The Hong Kong Polytechnic University
香港理工大學

DEPARTMENT OF
BUILDING SERVICES ENGINEERING
屋宇設備工程系

Model predictive control of residential HVAC systems responding to dynamic electricity prices:

Case studies in Hong Kong and Denmark

Maomao Hu

Department of Building Services Engineering

The Hong Kong Polytechnic University

Email: *chace.hu@connect.polyu.hk*

DTU

MPC workshop in Technical University of Denmark, 18 May 2018

Overview

❖ **Introduction**

Research background, motivations and aim

❖ **Methodology**

- **Offline system model development**
- **Online MPC**

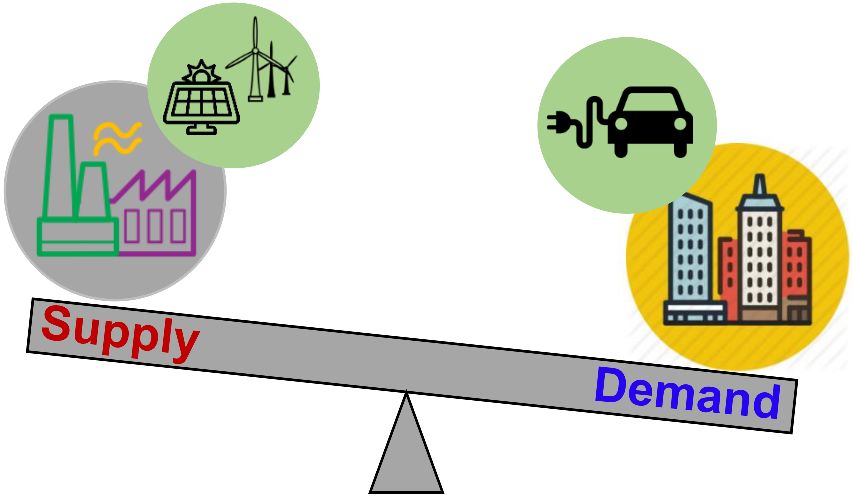
❖ **Test results**

❖ **Conclusions**

Introduction

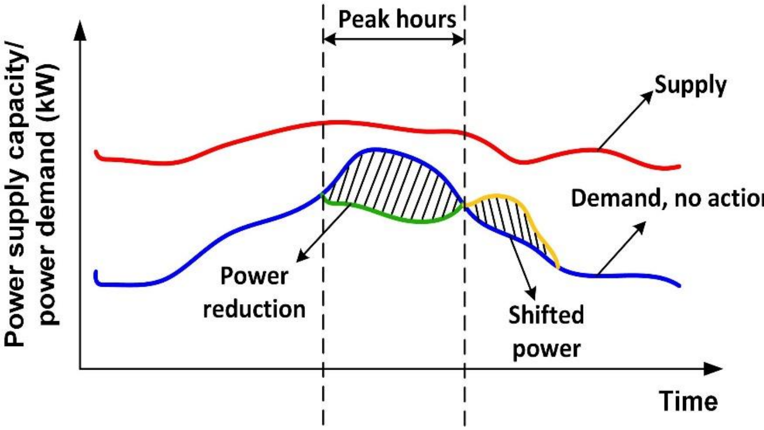
❑ Power imbalance and demand response in today's grids

- **Power imbalance issue**

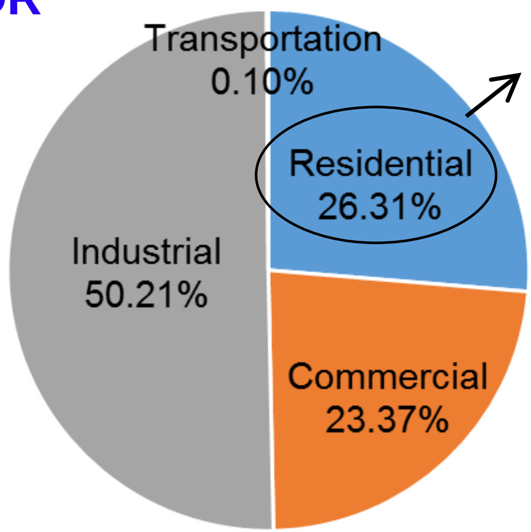


Solution

- **Demand response**



- **Residential DR**



According to FERC
- Most untapped DR potentials
- over 45% in 2019.

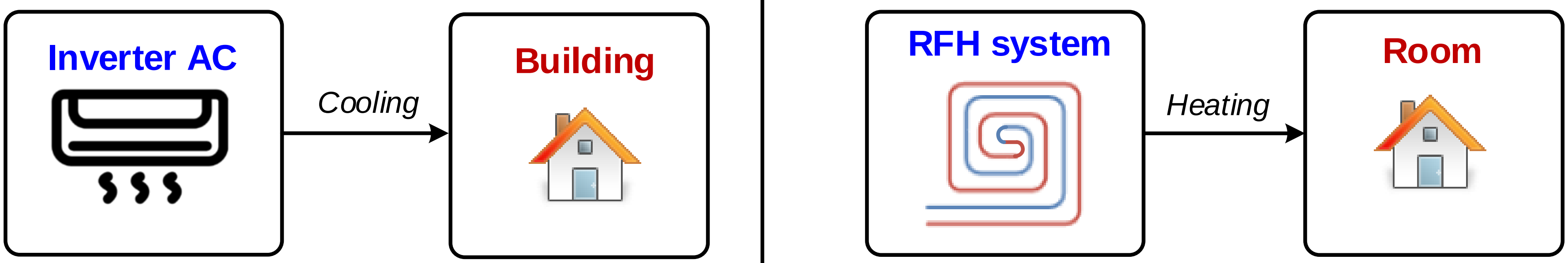
Fig. Actual peak demand savings in US (13,036 MW in 2015)

