JOINT RESEARCH CENTRE
European Energy Efficiency Platform (E3P)

Technical University of Munich

11th International Conference on Improving Energy Efficiency in Commercial Buildings and Smart Communities (IEECB&SC'20)

Uncertainty and Sensitivity Analyses of Operational Errors in Air Handling Units and Unexpected User Behavior for Energy Efficiency and Thermal Comfort

Speakers:

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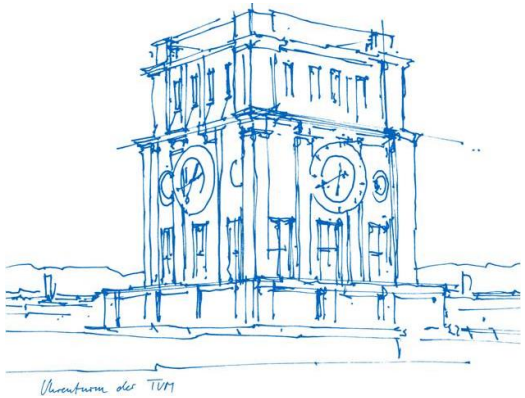
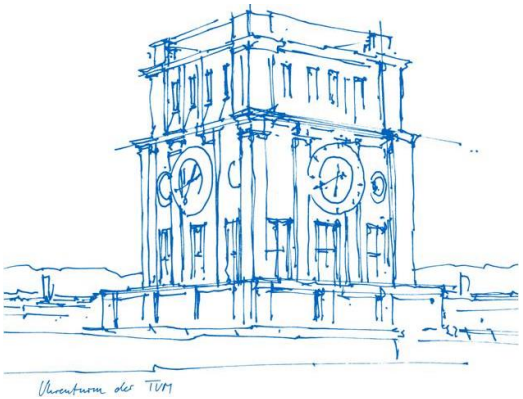
Technical University Munich
Germany



Content

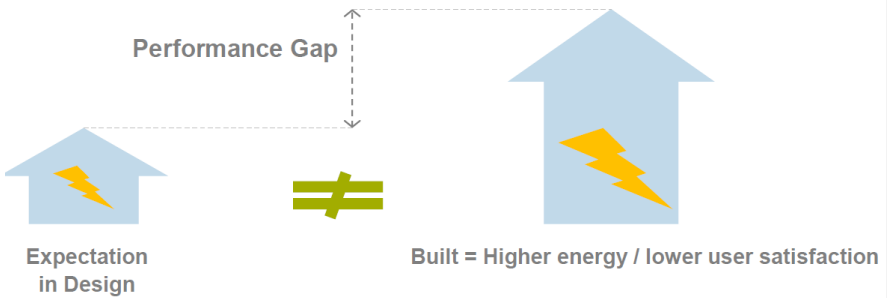


Background and Problem Definition

- climate protection targets: 2050 primary energy demand decreased by 80 % of 2008
- construction climate-neutral buildings ≠ ecological footprint existing building stock
- → energy saving potentials identified and exploited: building technology essential role
- particularly non-residential buildings: thermal comfort, user satisfaction, productivity factors
- various influences: weather conditions and user behaviour → BACS
- not only energy-efficient, but also correct and fault-free operation;
  further operational optimization
- → performance gap: operating faults in building technology and automation

