What can we learn from data?

Annex 58, 60 and 66 Meeting

LBNL, Berkeley, September 2014

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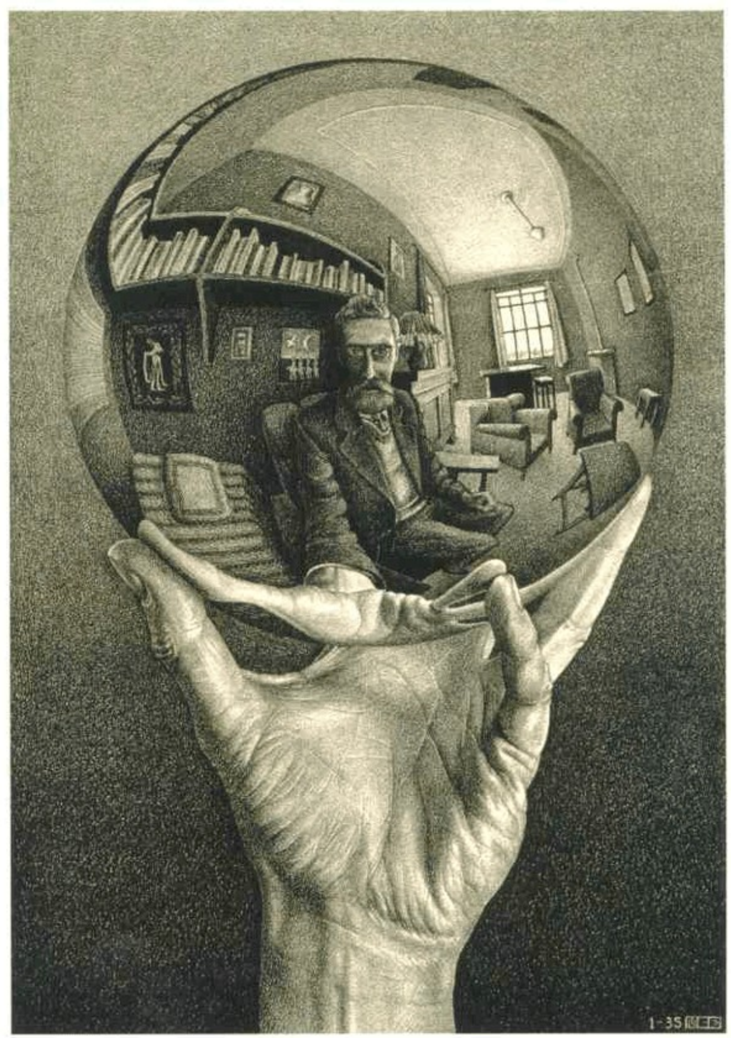

- Non-parametric, conditional-parametric and semi-parametric models, .. (in **Annex ??**)
- RC-network, Lumped, ARMAX and grey-box models, .. (**Annex 58**)
- Markov chain models, Generalized linear models, .. (**Annex 66**)

Examples only!

Part 1
Non-parametric methods

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

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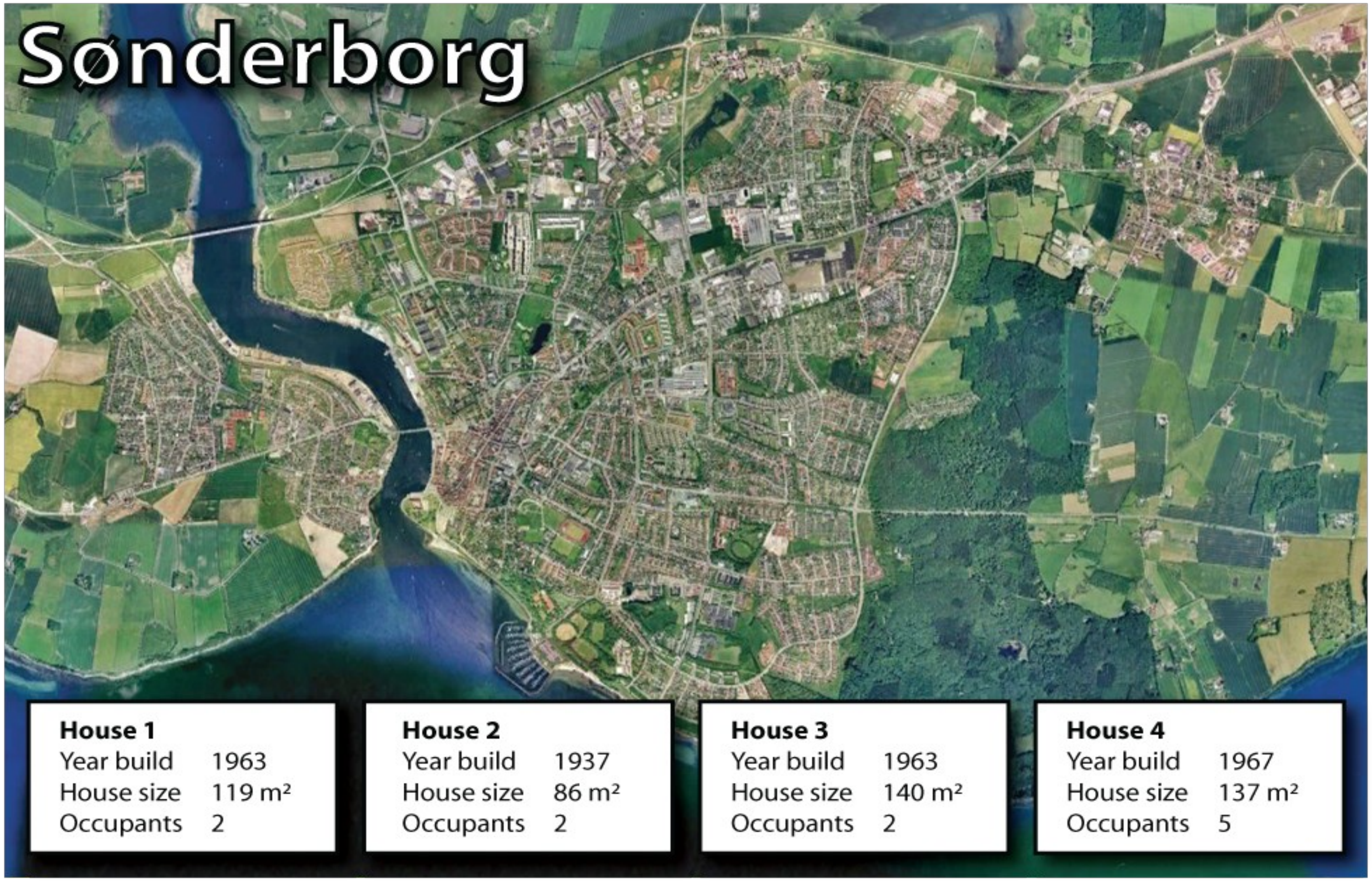
Data

