Comparison of MPC Strategies for Building Control

J. Drgoňa and M. Kvasnica

Slovak University of Technology in Bratislava, Slovakia

June 20, 2013

STU FCHPT

IAM

Motivation

Problem: Almost 40% of final energy use in the world goes towards comfort control in buildings - heating, ventilation and air conditioning (HVAC).*

*International Energy Agency 'Energy efficiency requirements in building codes, energy efficiency policies for new buildings' 2013 OECD/IEA.

Motivation

Problem: Almost 40% of final energy use in the world goes towards comfort control in buildings - heating, ventilation and air conditioning (HVAC).*

In European countries it is over

76% !!!*

*International Energy Agency 'Energy efficiency requirements in building codes, energy efficiency policies for new buildings' 2013 OECD/IEA.

Motivation

Problem: Almost 40% of final energy use in the world goes towards comfort control in buildings - heating, ventilation and air conditioning (HVAC).*

In European countries it is over

76% !!!*

Goal: Increasement of building's energy efficiency

*International Energy Agency 'Energy efficiency requirements in building codes, energy efficiency policies for new buildings' 2013 OECD/IEA.

Motivation

Problem: Almost 40% of final energy use in the world goes towards comfort control in buildings - heating, ventilation and air conditioning (HVAC).*

In European countries it is over

76% !!!*

Goal: Increasement of building's energy efficiency

Solution: Building control

*International Energy Agency 'Energy efficiency requirements in building codes, energy efficiency policies for new buildings' 2013 OECD/IEA.

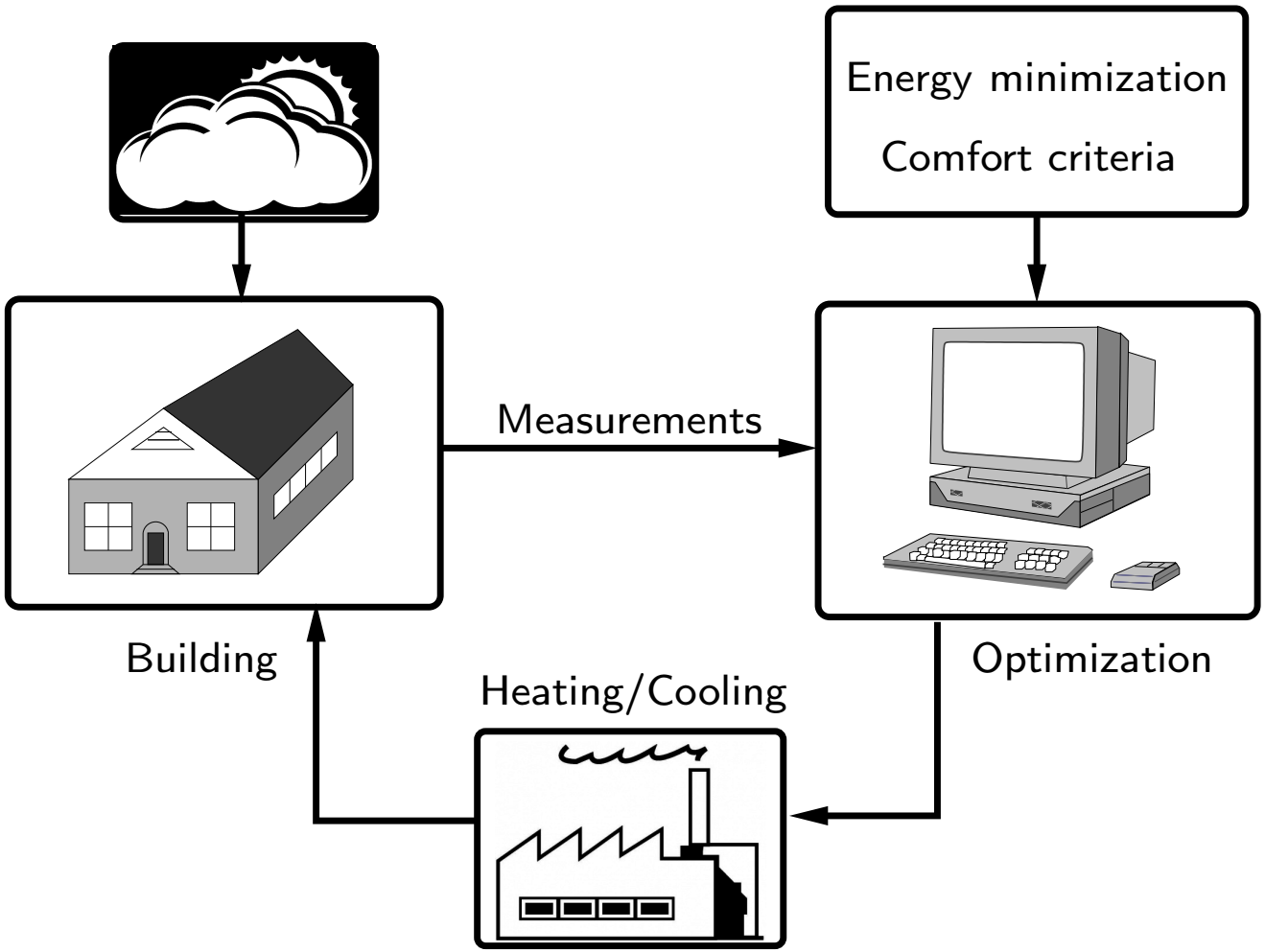
Presentation Outline

1. Building Modeling and Control
2. Model Predictive Control
3. Case Study

Presentation Outline

1. Building Modeling and Control
2. Model Predictive Control
3. Case Study

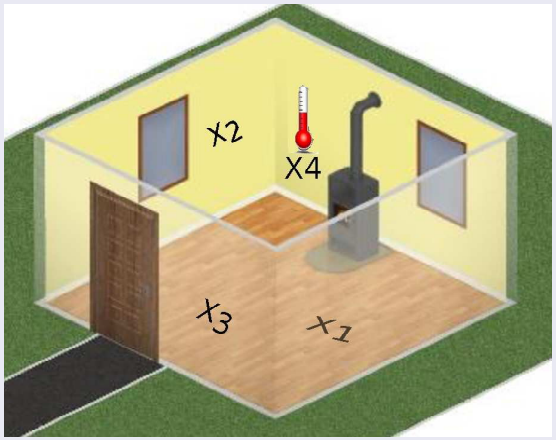
Building Thermal Control Scheme



Single Zone Building Model

State Variables

x_1 – floor temperature
x_2 – internal facade temperature
x_3 – external facade temperature
x_4 – internal temperature



