# - Energy efficient building climate control -

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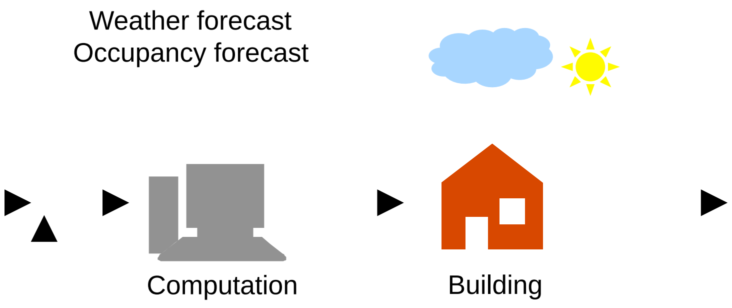
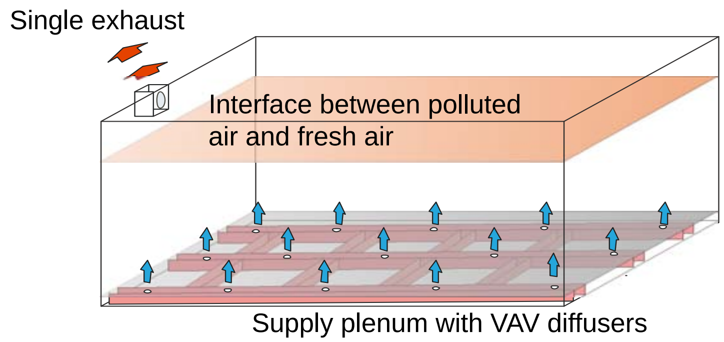
# Multidisciplinary Team




*MPC controlled HVAC system*




*Underfloor ventilation system*

## OptiControl

## Energy Efficient Ventilation

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Confédération suisse
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EMPA
Materials Science & Technology

MIT Sloan

SIEMENS
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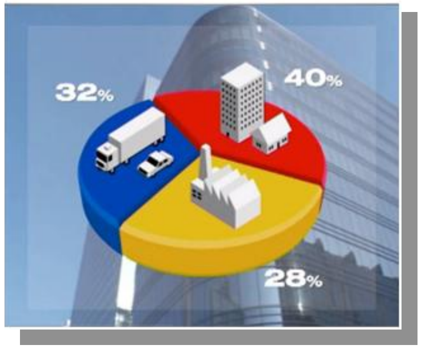
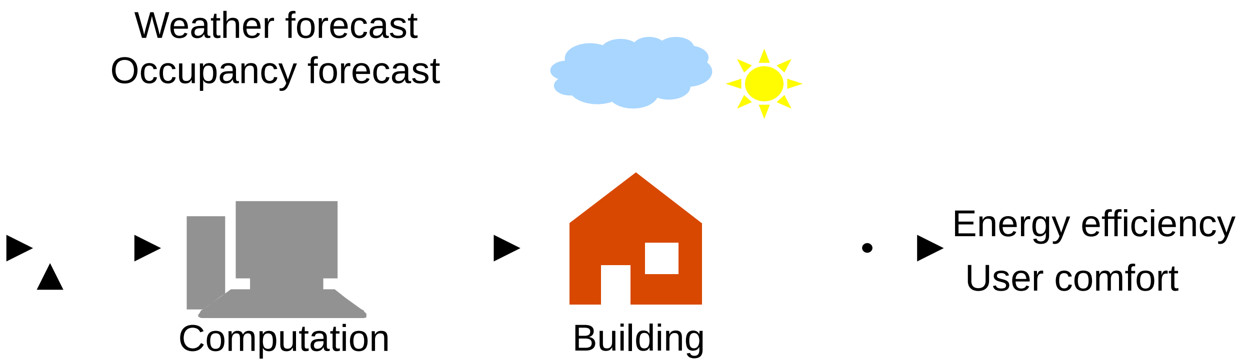
Institute
...iversity of Cambridge

