Performance Plus
Integrated Energy Management and Storage Control

1st European Performance Plus Workshop

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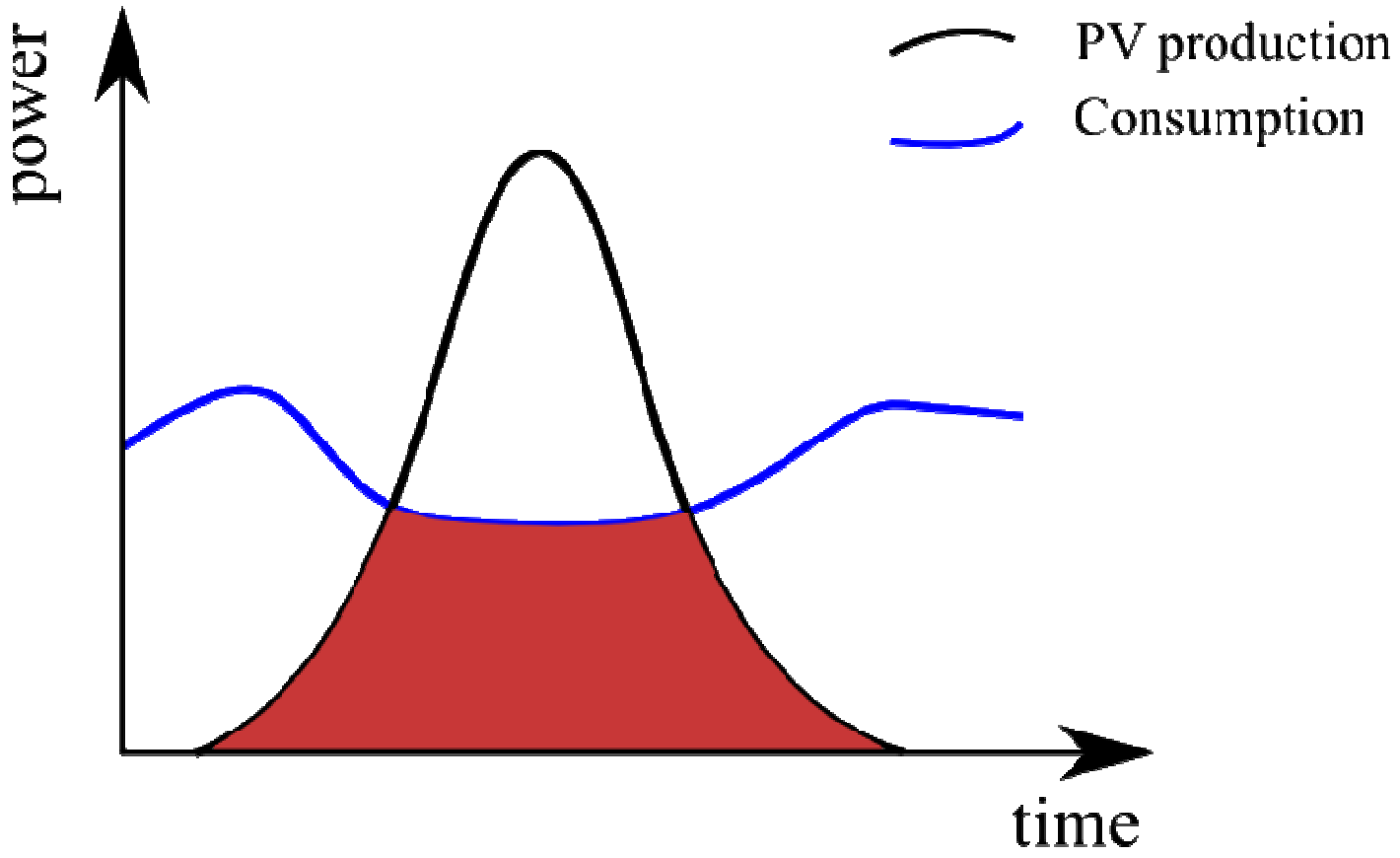

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Integrated Energy Management and Storage Control

System with
PV electricity **production**,
controllable electricity
consumption

- Electrical consumption can be shifted in time

- 3 typical use cases:
  - Electrical + thermal: **heating** dominated
  - Electrical + thermal: **cooling** dominated
  - Electrical only

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Use Cases PV + Controllable Load

- Electrical + thermal: heating dominated
  - Large office buildings with PV plant
  - Control thermal comfort
  - Control use of heat pumps
  - Thermal energy storage:
    - Heat building,
    - Hot water storage

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Use Cases PV + Controllable Load

- Electrical + thermal: cooling dominated
  - Cold warehouse (deepfreeze and/or refrigeration)
  - Large electricity consumer
  - Control product specific temperature boundaries
  - Control use of the Cooling/Air Handling Unit
  - Thermal energy storage
    - Refrigerate building
    - Heat capacity products

