

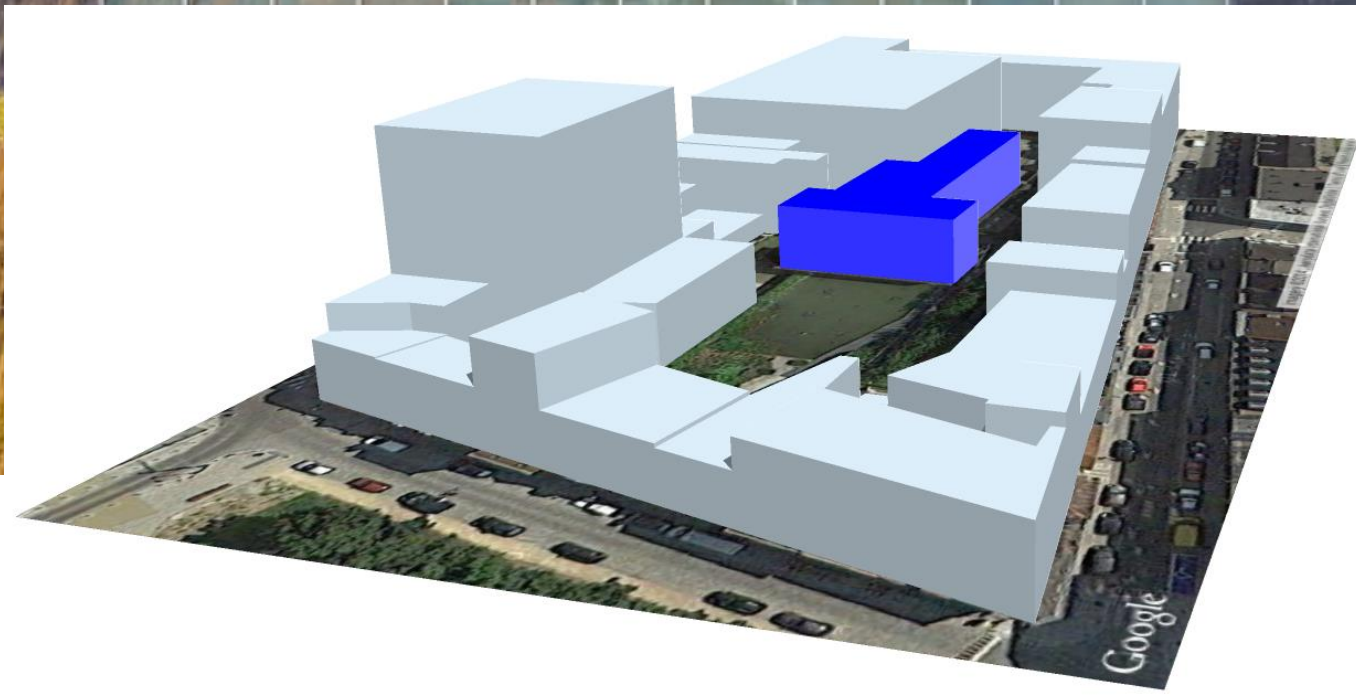


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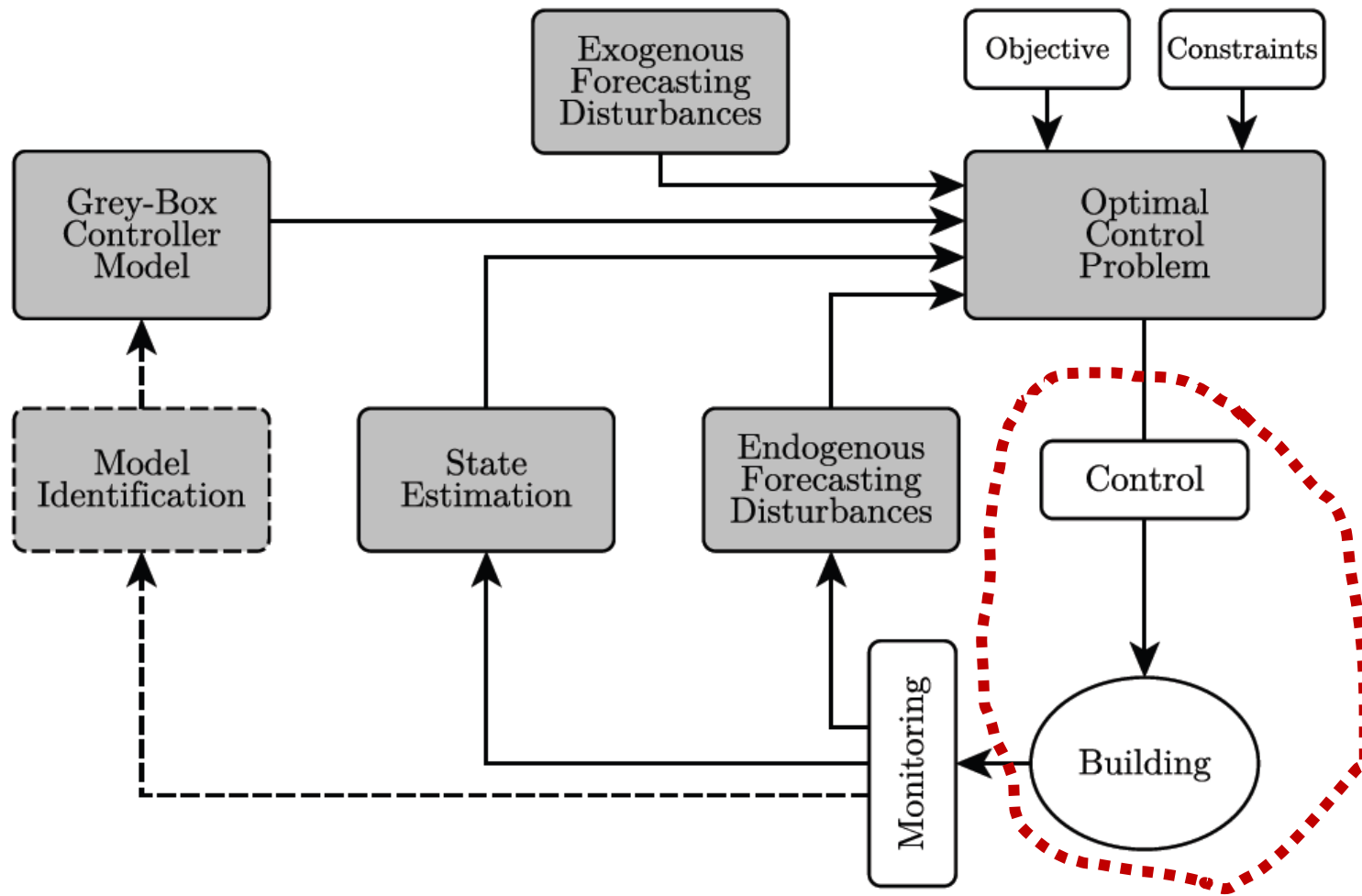
Practical implementation and evaluation of Model Predictive Control (MPC) for an occupied office building in Brussels

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Lieve Helsen, *KU Leuven*

Optimal control of thermal systems in buildings using Modelica
Freiburg, 23-24 March 2015