Lucerne University of
Applied Sciences and Arts
HOCHSCHULE
LUZERN

# Use of weather and occupancy forecasts for optimal building climate control




## Europe : 40% energy used in buildings



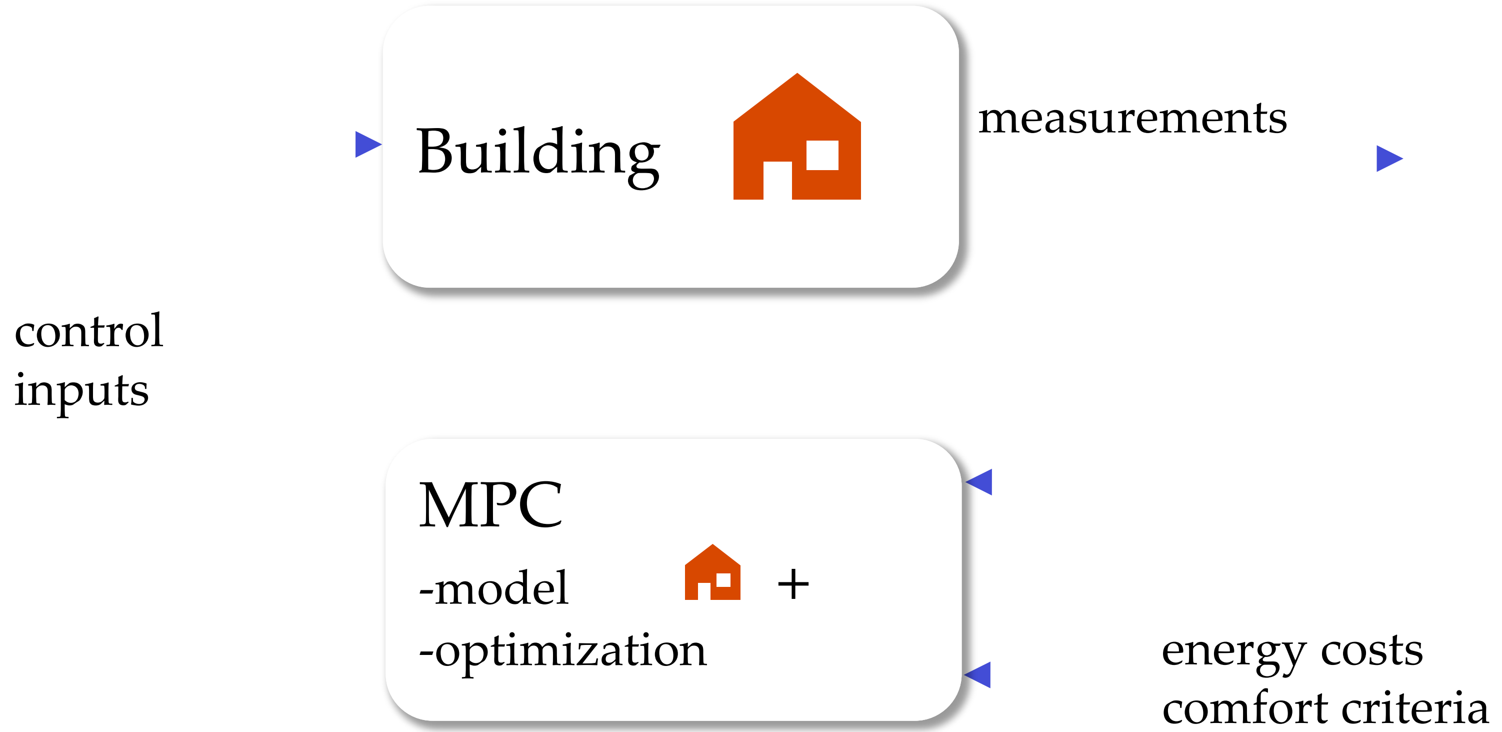

**Standards:** Keep room temperature in comfort range x % of time

**Goal:** Satisfy constraints with a minimum amount of energy

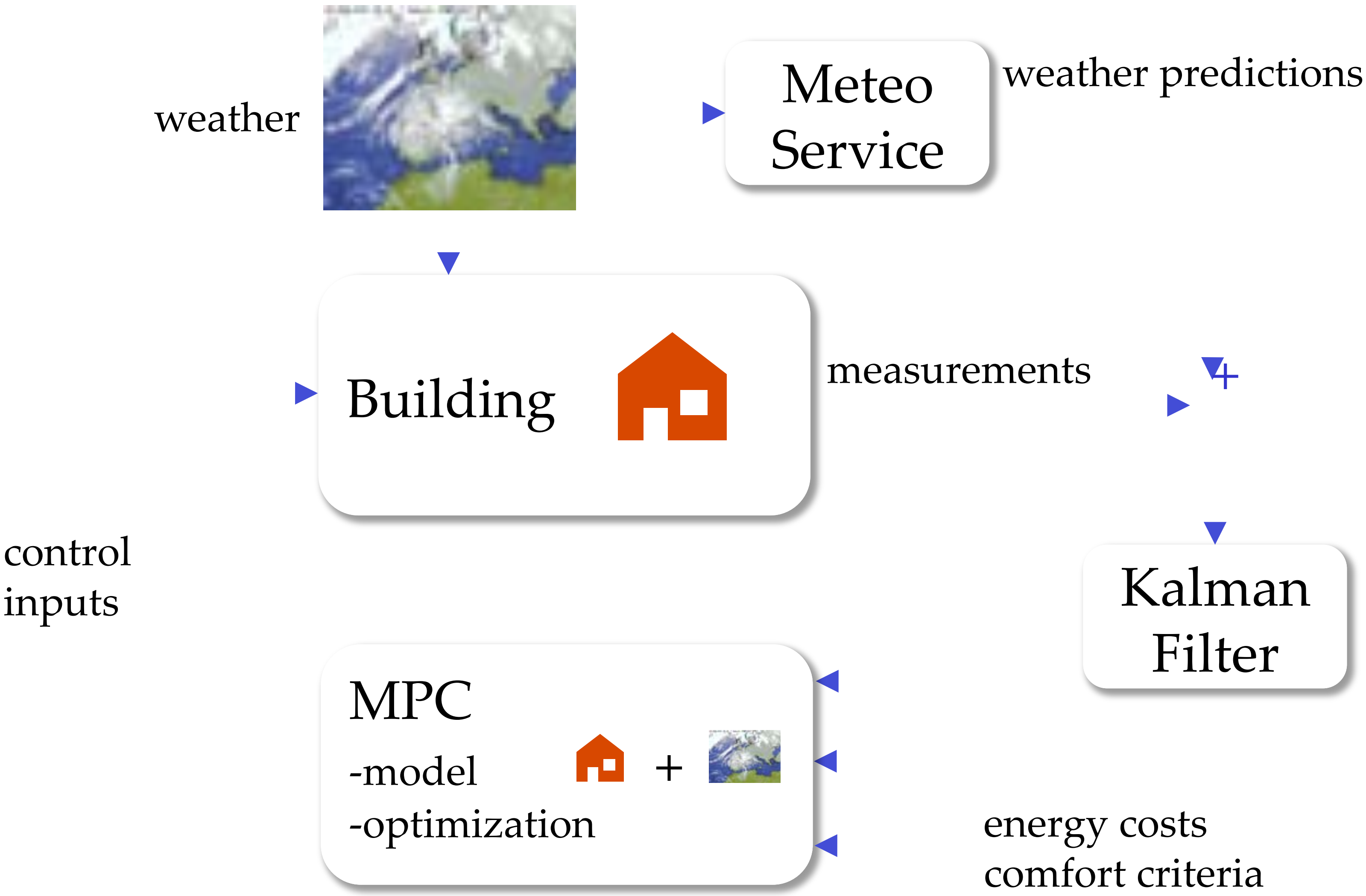
**Idea:** Low carbon energy sources intermittent, building dynamics slow – use weather forecast for planning

**Method:** Model Predictive Control using weather and occupancy forecasts

# Motivation
# - Model predictive control for buildings



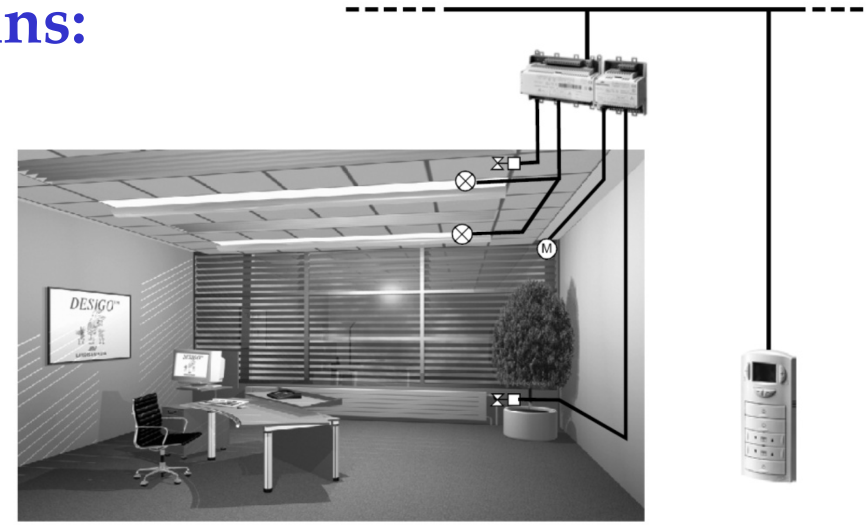
# Motivation
# - Model predictive control for buildings

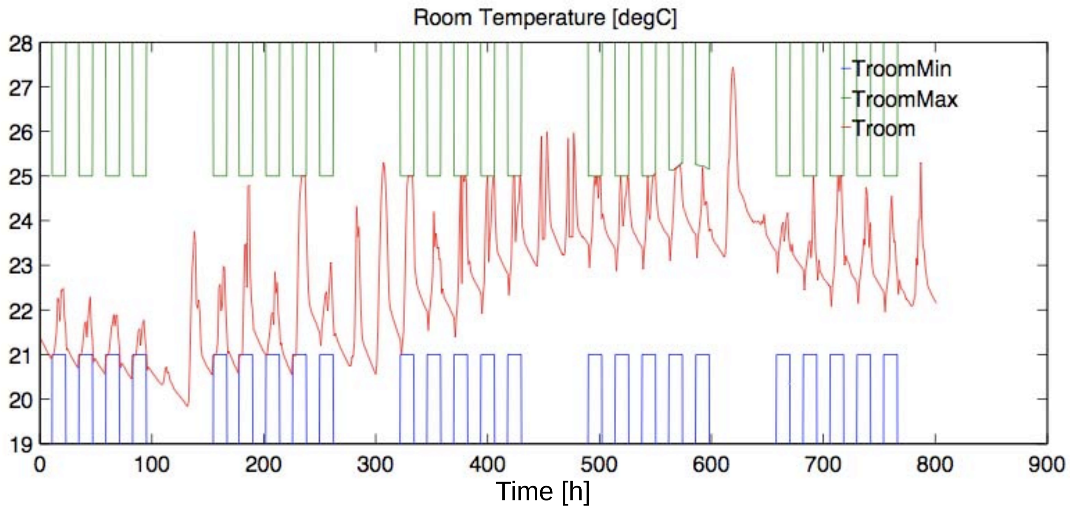


# Application - Integrated room automation

## 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?

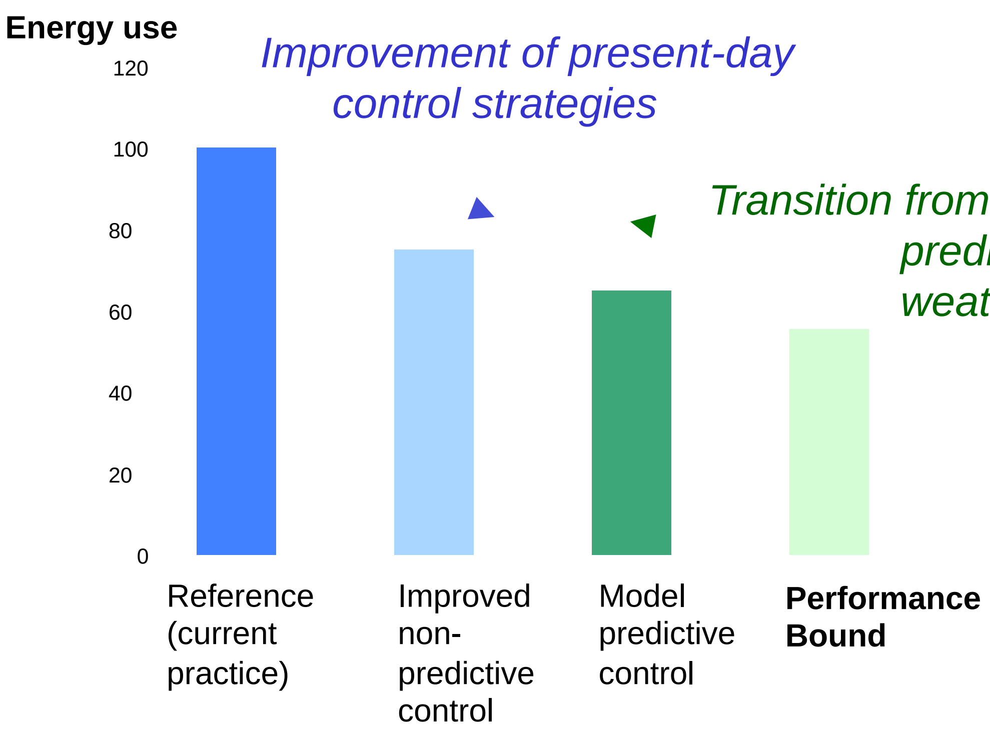
- In which buildings and in which weather conditions can savings be achieved?

