CITIES
Centre for IT Intelligent Energy Systems

Energy Consumption in Buildings; What can we learn from data? -

Energy Systems Integration 101
KU Leuven, May 2015

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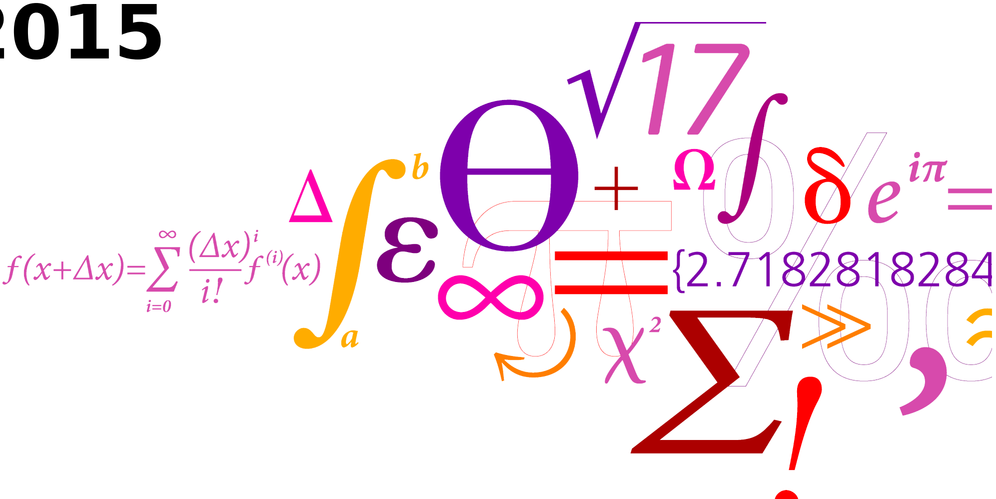


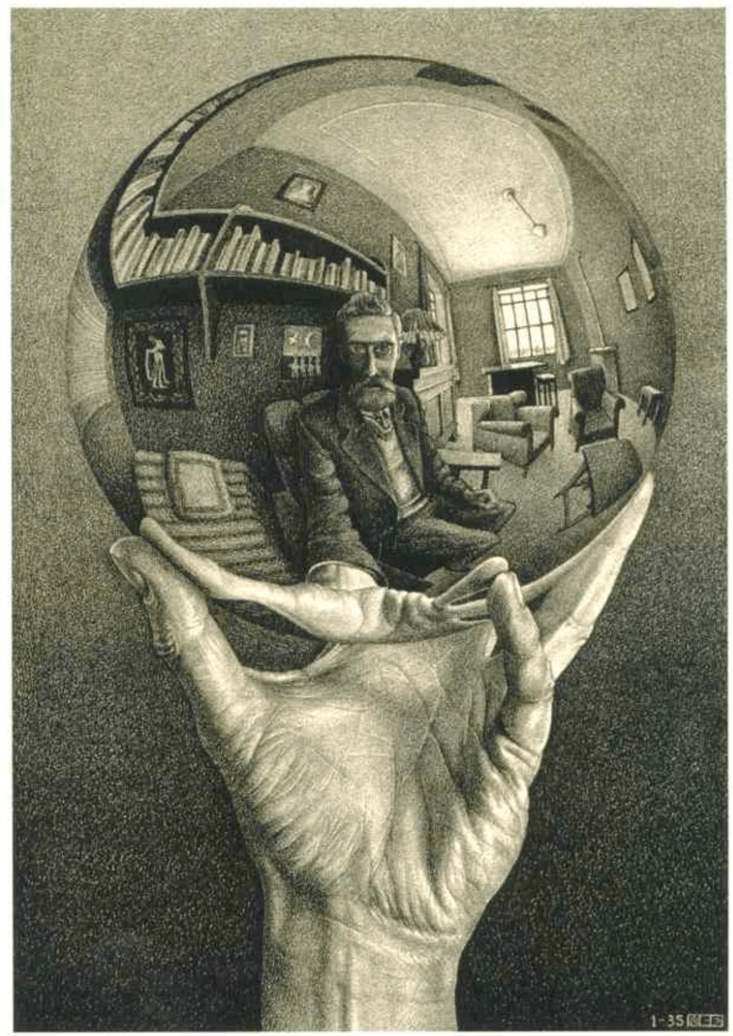
DTU Compute
Department of Applied Mathematics and Computer Science

Contents

- Non-parametric, conditional-parametric and semi-parametric models, ..
- RC-network, Lumped, ARMAX and grey-box models, ..
- Markov chain models, Generalized linear models, ..

Examples only!

Part 1
Non-parametric methods

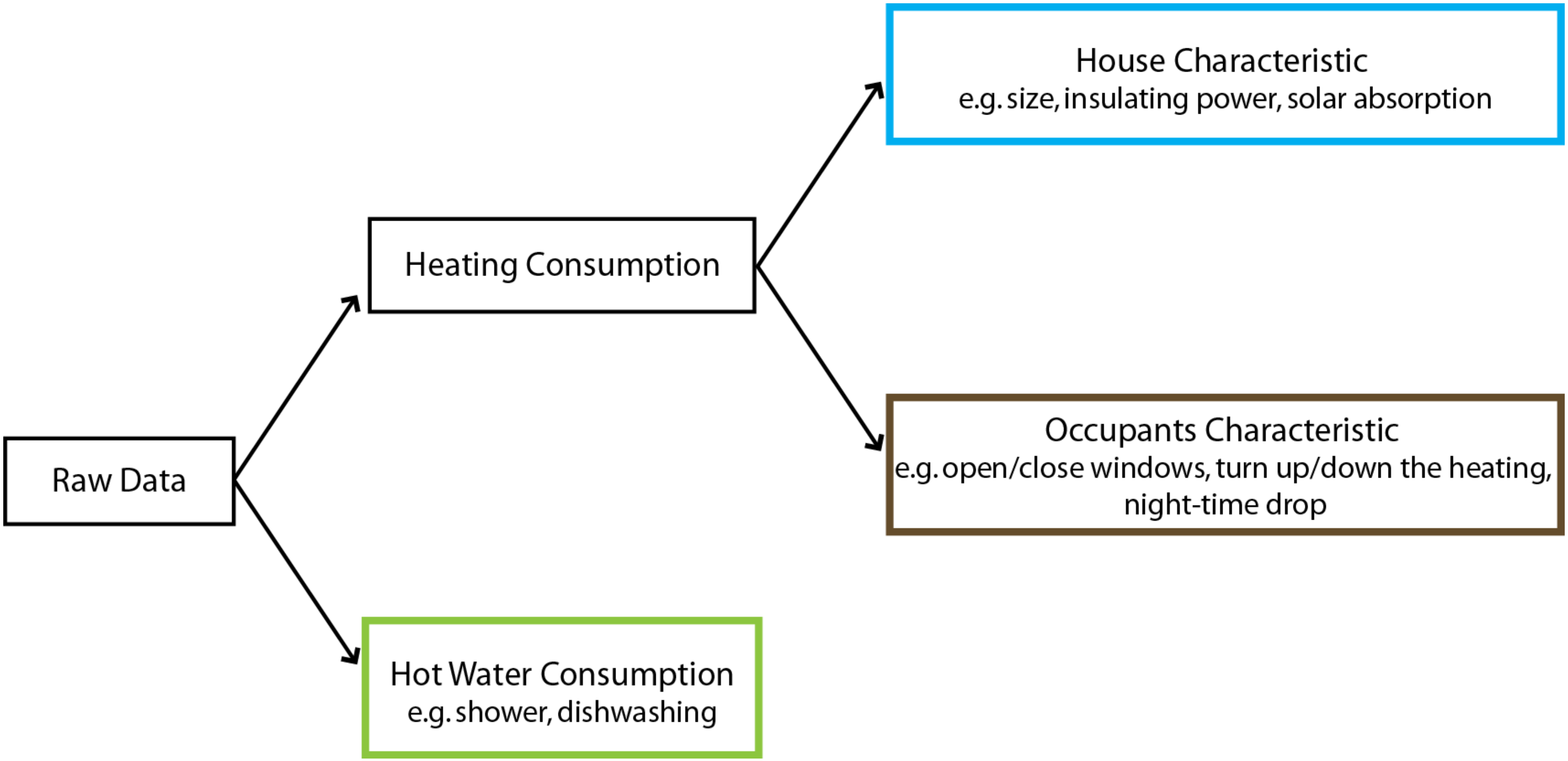


Typically only data from smart meter (and a nearby existing MET station)

