- Energy efficient building climate control -

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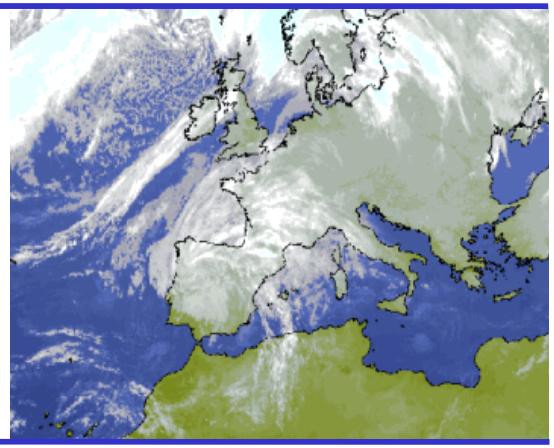

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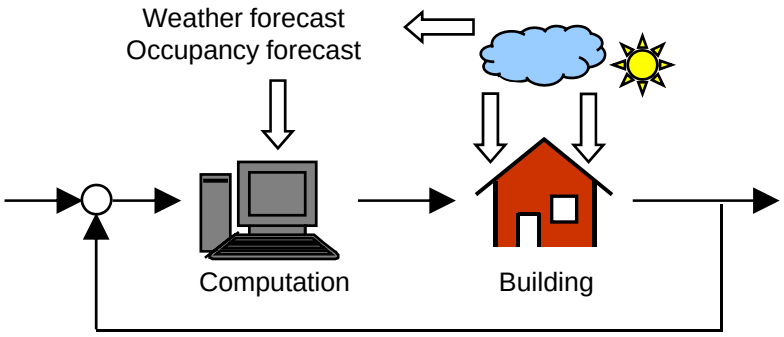
swisselectric research

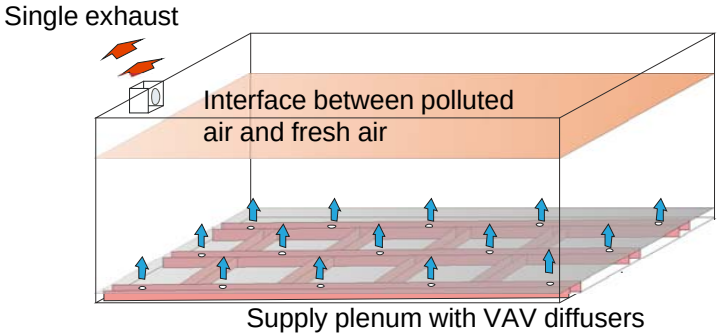
CCEM-CH Competence Center Energy and Mobility

Automatic Control Laboratory, ETH Zürich

Multidisciplinary Team



MPC controlled HVAC system



Underfloor ventilation system

ifn

OptiControl

Energy Efficient Ventilation

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MITSloan

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BP Institute
University of Cambridge

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Applied Sciences and Arts
HOCHSCHULE
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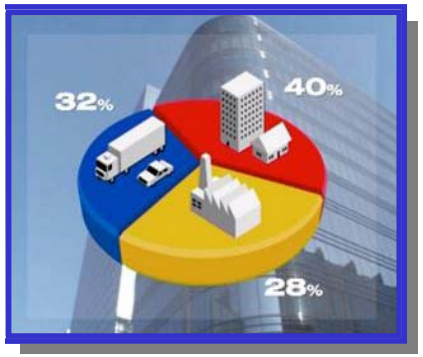
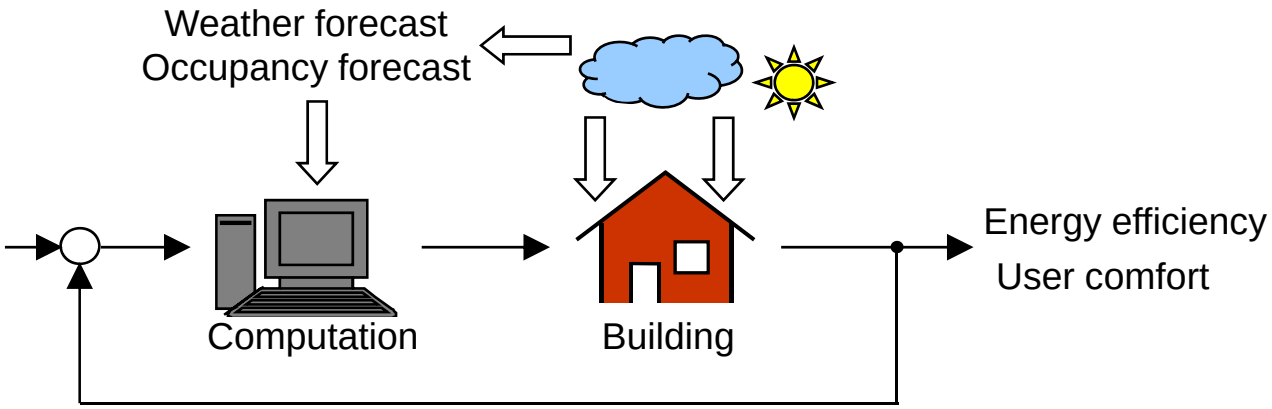
Use of weather and occupancy forecasts for optimal building climate control



Europe : 40% energy used in buildings



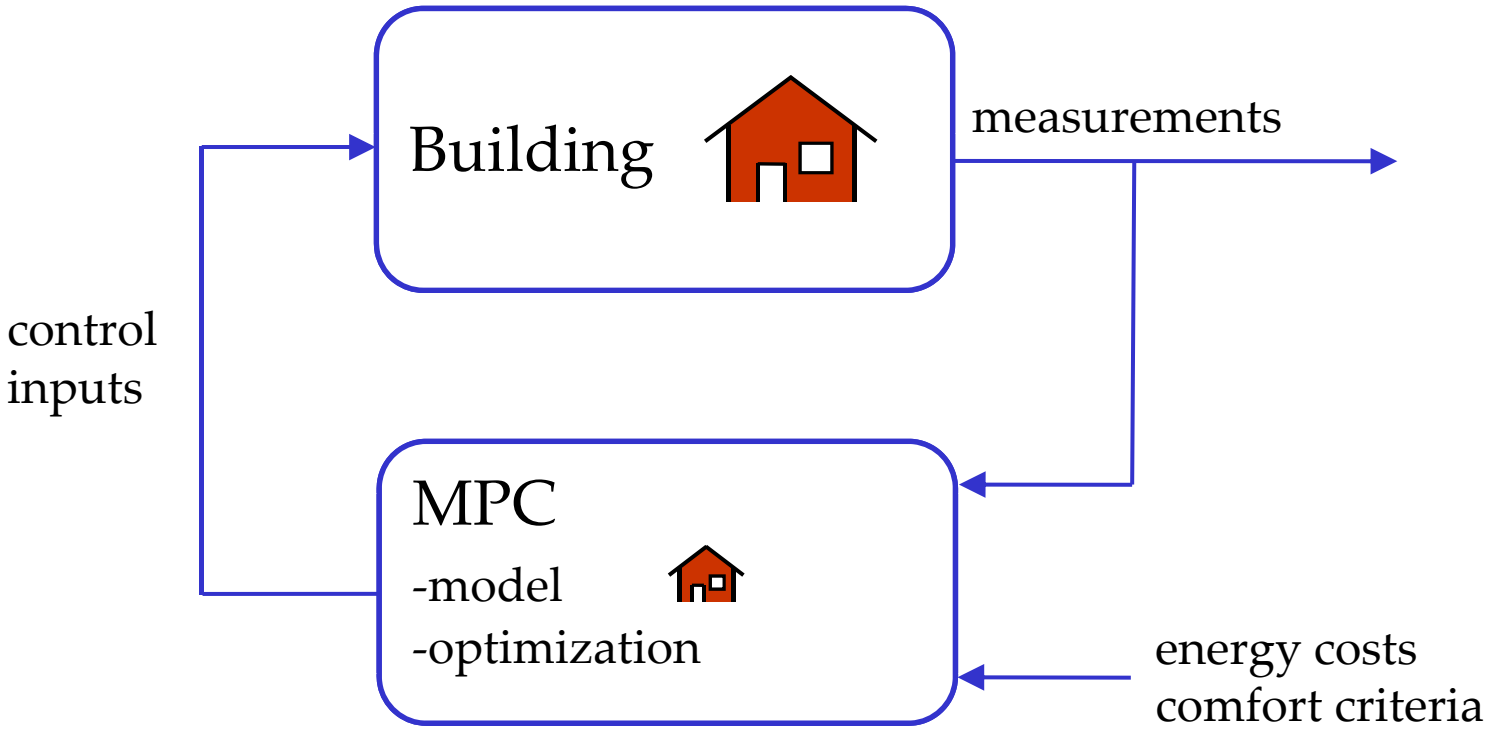
Standards: Keep room temperature in comfort range with a given probability

Goal: Satisfy constraints with a minimum amount of energy

Idea: Low carbon energy sources and building dynamics are slow and intermittent – use weather forecast for planning

