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Statistics and Crystall Ball Techniques

... on the use of Hidden Markov Models

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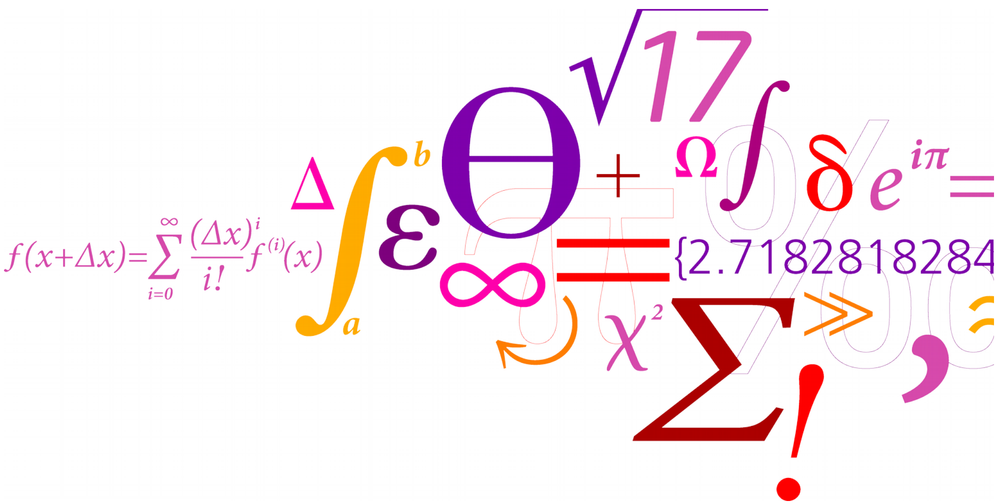

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Contents

Applications of Hidden Markov Models for:

- Geolocation of fish
- Energy optimization of buildings
- Automatic dosing of insulin
- Energy systems integration

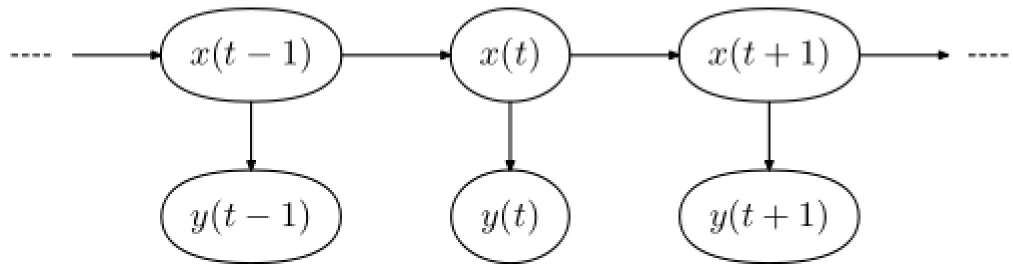
Case Study No. 1

Geolocation of Fish

Geolocation of fish

- Goal: Identify models for the movements of fish.
- GPS systems do not work under water.
- 'Data storage tags' for measuring the pressure (depth under the surface).
- Data gets available at capture of the fish.

Hidden Markov Model



- *x(t)*: **States** (are not observed) – describes the evolution in time of the system
- *y(t)*: **Observations**

Typical application: Find the values for *x* !

Hidden Markov Model

The probability Φ for, that the fish at time t is in position x, is:

$$\text{Systemet (generelt):} \quad \frac{\partial \phi}{\partial t} = -\nabla(u\phi - D\nabla\phi)$$

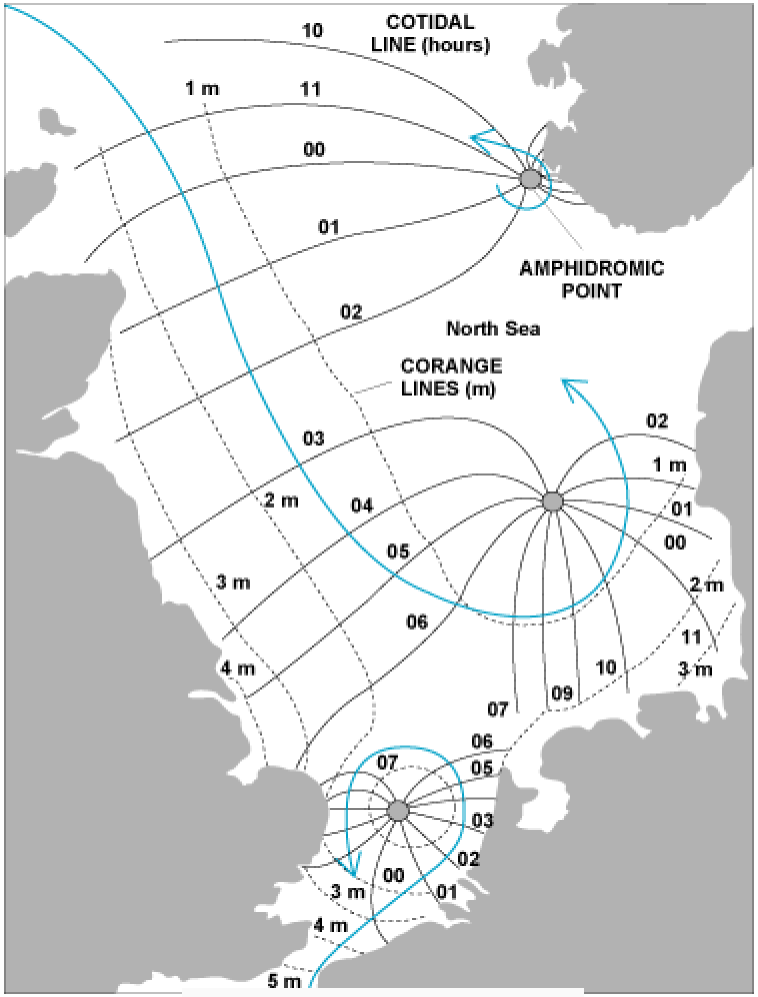
$$\text{Systemet (her):} \quad \frac{\partial \phi}{\partial t} = D\left(\frac{\partial^2 \phi}{\partial x_1^2} + \frac{\partial^2 \phi}{\partial x_2^2}\right)$$

Data is (as mentioned):

$$\text{Observationer:} \quad Y_k \quad : \quad \text{Dybden (til tidspunkt } t_k)$$

Further information

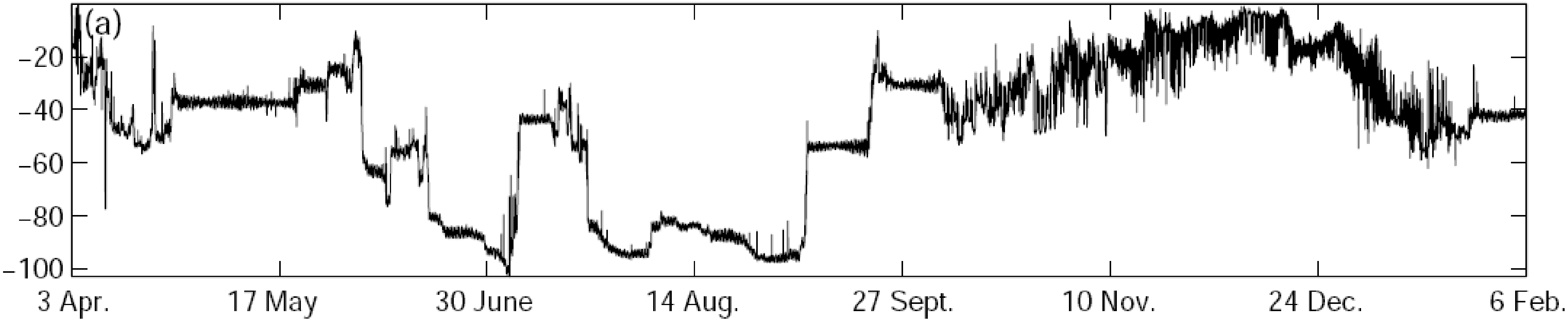
- Bathymetry (depths)
- Time and place for release and capture
- Information about the tide system – see the graph



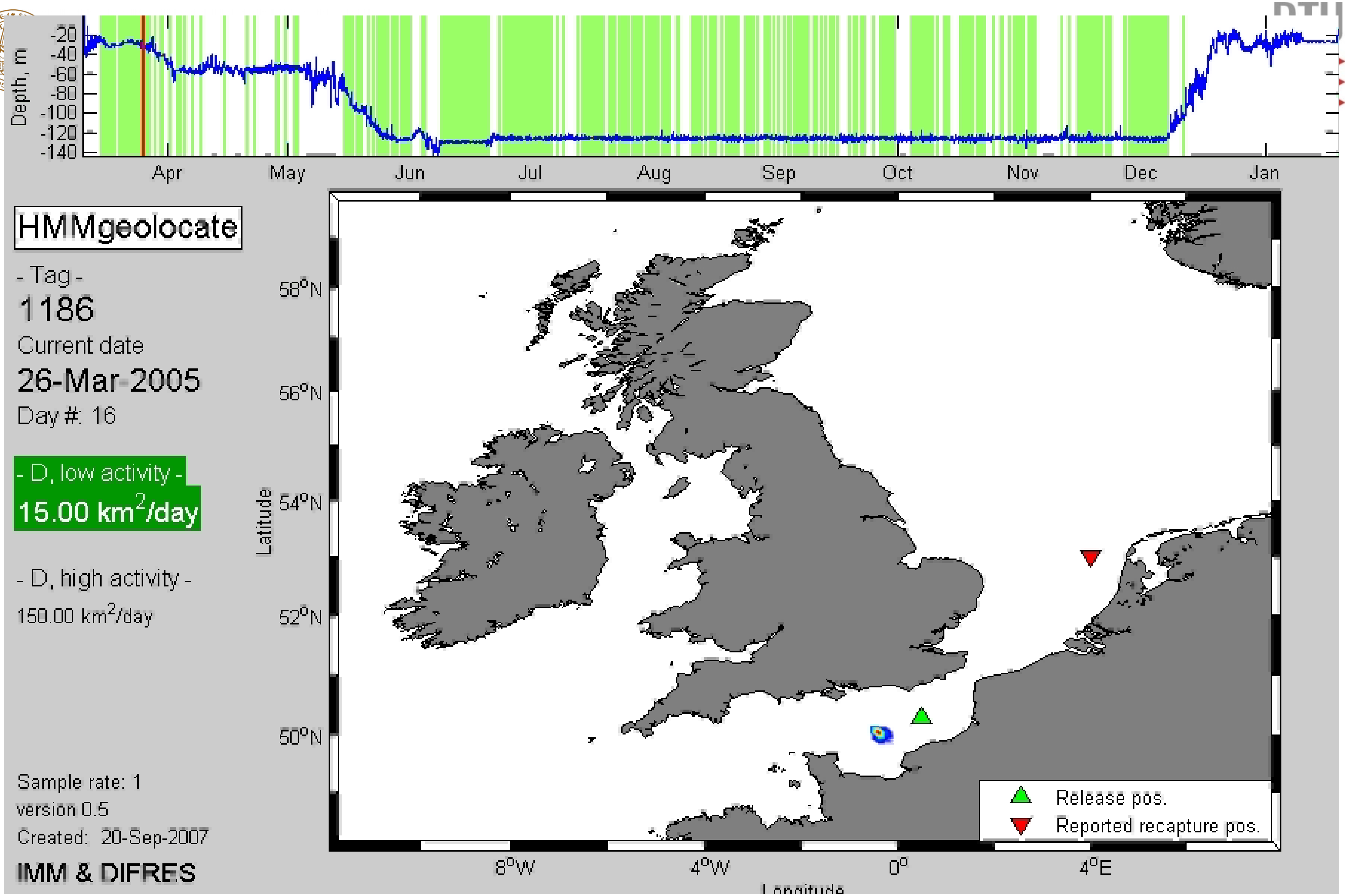
egeology.blogfa.com

Observations

Measured sequence of depths from release to capture:



Where has the fish been?