Introduction

❑ Typical residential HVAC systems in Hong Kong and Denmark

- **Hong Kong**
  (building + inverter AC)

- **Denmark**
  (building + radiant floor heating)



❑ Research aim

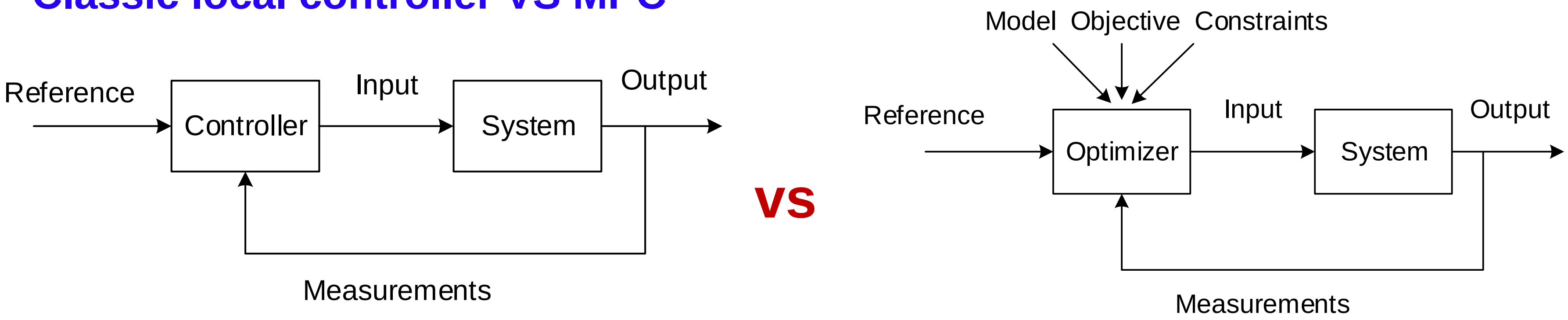
To use MPC method to control the residential HVAC systems making them respond to dynamic electricity prices and reduce electricity bills.

Methodology

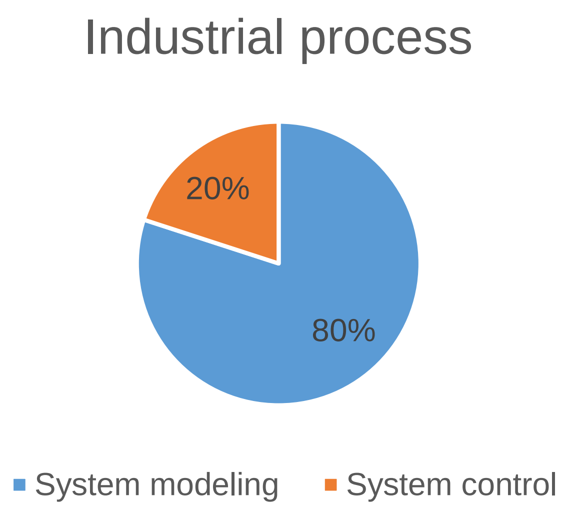
- **Main idea**

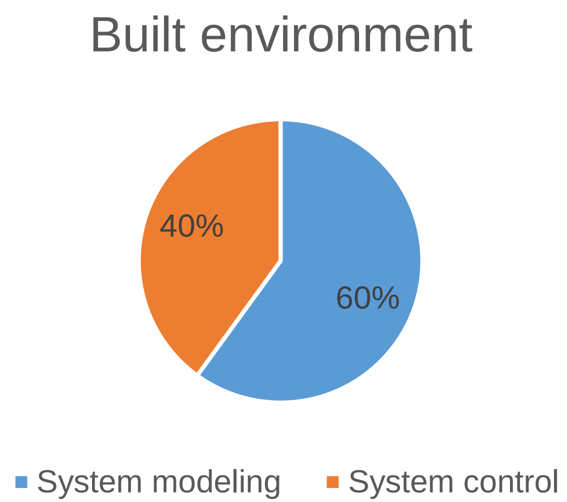
  Use system model to predict the future evolution of the system and make some preparations in advance