Method: Model Predictive Control using weather and occupancy forecasts

Motivation
- Model predictive control (MPC) for buildings



Motivation
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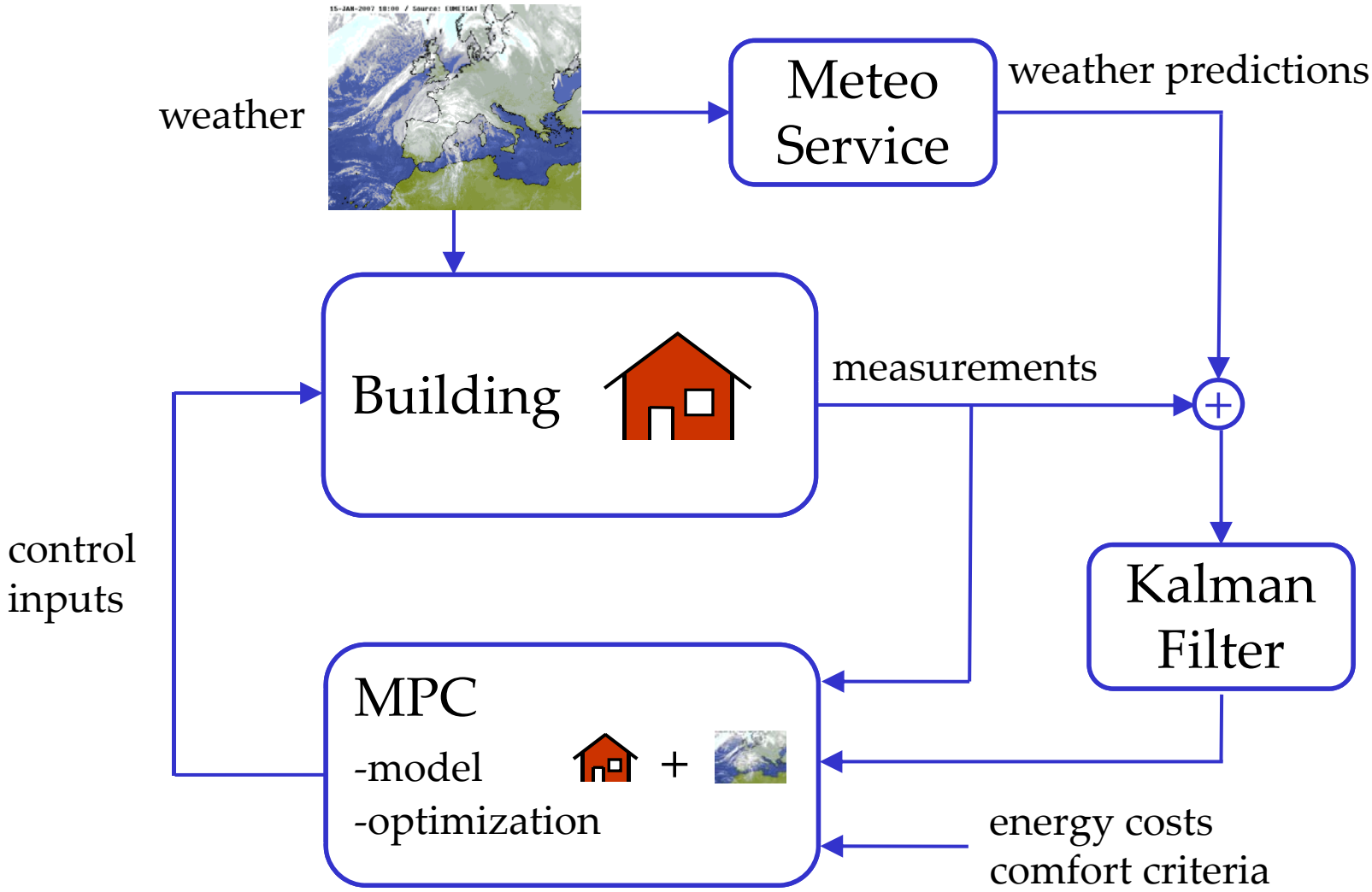
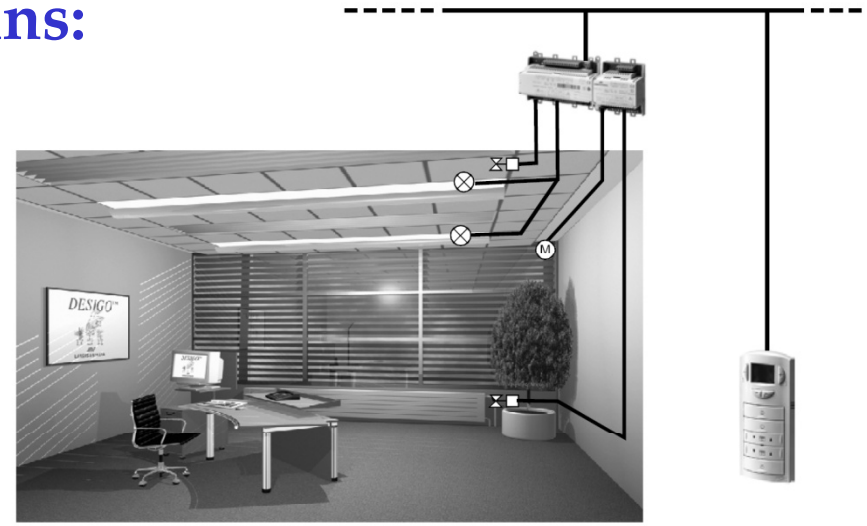
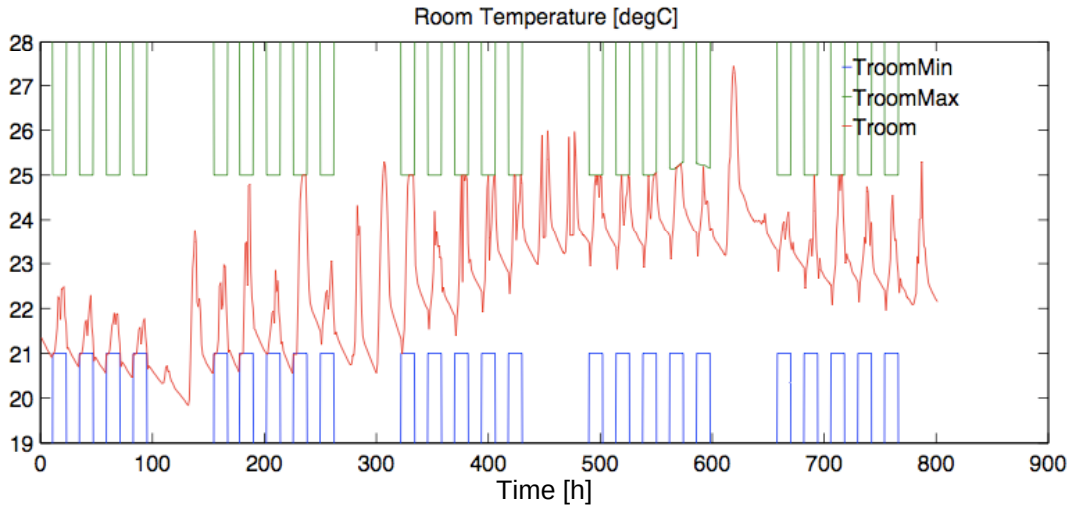


Application - Integrated room automation

Integrated room automation means:

Integrated control of the heating and cooling system, the blinds and the electrical lighting of a room





Control task:

Keep the room temperature, illuminance level and CO_2 concentration in prescribed ranges

Research questions

- How much energy can be saved by using advanced control techniques and weather predictions?

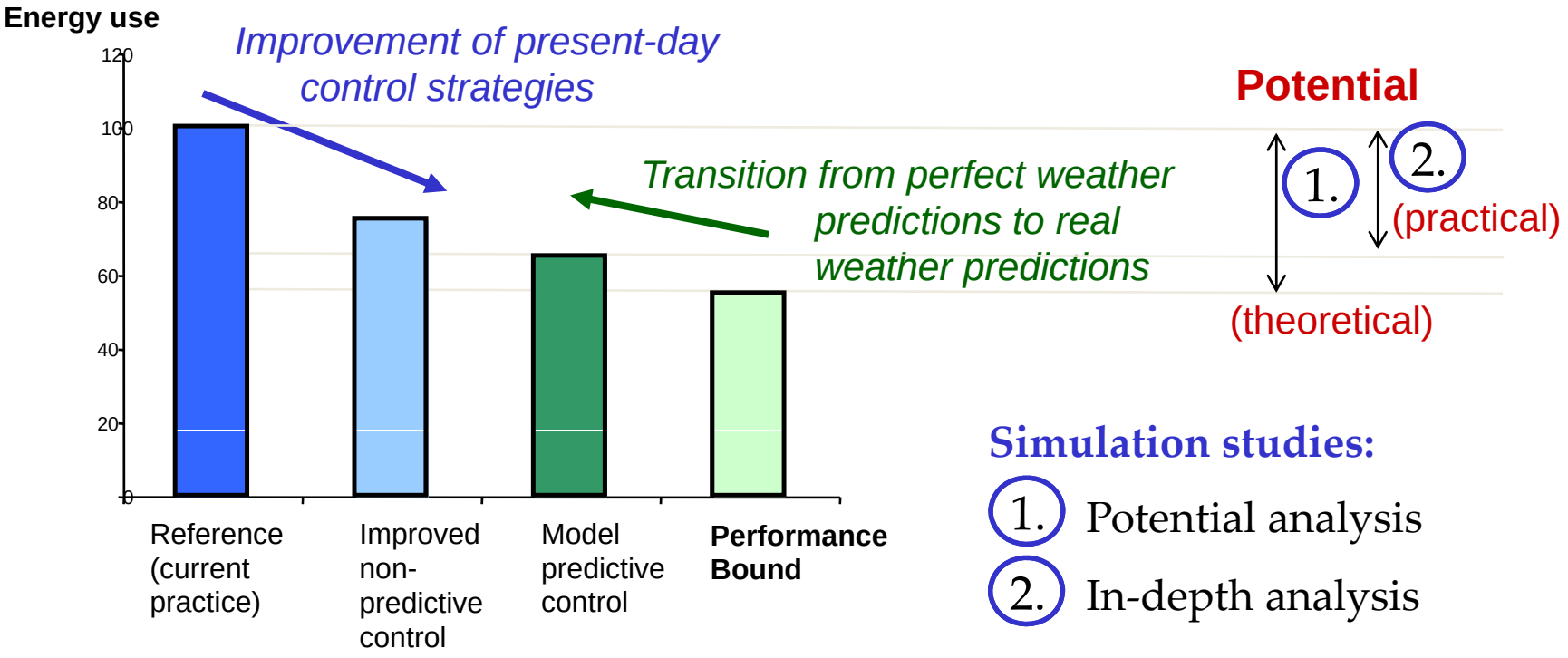
- In which buildings and in which weather conditions can savings be achieved?