- 10 min averages from 56 houses in Sønderborg



Case Study No. 1

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

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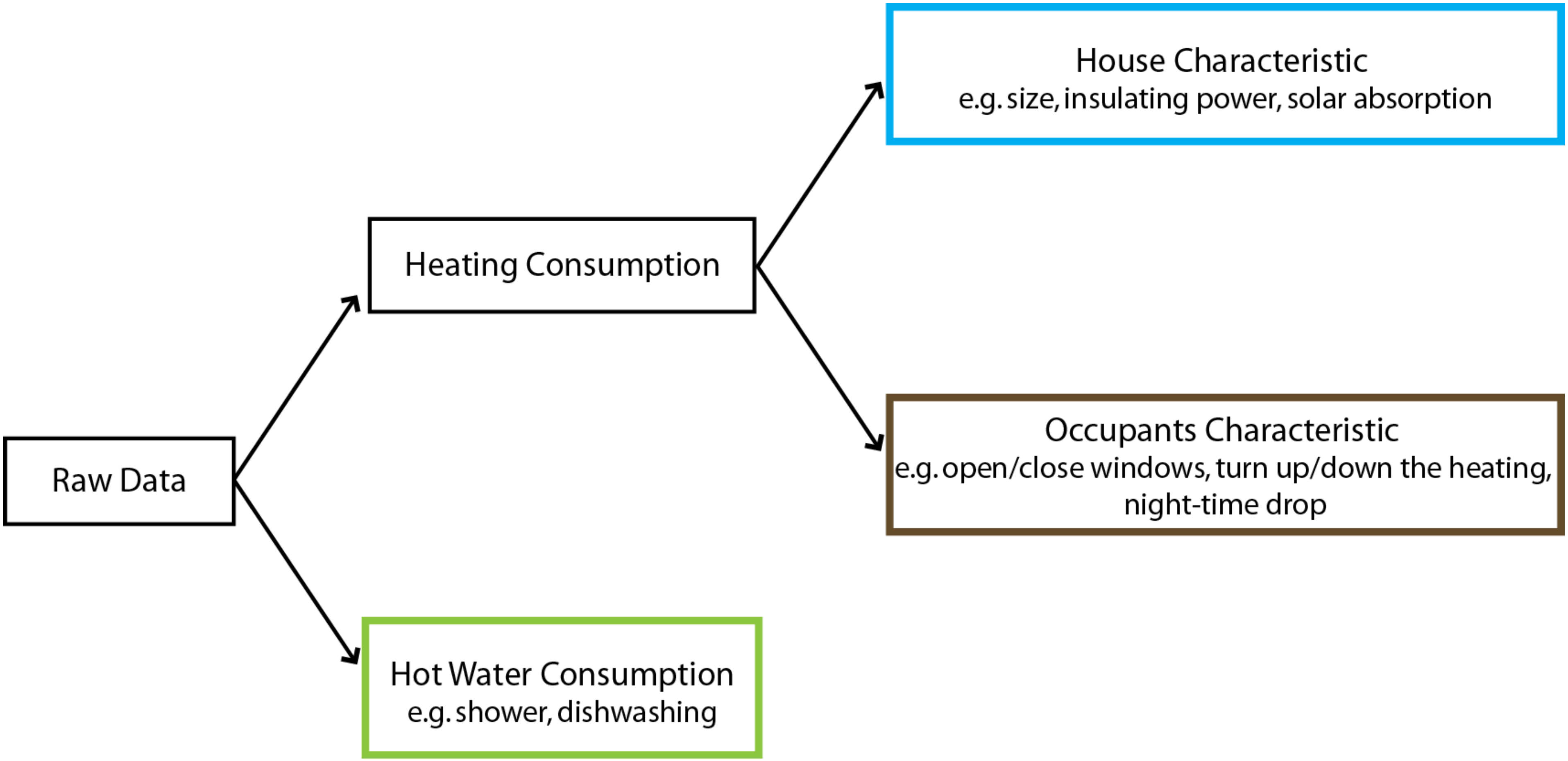
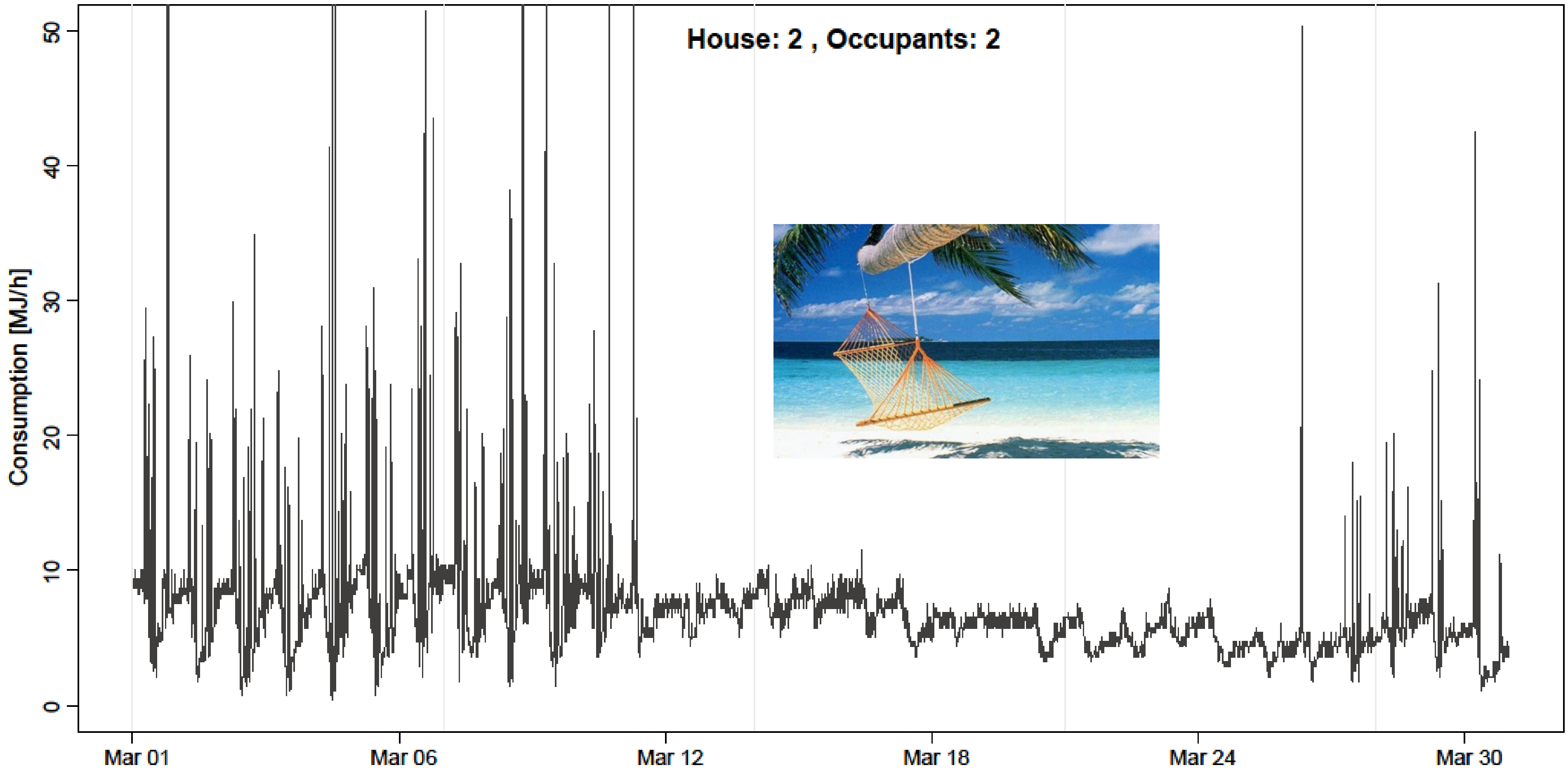
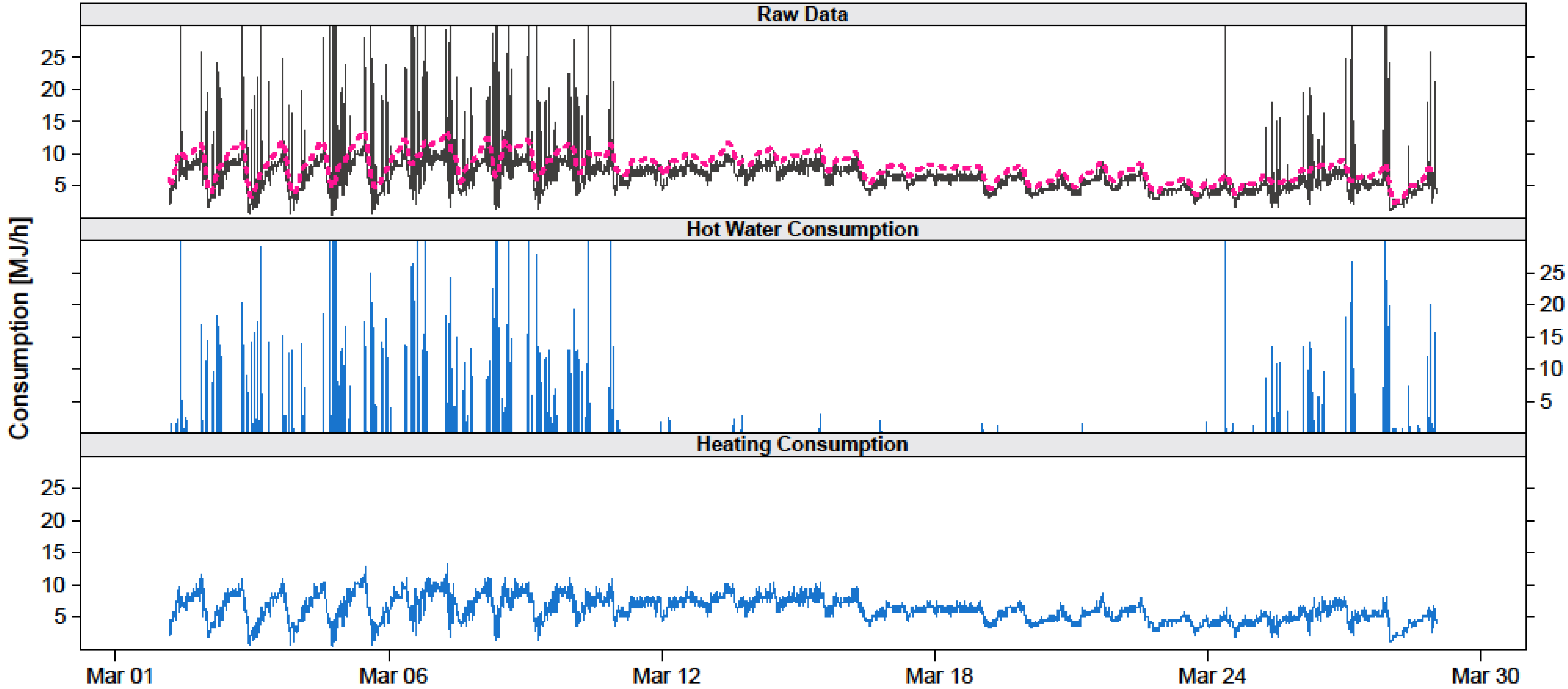
Splitting of total meter readings