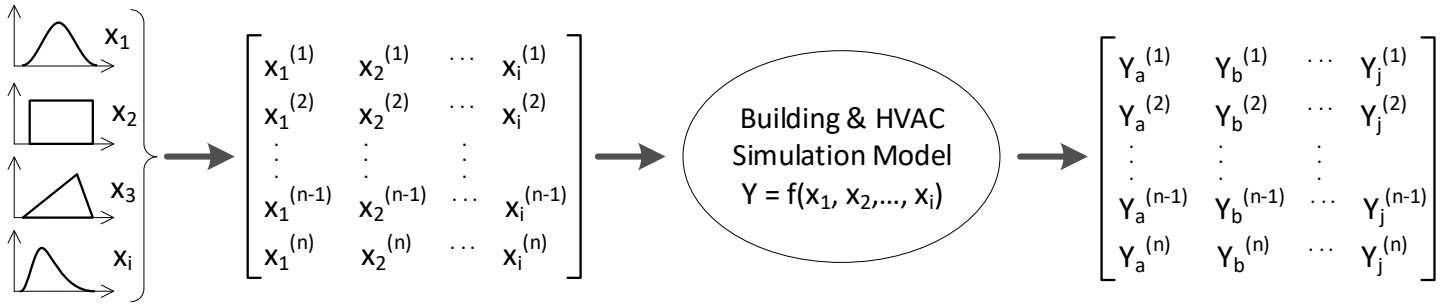
Motivation and Task

- erect buildings: functions perfectly for users, low energy requirements, cost-effective building technology
- life cycle of buildings: performance gap → quality risk investments energy efficiency and user satisfaction
- analyse and evaluate operating faults in building technology systems → optimise building performance
- identify influencing parameters and adjusting screws for energy-efficient building and system operation
- explore effects of operation faults in context performance gap → quantification energy saving potentials
- model-based procedure developed and applied → BPS combined uncertainty & sensitivity analyses

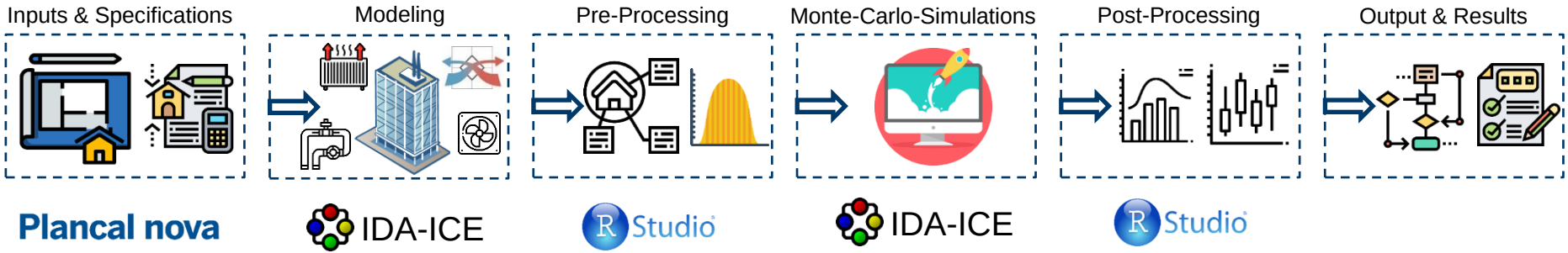


Building Performance Simulations

- HVAC systems not subject to fixed system scheme → type, number of components, automation level, etc.
- building technology: many correct operating states → parameters value range, not static or fixed numbers
- map dynamics: process statistical variation input parameters → analysis impact building performance
- stochastic fluctuations operational faults: variance, frequency, probability of occurrence → Monte-Carlo simulations combined with sensitivity and uncertainty analyses