Approach: Large-scale simulation study

Controller assessment – Concept

Consideration of weather prediction:

1. "**perfect world**–perfect weather prediction"
2. "**real world,** no weather prediction"
3. "**real world**, real weather prediction"



Simulation studies:

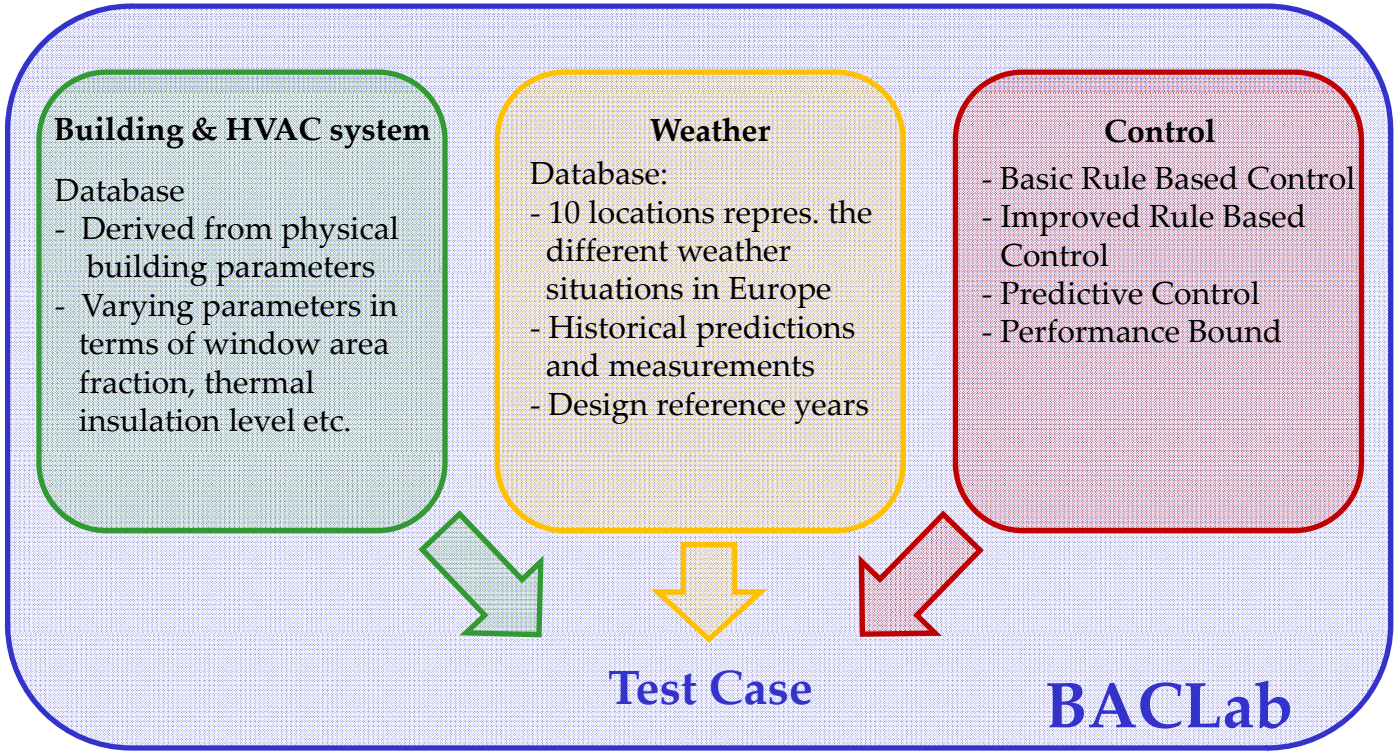
1. Potential analysis
2. In-depth analysis

Outline

- Modeling/ Setup simulation study
- Potential analysis
  → Comparison of current practice with Performance Bound
  – Example 1: Importance of blind control
  – Example 2: Potential of advanced control
  – Example 3: Prediction horizon length
- In-depth analysis
  → Comparison of advanced control with current practice
  – Stochastic MPC
- Hierarchical control with hybrid MPC

BACLab – Software tool

- **B**uilding **A**utomation and **C**ontrol **Lab**oratory
- MATLAB-based building modeling and simulation environment
- Developed within OptiControl project



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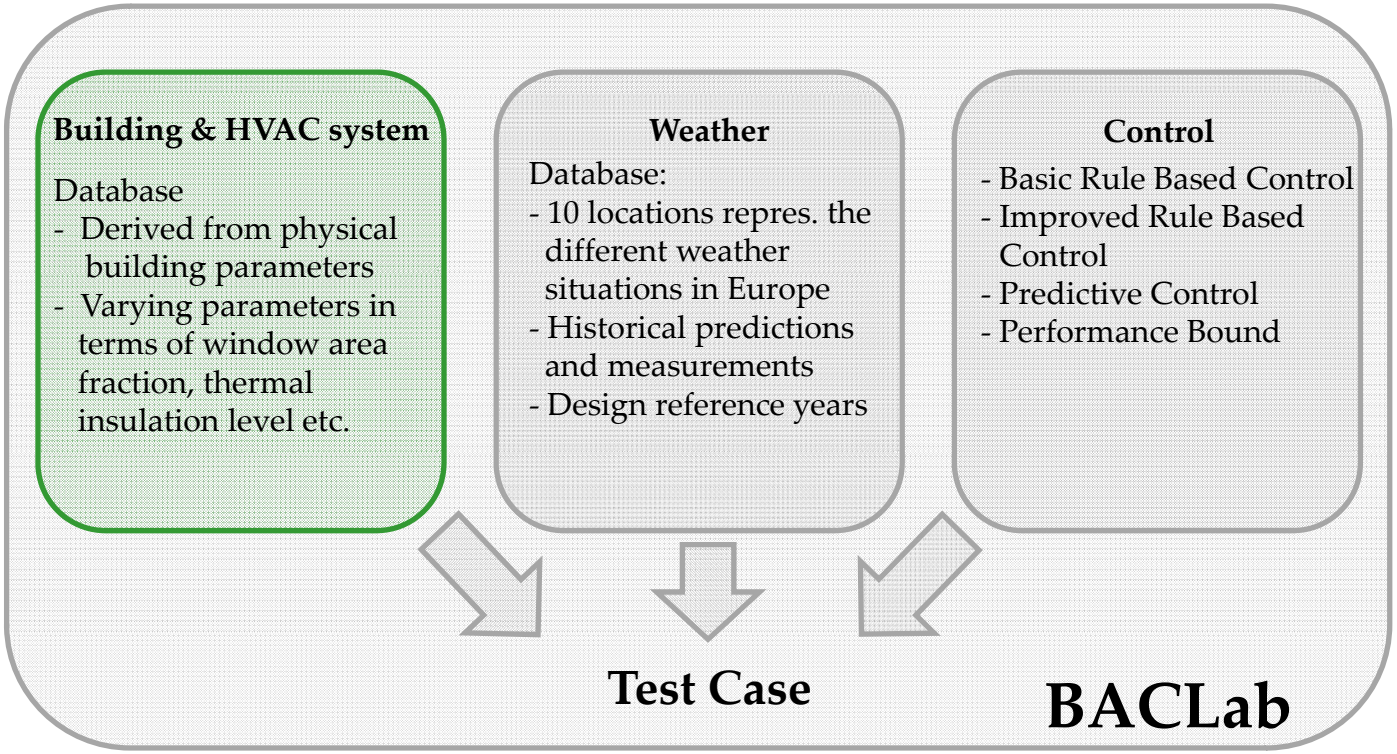

Factorial study
5 building systems – 7 parameter sets

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- Database of building & HVAC models typical for Europe
- Models validated with TRNSYS

Building systems

	S1	S2	S3	S4	S5
Blinds	x	x	x	x	x
Electric lighting	x	x	x	x	x
Mech. ventilation flow, heating, cooling	–	x	x	x	x
Mech. ventilation energy recovery	–	x	x	x	–
Natural ventilation (night-time only)	–	–	–	x	–
Cooled ceiling (capillary tube system)	x	x	–	–	–
Free cooling with wet cooling tower	x	x	–	–	–
Radiator heating	x	x	–	–	–
Floor heating	–	–	–	x	–
TABS	–	–	–	–	x

Factorial study
5 building systems – 7 parameter sets

EMPA
Materials Science & Technology

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Parameter Sets:

Building standard	Swiss average		Passive house
Construction type	heavy		light
Window area fraction	high		low
Internal gains (occupancy/equipment)	high		low
Thermal comfort: Setbacks	yes		no
Thermal comfort: Comfort range	wide		narrow
Ventilation	none	two-stage	CO_2 sensor