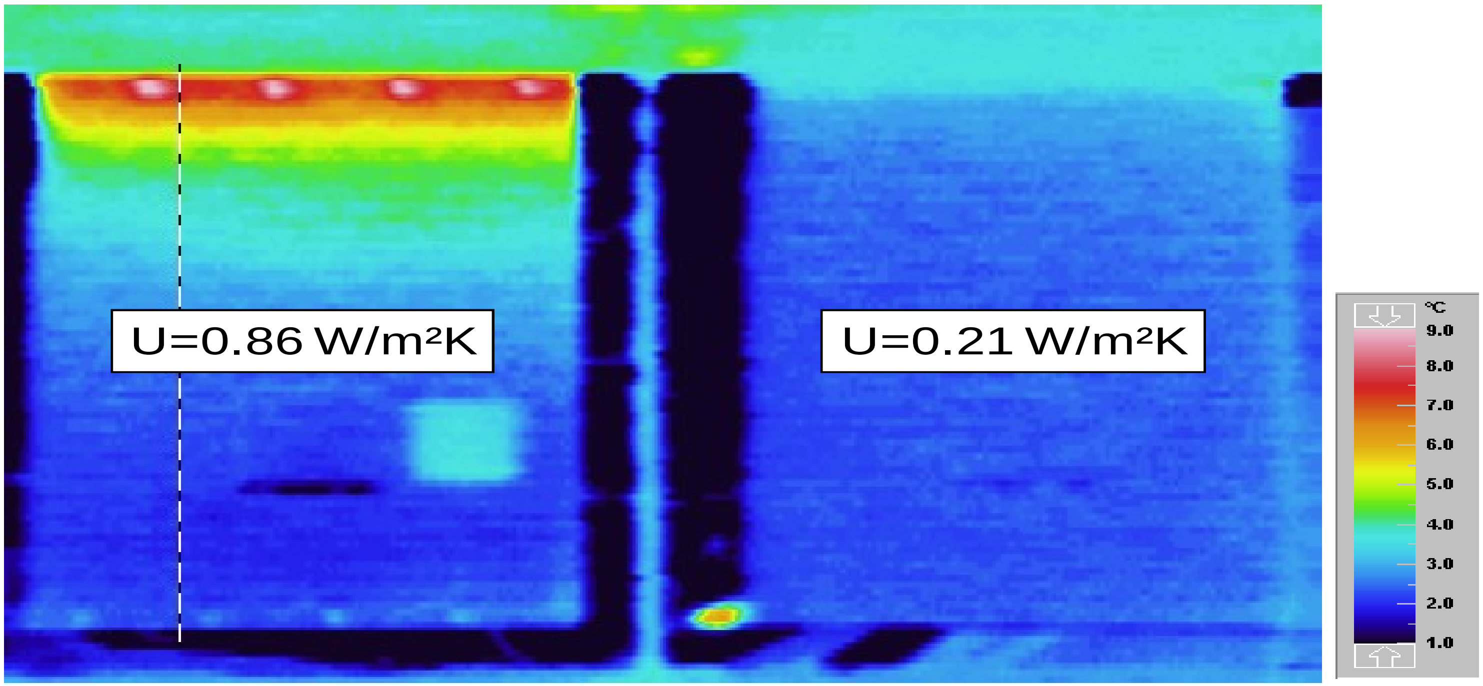


Depth, m
-20
-40
-60
-80
-100
-120
-140
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
HMMgeolocate
- Tag -
1186
Current date
26-Mar-2005
Day #: 16
- D, low activity -
15.00 km²/day
- D, high activity -
150.00 km²/day
Sample rate: 1
version 0.5
Created: 20-Sep-2007
IMM & DIFRES
58°N
56°N
54°N
52°N
50°N
Latitude
8°W
4°W
0°
4°E
Release pos.
Reported recapture pos.

Case Study No. 2

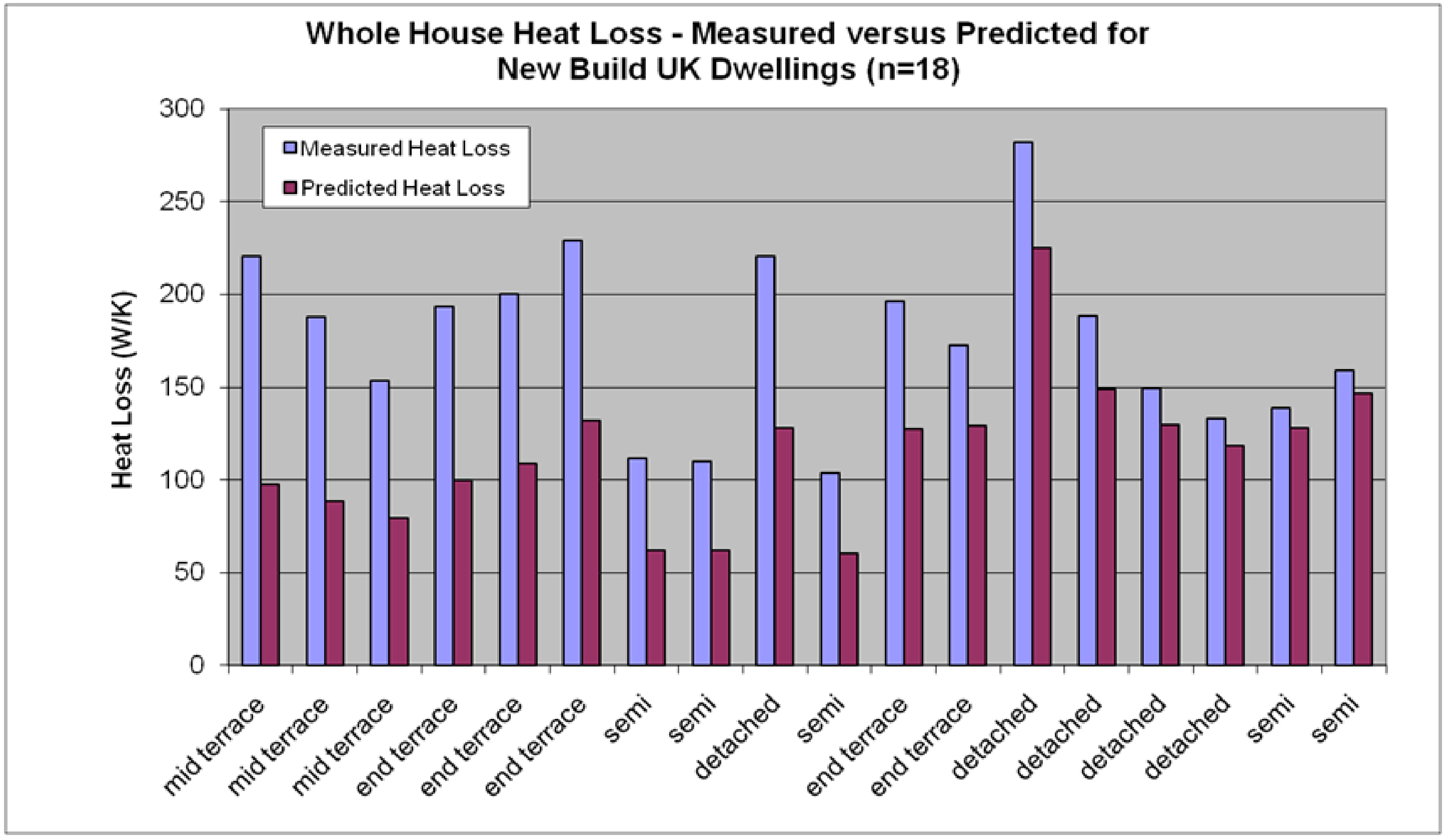
Characterising the Energy Performance of Buildings

Example



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

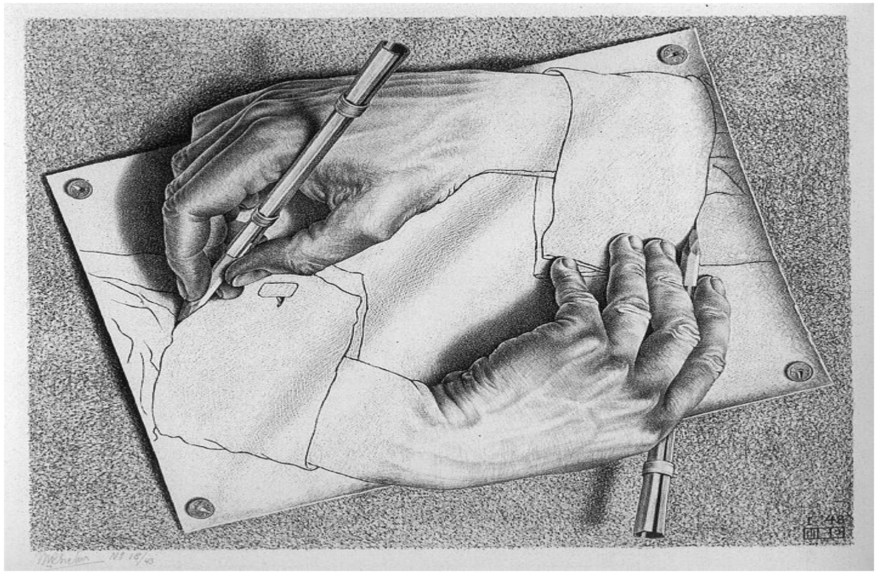
Examples (2)



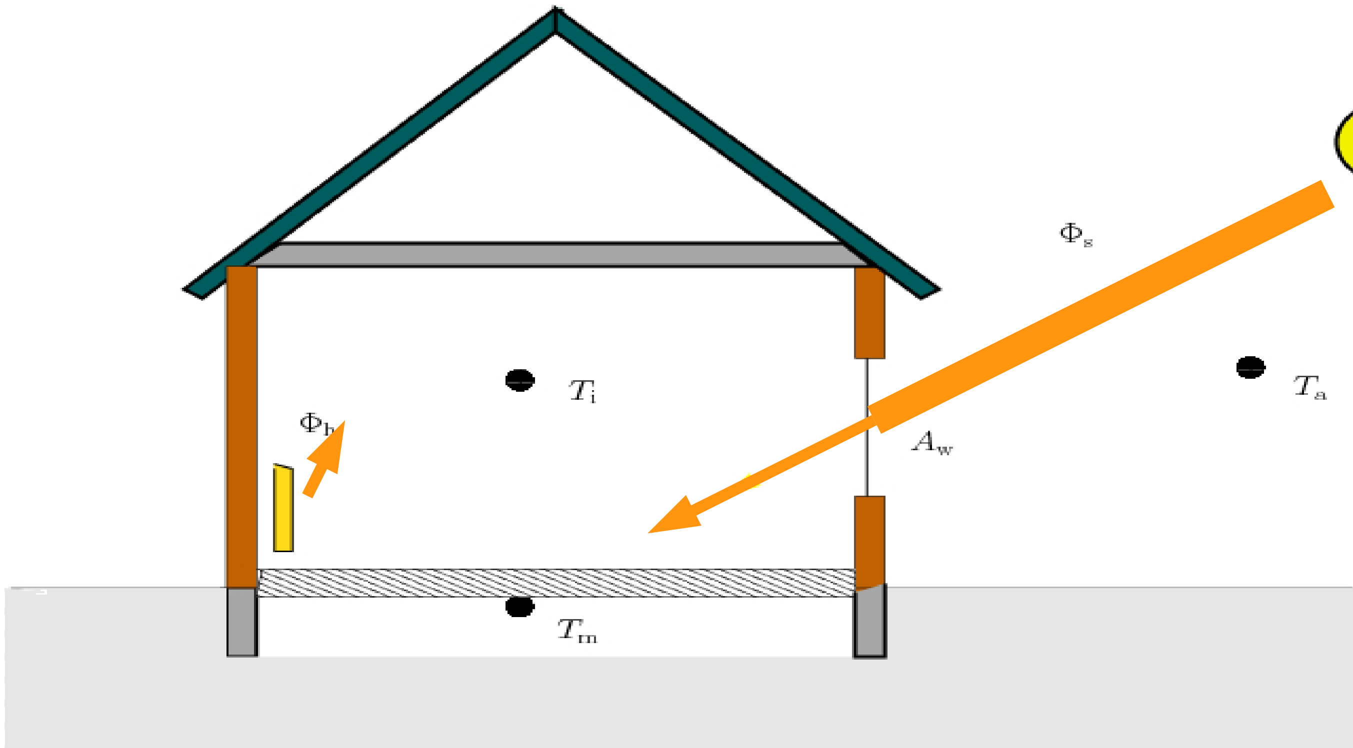
Measured versus predicted energy consumption for different dwellings

Energy Labelling of Buildings

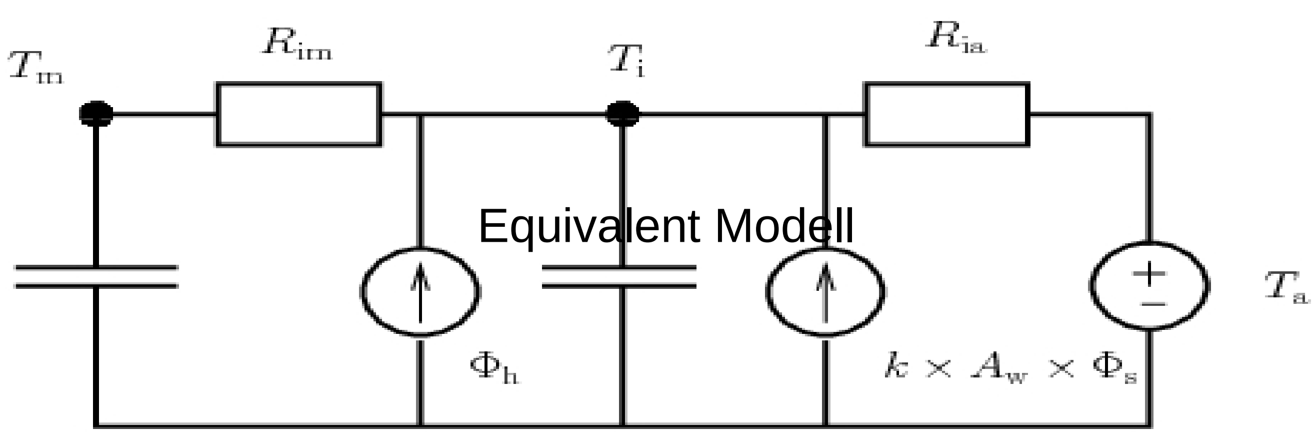
- Today building experts make judgements of the energy performance of buildings based on drawings and prior knowledge.
- This leads to 'Energy labelling' of the building
- However, it is noticed that two independent experts can predict very different consumptions for the same house.