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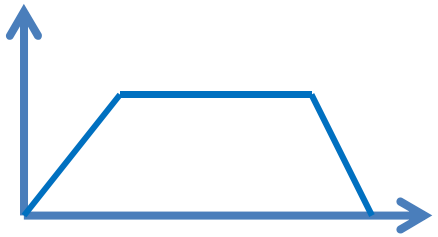
Use Cases PV + Controllable Load

- Electrical only:
  - Optimize battery inverter controls
  - Electrical energy storage

1. Large PV plant delivers trapezoidal output (
   - Day ahead prediction:
     - Ramp up rate
     - Maximum
     - Length maximum
     - Ramp down rate



2. Maximize injection to/minimize demand from the grid (max self-consumption*)
   - PV + battery in smaller scale (premium Germany)

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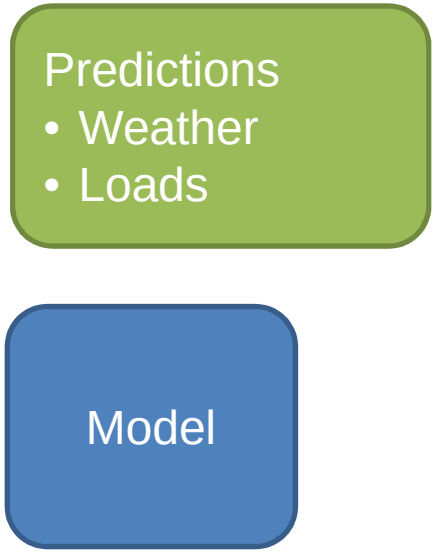
Improve on Current System Control

- Current practice:
  - Rule-based PID controllers: Rules of thumb, experience
  - Inefficient control and sizing

- Performance Plus:
  - **Model Predictive Control** (MPC)
  - Use knowledge of the system and of the future
  - Iteratively decide optimal control over future horizon



