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Asian Modelica & FMI Conference 2026
Hangzhou · China

An FMI Co-simulation Framework for Day-ahead Optimization of DCS Based on Modelica

基于 MODELICA的区域供冷系统日前运行策略优化FMI联合仿真框架



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01 Background

02 Method

03 Results

04 Conclusions and Outlook

MOTIVATION

Renewable electricity is essential for carbon neutrality, but variability increases the risk of supply-demand imbalance during summer peaks.

绿电波动导致电网稳定性降低，区域供冷系统可通过需求响应为电网提供用电柔性。

1 Renewable variability

Variable generation and electrification increase balancing pressure.

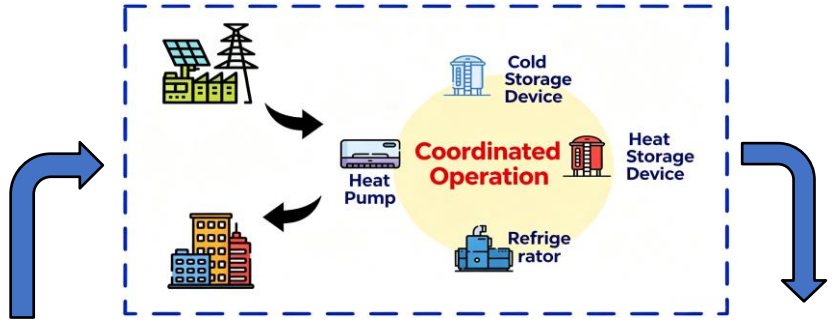
2 DCS flexibility

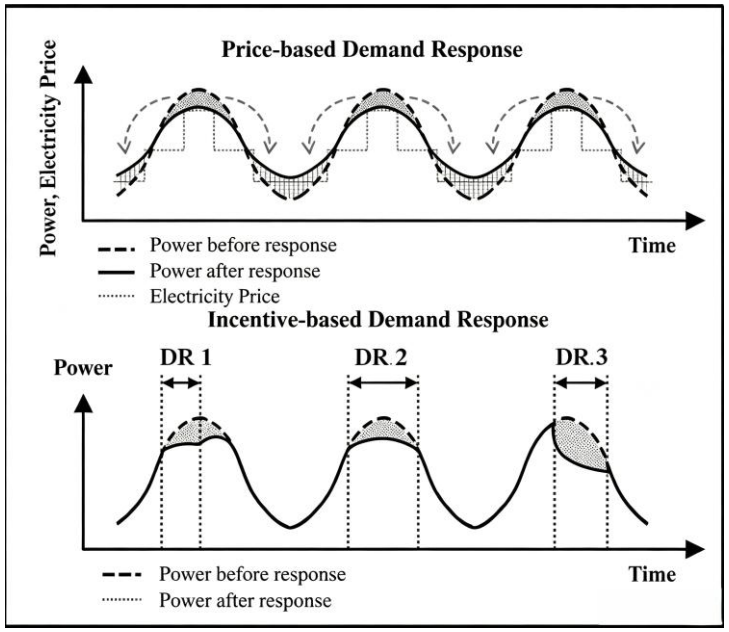
Storage turns thermal inertia into flexible electric demand.

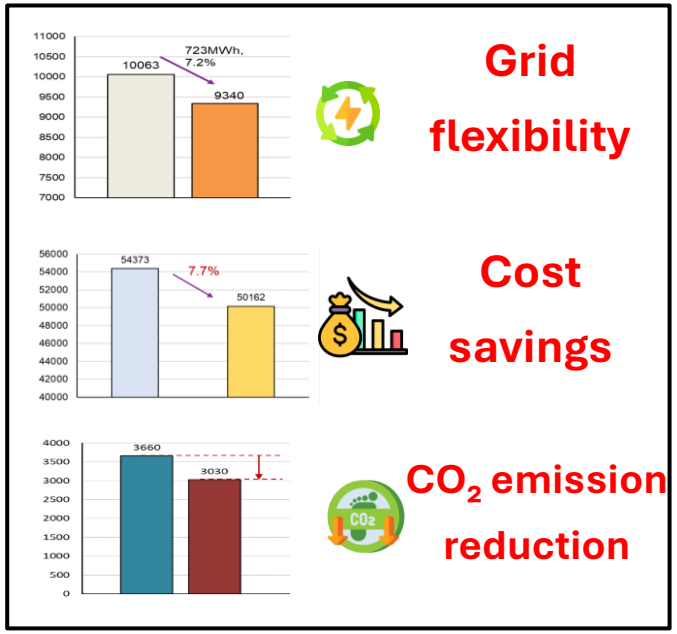
3 Coupled dynamics

Equipment, networks, buildings and unit commitment interact.

DCS demand response links grid flexibility with lower operating cost and emissions.







MOTIVATION

Dynamic coupling makes static dispatch unreliable

需要能够响应区域供冷系统多因素动态耦合特性的控制策略来发挥其柔性潜力。

A 24-hour DCS schedule must stay feasible as load, weather, tariff and carbon signals change.

WHY STATIC DISPATCH IS LIMITED

Four effects must be evaluated together:

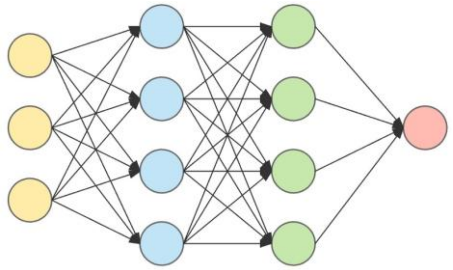
1. **Coupled physics**
   Heat, flow, equipment and controls change together.
2. **Changing boundaries**
   Load, weather, price and carbon data change by hour.
3. **Conflicting targets**
   Cost, emissions, comfort and flexibility can conflict.

Feasible schedules of DCS need dynamic simulation in addition to energy balance.

KEY REQUIREMENT

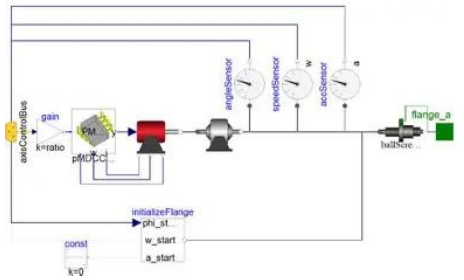
Use a dynamic evaluator inside the optimizer.

