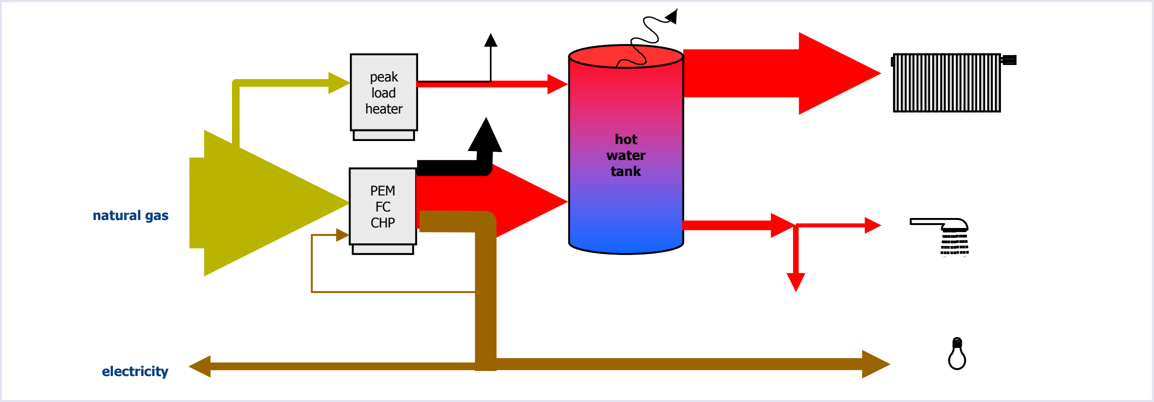
Optimal dimensioning and operation of micro-CHP units

Micro-CHP units for domestic use

Alexander Hlawenka

f-cell 2007
Stuttgart
September 25-26, 2007



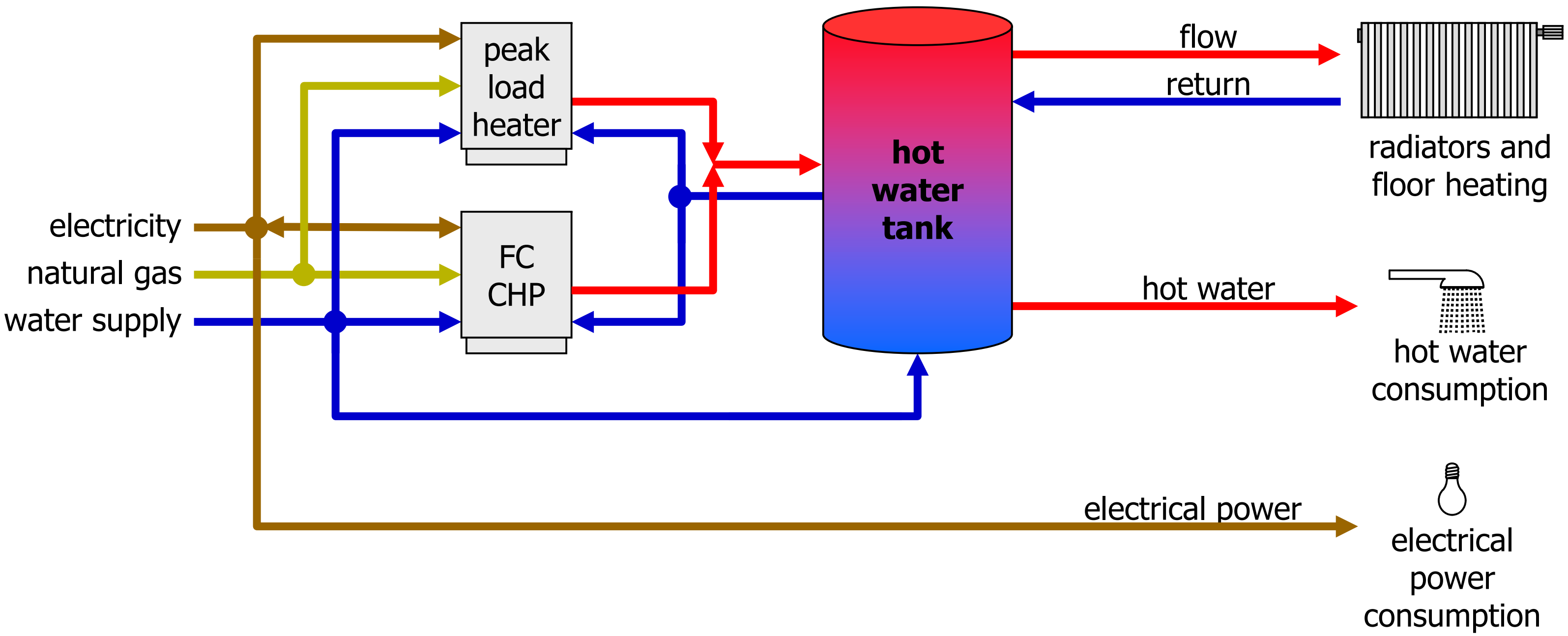
Dennewartstraße 25-27, 52068 Aachen, Germany www.eutech-scientific.de Phone:+49/241/963-23-80 Fax:+49/241/963-23-81