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MPC Framework

power peaks

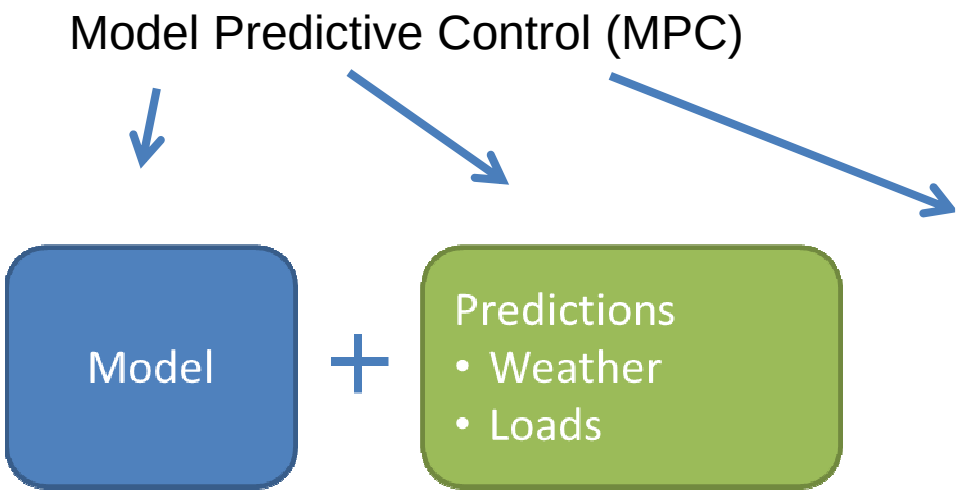
costs

CO_2

energy

self-consumption

comfort



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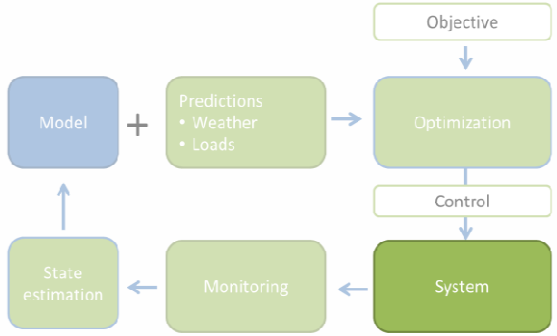
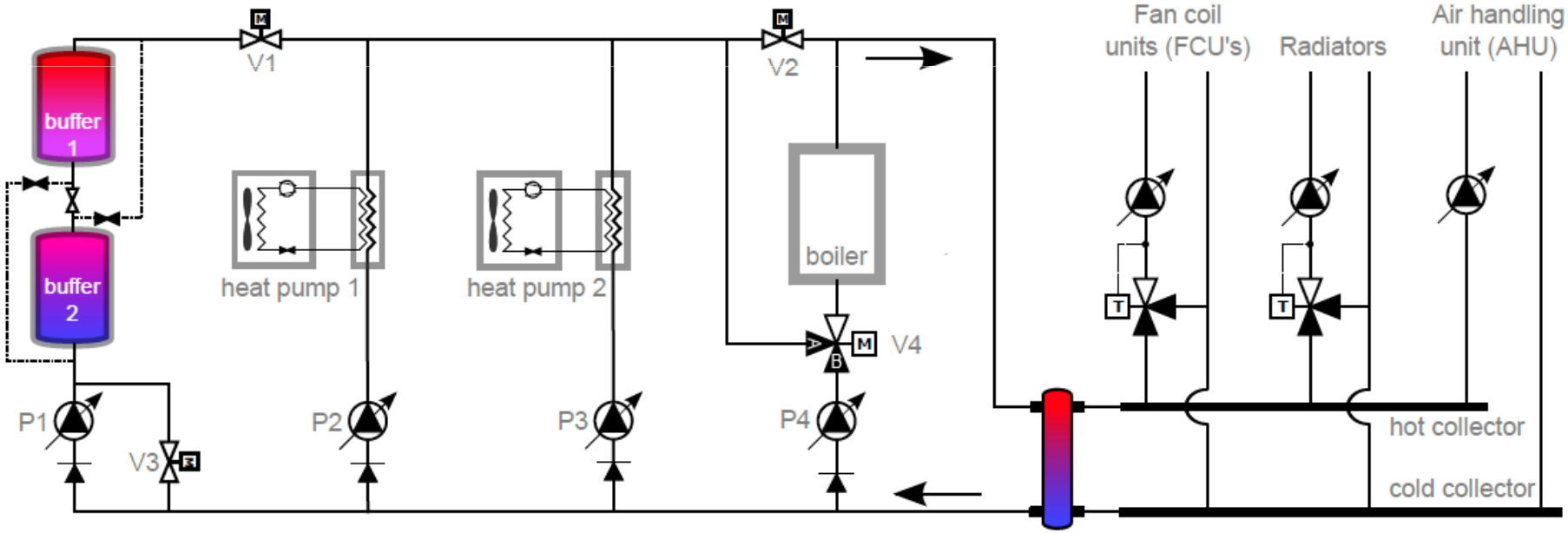
System

Electrical + thermal: heating dominated case study

Office building with heat pumps
(3E, Brussels)





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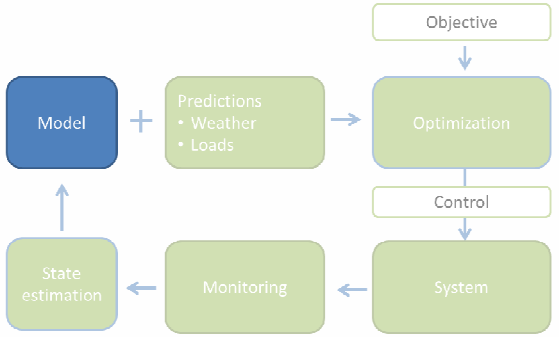
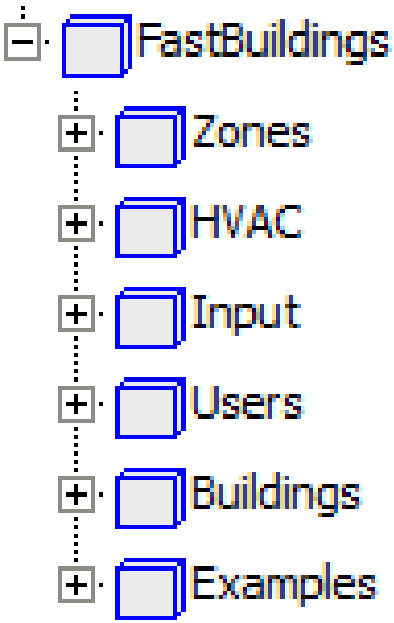
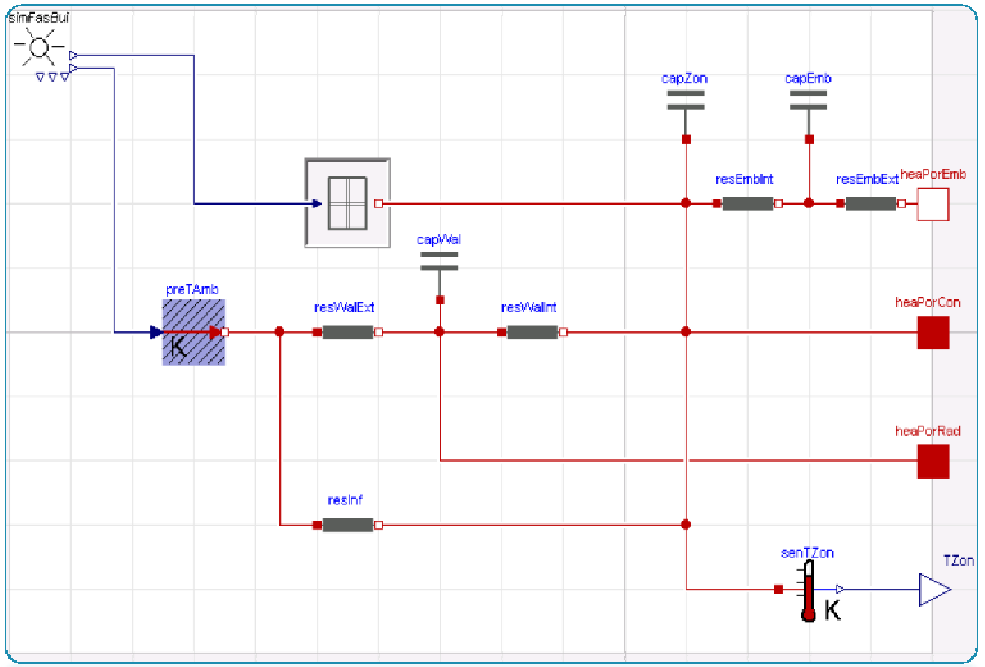
Controller models library

