Data-driven models for demand-side management

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IEA Symposium on Demand Flexibility and RES Integration

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Data analysis and statistics

- How can we gain as much as possible useful information from data?
- Statistical inference: the process of drawing conclusions from data that is subject to random variation
- Time-series models for describing a dynamical system

Model complexity

- Einstein: *"Everything should be made as simple as possible, but not simpler"*
- Fundamental question: "Which model and how complex should it be for *optimally* for providing the answers?"

Model complexity

- Einstein: *"Everything should be made as simple as possible, but not simpler"*
- Fundamental question: "Which model and how complex should it be for *optimally* for providing the answers?"
- Answer: it depends on the data!
  - 'simple data' $\Rightarrow$ 'simple model'
  - 'complex data' $\Rightarrow$ 'complex model'
- It is a matter of what we need to know or simply economical investment. Which sensors are needed for providing the needed information?
- or the other way around what can be achieved with current resources

Model complexity

From statistical theory a wide range of techniques are available:

- Find the most suitable model to describe the data
- Estimate the uncertainty
- Validate the model fit (likelihood)

Model structure

Different types of *time series* models:

- Static models, *no dynamics* (e.g. for daily values)
- ARMAX, discrete models based on transfer functions, *black-box dynamics, however for control and steady-state parameters (e.g. UA-value, gA-value) fully applicable*
- Grey-box models. *Continuous (or discrete) time models, combination of physics and statistics*

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Static models (linear function):

$$\text{Measurements} = \text{Function}(\text{Inputs}) + \text{Residual}$$

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ARMAX model:

$$\text{Measurements} = \text{Transferfun}_1(\text{Inputs}) + \text{Transferfun}_2(\text{Error})$$

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Grey-box model:

$$\begin{aligned} \text{States} &= \text{Fun}_1(\text{States}, \text{Inputs}) + \text{Fun}_2(\text{SystemError}) \\ \text{Measurements} &= \text{Fun}_3(\text{States}, \text{Inputs}) + \text{Fun}_4(\text{MeasurementError}) \end{aligned}$$

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Note that part of the model is a description of the error(s)

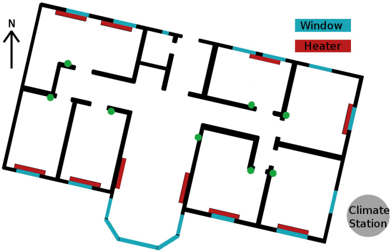
Annex 58: Guidelines

- In Annex 58 we developed guidelines (focus on *energy performance assessment*)
- 'Physical guidelines': setup of measuring campaign and experiments
- 'Statistical guidelines': models for data from buildings (unoccupied, e.g. from a test sequence run 3-7 days):
  - Static, ARX and grey-box models
  - Model selection procedure
  - Examples and implementations i R

TEST CASE: ONE FLOORED 120 M^2 BUILDING

Objective

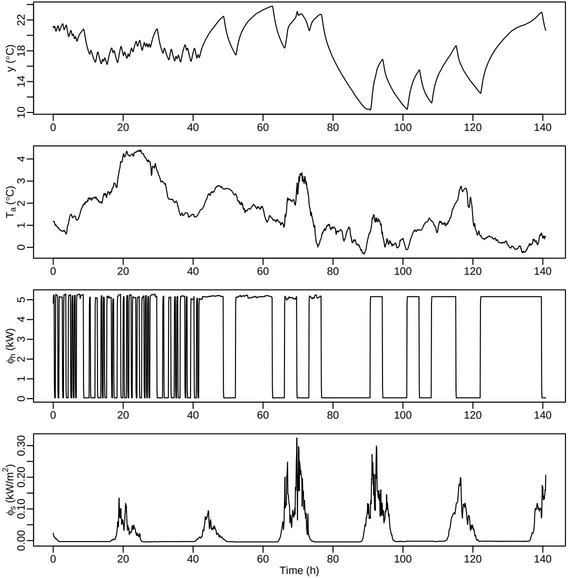
Find the best model describing the heat dynamics of this building



DATA

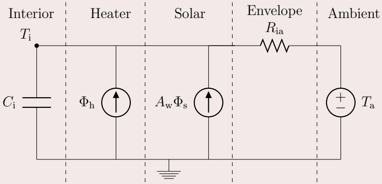
Measurements of:

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



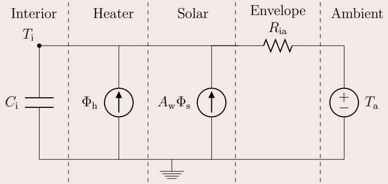
IDENTIFY THE BEST PHYSICAL MODEL FOR THE DATA

Simplest model

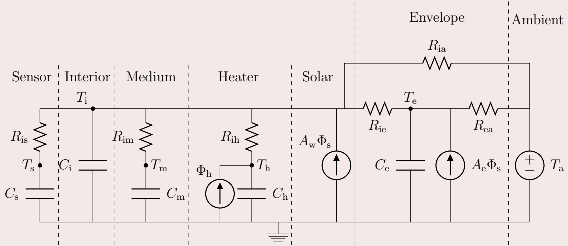


Identify the best physical model for the data

Simplest model



Most complex model applied



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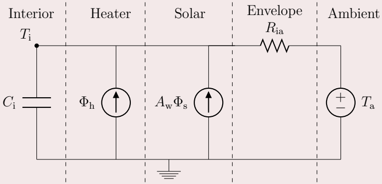
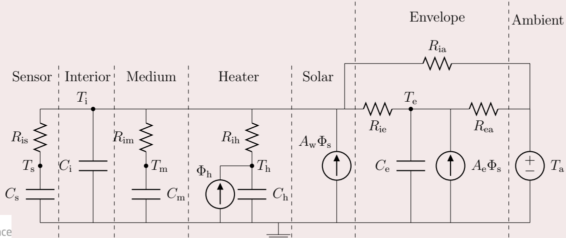


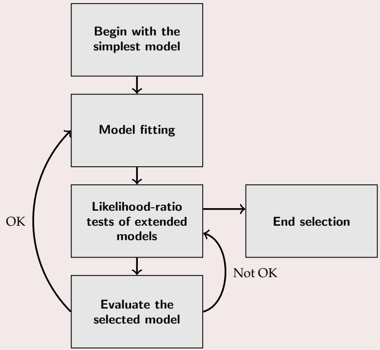
The best model for the given data is probably in between

Most complex model applied



SELECTION PROCEDURE

Iterative procedure using statistical tests



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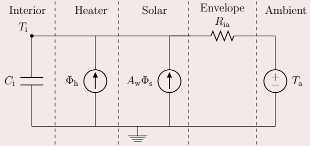

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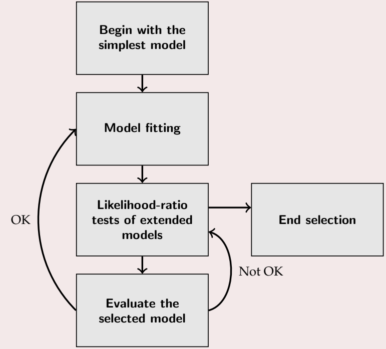

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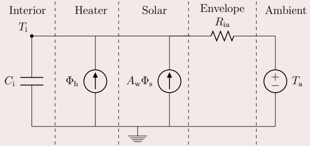
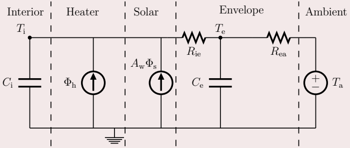


First extension: building envelope part



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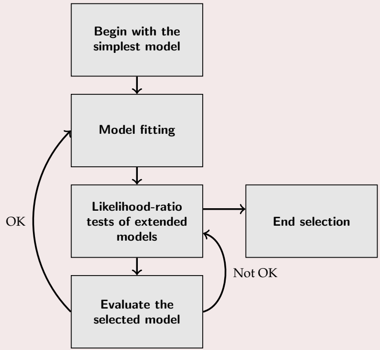
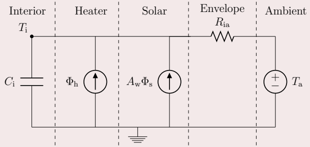
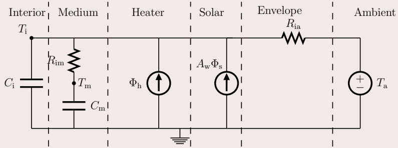