Model for the heat dynamics



- Measurements:
  - Indoor air temp
  - Radiator heat sup.
  - Ambient air temp
  - Solar radiations
- Hidden states are:
  - Heat accumulated in the building
  - *k*: Fraction of solar radiation entering the interior



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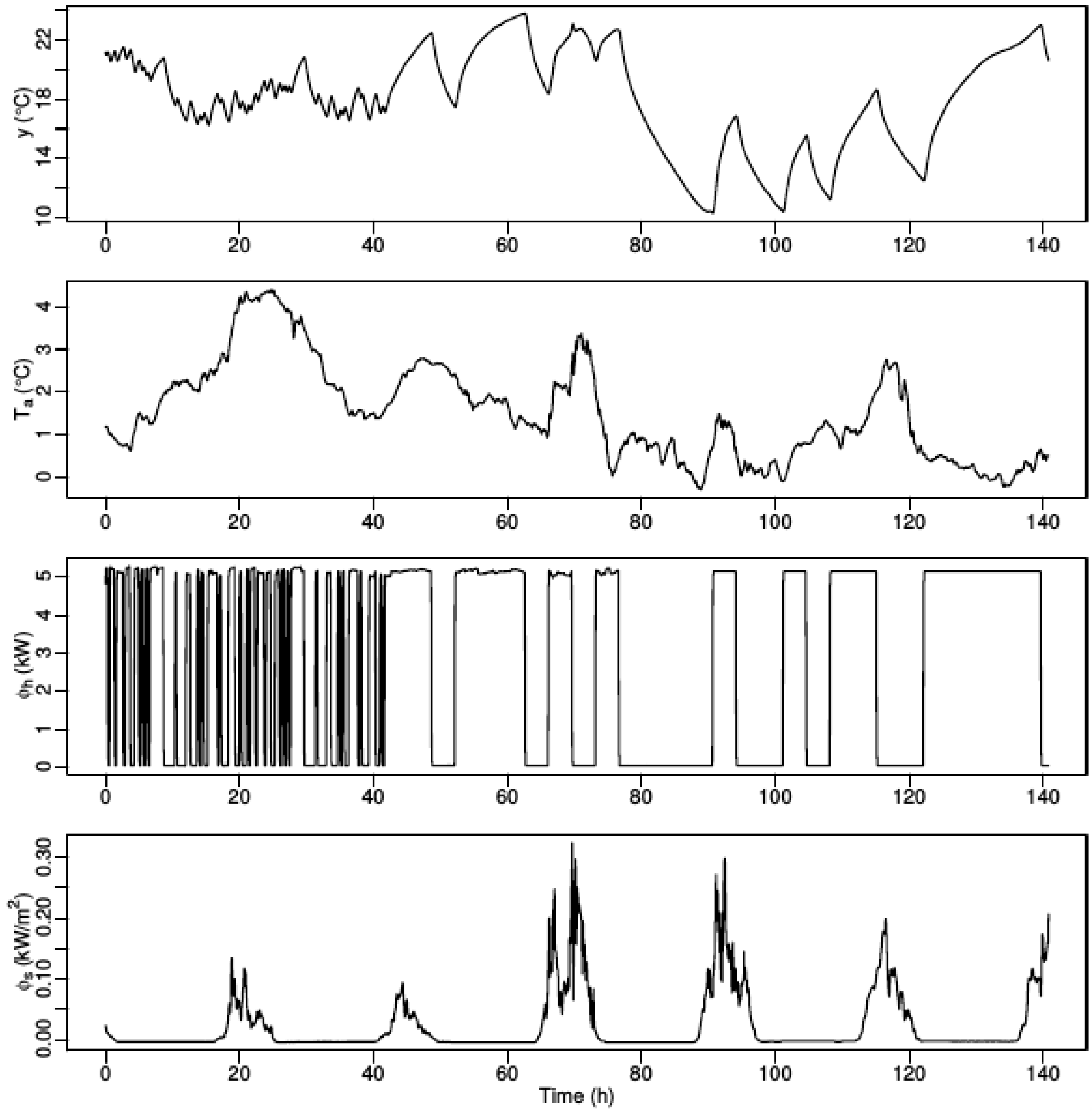
DATA

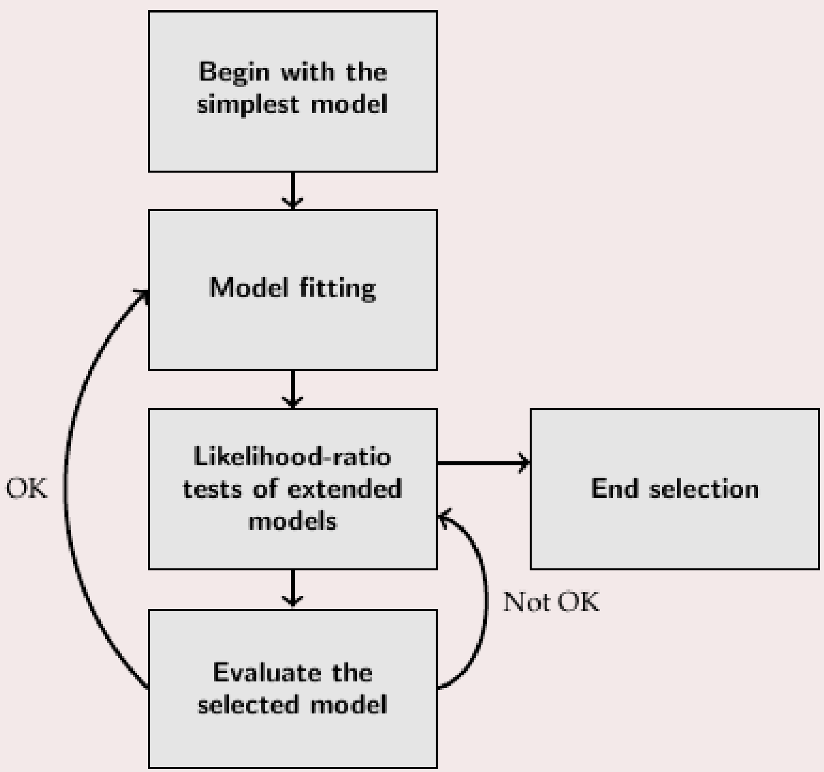
Measurements of:

- y_t Indoor air temperature
- T_a Ambient temperature
- Φ_h Heat input
- Φ_s Global irradiance

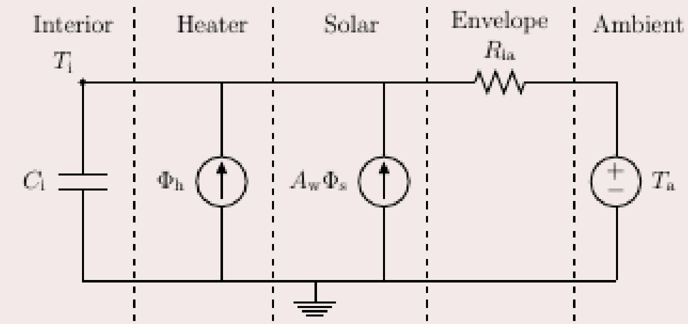


SELECTION PROCEDURE

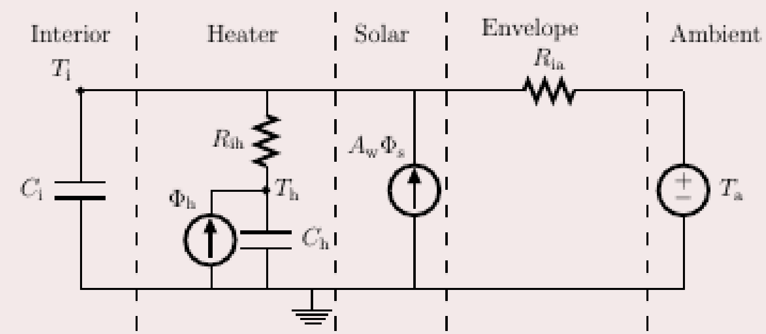
Iterative procedure using statistical tests



Simplest model



First extension: heater part



Start	$Model_{\text{Ti}}$			
$l(\theta; \mathcal{Y}_N)$	2482.6			
m	6			
1	$Model_{\text{TiTe}}$	$Model_{\text{TiTm}}$	$Model_{\text{TiTs}}$	$Model_{\text{TiTh}}$
$l(\theta; \mathcal{Y}_N)$	3628.0	3639.4	3884.4	3911.1
m	10	10	10	10
2	...			