MPC framework

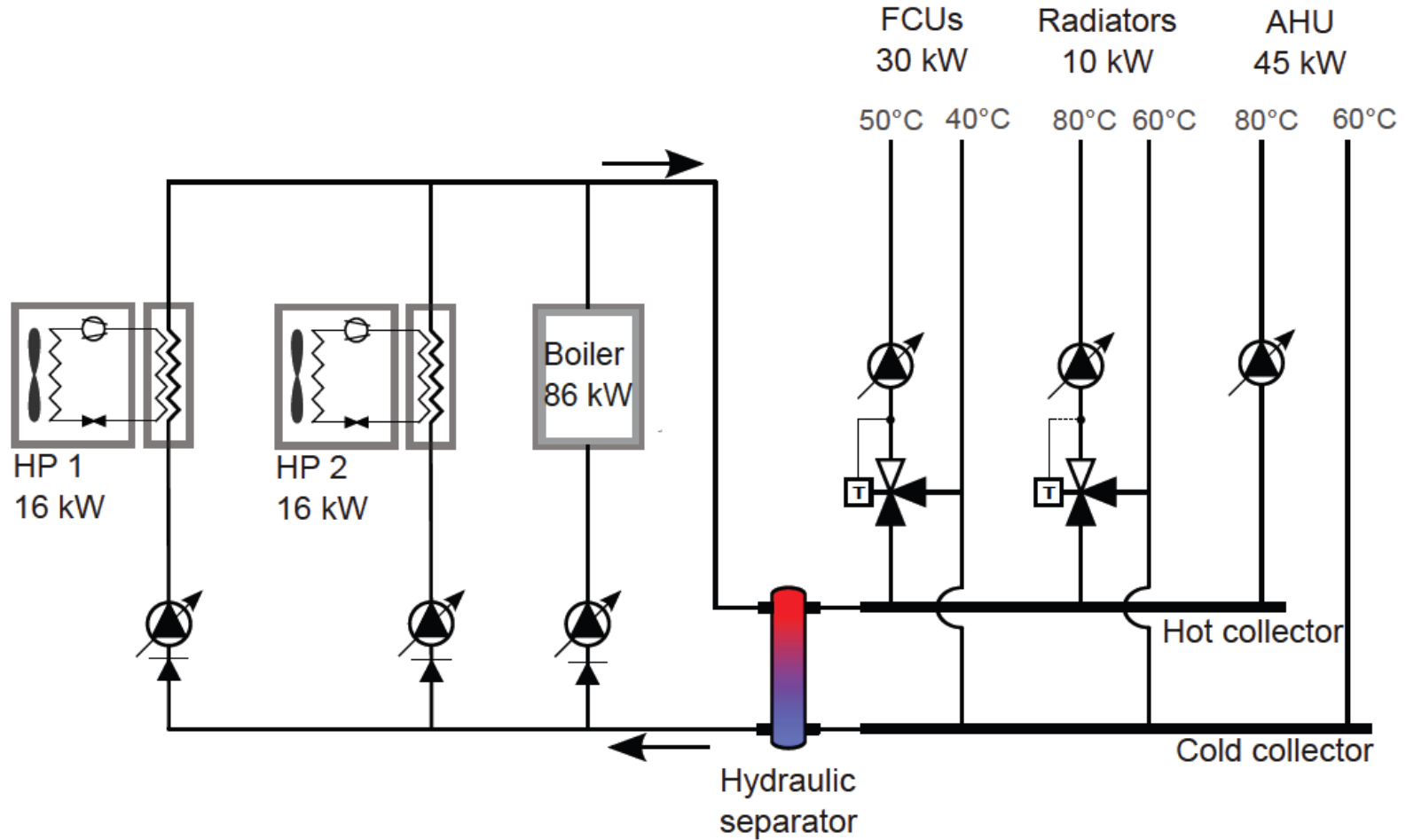


Kalkkaai building

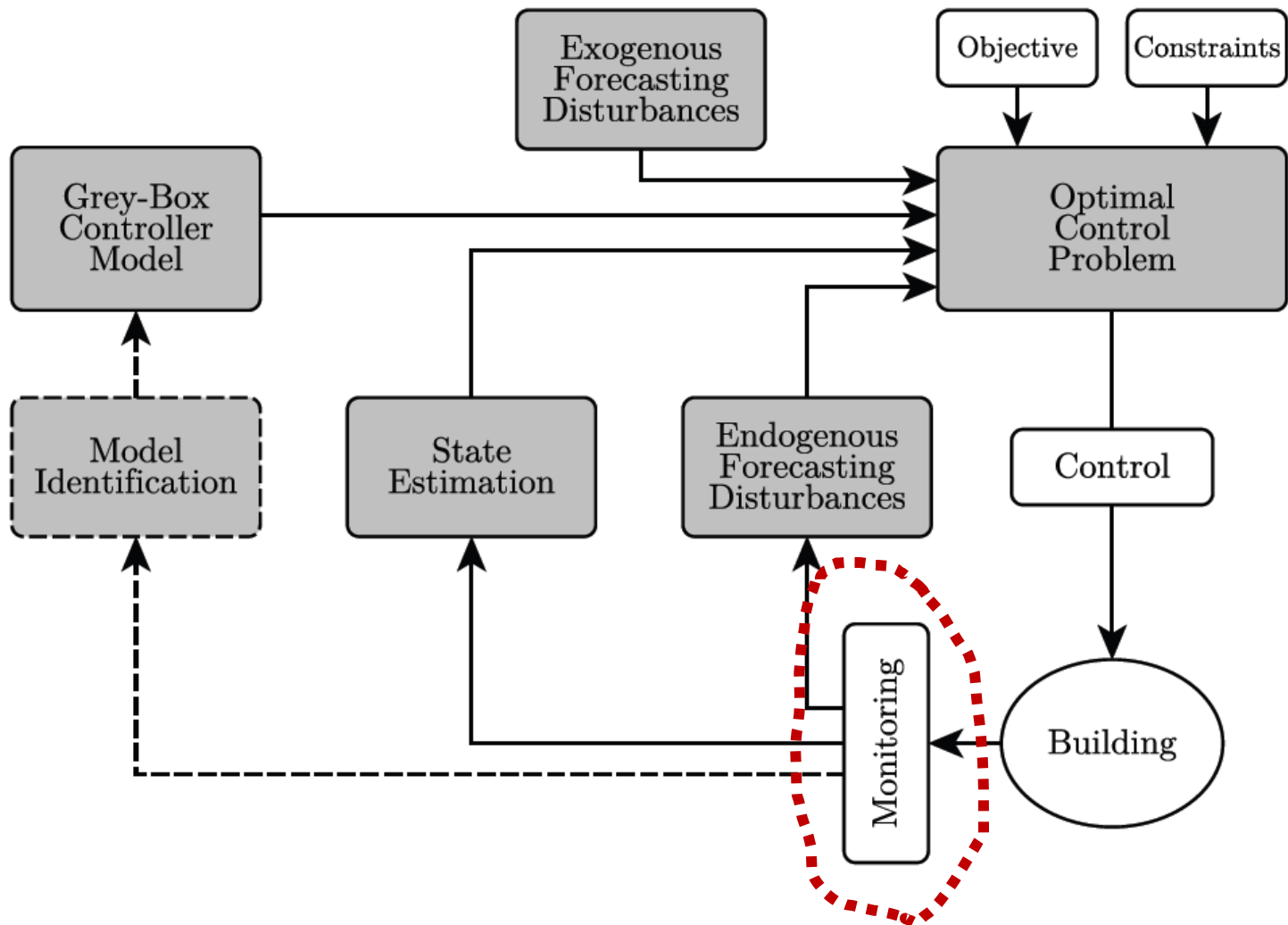
- 2 floors of 480 m² each
- Only west-façade has high glazing fraction
- Landscape type offices on ground floor
- Individual / small landscapes / meeting rooms on 1st floor
- Occupation: 40-70 persons, office hours
- Hybrid heating system
- Condensing gas boiler, 86 kW
- 2 identical air/water heat pumps, 16 kWth each



Hybrid heating system



MPC framework



Monitoring systems





Monitoring systems

Monitoring systems

HVAC monitoring

- Temperatures, thermal fluxes, electrical power
- Pull data from BEMS and put in Kairos TSDB (15s)

Building monitoring

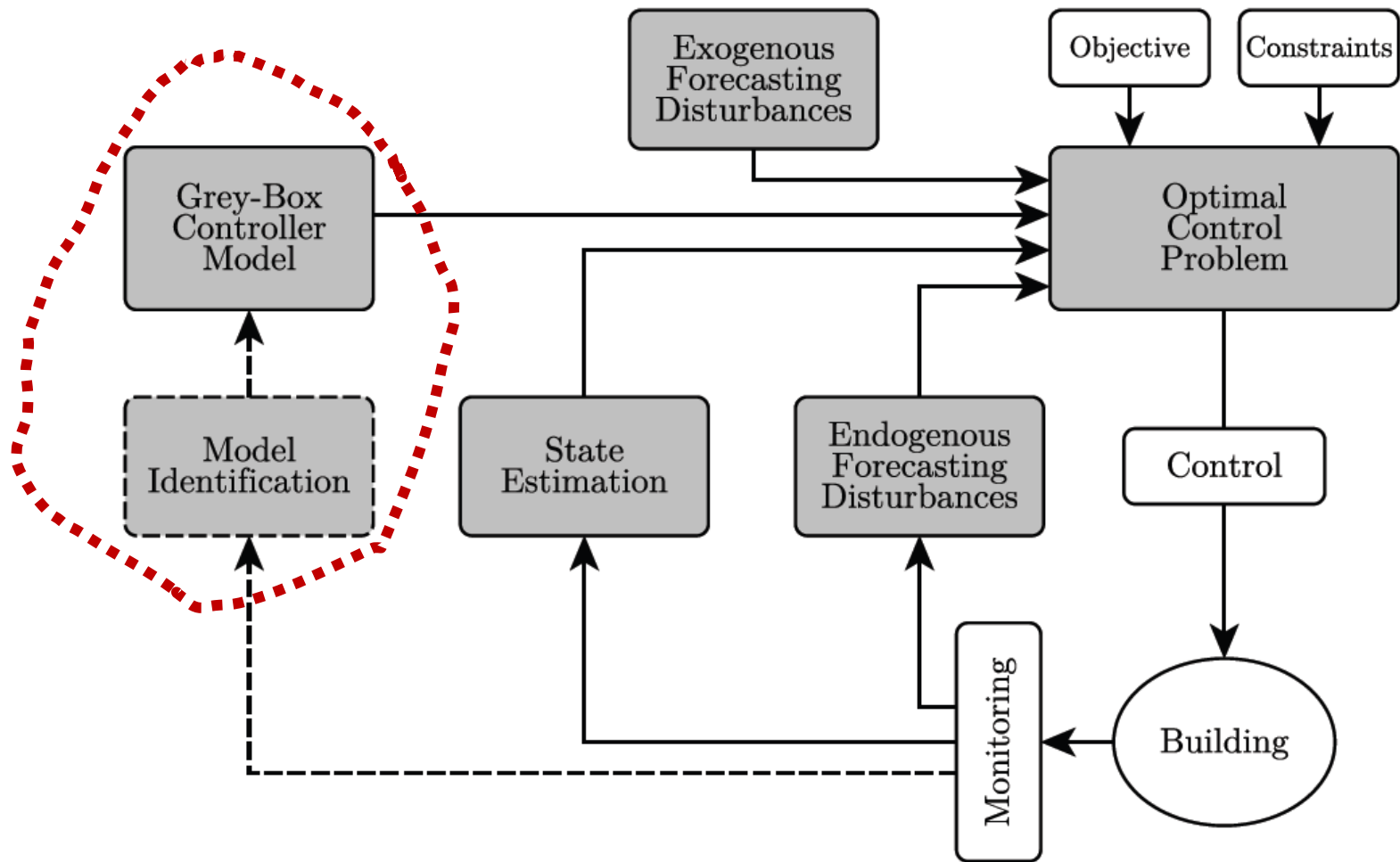
- Temperature, humidity, electricity consumptions (many submeters)
- Bad resolution (15 minutes – 1 hour)
- Pull data (http requests) and put in Kairos TSDB