Simplest model



First extension: indoor medium part



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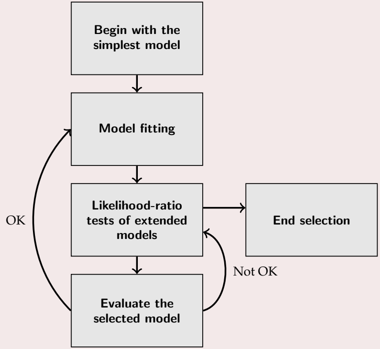
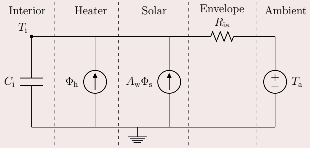
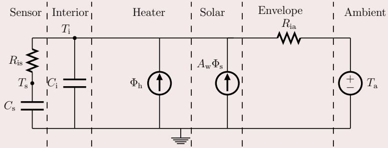


Simplest model



First extension: sensor part



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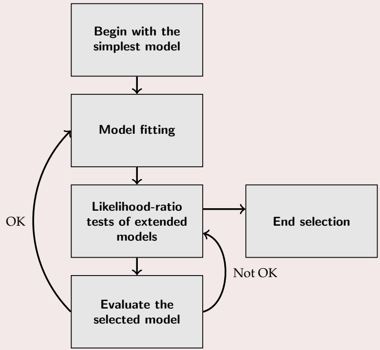

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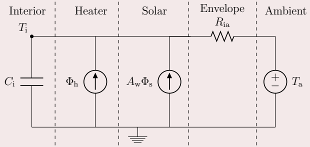
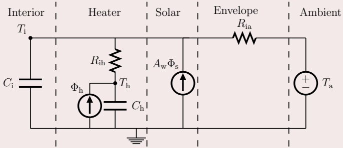
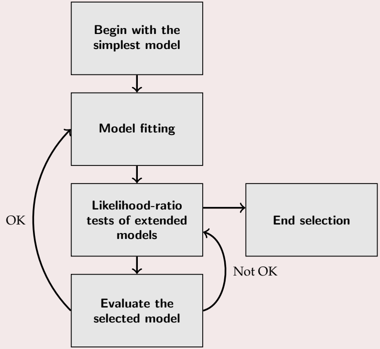


First extension: heater part

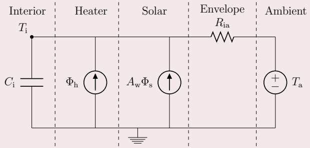


Selection procedure

Iterative procedure using statistical tests



Simplest model



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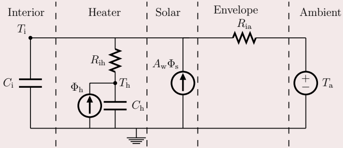
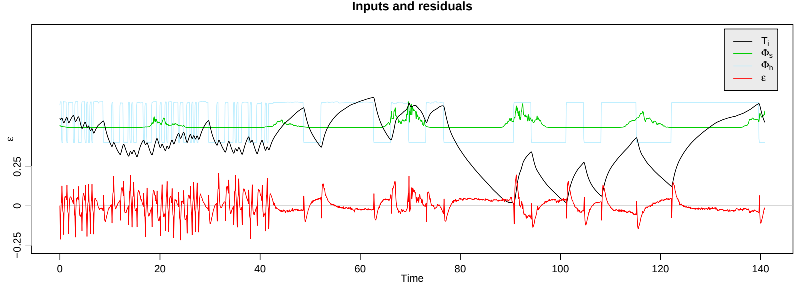
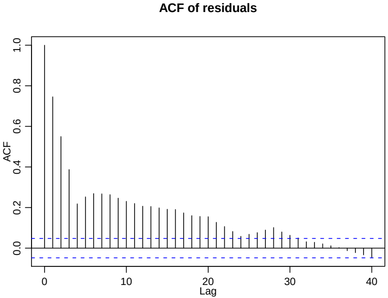
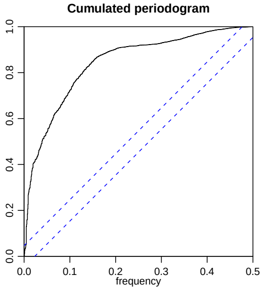


Start	$Model_{\text{Ti}}$			
$l(\theta;\mathcal{Y}_N)$	2482.6			
m	6			
1	$Model_{\text{TiTe}}$	$Model_{\text{TiTm}}$	$Model_{\text{TiTs}}$	$Model_{\text{TiTh}}$
$l(\theta;\mathcal{Y}_N)$	3628.0	3639.4	3884.4	3911.1
m	10	10	10	10
2 ...				