**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"




*Transition from perfect weather predictions to real weather predictions*

**Potential**

1. (theoretical)

2. (practical)

## Simulation studies:

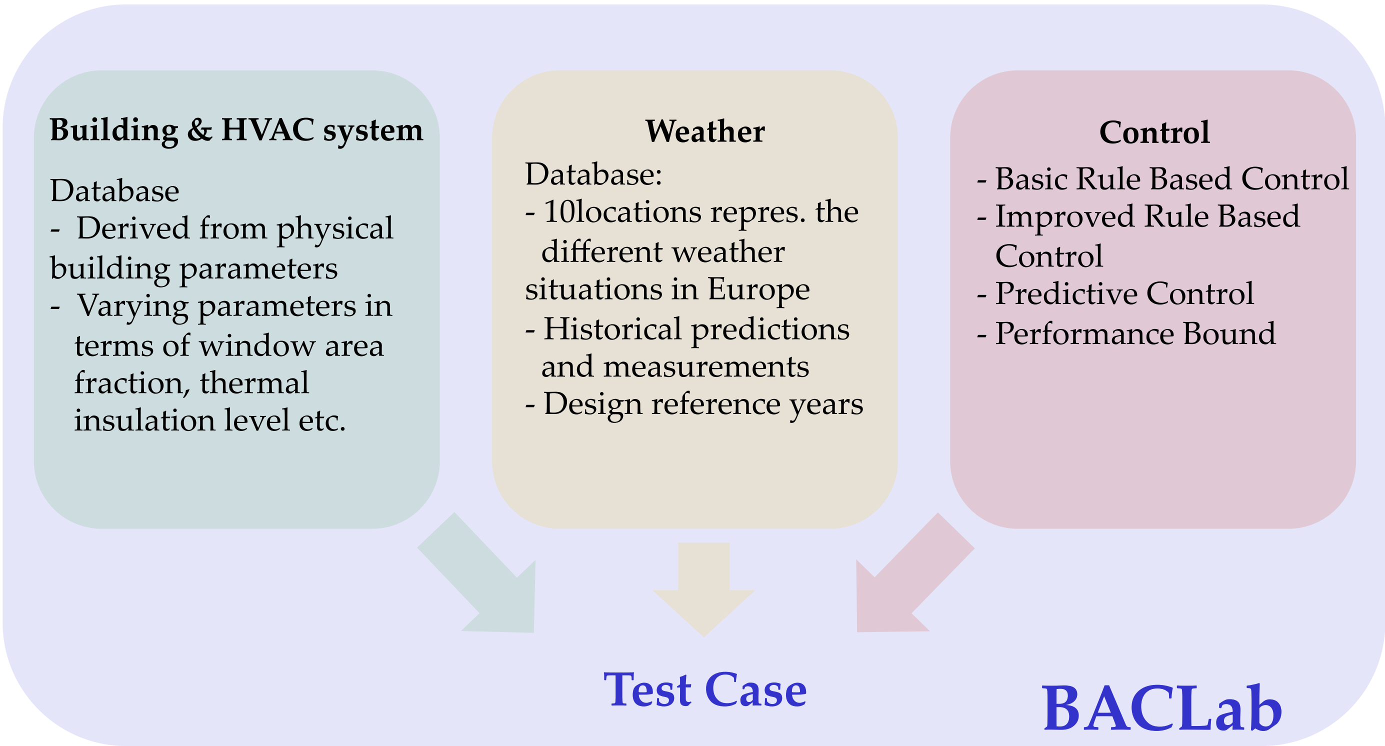
1. Potential analysis
2. In-depth analysis

# 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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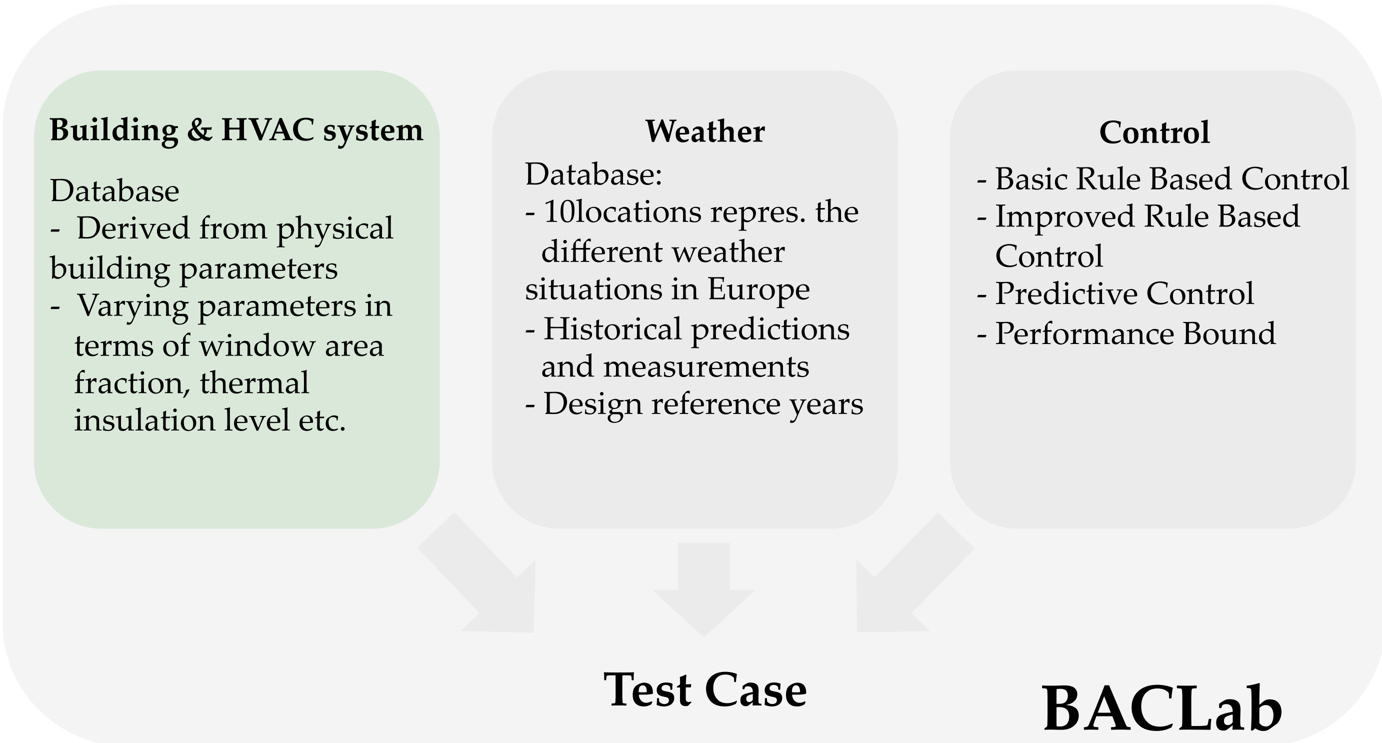

# Factorial study
# 5 building systems – 7 parameter sets

- 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

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

**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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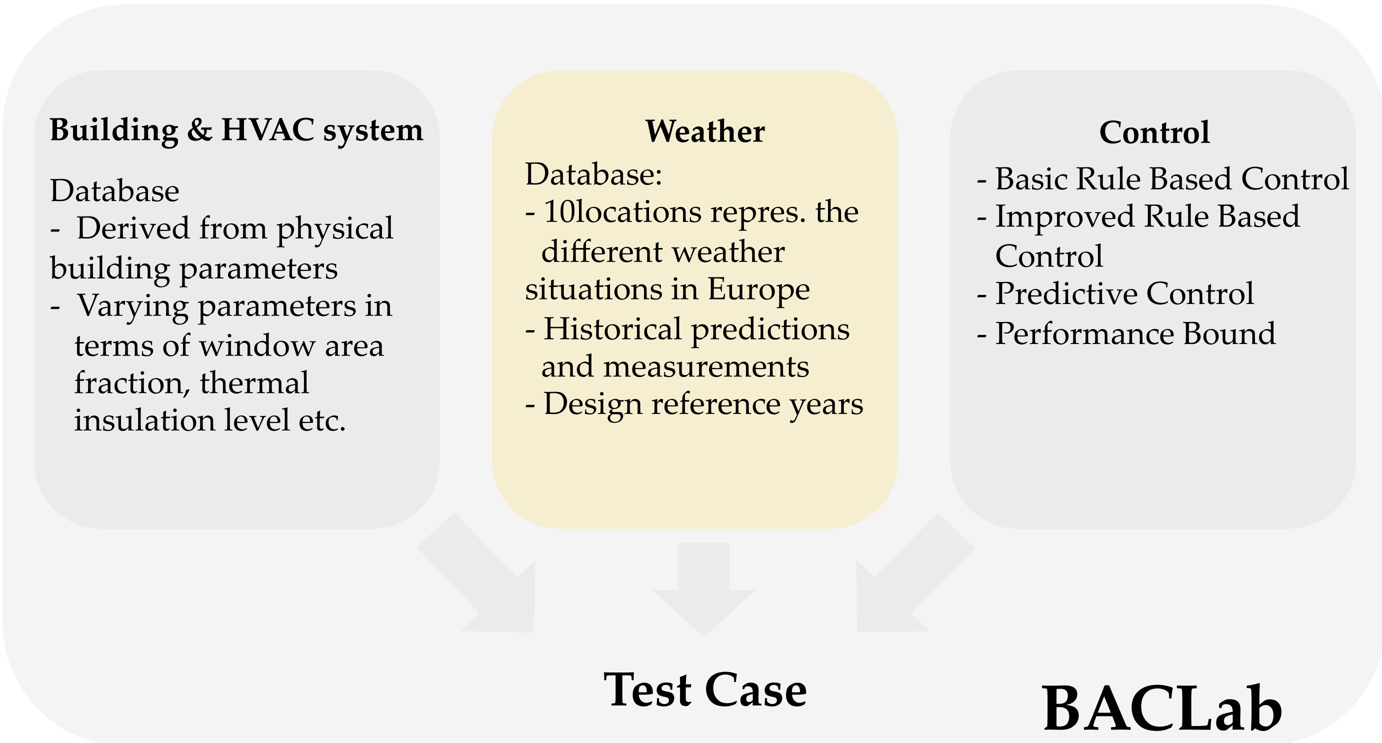