Overview

- Introduction
- Modeling of fuel cell based heating installation
- Model analysis and optimization potential
- Energy management strategies
- Simulation results
- Summary

EUtech Scientific Engineering

FC based micro CHP heating installation



Design questions

- Dimensioning of peak load heater, CHP and hot water storage tank
- Design of interconnection of subsystems
- Energy management for peak load heater and FC

EUtech Scientific Engineering

Approach

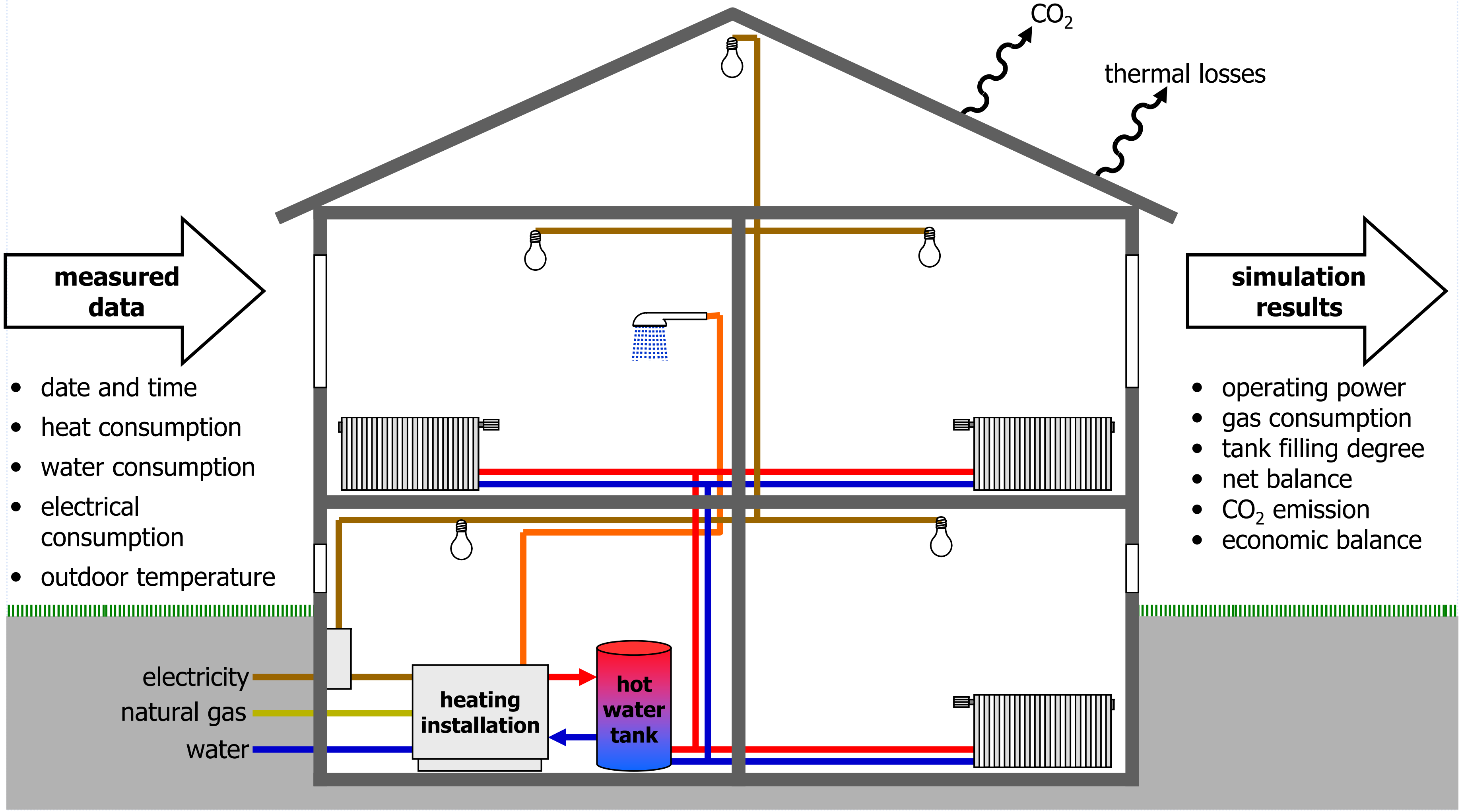
- Model based design of heating installation and energy management strategy
- Procedure:
  1. Develop a mathematical model of the heating installation
  2. Feed the model with real data taken from the field
  3. Analysis of the model to identify optimization potentials
  4. Design different controller types and choose initial dimensioning parameters
  5. Perform high resolution long term simulations (1 year, T_{samp} = 10s) to optimize control and dimensioning parameters
- Design tools
  1. Thermodynamic Simulink library FClib
  2. System simulation tool EshSimulation