Weather data

- Meteo service (University Oldenburg)
- Files on FTP → processing and on Kairos TSDB



MPC framework




Selecting disturbances

Weather

- Ambient temperature: locally measured
- Solar radiation: start with global horizontal

Building

- Zone temperature: arithmetic mean of 5 zones
- Heating power: total emission by 3 circuits
- Air handling unit: schedule from monitoring data
- Internal gains: electrical appliances and body heat gains



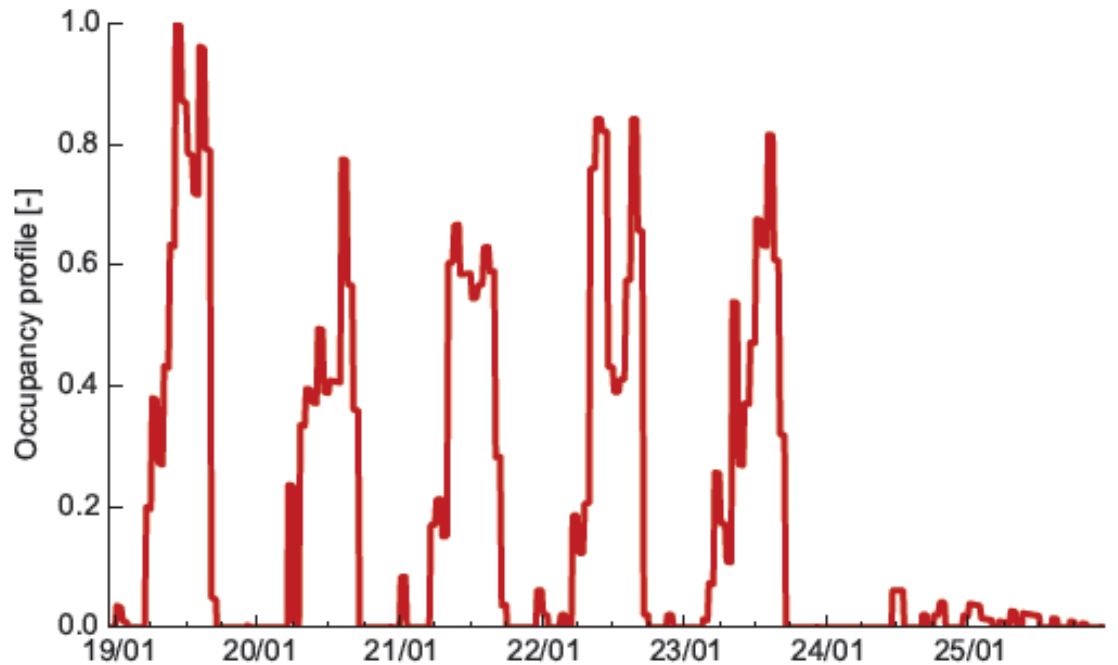
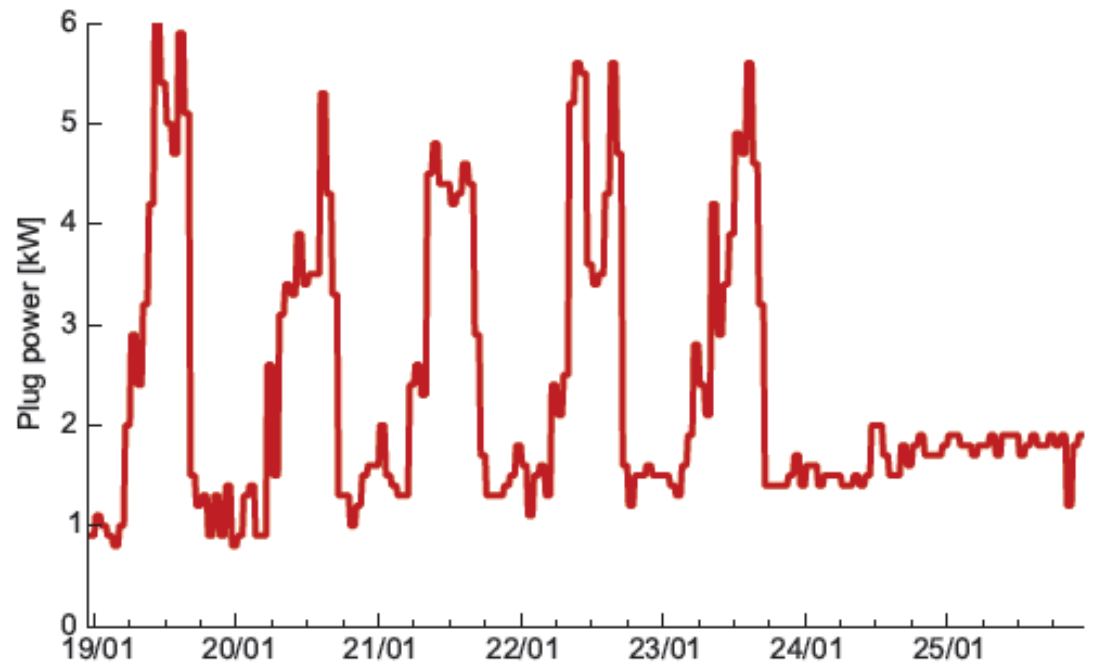
Electricity
measurements:
All - HVAC



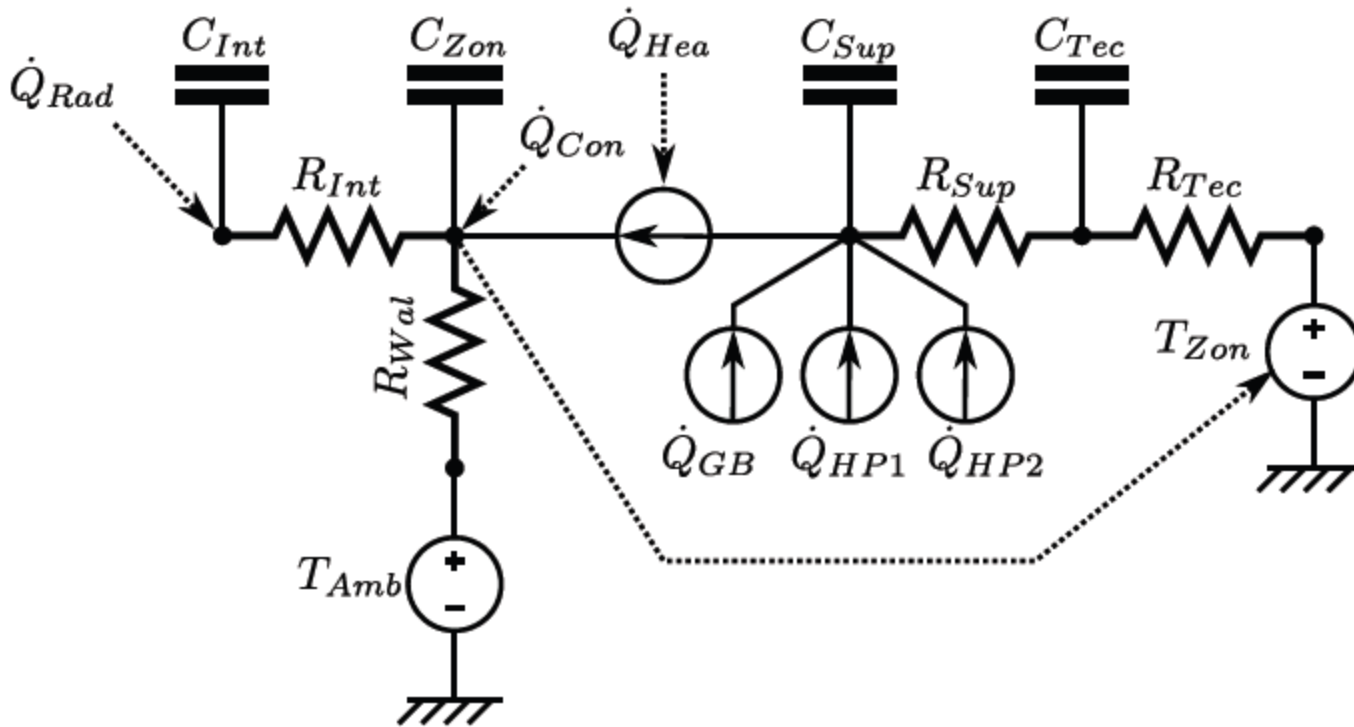
Occupancy from
plug power



Occupancy profile



Control model: building



4 control variables in optimal control problem (OCP)