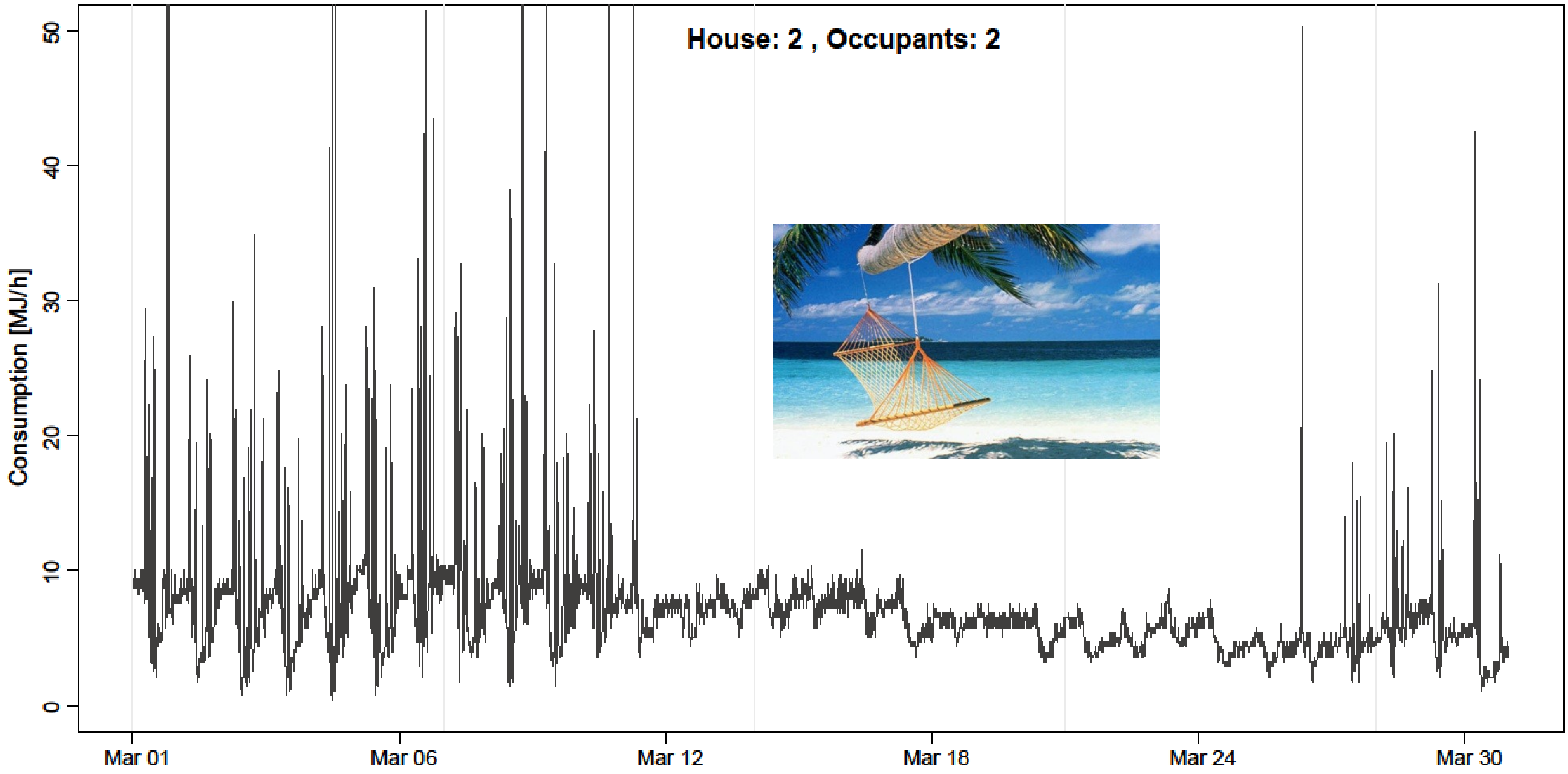
Case Study No. 1

Split of total readings into space heating and domestic hot water using data from smart meters