Data-driven model



Fast solving speed
Poor interpretability
High data demand

Physics-based model



Slow solving speed
Good interpretability
Low data demand

CONTENTS

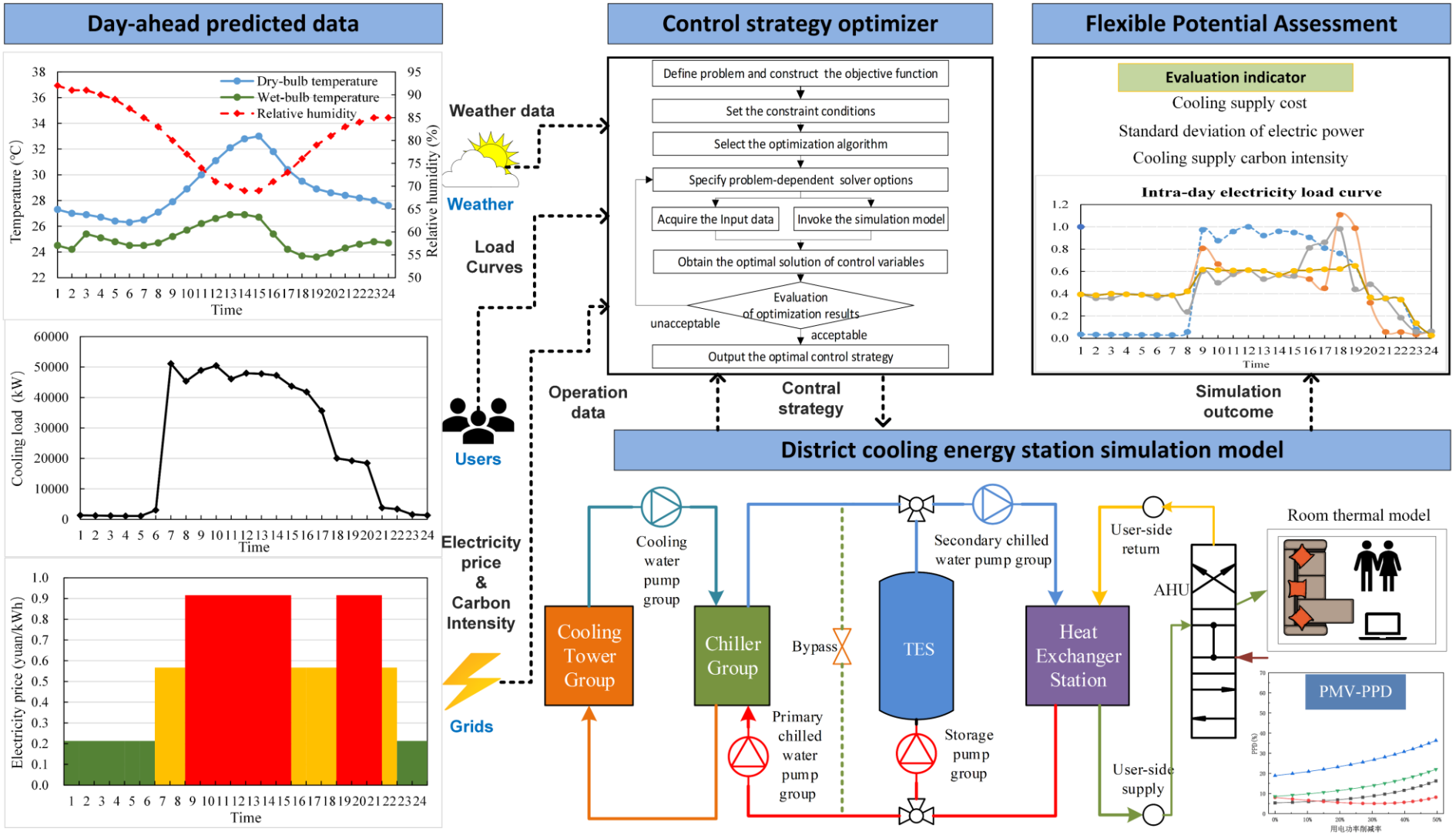
02 Method

- Framework and Workflow
- Study case
- Model and Validation
- Optimizer
- Implementation

FRAMEWORK

This study couples a Modelica-based DCS model with day-ahead optimization

基于物理模型的区域供冷系统控制策略日前优化框架



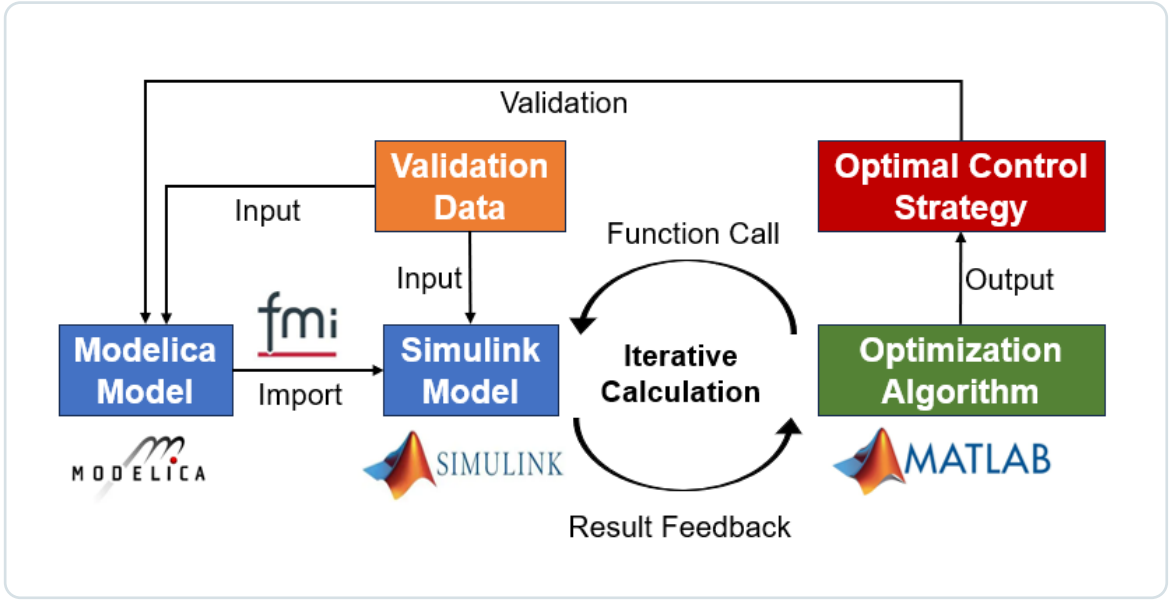
The framework combines boundary forecasts, full-process dynamic simulation and external optimization to generate physically feasible schedules.

METHOD

The workflow links decisions with dynamic simulation

FMI 联合仿真工作流程

FMI provides a portable interface between the physical plant model and the optimization algorithm.