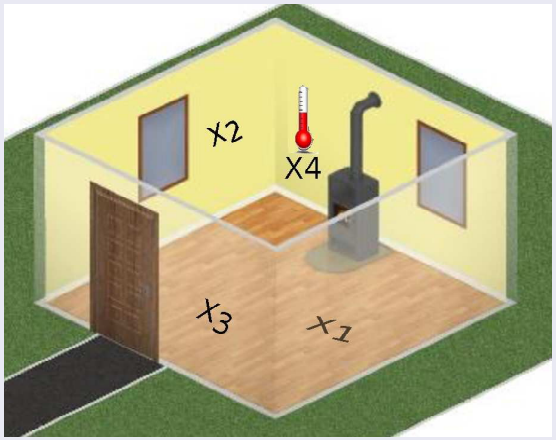
Disturbances

d_1 – external temperature
d_2 – occupancy
d_3 – solar radiation

Single Zone Building Model

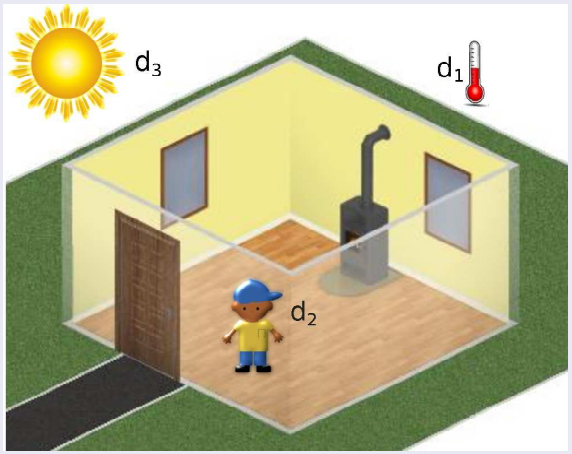
State Variables

x_1 – floor temperature
x_2 – internal facade temperature
x_3 – external facade temperature
x_4 – internal temperature



Disturbances

d_1 – external temperature
d_2 – occupancy
d_3 – solar radiation



Control Objectives

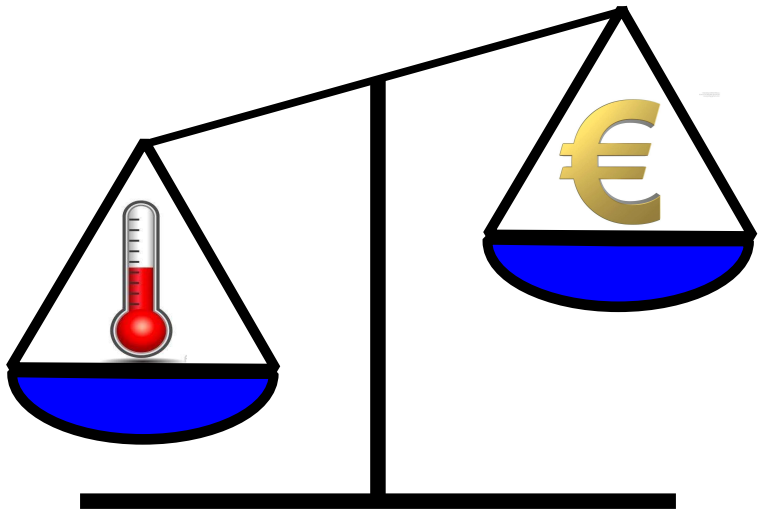
- Thermal Comfort
- Minimization of Energy Consumption

Control Objectives

- Thermal Comfort
- Minimization of Energy Consumption

Control Objectives

- Thermal Comfort
- Minimization of Energy Consumption



Presentation Outline

1. Building Modeling and Control
2. Model Predictive Control
3. Case Study

Model Predictive Control

- Objective function

$$\min_{u_0,\ldots,u_{N-1}} \sum_{k=0}^{N-1} \ell(x_k, u_k)$$

- Constraints

$$x_{k+1} = Ax_k + Bu_k + Ed_k,$$
$$\underline{x} \leq x_k \leq \overline{x},$$
$$\underline{u} \leq u_k \leq \overline{u},$$
$$x_0 = x(t)$$

Model Predictive Control

- Objective function

$$\min_{u_0,\ldots,u_{N-1}} \sum_{k=0}^{N-1} \ell(x_k, u_k)$$

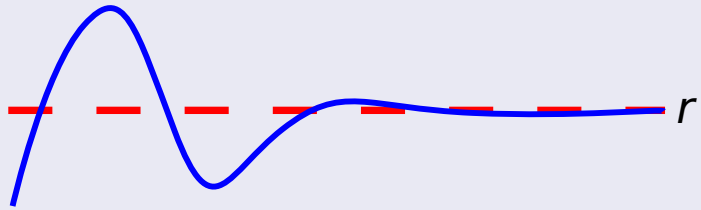
- Constraints

$$\begin{aligned} x_{k+1} &= Ax_k + Bu_k + Ed_k, \\ \underline{x} &\leq x_k \leq \overline{x}, \\ \underline{u} &\leq u_k \leq \overline{u}, \\ x_0 &= x(t) \end{aligned}$$

Different Formulations of the Objective Function

Reference Tracking + Energy Minimization (Basic)

$$\ell(x_k, u_k) = q_x(Cx_k - r)^2 + q_u u_k^2$$



Comfort Zone Tracking + Energy Minimization (CZT)

$$\ell(s_k, u_k) = q_s s_k^2 + q_u u_k^2$$
$$\text{s.t. } r - \epsilon - s_k \leq Cx_k \leq r + \epsilon + s_k$$

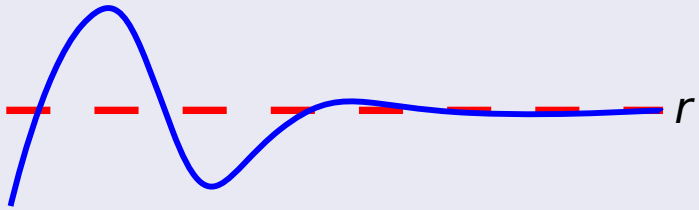
Minimization of Zone Violations + Energy Minimization (Hybrid)

$$\ell(\delta_k, u_k) = q_\delta \delta_k + q_u u_k^2$$
$$\text{s.t. } r - \epsilon - s_k \leq Cx_k \leq r + \epsilon + s_k$$
$$(s_k > 0) \Longrightarrow (\delta_k = 1)$$

Different Formulations of the Objective Function

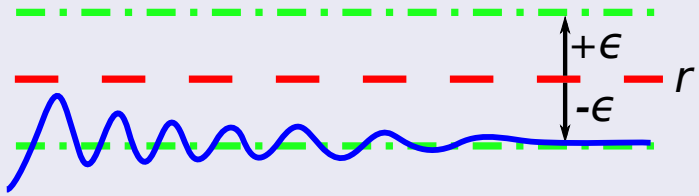
Reference Tracking + Energy Minimization (Basic)

$$\ell(x_k, u_k) = q_x(Cx_k - r)^2 + q_u u_k^2$$



Comfort Zone Tracking + Energy Minimization (CZT)

$$\ell(s_k, u_k) = q_s s_k^2 + q_u u_k^2$$
$$\text{s.t. } r - \epsilon - s_k \leq Cx_k \leq r + \epsilon + s_k$$