960 building cases · 10 locations · 4 orientations = 38.400 cases

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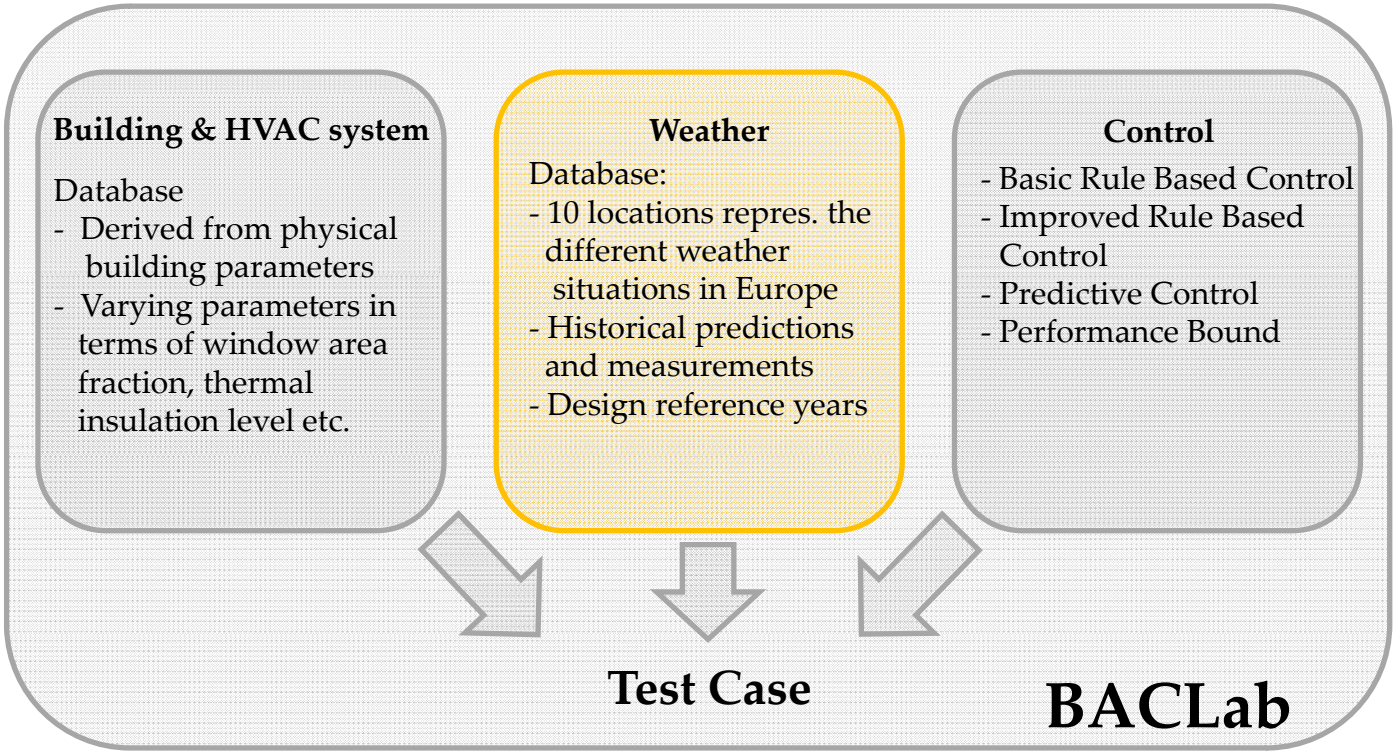

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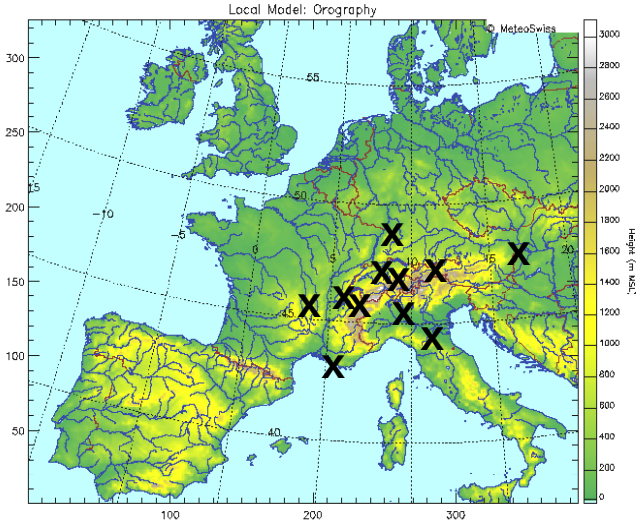
Weather predictions



Weather data:

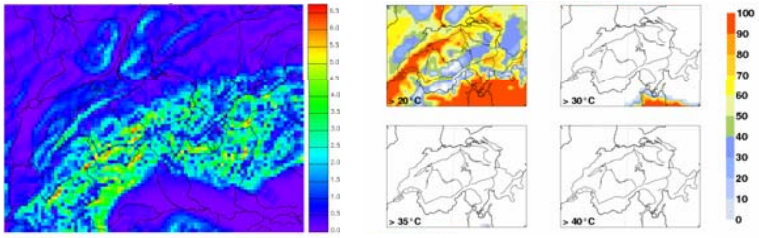
- Historical measurements
- Design reference year: representative annual data sets (according to SIA standard)

Weather predictions:

- Output of weather model by MeteoSwiss
- Persistence: next hour is like 24 hours ago

Zürich
Basel-Binningen
Genève-Cointrin
Lugano
Modena
Marseille-Marignane
Clermont-Ferrand
Mannheim
Hohenpeissenberg
Wien Hohe Warte

COSMO 7 weather model
- deterministic forecast
- 2 daily 72 hour forecast
- Region of Europe
- 385 x 325 gridpoints, 7km mesh
- 45 terrainfollowinglevels



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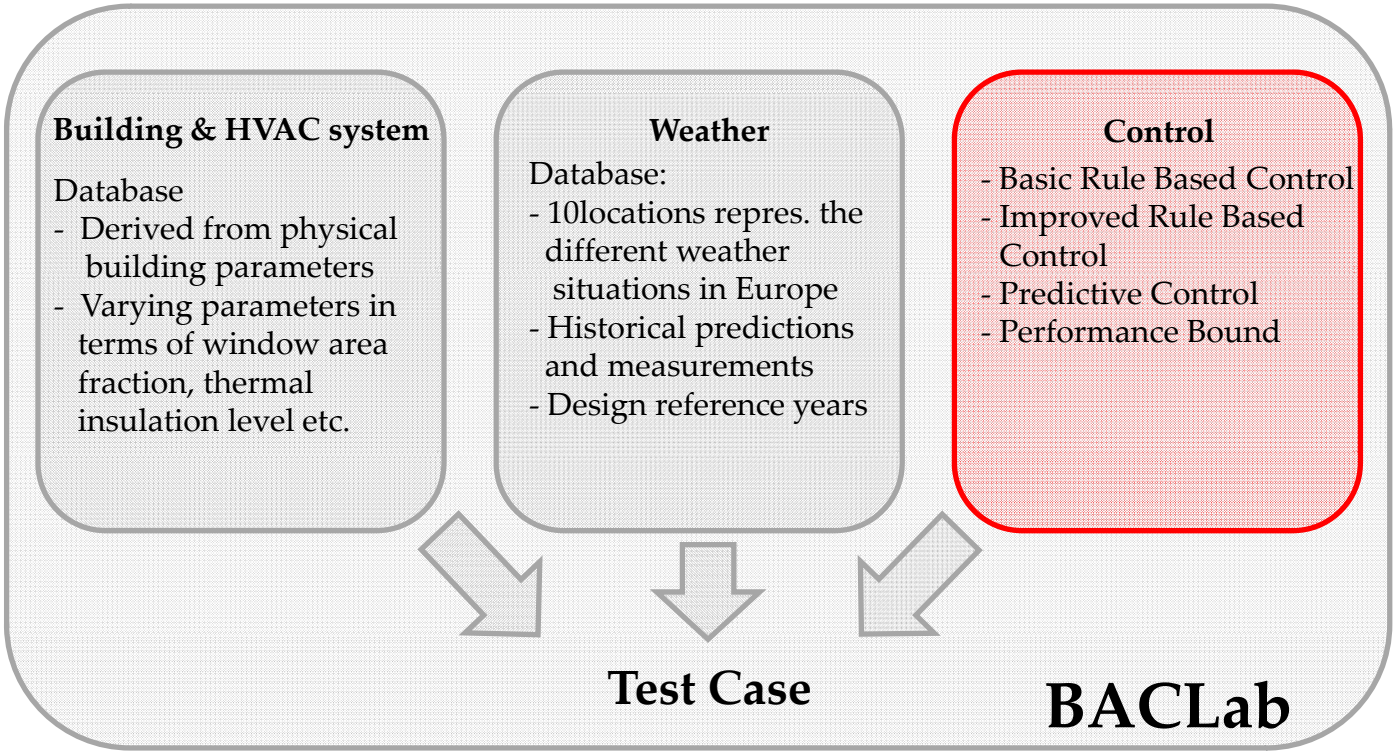
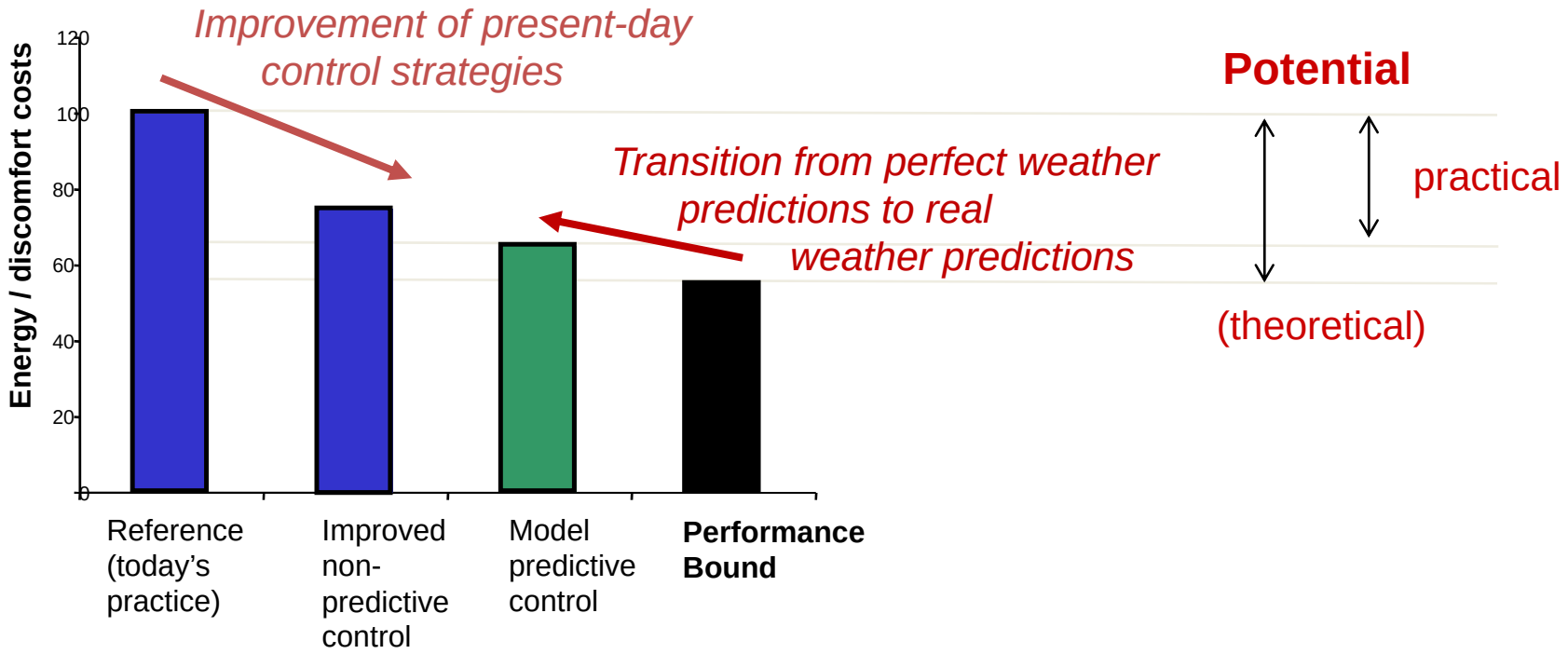