Holiday period



Robust Polynomial Kernel



Case Study No. 2

Ident. of Thermal Performance using Smart Meter Data

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)

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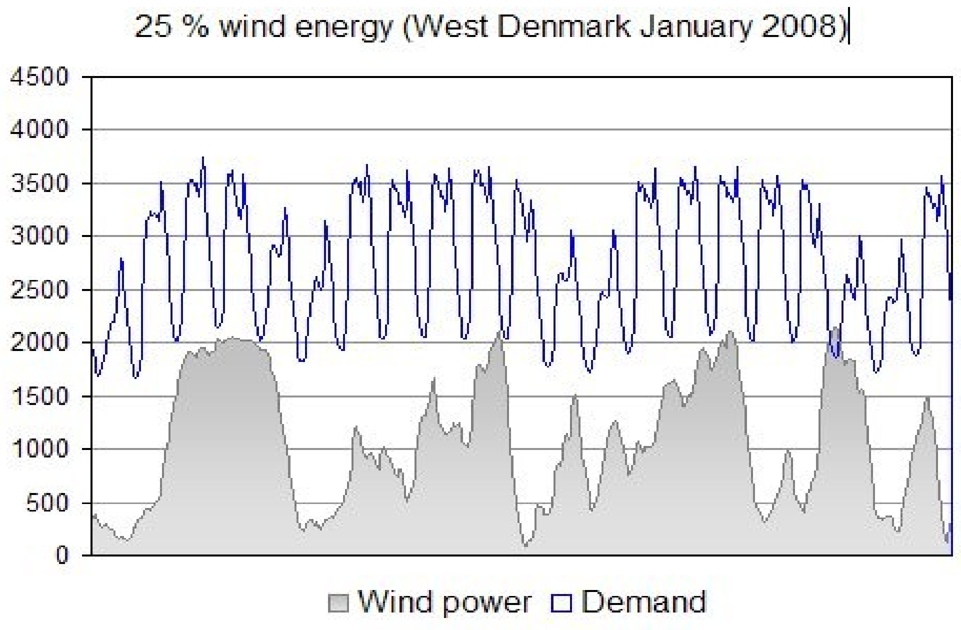
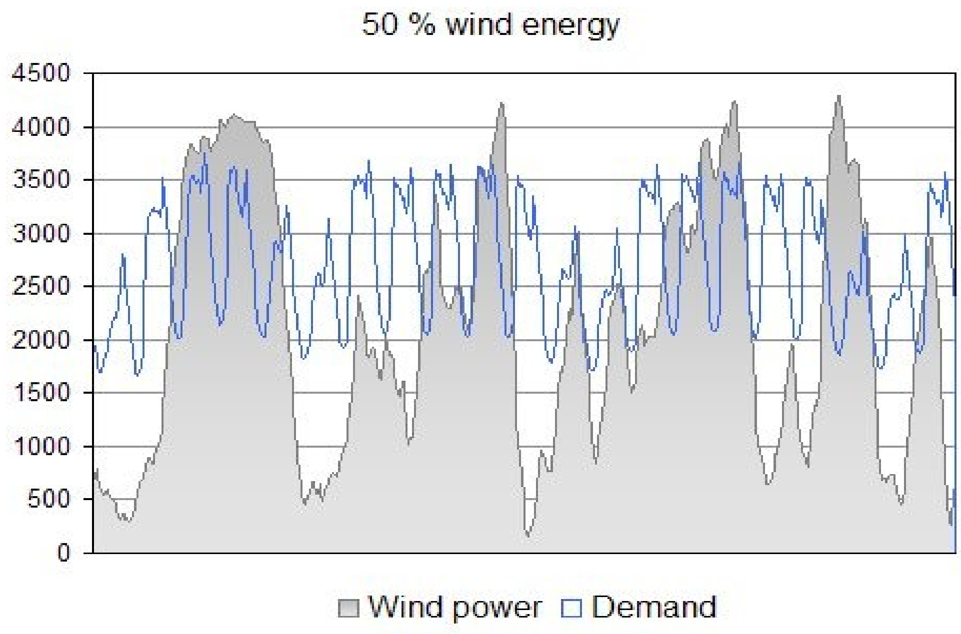
The Danish Wind Power Case

.... balancing of the power system



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

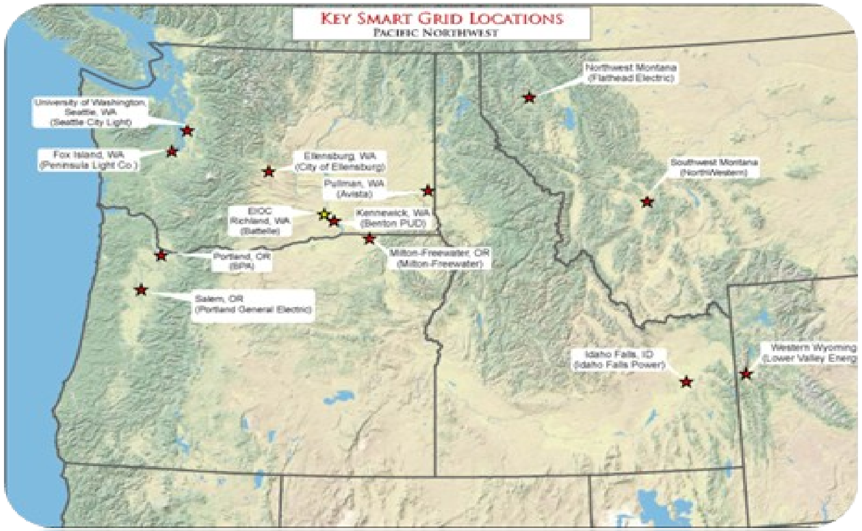


In December 2013 and January 2014 more than 55 pct of electricity load was covered by wind power. And for several days the wind power production was more than 120 pct of the power load