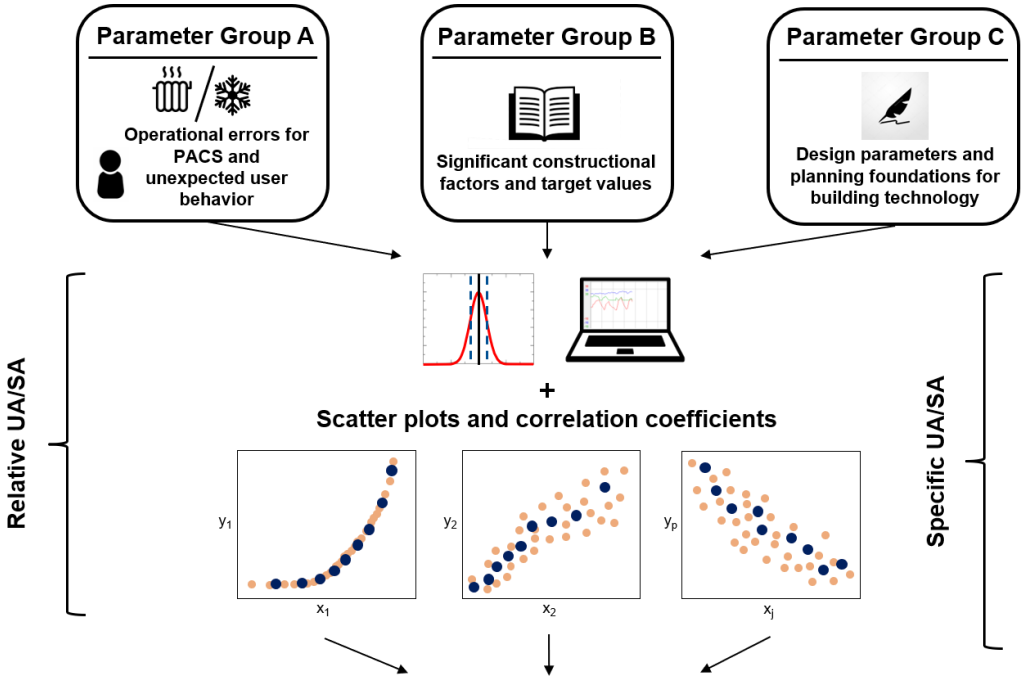


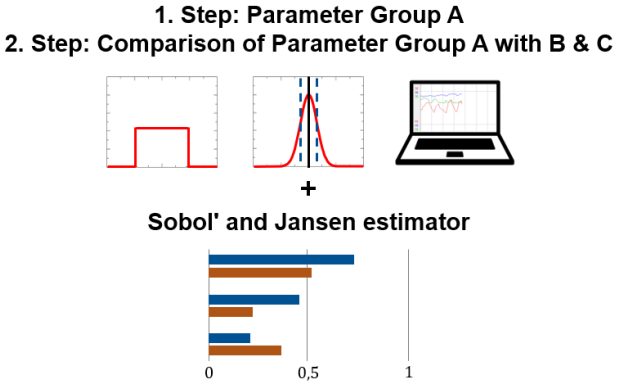
Simulation Setup



coupling a Monte-Carlo approach with BPS → automated analyses and evaluation of performance HVAC systems

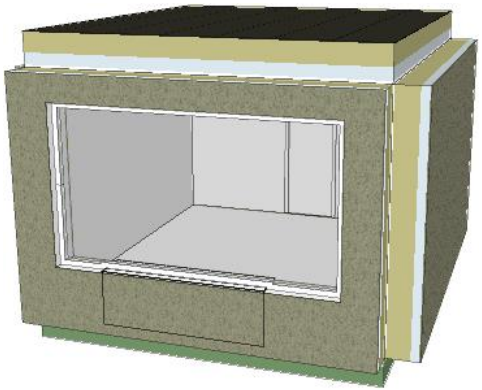
Methodology





Case Study

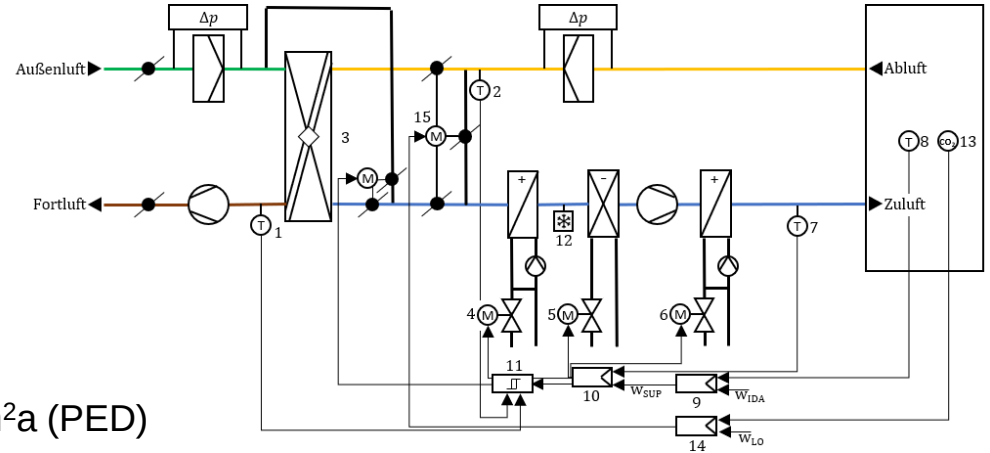
Building-specific parameters according to DIN EN 15232 & EnEV 2007