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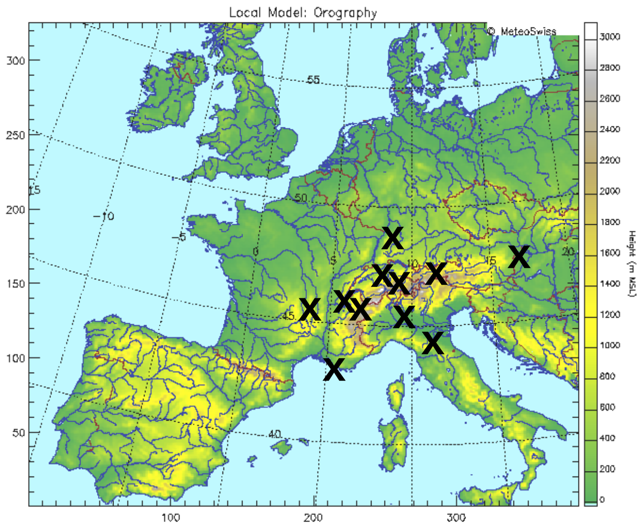
# Weather predictions




## Weather data:

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

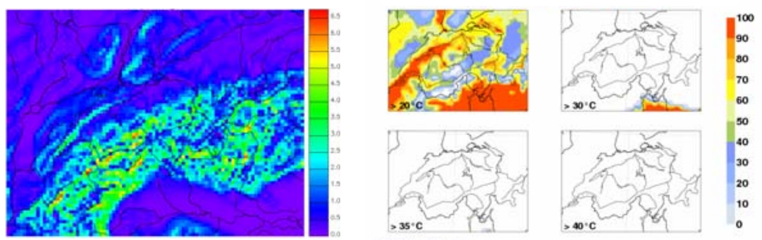
## Weather predictions:

- 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 terrain following levels



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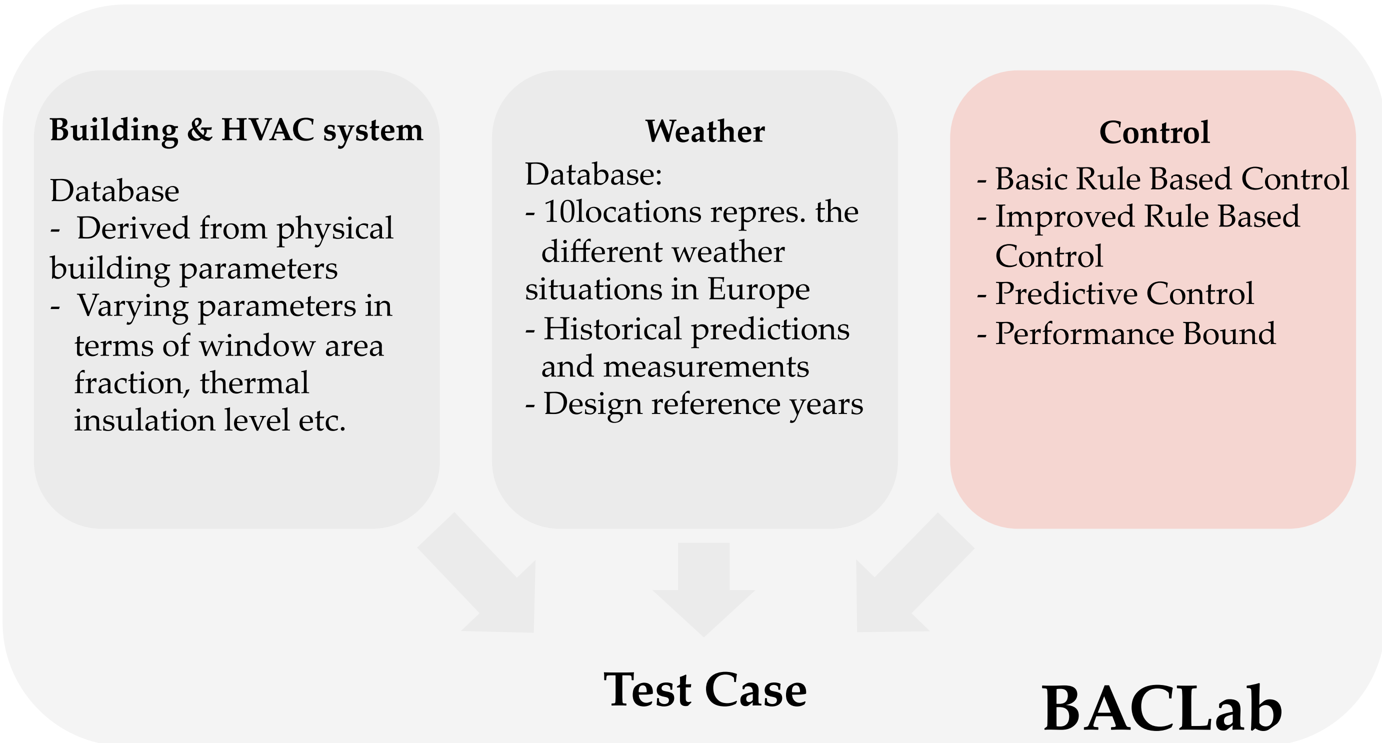
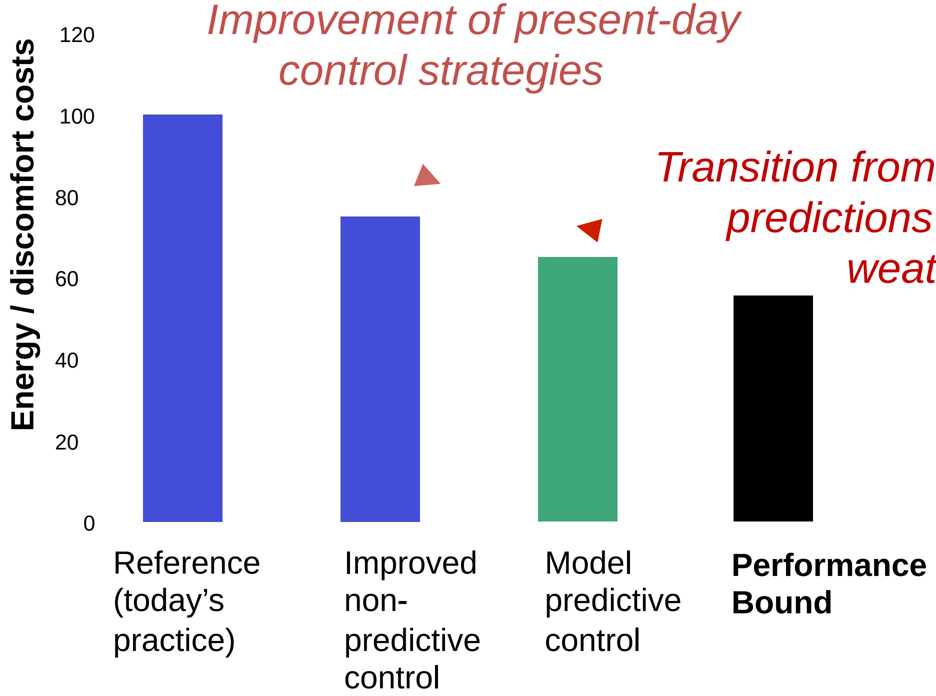


# Controller approaches

realistic < > theoretical

**Based on rules** | **Based on MPC** | **Performance Bound**

*Improvement of present-day control strategies*




*Transition from perfect weather predictions to real weather predictions*

**Potential**

^ ^

practical

v v

(theoretical)