- **Classic local controller VS MPC**



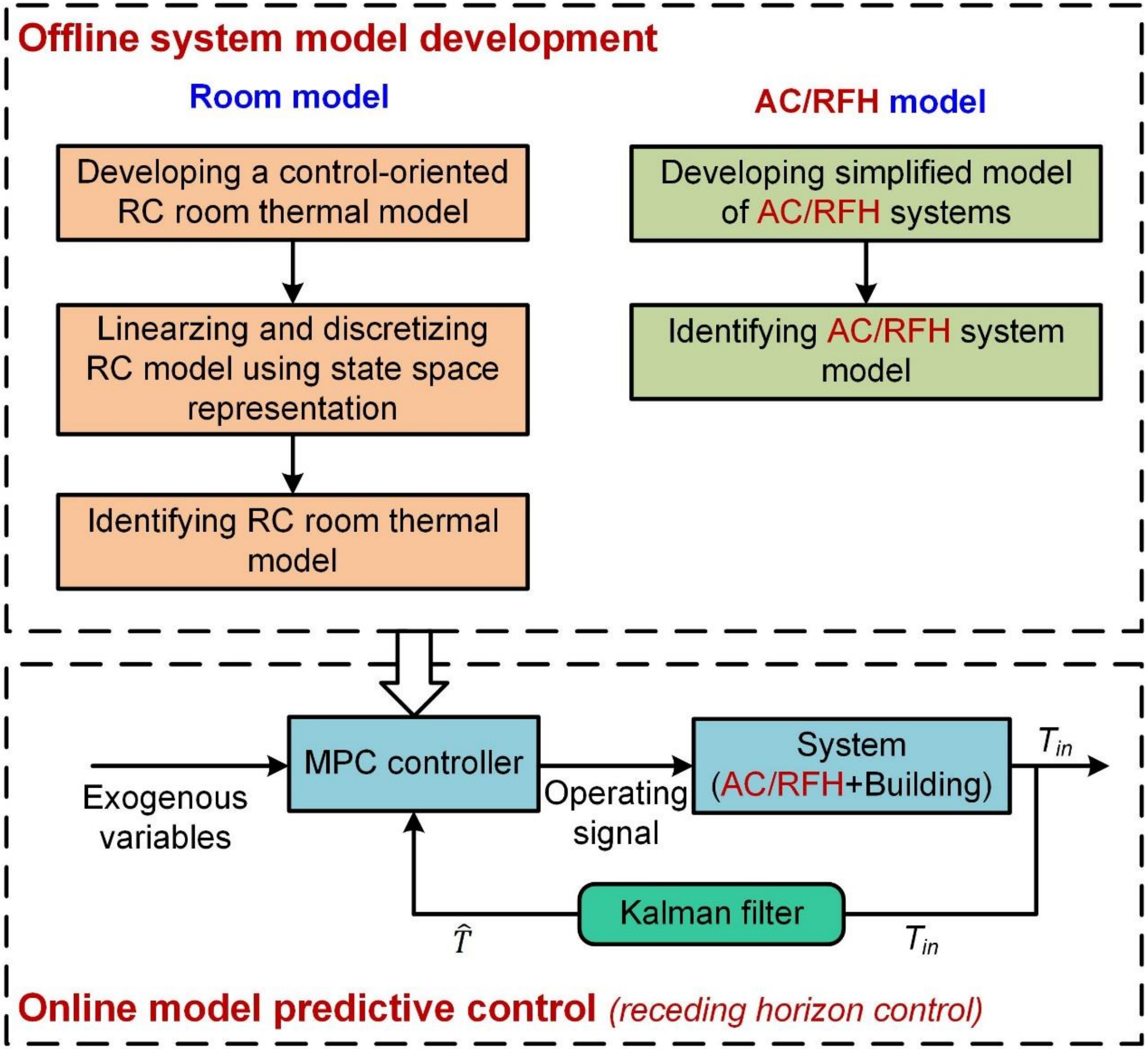
- **Development cycle of a MPC controller**





Methodology

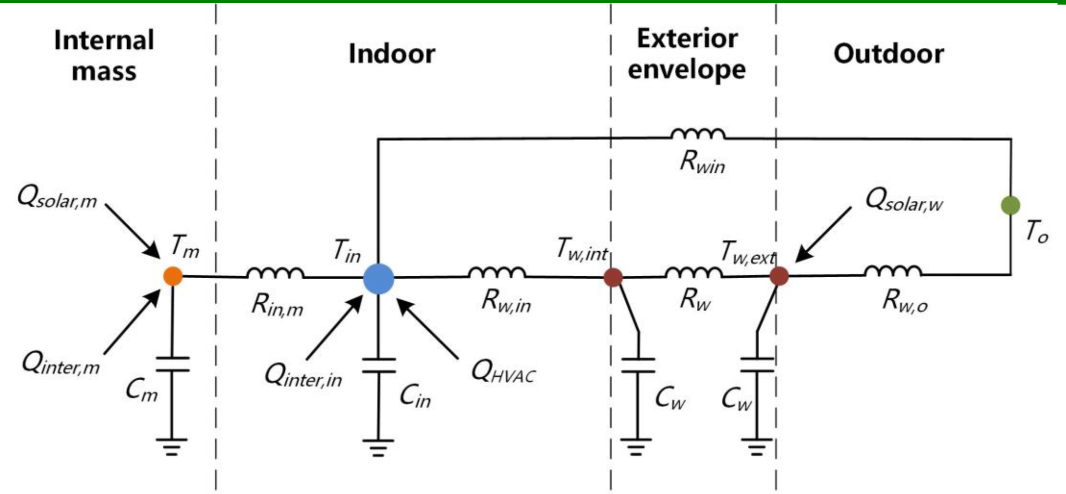
- **Framework of the whole implementation of MPC**