92.9 kWh/m²a (PED)

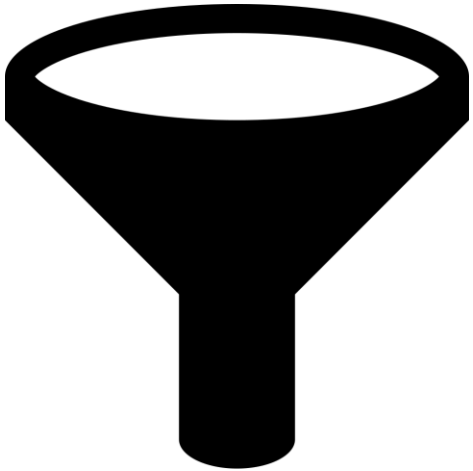
100.4 Kh/a (OHH)

140.9 Kh/a (UHH)



partial air conditioning system
(controlled by the exhaust air temperature)

Relative Uncertainty and Sensitivity Analysis



Relative Uncertainty and Sensitivity Analysis

error 1.1 – volume flow zone level
error 2.1 – differential pressure supply air fan
error 2.2 – differential pressure exhaust air fan
error 2.4 – start of operation of PACS
error 2.5 – termination of PACS
error 3.1 – adjustment range of the air recirculation flap
error 4.1 – blocking temperature heat recovery
error 4.5 – heat number of the heat recovery
error 5.1 – heat transfer pre-heating register
error 5.2 – control valve pre-heating register
error 5.3 – pump pre- and post-heating register
error 5.4 – temperature spread pre-heating register
error 5.6 – heat transfer post-heating register
error 5.7 – control valve post-heating register
error 5.8 – temperature spread post-heating register
error 5.10 – heat transfer cooling register
error 5.11 – control valve cooling register
error 5.12 – pump cooling register
error 5.13 – temperature spread cooling register
error 5.19 – room air temperature sensor
error 6.1 – humidity sensor
error 8.1 – number of people
error 8.2 – sun protection
error 8.3 – window opening time

PACS means partial air conditioning system

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PACS means partial air conditioning system

Specific Uncertainty and Sensitivity Analysis: Step 1

Parameter Group A

error 1.1 – volume flow zone level	~ U(0.000; 1.609)
error 2.1 – differential pressure supply air fan	~ U(0.0; 700.0)
error 2.5 – termination of partial air conditioning system	~ U(05:00; 24:00)
error 5.8 – temperature spread post-heating register	~ U(0.1; 50.0)
error 5.19 – room air temperature sensor	~ N(0.000; 0.970)
error 8.1 – number of people	~ N(2.0; 1.0)
error 8.2 – sun protection	~ U(0.0; 1000.0)
error 8.3 – window opening time	~ U(0.0; 0.25)