# Controller approaches

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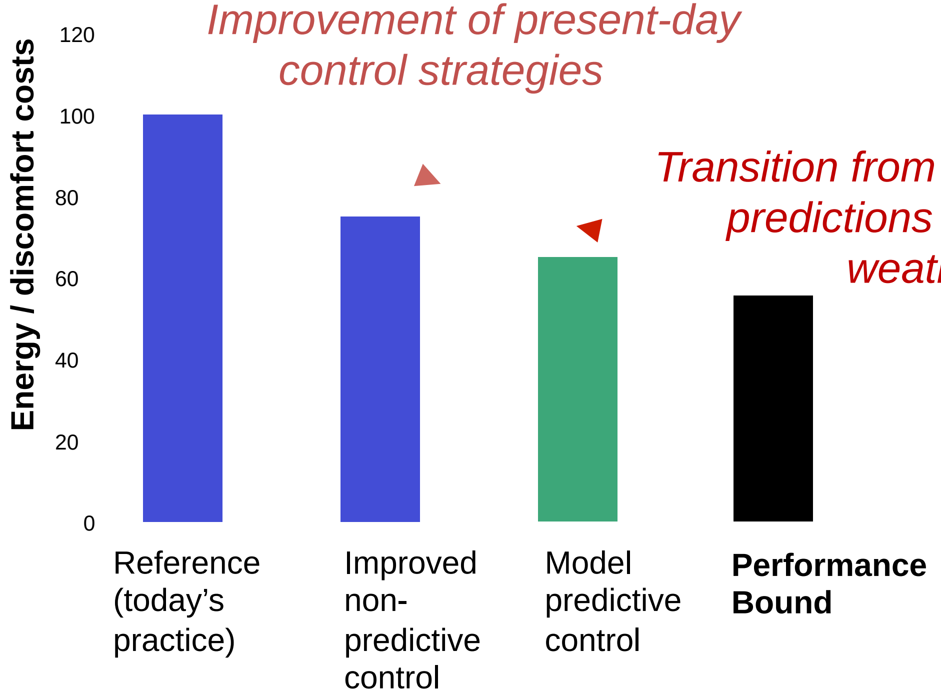
| Based on rules | Based on MPC | Performance Bound |
| --- | --- | --- |

*Improvement of present-day control strategies*




*Transition from perfect weather predictions to real weather predictions*

**Potential**

practical

(theoretical)

Performance Bound = optimal control with perfect weather prediction

# Controller approaches

realistic < > theoretical

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|---|---|---|---|

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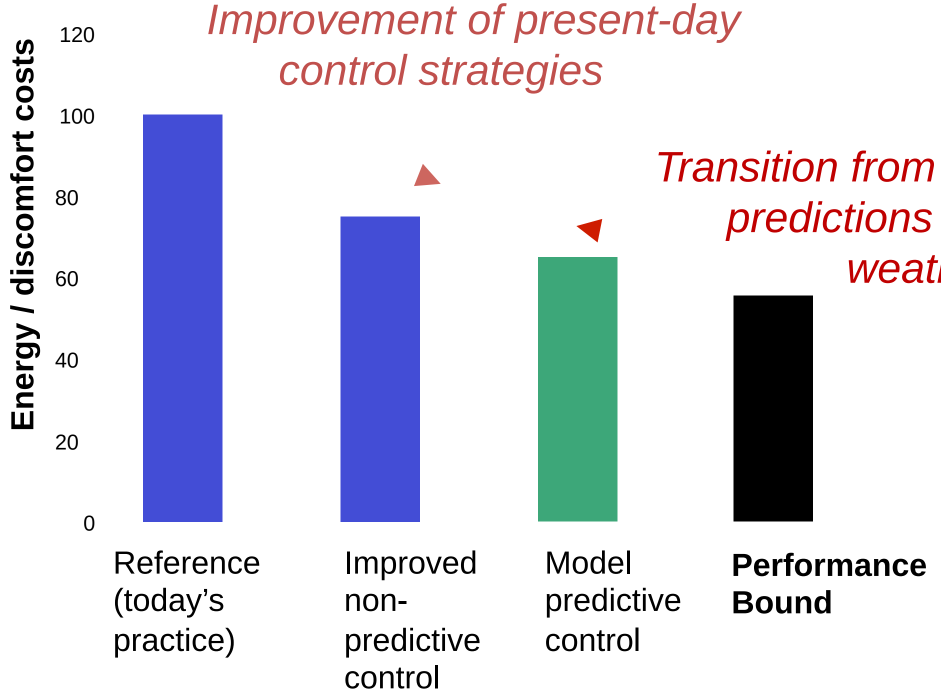


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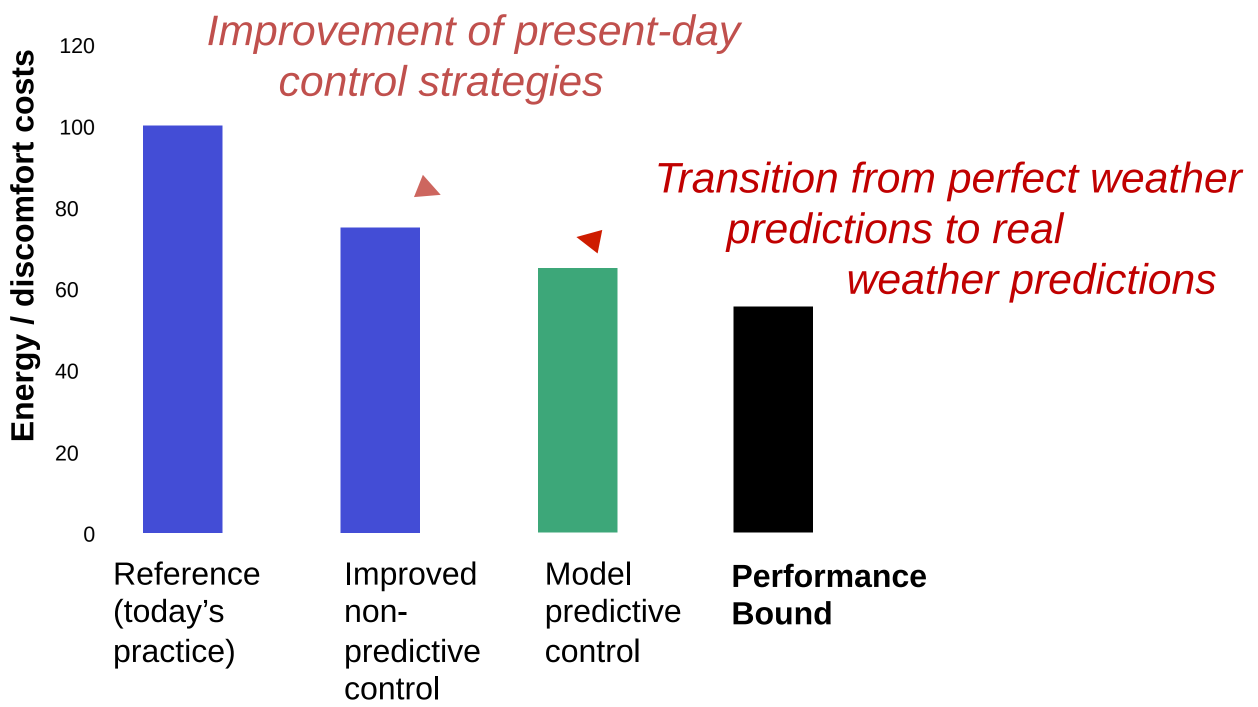
Current Practice

Improved Rule Based Control




**Potential**

^ ^

realistic

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# Controller approaches

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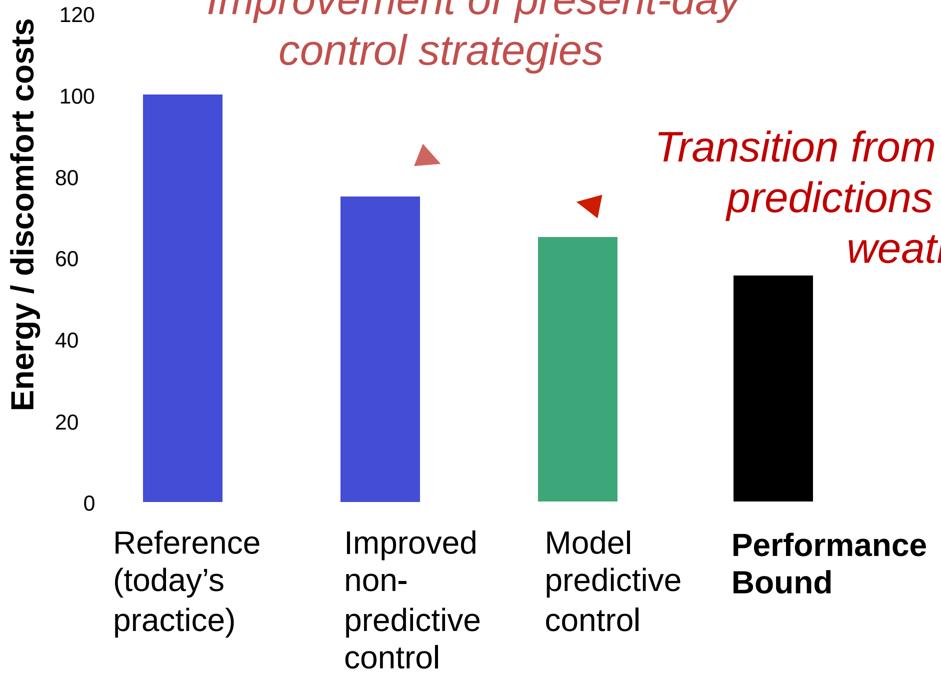
| | Based on rules | | Based on MPC | | Performance Bound |
|---|---|---|---|---|---|
| | Current Practice | Improved Rule Based Control | Deterministic MPC | Stochastic MPC | |

