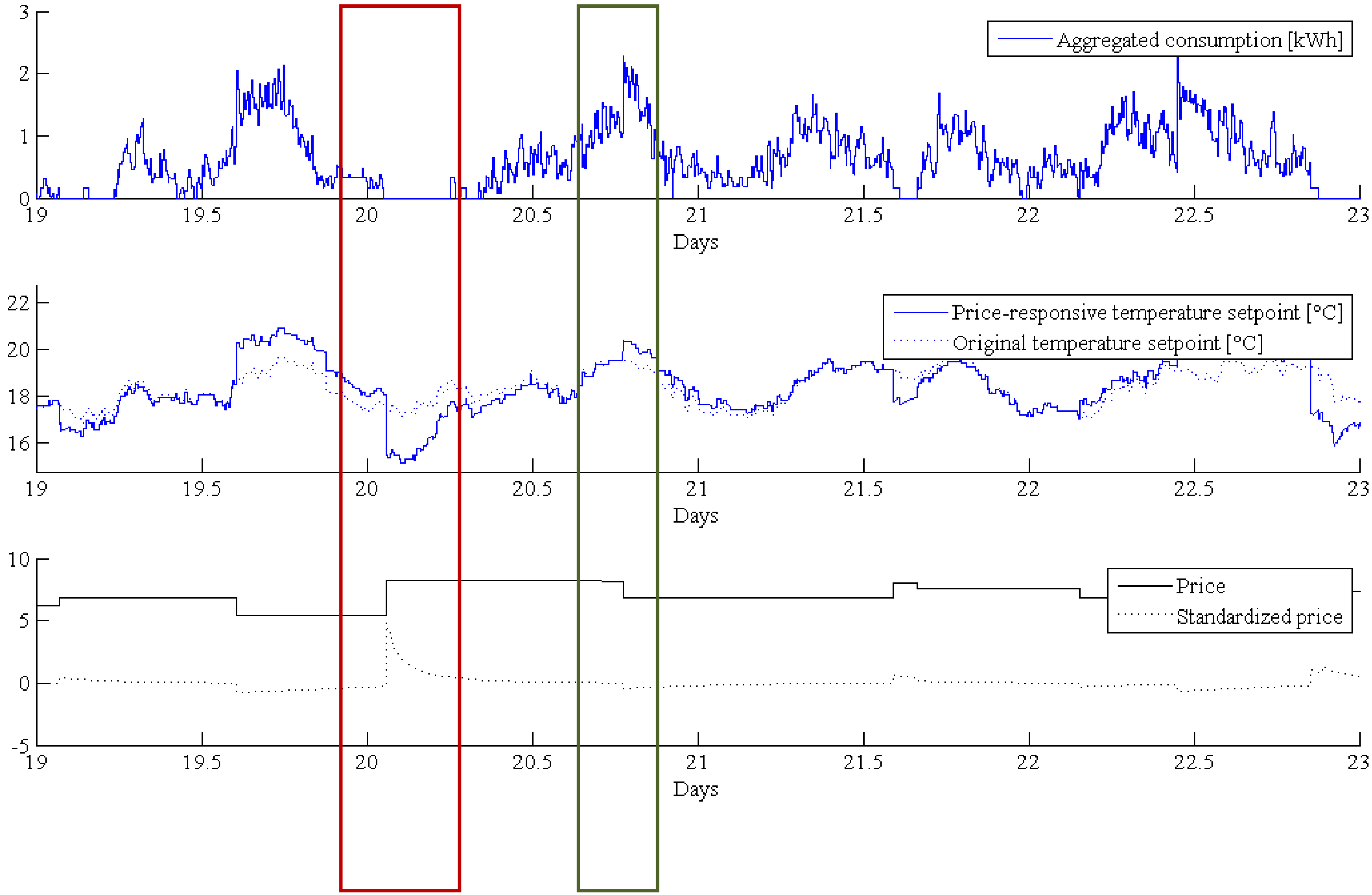
Control of Power Consumption using the Thermal Mass of Buildings (Peak shaving)