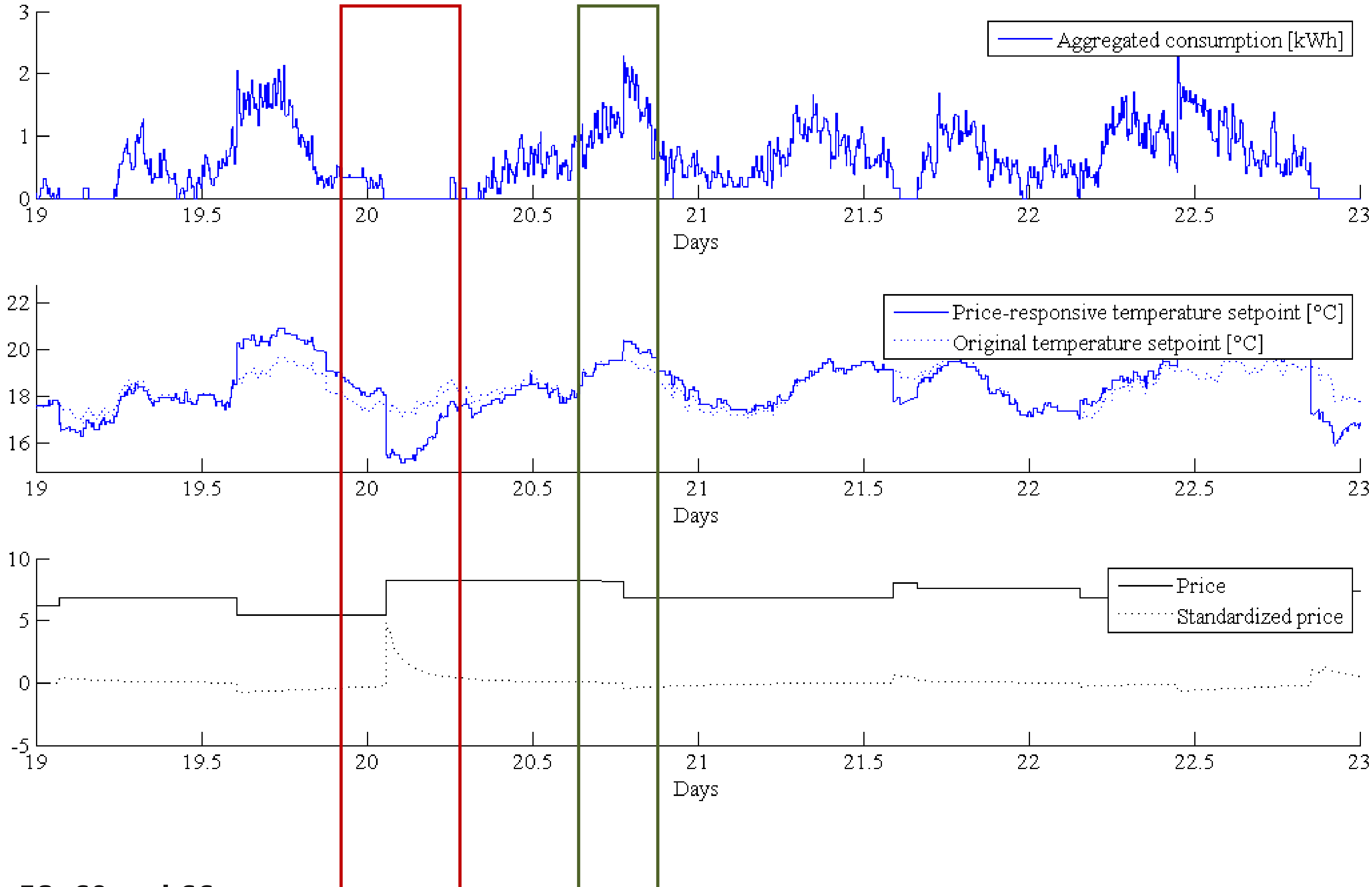
Data from BPA

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)



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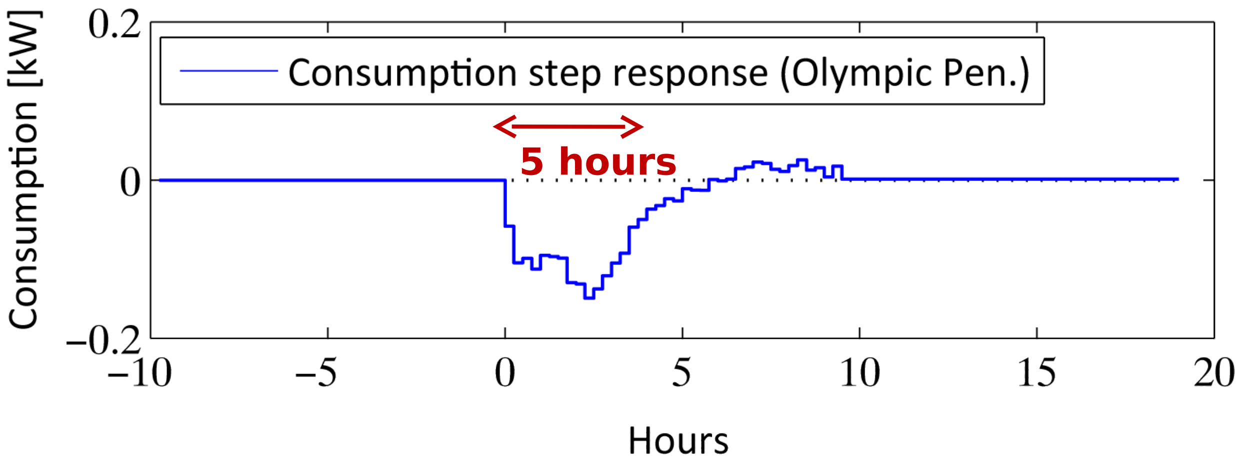
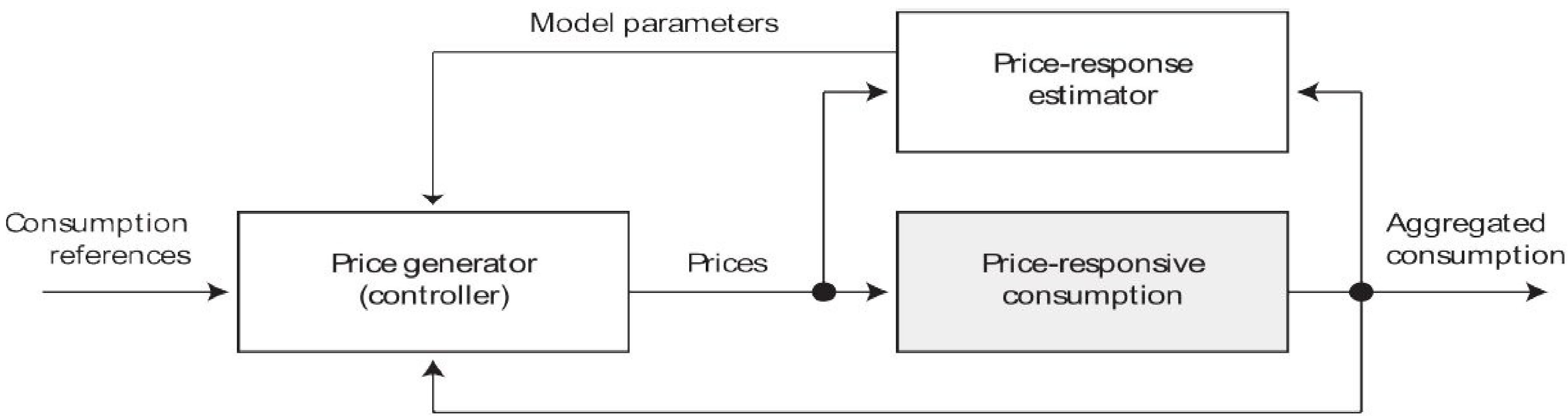
Non-parametric Response on Price Step Change

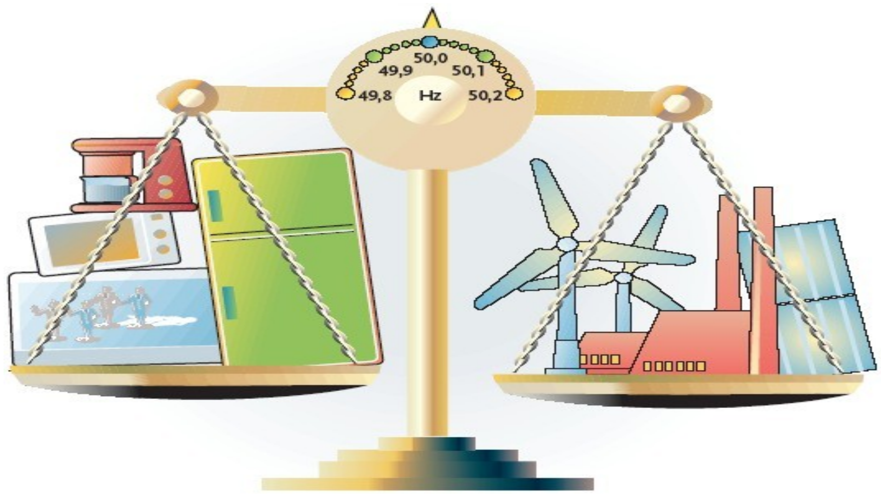
Model inputs: price, minute of day, outside temperature/dewpoint, sun irrandiance