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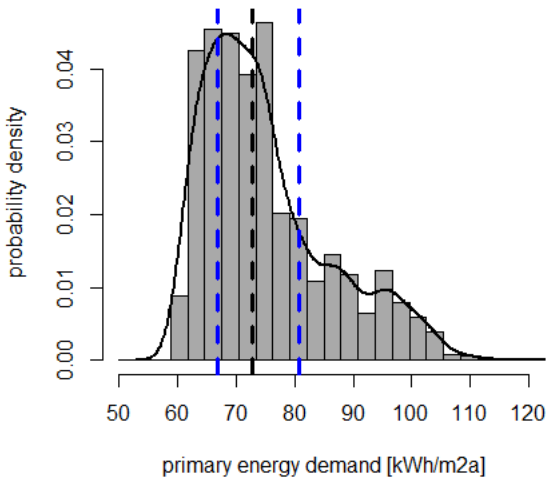
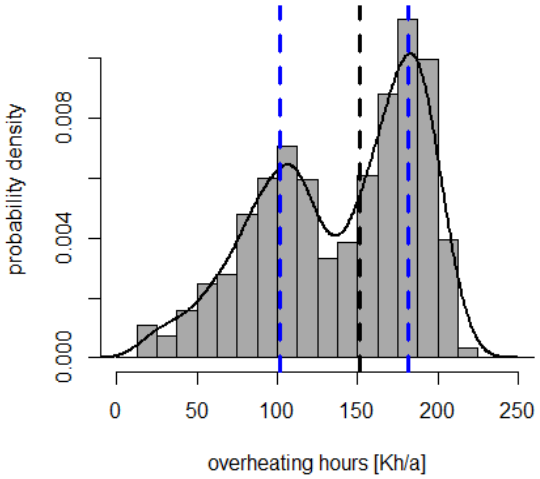
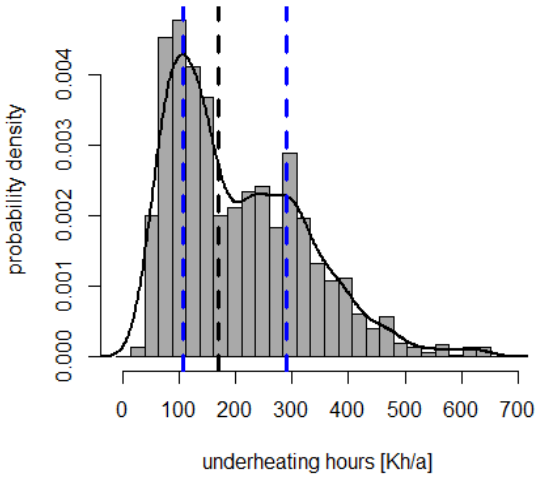
Specific Uncertainty and Sensitivity Analysis: Step 1



1st Qu.: 66.9 kWh/(m²a)
Median: 72.6 kWh/(m²a) [-22 %]
3rd Qu.: 80.7 kWh/(m²a)