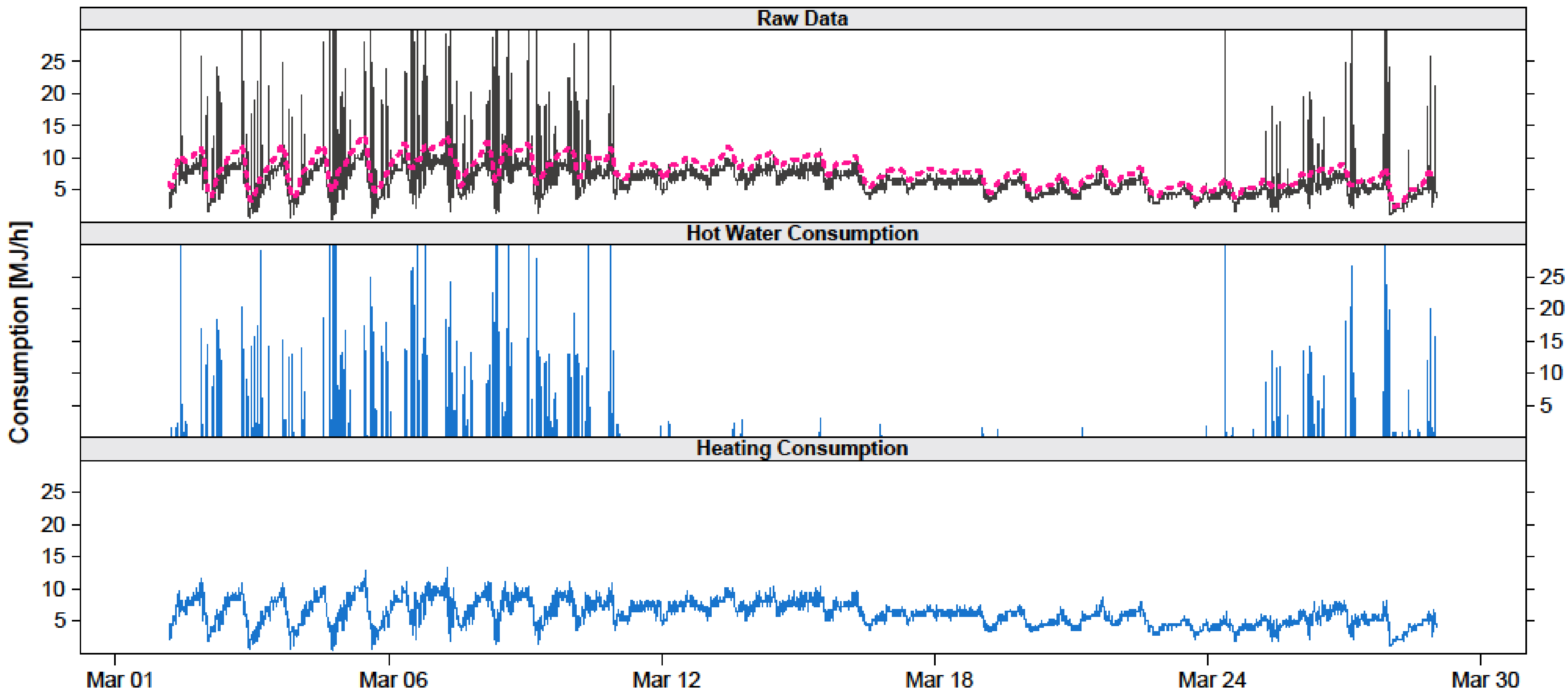
Splitting of total meter readings



Holiday period



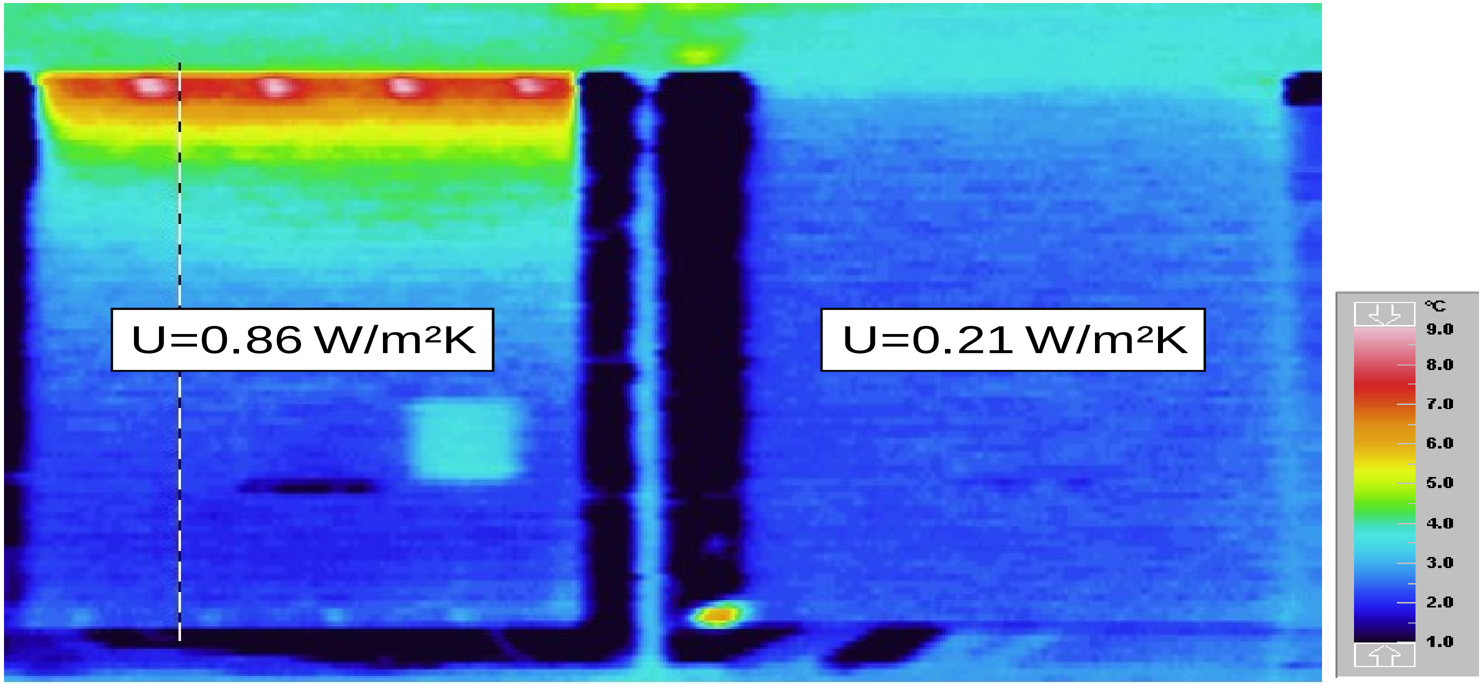
Robust Polynomial Kernel



Case Study No. 2

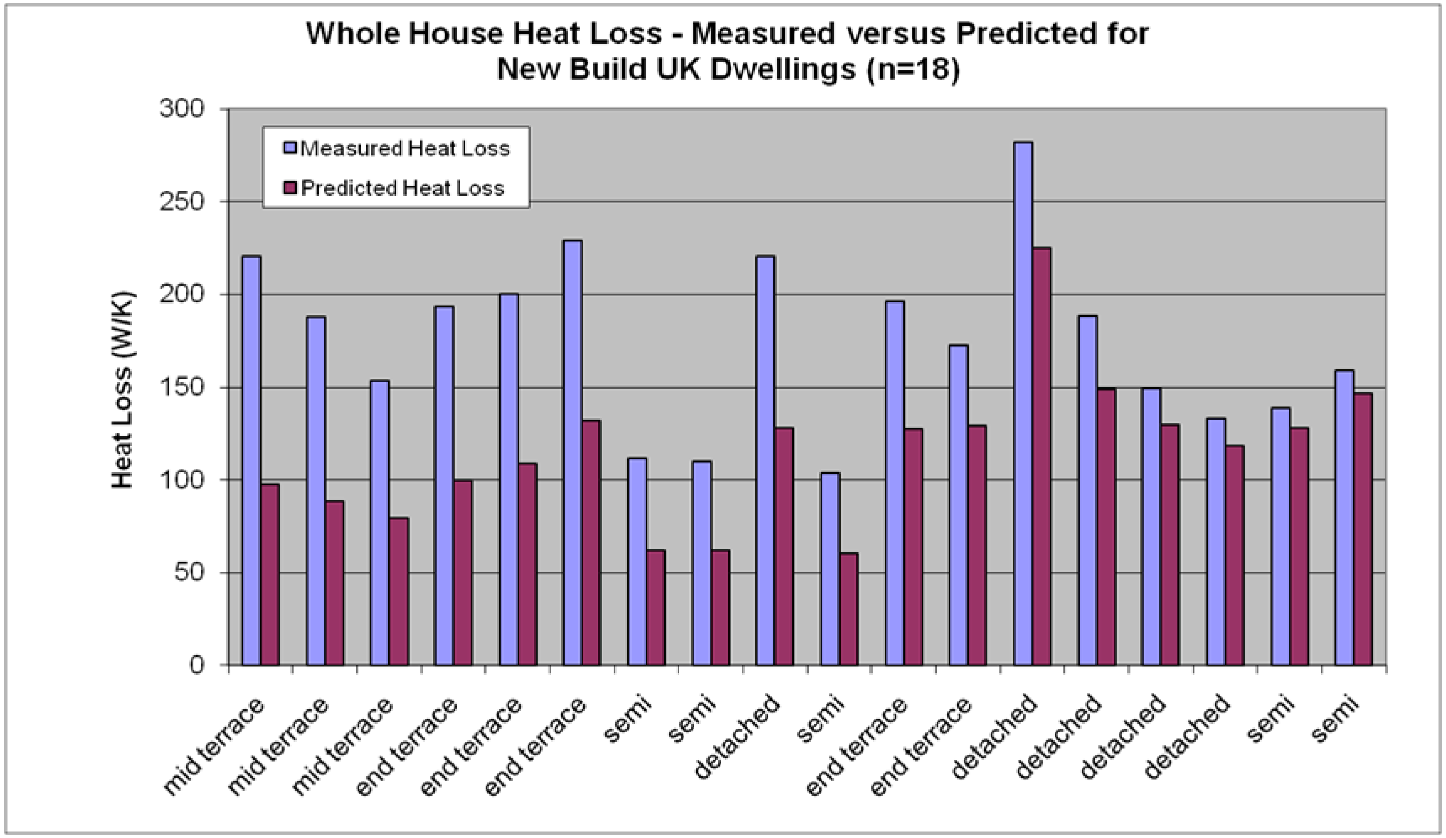
Ident. of Thermal Performance using Smart Meter Data

Example



Consequence of good or bad workmanship (theoretical value is U=0.16W/m2K)

Examples (2)



Measured versus predicted energy consumption for different dwellings

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
.	.	.	.	.	.	.	.	.

Perspectives for using data from Smart Meter

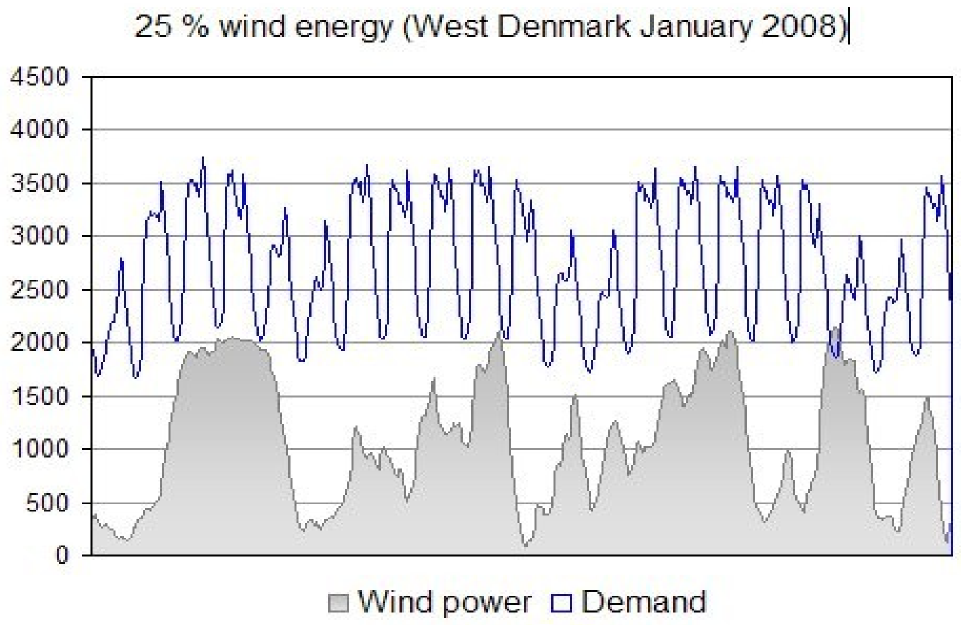
- Reliable Energy Signature.
- Energy Labelling
- Time Constants (eg for night set-back)
- Proposals for Energy Savings:
  - Replace the windows?
  - Put more insulation on the roof?
  - Is the house too untight?
  - ......
- Optimized Control
- Integration of Solar and Wind Power using DSM