Controller approaches

practical ⟷ theoretical

	Based on rules		Based on MPC		Performance Bound



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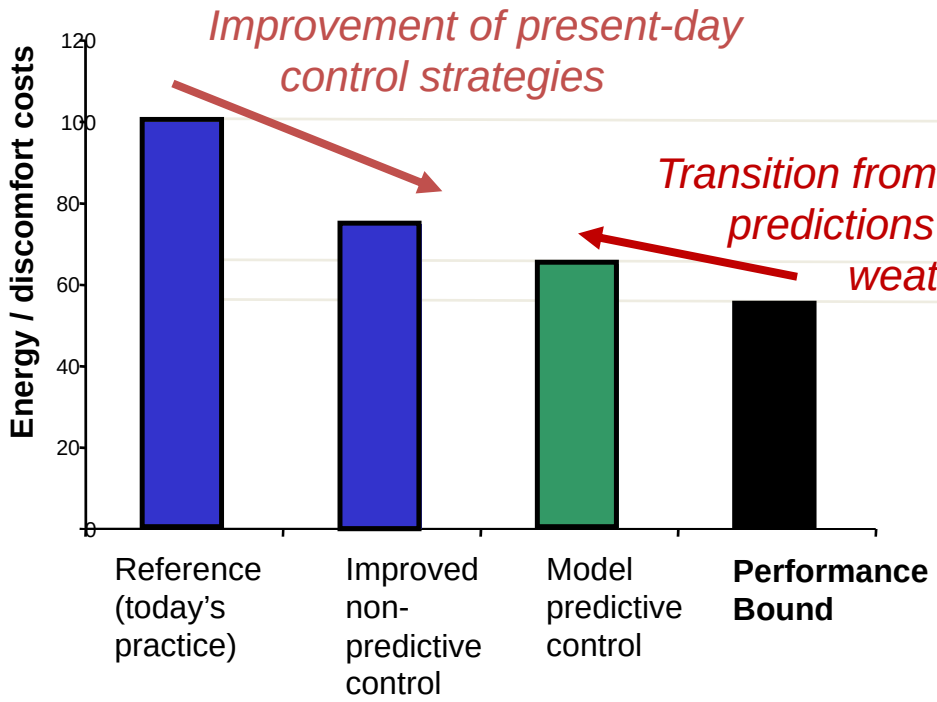


Potential

practical

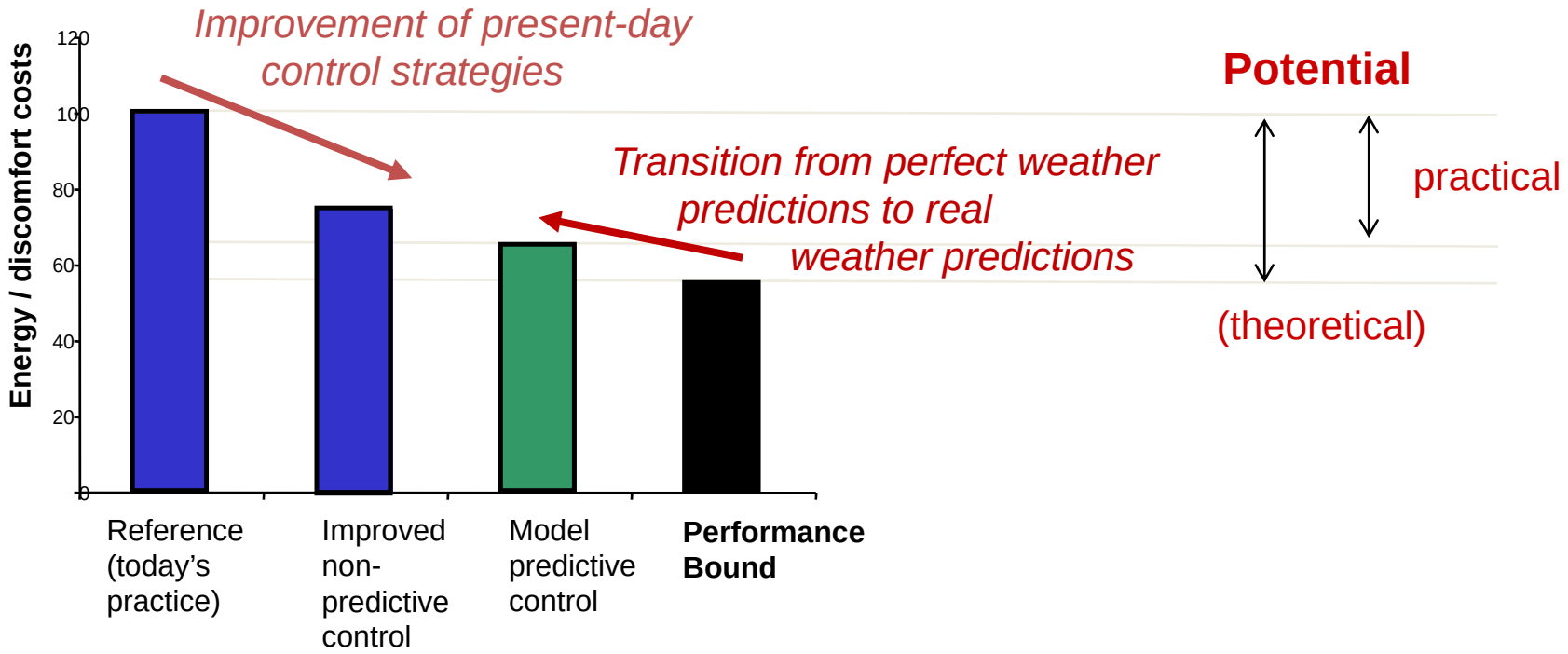
(theoretical)

Performance Bound = optimal control with perfect weather prediction

Controller approaches

practical ⟷ theoretical

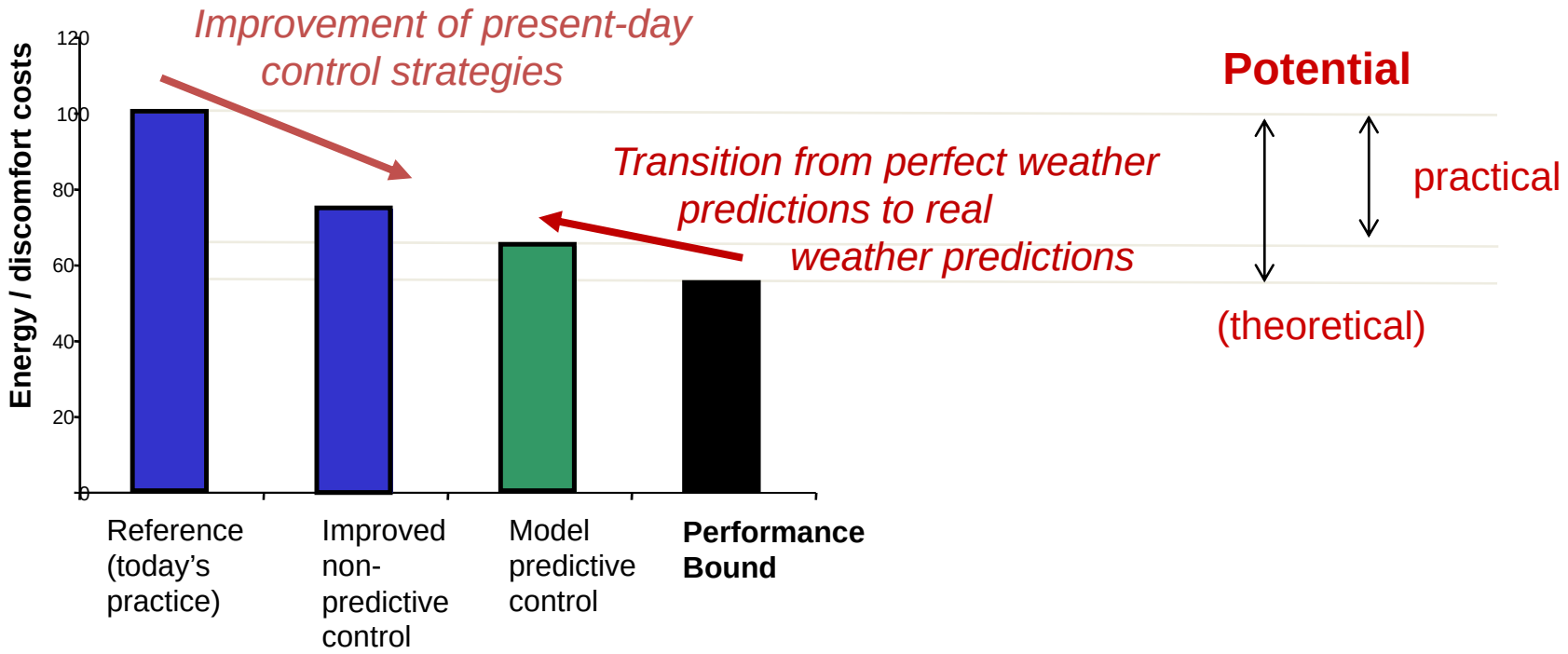
	Based on rules		Based on MPC		Performance Bound
	Current Practice	Improved Rule Based Control			



