Towards optimised control of heating in households

NEOGRID TECHNOLOGIES

An introduction to predictive control and application to building heating from heat-pumps

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Plan

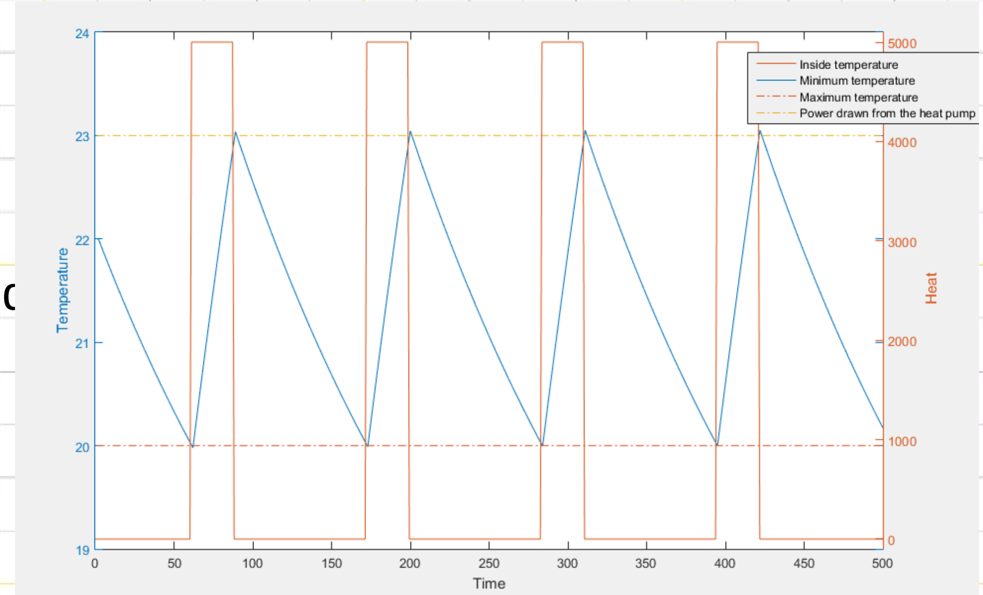
1. Why optimising heating?
2. How to optimise the control?
3. How to model the system?
4. Conclusion
5. References

Why optimising heating ?

Research topic : Individual house EHP

Today in the house:

- Thermostatic control in rooms
  - Too cold NOW? -> Start heating NOW!
  - Too warm NOW? -> Stop heating NOW!