CITIES
Centre for IT Intelligent Energy Systems

Innovation Fund Denmark

DTU

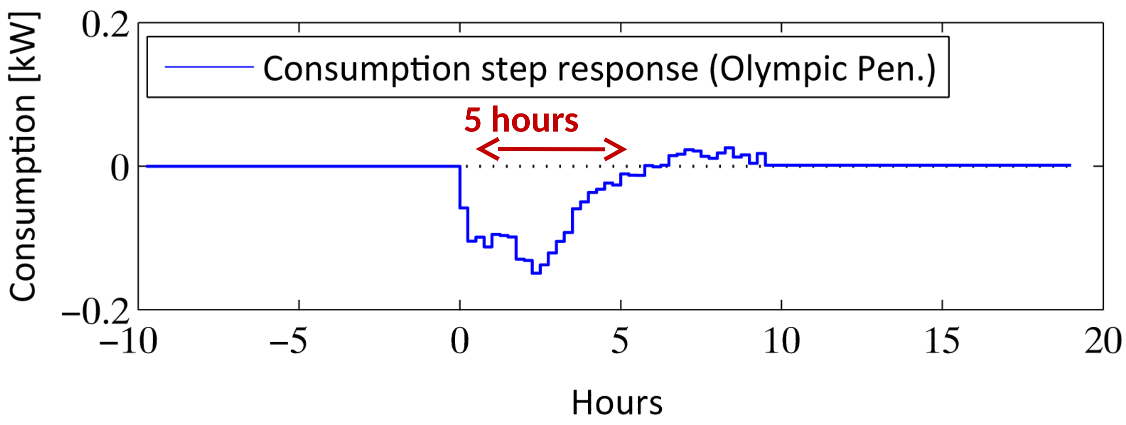
Aggregation (over 20 houses)



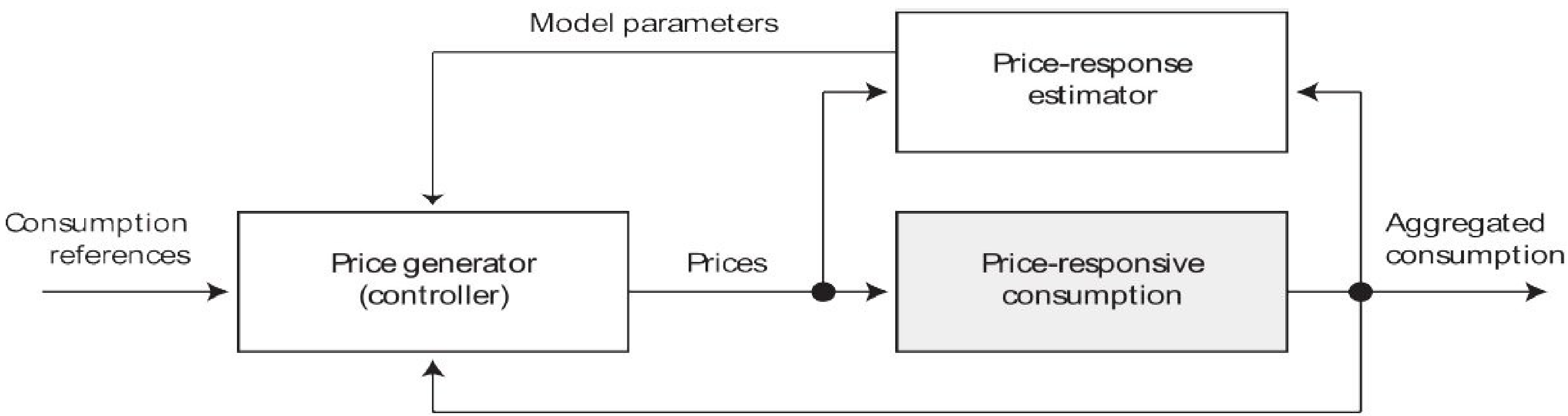
CITIES
Centre for IT Intelligent Energy Systems