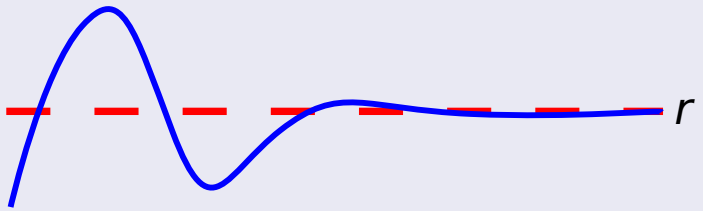
Minimization of Zone Violations + Energy Minimization (Hybrid)

$$\ell(\delta_k, u_k) = q_\delta \delta_k + q_u u_k^2$$
$$\text{s.t. } r - \epsilon - s_k \leq Cx_k \leq r + \epsilon + s_k$$
$$(s_k > 0) \Longrightarrow (\delta_k = 1)$$

Different Formulations of the Objective Function

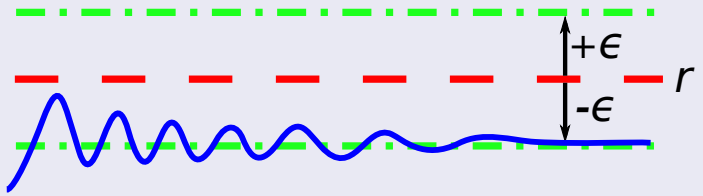
Reference Tracking + Energy Minimization (Basic)

$$\ell(x_k, u_k) = q_x(Cx_k - r)^2 + q_u u_k^2$$



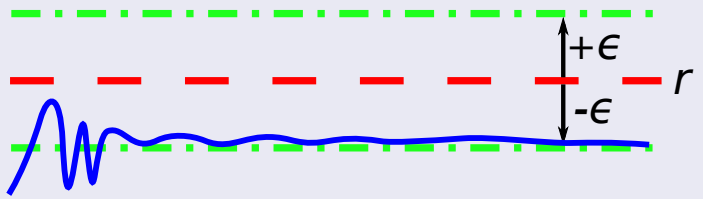
Comfort Zone Tracking + Energy Minimization (CZT)

$$\ell(s_k, u_k) = q_s s_k^2 + q_u u_k^2$$
$$\text{s.t. } r - \epsilon - s_k \leq Cx_k \leq r + \epsilon + s_k$$



Minimization of Zone Violations + Energy Minimization (Hybrid)

$$\ell(\delta_k, u_k) = q_\delta \delta_k + q_u u_k^2$$
$$\text{s.t. } r - \epsilon - s_k \leq Cx_k \leq r + \epsilon + s_k$$
$$(s_k > 0) \Longrightarrow (\delta_k = 1)$$



Presentation Outline

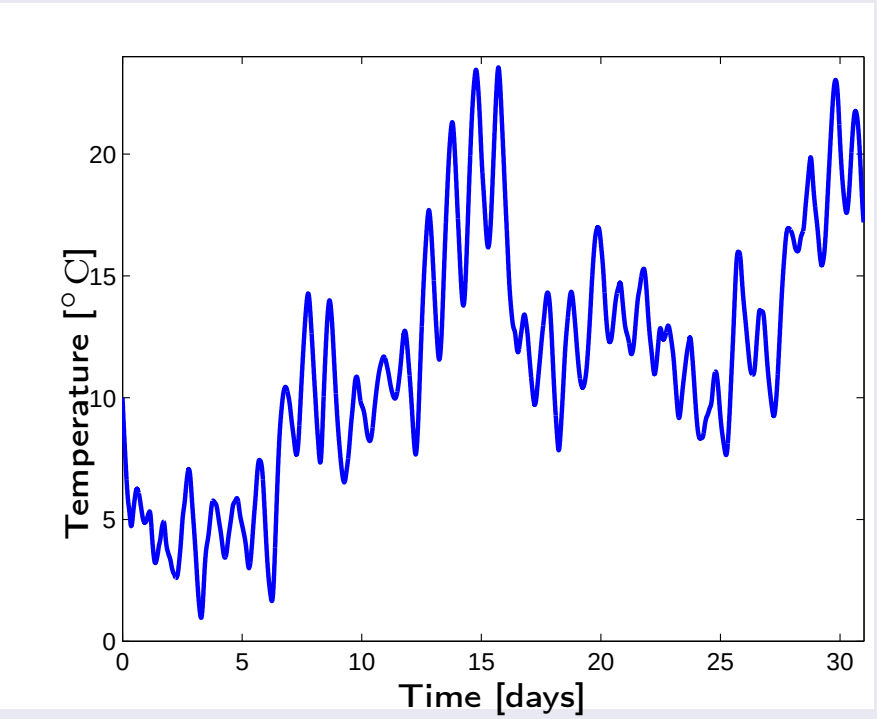
1. Building Modeling and Control
2. Model Predictive Control
3. Case Study

Simulation Study

Closed Loop Simulation Parameters

- Prediction horizon:
  $N = 10$
- Sampling time:
  $T_s = 444$ sec
- Simulation time:
  $T_{sim} = 31$ days
- Initial indoor temperature:
  $x_4 = 10°C$
- No weather predictions