Modelica **FMI 2.0 FMU** **MATLAB**

Inputs Weather, tariff, load, carbon intensity

↓

FMU call Advance the dynamic plant model

↓

Outputs Energy, thermal, comfort and emissions

↓

Feedback Objective value and feasibility

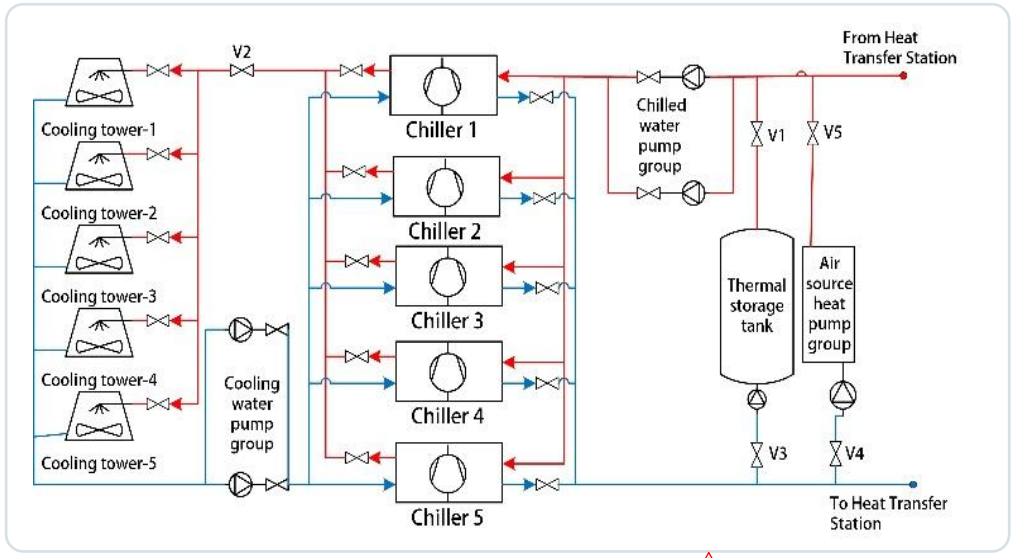
A single Modelica model is reused across simulation, export and optimization.

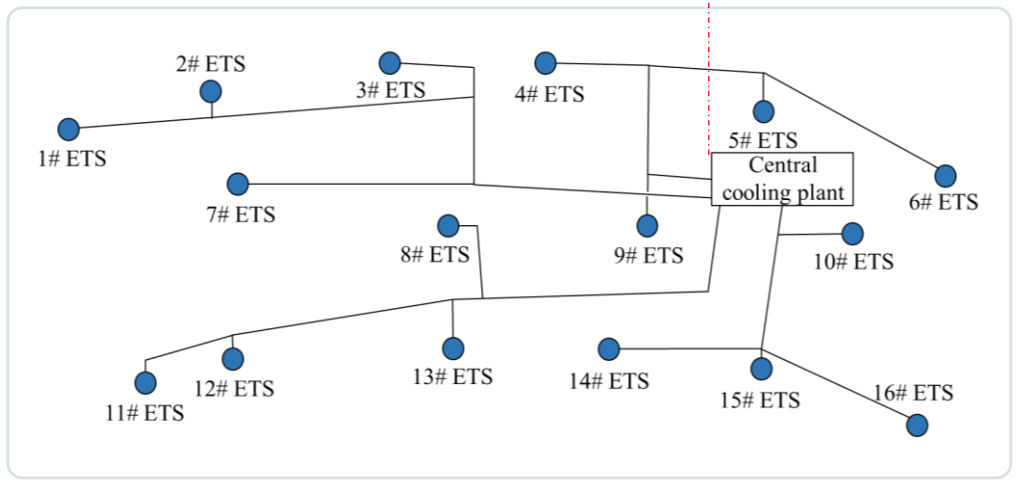
CASE STUDY

A Shanghai district cooling system provides the case study

区域供冷系统工程案例

The structure diagram of DCS case as follow:





Peak cooling load
55.8 MW

Storage tank
20,000 m^3

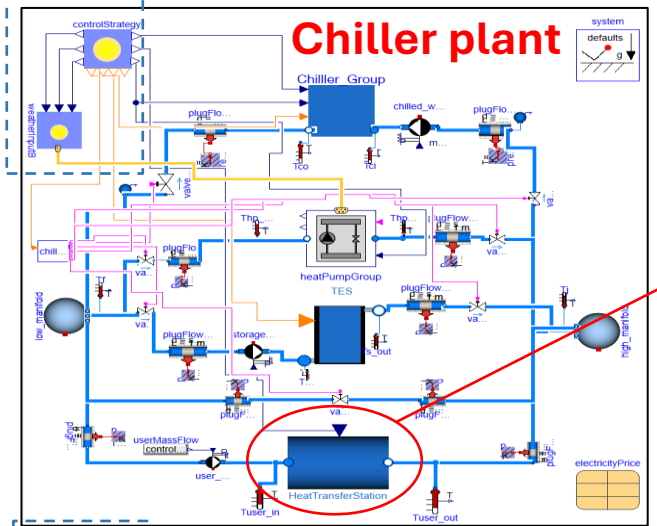
Served buildings
16

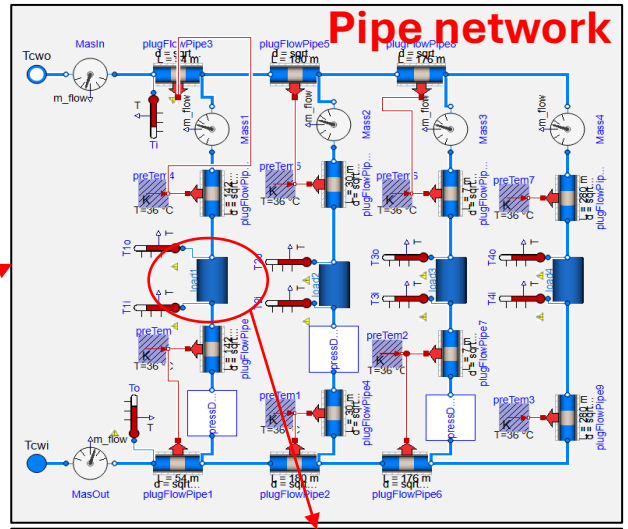


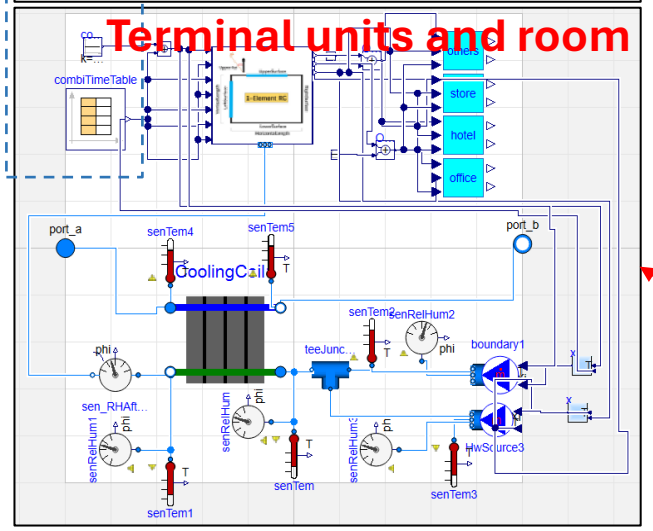
MSL and Buildings form the system-level Modelica DCS model