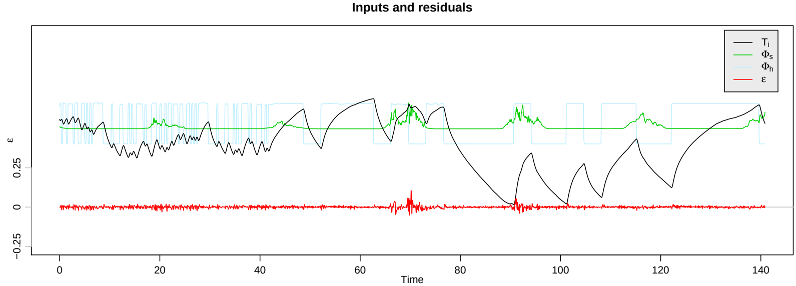
Evaluate the simplest model

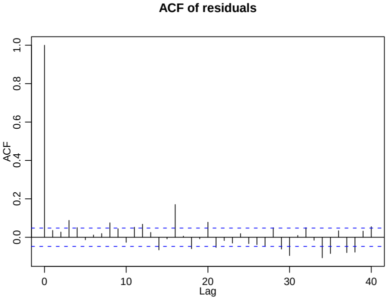


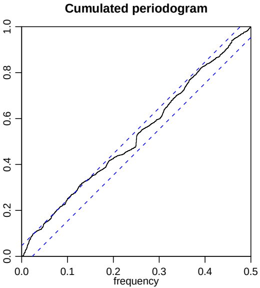




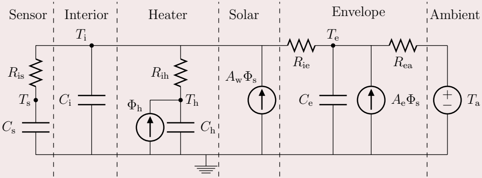
EVALUATE THE SELECTED MODEL







Selected model



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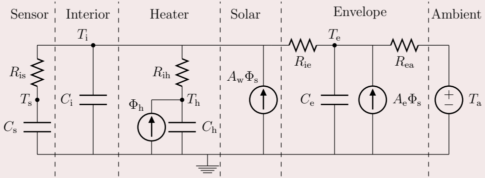

Estimated parameters

$\hat{C}_i$	0.0928	(kWh/C)
$\hat{C}_e$	3.32	-
$\hat{C}_h$	0.889	-
$\hat{C}_s$	0.0549	-
$\hat{R}_{ie}$	0.897	(°C/kW)
$\hat{R}_{ea}$	4.38	
$\hat{R}_{ih}$	0.146	-
$\hat{R}_{is}$	1.89	-
$\hat{A}_w$	5.75	(m^2)
$\hat{A}_e$	3.87	-

Estimated time constants

$\hat{\tau}_1$	0.0102	hours
$\hat{\tau}_2$	0.105	-
$\hat{\tau}_3$	0.788	-
$\hat{\tau}_4$	19.3	-

Important points

- Need to excite the dynamics of the system!
- Hence you need data with variation in the inputs:
  - Turn on/off the heaters
  - Low ambient temperature preferable
  - You need direct solar radiation
- Data from buildings with thermostatic control wont work (flexibility can be with hot water tank)

MPC

- We have a model to predict the indoor temperature:
  - Input: heating and climate
  - Output: indoor temperature
- Model Predictive Control (MPC):
  - Setup a cost function (e.g. monetary and indoor climate)
  - Constrains (max heating etc.)
  - Use weather forecasts and calculate an optimized heat input

More time series modelling techniques

- Model selection (likelihood-ratio test, AIC, BIC)
- Parametric, semi-parametric and non-parametric models:
  - splines, kernels, regression trees, neural-networks, ...

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- Kalman filtering (grey-box models)
- Hidden Markov models (regime models)
- Robust estimation and outlier detection
- Time adaptive models

We are setting up a new Annex: focus models for occupied buildings(contact Staf Roels, KU Leuven)

Some links

- Annex 58 Statistical Guidelines
- Summer school on these matters (time-series modelling for buildings), 19. to 24. June, Grenada, Spain
- DTU Compute, Dynamical Systems
  - Solar and wind forecasting, load forecasting, data-driven models for: buildings, user behaviour, EVs, district heating, grids
  - MPC and optimization
- CITIES project
- Send me a mail pbac@dtu.dk

Thanks for your time!