- Same ‘dumb’ control on heat-pump and pipe valves

Research topic : Individual house EHP

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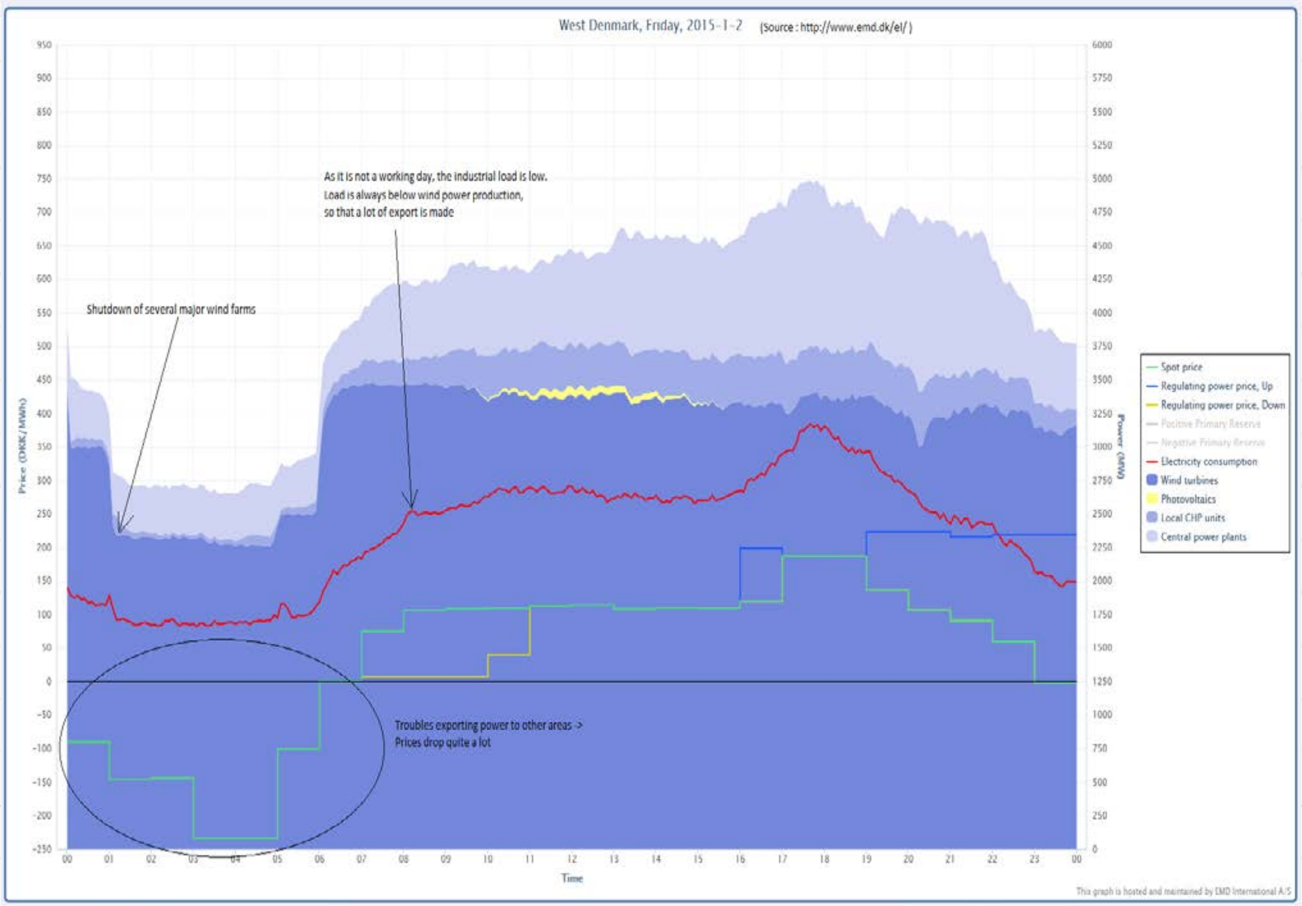
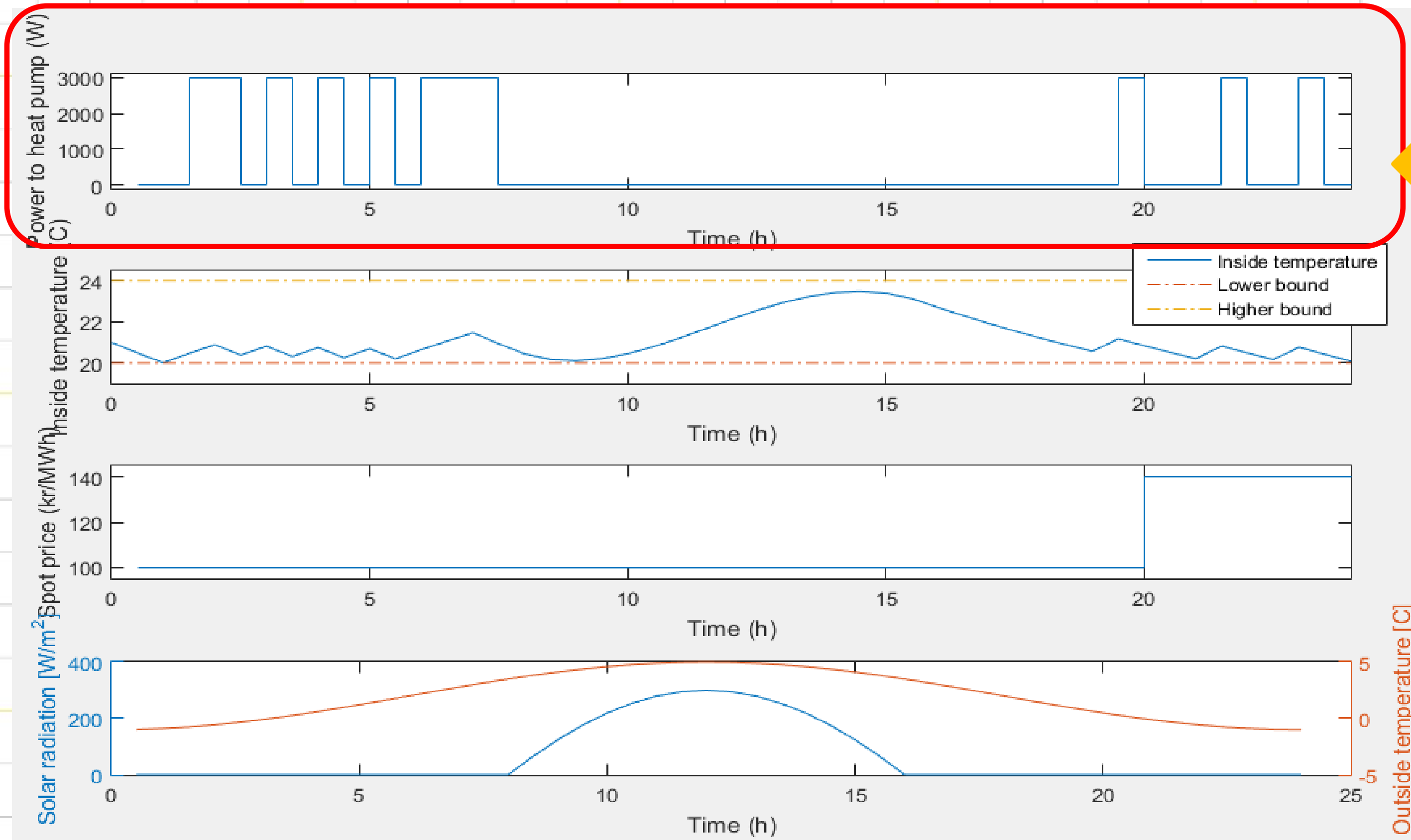
Today on the grid :