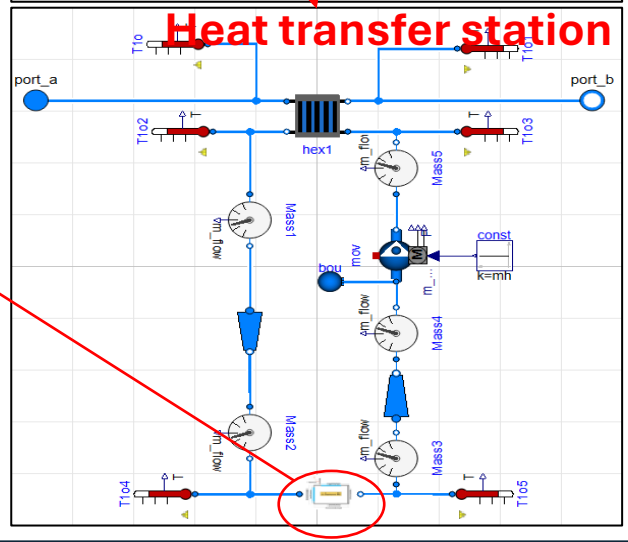
系统级Modelica 物理模型

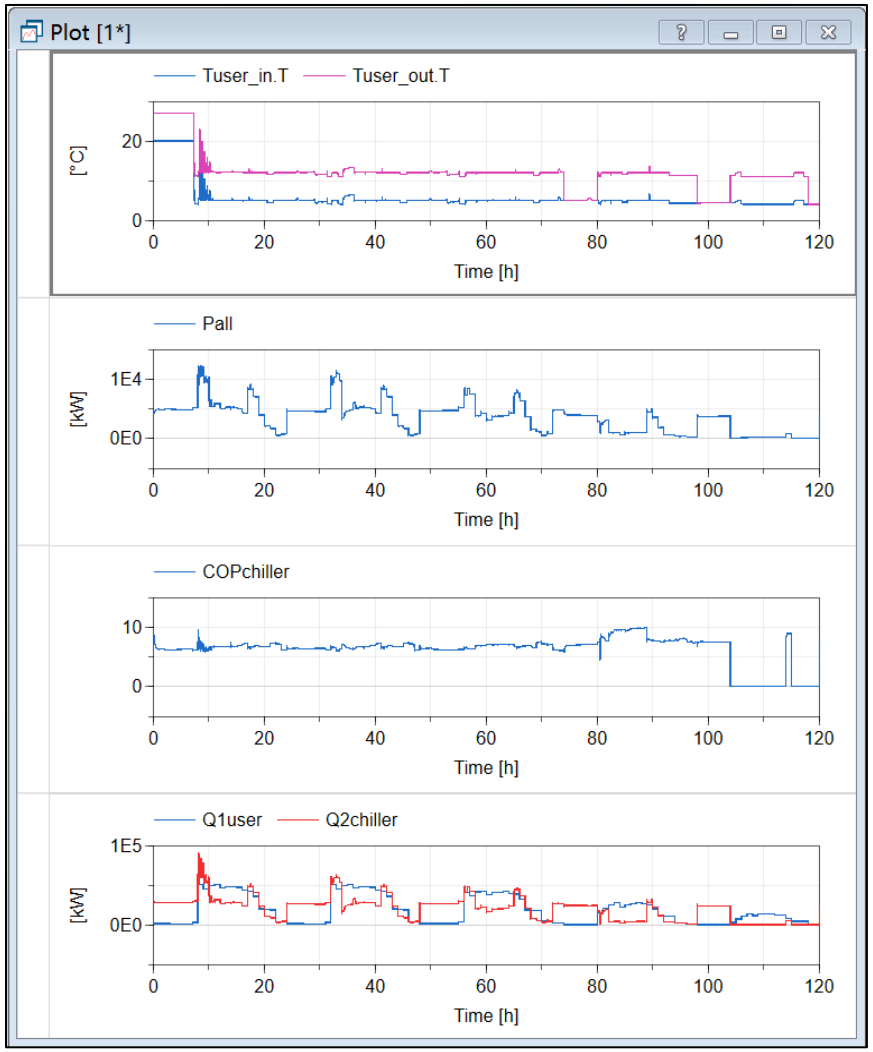
Equipment, transport and building dynamics remain in one executable system representation.