Response on Price Step Change

Olympic Peninsula

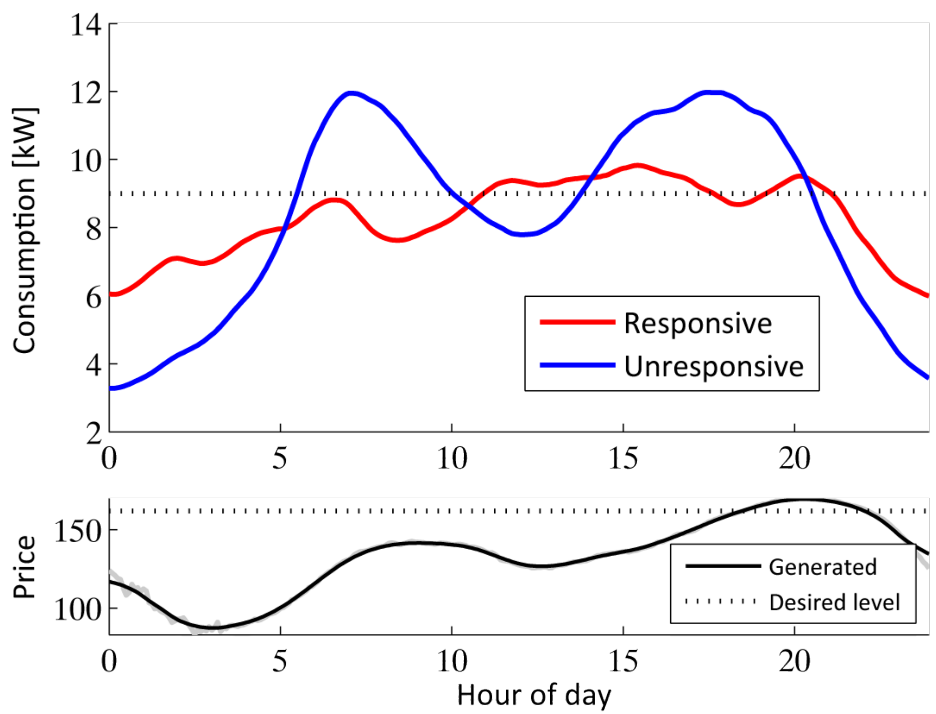


Control of Energy Consumption



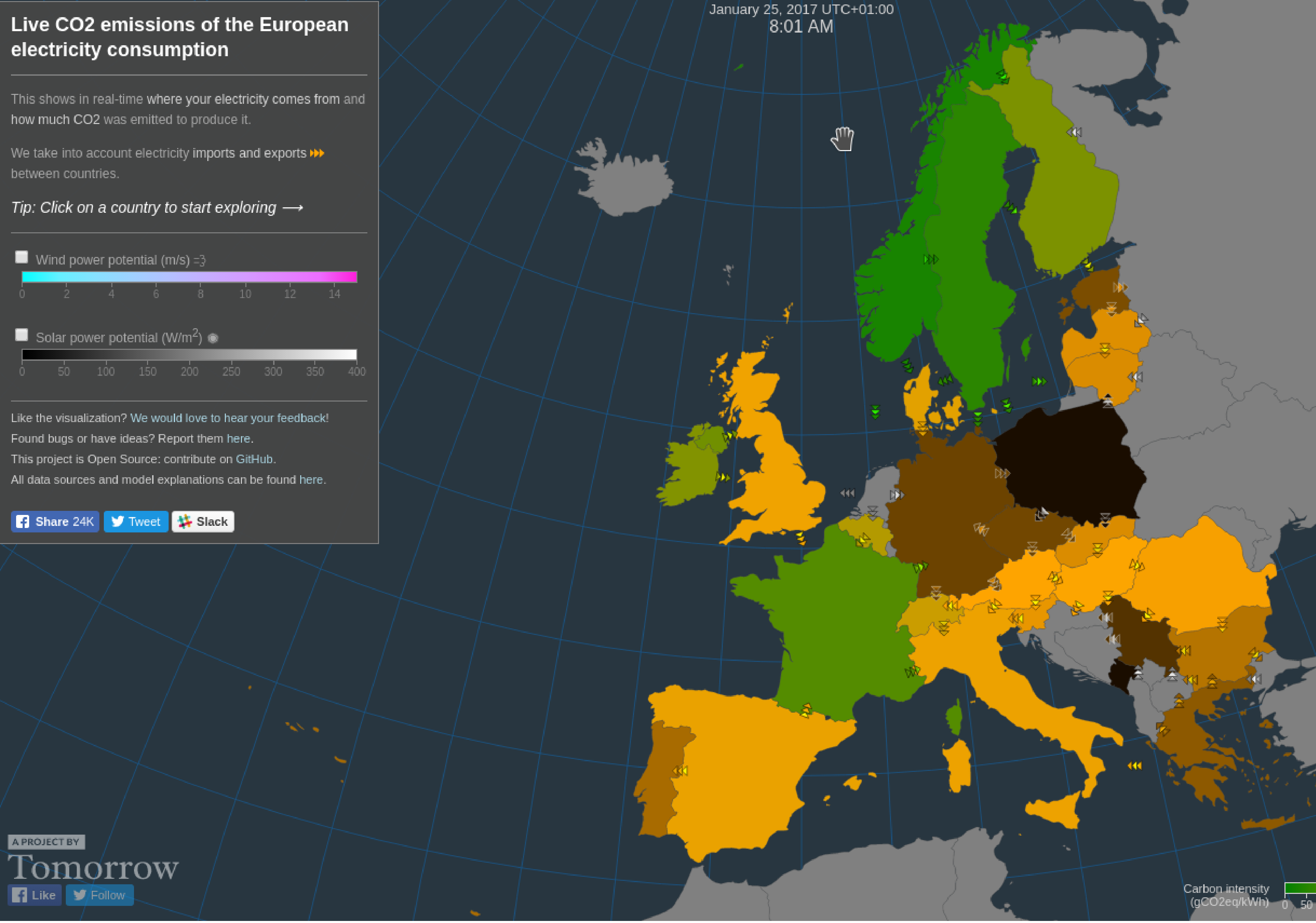
Control performance

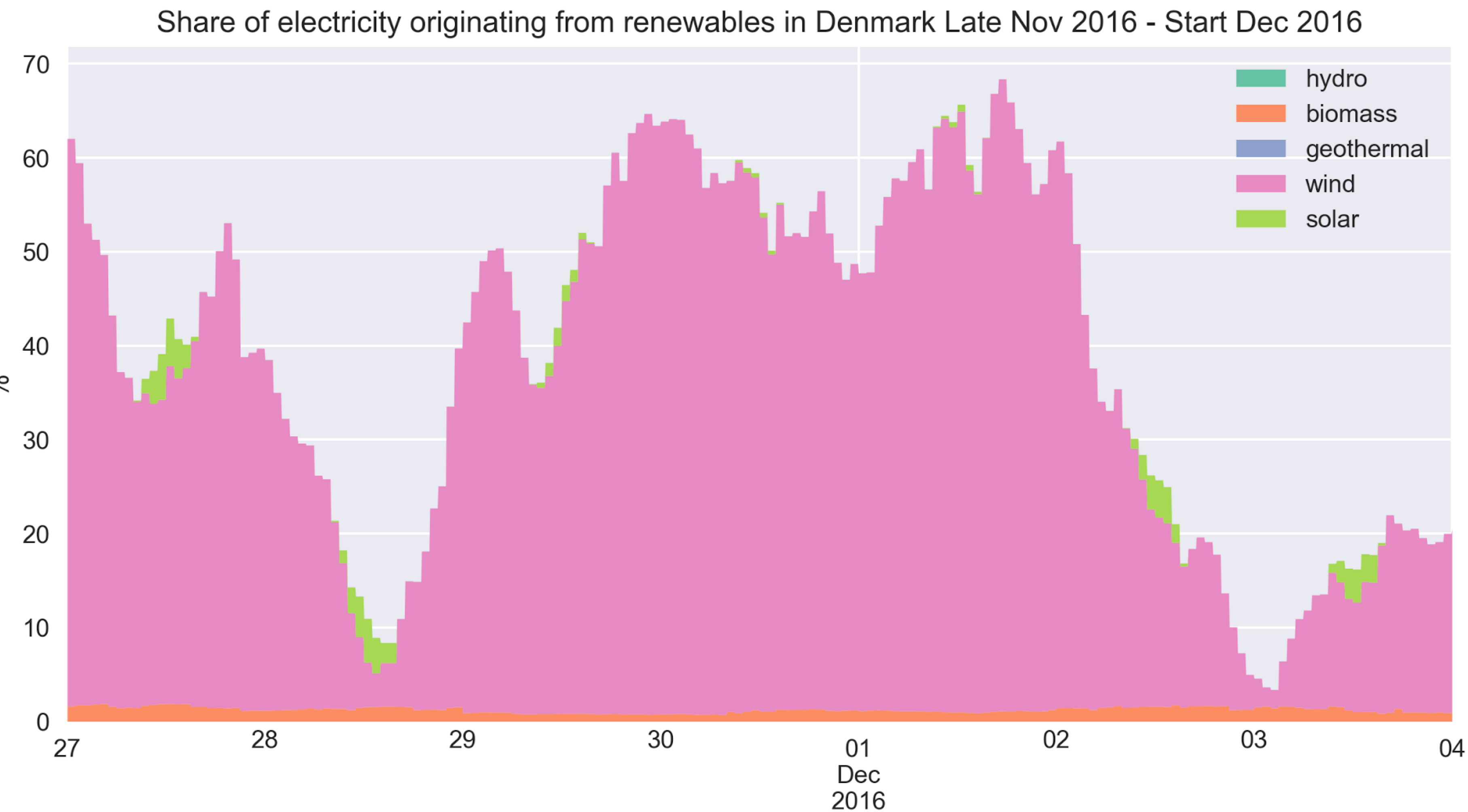
Considerable **reduction in peak consumption**
Mean daily consumption shift



Case study No. 2

Control of Heat Pumps
Summer Houses with a Swimming Pool
(CO_2 minimization)


Live CO2 emissions of the European electricity consumption
This shows in real-time where your electricity comes from and how much CO2 was emitted to produce it.
We take into account electricity imports and exports between countries.
Tip: Click on a country to start exploring ⟶
Wind power potential (m/s)
0 2 4 6 8 10 12 14
Solar power potential (W/m2)
0 50 100 150 200 250 300 350 400
Like the visualization? We would love to hear your feedback!
Found bugs or have ideas? Report them here.
This project is Open Source: contribute on GitHub.
All data sources and model explanations can be found here.
Share 24K
Tweet
Slack
January 25, 2017 UTC+01:00
8:01 AM
A PROJECT BY
Tomorrow
Like
Follow
Carbon intensity
(gCO2eq/kWh)
0 50