Olympic Peninsula



Control of Energy Consumption

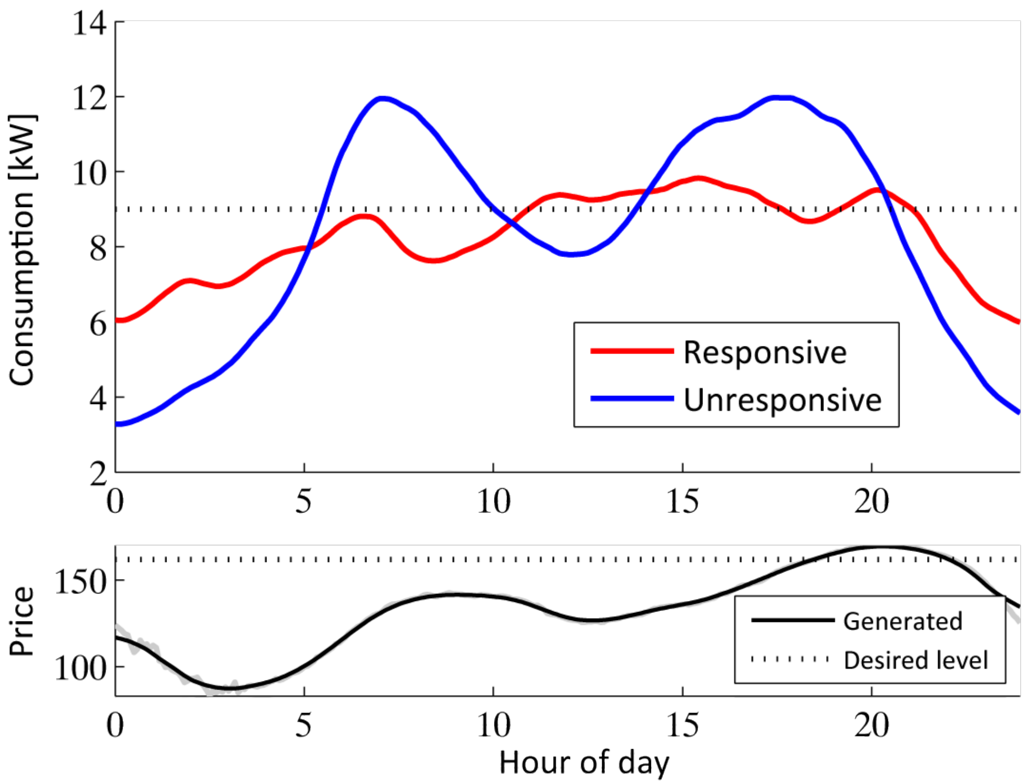




Control performance

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

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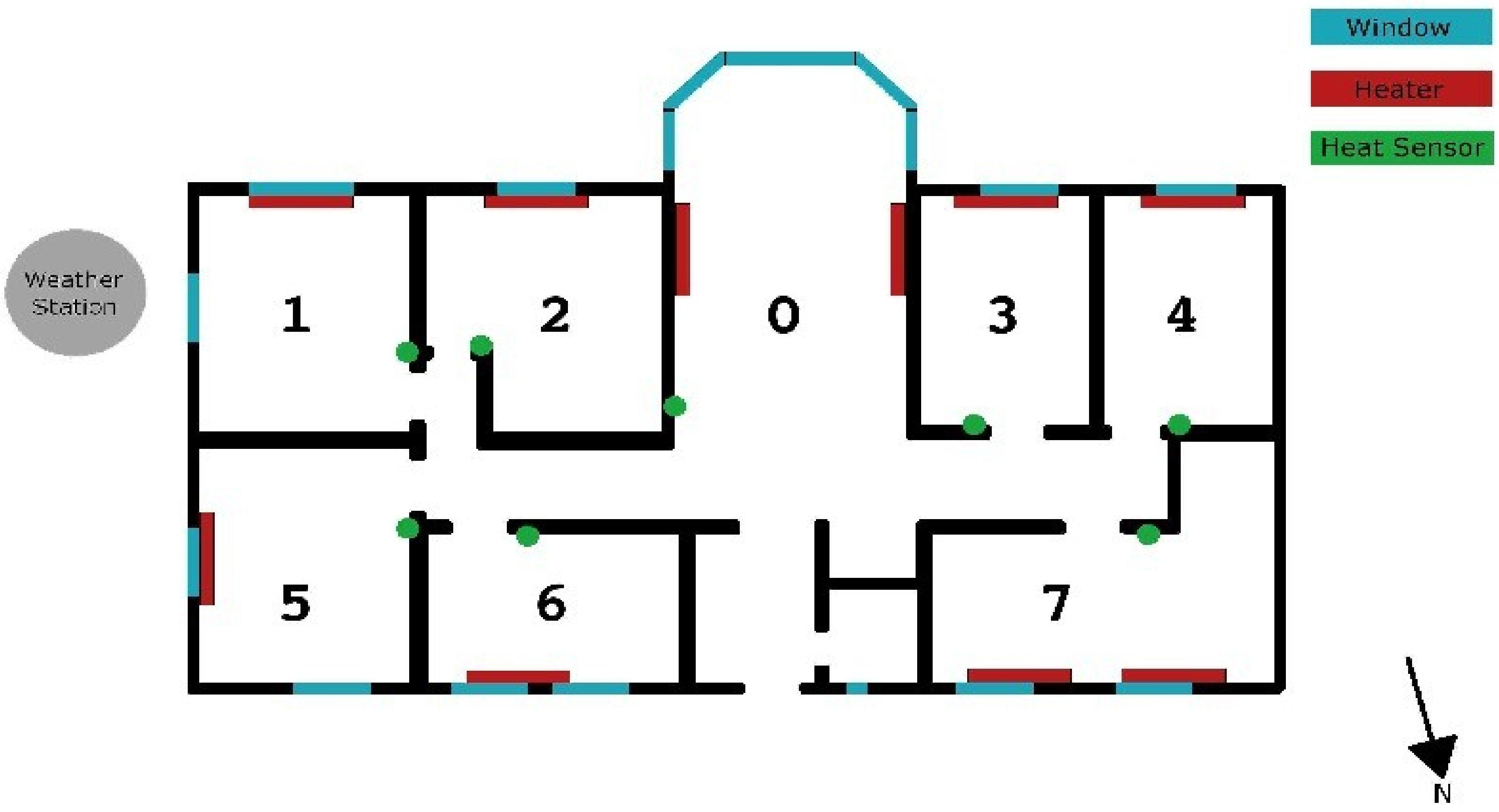