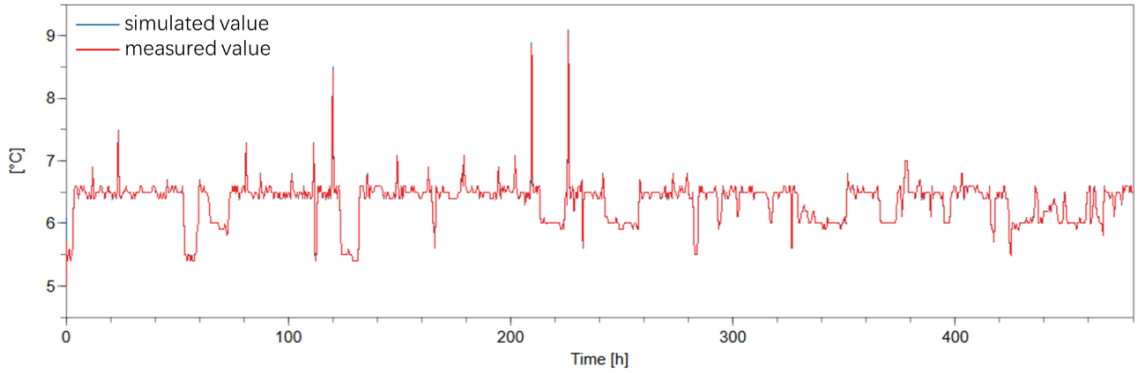




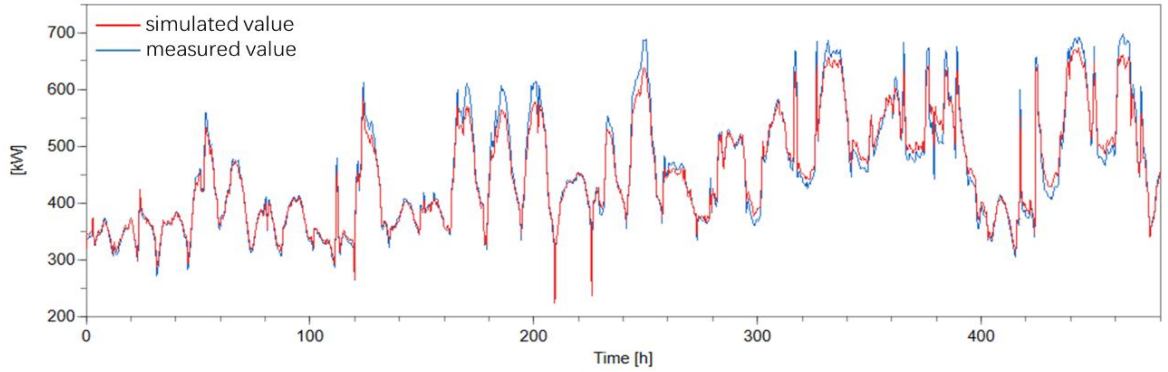
Reference-case validation supports the modeling approach

仿真模型精度校验

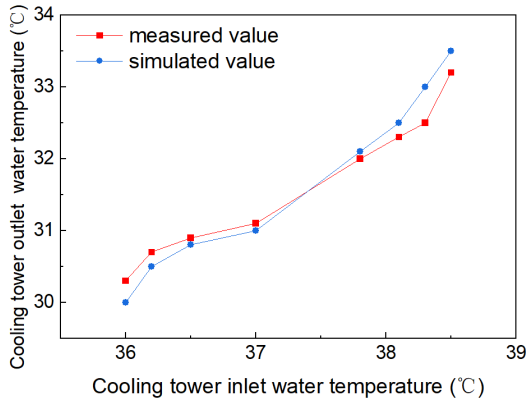
chiller power CVRMSE	cooling capacity CVRMSE	chilled-water error	cooling-tower error
3.17%	0.28%	< 0.5°C	± 0.8°C



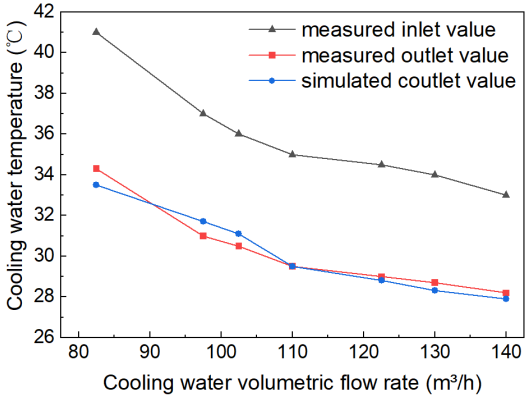
(a) Chilled water outlet



(b) Chiller electric power



(c) Constant cooling-water flow rate



(d) Variable cooling-water flow rate

The target project was under construction, so measured data from an operational reference system validate the modeling method, and direct calibration of the target project remains future work.

Day-ahead scheduling is a 24-hour MINLP

日前 MINLP 问题优化函数及求解工具

The decision vector combines continuous storage actions with integer unit-commitment variables.

Energy minimize daily electricity use

$$f(Q_{cs,1}, \dots, Q_{cs,24}, n_1, \dots, n_{24}) == min(\sum_{i=1}^{24} P_i)$$

Cost minimize time-of-use cost

$$f(Q_{cs,1}, \dots, Q_{cs,24}, n_1, \dots, n_{24}) = min(\sum_{i=1}^{24} Pr_i \cdot P_i)$$

Carbon minimize CO_2 emissions

$$f(Q_{cs,1}, \dots, Q_{cs,24}, n_1, \dots, n_{24}) = min(\sum_{i=1}^{24} f_i \cdot P_i)$$