Case Study No. 3

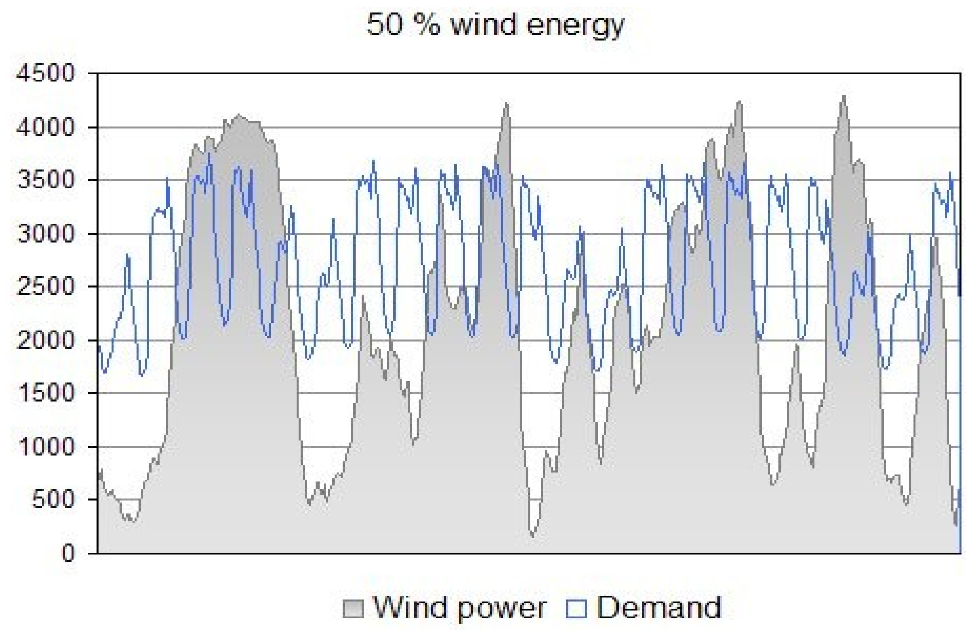
Control of Power Consumption (DSM)

The Danish Wind Power Case

.... balancing of the power system



In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

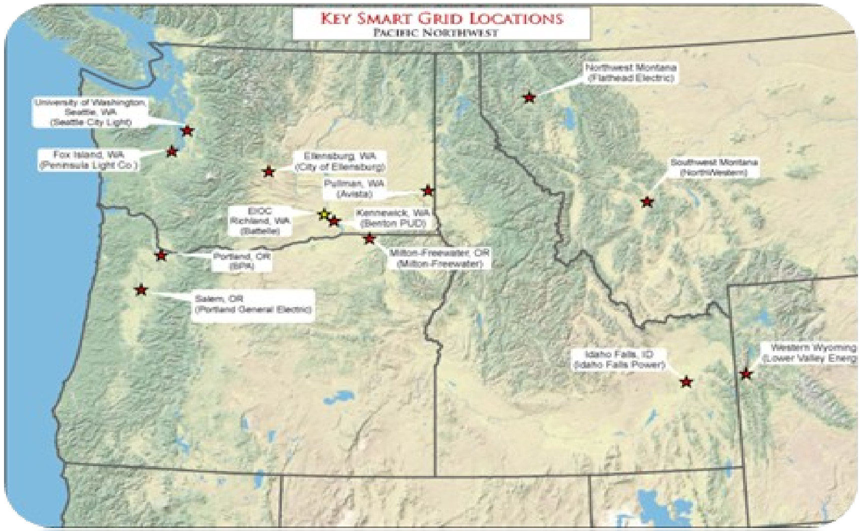


In December 2013 and January 2014 more than 55 pct of electricity load was covered by wind power. And for several days the wind power production was more than 120 pct of the power load

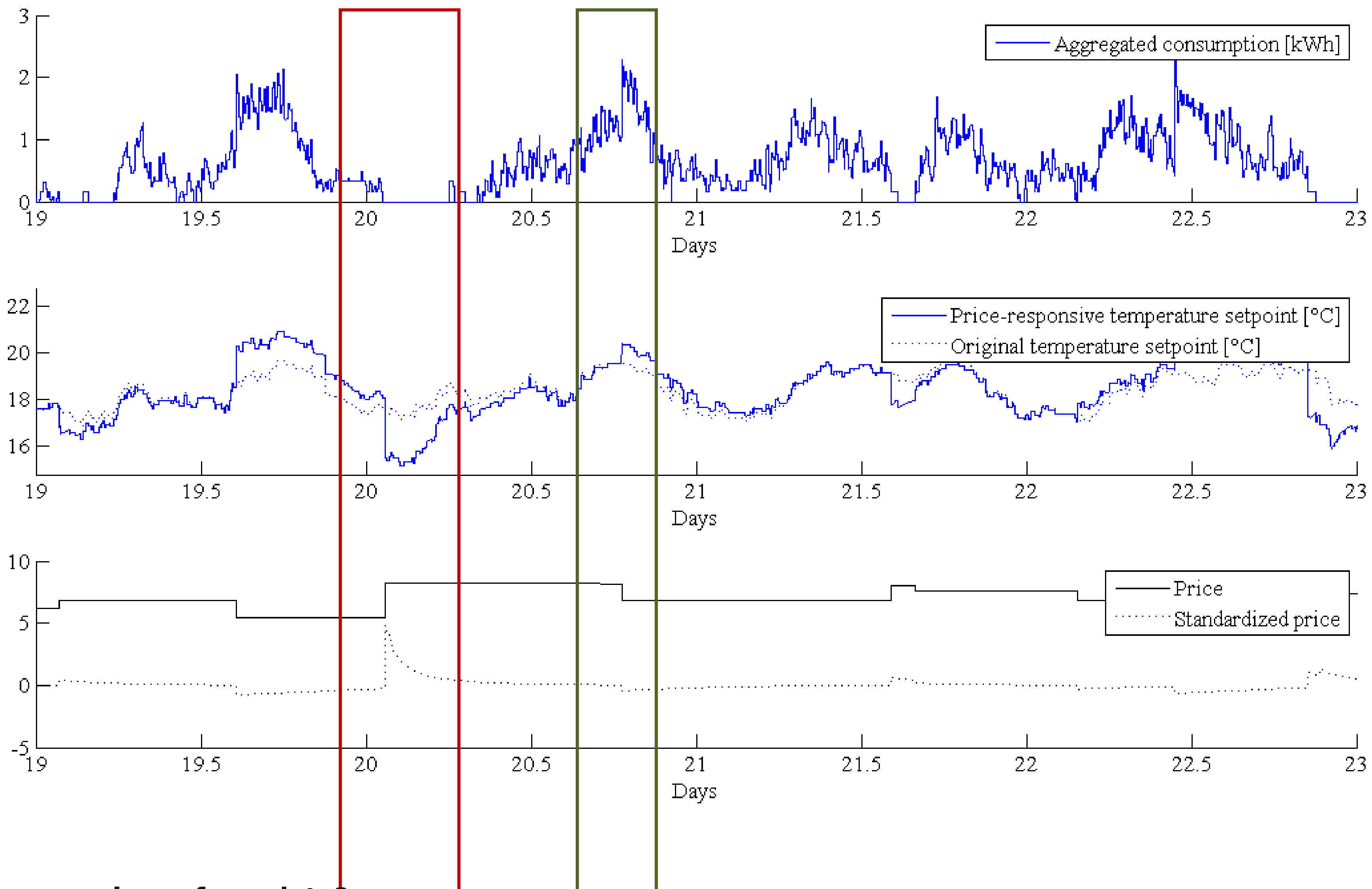
Data from BPA

Olympic Pensinsula project

- 27 houses during one year
- Flexible appliances: HVAC,
  cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption