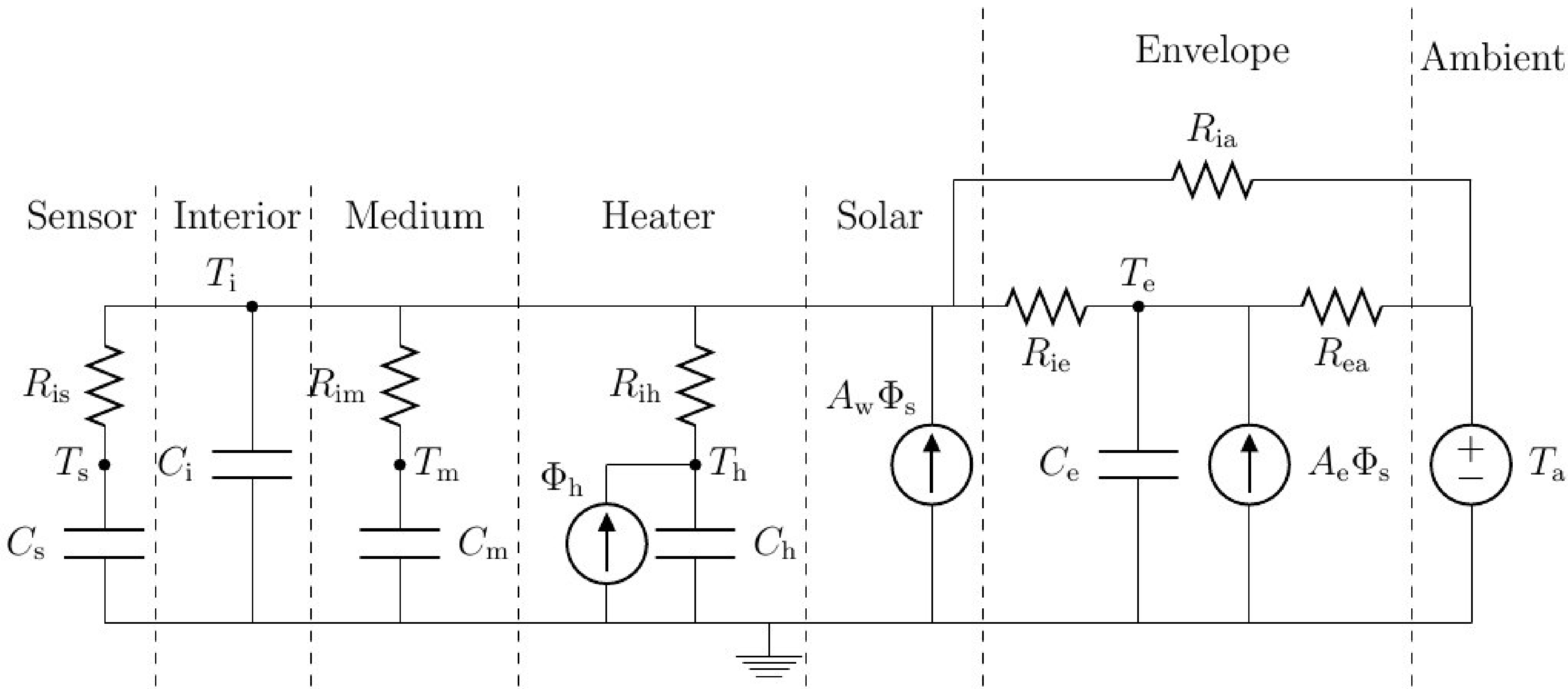
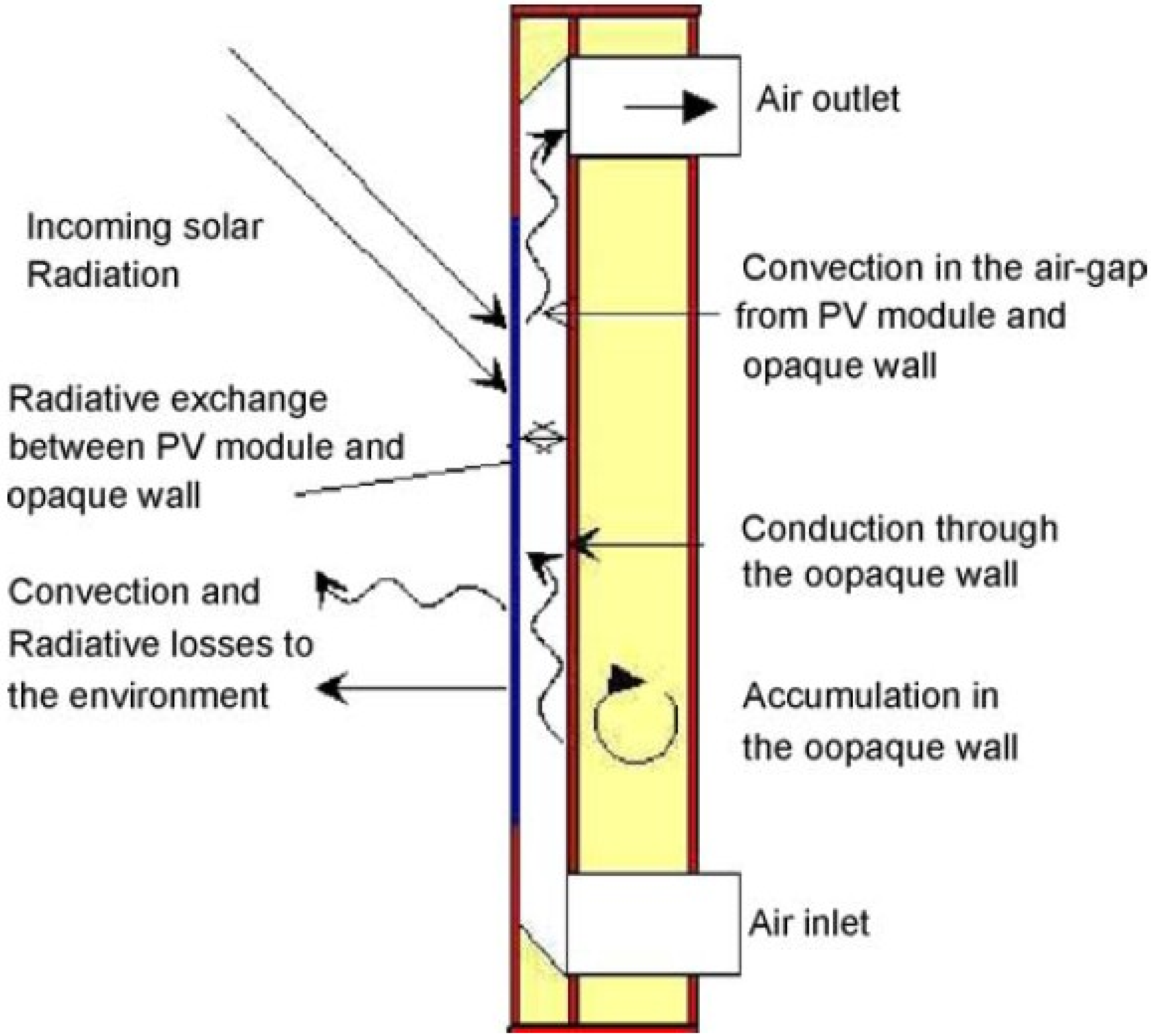
Flexhouse at SYSLAB (DTU Risø)



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

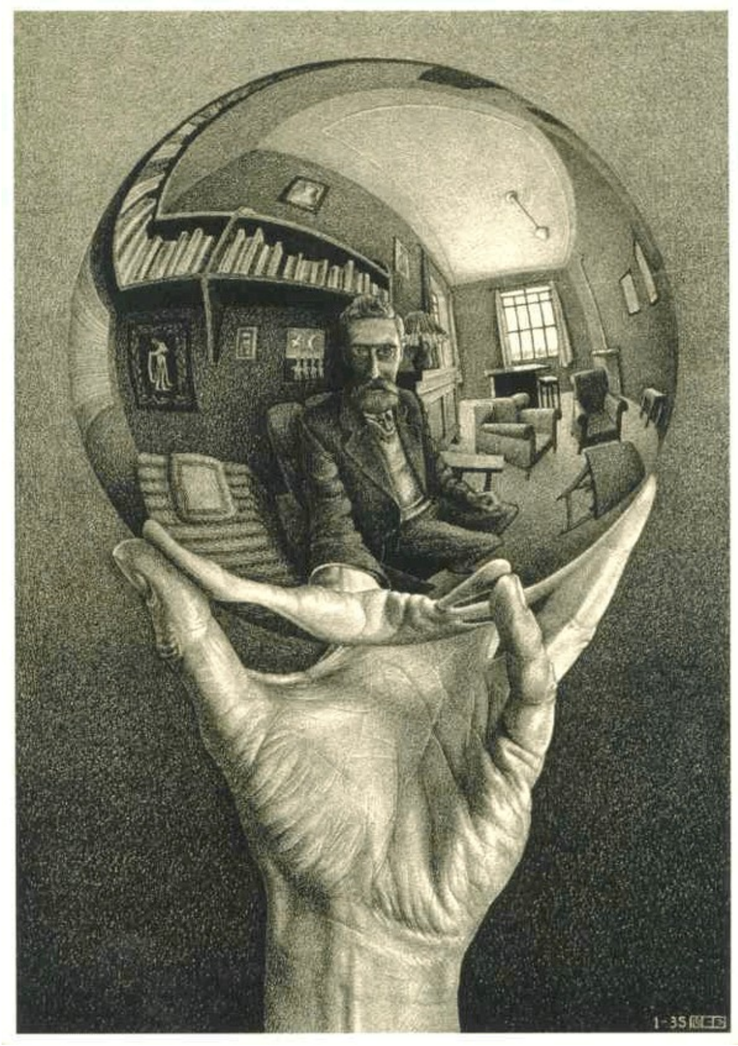


Several non-linear and time-varying phenomena.