FClib THE FUEL CELL SYSTEMS LIBRARY

MATLAB SIMULINK

Modeling FC based heating installation

Simulation model inputs and outputs



measured data

- date and time
- heat consumption
- water consumption
- electrical consumption
- outdoor temperature

simulation results

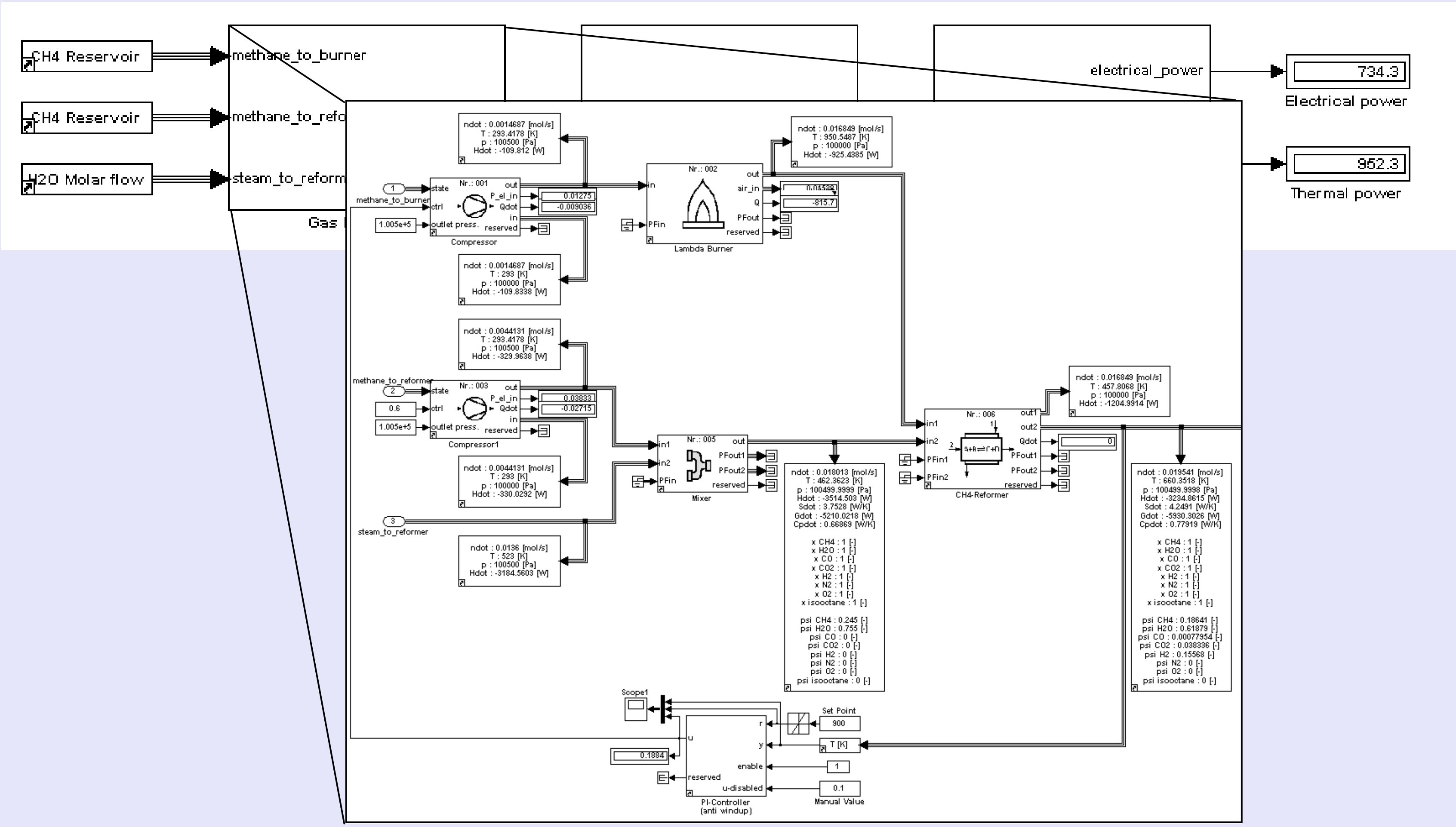
- operating power
- gas consumption
- tank filling degree
- net balance
- CO_2 emission
- economic balance