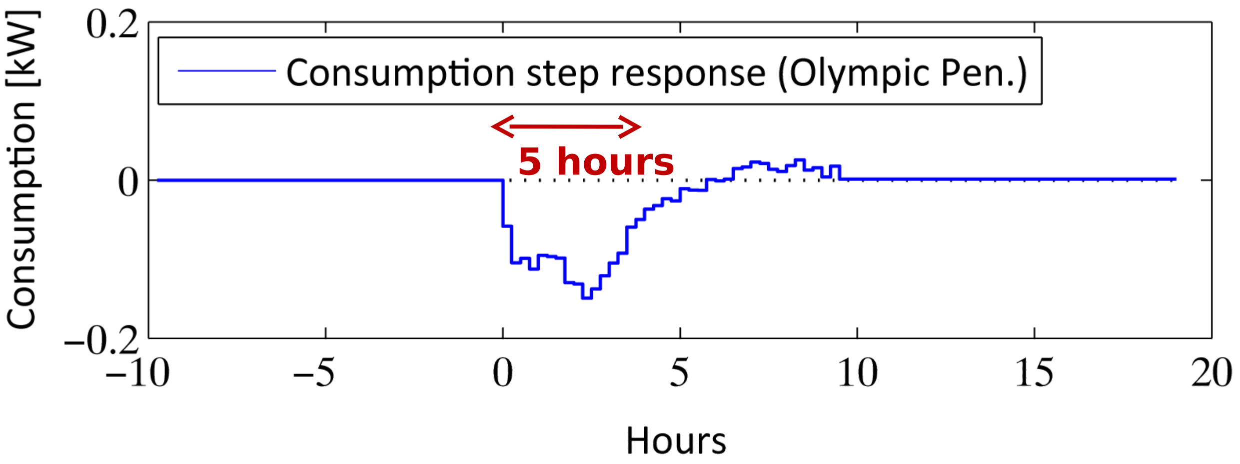
Aggregation (over 20 houses)



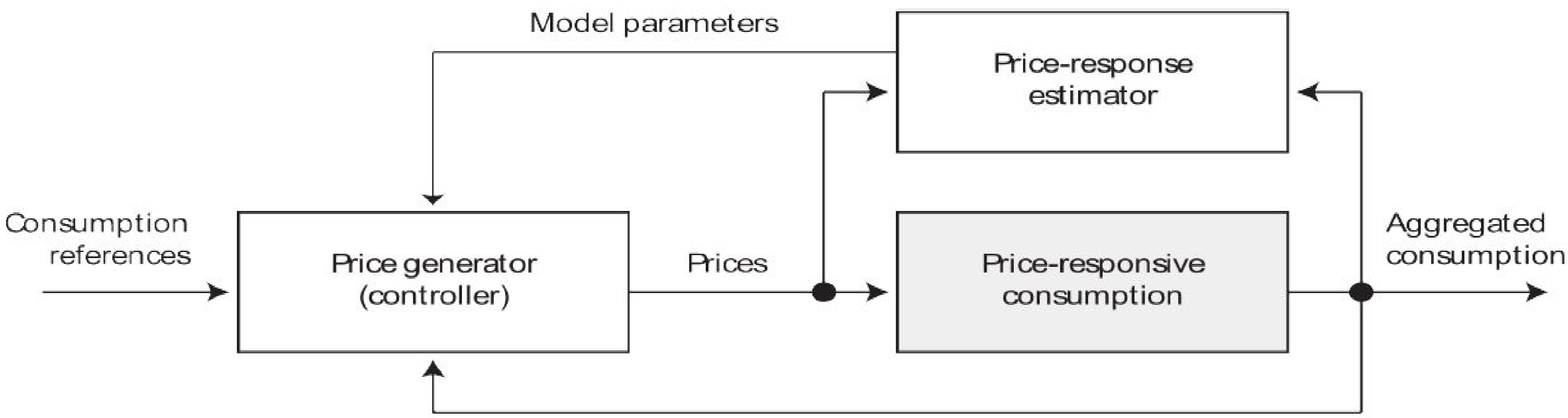
Non-parametric Response on Price Step Change

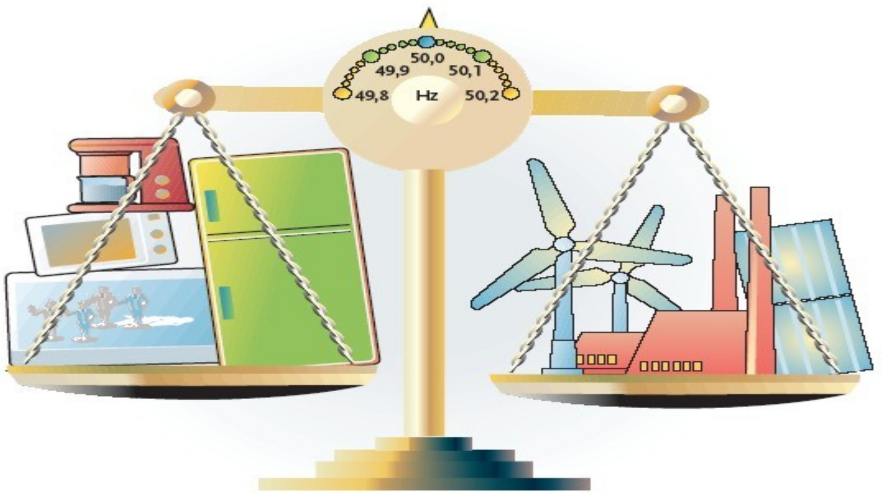
Model inputs: price, minute of day, outside temperature/dewpoint, sun irrandiance