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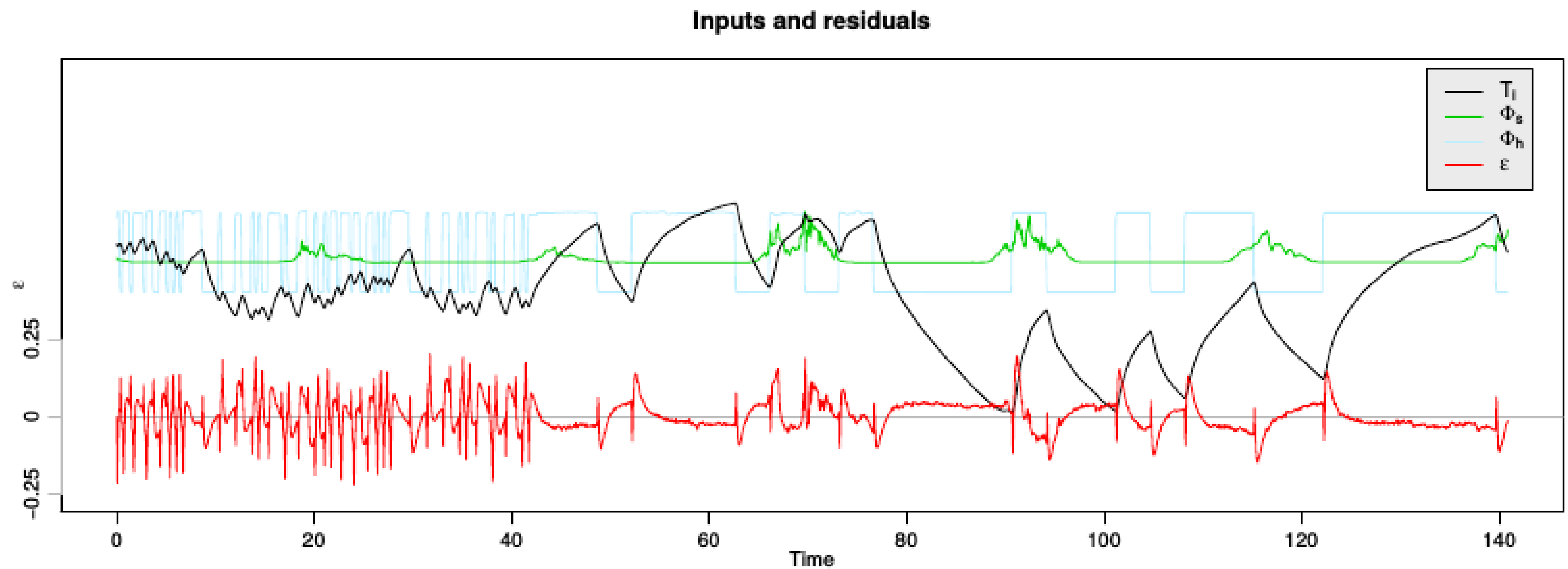
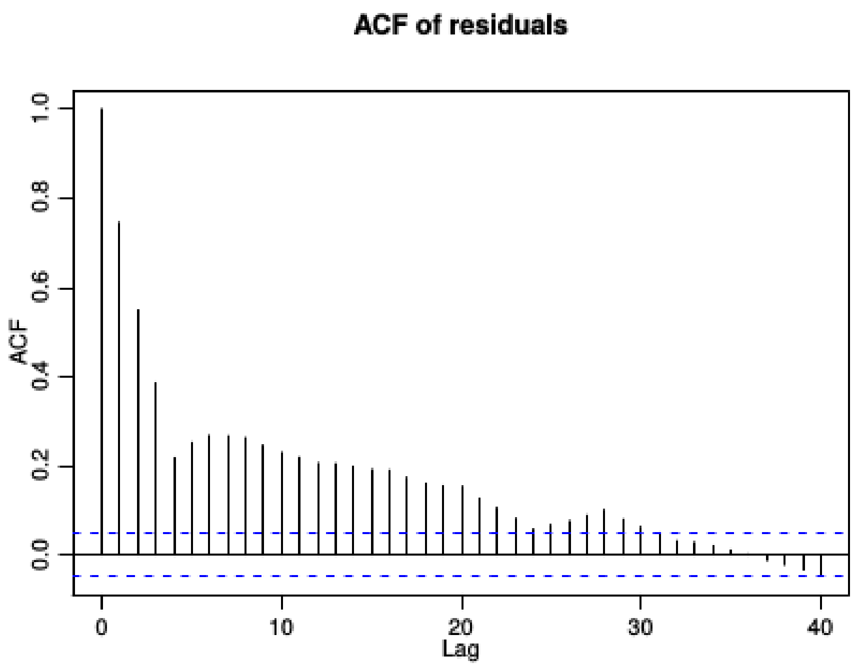
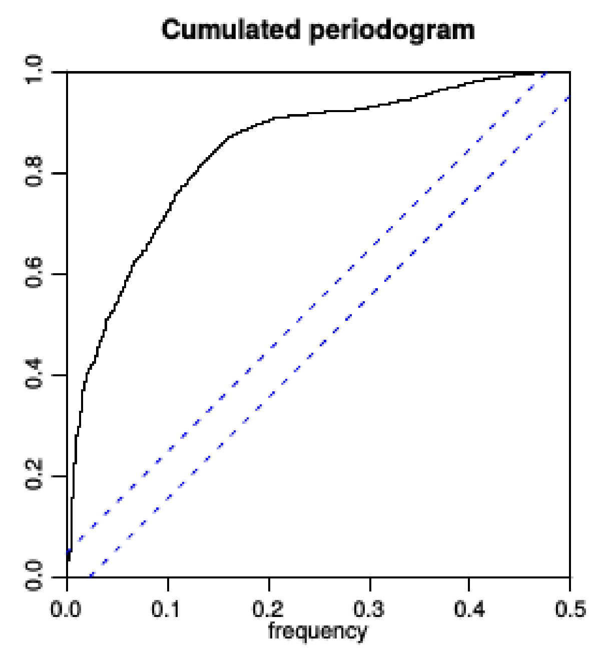
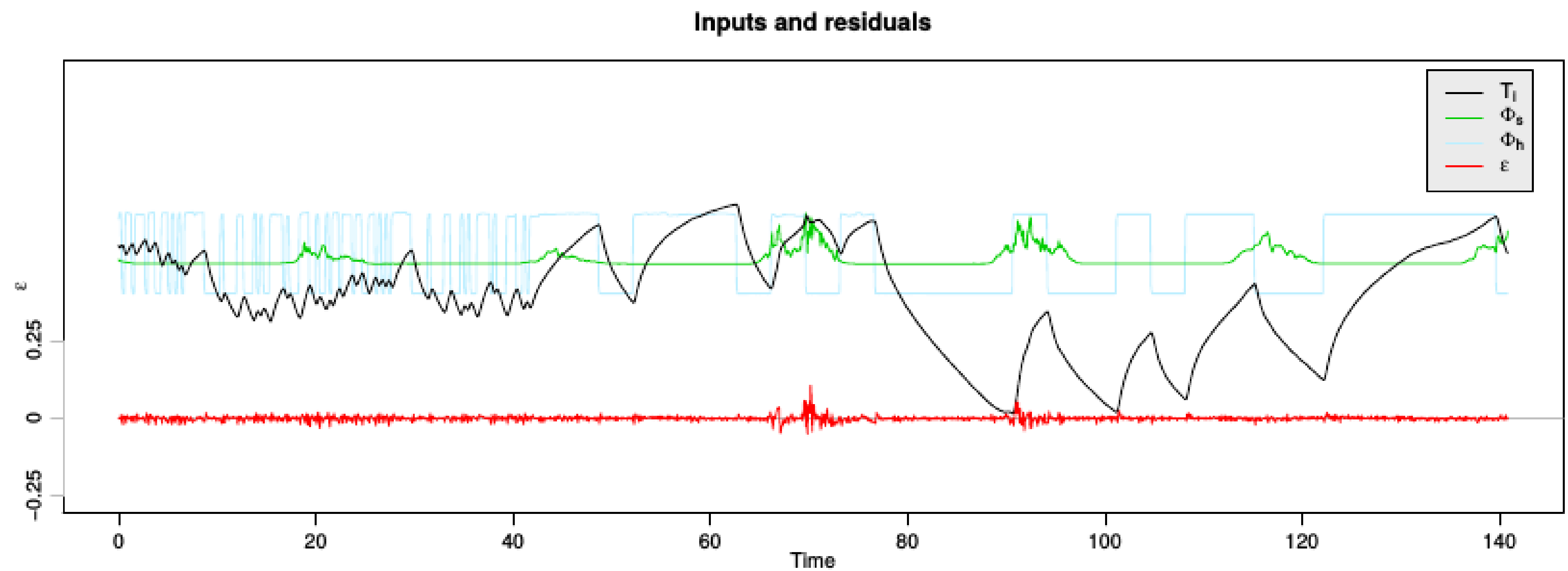
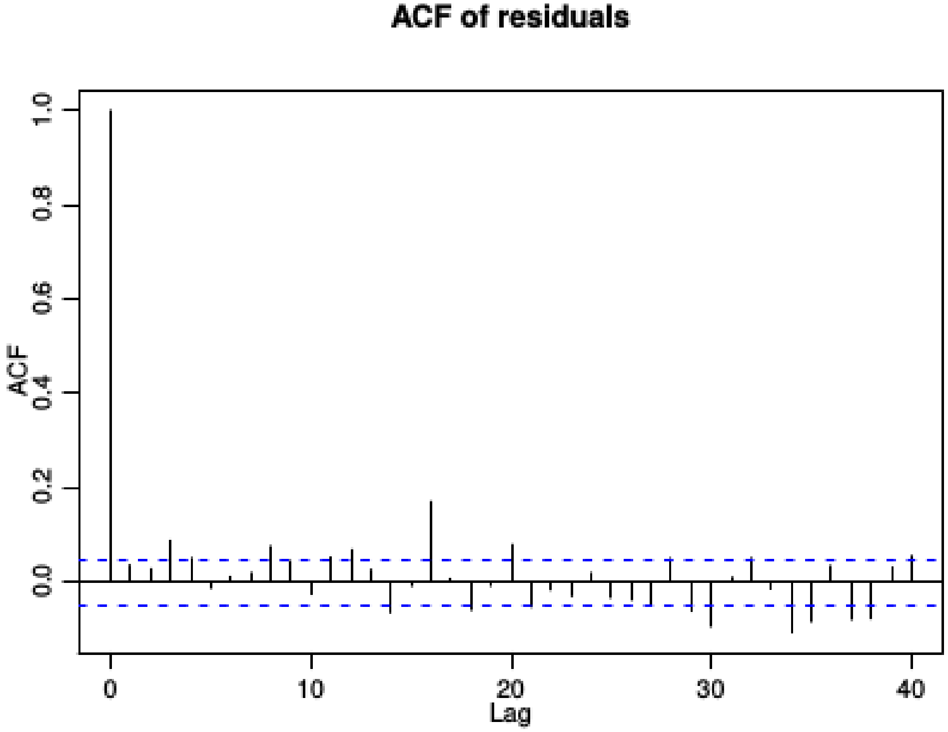
Evaluate the simplest model

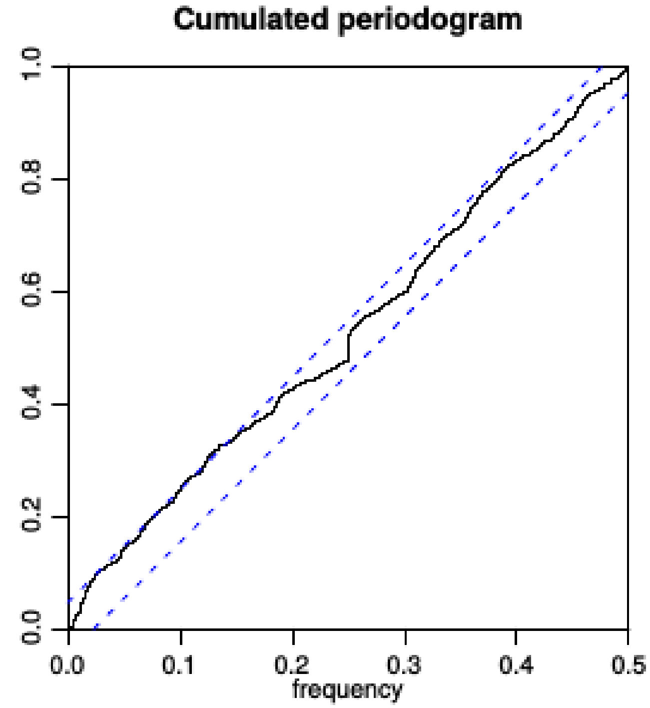







Inputs and residuals
T_i
Φ_s
Φ_h
ε
Time


ACF of residuals
ACF
Lag

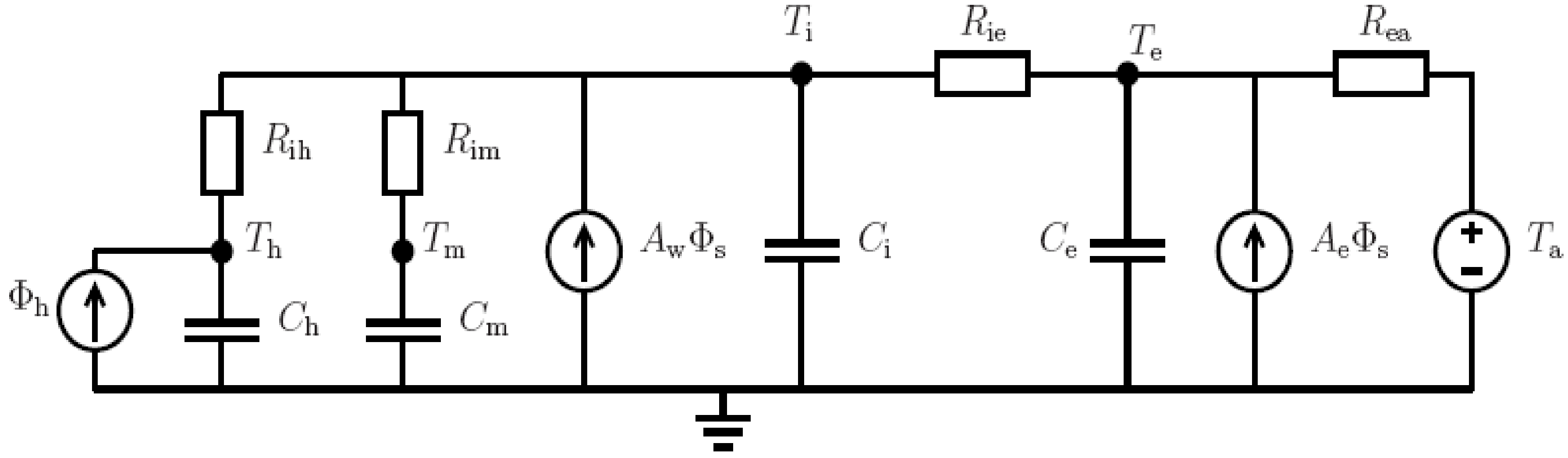

Cumulated periodogram
frequency

Final model for the heat dynamics

- Again: HMM - or state space - model

$$\begin{aligned} \text{Systemet:} \quad d\boldsymbol{x}_t &= \boldsymbol{f}(\boldsymbol{x}_t, \boldsymbol{u}_k, t, \boldsymbol{\theta})dt + \boldsymbol{\sigma}(\boldsymbol{u}_t, t, \boldsymbol{\theta})d\boldsymbol{\omega}_t \\ \text{Observationer:} \quad \boldsymbol{y}_k &= \boldsymbol{h}(\boldsymbol{x}_k, \boldsymbol{u}_k, t_k, \boldsymbol{\theta}) + \boldsymbol{e}_k \end{aligned}$$

- Model found using statistical modelling:



Perspectives

- Identification of most problematic buildings
- Automatic energy labelling
- Recommendations:
  - Should they replace the windows?
  - Or put more insulation on the roof?
  - Or tigthen the building?
  - Should the wall against north be further insulated?
  - ......
- Better control of the heat supply

Perspectives (2)

"Skat, jeg kan se på k-værdierne, at vinduerne skal pudses"