Dennewartstraße 25-27, 52068 Aachen, Germany www.eutech-scientific.de Phone:+49/241/963-23-80 Fax:+49/241/963-23-81

Modeling FC based heating installation

EUtech Scientific Engineering

PEM Fuel Cell CHP unit with gas production on board



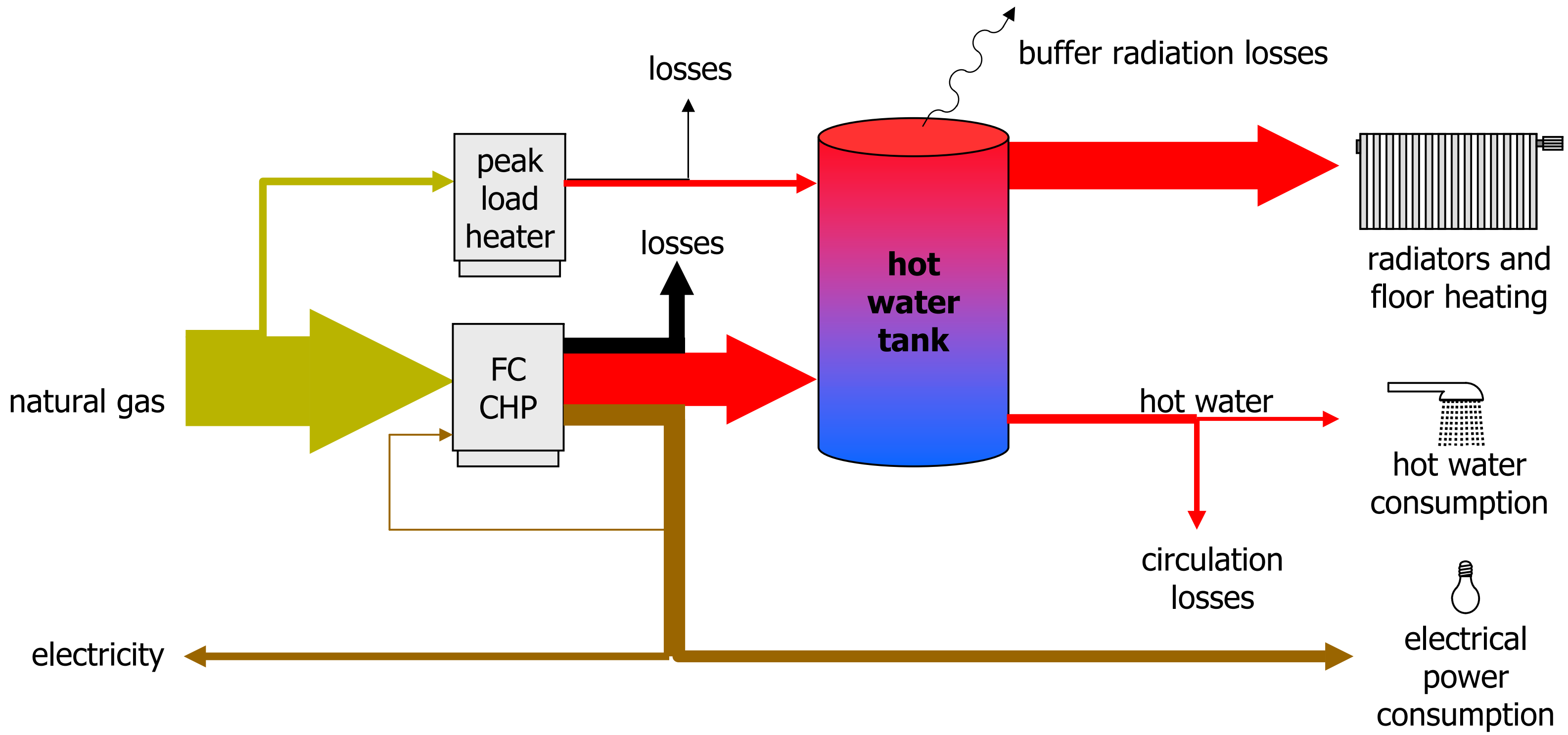
Model analysis and optimization potentials