Controller approaches

practical ⟷ theoretical

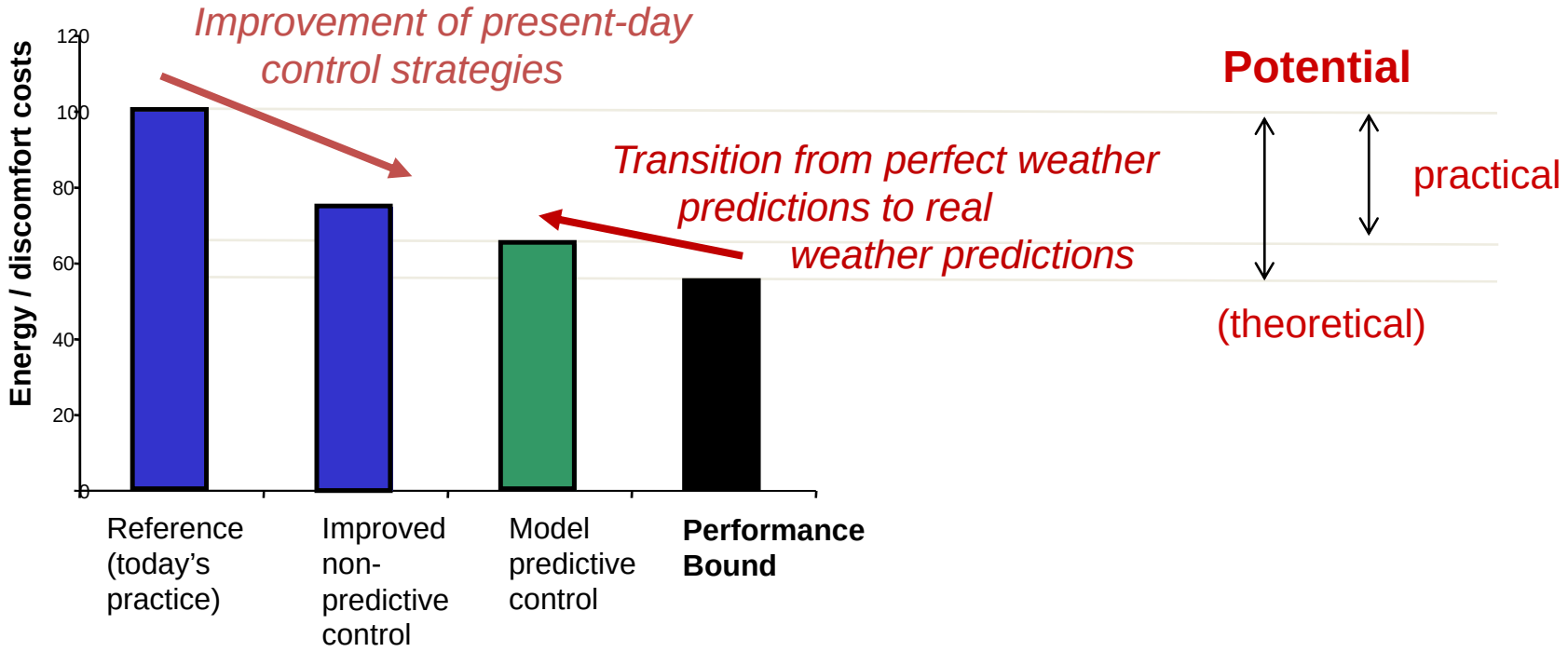
	Based on rules		Based on MPC		Performance Bound
	Current Practice	Improved Rule Based Control	Deterministic MPC	Stochastic MPC	



Controller approaches

practical ⟷ theoretical

	Based on rules		Based on MPC		Performance Bound
	Current Practice	Improved Rule Based Control	Deterministic MPC	Stochastic MPC	
Model based	no	no	yes	yes	yes
Weather pred.	none	none	realistic	realistic	perfect



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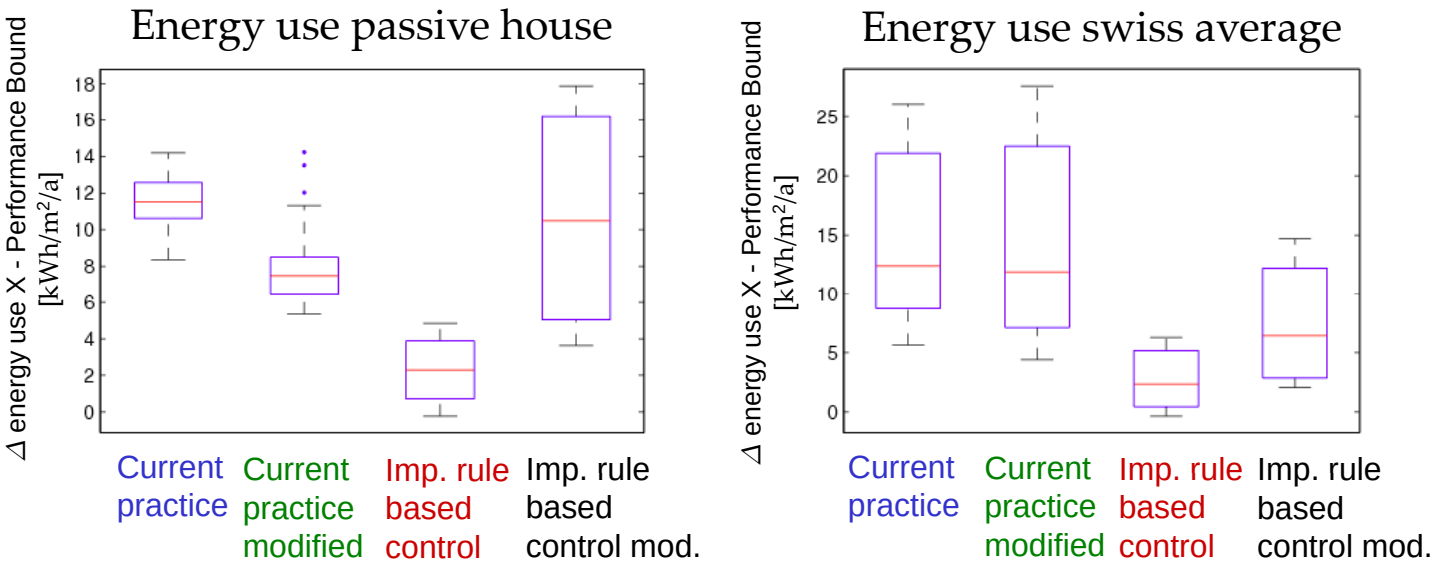
Potential analysis
- Example 1: Importance of blind control

	Current Practice	Current Practice modified (more blind freedom)	Improved Rule Based Control (more info)	Imp. Rule Based Control modified (blinds hourly)
avail. position	open, 50%,closed	continuous	continuous	continuous
movement frequency	hourly	continuous	continuous	hourly
measurements used	current	current	current + past	current + past



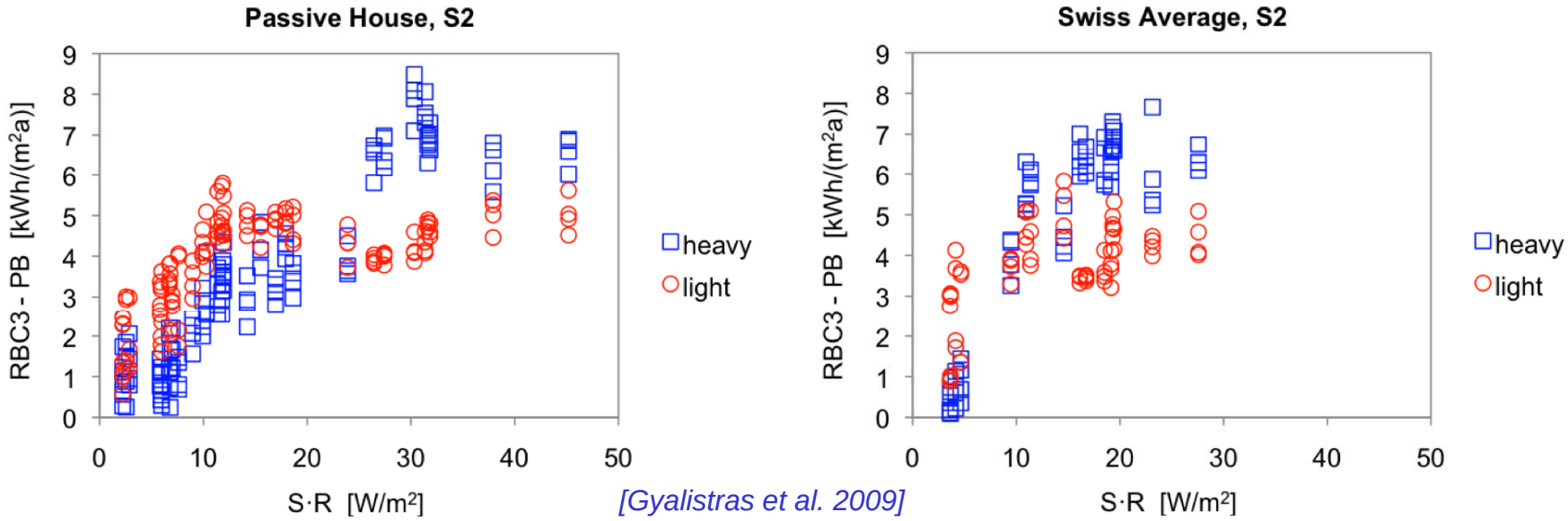
[Gyalistras et al. 2009]