Constraints

$$OC1: Q_{cs,i} + Q_{chiller,i} = Q_{c,i}$$

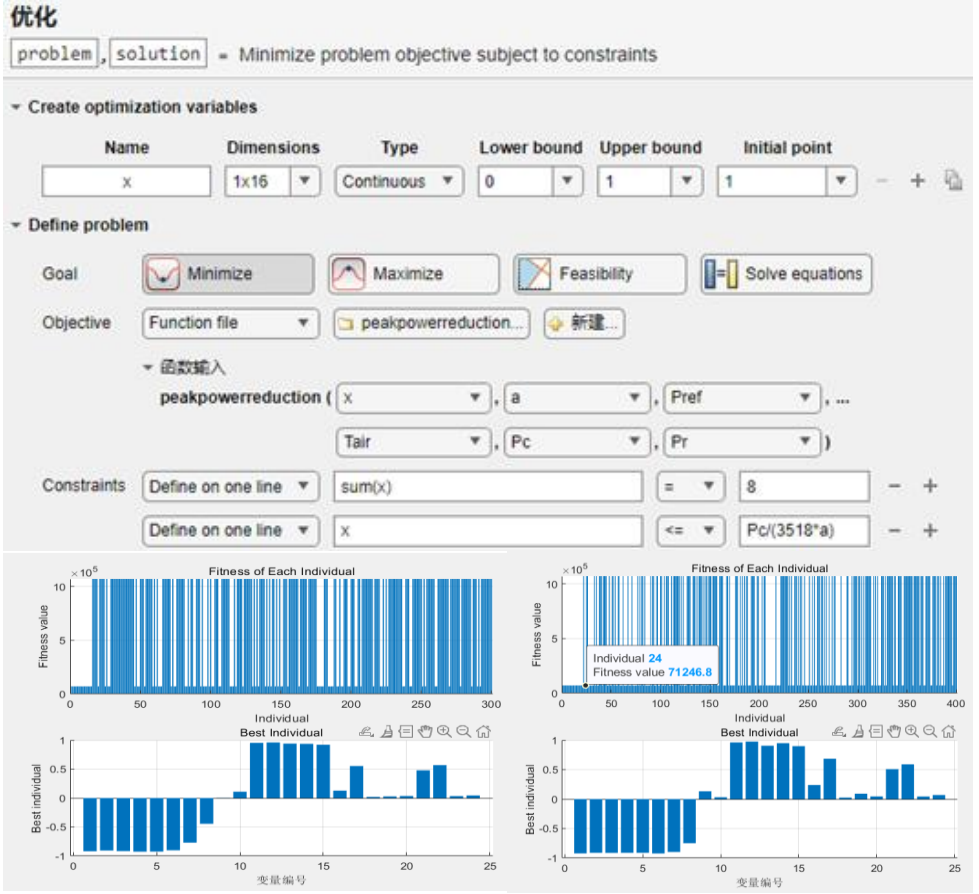
$$OC2: \sum_{i=1}^{n} Q_{cs,i} = 0$$

$$OC3: 0 \le E_{s,i} \le E_{sa} \quad i = 1, \dots, n$$

$$OC4: -Q_{sa} \le Q_{cs,i} \le Q_{sa} \quad i = 1, \dots, n$$

$$OC5: 0 \le Q_{chiller,i} \le Q_{ref} \quad i = 1, \dots, n$$

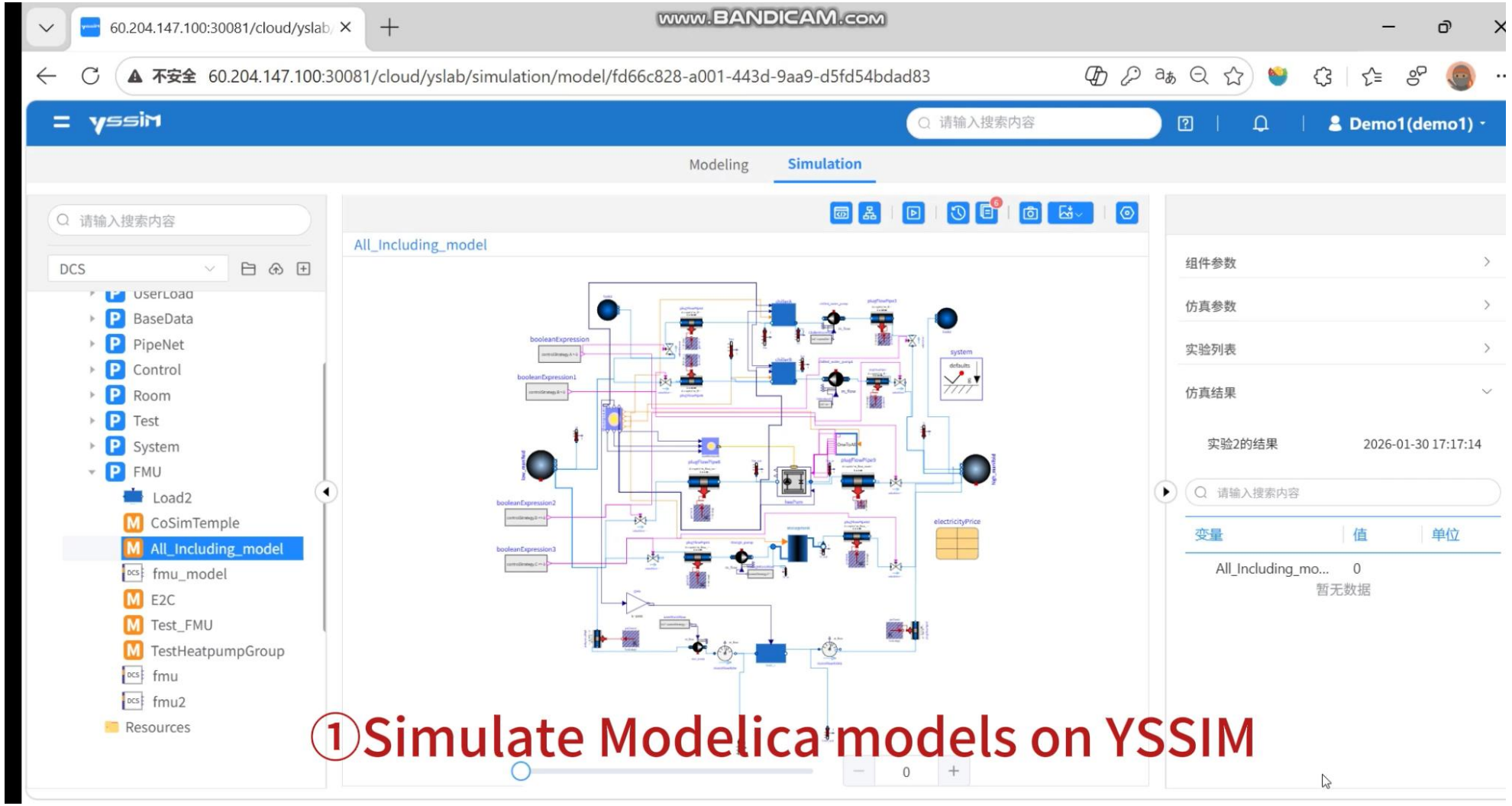
The FMU is the evaluator inside the optimization loop.



Solver: MATLAB Global Optimization Toolbox

IMPLEMENTATION

- YSSIM exports the Modelica plant model as an FMU for optimization **联合仿真实现流程**
- MATLAB Global Optimization Toolbox calls the FMU during automated schedule search.



CONTENTS

03 Results

- Optimization Results
- FMI Settings
- Algorithm Comparison

EXPERIMENT DESIGN

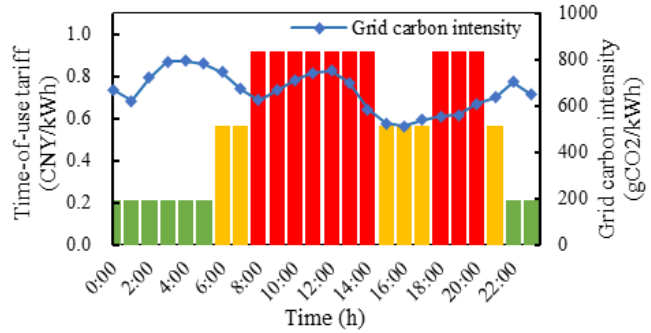
One typical summer day compares four operating strategies

夏季典型日的优化场景设置

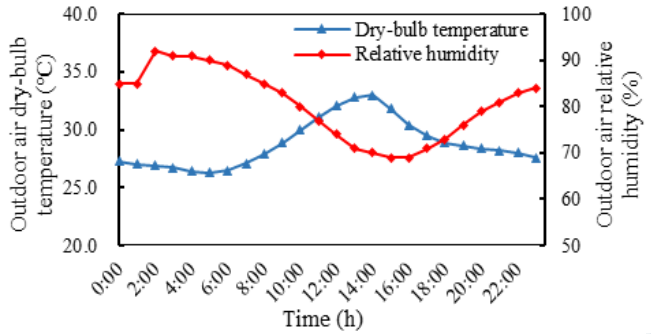
All strategies meet the same cooling service requirement; the selected objective determines plant operation.