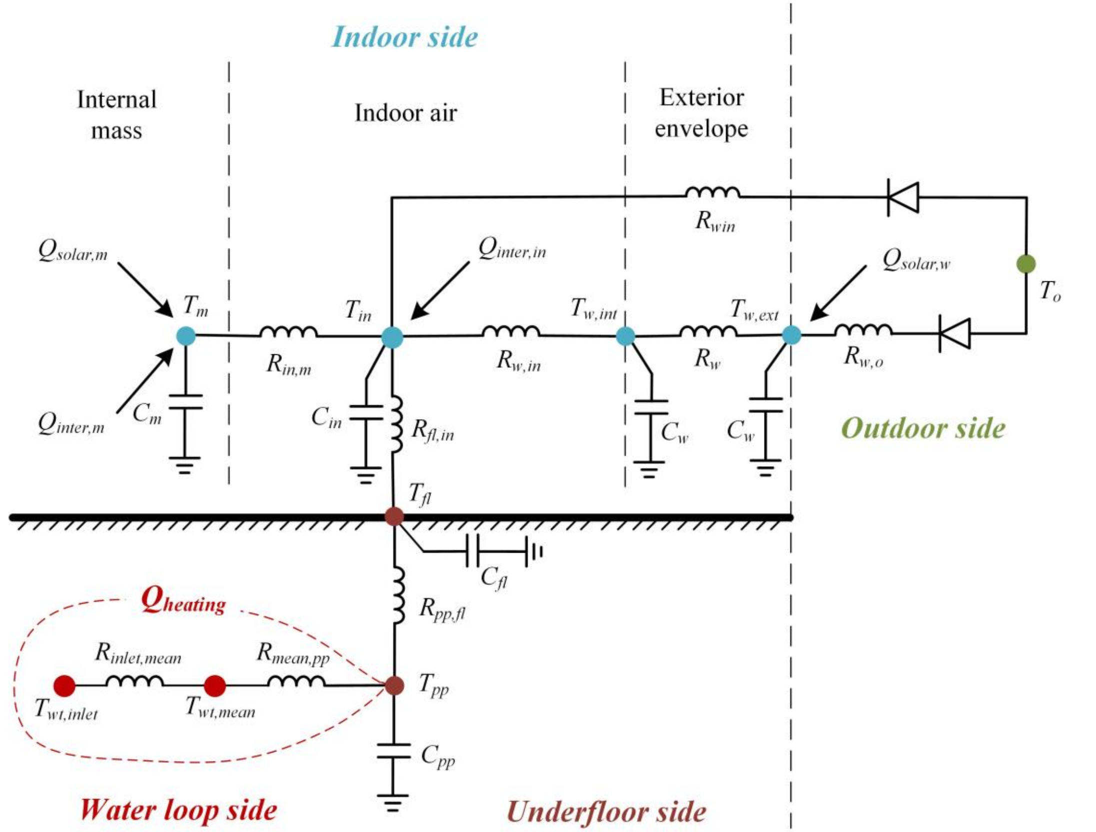
Methodology --- offline system model development

❑ Room thermal model

- AC + building in Hong Kong



- RFH + building in Denmark



Methodology --- offline system model development

❑ Room model in state space form

$$dx = (Ax + Bu + Ed)dt + \sigma dw(t)$$

$$y = Cx + v$$

- AC + building in Hong Kong

System state $x = [T_{w,ext} \quad T_{w,int} \quad T_{in} \quad T_m]^T$;

Input vector $u = Q_{HVAC}$;

Disturbance vector $d = [T_o \quad I_{solar} \quad Q_{inter}]^T$;

- RFH + building in Denmark

System state $x = [T_{w,ext}\ T_{w,int}\ T_{in}\ T_m\ T_{fl}\ T_{pp}]^T$;

Input vector $u = Q_{heating}$;

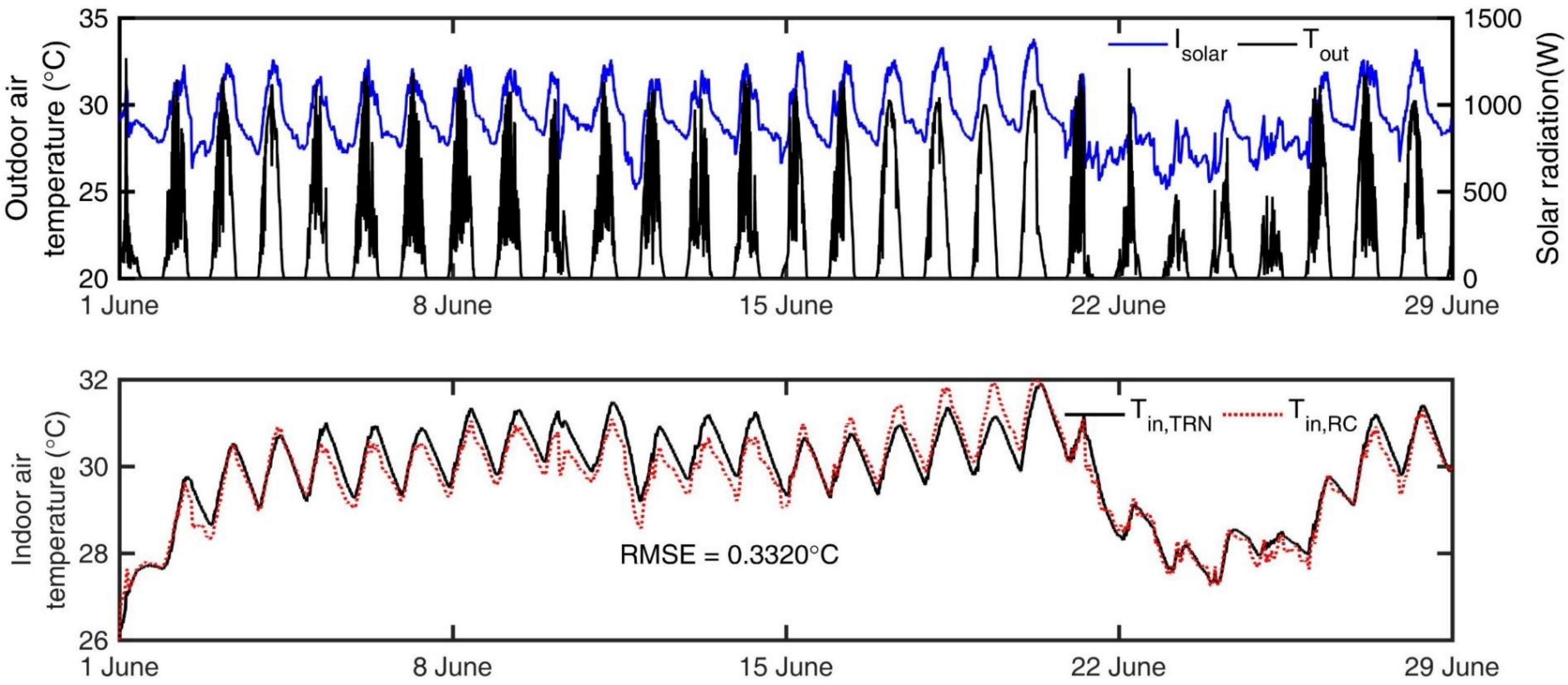
Disturbance vector $d = [T_o \quad I_{solar} \quad Q_{inter}]^T$;