Control model: HVAC efficiencies

$$\eta = 0.87 - 8.85e^{-7} \dot{Q}_{GB}^* + 4.82e^{-3} T_{Amb}^*$$

$$COP_{HP1} = 2.61 + 5.45e^{-2} T_{Amb}^* - 1.23e^{-2} T_{Sup}^* \\ - 1.18e^{-4} \dot{P}_{HP1}^* - 1.54e^{-5} T_{Amb}^* \dot{P}_{HP1}^*$$

$$COP_{HP2} = 2.58 + 3.84e^{-2} T_{Amb}^* - 2.50e^{-2} T_{Sup}^* \\ - 1.42e^{-4} \dot{P}_{HP2}^* - 1.50e^{-5} T_{Amb}^* \dot{P}_{HP2}^*$$

Linear regression
based on 3 predictors
and their combination:

- T_{Amb} ,
- T_{Sup}
- Q or P

Shifting of predictors
to obtain physically
interpretable
parameters

$$\dot{Q}_{GB}^* = \dot{Q}_{GB} - 86000$$

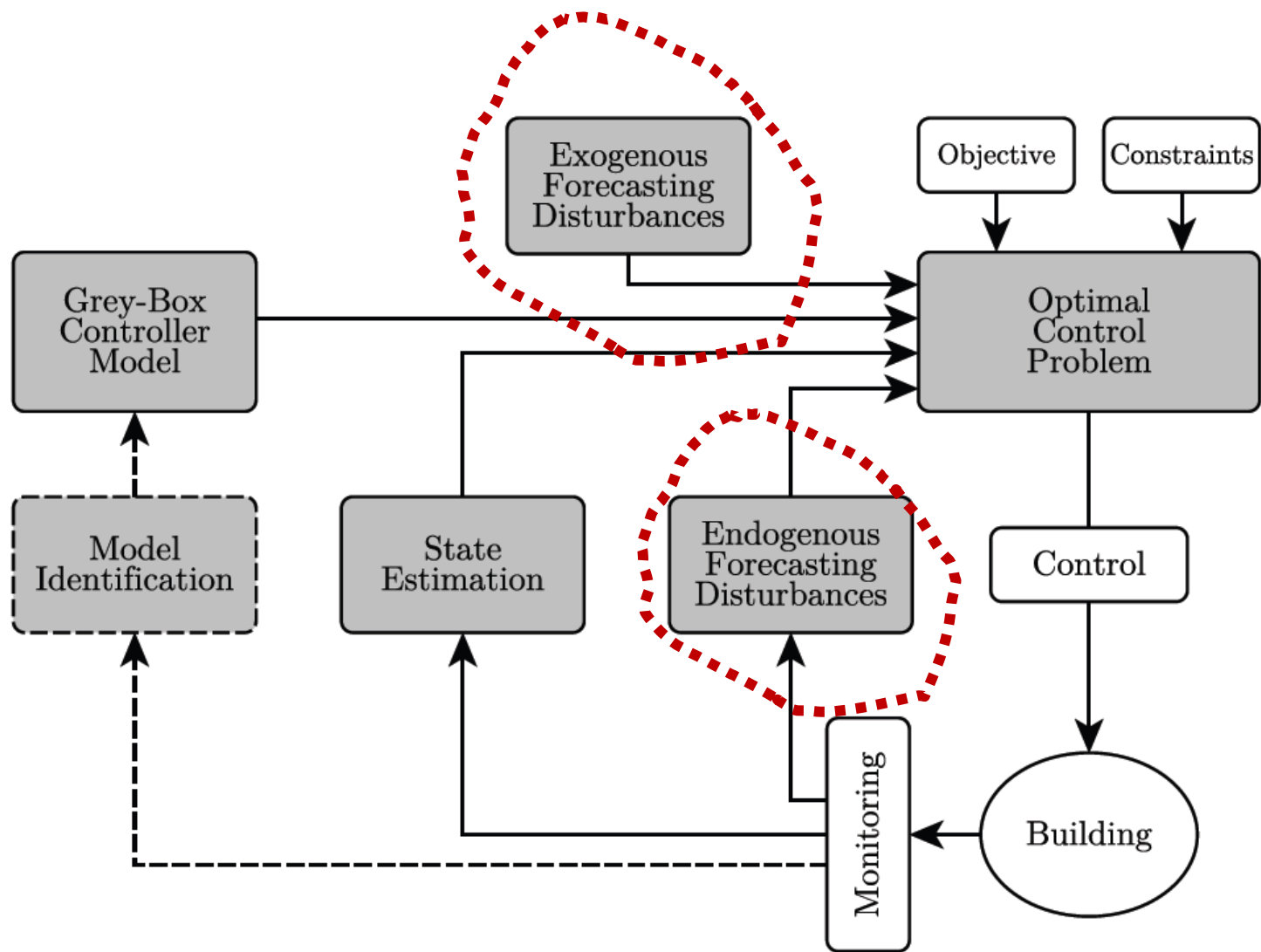
$$\dot{P}_{HP}^* = \dot{P}_{HP} - 6500$$