Importance of solar gain area

Specific solar gain area

$$S = \frac{g \cdot A_{win}}{A_{floor}}$$

R = annual average of vertical global radiation components



[Gyalistras et al. 2009]

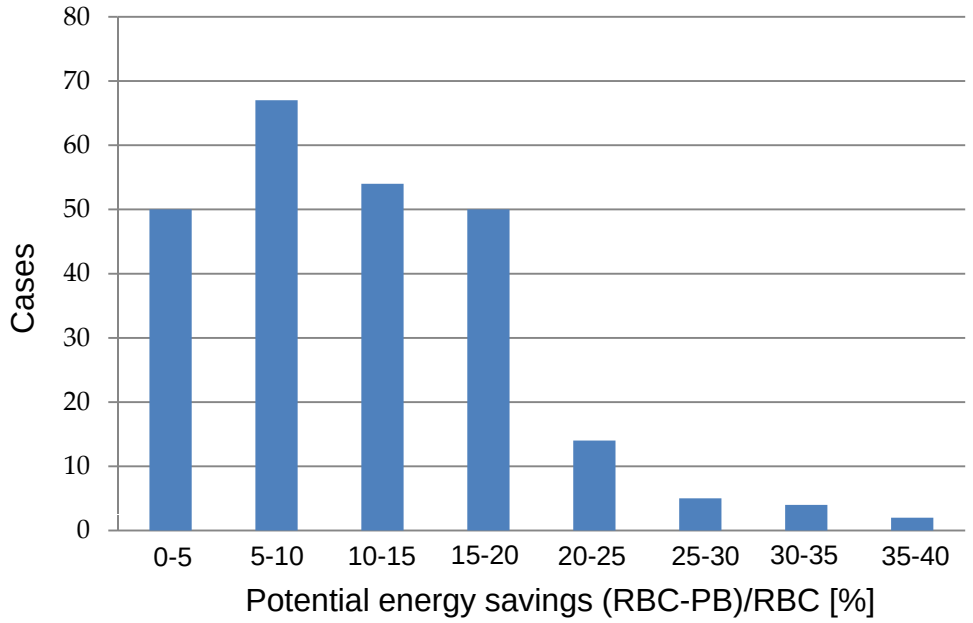
Large savings potentials:

- with high solar gains are and heavy building
- with low solar gains and light building

Potential analysis
- Example 2: Potential for advanced control

Goal: Isolate effect of advanced control

Comparison: Performance Bound vs. Improved Rule Based Control
- Blind control perfect (continuous)
- 250 cases considered



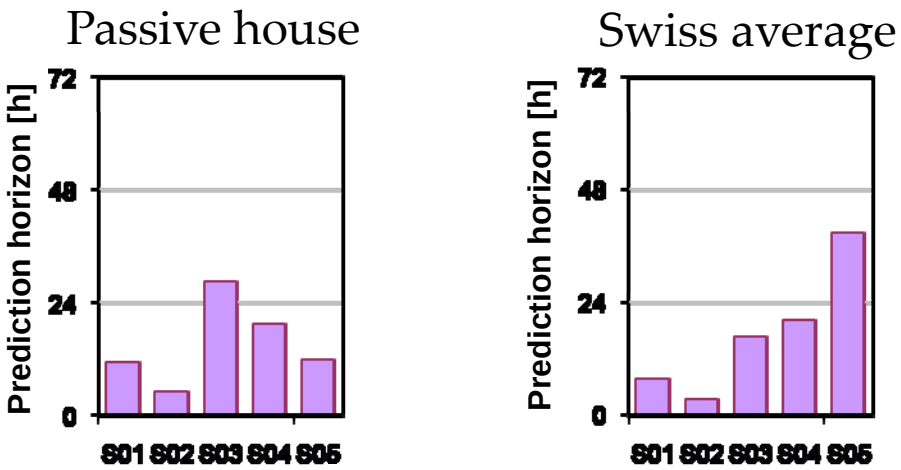
[Oldewurtel et al. 2009]

→ Even with Improved Rule Based Control and perfect blind control: Large potential in many cases!

Potential analysis
- Example 3: Prediction horizon length

Goal: Choose horizon length, get error to Performance Bound to 5%

Comparison: Performance Bound vs. Performance Bound with shorter horizon lengths



[Gyalistras et al. 2009]

→ In the following investigations we use a horizon of 24h.

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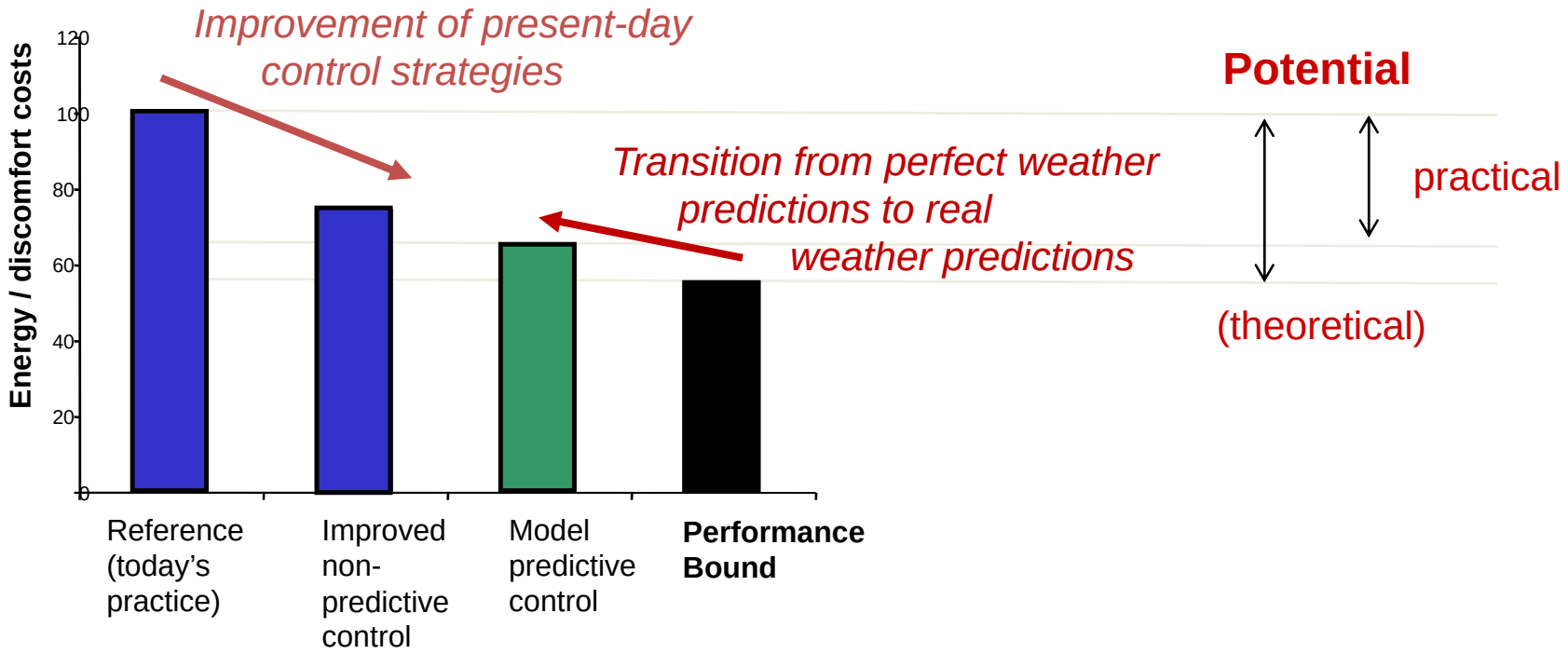
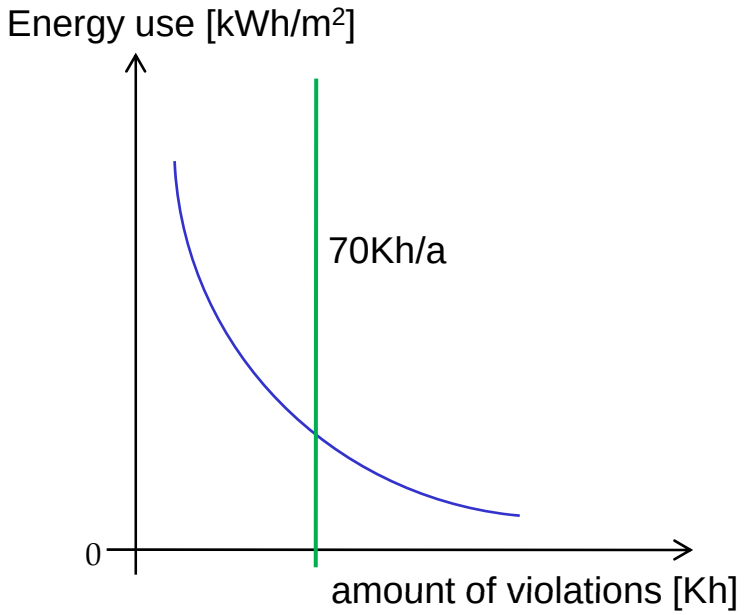
	Current Practice	Improved Rule Based Control	Deterministic MPC	Stochastic MPC	