Methodology --- offline system model development

- **Identify a room built in TRNSYS** *(Transient System Simulation Tool)*

  Residential building in Hong Kong (L×W×H: 4.8m×3.6m×3m; *WWR* = 0.2)

- **Comparisons between data from TRNSYS and RC model**

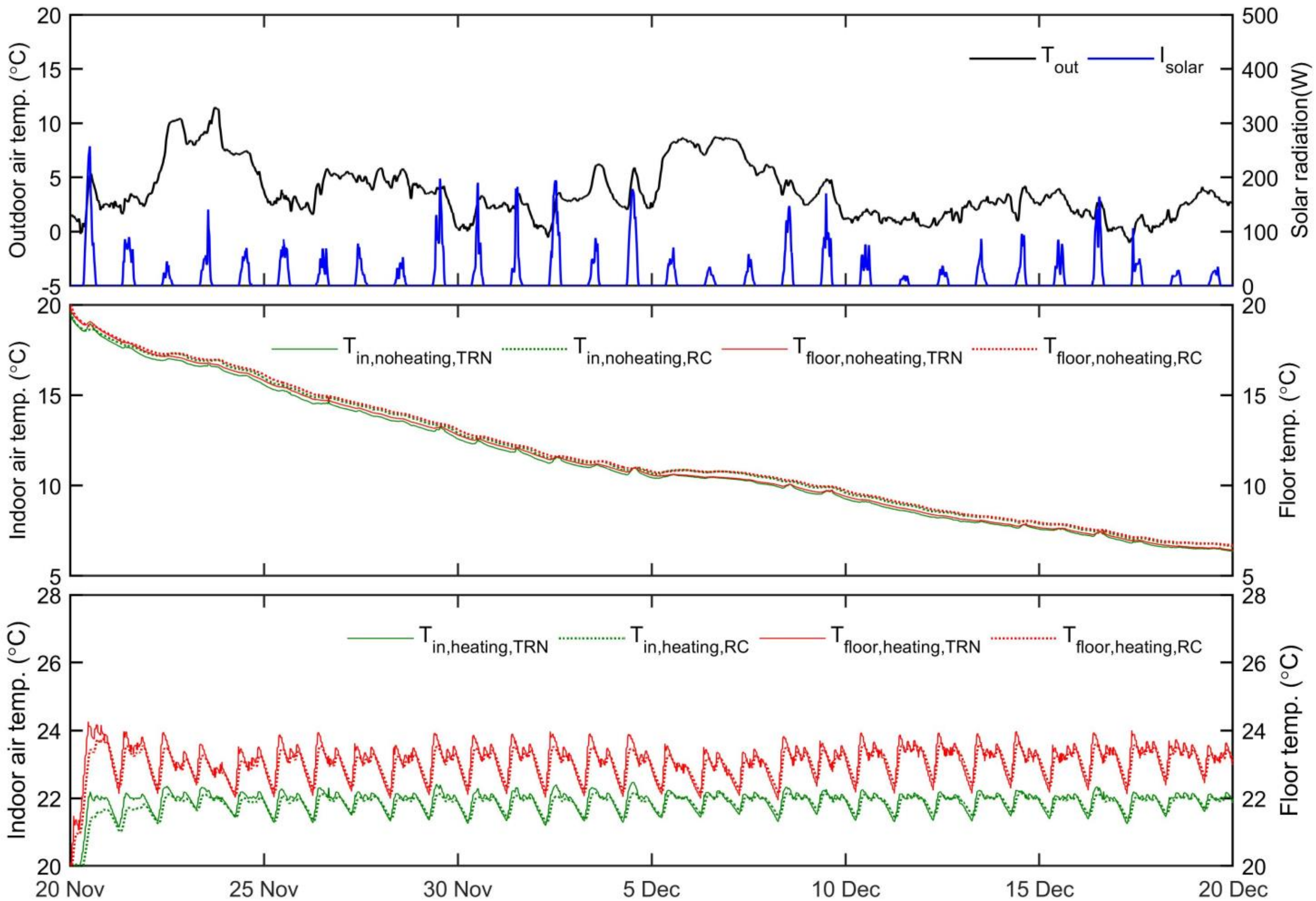


Methodology --- offline system model development

- **Identify a room built in TRNSYS**

  Residential building in Nordhavn, Denmark (L×W×H: 8.9m×6.22m×3m; *WWR* = 0.45)