$$T_{Amb}^* = T_{Amb} - (7 + 273.15)$$

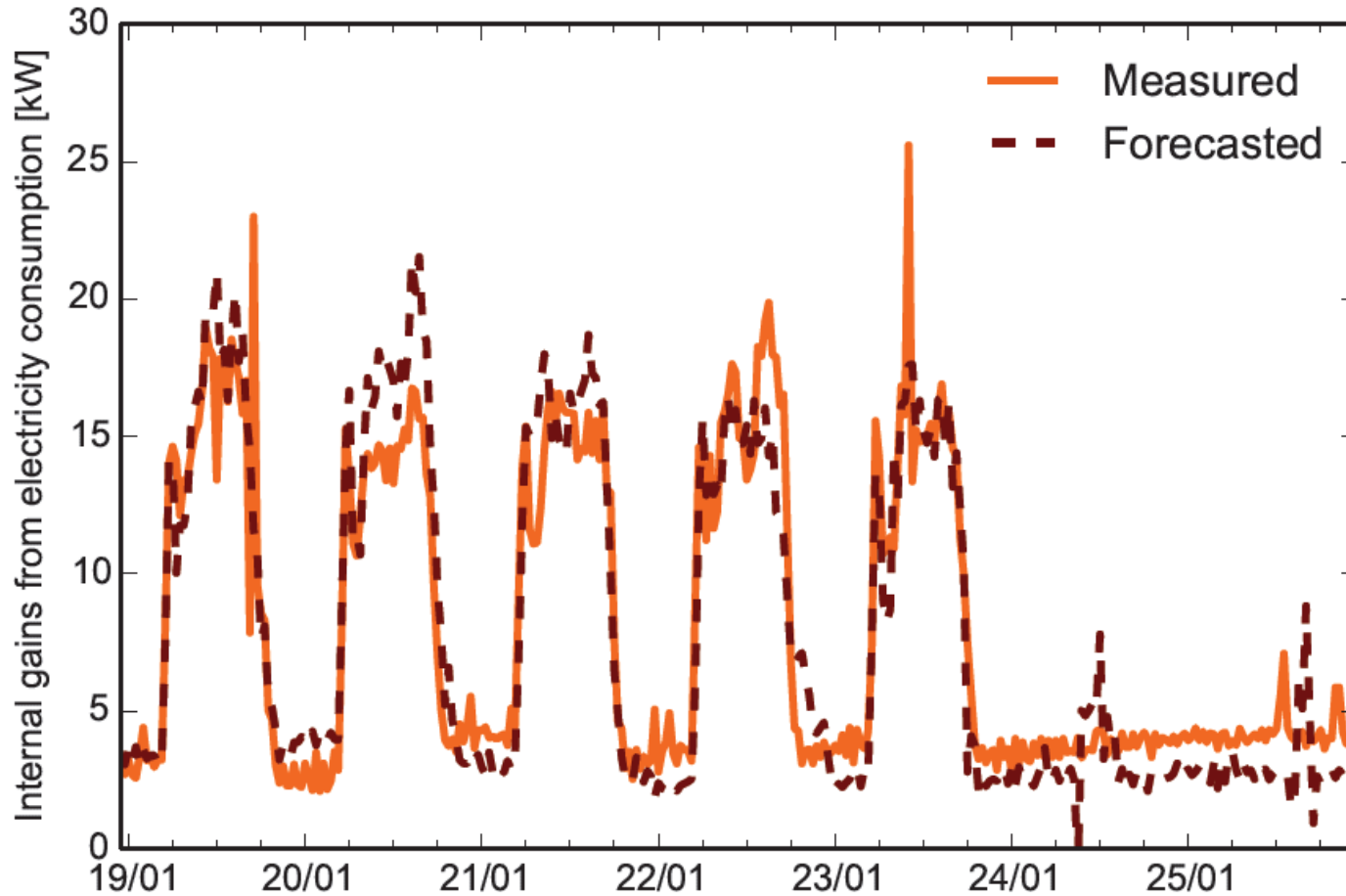
$$T_{Sup}^* = T_{Sup} - (35 + 273.15)$$



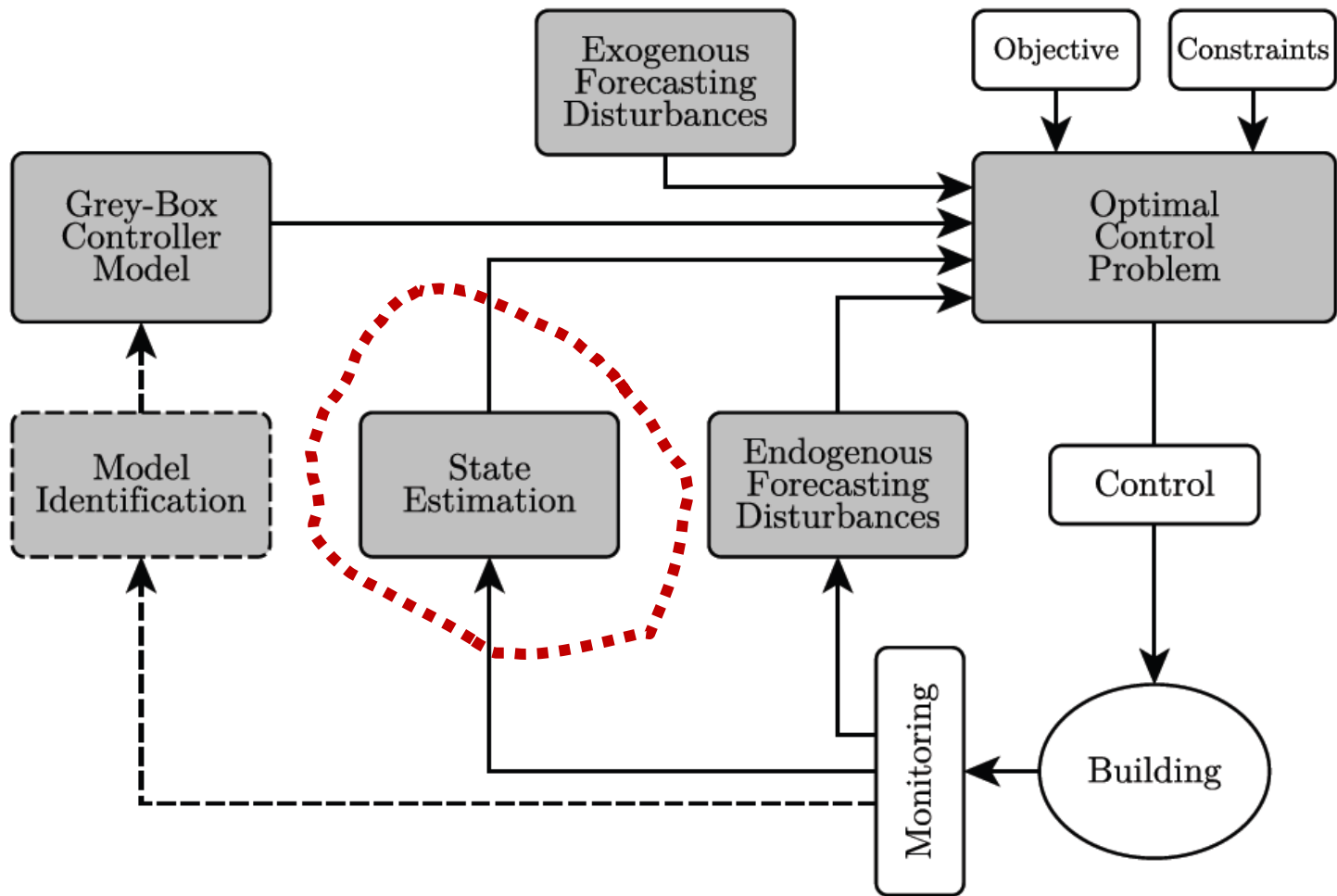
MPC framework



Internal gains from electrical appliances



MPC framework

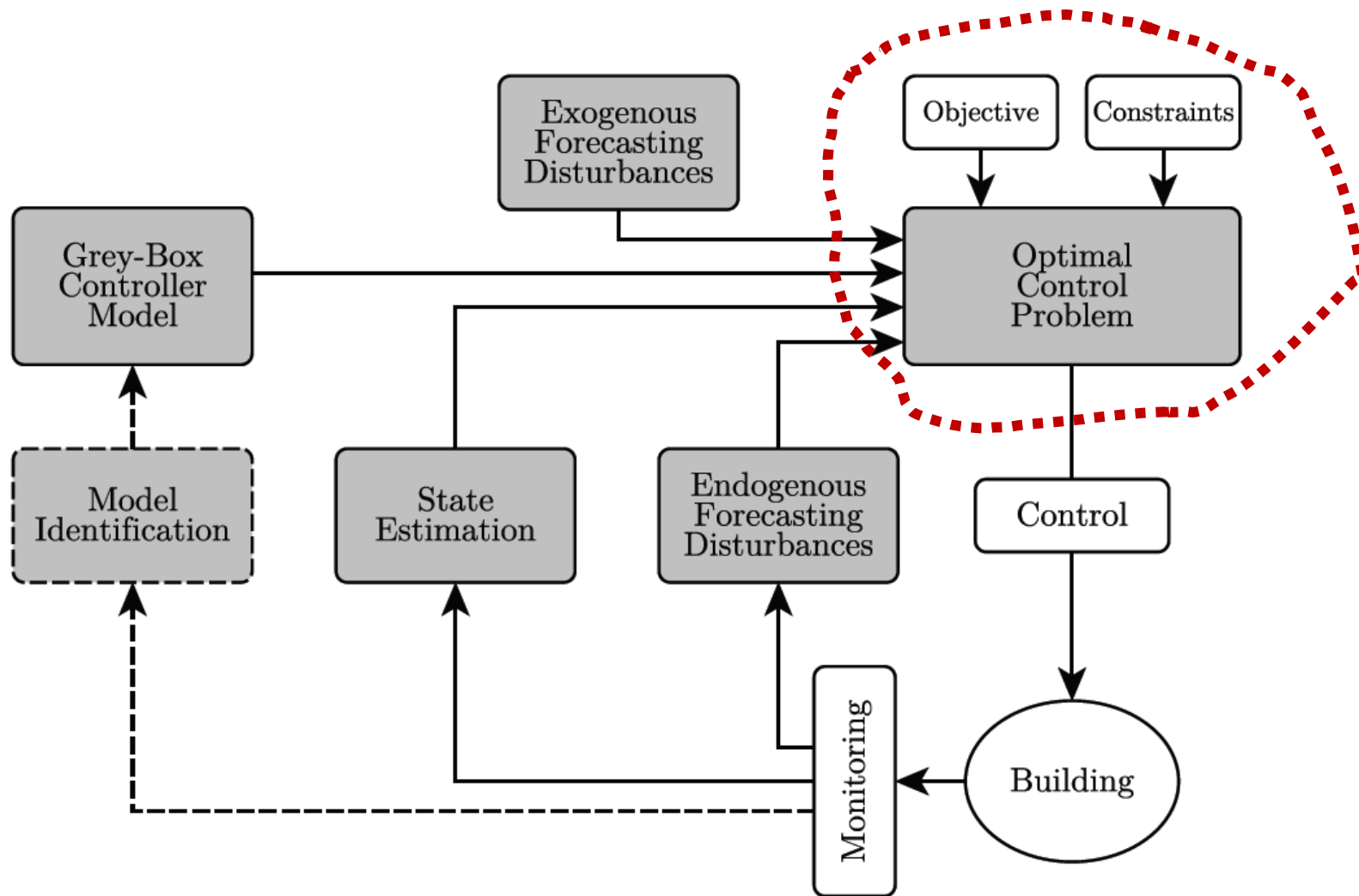


State estimation

- Very simple implementation of moving horizon estimation
- Based on grey-box toolbox
- ~ parameter estimation, free parameters are initial state 24h ago
- Corrections:
 1. For measured states, take measurement
 2. For TZon, if deviation from tracking setpoint $TSet < 0.2$ K: use TSet



MPC framework



Objective

$$J = J_c + \gamma J_d$$

$$J_c = \int_0^{t_h} (c_g \dot{P}_g + c_e \dot{P}_e) dt$$

$$J_d = \int_0^{t_h} \theta_{occ} (T_{Zon} - T_{Set})^2 dt$$

Constraints

- Maximal thermal power of production units
- Minimal thermal power = 0
- Fix starting values for thermal power control signals at last sent control values