Boundary conditions

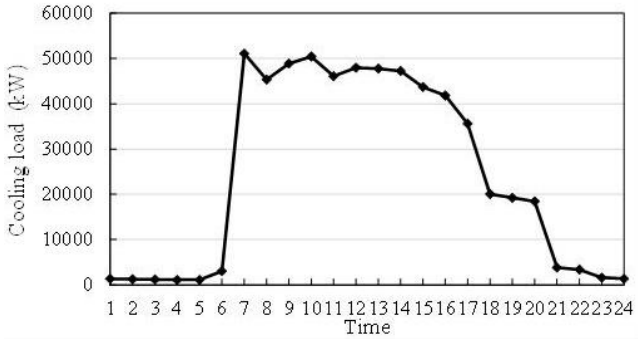
Tariff & Carbon intensity



Weather



Cooling load



Optimization objective

Baseline storage-priority control

Strategy 1 minimum electricity use

Strategy 2 minimum operating cost

Strategy 3 minimum CO_2 emissions

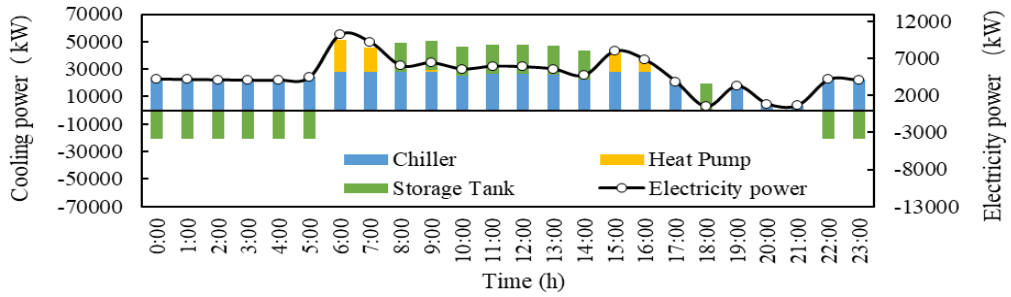
The comparison isolates the value of optimization from the value of simply having storage.

Optimized schedules remain physically interpretable

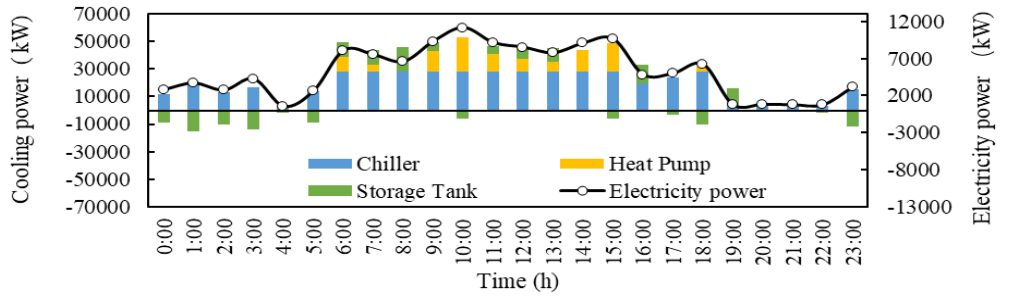
优化调度结果分析

The optimizer changes chiller commitment and storage timing, rather than only returning an objective value.

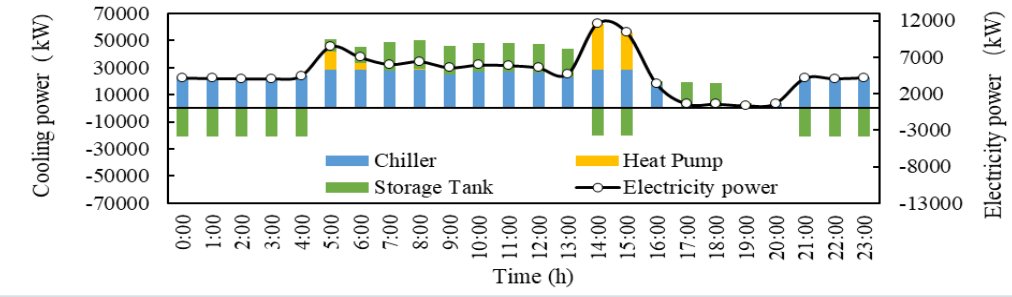
Baseline



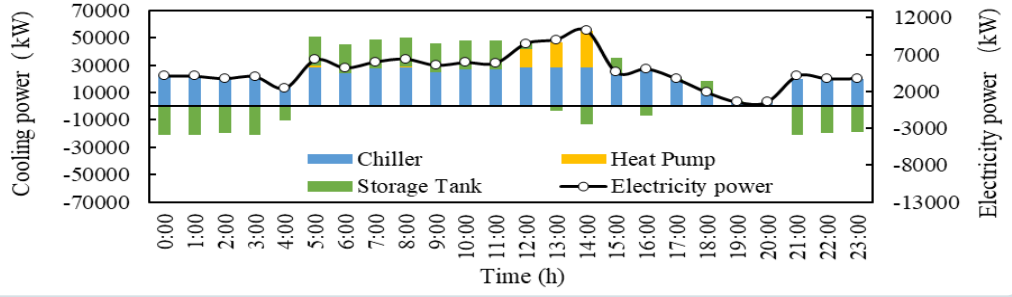
Strategy 1 electricity consumption **−4.58%**



Strategy 2 operating cost **−0.97%**



Strategy 3 CO_2 emissions **−4.20%**

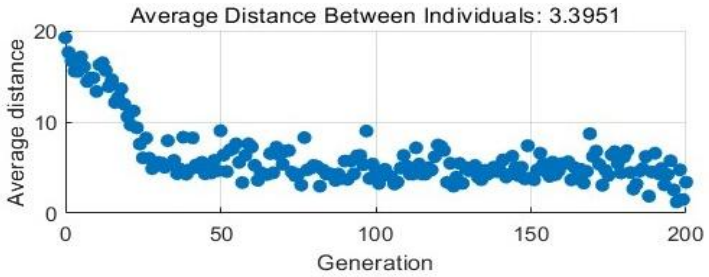


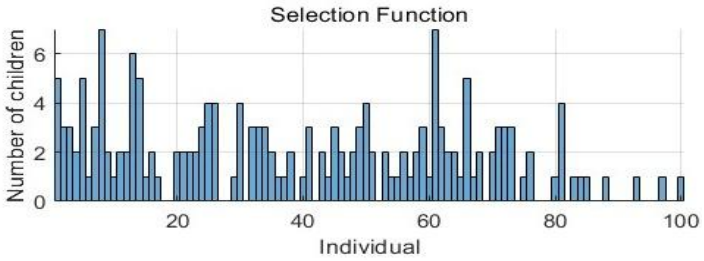
Storage timing changes first; equipment commitment follows the selected objective.