1st Qu.: 101.9 Kh/a
Median: 151.4 Kh/a [+51 %]
3rd Qu.: 181.9 Kh/a

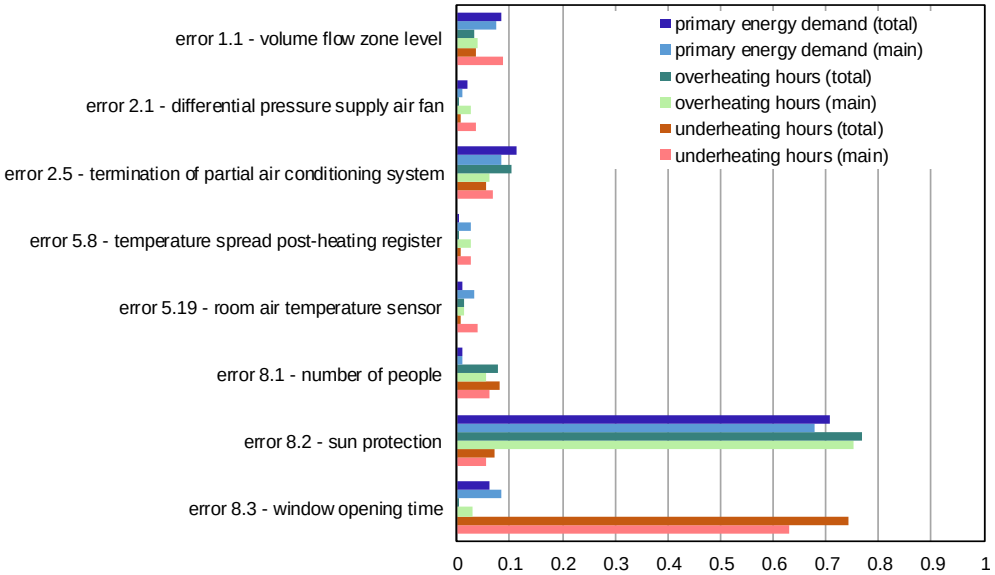


1st Qu.: 106.3 Kh/a
Median: 170.2 Kh/a [+21 %]
3rd Qu.: 289.2 Kh/a

[ ] compared to the basic simulation

Specific Uncertainty and Sensitivity Analysis: Step 1

Input parameter	Total effect	Main effect
Primary energy demand [kWh/(m²a)]		
error 8.2 - sun protection	0,71	0,68
error 2.5 - termination of PACS	0,11	0,08
Overheating hours [Kh/a]		
error 8.2 - sun protection	0,77	0,75
error 2.5 - termination of PACS	0,10	0,06
Underheating hours [Kh/a]		
error 8.3 - window opening time	0,74	0,63
error 8.1 - number of people	0,08	0,06



Specific Uncertainty and Sensitivity Analysis: Step 2

Comparison of Parameter Group A with B & C

error 2.5 – termination of partial air conditioning system	~ *U*(05:00; 24:00)	Parameter Group A
error 8.1 – number of people	~ *N*(2.0; 1.0)	
error 8.2 – sun protection	~ *U*(0.0; 1000.0)	
error 8.3 – window opening time	~ *U*(0.0; 0.25)	
minimum room air temperature setpoint	~ *N*(21.000; 0.970)	Parameter Group B
maximum room air temperature setpoint	~ *N*(24.000; 0.970)	
gas boiler efficiency	~ *U*(0.880; 0.990)	Parameter Group C
plant engineering (start of operation)	~ *U*(03:00; 05:00)	
plant engineering (end of operation)	~ *U*(18:00; 21:00)	
flow temperature cooling register	~ *U*(6.0; 14.0)	

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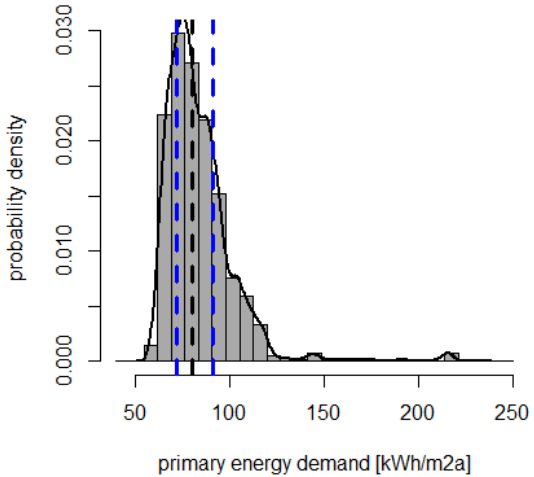
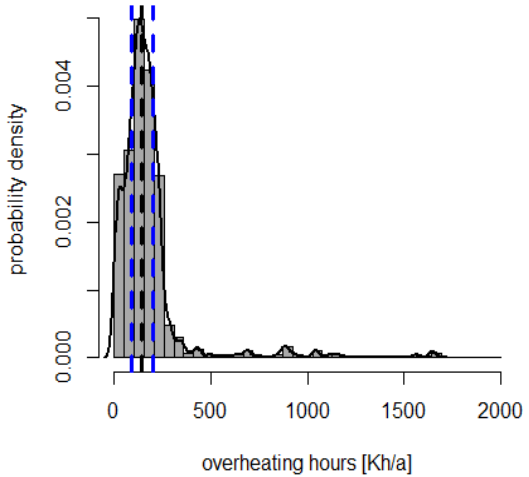
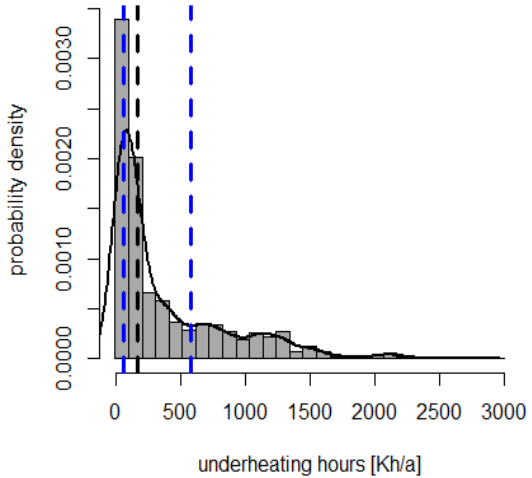
Specific Uncertainty and Sensitivity Analysis: Step 2