Horizon and numerical options

1 day horizon

15 minute collocation elements

2 collocation points per element

IPOPT / MA27 solver



Results

Winter 2014-2015

Periods with RBC / MPC

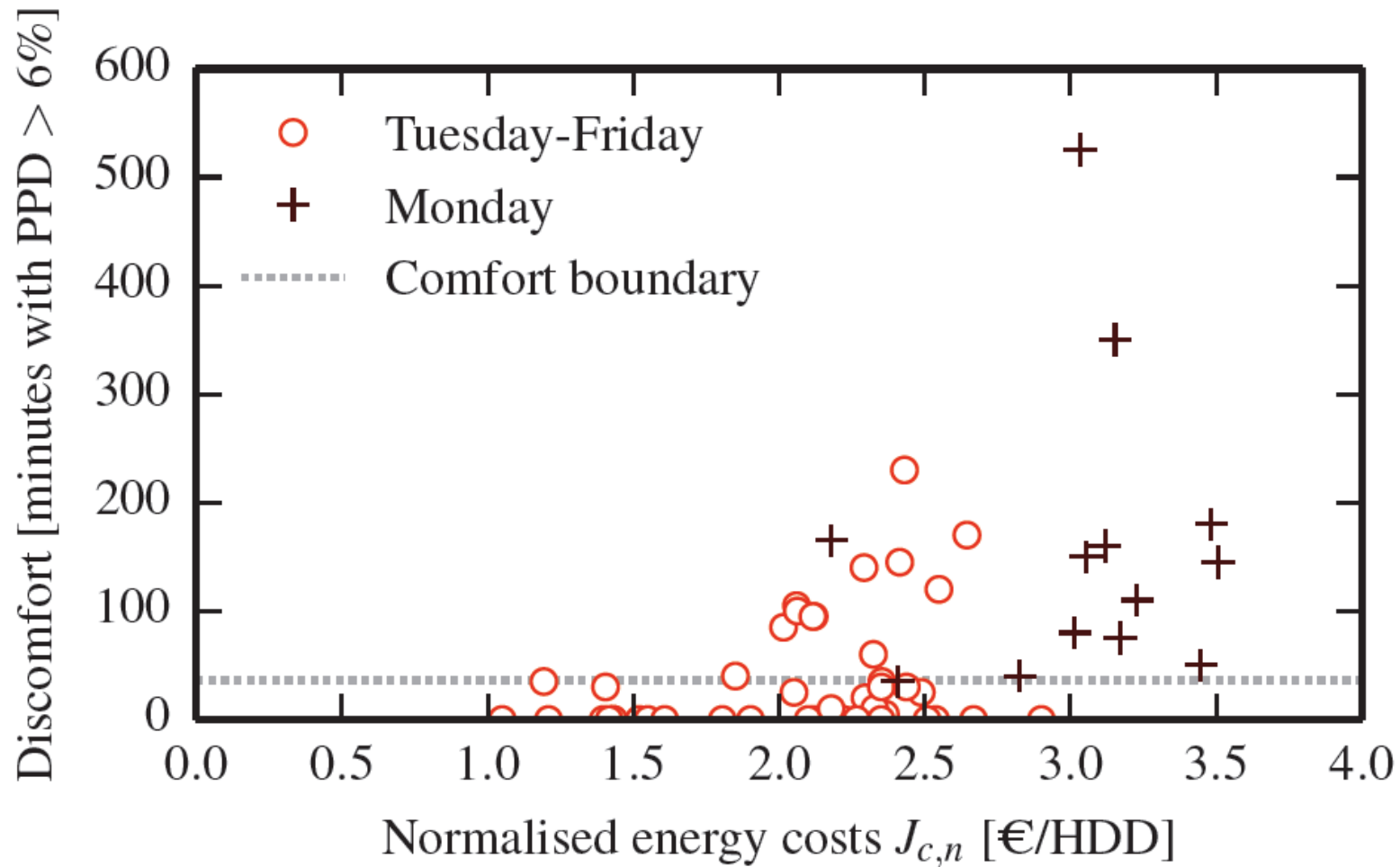
How to analyse the performance?

Building performance indicators

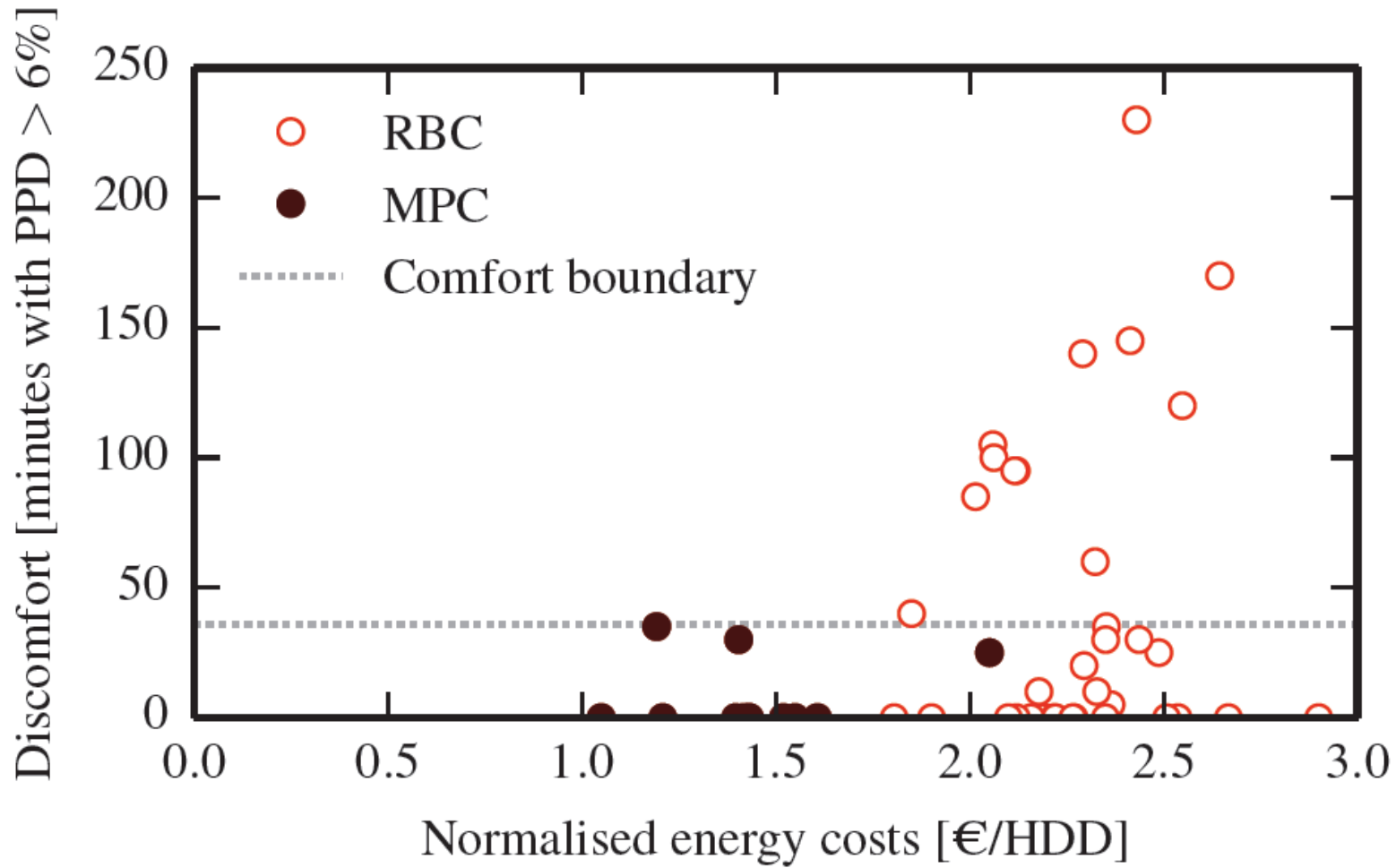
Symb.	Unit	Meaning
J_c	€	Energy cost
J_e	kWh	Primary energy consumption
J_d^*	minutes	Thermal discomfort
HDD	K d	Heating degree days (normalisation variable)