Optimality criteria

- What is optimal operation?
  - Minimal CO_2 emission
  - Minimal operational costs
    (electricity drawn from and fed back to grid, natural gas consumption, maintenance costs)
  - Maximal stack durability
    (minimize number of on-off cycles)
  - Minimal heat losses of the hot water storage tank (can be influenced by the control algorithm and resulting operational range of tank temperatures)

Model analysis and optimization potentials

Typical energy flow chart (cumulated energy flow 1 year)

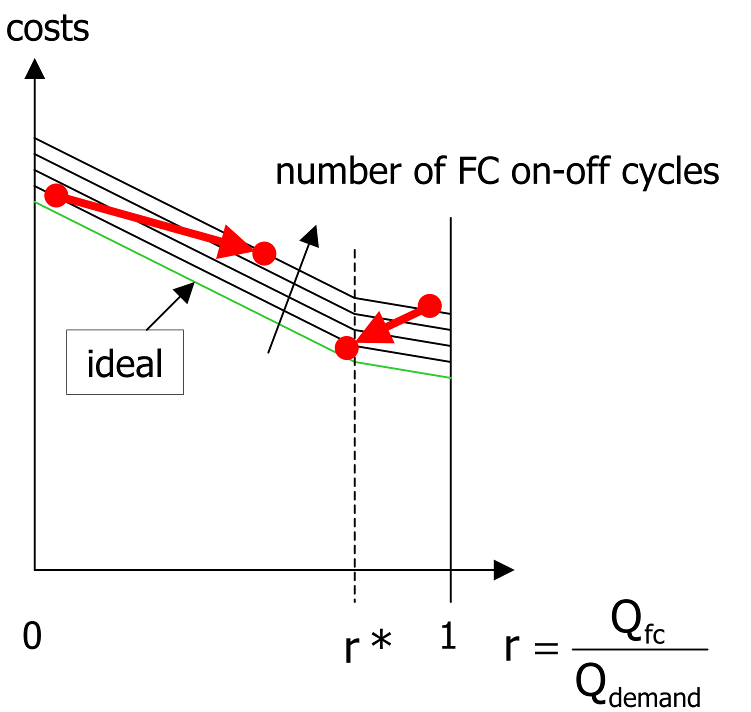


- Energy flow chart shows most promising approaches to reduce primary energy consumption:
  - saving heat consumption
  - improving FC efficiency

Model analysis and optimization potentials

EUtech Scientific Engineering

Ratio of fuel cell usage and it's effects on cost



$$\text{cost} = \$_{el}\left(\int P_{el,cons}\,d\tau - \frac{\eta_{el,FC}}{\eta_{th,FC}}Q_{cons}r\right) + \$_{CH4}Q_{cons}\left(\frac{1}{\eta_{th,FC}}r + \frac{1}{\eta_{th,PLH}}(1-r)\right)$$

$$r^* = \frac{\int P_{el,cons}\,d\tau}{Q_{cons}}\,\frac{\eta_{th,FC}}{\eta_{el,FC}}$$

$$\$_{el} = \begin{cases} \$_{draw}, & r \le r^* \\ \$_{feed}, & r > r^* \end{cases}$$

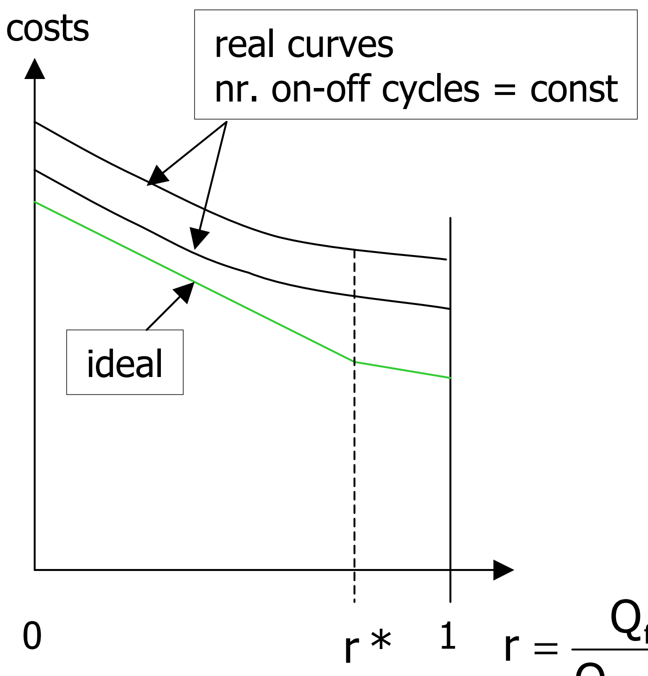
$$\min(\text{cost}) = \$_{el}\left(\int P_{el,cons}\,d\tau - \frac{\eta_{el,FC}}{\eta_{th,FC}}Q_{cons}\right) + \$_{CH4}\frac{Q_{cons}}{\eta_{th,FC}}$$