Evolution of External Temperature

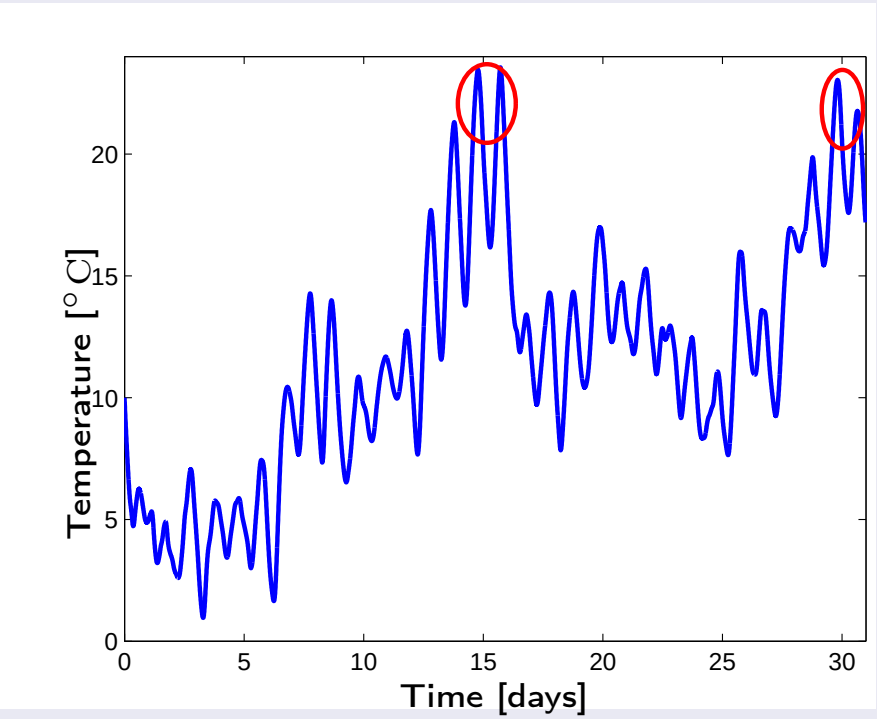


Simulation Study

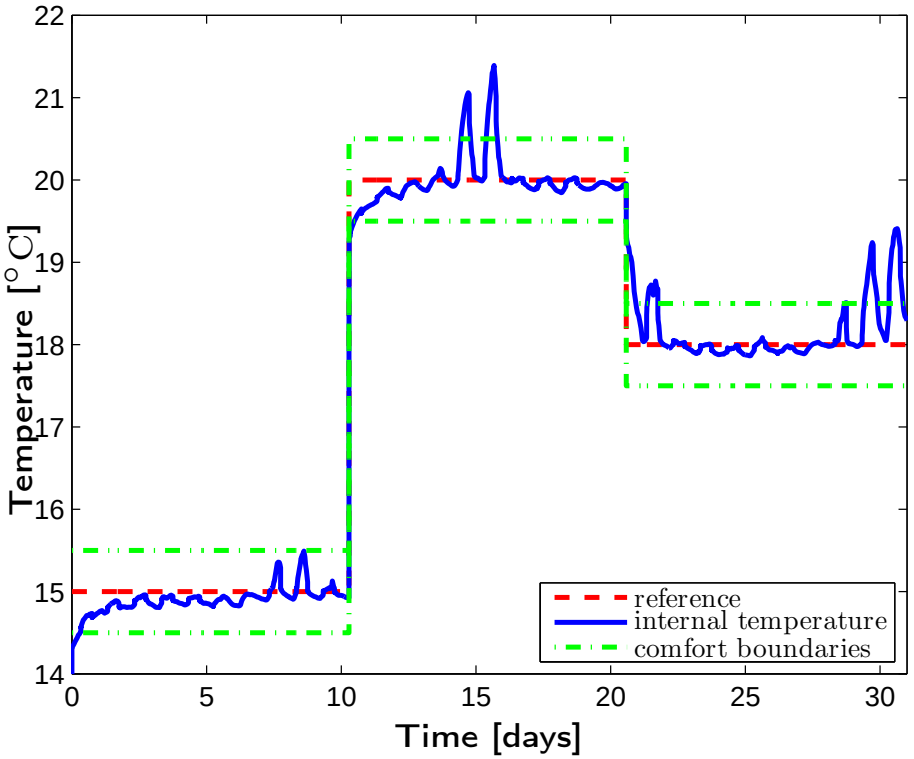
Closed Loop Simulation Parameters

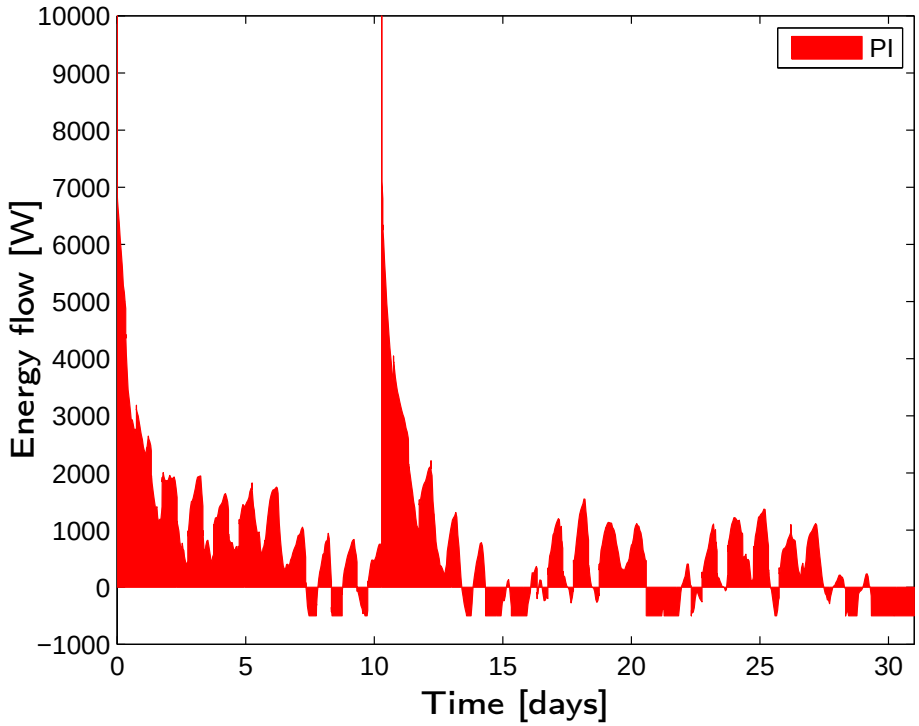
- Prediction horizon:
  $N = 10$
- Sampling time:
  $T_s = 444$ sec
- Simulation time:
  $T_{sim} = 31$ days
- Initial indoor temperature:
  $x_4 = 10°C$
- No weather predictions