*Improvement of present-day control strategies*

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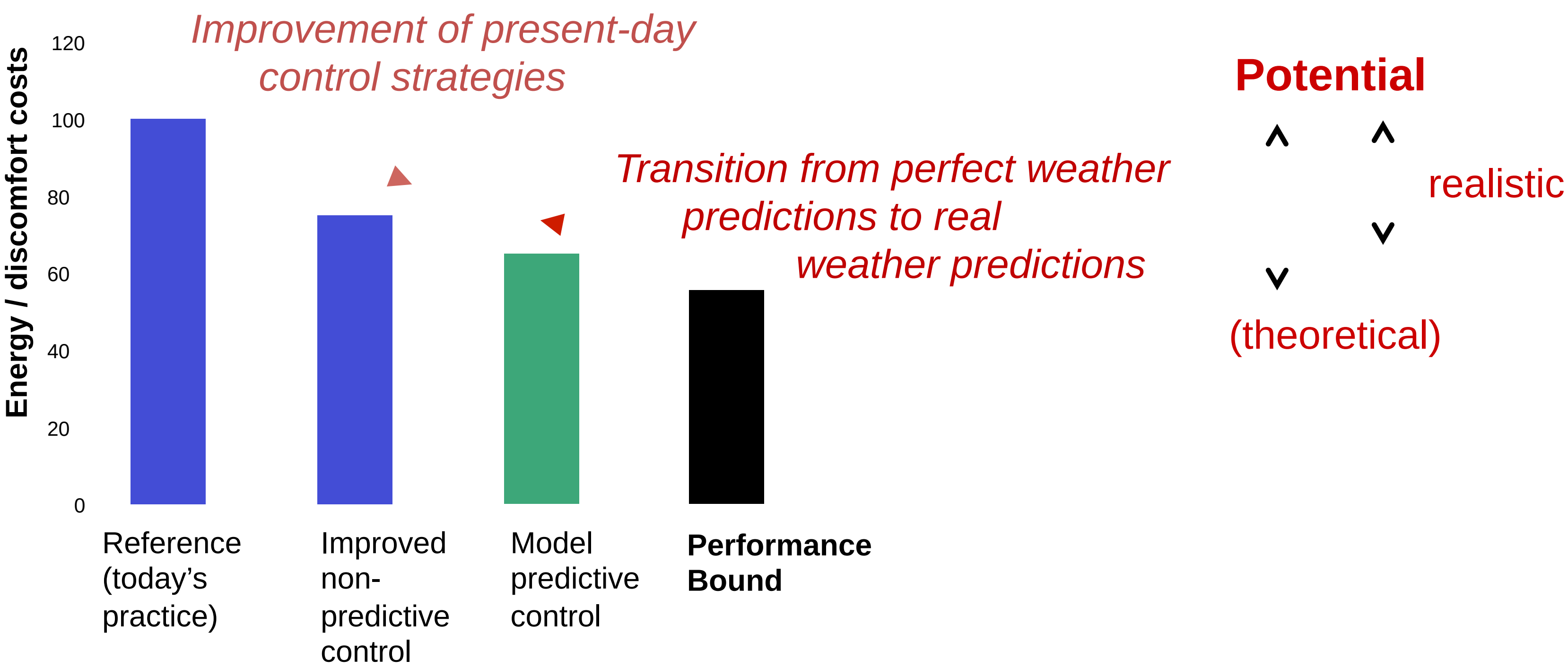
realistic < > theoretical

| | 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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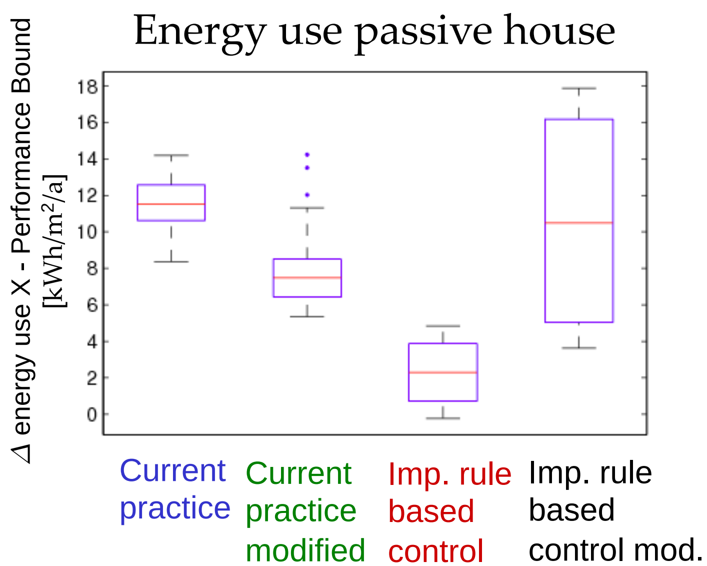
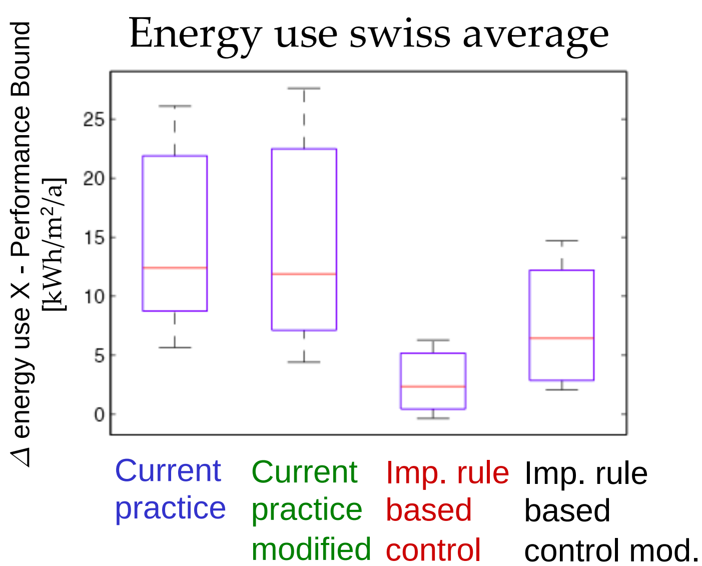
# Potential analysis
# - Example 1: Importance of blind control