- **Comparisons between data from TRNSYS and RC model**



Methodology --- offline system model development

❑ Inverter AC model

- **Objectives**

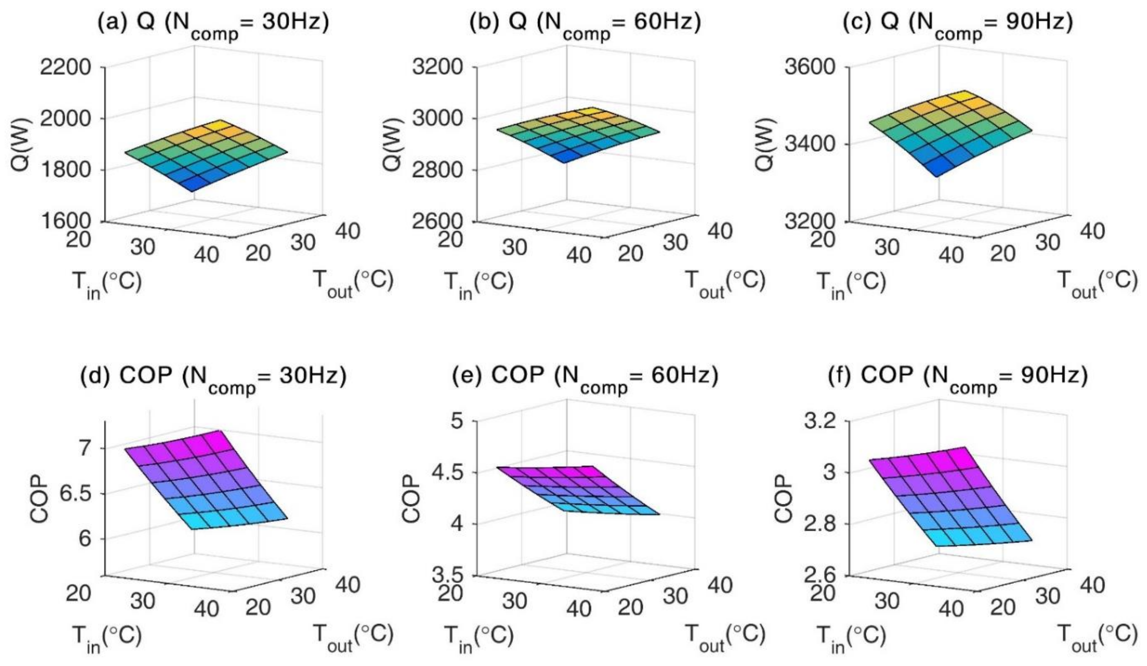
  Obtain steady-state performance data under a range of operating conditions

  i.e. $Q = f(N_{comp}, T_{out}, T_{in})$ $COP = f(N_{comp}, T_{out}, T_{in})$

- **Solution**

  Physical modeling $\Rightarrow$ Performance maps (control-oriented)

- **Performance map of an inverter AC**



Methodology --- online model predictive control

❑ Optimization problem formulation

- AC + building

$$\min_{P_1,P_2,\dots,P_{N-1}} \sum_{k=1}^{N-1} P_k \Delta t \cdot RTP_k + \rho_e e_k$$

$$T_{k+1} = A_d \cdot T_k + B_d \cdot COP_k \cdot P_k + E_d \cdot d_k + w_k$$

$$y_k = C_d T_k + v_k$$

$$y_{lb,k} - e_k \leq y_k \leq y_{ub,k} + e_k$$

$$e_k \geq 0$$

$$P_k = 0 \text{ or } P_{min} \leq P_k \leq P_{thsh,k}$$

- RFH + building

$$\min_{u_1,u_2,\dots,u_{N-1}} \sum_{k=1}^{N-1} (u_k/COP)\Delta t \cdot DAP_k + \rho_e e_k$$

$$x_{k+1} = A_d x_k + B_d u_k + E_d d_k + w_k$$

$$y_k = C_d x_k + v_k$$

$$y_{lb,k} - e_k \leq y_k \leq y_{ub,k} + e_k$$

$$e_k \geq 0$$

$$u_k = 0 \quad \text{or} \quad u_k = \quad Q_{heating,k}$$

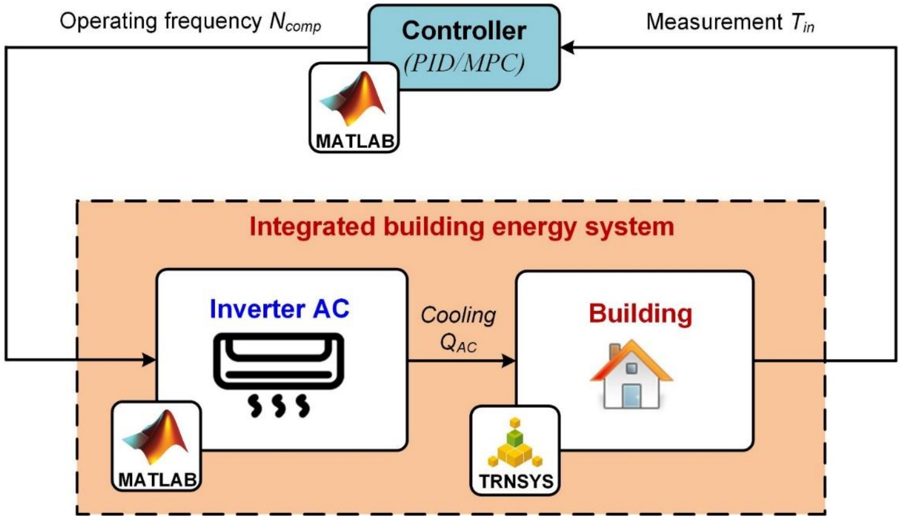
	AC+building in HK	RFH+building in DK
Prediction interval	5 mins	15 mins
Prediction horizon	3 hrs	20 hrs

Why?