Evolution of External Temperature



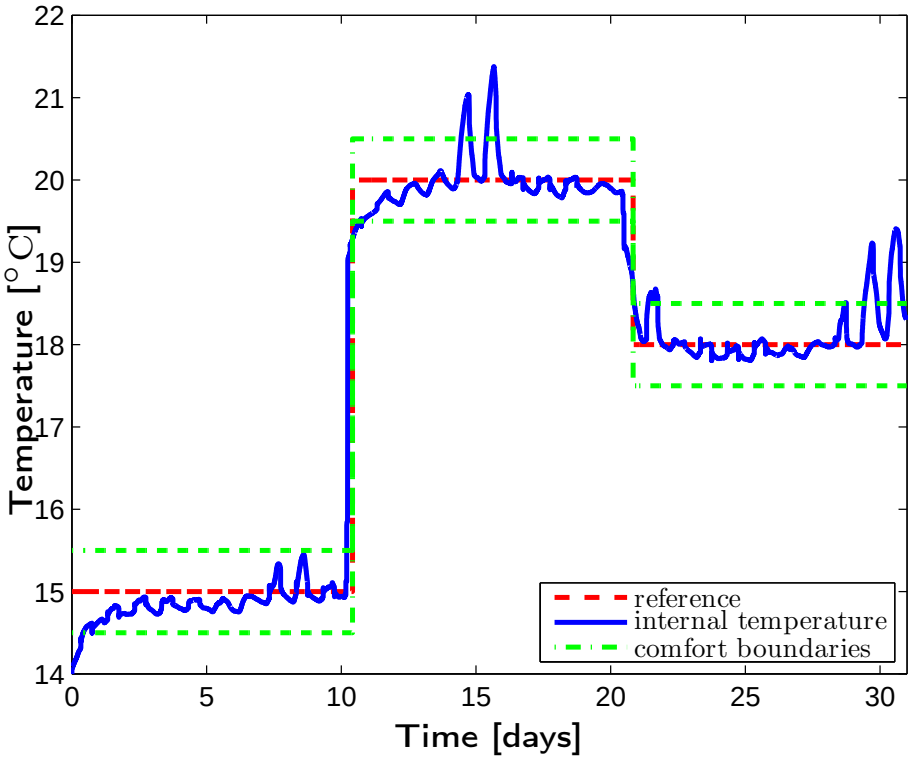
PI Controller

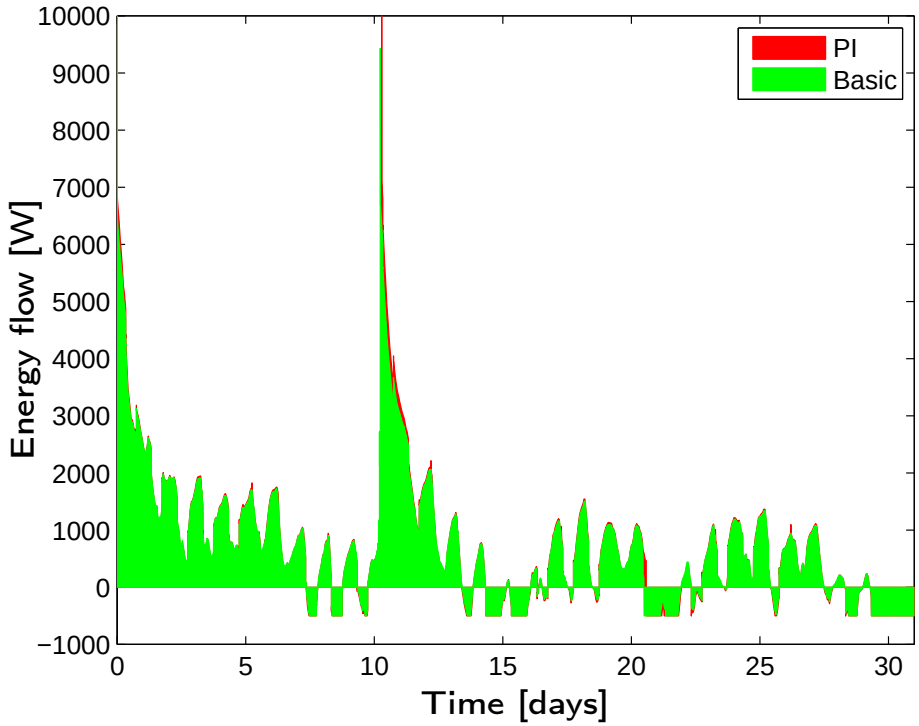




Control strategy	PI
Thermal comfort [%]	87.5
Energy consumption [kWh]	753.0
Energy savings [%]	-

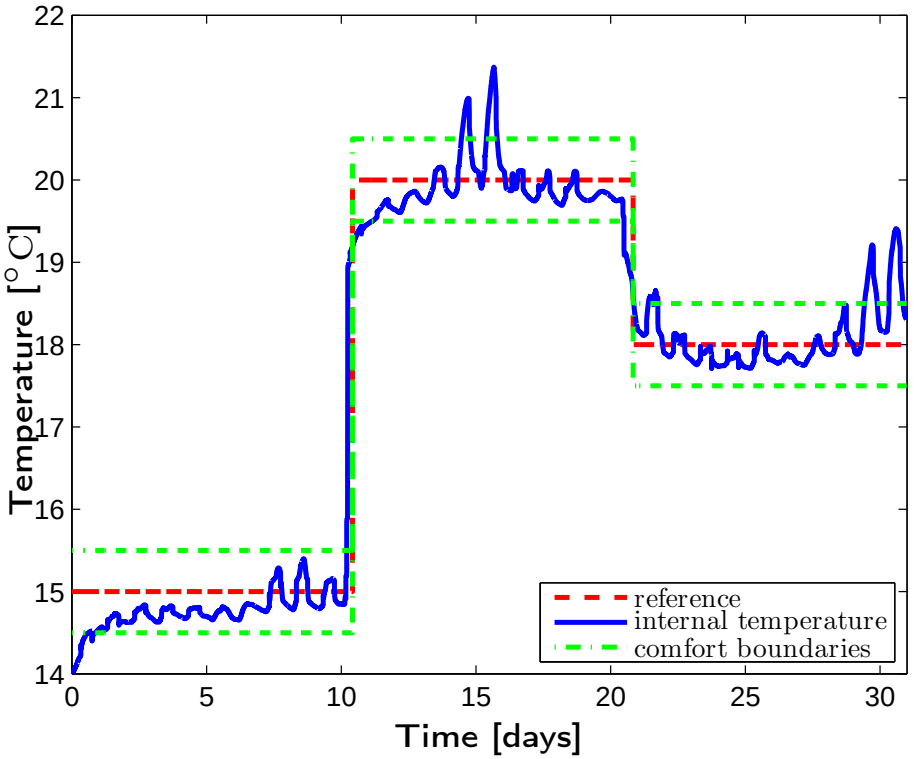
Reference Tracking (Basic)

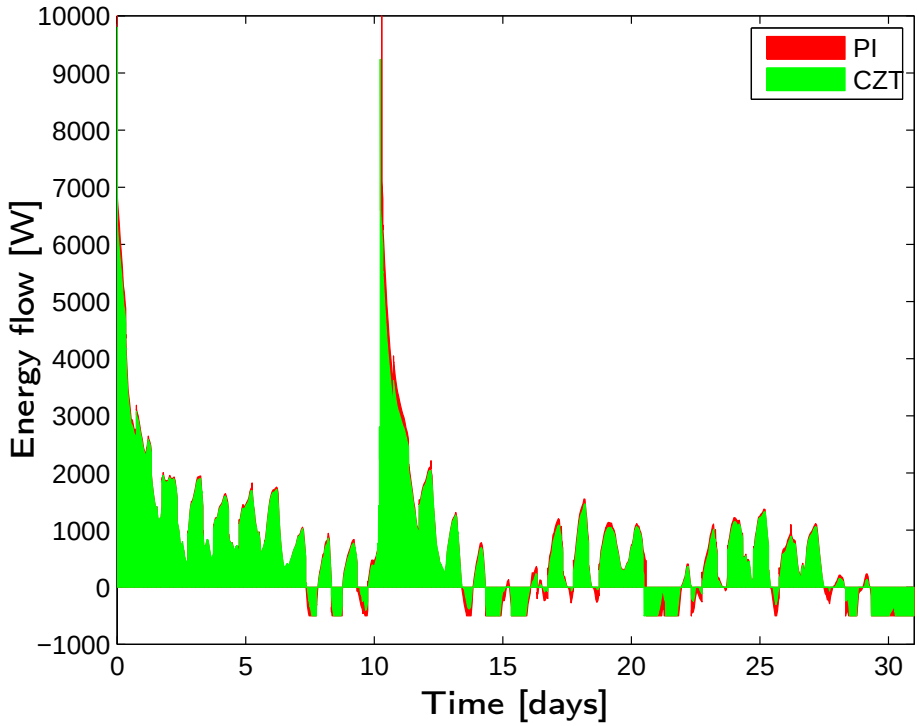




Control strategy	PI	Basic
Thermal comfort [%]	87.5	89.2
Energy consumption [kWh]	753.0	722.7
Energy savings [%]	-	4.0