- Modelica language
- Grey-Box models
- Available: https://github.com/open-ideas







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From Data to Models

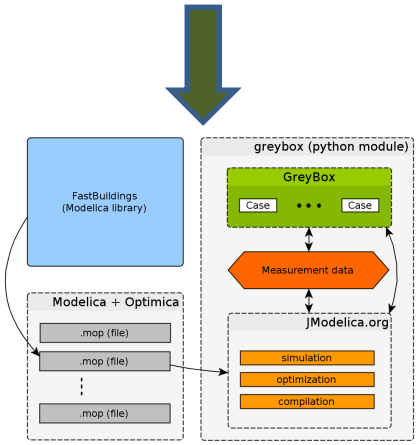
Data

Automation of data-driven low-order modelling

- Data exploration
- Model specification
- Parameter estimation
- Model validation

Models

From:
- monitored systems
- simulation



Use:
- **Model Predictive Control (MPC)**
- Forecasting
- Fault detection and diagnostics (FDD)
- Large-scale simulations with reduced-order models

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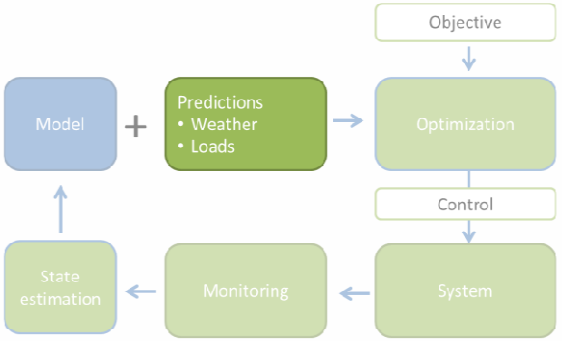
Predictions



- Weather data: daily updates through FTP site
  - Interaction work Oldenburg
  - Predictions of solar radiation, temperature and relative humidity
  - Measurements for post-evaluation
- Occupancy: time-series models based on past data
  - Electricity consumption as proxy

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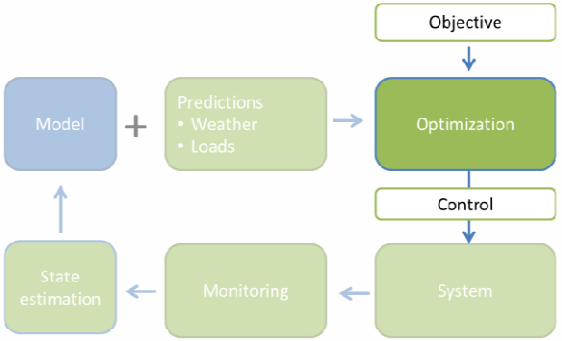
Optimization

$$\min_{u} \sum (x - x_{ref})^T \boldsymbol{Q}^{-1} (x - x_{ref})$$

$$s.t.$$
$$f(x_{k+1}, x_k, u_k, d_k, p_k) = 0$$
$$0 \leq Q_{hea} \leq \mathbf{50000}\ [\boldsymbol{W}]$$
$$\dots$$



- Control inputs
- Objective function
- Constraints

- Use of JModelica.org software for translating Modelica model to constraint equations
  - Gradient-based optimization
  - Automatic differentiation (CasADi)