Simulations

Tradeoff curve
energy vs. violations

- comfort level can be adjusted
- standards: 70Kh/a



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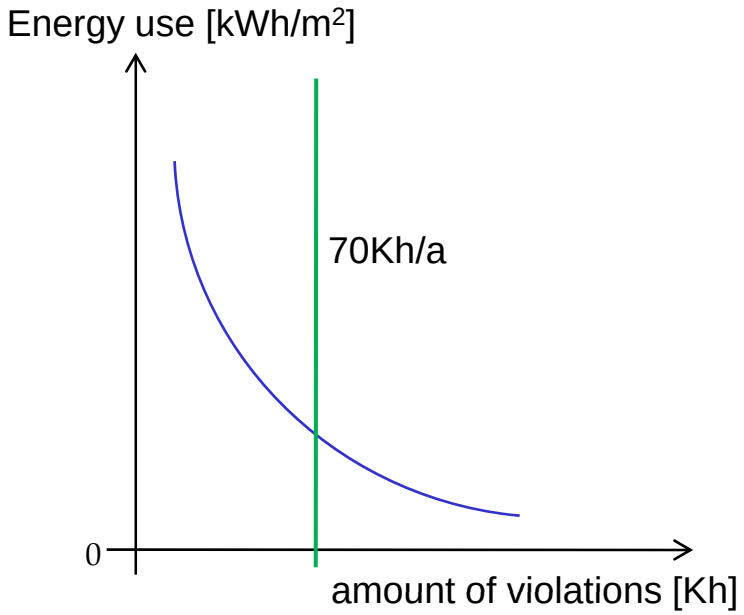
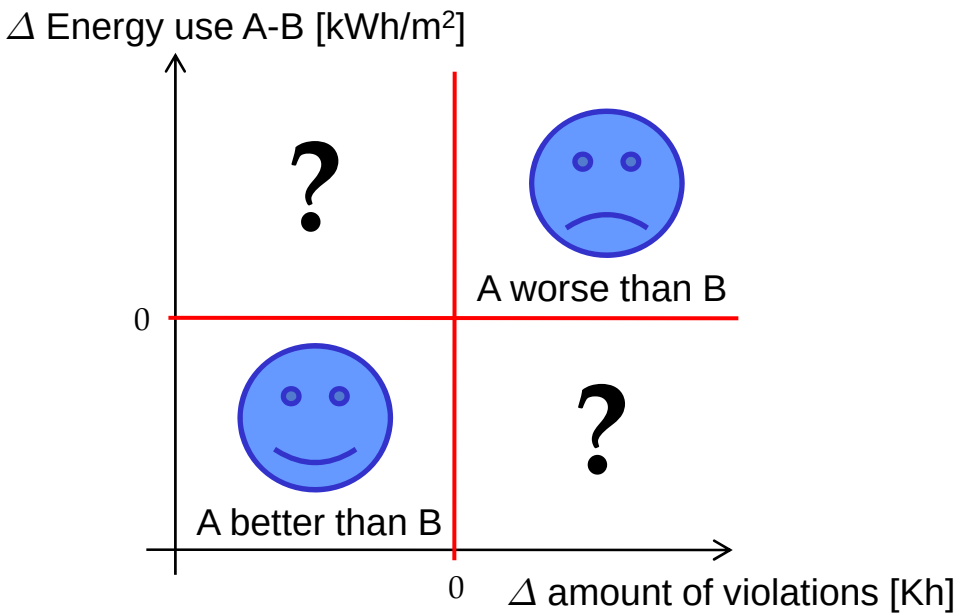


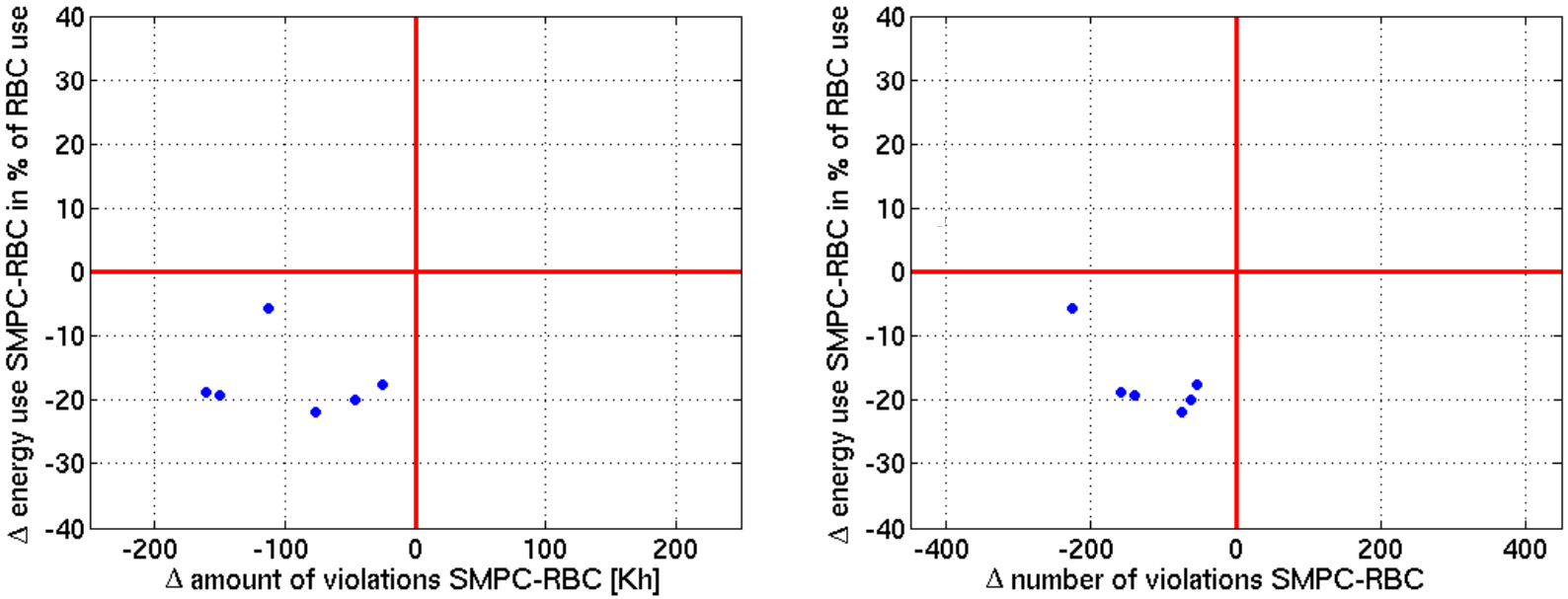
Comparison of controllers A and B
- 4 possible cases
- 2 cases undetermined (controller need to be tuned to be comparable)



Simulation results

Goal: Investigate improvement with Stochastic MPC
Comparison: Stochastic MPC vs. Improved Rule Based Control with hourly blind movement

- Difference in energy use as % savings of improved rule based control
- Difference in violations (amount & number) as absolute values



[Oldewurtel et al. 2009]

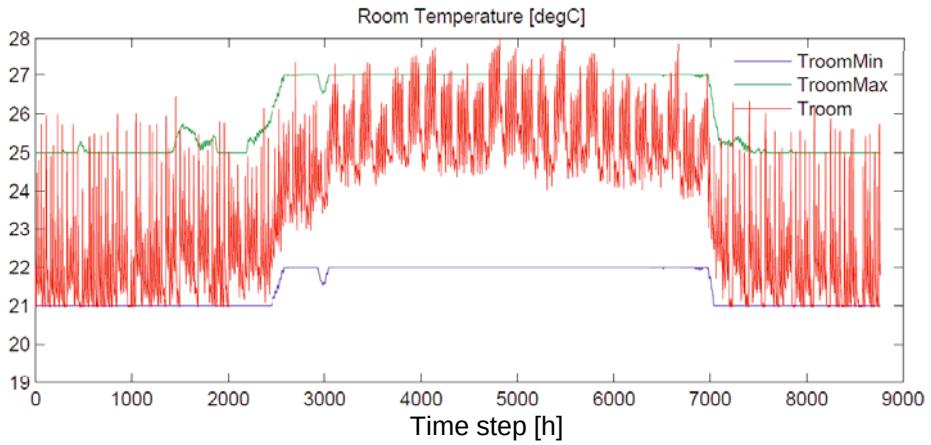
→ Stochastic MPC outperforms Improved Rule Based Control!

Simulation results

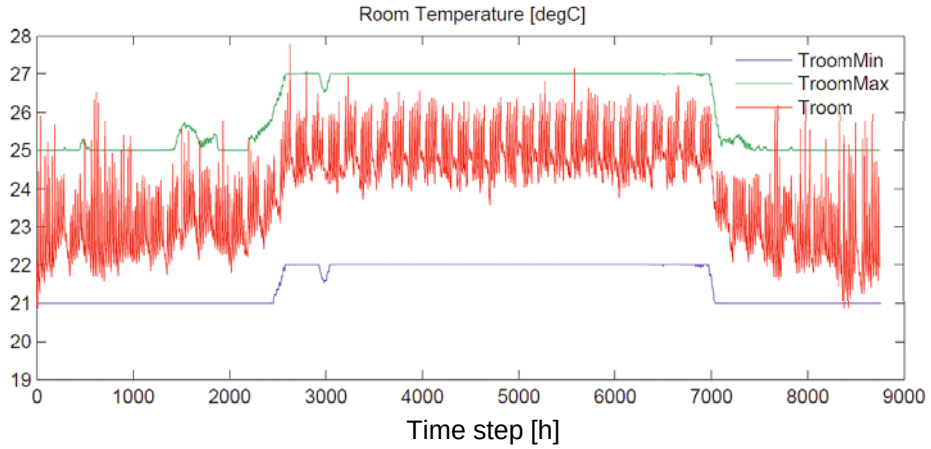
Room temperature behavior

- Energy saving with Stochastic MPC: up to 22%
- Violation savings with Stochastic MPC: up to 160Kh

Improved rule-based control (current and past measurements, hourly blind movement)



Stochastic MPC



[Oldewurtel et al. 2009]

→ Diurnal temperature variations are more favorable with Stochastic MPC!

Dimitrios Gyalistras & Markus Gwerder (Eds.)

Use of Weather and Occupancy Forecasts For Optimal Building Climate Control (OptiControl): Two Years Progress Report

Reporting Period May 2007–April 2009

[illegible]

Available December 2009!

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R&D HVAC Products, Building Technologies Division, Siemens Switzerland Ltd., Zug

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Summary

- **Large-scale simulation studies** carried out
- **Large potential** for advanced control strategies in many cases
- **Stochastic MPC** can significantly **improve performance**
- **Hybrid MPC** solution for **hierarchical control** can significantly **improve performance**

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Fig: View at the buildings in ETH Hönggerberg.