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

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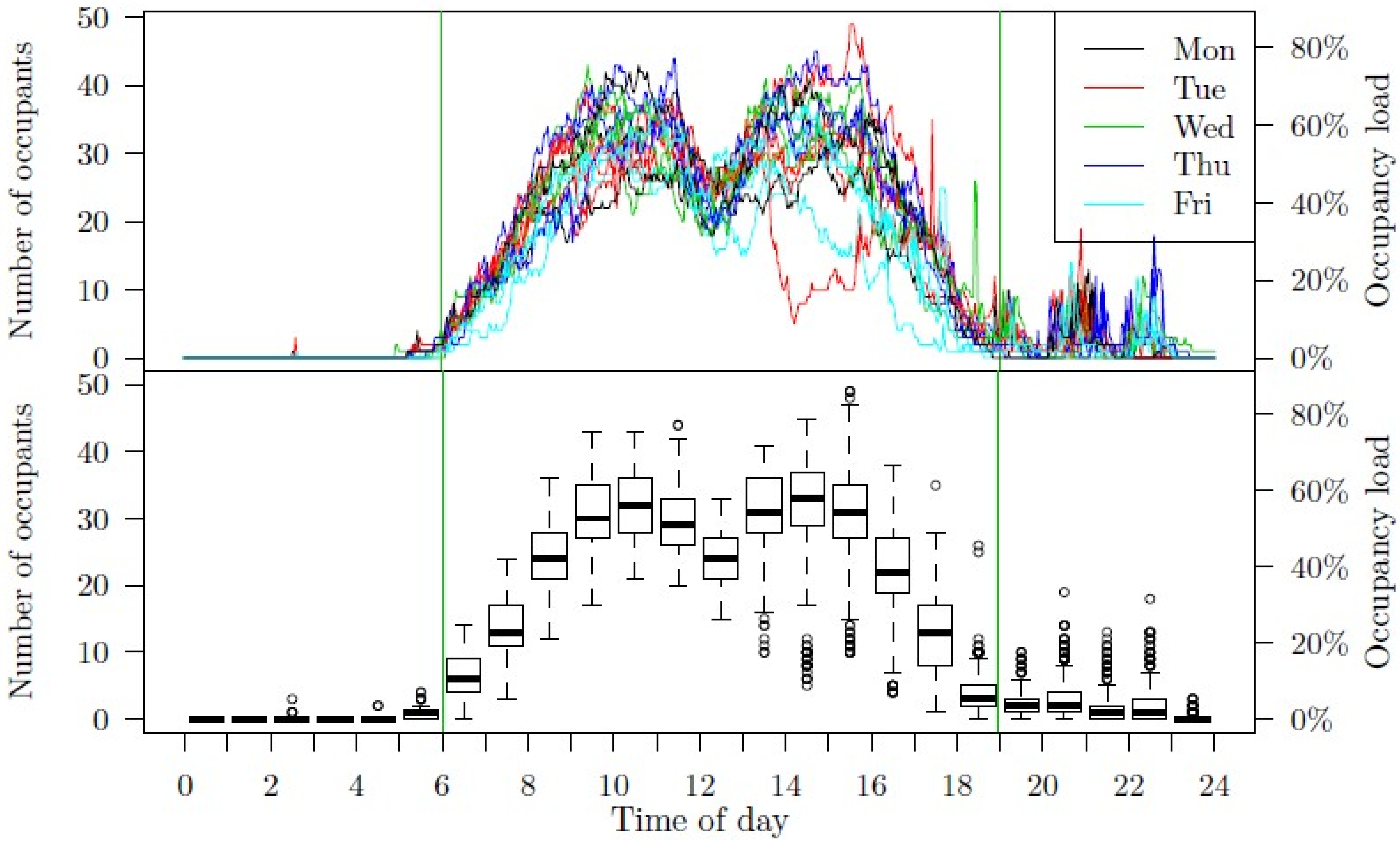
Occupant presence (office building in SF!)



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

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

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

where the logistic function denoted logit is defined as

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

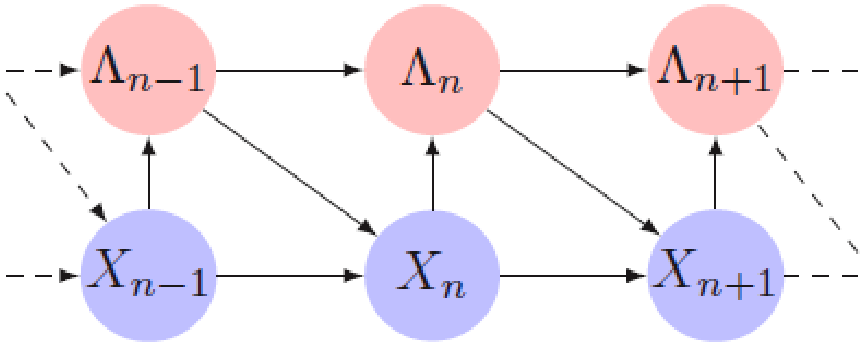
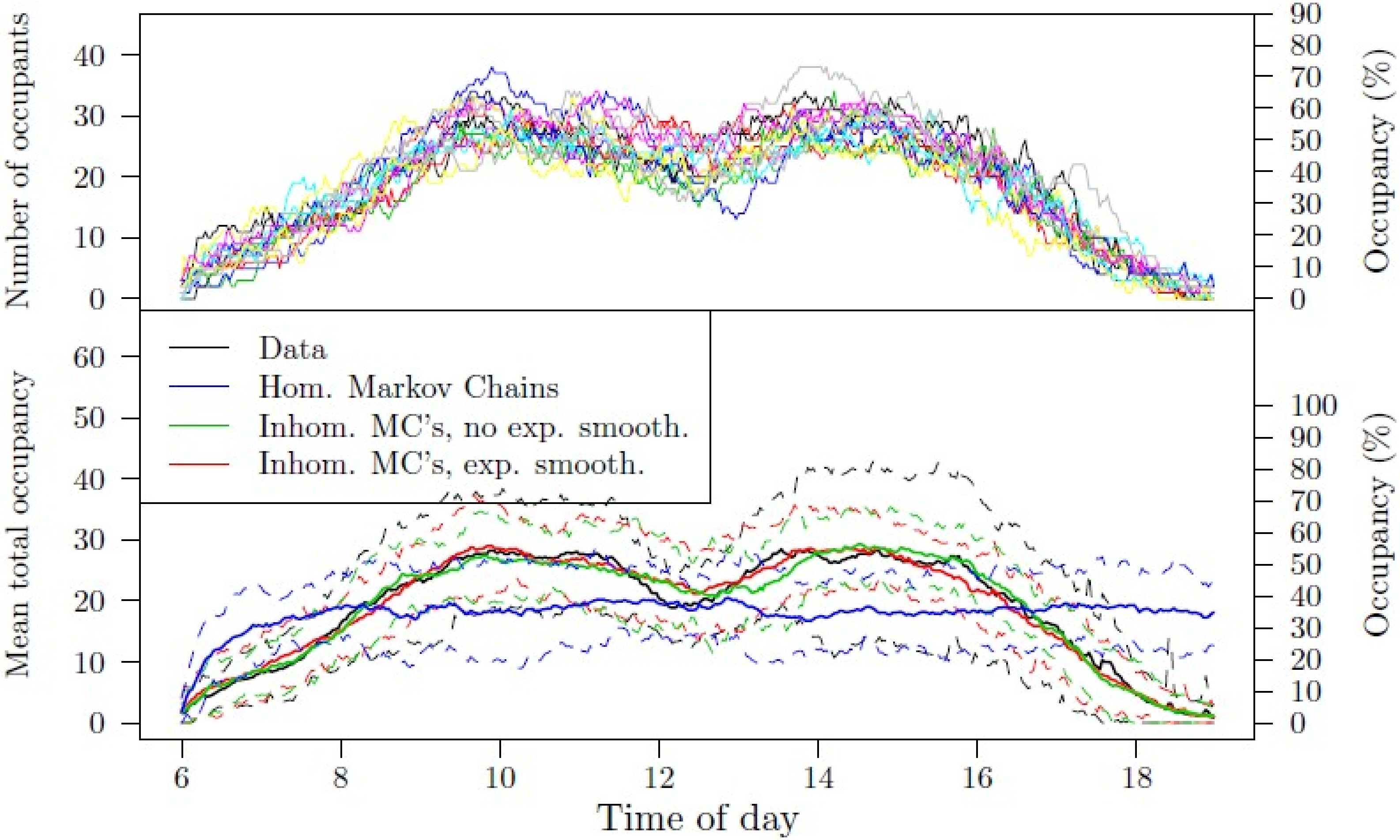