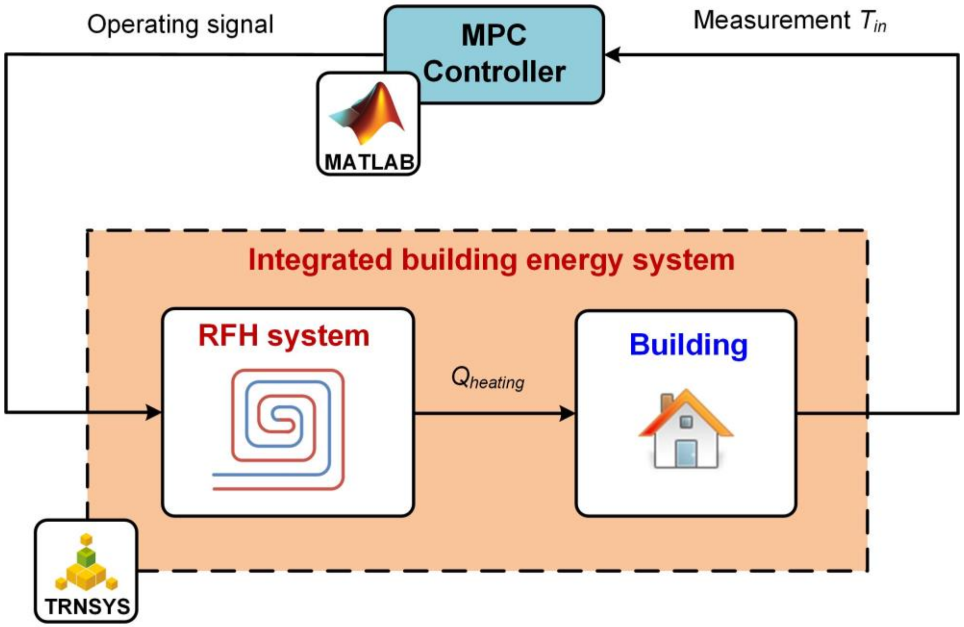
Test results

❑ A TRNSYS-MATLAB co-simulation testbed

- **AC + building in HK**

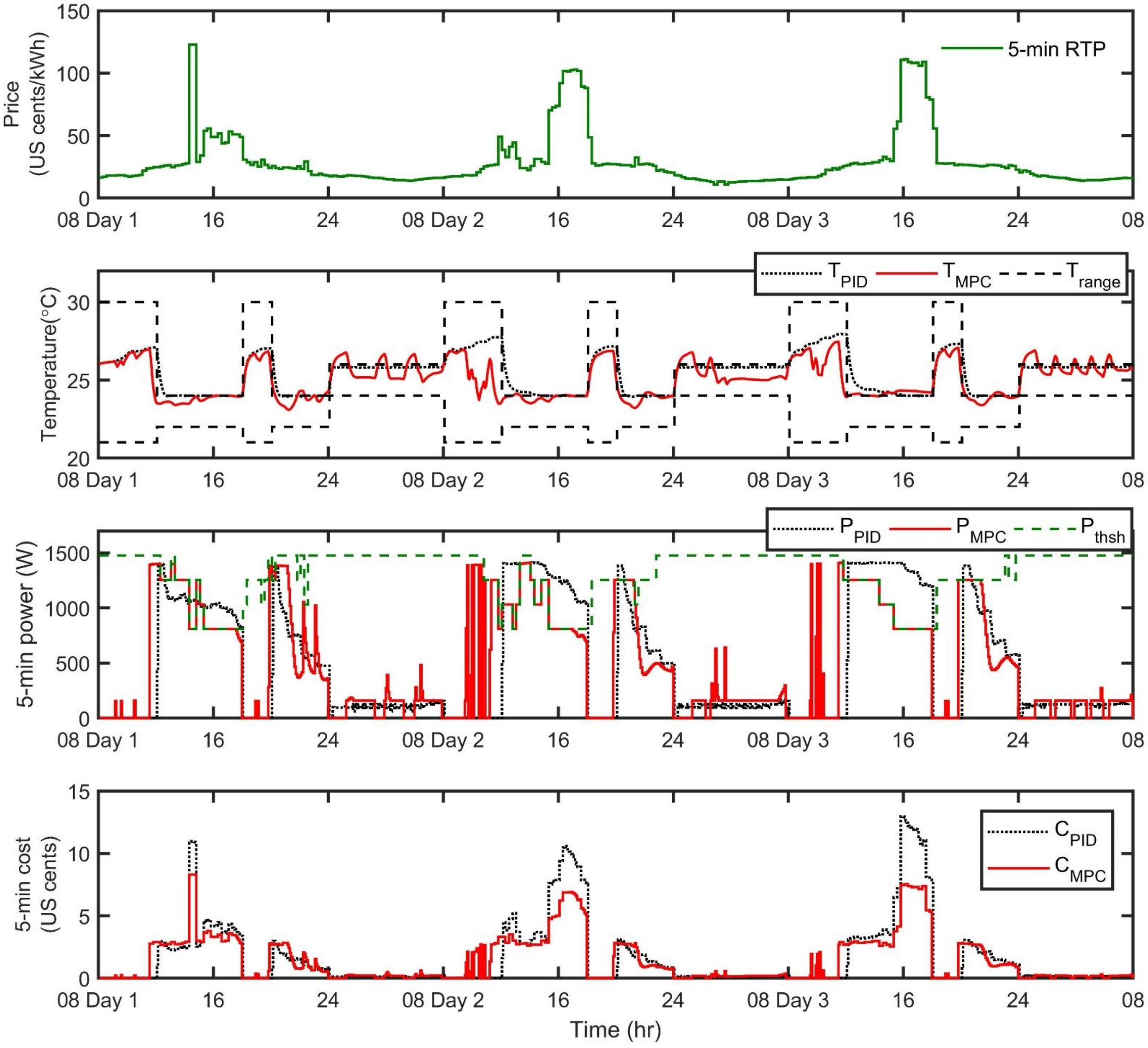


- **RFH + building in DK**



Test results

- **MPC for AC**

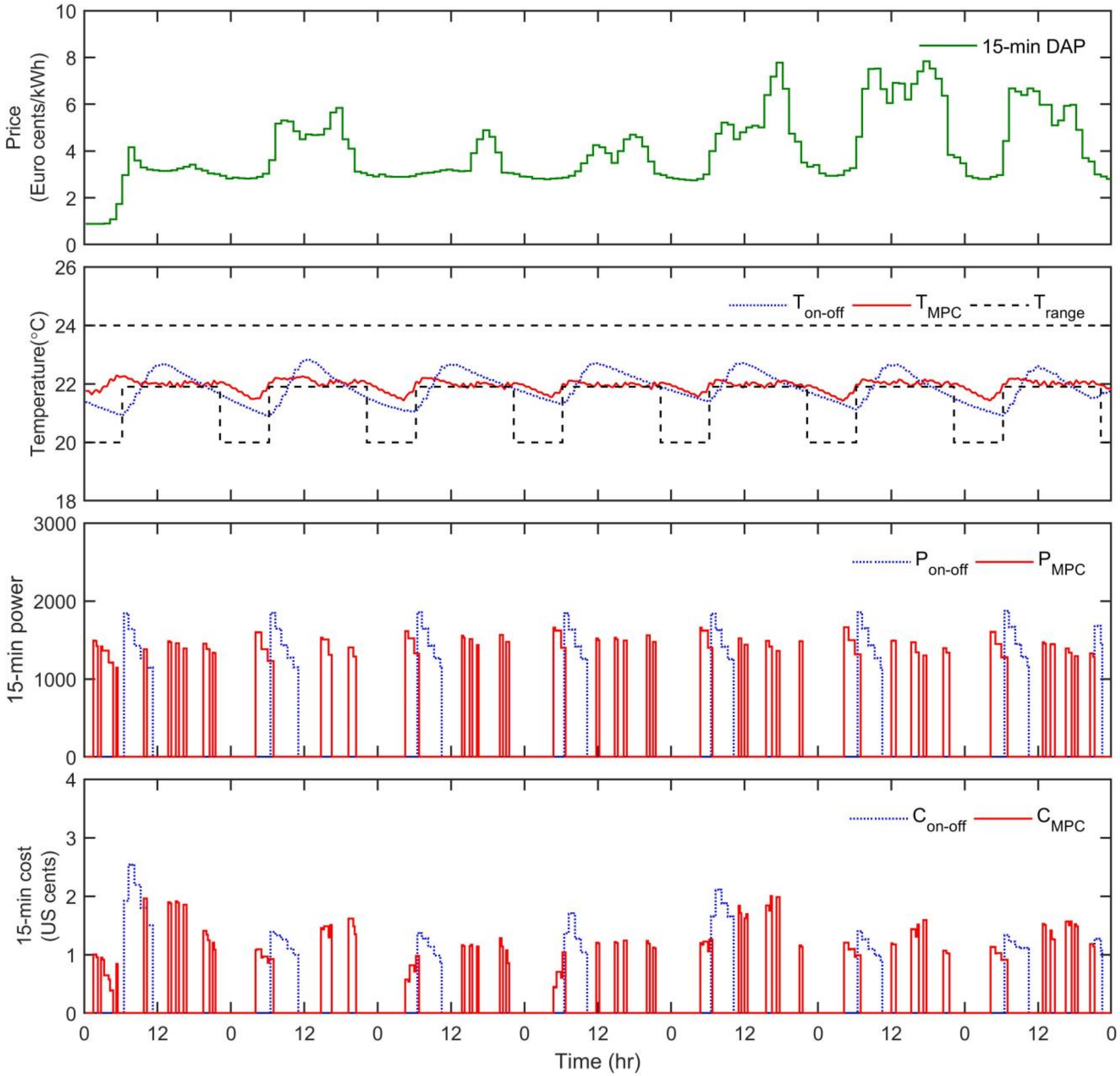


Main advantages:

- Improve the thermal comfort at the beginning of occupancy
- Reduce peak power demand
- Reduce electricity costs (0.5% -22%)

Test results

- **MPC for RFH**



Main advantages:

- Improve the thermal comfort
- Shift power demands to night
- Reduce electricity costs

Conclusions

❑ Contributions:

- A simple-structured grey-box room thermal model is developed, linearized, discretized and identified.

- MPC controllers for AC/RFH systems are designed and tested. Simulation results show that MPC controllers for AC/RFH systems are able to respond to dynamic electricity prices from smart grids. They help to reduce the peak power demands and electricity costs in both Hong Kong and Denmark. Compared with the conventional rule-based controllers, the MPC controllers are cost-efficient and grid-friendly.

Thank You!