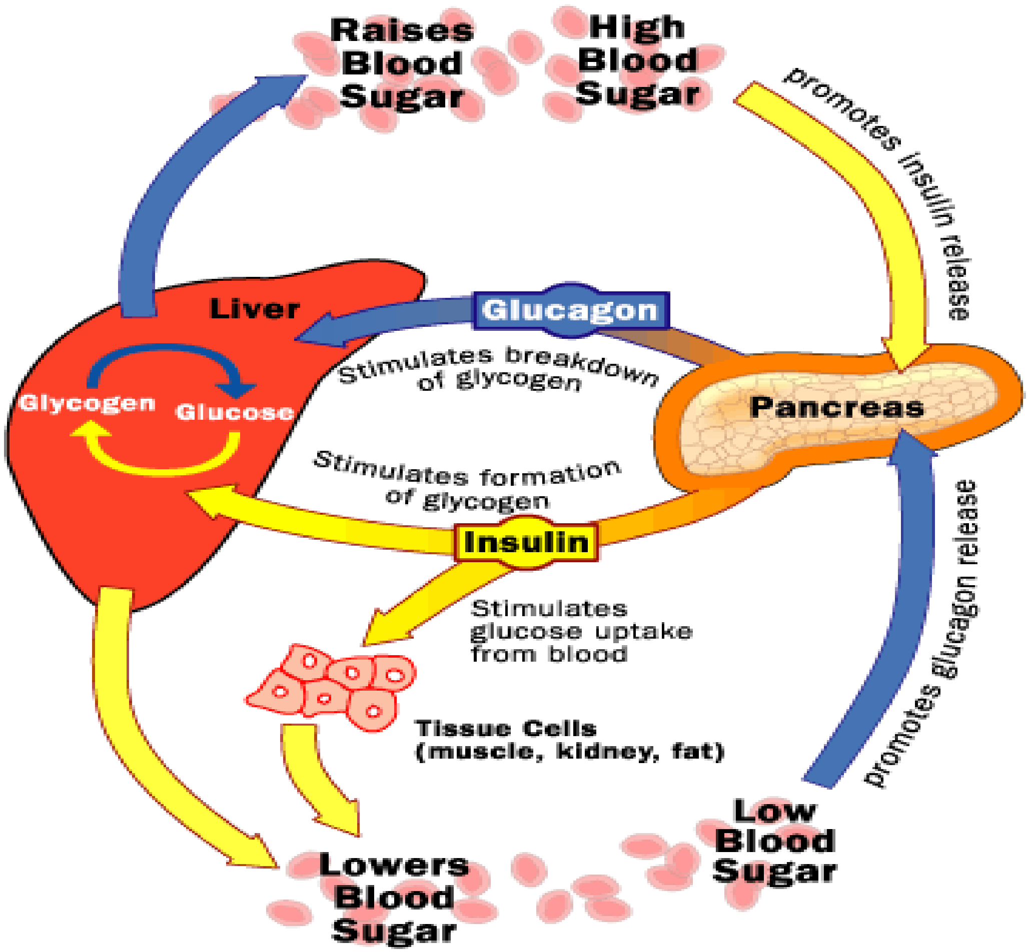
Case Study No. 3

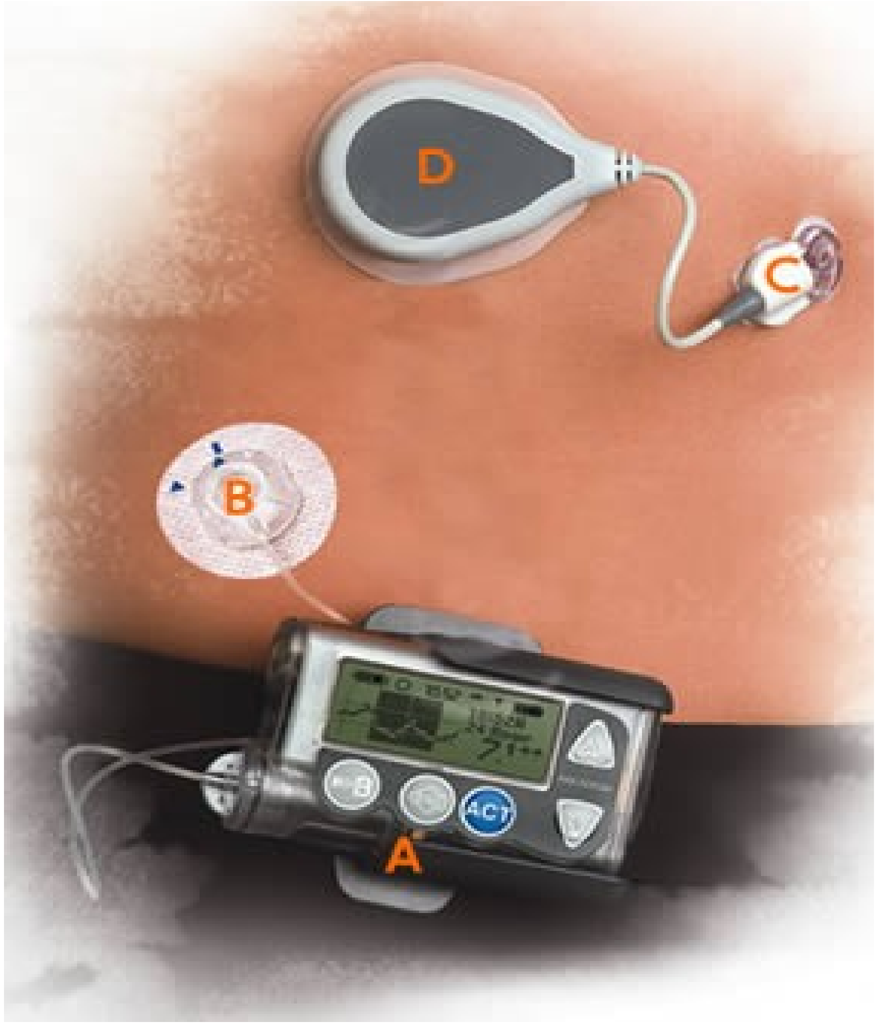
Insulin – Glucose Models

Insulin – Glucose models

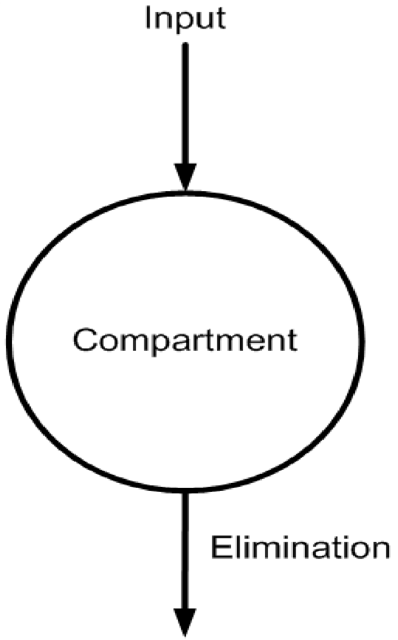
- Today a diabetic person must measure the blod succer in order to provide the correct dose of insulin
- A correct dose depends on a lot of factores like: activity, stress level, hormonale state, meals, etc.

Intelligent device (A) for optimal dosing of insulin (B) based on measurements of glucose (C and D)



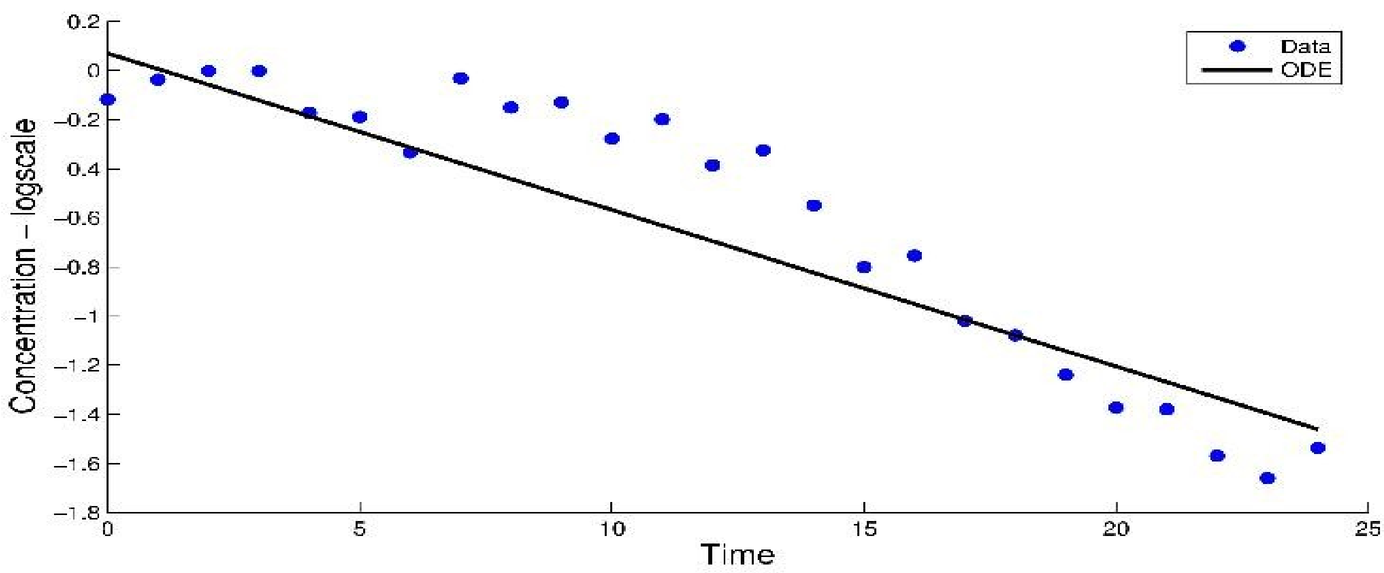


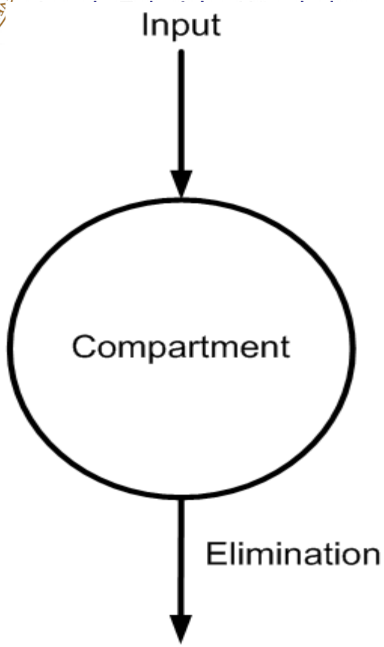
Traditional Dynamic model



- Ordinary Differential Equation:

$$\begin{aligned} dA &= -KAdt \\ Y &= A + \epsilon \end{aligned}$$

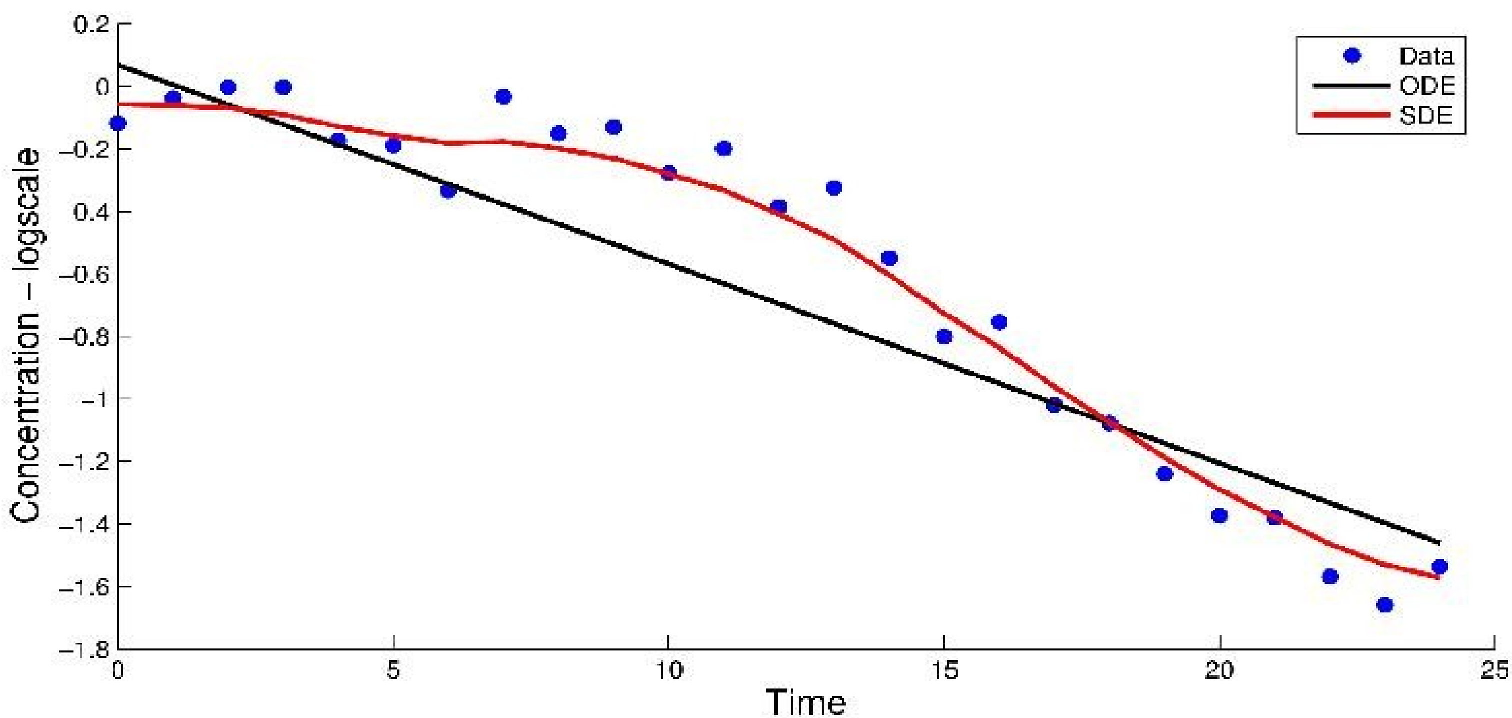




Stochastic Dynamic Model

- Stochastic Differential Equation:

$$
\begin{aligned}
dA &= -KAdt + \sigma dw \\
Y &= A + e
\end{aligned}
$$



HMM or State Space Model

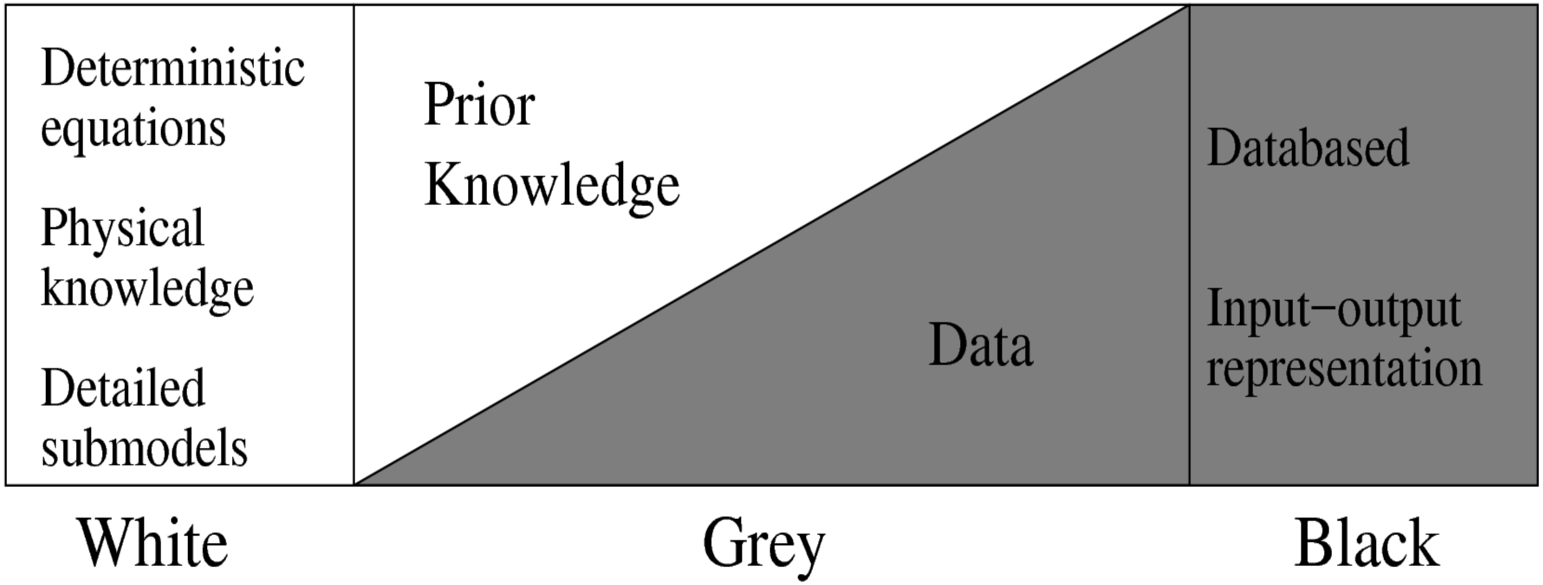
Model for a description of glucose-insulin relation:

$$\begin{aligned} \text{Systemet:} \quad d\boldsymbol{x}_t &= \boldsymbol{f}(\boldsymbol{x}_t, \boldsymbol{u}_k, t, \boldsymbol{\theta})dt + \boldsymbol{\sigma}(\boldsymbol{u}_t, t, \boldsymbol{\theta})d\boldsymbol{\omega}_t \\ \text{Observationer:} \quad \boldsymbol{y}_k &= \boldsymbol{h}(\boldsymbol{x}_k, \boldsymbol{u}_k, t_k, \boldsymbol{\theta}) + \boldsymbol{e}_k \end{aligned}$$

Using appropriate statistical methods we can again :

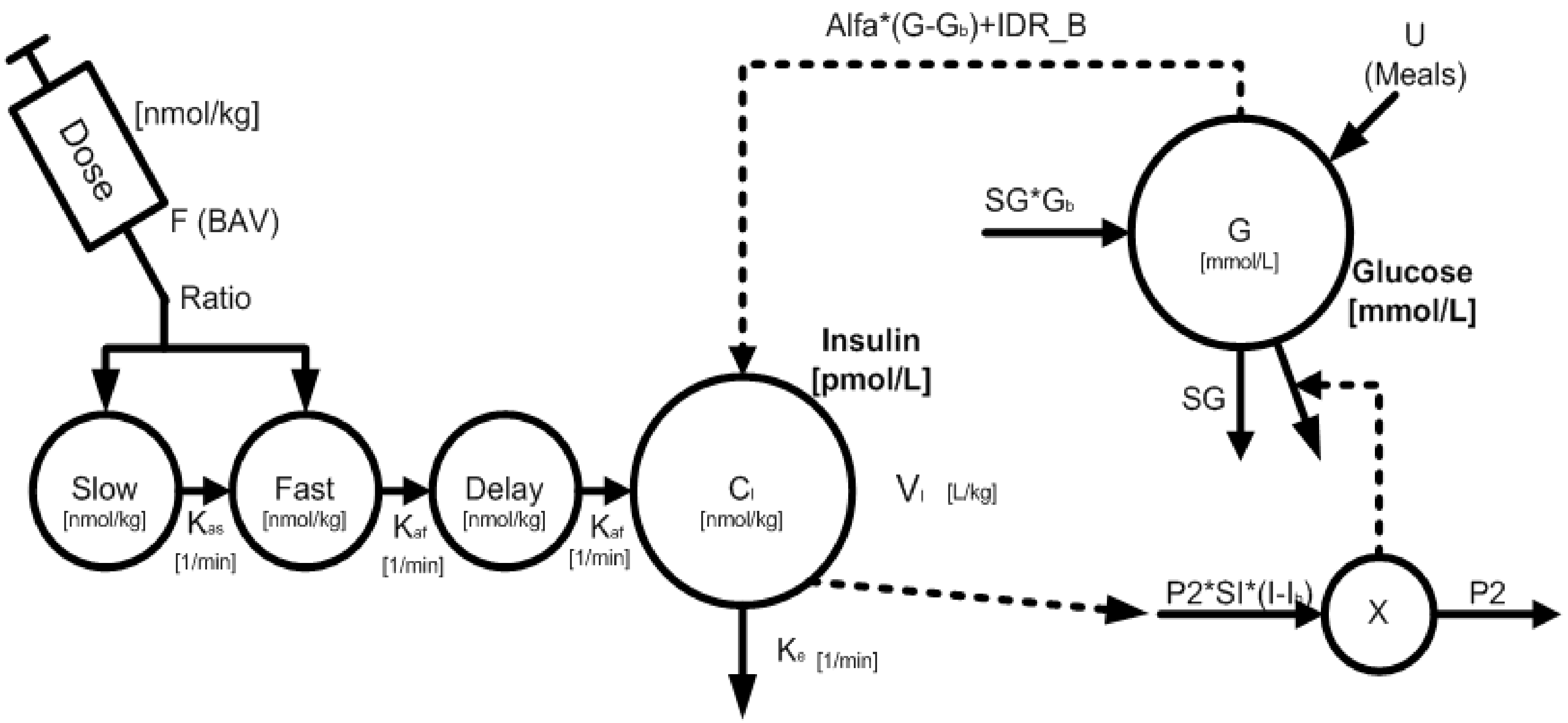
- Find the best model and the hidden states

Grey-box modelling concept



- Combines prior physical knowledge with information in data
- Equations and parameters are physically interpretable

Best model found ...



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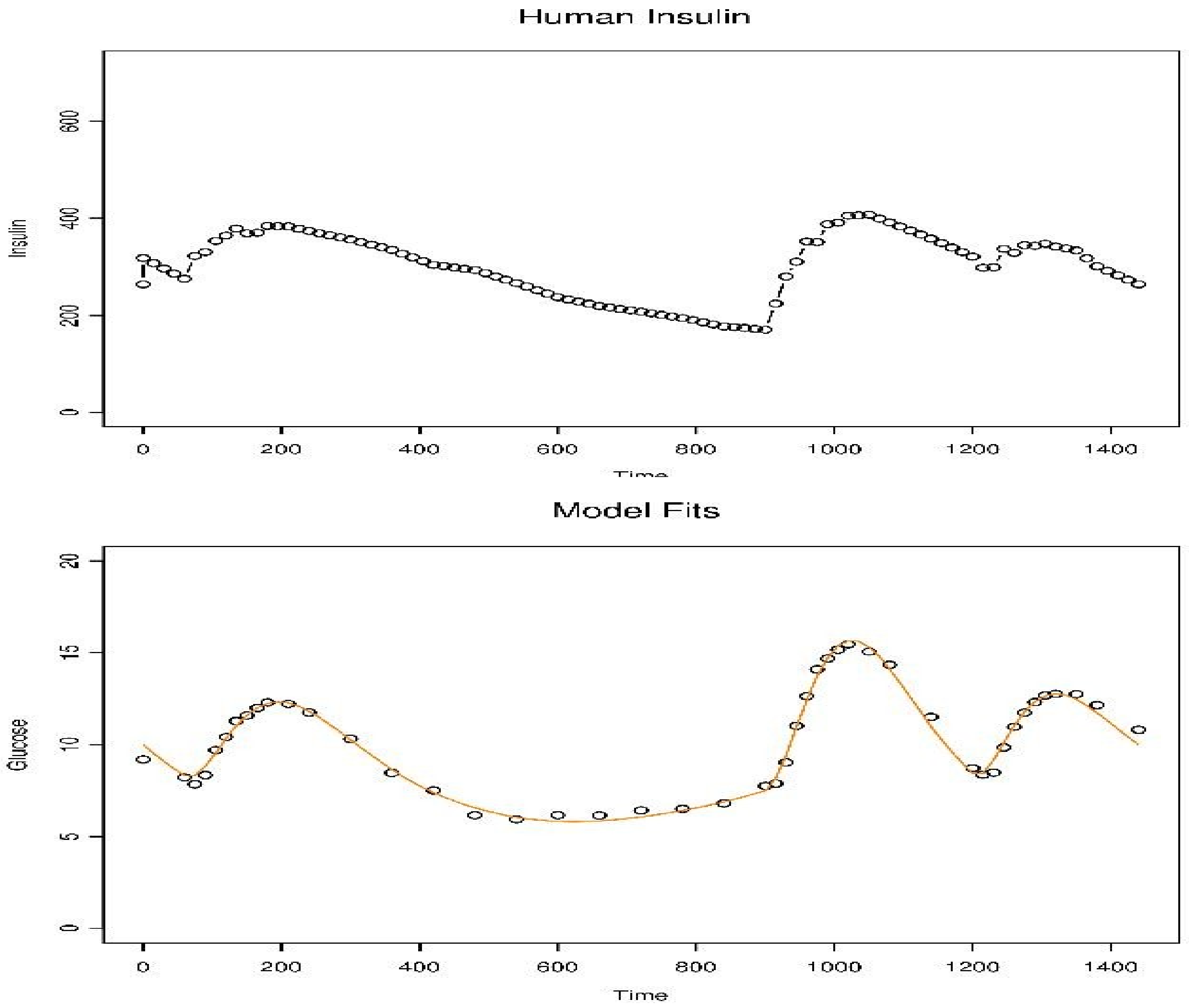

Case Study No. 4

Intelligent and Integrated Energy Systems

Quote by B. Obama at the Climate Summit 2014
in New York:

We are the ***first generation*** *affected by climate changes,*

and we are the ***last generation*** *able to do something about it!*

Potentials and Challenges for renewable energy

- **Scenario**: We want to cover the worlds entire need for power using wind power.
- How large an area should be covered by wind turbines?