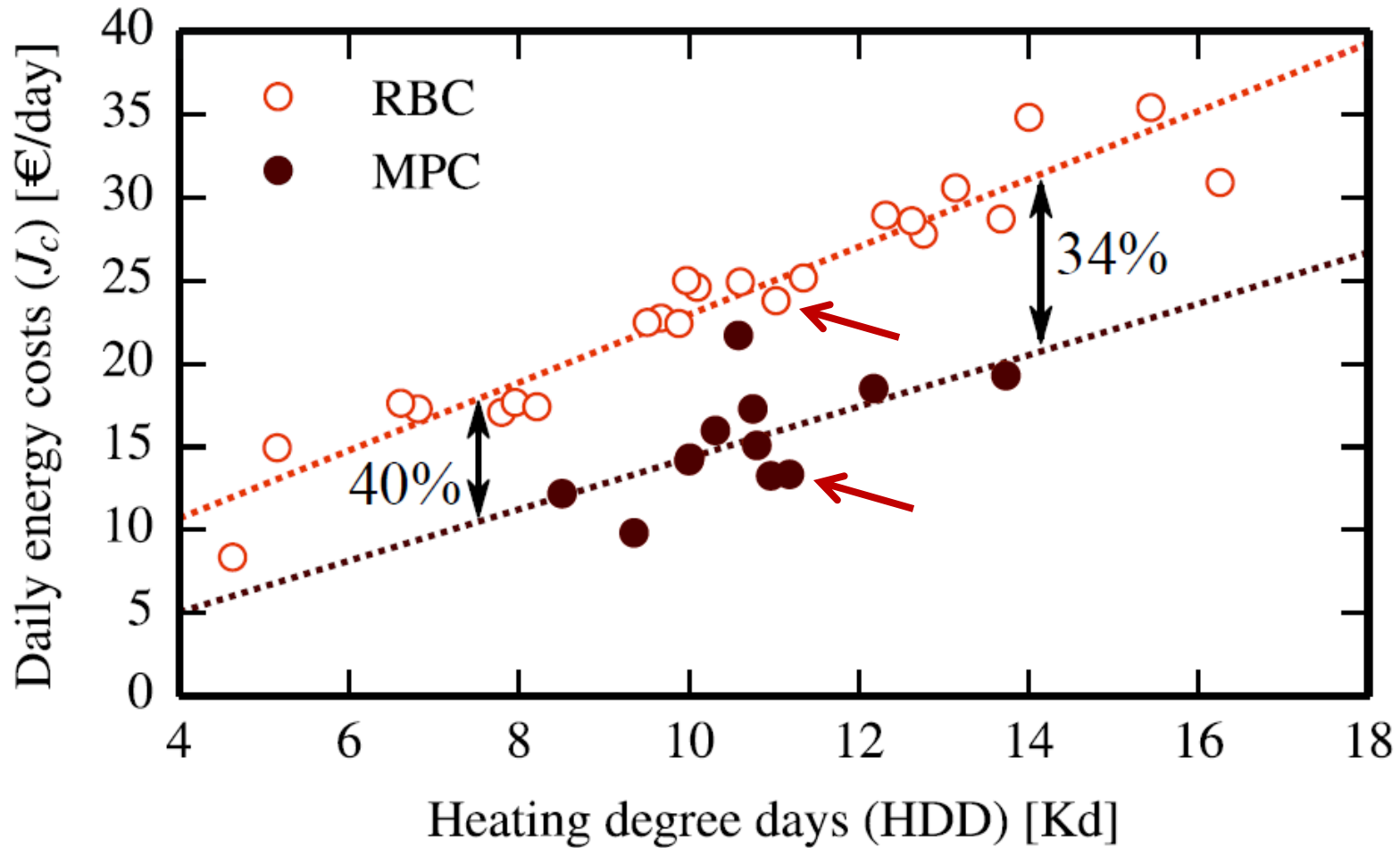
Results



Results



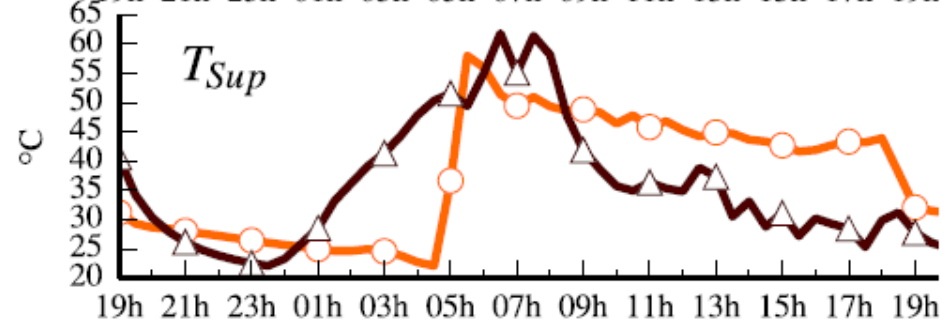
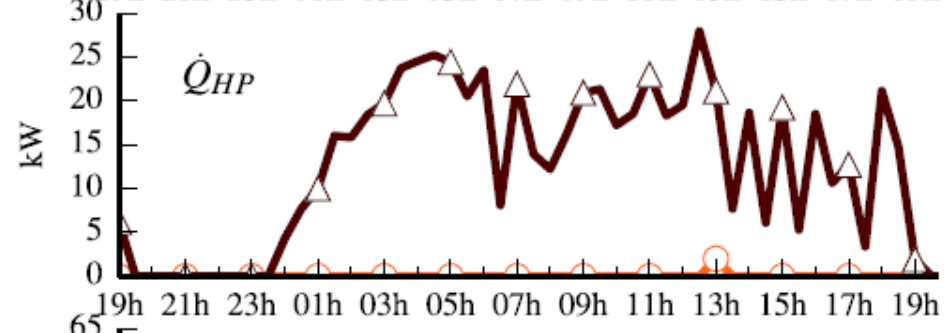
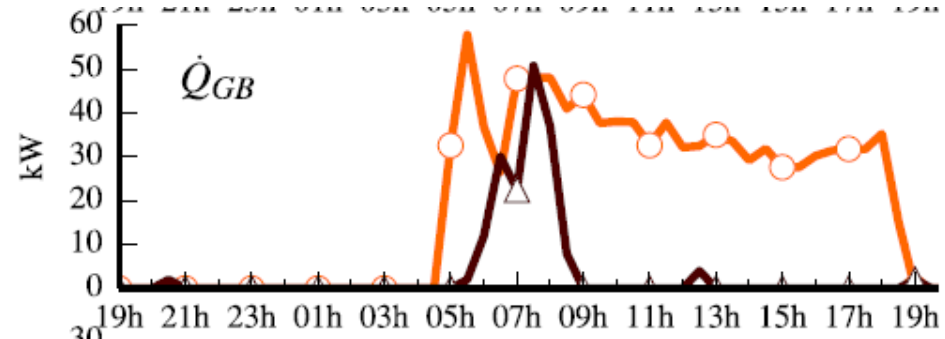
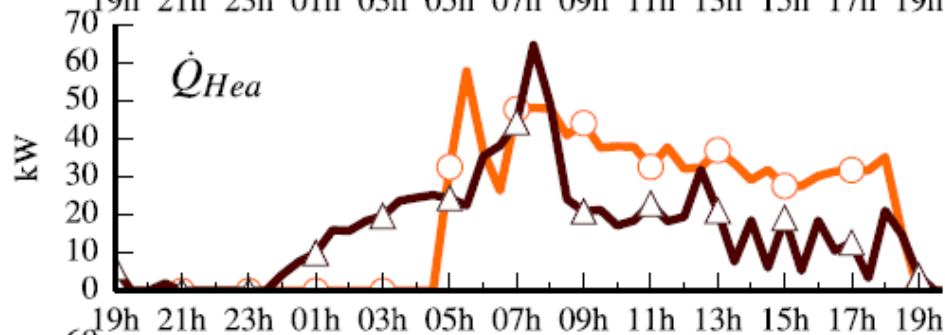
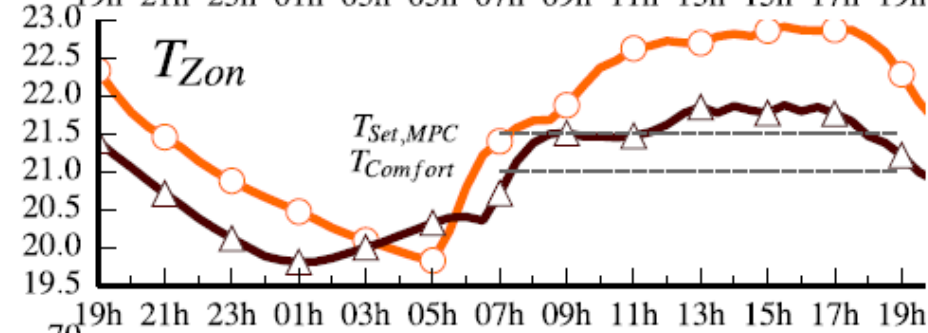
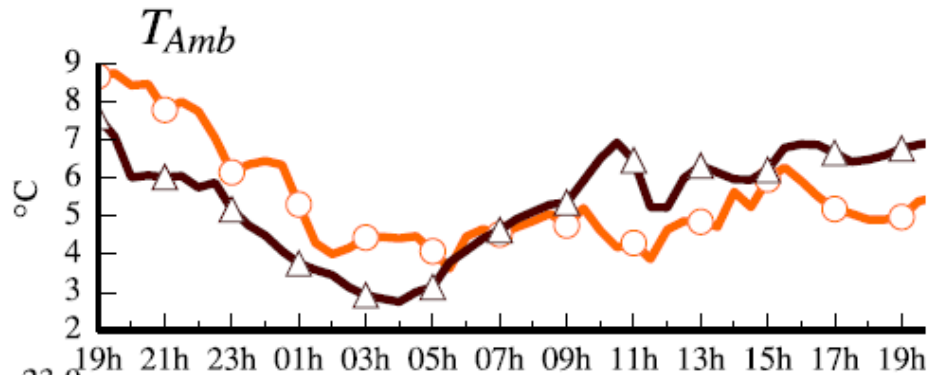
Results