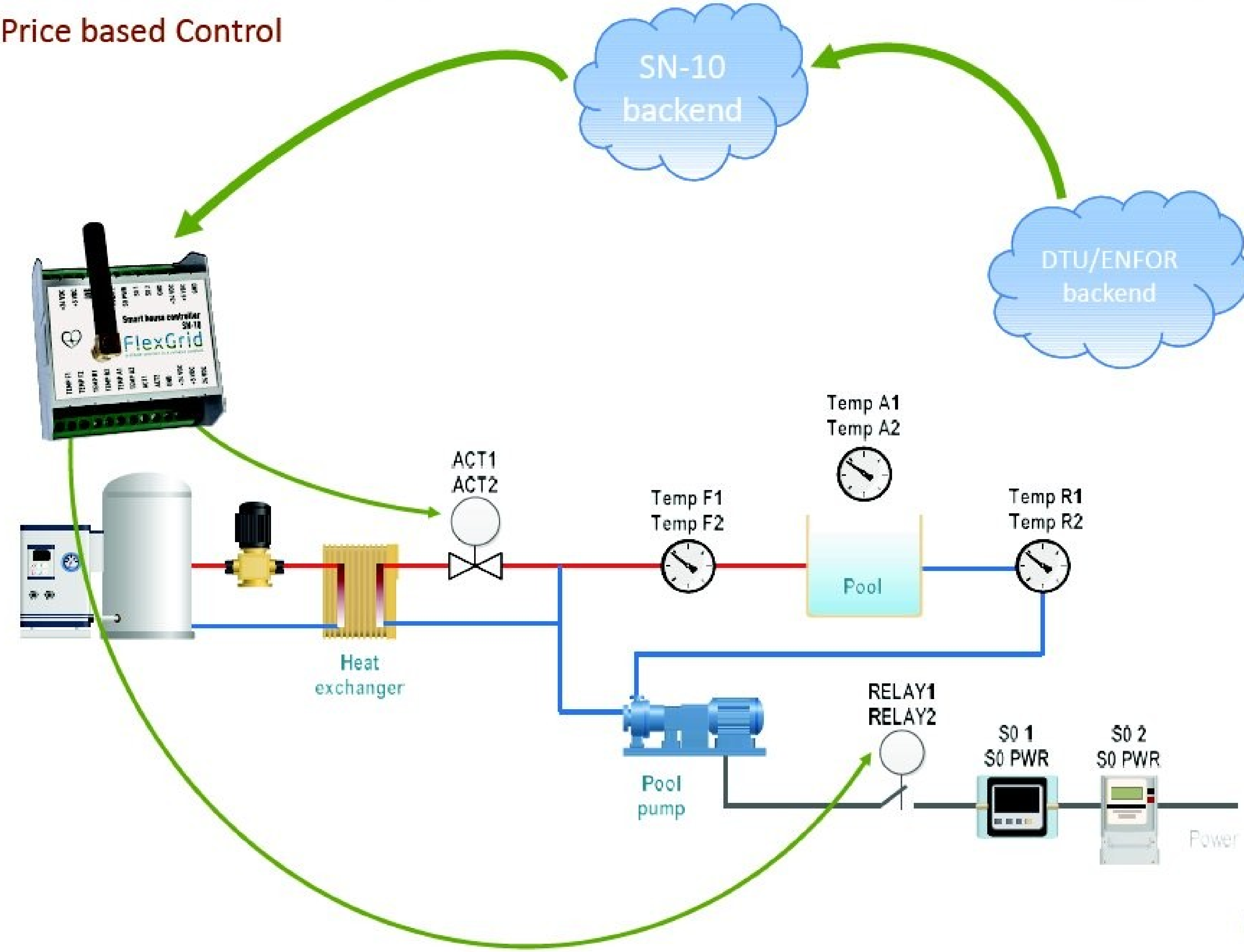


Source: pro.electicitymap.