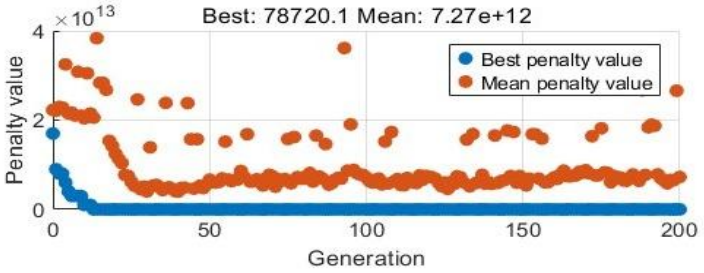
FMI settings shape the accuracy-runtime trade-off

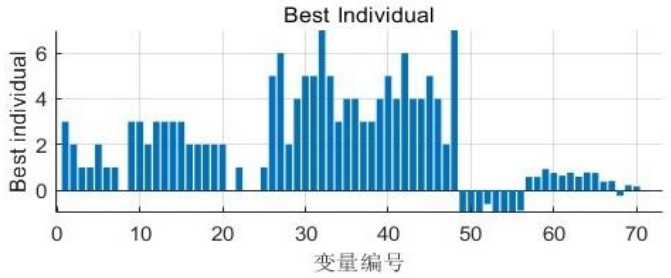
FMU 参数对精度和运行时间的影响

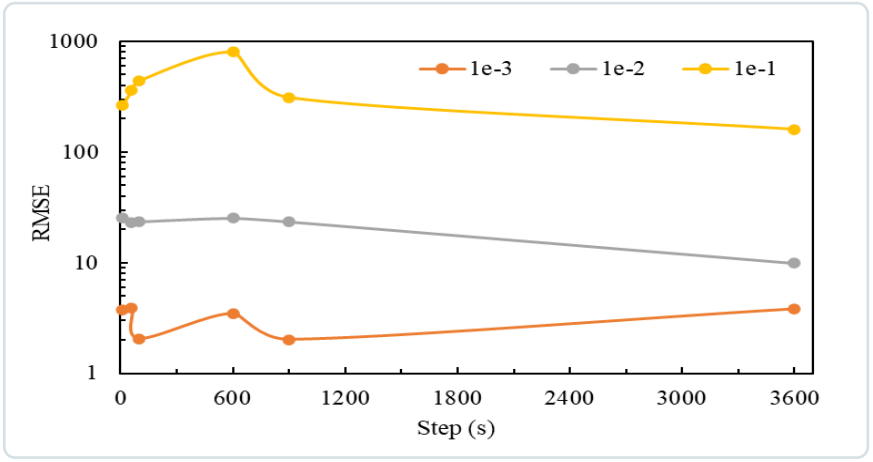
Each FMU call has a computational cost, so interface settings are part of the optimization design.
Test platform: Intel Core i7-10750H CPU @ 2.60 GHz, 32 GB RAM.

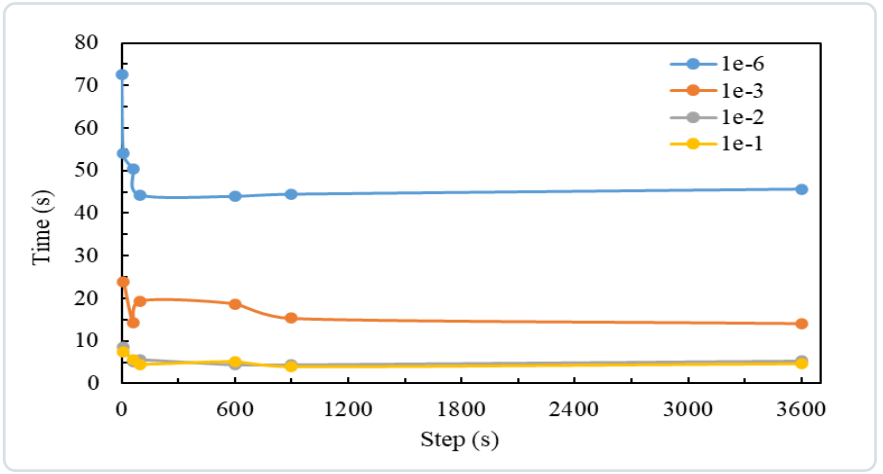












Recommended setting for this case

Step size = 900 s
Relative tolerance = 1e-3

Tolerance primarily controls accuracy; smaller step sizes mainly increase exchange frequency.

ALGORITHM COMPARISON

GA gives the best cost, while surrogateopt saves FMU calls

Surrogate与GA优化算法表现对比

For day-ahead operation, optimizer choice depends on the allowed runtime.

Algorithm logic

- **Surrogateopt** learns an adaptive response model and uses fewer FMU calls.
- **GA** searches many on and off schedules and can improve final cost.

Algorithm	Best cost	FMU calls	Interpretation
surrogateopt	80,016 RMB	4,000	fast early gain
GA, pop. 100	78,720 RMB	20,000	lowest reported cost
GA, pop. 50	78,720 RMB	10,000	same cost, fewer calls
GA, pop. 20	84,858 RMB	2,000	limited exploration

Practical use

Fast daily scheduling: surrogateopt gives a good schedule with fewer FMU calls.

Refined study: GA, pop. 50, reaches the best reported cost with fewer calls than pop. 100.

CONTENTS

04 Conclusions and Outlook

CONCLUSIONS AND OUTLOOK

Modelica-to-FMI co-simulation makes optimization physically accountable

结论与后续工作

Three contributions

01 FMU-in-the-loop workflow

Modelica DCS, FMI 2.0 FMU, MATLAB

02 Day-ahead MINLP scheduling

Discrete chiller commitment and storage operation over 24 hours

03 Accuracy-runtime trade-off

Communication step size and tolerance define FMU evaluation cost

Next steps

- Target-site calibration
- Multi-day and seasonal validation
- Stochastic or robust optimization

Questions and discussion



Physical world unfolds here.....