1st Qu.: 72.2 kWh/(m^{2}a)
Median: 79.8 kWh/(m^{2}a) [-14 %]
3rd Qu.: 91.1 kWh/(m^{2}a)



1st Qu.: 88.2 Kh/a
Median: 142.5 Kh/a [+42 %]
3rd Qu.: 199.8 Kh/a

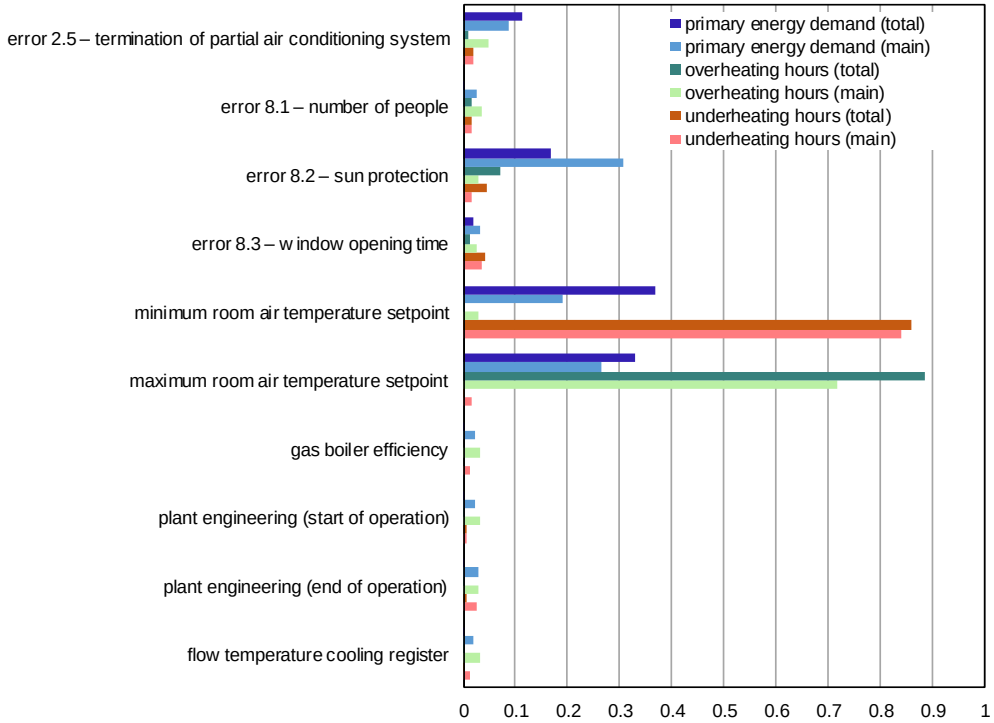


1st Qu.: 58.9 Kh/a
Median: 157.2 Kh/a [+12 %]
3rd Qu.: 577.1 Kh/a

[ ] compared to the basic simulation

Specific Uncertainty and Sensitivity Analysis: Step 2

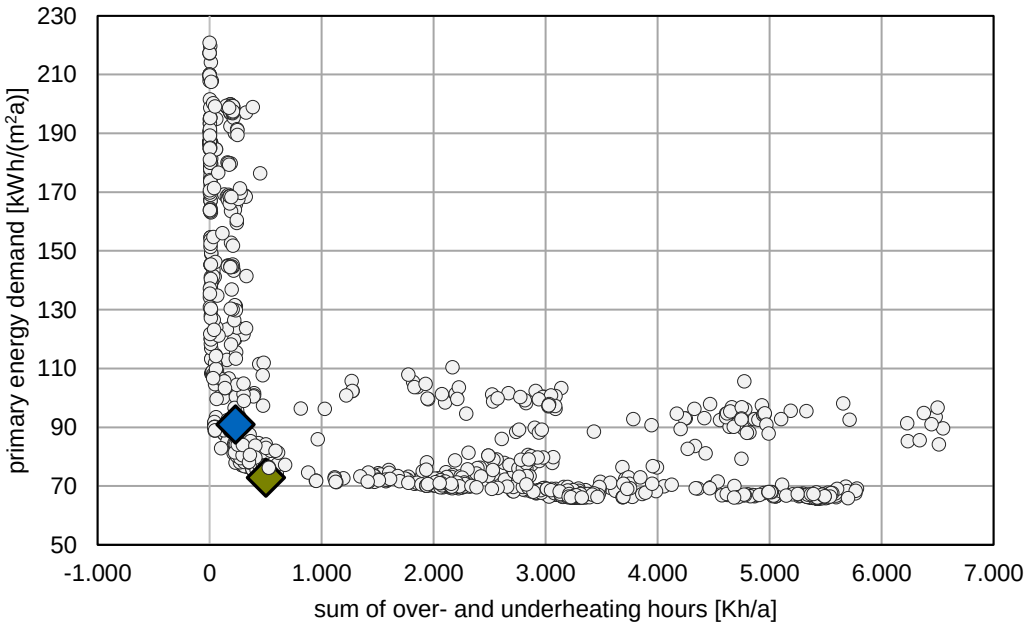
Input parameter	Total effect	Main effect
Primary energy demand [kWh/(m²a)]		
min. room air temperature setpoint	0,37	0,19
max. room air temperature setpoint	0,33	0,26
Overheating hours [Kh/a]		
max. room air temperature setpoint	0,89	0,71
error 8.2 - sun protection	0,07	0,03
Underheating hours [Kh/a]		
min. room air temperature setpoint	0,86	0,84
error 8.2 - sun protection	0,05	0,02



Optimisation

Input-Parameter	Einheit	Basisvar.	Präferierte Lösung
error 8.1 - number of people	-	2	5
error 8.2 - sun protection	W/m2	200,0	911,1
error 8.3 - window opening time	h/Tag	0,0	$1{,}7 \times 10^{-3}$
min. room air temperature setpoint	°C	21,0	20,8
max. room air temperature setpoint	°C	24,0	23,7

- 8 populations / 150 generations (1.200 simulations)



Conclusion

- Operational errors in PACS were examined for the first time with a MCS
- The operational errors have lower relevance than the *min.* and *max. room air temperature setpoint*
- Operational error *2.5 – termination of PACS* has a total effect of 11 % for the PED (Step 2)
- Parameter *8.2 – sun protection* has a total effect of 17 % and 7 % for the PED and the OHH (Step 2)
- Results from fault detection and diagnosis can be quantified with the simulation results

Outlook

- Mechanical and hydraulic errors could only be mapped to a limited extent
  → Use of equation-based software (e.g. Modelica)

- The analysis methods used resulted in long computing times (up to five days)
  → Mathematical replacement model

- With PACS only a part of the building technology could be examined

- Recommendation: taking into account constructional factors and target values in future work
  → mapping with little effort but increased informative value and comparability

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Question and Comments

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