Results

○ RBC

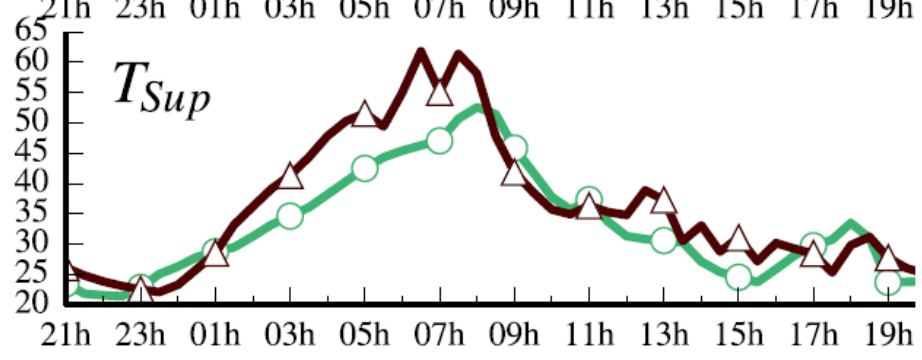
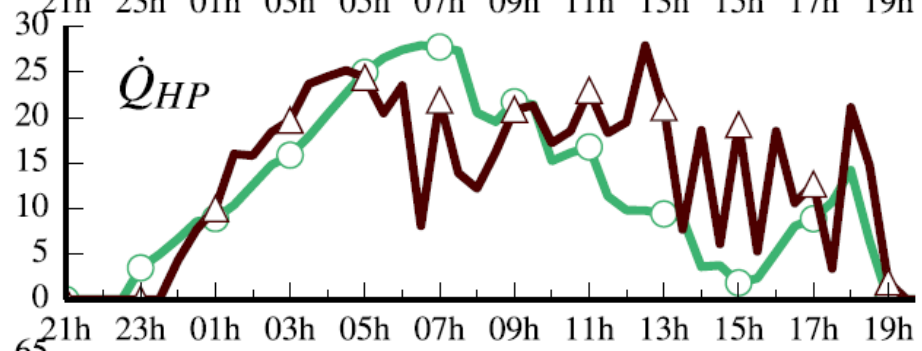
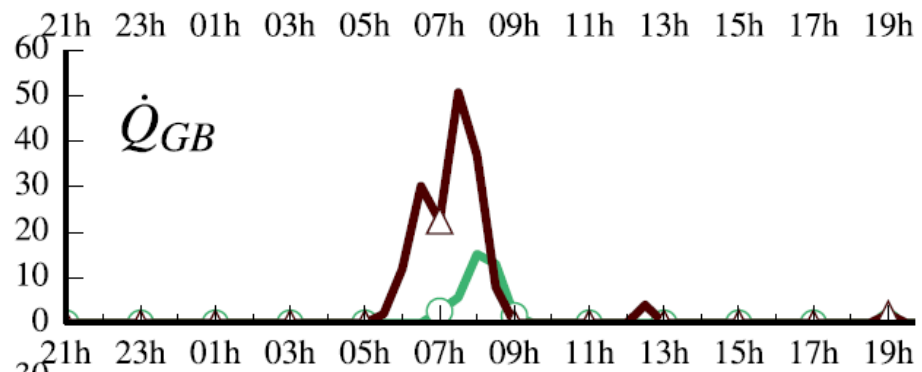
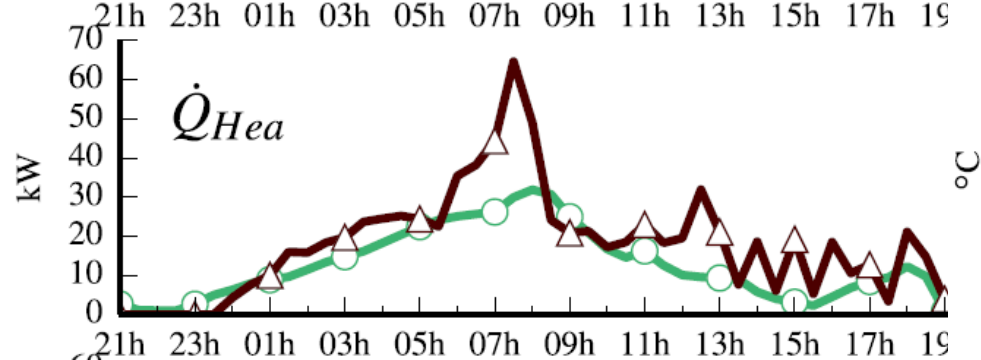
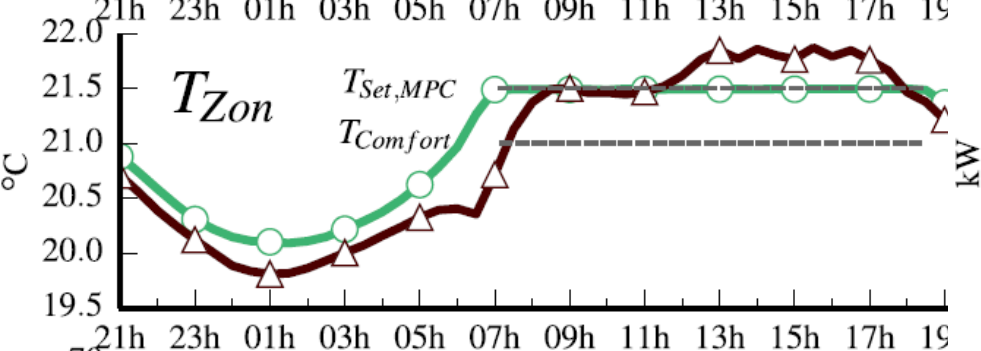
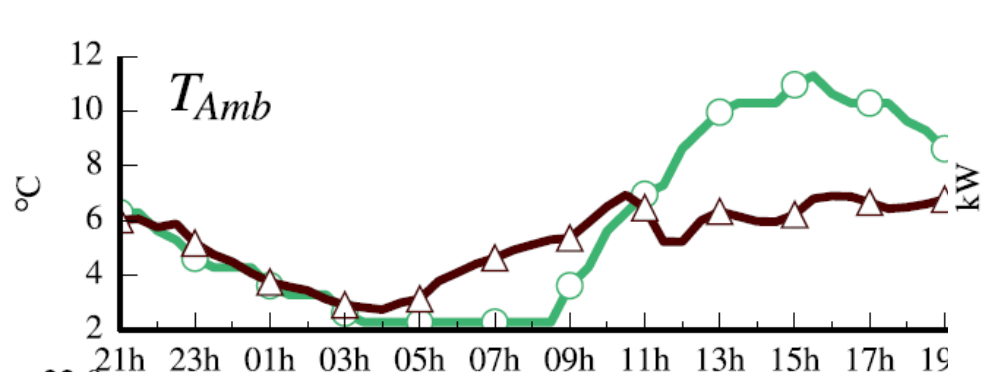
△ MPC



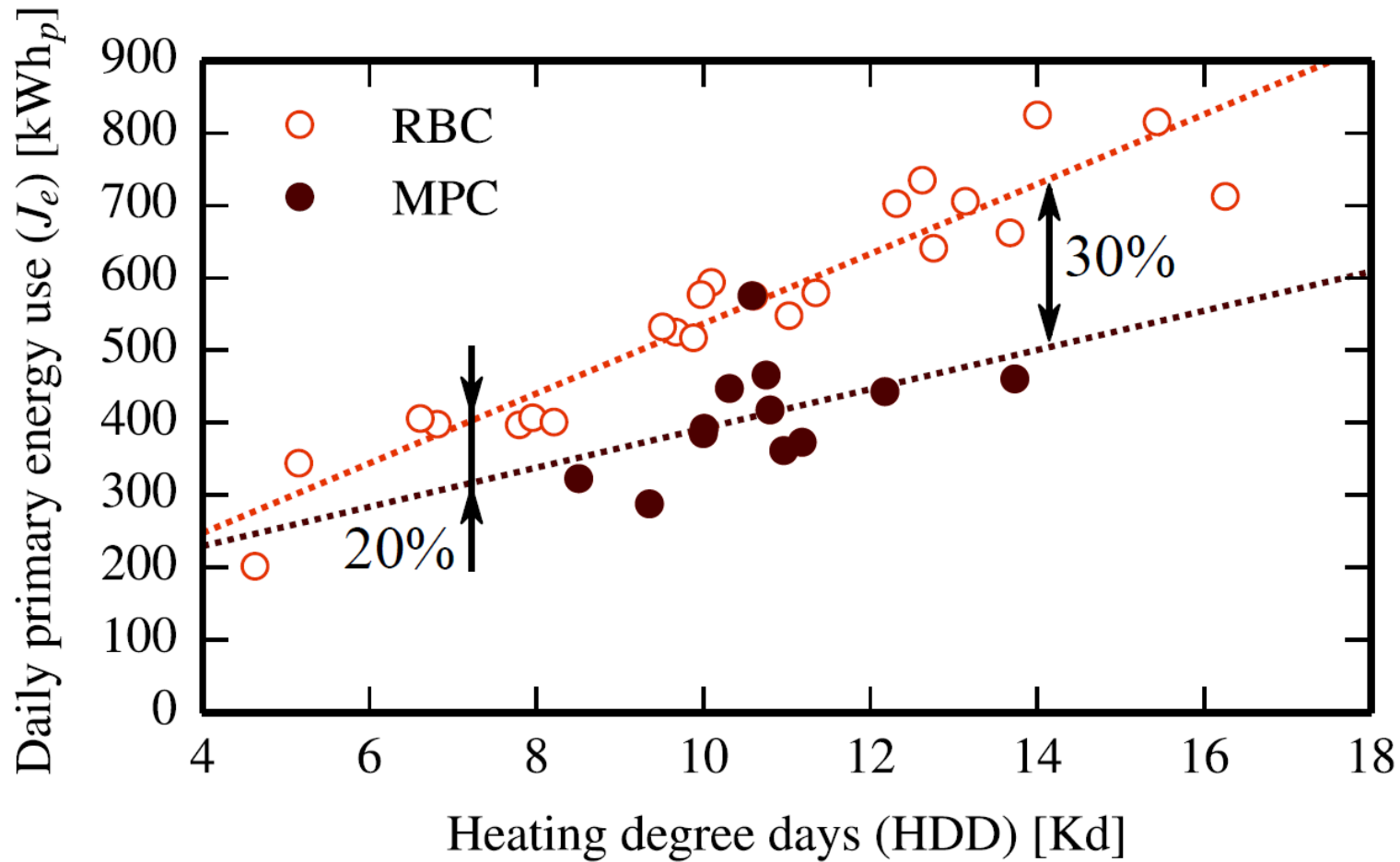
Results

○ OCP

△ MPC



Energy consumption



Conclusion

- Tool chain MPC
- Implementation on real building \Leftrightarrow implementation on emulator
- Good results by
 - Better use of heat pumps
 - Adapted TSup : not possible to describe by rules
- Still many opportunities for improvements?
- Tests on emulator model for isolation of effects



Thank you for your attention!

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