| | 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 |



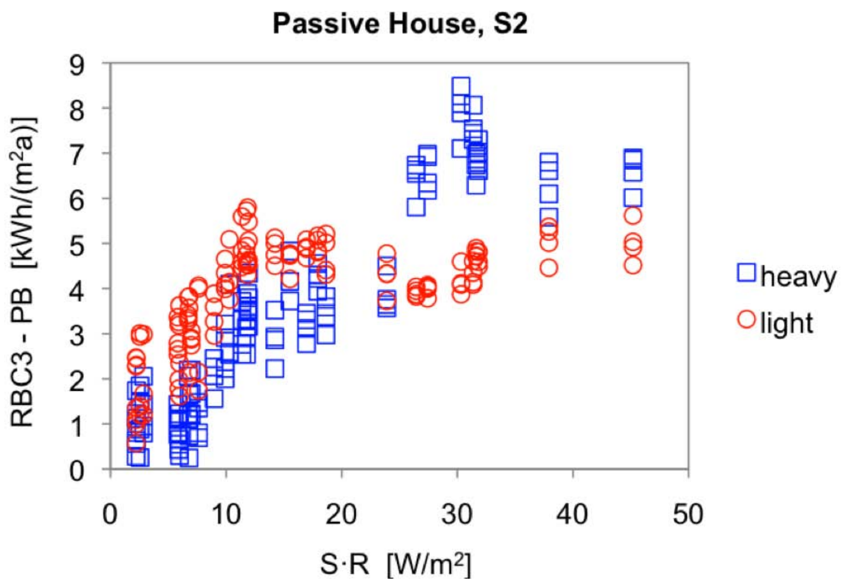



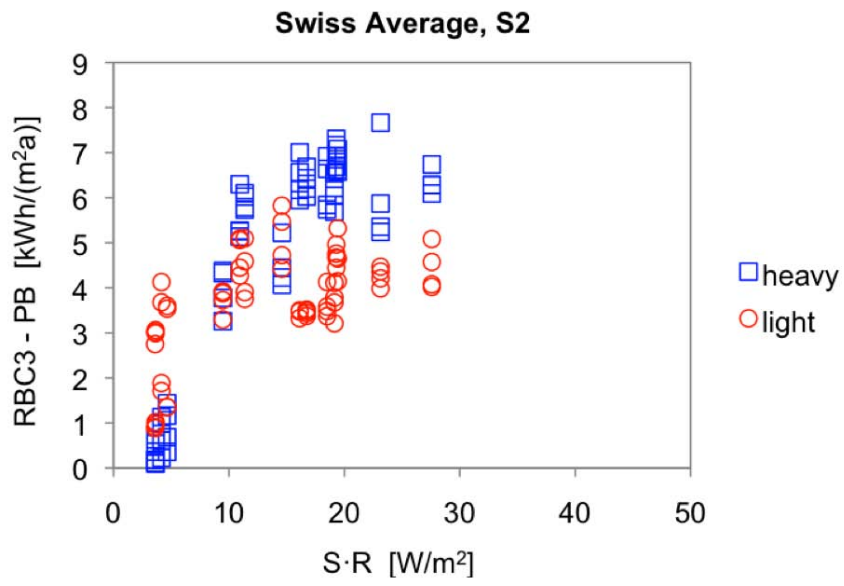
# Importance of solar gain area

**Specific solar gain area**

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

R = annual average of vertical global radiation components



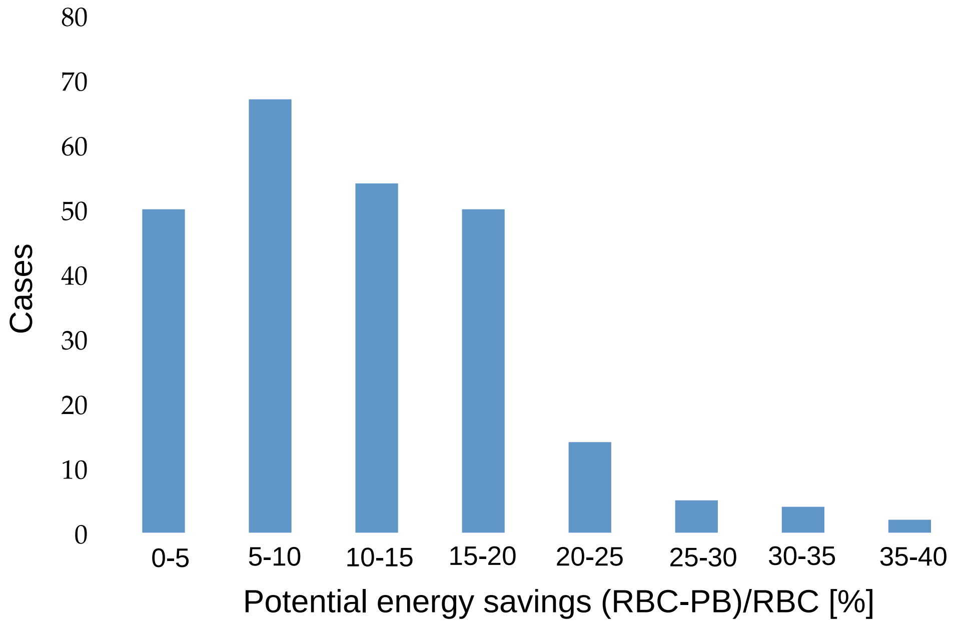

**Large savings potentials:**

- with high solar gains 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

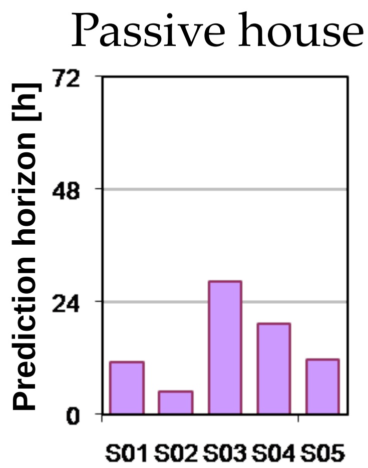


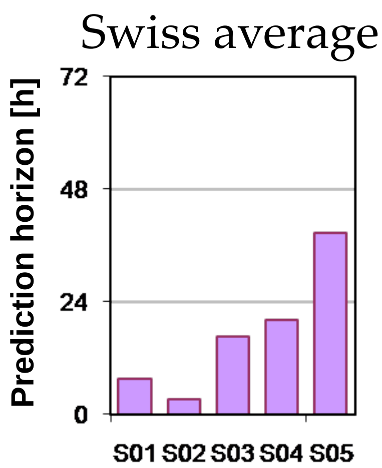

→ Even with Improved Rule Based Control and perfect blind control:
Large potential in many cases!

# 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




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

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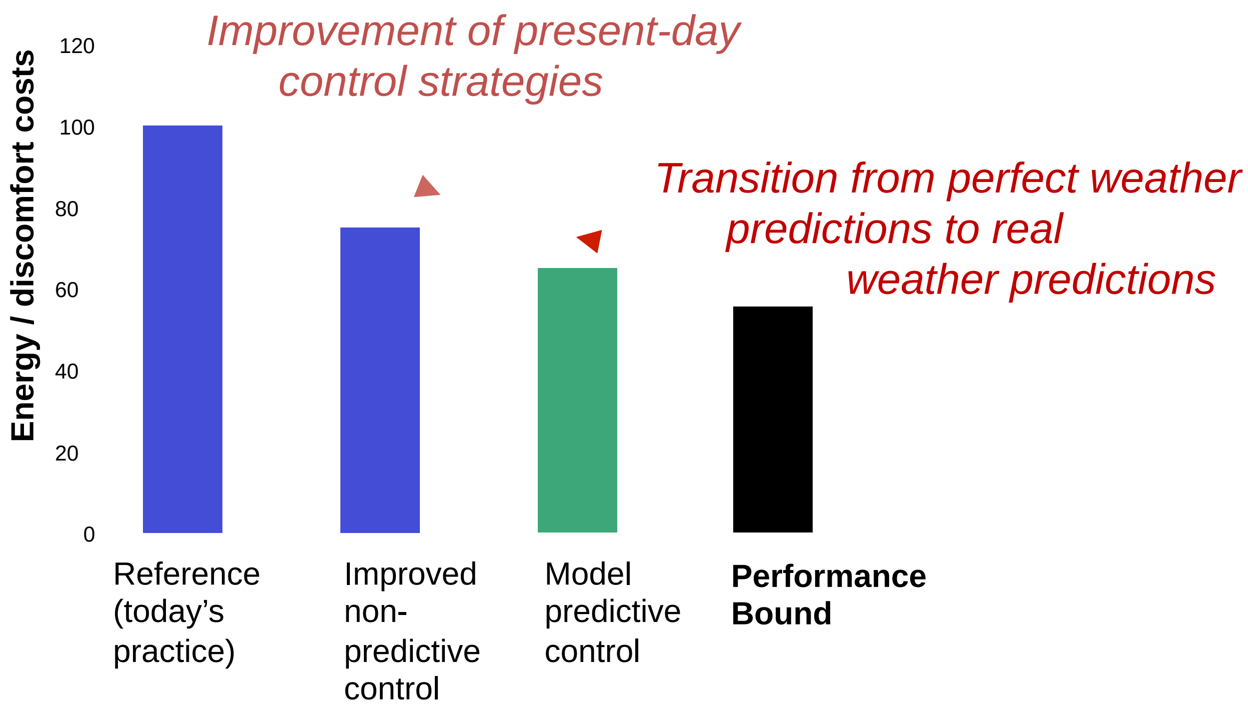
| Current Practice | Improved Rule Based Control | Deterministic MPC | Stochastic MPC | |




**Potential**

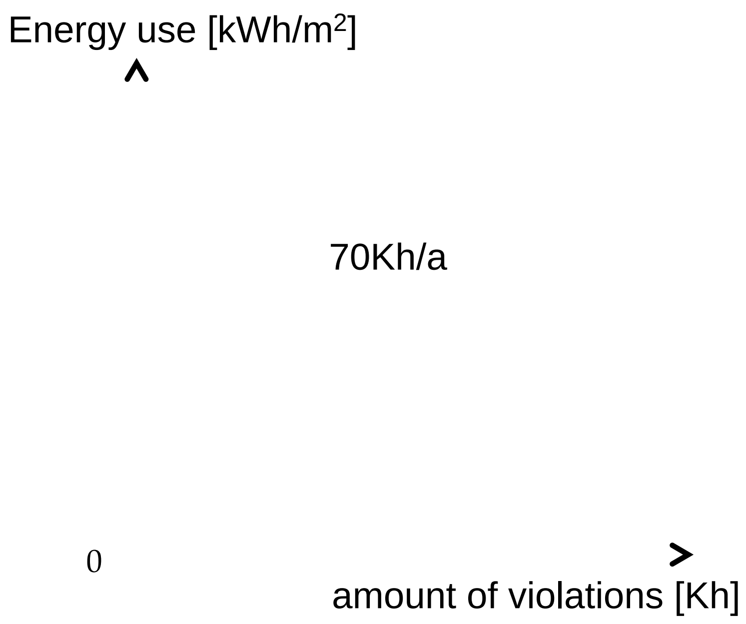
realistic

(theoretical)