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A optimization step

$$\min_{u} \sum (x - x_{ref})^T \boldsymbol{Q}^{-1} (x - x_{ref})$$

$$s.t.$$
$$f(x_{k+1}, x_k, u_k, d_k, p_k) = 0$$
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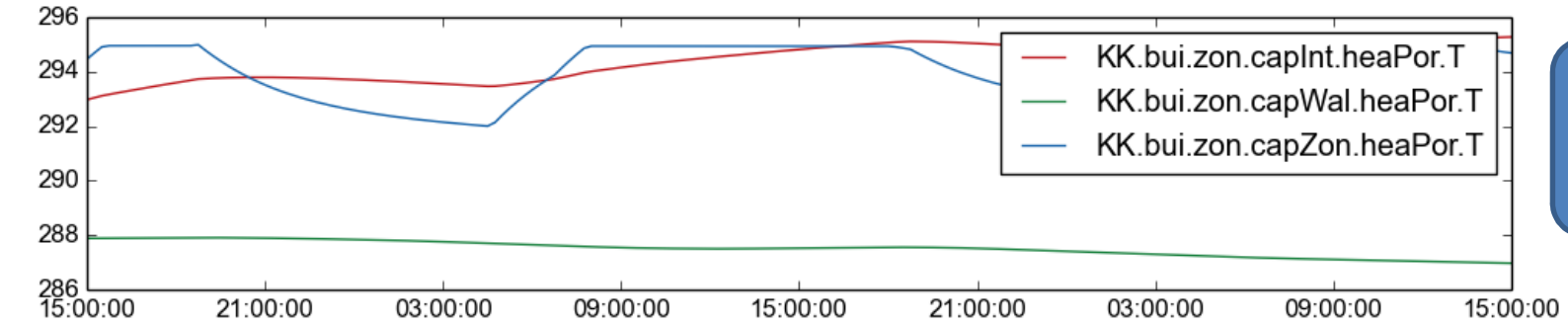
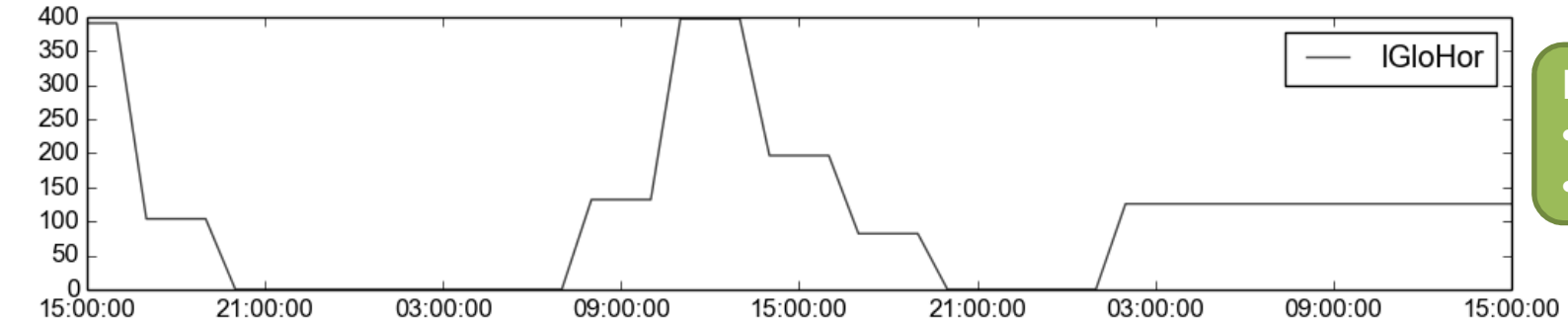
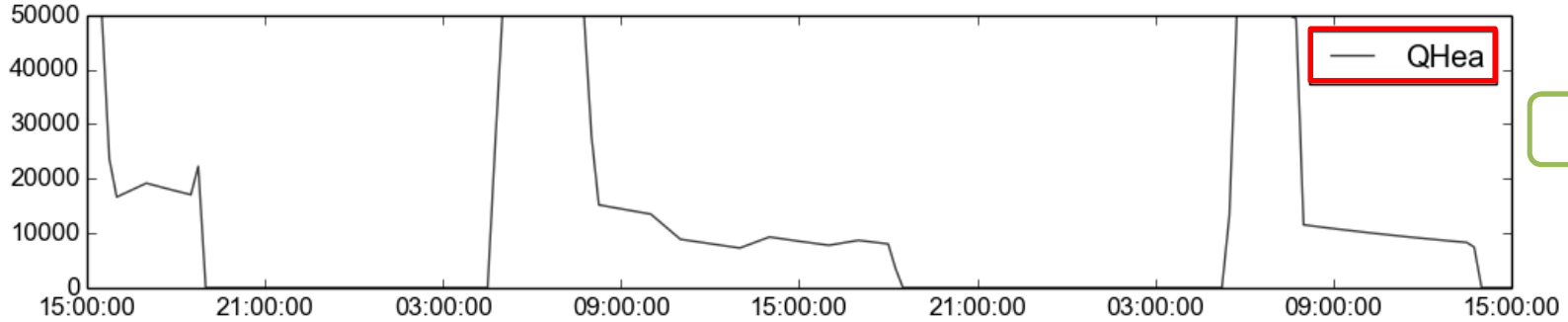