Fig. 3. A Markov chain with exponential smoothing as covariate in the transition probabilities.

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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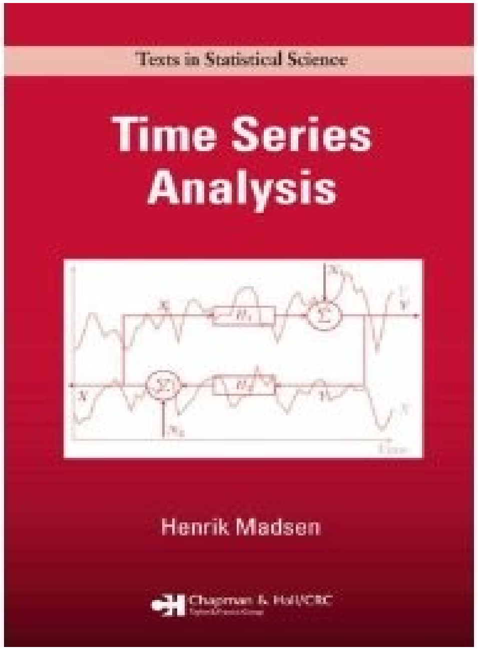
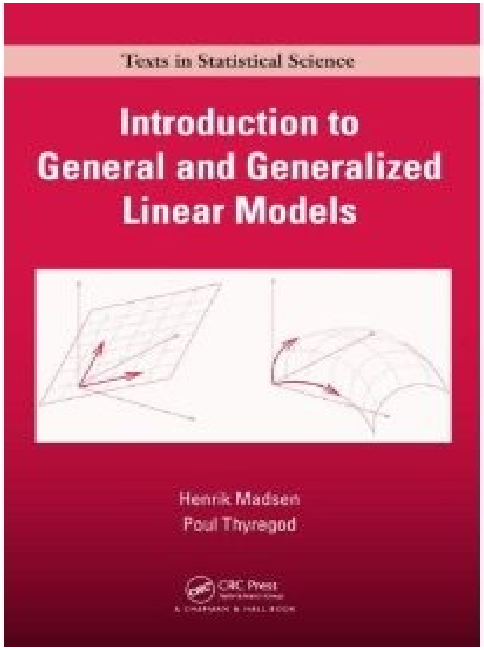
- Acknowledgement CITIES (DSF 1305-00027B)

Some 'randomly picked' books on modeling ....



2008



2011

Some References - Generic

- H. Madsen: *Time Series Analysis*, Chapman and Hall, 392 pp, 2008.
- H. Madsen and P. Thyregod (2011): *An Introduction to General and Generalized Linear Models*, Chapman and Hall, 340 pp.
- J.M. Morales, A.J. Conejo, H. Madsen, P. Pinson, M. Zugno: *Integrating Renewables in Electricity Markes*, Springer, 430 pp., 2013.
- H.Aa. Nielsen, H. Madsen: *A generalization of some classical time series tools*, Computational Statistics and Data Analysis, Vol. 37, pp. 13-31, 2001.
- H. Madsen, J. Holst: *Estimation of Continuous-Time Models for the Heat Dynamics of a Building*, Energy and Building, Vol. 22, pp. 67-79, 1995.
- P. Sadegh, J. Holst, H. Madsen, H. Melgaard: *Experiment Design for Grey Box Identification*, Int. Journ. Adap. Control and Signal Proc., Vol. 9, pp. 491-507, 1995.
- P. Sadegh, L.H. Hansen, H. Madsen, J. Holst: *Input Design for Linear Dynamic Systems using Maxmin Criteria*, Journal of Information and Optimization Sciences, Vol. 19, pp. 223-240, 1998.
- J.N. Nielsen, H. Madsen, P.C. Young: *Parameter Estimation in Stochastic Differential Equations; An Overview*, Annual Reviews in Control, Vol. 24, pp. 83-94, 2000.
- N.R. Kristensen, H. Madsen, S.B. Jørgensen: *A Method for systematic improvement of stochastic grey-box models*, Computers and Chemical Engineering, Vol 28, 1431-1449, 2004.
- N.R. Kristensen, H. Madsen, S.B. Jørgensen: *Parameter estimation in stochastic grey-box models*, Automatica, Vol. 40, 225-237, 2004.
- J.B. Jørgensen, M.R. Kristensen, P.G. Thomsen, H. Madsen: *Efficient numerical implementation of the continuous-discrete extended Kalman Filter*, Computers and Chemical Engineering, 2007.

Some References - Heat Dynamics of Buildings

- H. Madsen, J. Holst: *Estimation of Continuous-Time Models for the Heat Dynamics of a Building*, Energy and Building, Vol. 22, pp. 67-79, 1995.
- B. Nielsen, H. Madsen: *Identification of Transfer Functions for Control of Greenhouse Air Temperature*. J. Agric. Engng. Res., Vol. 60, pp. 25-34. 1995.
- K.K. Andersen, H. Madsen, L. Hansen: *Modelling the heat dynamics of a building using stochastic differential equations*, Energy and Buildings, Vol. 31, pp. 13-24, 2000.
- K.K. Andersen, O.P. Palsson, H. Madsen, L.H. Knudsen: *Experimental design and setup for heat exchanger modelling*, International Journal of Heat Exchangers, Vol. 1, pp. 163-176, 2001.
- H.Aa. Nielsen, H. Madsen: *Modelling the heat consumption in district heating systems using a grey-box approach*, Energy and Buildings, Vol. 38, pp. 63-71, 2006.
- M.J. Jiménez, H. Madsen: *Models for Describing the Thermal Characteristics of Building Components*, Building and Energy, Vol. 43, pp. 152-162, 2008.
- M.J. Jiménez, H. Madsen, K.K. Andersen: *Identification of the Main Thermal Characteristics of Building Components using MATLAB* , Building and Energy, Vol. 43, pp. 170-180, 2008.
- N. Friling, M.J. Jimenez, H. Bloem, H. Madsen: *Modelling the heat dynamics of building integrated and ventilated photovoltaic modules*, Energy and Building, Vol. 41(10), pp. 1051-1057, 2009.
- P. Bacher, H. Madsen: *Identifying suitable models for the heat dynamics of buildings*, Vol. 43, pp. 1511-1522, 2011.
- O. Corradi, H. Ochesenfeld, H. Madsen, P. Pinson, *Controlling Electricity Consumption by Forecasting its Response to Varying Prices*, IEEE Transactions, Vol. 8, pp. 421-429, 2013.
- P.H. Delff Andersen, A. Iversen, H. Madsen, C. Rode: *Dynamic Modeling of Presence of Occupants using Inhomogeneous Markov Chains*, Energy and Buildings, Vol. 69, pp. 213-223, 2014.
- I. Naveros, P. Bacher, D.P. Ruiz, M.J. Jimenez, H. Madsen: *Setting up and validating a complex model for a simple homogeneous wall*, Energy and Buildings, Vol. 70,pp. 303-317, 2014.