# Simulations

**Tradeoff curve**
**energy vs. violations**

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



# Simulations

## Tradeoff curve energy vs. violations

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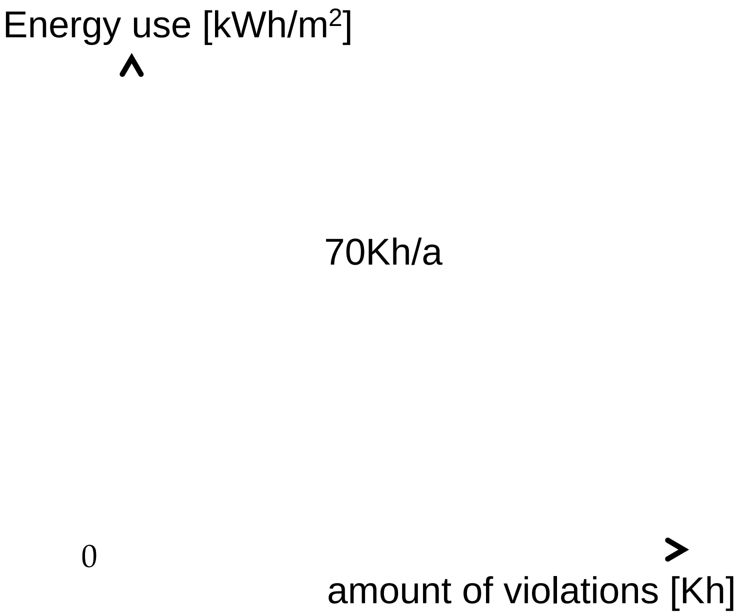
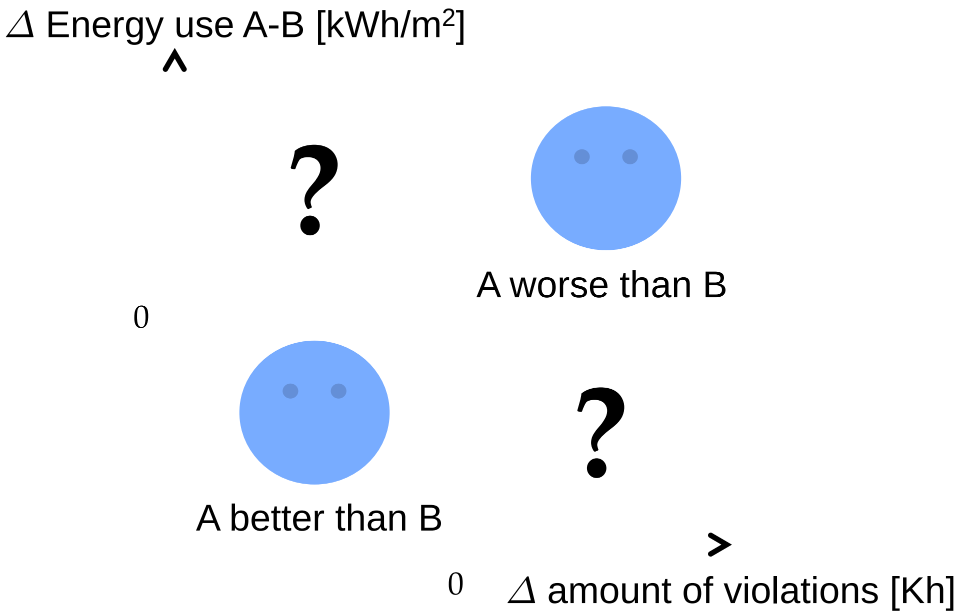



## Comparison of controllers A and B

- 4 possible cases
- 2 cases undetermined (controller need to be tuned to be comparable)

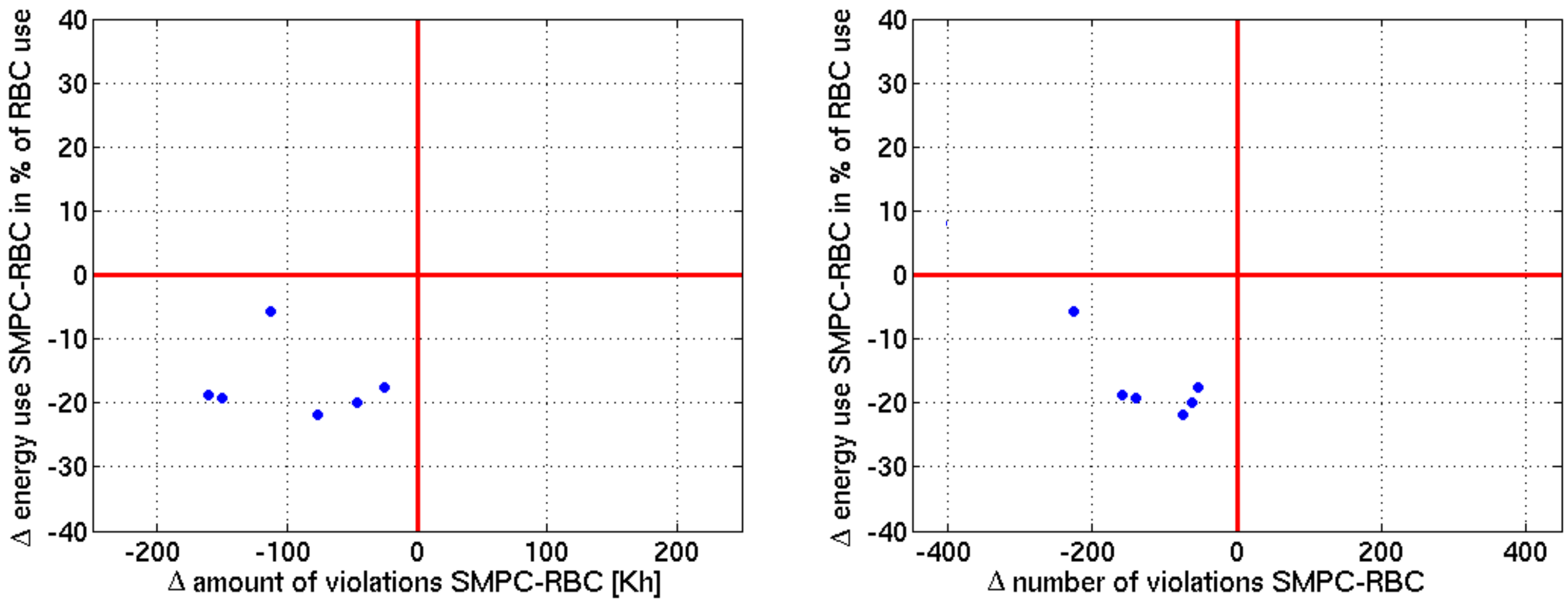


# Simulation results

**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



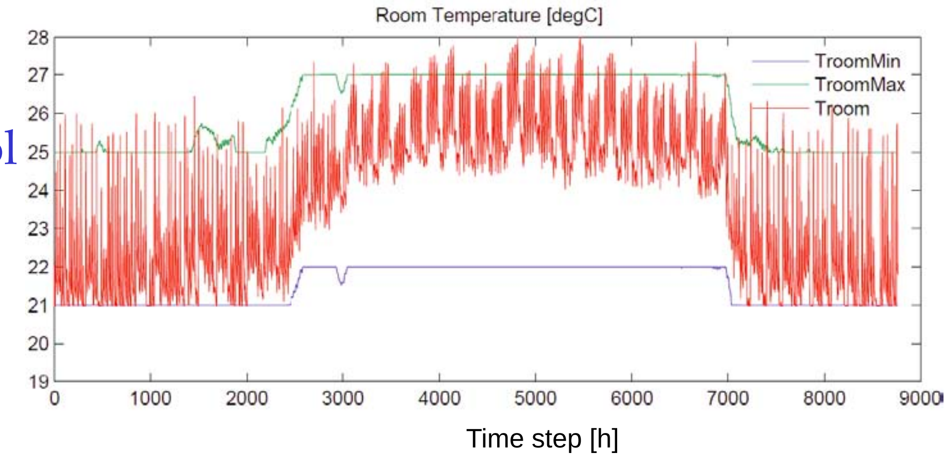

→ Stochastic MPC outperforms Improved Rule Based Control!

# Simulation results

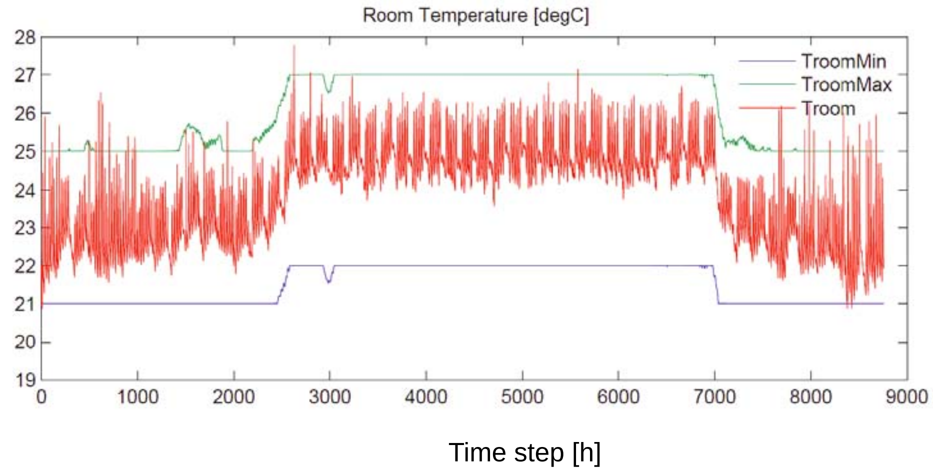
## Room temperature behavior

- 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




→ 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

Available December 2009!

*Terrestrial Systems Ecology ETH Zurich*
*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**