Model



Predictions
- Weather
- Loads

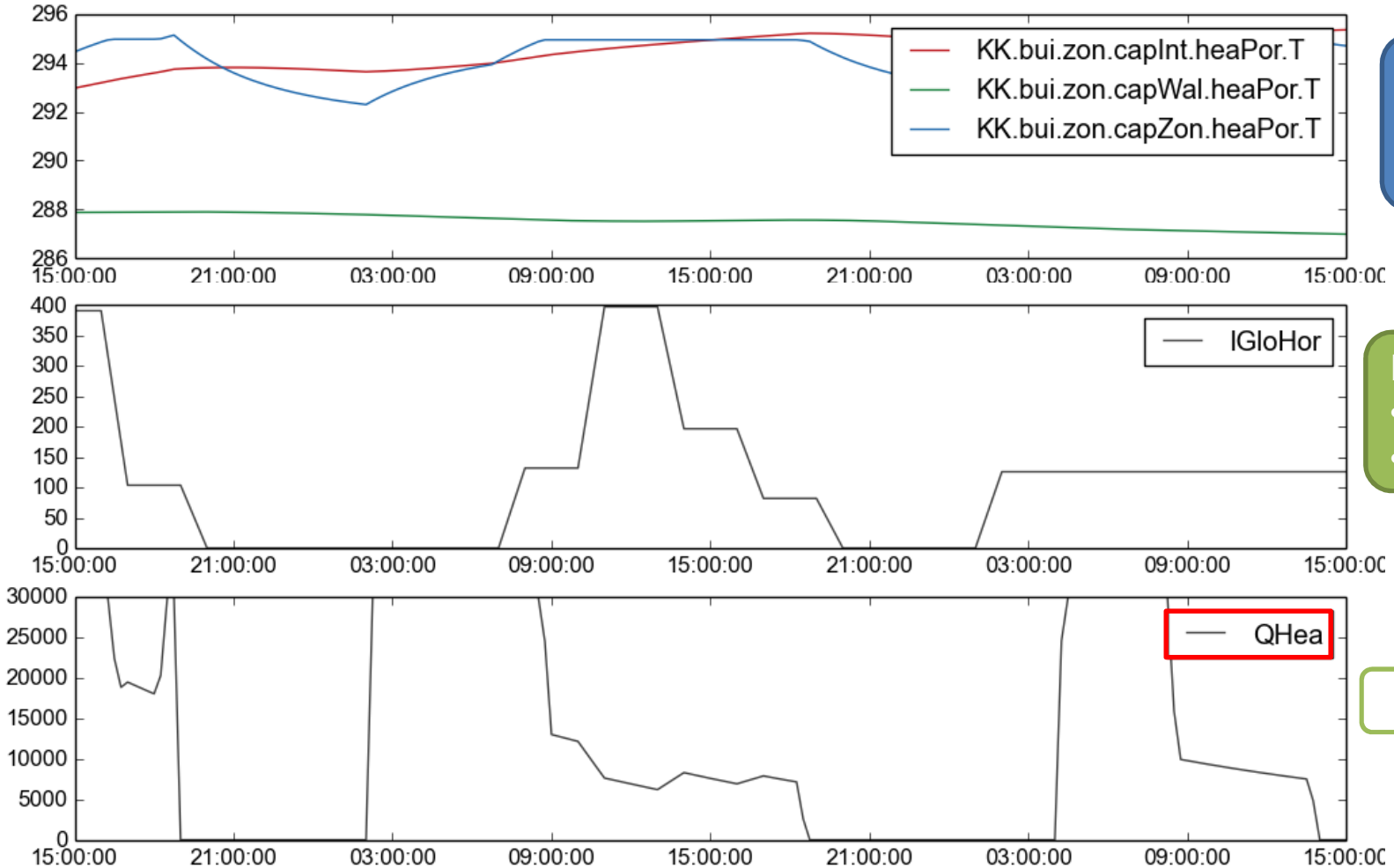


Control

A optimization step

$$\min_{u} \sum (x - x_{ref})^T \boldsymbol{Q}^{-1} (x - x_{ref})$$

$$s.t.$$
$$f(x_{k+1}, x_k, u_k, d_k, p_k) = 0$$
$$0 \leq Q_{hea} \leq \mathbf{30000}\ [\boldsymbol{W}]$$



Model

Predictions
- Weather
- Loads

Control

State estimation

- Current state is starting point for optimizing inputs
- ! Current state of system ≠ current state controller model (**model mismatch**)
- Measurement feedback
  - Limited amount of measurements → Full state vector of controller model
  - Measurements have uncertainty and/or bias
- Different state estimation techniques can be used