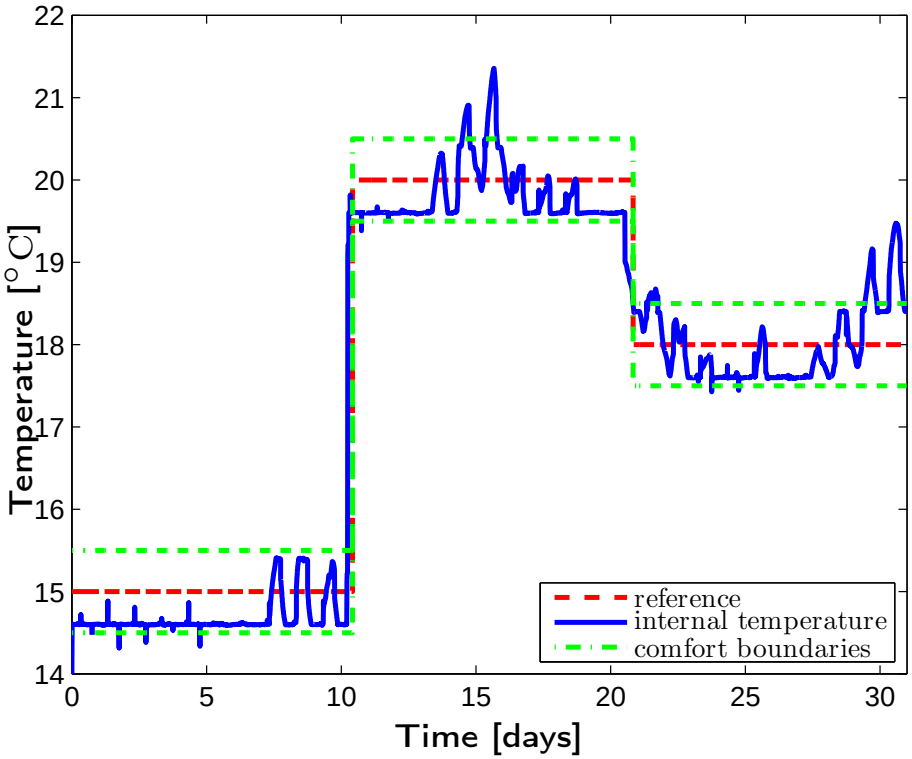
Comfort Zone Tracking (CZT)

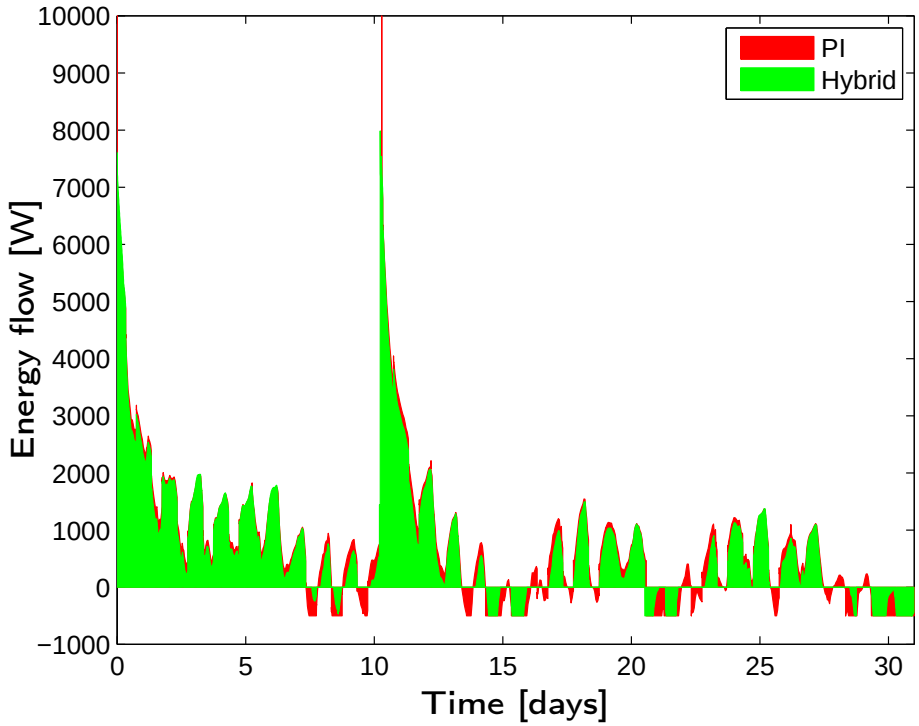




Control strategy	PI	Basic	CZT
Thermal comfort [%]	87.5	89.2	84.1
Energy consumption [kWh]	753.0	722.7	684.0
Energy savings [%]	-	4.0	9.1

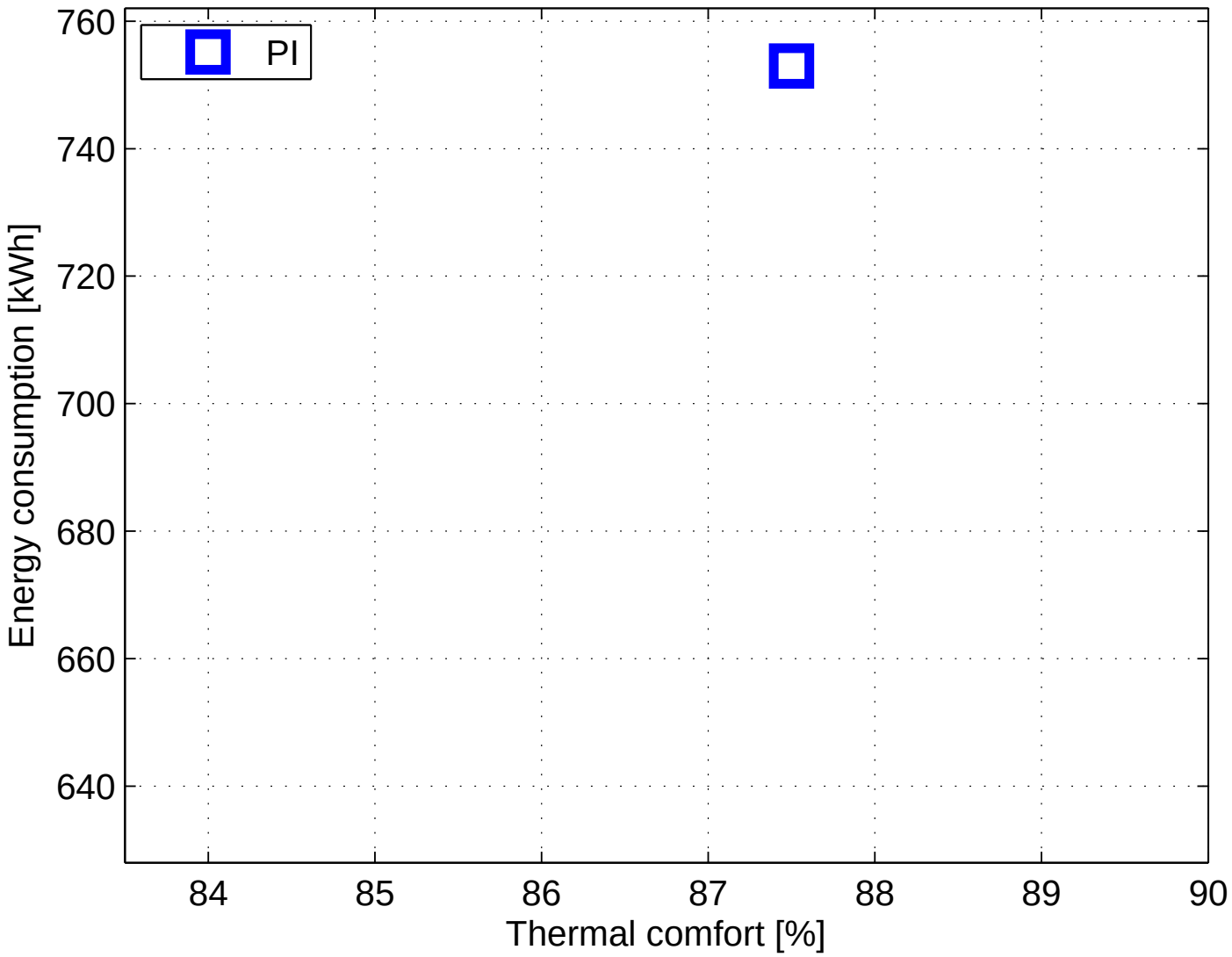
Minimization of Comfort Zone Violations (Hybrid)