Olympic Peninsula



Control of Energy Consumption

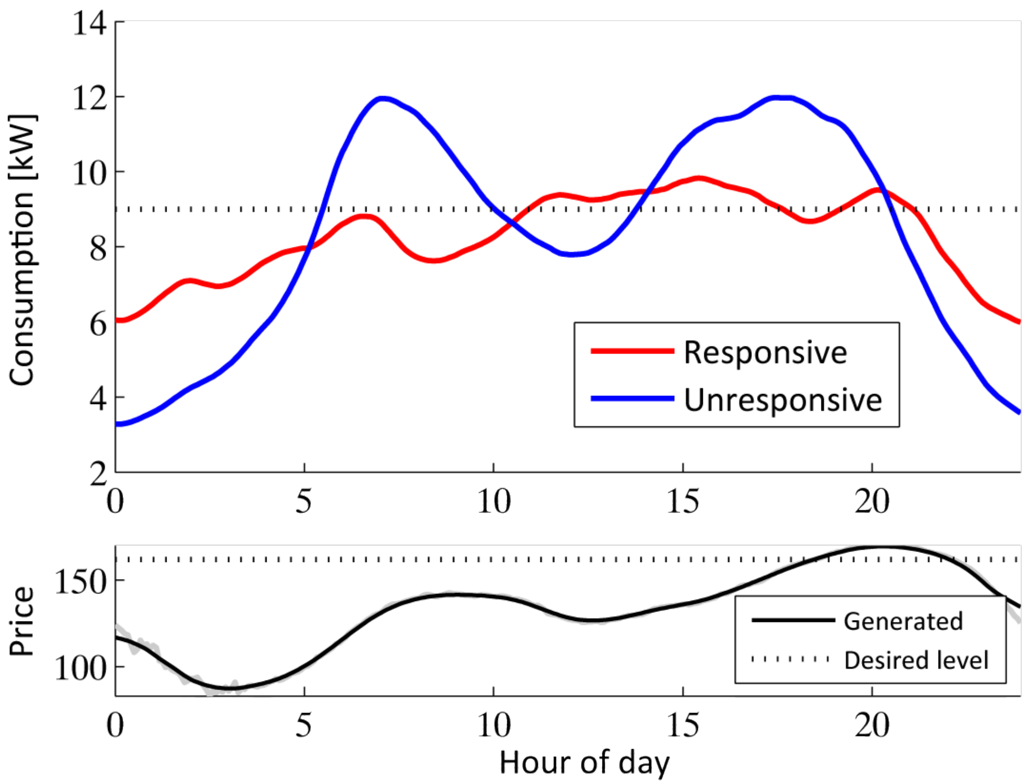




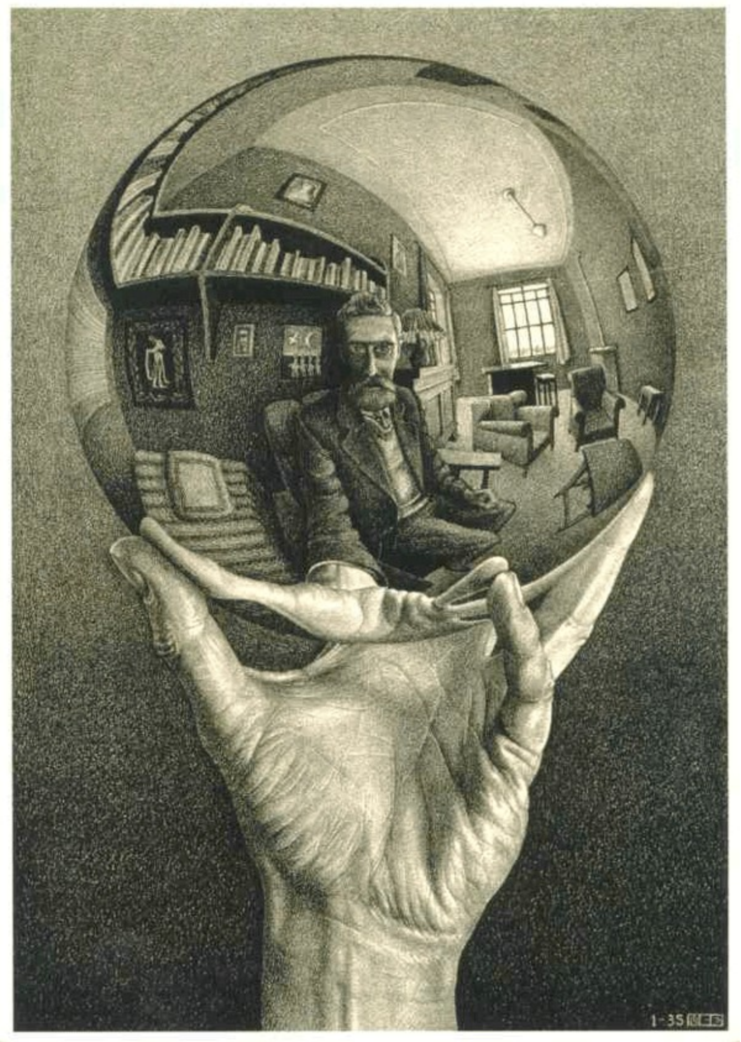
Control performance

With a price penality avoiding its divergence

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



Part 2
Parametric Models

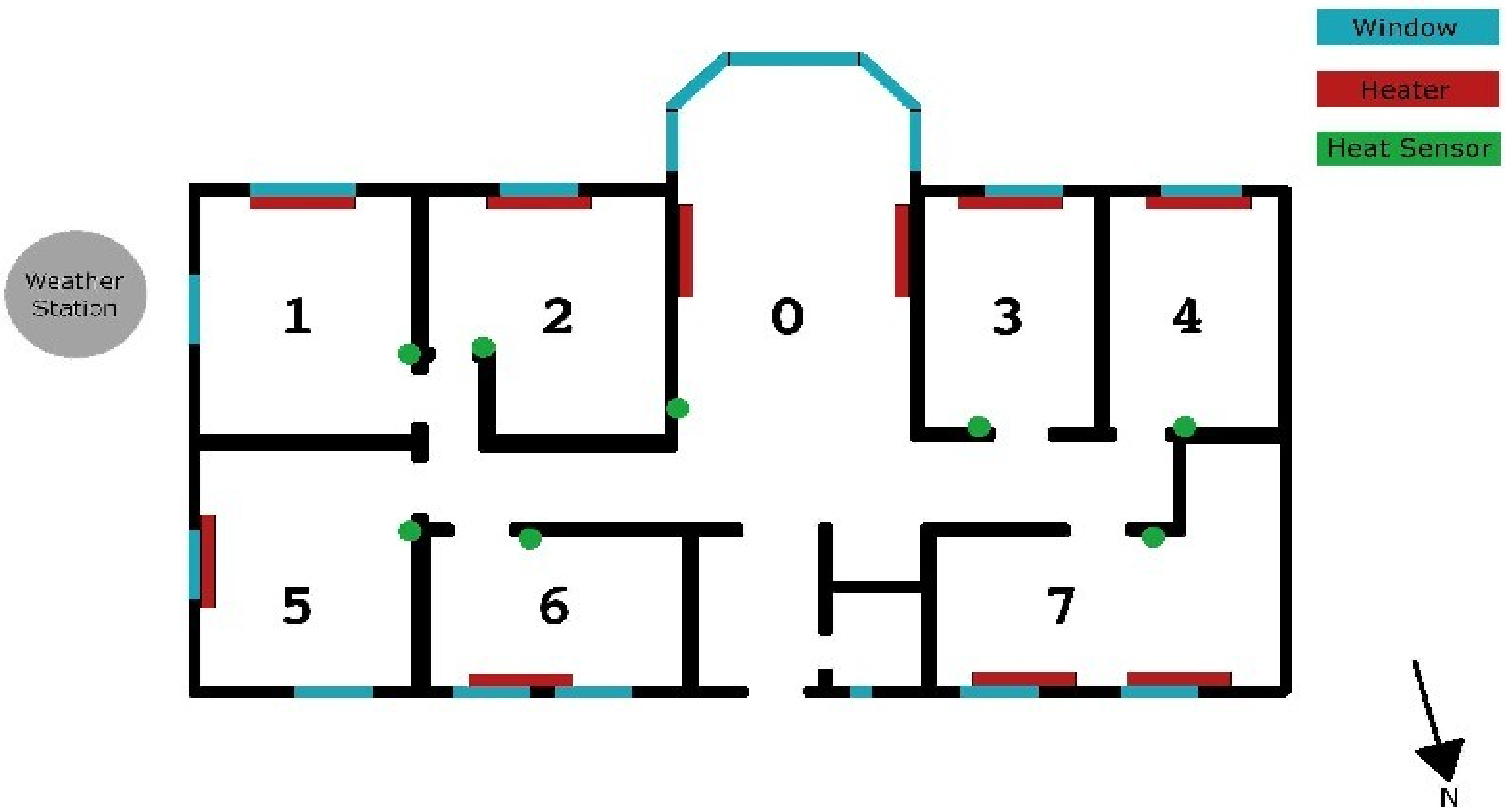


- A model for the thermal characteristics of a small office building
- A nonlinear model for a ventilated facade