Necessary condition to make FC usage cost optimal

$$\frac{\eta_{th,FC}}{\eta_{el,FC}}\left(\frac{1}{\eta_{th,FC}} - \frac{1}{\eta_{th,PLH}}\right) < \frac{\$_{el}}{\$_{CH4}}$$

Model analysis and optimization potentials

Ratio of fuel cell usage and it's effects on cost



$$r = \frac{Q_{fc}}{Q_{demand}}$$

$$cost = \$_{el}\left(\int P_{el,cons}\, d\tau - \frac{\eta_{el,FC}}{\eta_{th,FC}} Q_{cons} r\right) + \$_{CH4} Q_{cons}\left(\frac{1}{\eta_{th,FC}} r + \frac{1}{\eta_{th,PLH}}(1-r)\right)$$

$$r^* = \frac{\int P_{el,cons}\, d\tau}{Q_{cons}} \frac{\eta_{th,FC}}{\eta_{el,FC}}$$

$$\$_{el} = \begin{cases} \$_{draw}, & r \leq r^* \\ \$_{feed}, & r > r^* \end{cases}$$

$$\min(cost) = \$_{el}\left(\int P_{el,cons}\, d\tau - \frac{\eta_{el,FC}}{\eta_{th,FC}} Q_{cons}\right) + \$_{CH4} \frac{Q_{cons}}{\eta_{th,FC}}$$

Necessary condition to make FC usage cost optimal

$$\frac{\eta_{th,FC}}{\eta_{el,FC}}\left(\frac{1}{\eta_{th,FC}} - \frac{1}{\eta_{th,PLH}}\right) < \frac{\$_{el}}{\$_{CH4}}$$

Simulation Results

Simulation Results

Case study data

- Object
  - One-family home
  - Year of construction: 1991
  - Heating: Floor heating and radiators
  - Location: Central Europe (Germany)
  - Consumption data acquired from 2002/2003
  - Sample time 60 s

- Annual energy consumptions:
  - Heating: 18,400 kWh
  - Hot water: 1,500 kWh
  - Circulation losses of hot water: 2,190 kWh
  - Electricity: 4,400 kWh

Simulation results

Comparison of different energy management strategies

- Classic PI control
  - Using hot water storage tang temperature only
  - 2 independent controllers for peak load heater and FC

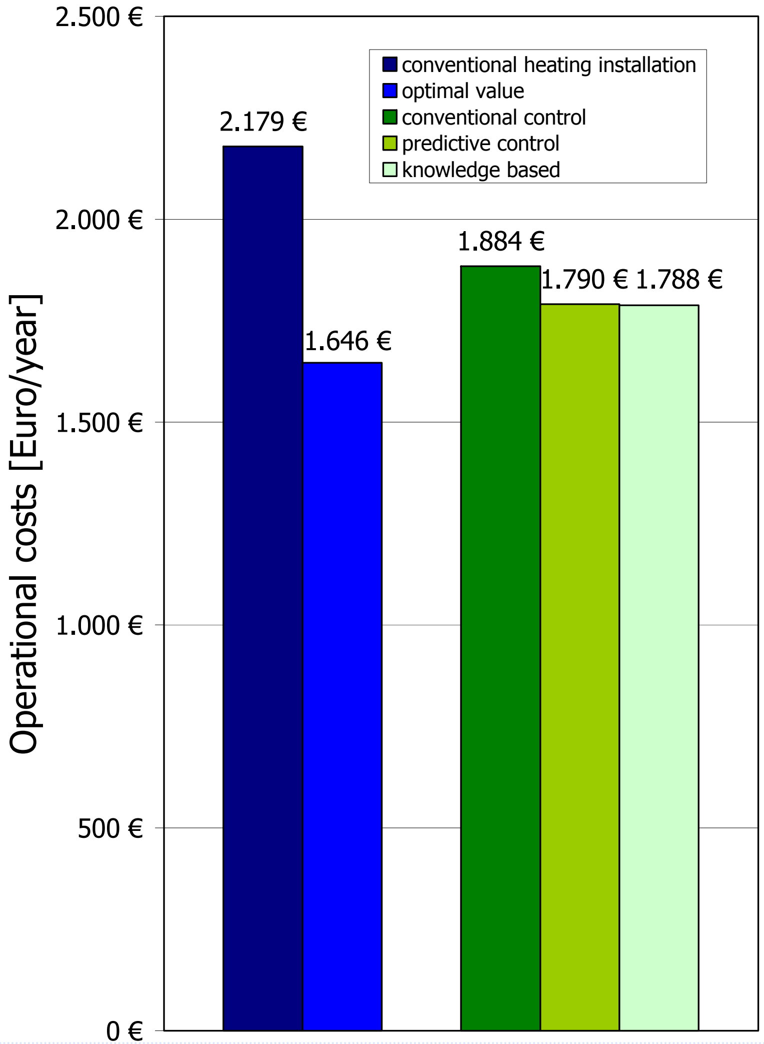
- Knowledge based energy management
  - Knowledge based control of operation
  - Considering season, time of day, outdoor temperature, tank condition