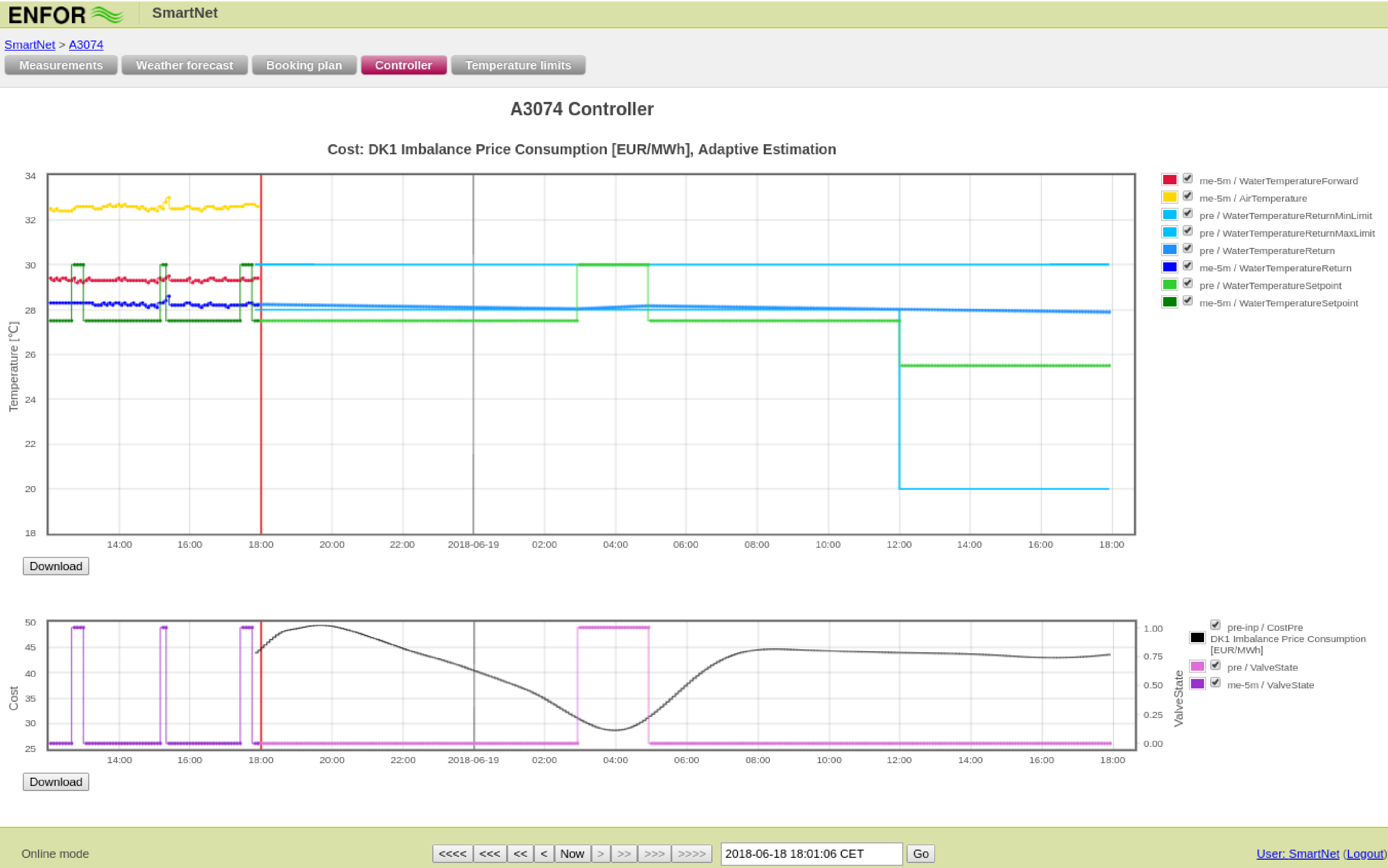
CITIES
Centre for IT Intelligent Energy Systems

How does it work?

Price based Control



Example: Price-based control



Example: CO2-based control
(40 pct less CO2 emission – 5 pct higher energy consumption)

Flexibility Function and Flexibility Index

Applied for Buildings and Districts

Flexibility Function (FF)