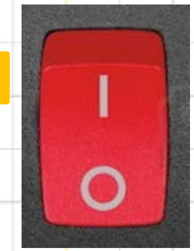


- Fluctuating renewables to integrate
- Fluctuation in price (even negative!)

Why optimising heating?

- Tomorrow :





Smar
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Optimising the cost (price, energy use, CO2 emissions, …)

Why optimising heating?

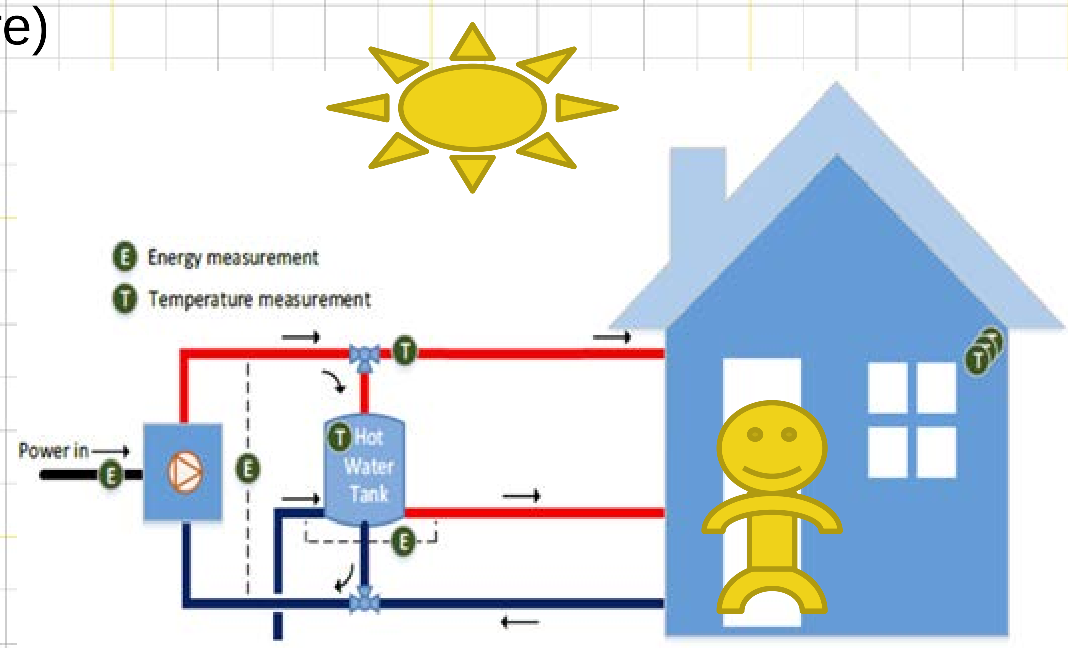
- Summary :
  - Retrofitting controllers of heating
  - More information used for control (future weather, occupancy, prices, …)
  - Different strategies can be applied, if data is available (CO_2 emissions, energy use, energy price, peak load reduction, …)

- Benefits are real in tests on large buildings
  - Savings in the range of 20% can be expected but depend on the weather and insulation [BMSM12], [MPCB11], [RCPT15]

How can we achieve this control in the future?

Achieving a better control

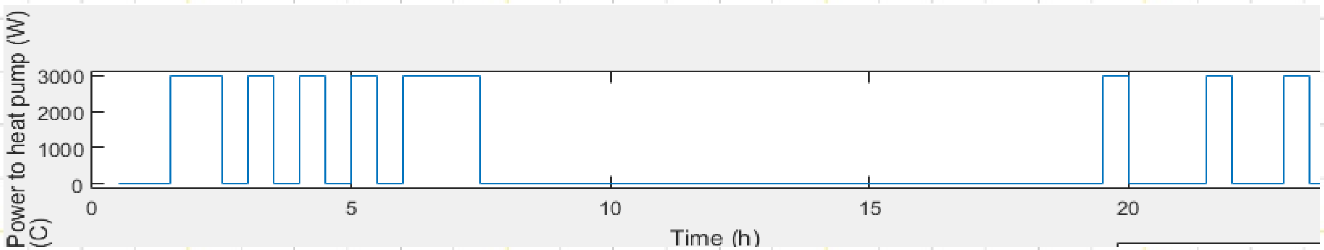
- What is the system to be controlled?
  - Inputs :
    - Weather (sun, temperature)
    - Power to the heating
  - Outputs / States :
    - Hot water temperature
    - Room temperature
  - Constraints
    - Human in the house needs comfort!



Achieving a better control

- What is a control?
  - Sequence of inputs to the system (here power to heating)

    e.g.



- **ON/OFF heating** : input at a time instant k = run the heating (1) or not (0)

- **Variable heating** : input at a time instant k = level of heating (continuum)

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Achieving a better control

- Collecting measurement in the building with sensors
  - Temperatures, power, heat, …
  - Get feedback for the control
  - Keeping track of the history

- Getting prognosis of future inputs from third parties
  - Weather data (temperature, solar radiation)
  - Electricity price

- Building a model (see next part)