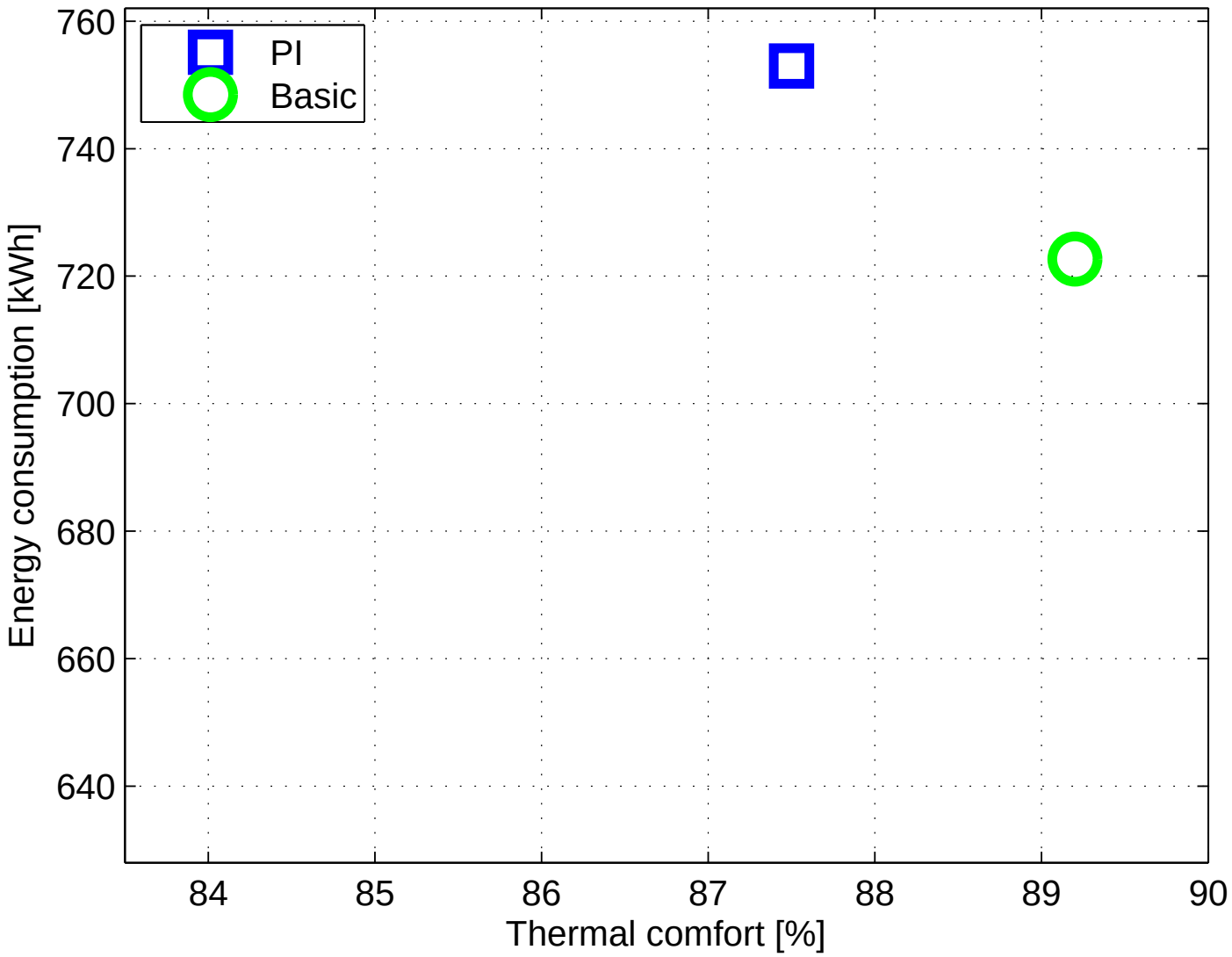


Control strategy	PI	Basic	CZT	Hybrid
Thermal comfort [%]	87.5	89.2	84.1	88.2
Energy consumption [kWh]	753.0	722.7	684.0	640.1
Energy savings [%]	-	4.0	9.1	15.0