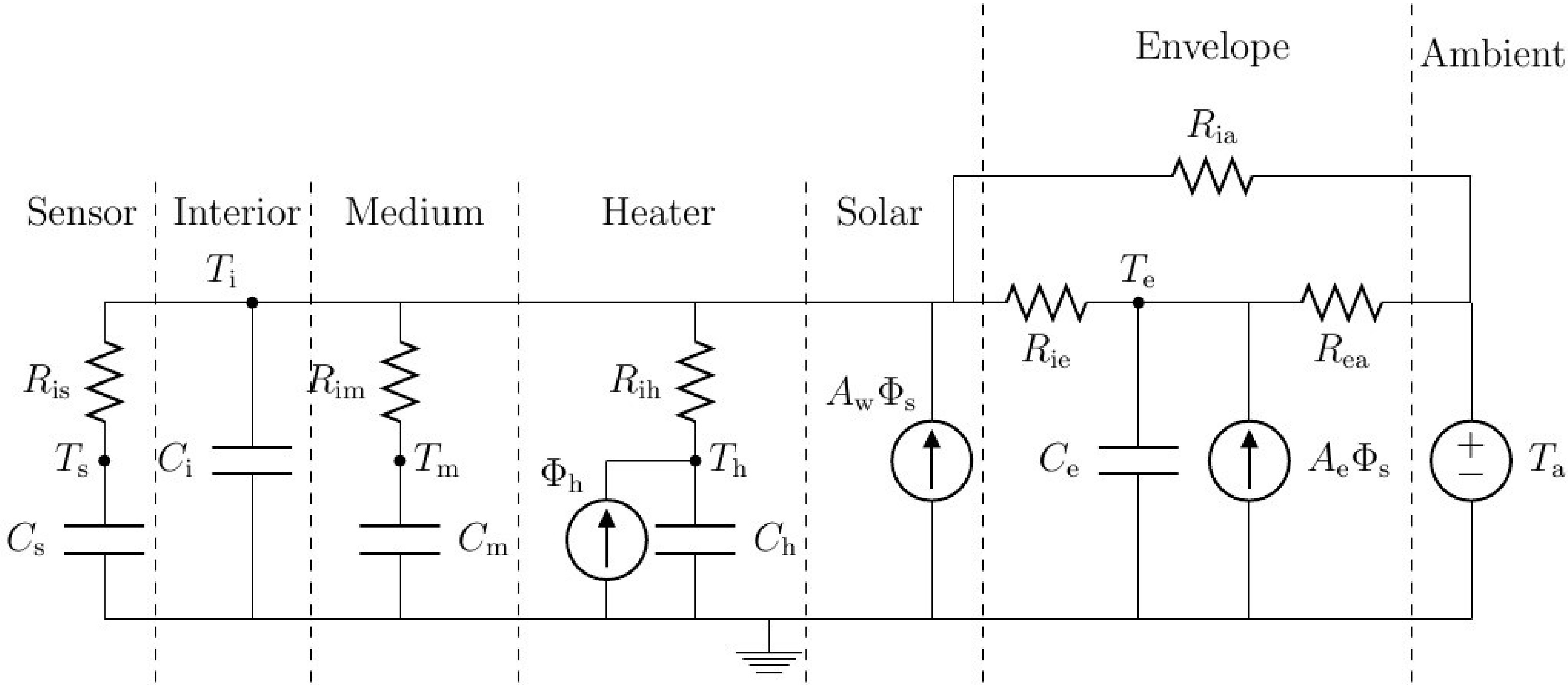
Case study

Model for the thermal characteristics of a small office building

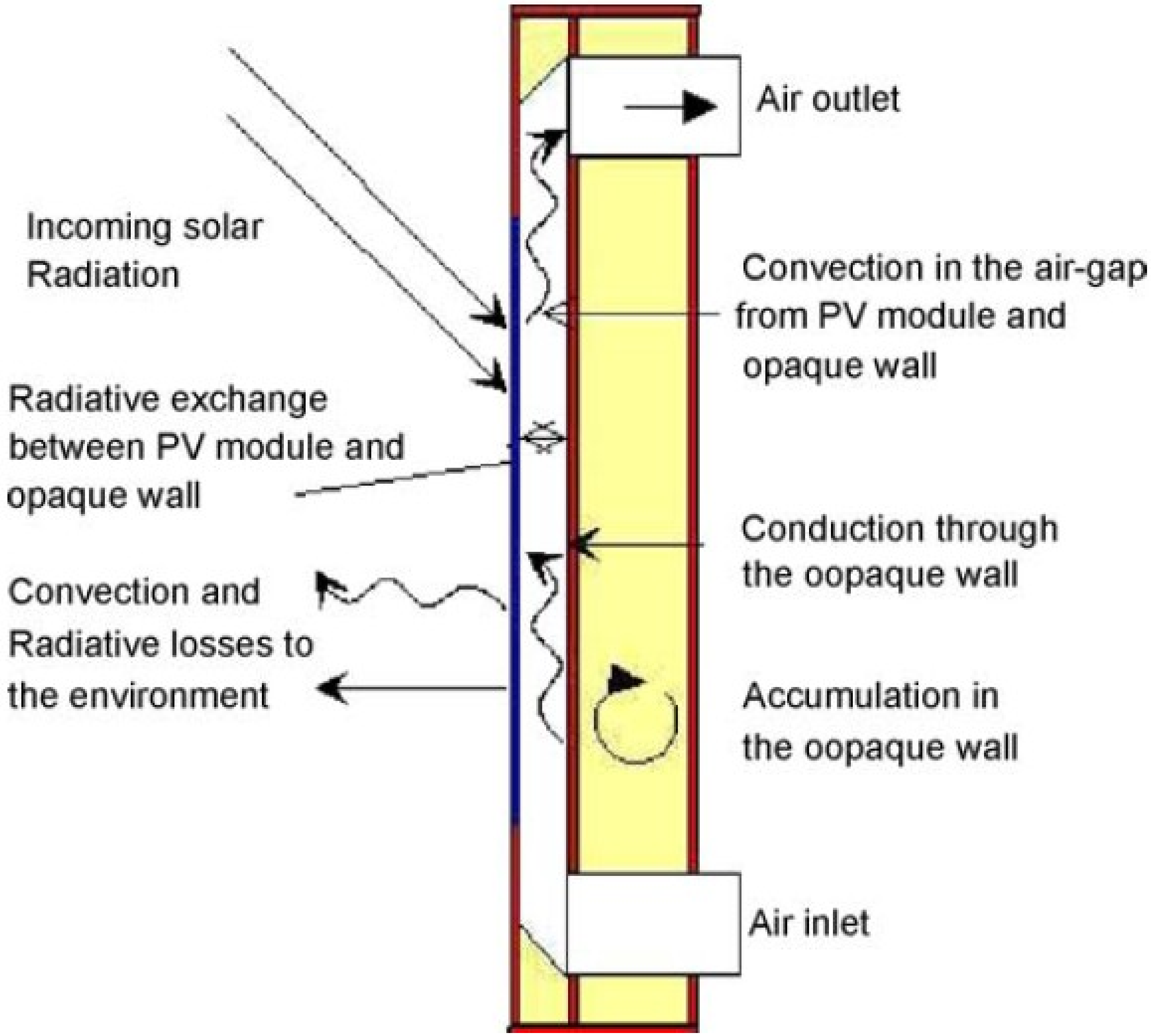
Flexhouse at SYSLAB (DTU Risø)



Model found using Grey-box modelling (using CTSM-R and a RC-model) Here we estimate the physical parameters



Modelling the thermal dynamics of a building integrated and ventilated PV module

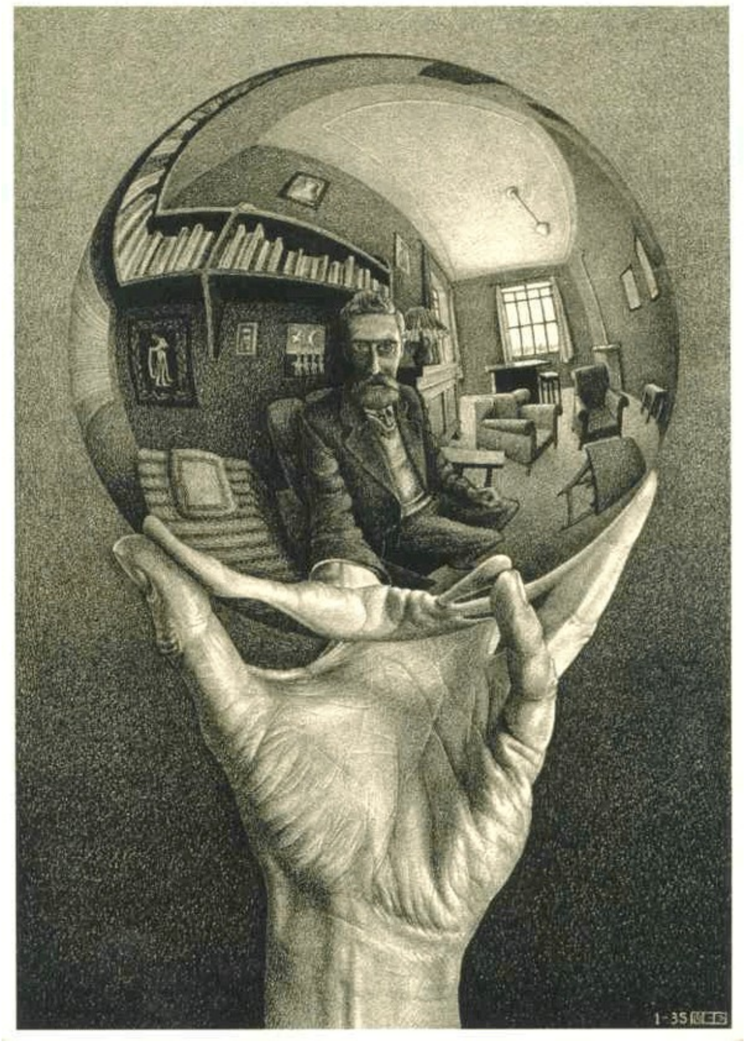


Several non-linear and time-varying phenomena.

Consequently linear RC-network models are not appropriate.