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Achieving a better control

- Economic Model Predictive Control (EMPC)

$$\min_{u_0,\ldots,u_{N-1}} \sum_{k=0}^{N-1} l_k(x_k, u_k) \qquad \text{Cost function} \qquad (1)$$

subject to

$$x_0 = x \qquad \text{Current state} \qquad (2)$$

$$x_{k+1} = f(x_k, u_k, w_k) \qquad \text{Dynamics – state update} \qquad (3)$$

$$y_k = g(x_k, u_k, w_k) \qquad \text{Dynamics – system output} \qquad (4)$$

$$(x_k, u_k) \in \mathcal{X}_k \times \mathcal{U}_k \qquad \text{Constraints} \qquad (5)$$

(from [JCPT13])

(u_k) : inputs (x_k) : states (y_k) : outputs

In practise:

- f, g linear (using matrices)

– l is typically a linear or quadratic function

Dedicated solvers/tools provide solutions (e.g. CVX, YALMIP tools in MATLAB)

Ref. MPC : [RHPT14], [FOPT11], [JCPT13], optimisation [COPT14] solvers/tools [CVXR15], [YALM15]

Achieving a better control

- Summary :

  - There is a mathematical framework for optimising control of heating/cooling in buildings

  - Understanding of the model and objective is key.

  - A model is required for using this sort of control

How do we get a model for doing that?

How to model thermal dynamics?

- Model : describes the system and its evolution

Next state

$$x[k+1] = f(x[0..k], u[0..k], w)$$

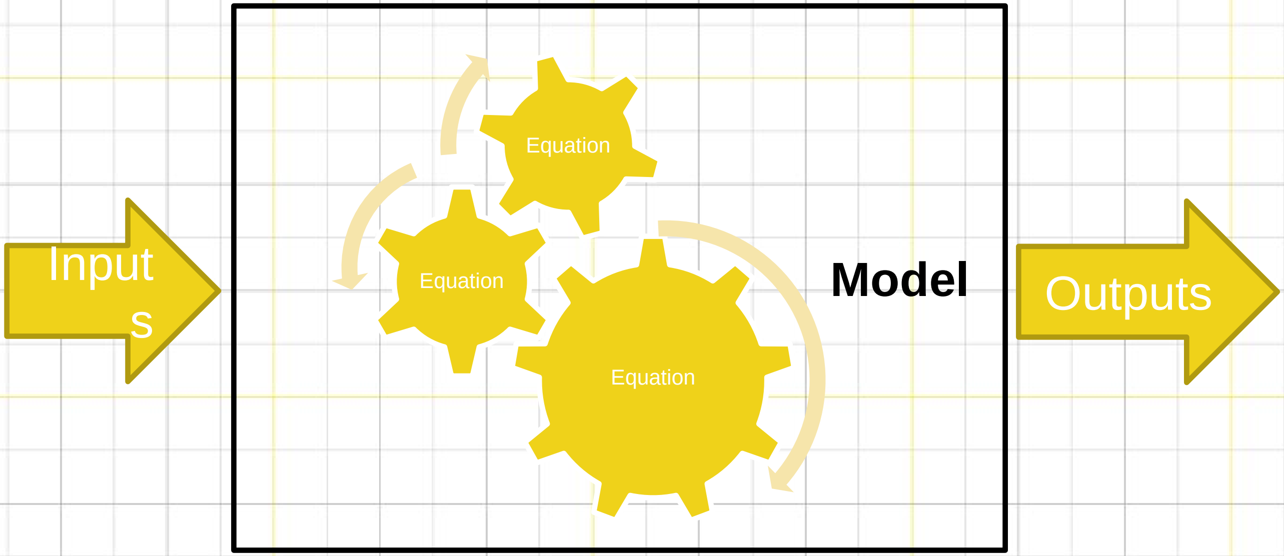
Output *Previous states* *Previous inputs* *Noise*

$$y[k] = g(x[0..k], u[0..k], w)$$

What sort of models are available?