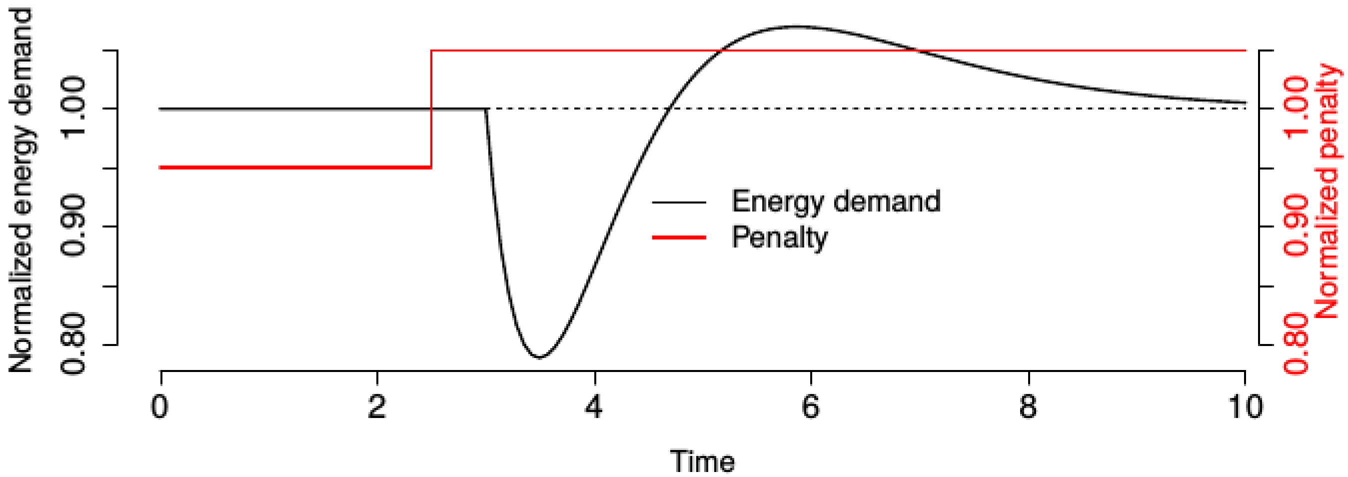


Figure 2: The energy consumption before and after an increase in penalty. The red line shows the normalized penalty while the black line shows the normalized energy consumption. The time scale could be very short with the units being seconds or longer with units of hours. At time 2.5 the penalty is increased,

Equivalent to: Impulse response, transfer function, and frequency res

Penalty Function (examples)

- **Real time CO_2.** If the real time (marginal) CO_2 emission related to the actual electricity production is used as penalty, then, a smart building will minimize the total carbon emission related to the power consumption. Hence, the building will be *emission efficient*.
- **Real time price**. If a real time price is used as penalty, the objective is obviously to minimize the total cost. Hence, the building is *cost efficient*.
- **Constant**. If a constant penalty is used, then, the controllers would simply minimize the total energy consumption. The smart building is, then, *energy efficient*.

FF for three buildings

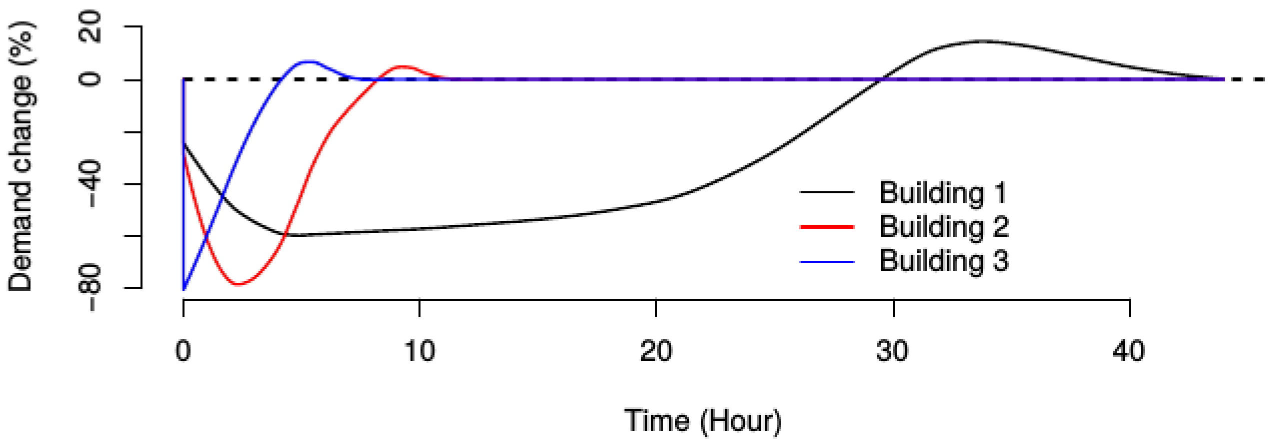


Figure 5: The Flexibility Function for three different buildings.

Innovation Fund Denmark

Flexibility Index

Table 2: Flexibility Index for each of the buildings based reference penalty signals representing wind, solar and ramp problems.

	Wind (%)	Solar (%)	Ramp (%)
Building 1	36.9	10.9	5.2
Building 2	7.2	24.0	11.1
Building 3	17.9	35.6	67.5

Innovation Fund Denmark

DTU

Summary

- We have defined two concepts :
  1) Flexibility Function
  2) Flexibility Index
- We have demonstrated a large potential for Demand Response using the ICT technologies
- CO_2-based control can be used to accelerate the clean energy transition
- The ICT-based SE-OS controllers can focus on
  - Peak Shaving
  - Smart Grid demand (like ancillary services needs, ...)
  - Energy Efficiency
  - Cost Minimization
  - Emission Efficiency

CITIES
Centre for IT Intelligent Energy Systems

Some references

Madsen, Henrik; Holst, Jan. Estimation of Continuous-Time Models for the Heat Dynamics of a Building. In: Energy and Buildings, Vol. 22, 1995

Andersen, Klaus Kaae; Madsen, Henrik; Hansen, Lars Henrik. Modelling the heat dynamics of a building using stochastic differential equations. In: Energy and Buildings, Vol. 31, No. 1, 2000, p. 13-24.