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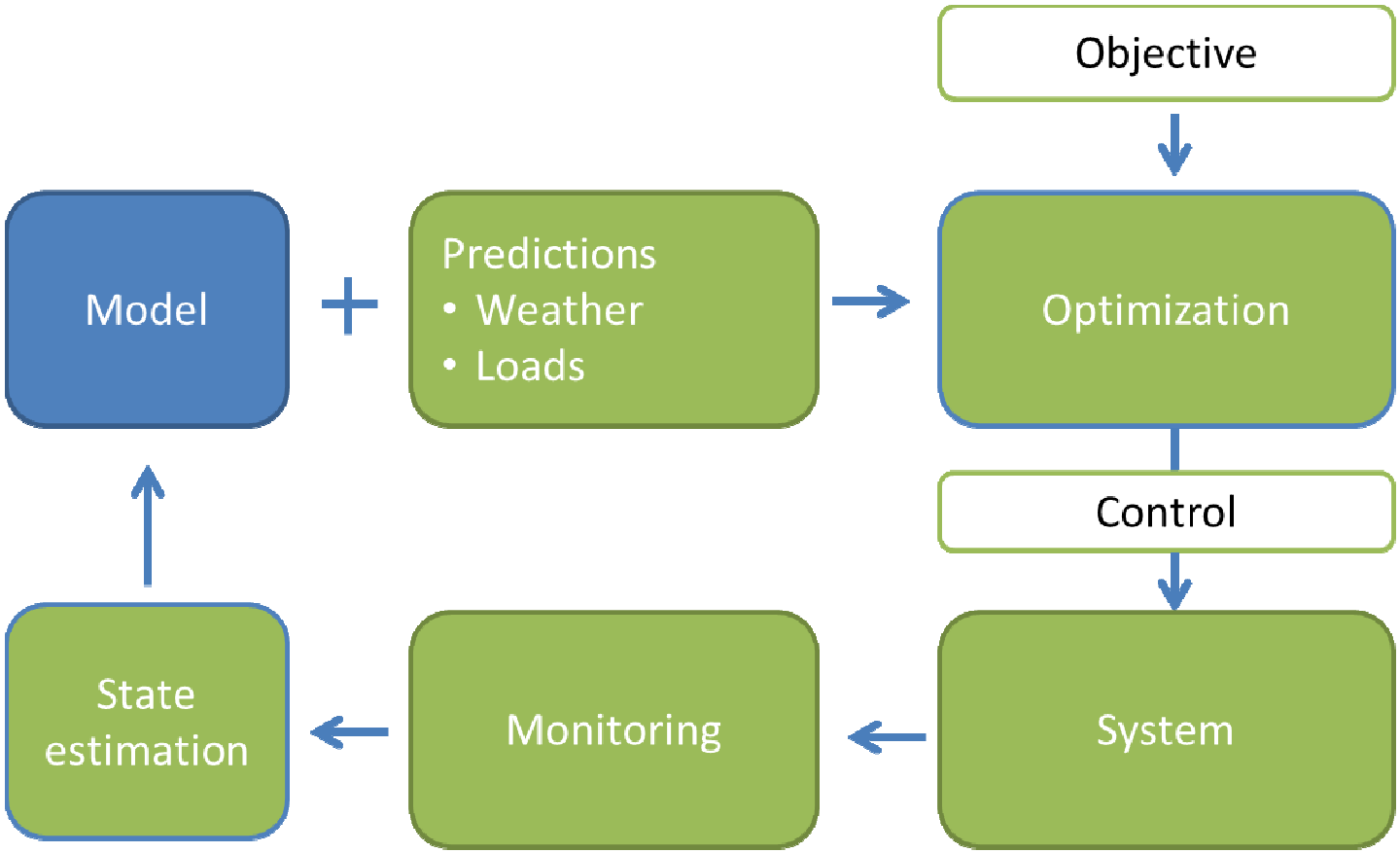
Performance MPC?



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Comparing Different Controllers

- Benchmark controllers on identical setup
  - Benchmark with current controller
  - Controller model and state estimation performance
  - Compare objectives (different controllers)

- Construct emulator model for real system
  - Behavior (model)
  - Interface (control inputs - optimized)
  - Disturbances (measurements - WP2 Oldenburg; load model + forecasting)
  - Output (‘measurements’ – simulation)