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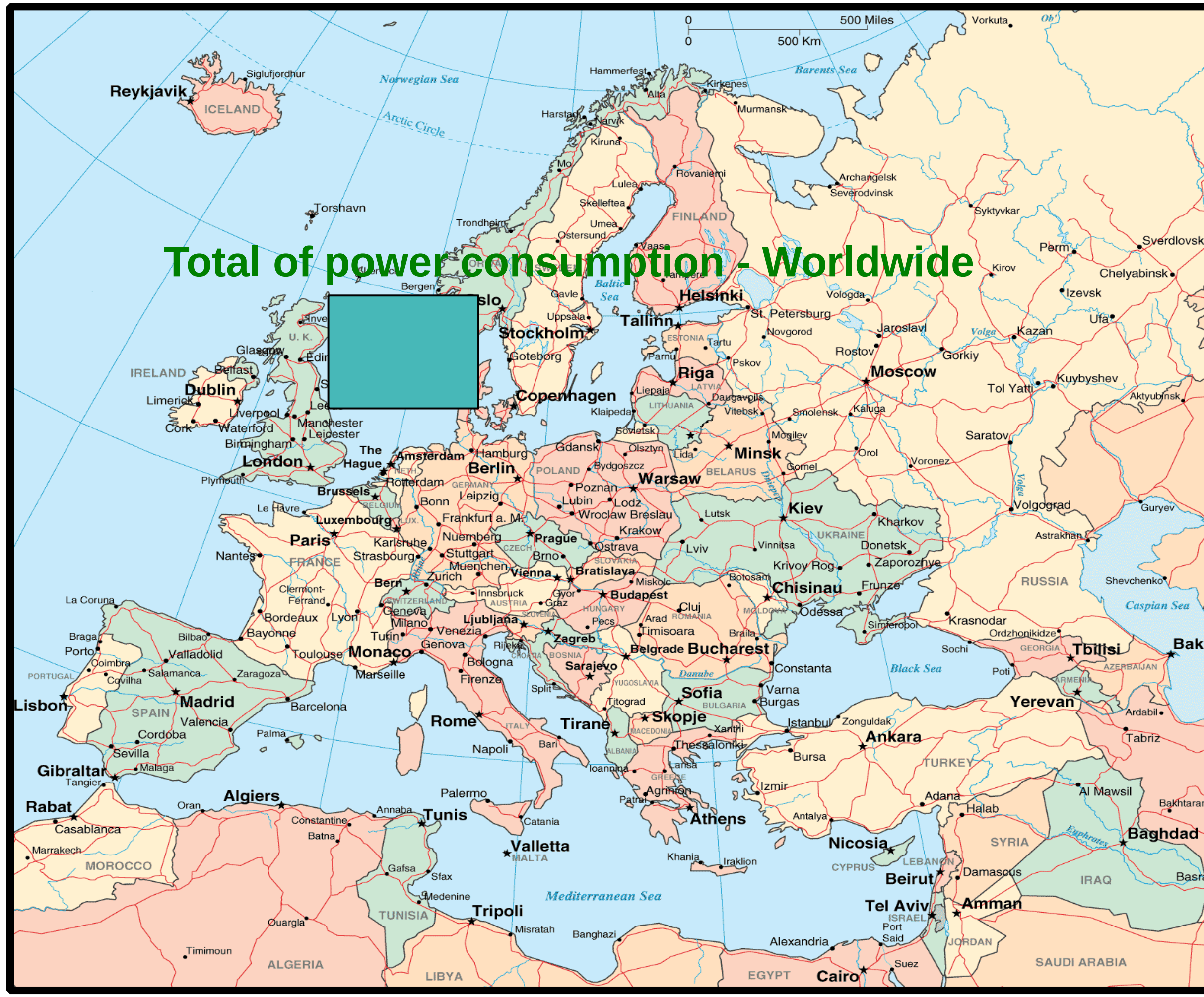
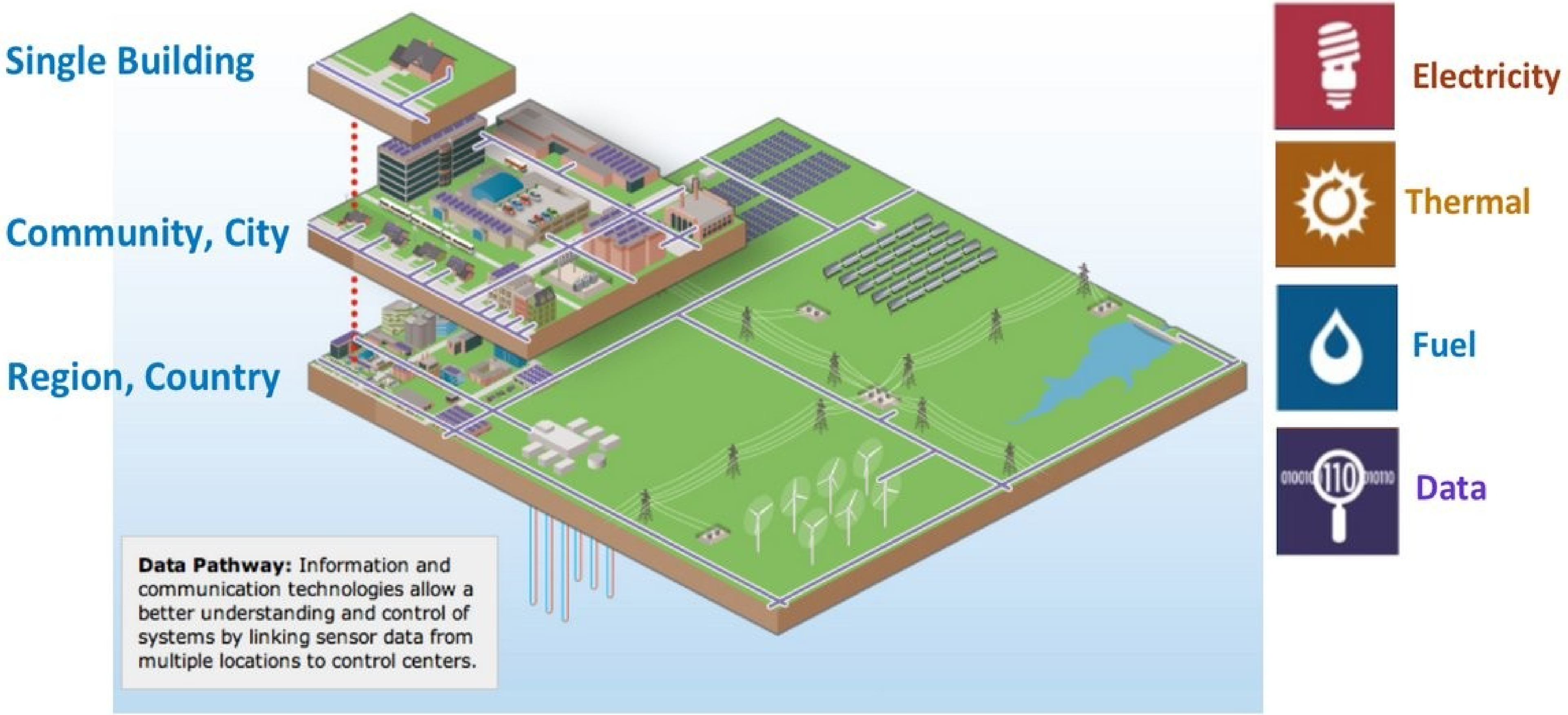
Potentials and Challenges for renewable energy

- **Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- **Conclusion**: Use data intelligence ....
- Calls for **IT / Big Data / Hidden Markov Models for Energy Systems Integration**



Energy Systems Integration

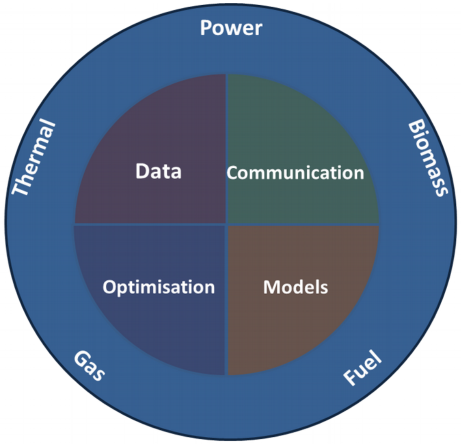
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



ESI – Hypothesis

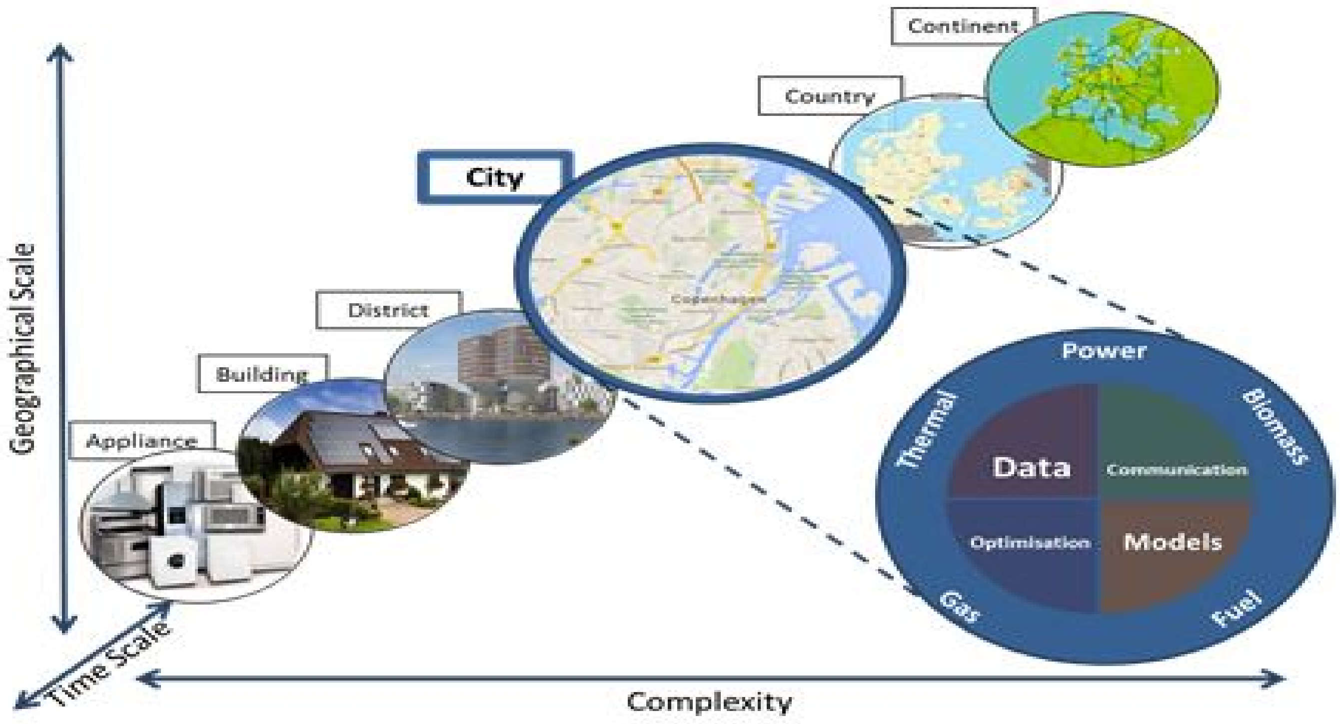
The **central hypothesis of ESI** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in we can enable very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

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



ESI – Research Challenges

To establish methodologies and models for operation of integrated electrical, thermal, fuel pathways at all scales



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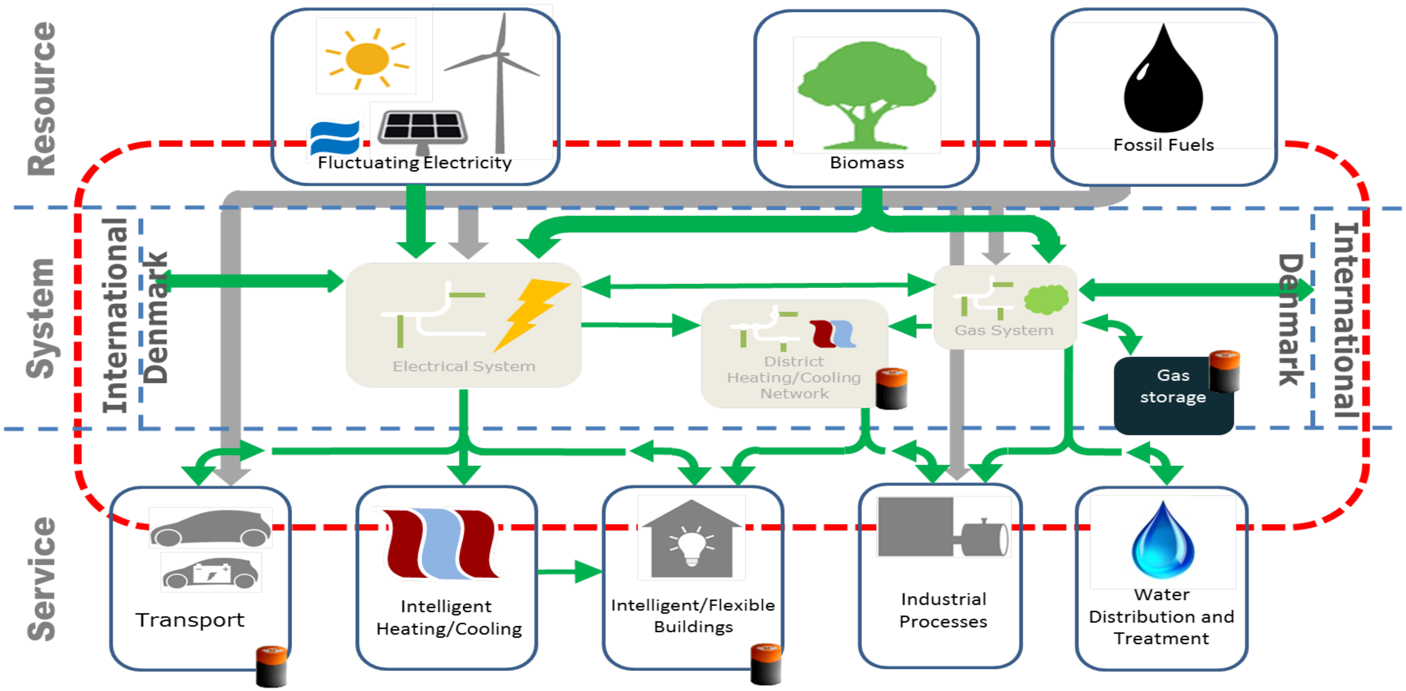
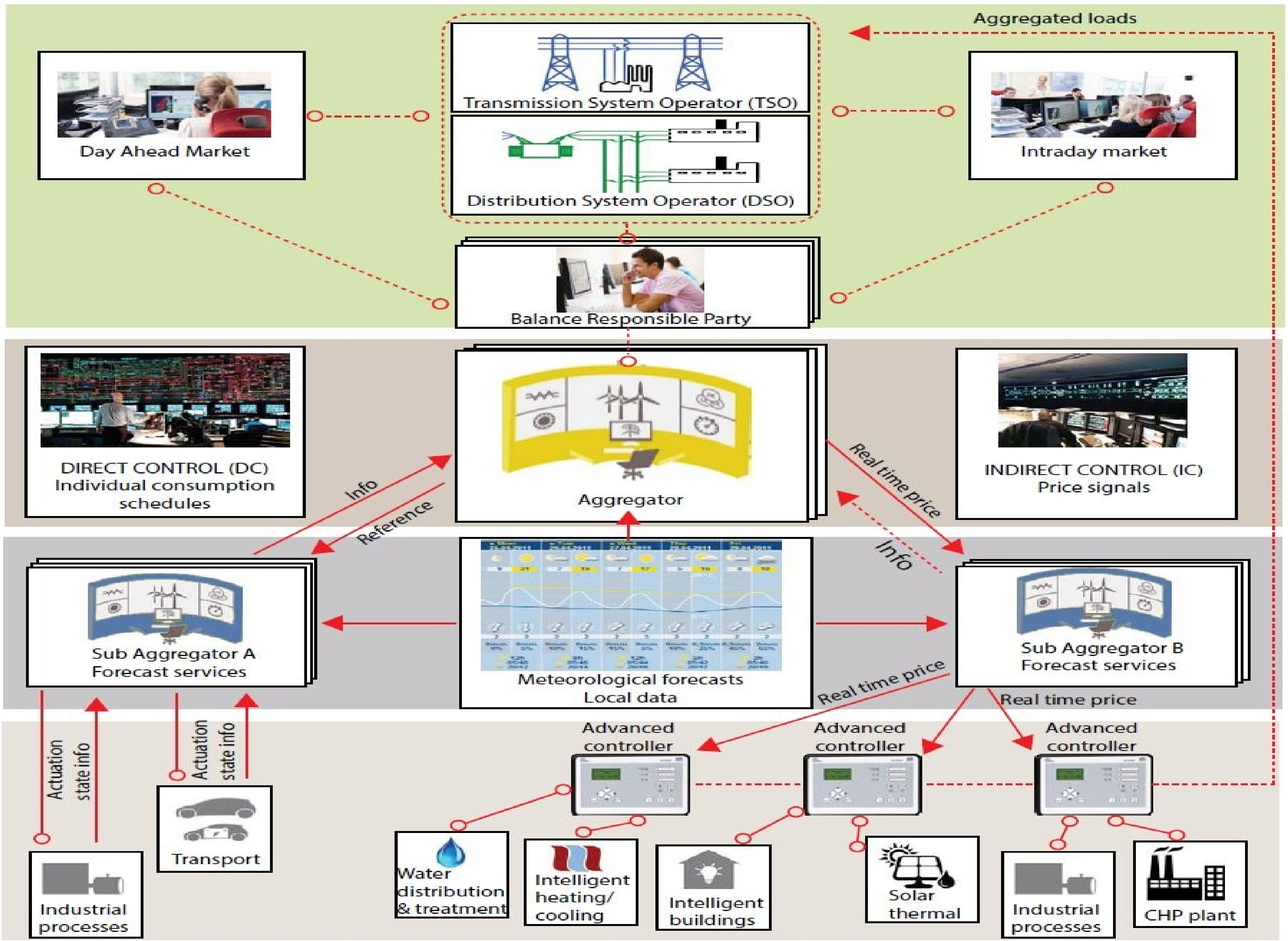
Modelling