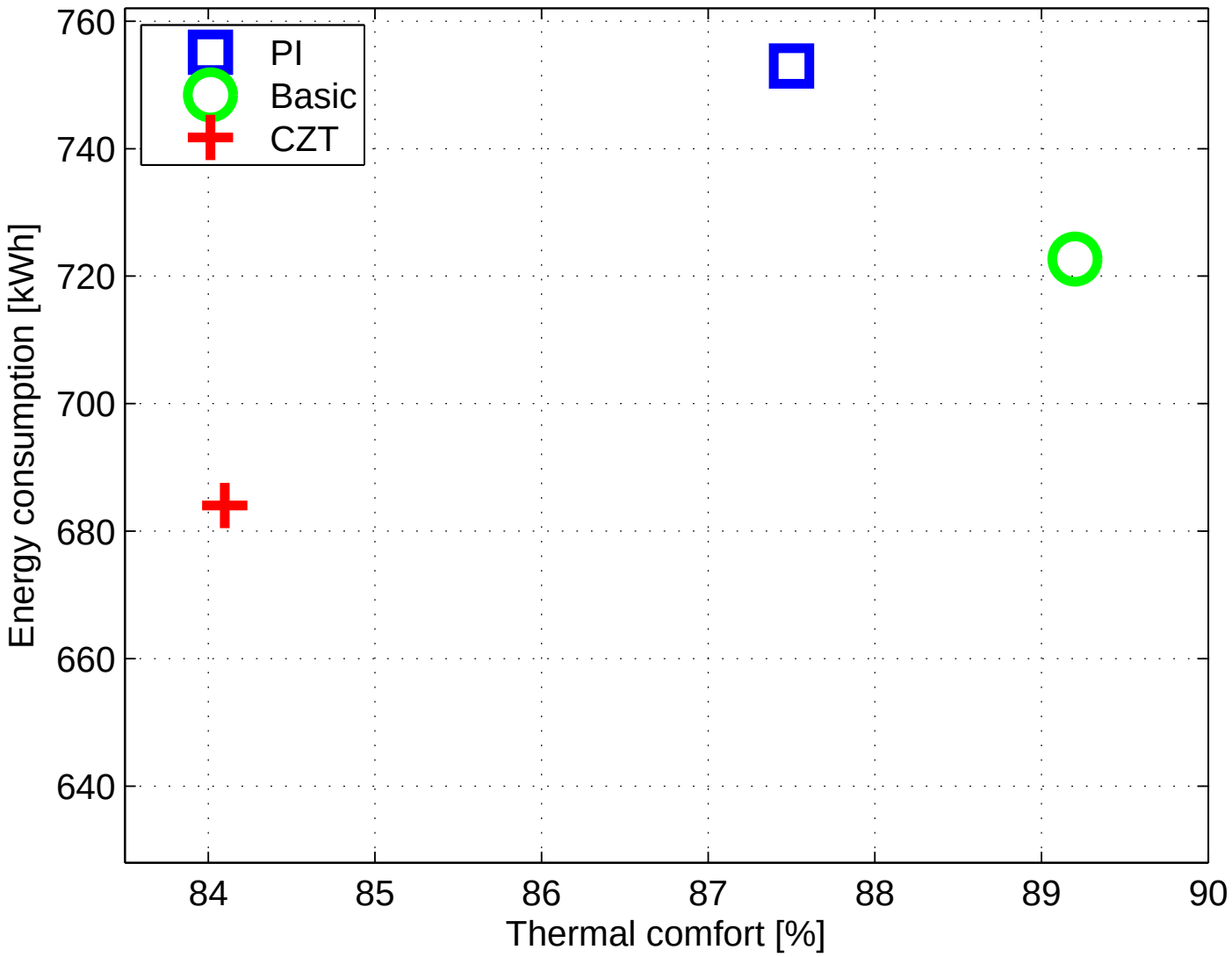
Conclusions - Comfort vs Energy Consumption



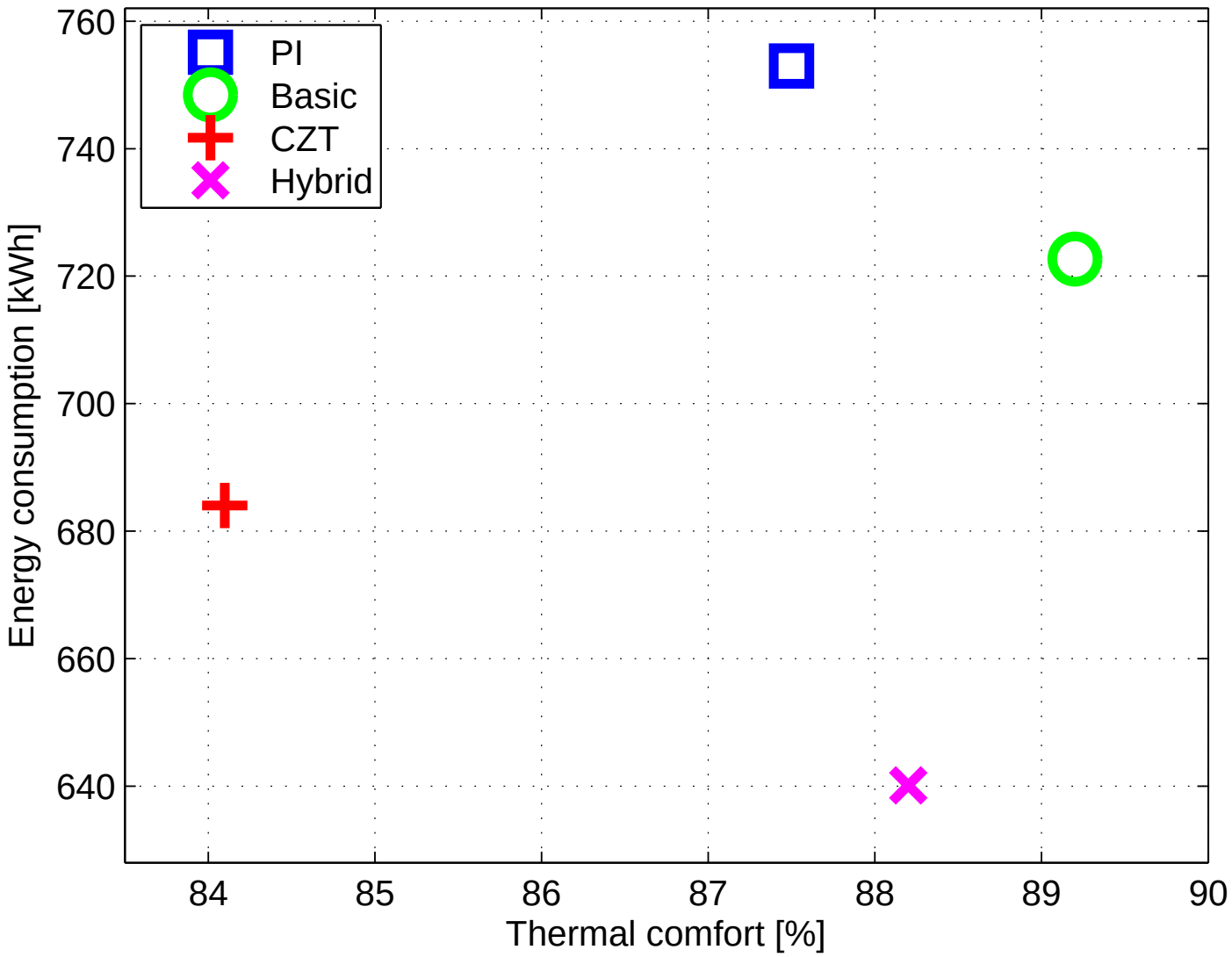
Conclusions - Comfort vs Energy Consumption



Conclusions - Comfort vs Energy Consumption



Conclusions - Comfort vs Energy Consumption



Conclusions

- Design and evaluation of different MPC strategies
- Best case: hybrid formulation with energy savings up to 15%
- Drawback: higher computational complexity
- No weather predictions
- Suitable for application in "intelligent" building

Conclusions

- Design and evaluation of different MPC strategies
- Best case: hybrid formulation with energy savings up to 15%
- Drawback: higher computational complexity
- No weather predictions
- Suitable for application in "intelligent" building

Conclusions

- Design and evaluation of different MPC strategies
- Best case: hybrid formulation with energy savings up to 15%
- Drawback: higher computational complexity
- No weather predictions
- Suitable for application in "intelligent" building

Conclusions

- Design and evaluation of different MPC strategies
- Best case: hybrid formulation with energy savings up to 15%
- Drawback: higher computational complexity
- No weather predictions
- Suitable for application in "intelligent" building

Conclusions

- Design and evaluation of different MPC strategies
- Best case: hybrid formulation with energy savings up to 15%
- Drawback: higher computational complexity
- No weather predictions
- Suitable for application in "intelligent" building