Physics based / white-box

-Using textbooks, blueprints and material properties
-Using softwares (IDA-ICE, EnergyPlus, TRNSYS, …)



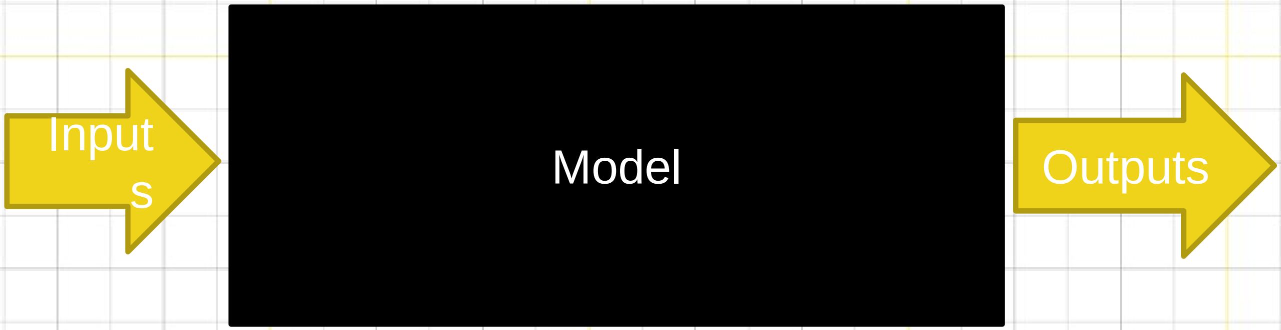
-> Building engineers approach

Refs : [SABM13], IDA-ICE [IDAI15], EnergyPlus [EPLU15], TRNSYS [TRNS15], …

What sort of models are available?

Data based / black-box

-Using statistical methods (ARX, ARMAX, Box-Jenkins, subspace identification …)



-> Statistician approach

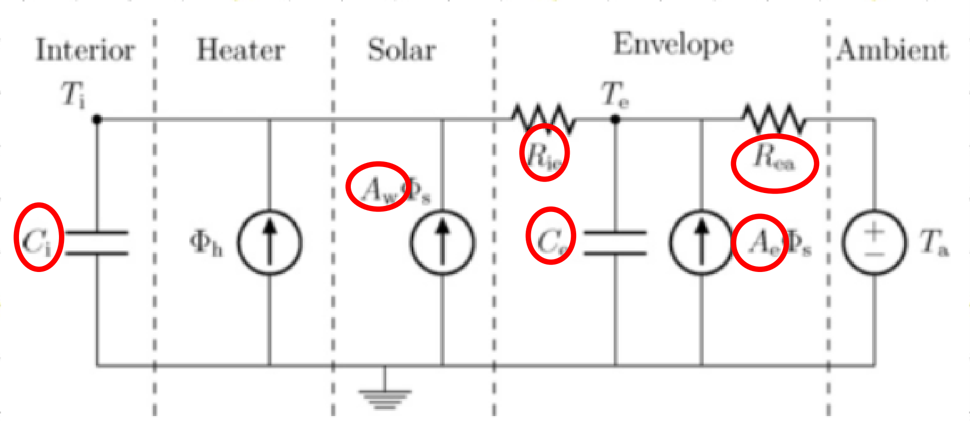
Refs : [SITU99], [TSAN08], [SIMP10]

What sort of models are available?

Semi-physical / grey-box :

Physics -> Structure of the model
Data -> Numerical values of parameters :

e.g.



(from [ISMH11])

Refs : [SITU99], [TSAN08], [ISMH11],[SABM13],[RCPT15]

What sort of models are available?

- Summary :
  - Three types of approaches
    - Physical modelling using equations
    - Statistical modelling using data
    - Hybrid using both data and equations
  - In practise, user behaviour is to be taken into account
    - Still under extensive research
  - Simplicity of the model is key in control applications

Time to conclude !

Conclusion

Predictive control has been proved the potential to allow more efficient heating in large buildings – extension to houses is worked upon!

Building the model is however a challenge, with limited intrusiveness and infrastructure

Conclusion

Smarter heating

=

Greener heating

=

Happier people and environment

Questions / Additional remarks

Speak now or forever hold your peace !

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