Kristensen, Niels Rode; Madsen, Henrik; Jørgensen, Sten Bay. Parameter Estimation in Stochastic Grey-Box Models. In: Automatica, Vol. 40, No. 2, 2004, p. 225-237.

Nielsen, Henrik Aalborg; Madsen, Henrik. Modelling the Heat Consumption in District Heating Systems using a Grey-box approach. In: Energy and Buildings, Vol. 38, No. 1, 2006, p. 63-71.

Friling, N.; Jimenez, M.J.; Bloem, H.; Madsen, Henrik. Modelling the heat dynamics of building integrated and ventilated photovoltaic modules. In: Energy and Buildings, Vol. 41, No. 10, 2009, p. 1051-1057.

Bacher, Peder; Madsen, Henrik. Identifying suitable models for the heat dynamics of buildings. In: Energy and Buildings, Vol. 43, No. 7, 2011, p. 1511-1522.

Lodi, C.; Bacher, Peder; Cipriano, J.; Madsen, Henrik. Modelling the heat dynamics of a monitored Test Reference Environment for Building Integrated Photovoltaic systems using stochastic differential equations. In: Energy and Buildings, Vol. 50, 2012, p. 273-281.

Halvgaard, Rasmus; Bacher, Peder; Perers, Bengt; Andersen, Elsa; Furbo, Simon; Jørgensen, John Bagterp; Poulsen, Niels Kjølstad; Madsen, Henrik. Model predictive control for a smart solar tank based on weather and consumption forecasts. In: Energy Procedia, Vol. 30, 2012, p. 270-278.

Dorini, Gianluca Fabio ; Pinson, Pierre; Madsen, Henrik. Chance-constrained optimization of demand response to price signals. In: IEEE Transactions on Smart Grid, Vol. 4, No. 4, 2013, p. 2072-2080.

Bacher, Peder; Madsen, Henrik; Nielsen, Henrik Aalborg; Perers, Bengt. Short-term heat load forecasting for single family houses. In: Energy and Buildings, Vol. 65, 2013, p. 101-112.

Corradi, Olivier; Ochsenfeld, Henning Peter; Madsen, Henrik; Pinson, Pierre. Controlling Electricity Consumption by Forecasting its Response to Varying Prices. In: IEEE Transactions on Power Systems, Vol. 28, No. 1, 2013, p. 421-430.

Some references (cont.)

Zugno, Marco; Morales González, Juan Miguel; Pinson, Pierre; Madsen, Henrik. A bilevel model for electricity retailers' participation in a demand response market environment. In: Energy Economics, Vol. 36, 2013, p. 182-197.

Meibom, Peter; Hilger, Klaus Baggesen; Madsen, Henrik; Vinther, Dorthe. Energy Comes Together in Denmark: The Key to a Future Fossil-Free Danish Power System. In: IEEE Power & Energy Magazine, Vol. 11, No. 5, 2013, p. 46-55.

Andersen, Philip Hvidthøft Delff ; Jiménez, María José ; Madsen, Henrik ; Rode, Carsten. Characterization of heat dynamics of an arctic low-energy house with floor heating. In: Building Simulation, Vol. 7, No. 6, 2014, p. 595-614.

Andersen, Philip Hvidthøft Delff; Iversen, Anne; Madsen, Henrik; Rode, Carsten. Dynamic modeling of presence of occupants using inhomogeneous Markov chains. In: Energy and Buildings, Vol. 69, 2014, p. 213-223.

Madsen, H, Parvizi, J, Halvgaard, RF, Sokoler, LE, Jørgensen, JB, Hansen, LH & Hilger, KB 2015, 'Control of Electricity Loads in Future Electric Energy Systems'. in AJ Conejo, E Dahlquist & J Yan (eds), Handbook of Clean Energy Systems: Intelligent Energy Systems. vol. 4, Wiley.

Halvgaard, RF, Vandenberghe, L, Poulsen, NK, Madsen, H & Jørgensen, JB 2016, Distributed Model Predictive Control for Smart Energy Systems IEEE Transactions on Smart Grid, vol 7, no. 3, pp. 1675-1682.

Bacher, P, de Saint-Aubain, PA, Christiansen, LE & Madsen, H, 2016, Non-parametric method for separating domestic hot water heating spikes and space heating Energy and Buildings, vol 130, pp. 107-112.

Junker, R.G., Azar, A.G. , Lopes, Rui A., Lindberg, KB, Reynders, G., Relan, R., Madsen, H., 2018, 'Characterizing the energy flexibility of buildings and districts', Applied Energy, Vol. 225, pp. 175-182.