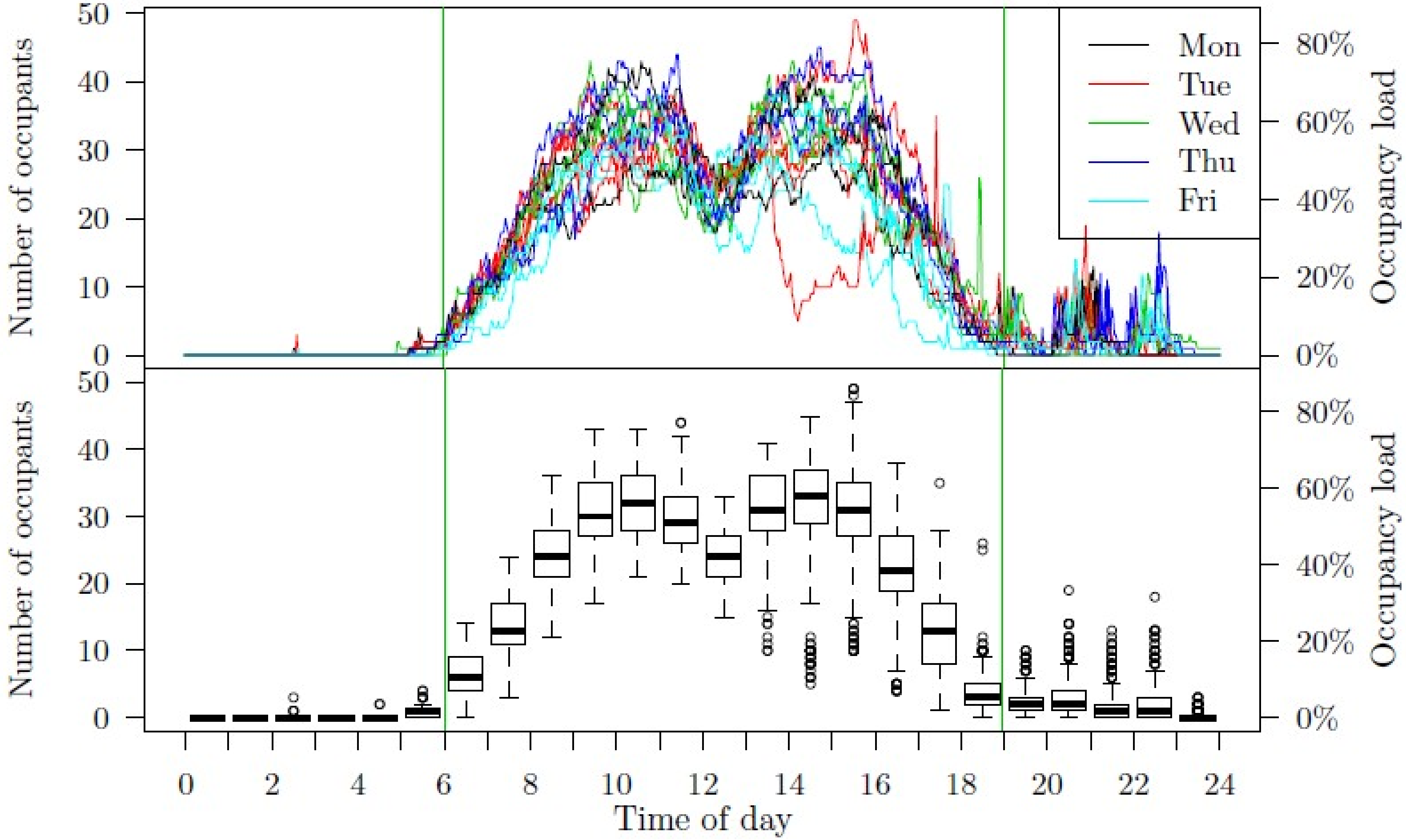
A grey-box approach using CTSM-R is described in Friling et.al. (2009)

Part 3
Non-gaussian models (Annex 66)



- Occupancy modelling is a necessary step towards reliable simulation of energy consumption in buildings

Occupant presence (office building in SF!)



Markov Chain Models

2.1.1.2. Two-state Markov chains with covariates. Covariates in Markov chains with only the two states, 0 and 1, can be modeled as

$$\operatorname{logit}\left(\mathbb{P}\left(X_{n+1}=0 \,\middle|\, X_n=0\right)\right)=Z_{1,n}\theta_1, \quad \theta_1 Z_{1,n}\in\mathbb{R}^p \tag{4a}$$

$$\operatorname{logit}\left(\mathbb{P}\left(X_{n+1}=1 \,\middle|\, X_n=1\right)\right)=Z_{2,n}\theta_2, \quad \theta_2 Z_{2,n}\in\mathbb{R}^q \tag{4b}$$

where the logistic function denoted logit is defined as

$$\operatorname{logit}:]0,1[\to\mathbb{R}, \quad \operatorname{logit}(x)=\log\left(\frac{x}{1-x}\right) \tag{5}$$

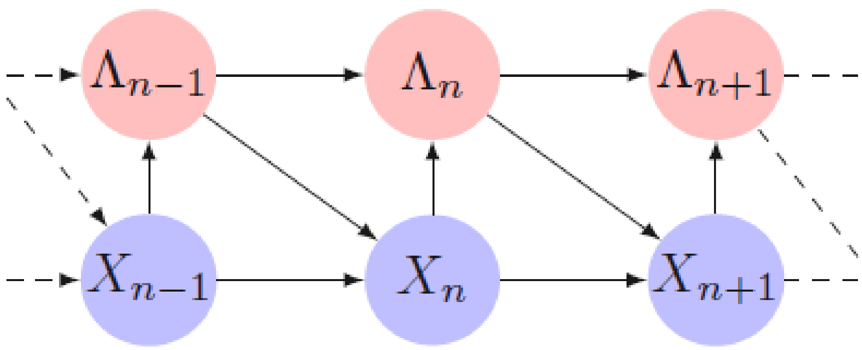
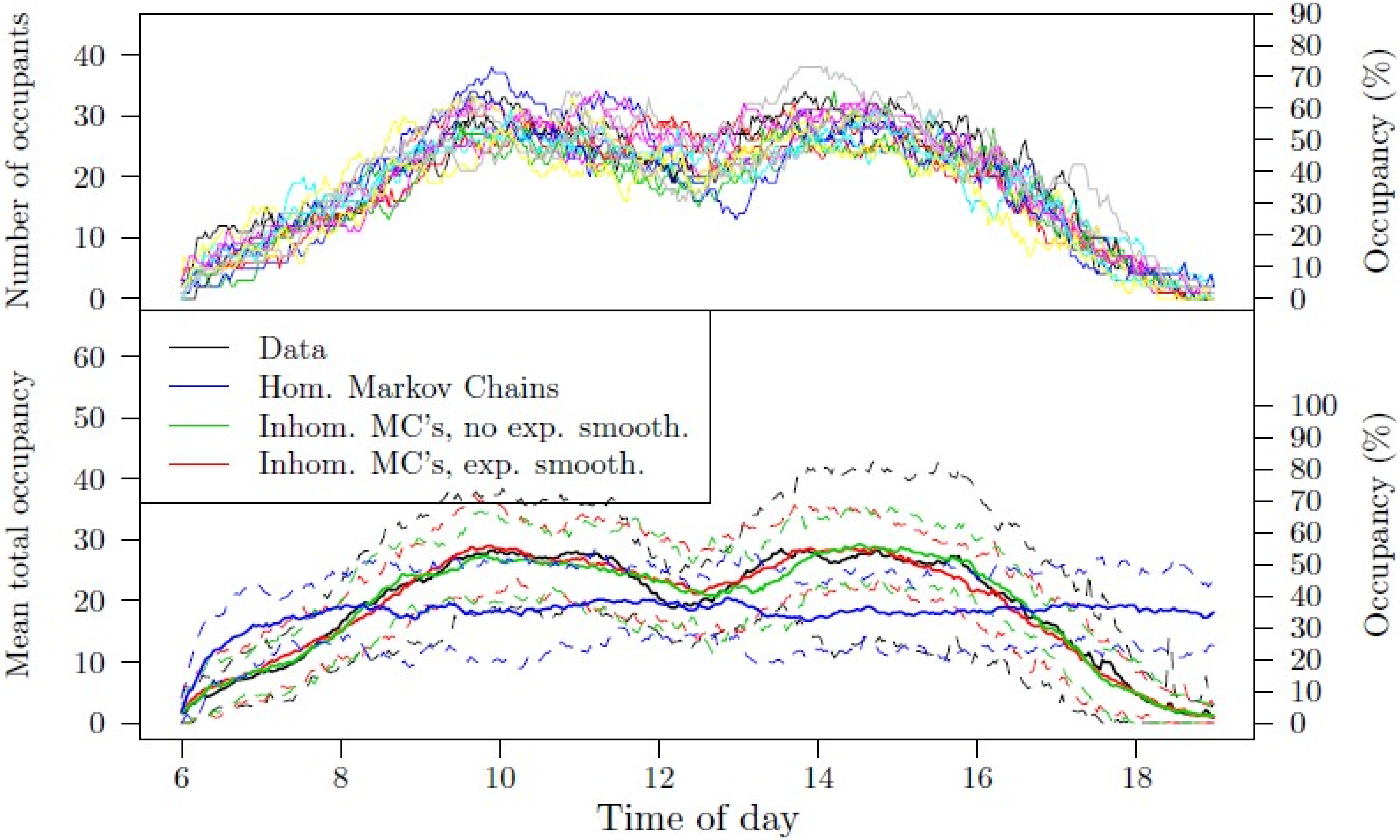


Fig. 3. A Markov chain with exponential smoothing as covariate in the transition probabilities.

Model simulations



Remarks and Summary

Other examples ... but not shown here:

- Shading (.. also dirty windows)
- Time-varying phenomena (.. eg. moisture in materials)
- Behavioural actions (opening of doors, windows, etc.)
- Appliance modelling
- Interactions with HVAC systems
- ....

... in general data and statistical methods (including tests) can be used to describe or model a number phenomena that cannot be described neither deterministically nor from first principles.

For more information ...

- See for instance

  www.henrikmadsen.org

  www.smart-cities-centre.org

- ...or contact
  - Henrik Madsen (DTU Compute)

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- Acknowledgement CITIES (DSF 1305-00027B)

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