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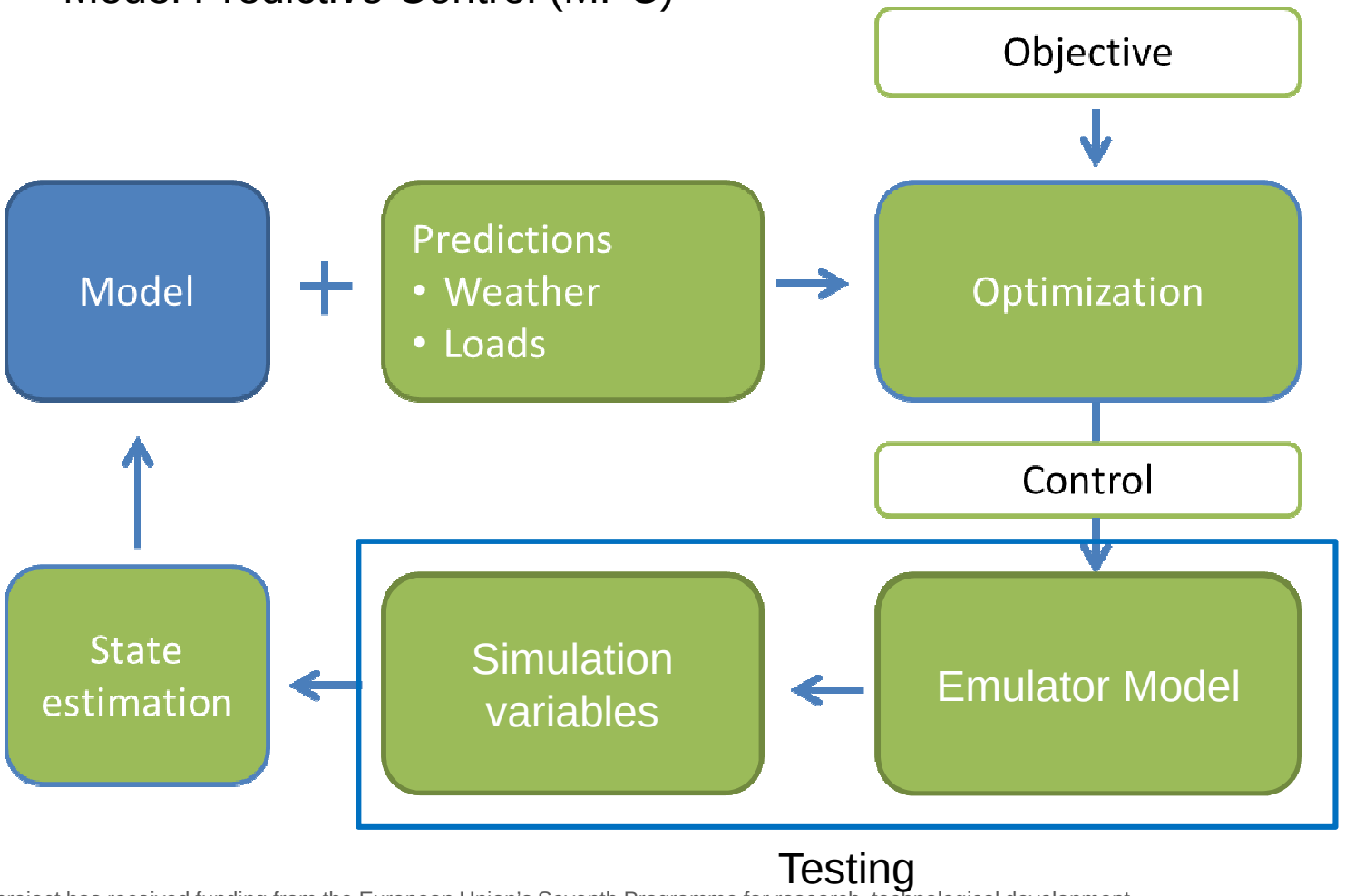
Comparing Different Controllers

Model Predictive Control (MPC)



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Calibrated emulator model

- Need good emulator model of the real system
  - Perform sensitivity analysis
  - Calibrate

- Industry viewpoint
  - Show improvements

- Academic viewpoint
  - Virtual test bench
  - Compare different optimization objectives
  - Compare different mathematical techniques

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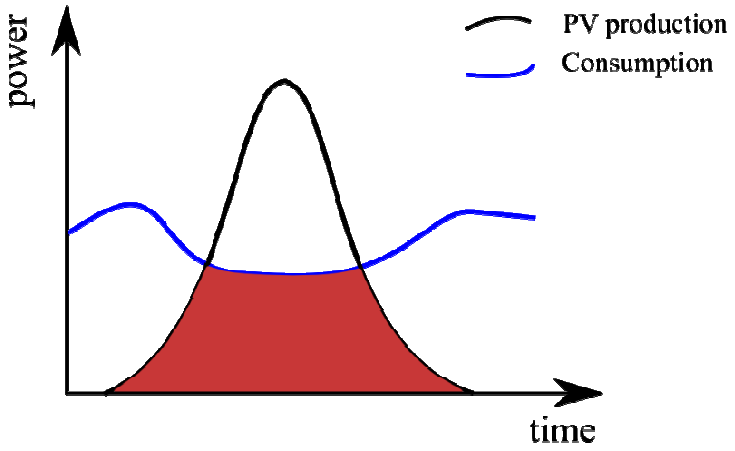

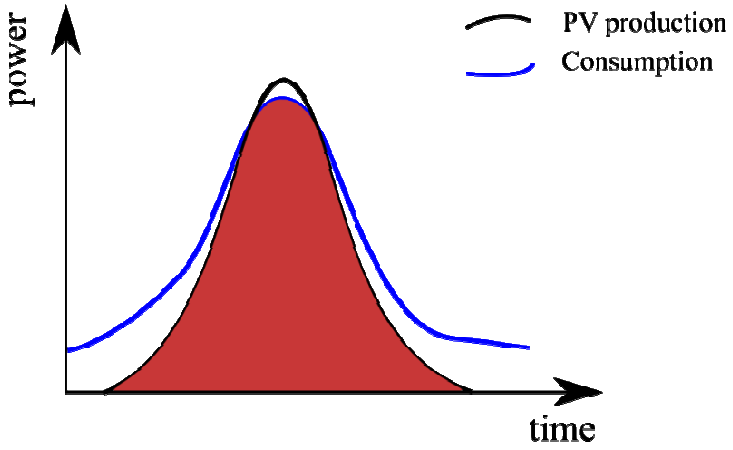

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Questions?

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