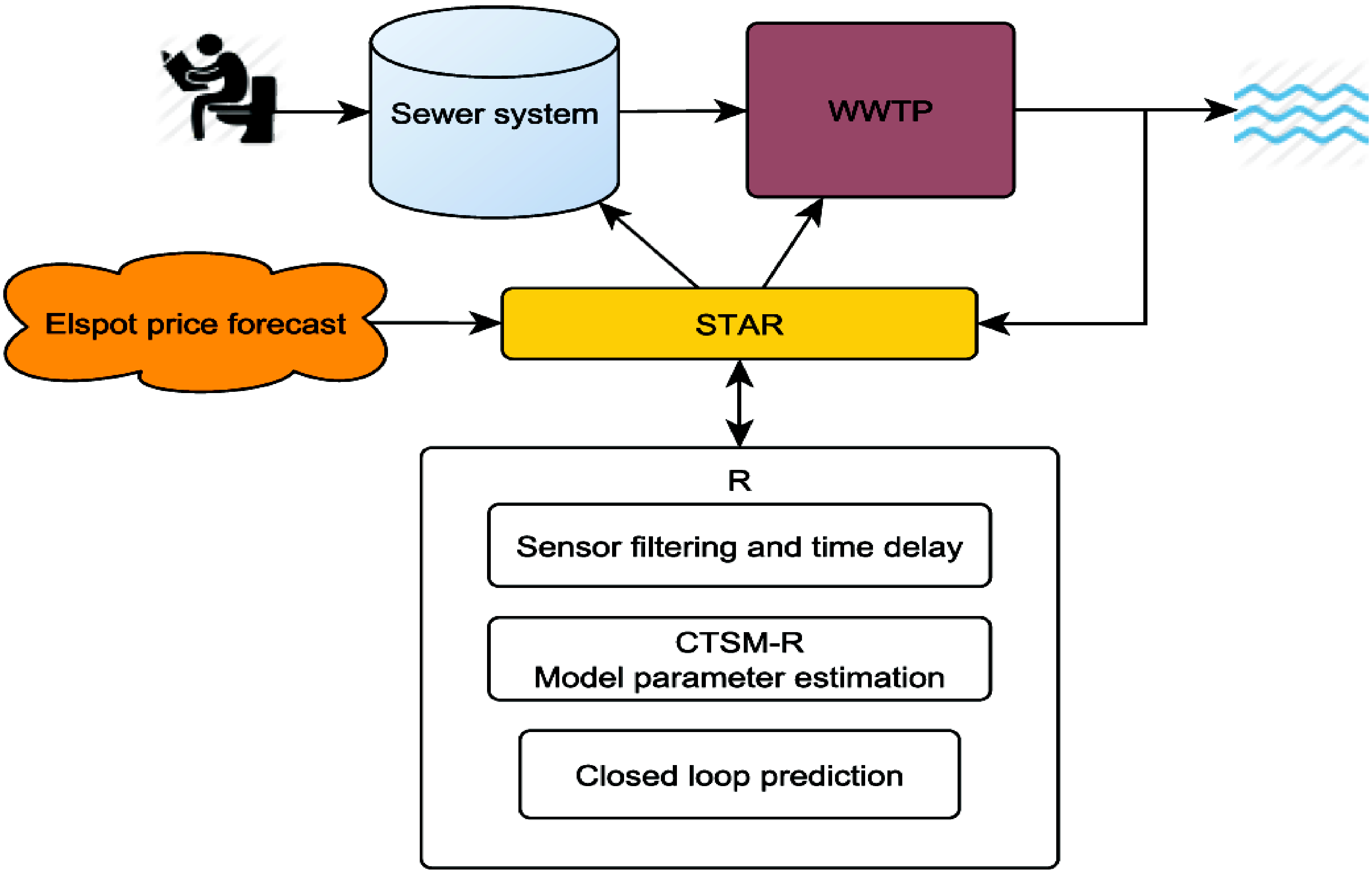
Use of **Hidden Markov Models** for operation of future integrated energy system.



Smart-Energy OS



Energy Flexibility in Wastewater Treatment



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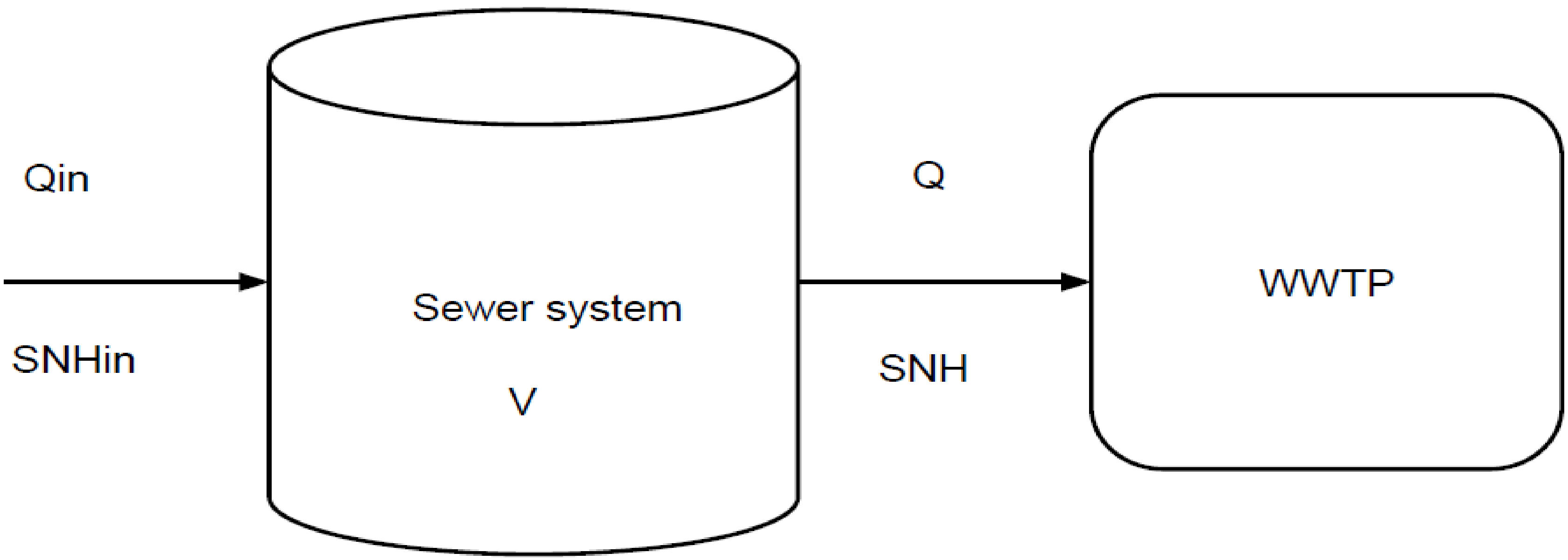
Sewer System Control Goal

$$\text{minimize overflow} + p_{elspot}^T f(Q)$$



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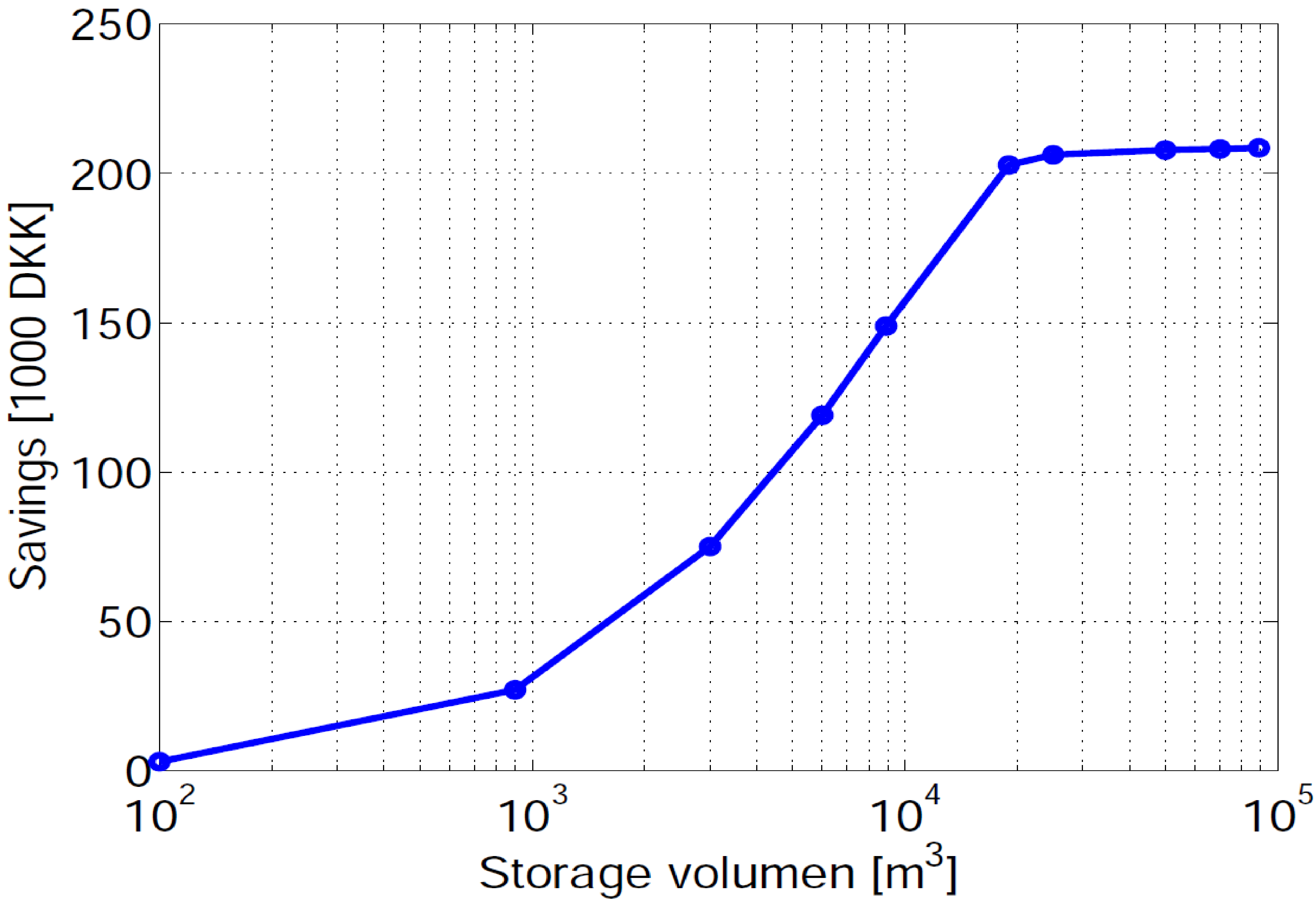
Sewer System Annual Elspot Savings



Hidden Markov Models

- Eksemples considered:
  - Geo-location of fish
  - Energy labelling and optimization
  - Control of insulin injection
  - Intelligent and integrated energy systems
- **In general: Hidden Markov Models are useful for observing phenomenas that we cannot otherwise observe**

Thank you for your attention ...

And thanks to:

Søren Klim, Andreas Bærentzen, Sten Frandsen, Peder Bacher,
Martin Wæver Petersen, John Bagterp Jørgensen, ...