- Model predictive control with prediction of consumption
  - Prediction of demand based on time, date, outdoor temperature, history
  - Optimization by means of process model and constraints

Simulation results

Optimal energy management strategy - costs

- All strategies perform better compared to the conventional heating system
- Best strategy is „Knowledge based“
- Optimal strategy is 8% above the theoretical minimal operational costs while classic PID misses 14 % to the optimum

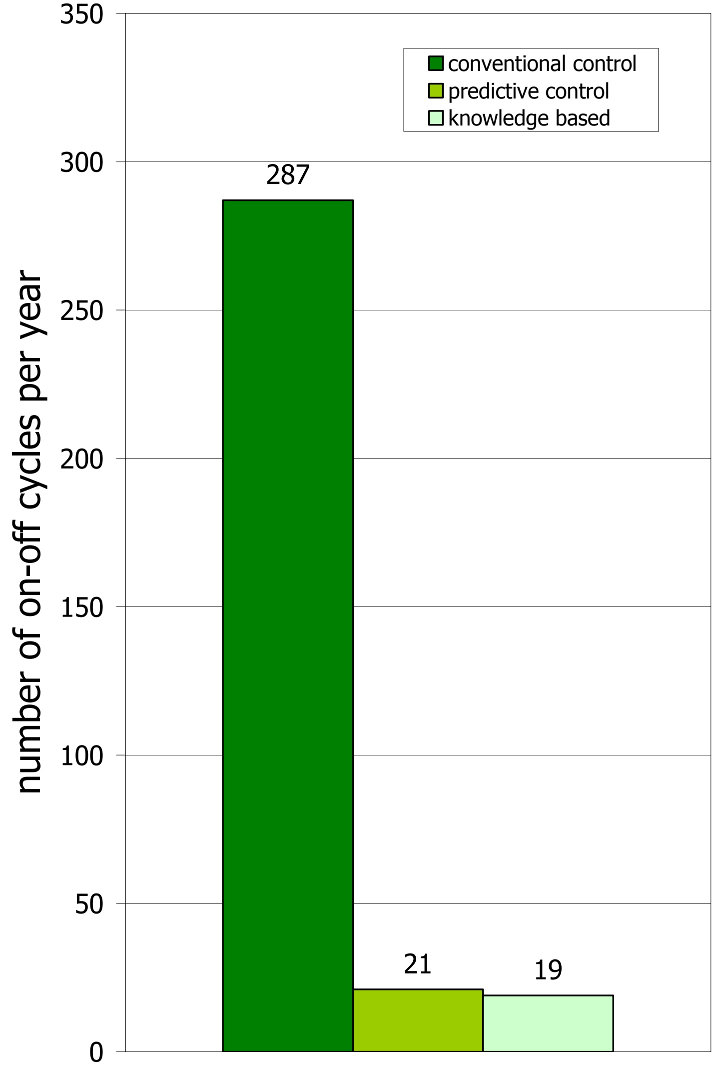


Simulation results

Optimal energy management strategy - number of on-off cycles

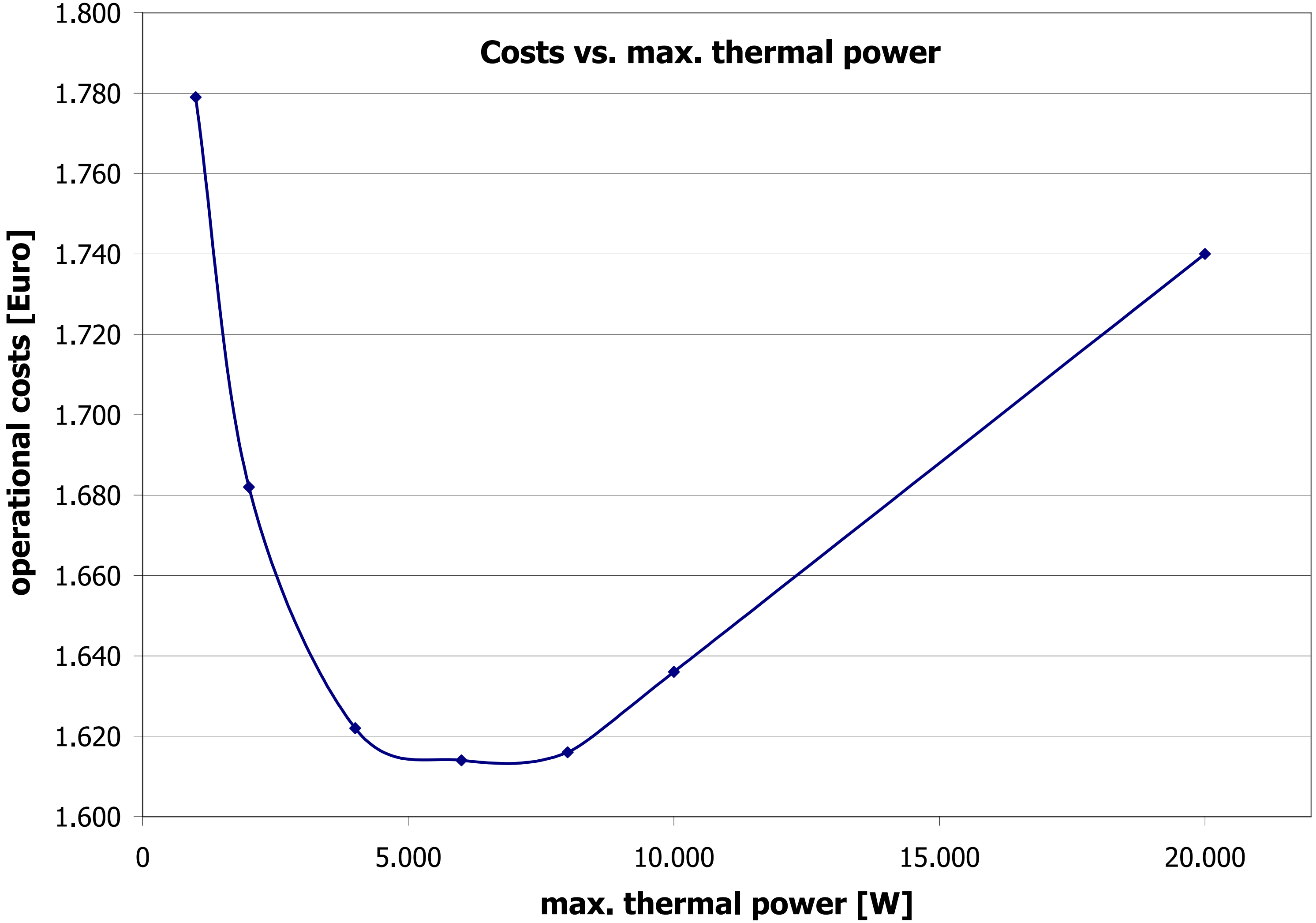
- Knowledge based and MPC based energy management can effectively reduce the number of on-off cycles

  => contribute to lifetime of stack



Simulation results

Optimal size of fuel cell system



EUtech
Scientific
Engineering

Summary

Optimal dimensioning and operation of micro-CHP units

EUtech Scientific Engineering

Summary

- System modeling and simulations based on FClib and EshSimulation used to optimize design and operation
- Optimized energy management can reduce the
  - CO_2 emissions
  - operational costs (electricity, natural gas, maintenance costs)
  - number of on-off-cycles
- Optimal dimensioning of the components has great impact on overall economic result

Outlook

- Optimal interconnection of the components (peak load heater, fuel cell, tank)
- Sensitivity analysis of costs with respect to system limitations (e. g. modulation).