Development of Model Predictive Control Method using ANN and Metaheuristics

Application to Cooling Operation of Building Energy Systems with Thermal Energy Storage (1)

Model predictive control, MPC

Model predictive control is one of the control methods and is close to the concept of feedforward control. While feedback control determines the control input based on the past information, In MPC, control input is decided based on the future status predicted by the model, so that the object is optimized through a certain period in the future.

Research purpose

The purpose of this study is to compare MPC with conventional rule based control (RBC) and confirm the effect of MPC application. Artificial neural network was used as prediction model which predicts the behavior of the building in order to reduce the iterative optimization calculation load.

Condition of simulation analysis

Eight-story office building located in Tokyo was assumed. Air conditioning was performed only in the work space, and was modeled as one lumped thermal zone.

Building

- Tool：OpenStudio, EnergyPlus
- U-value：Exterior wall 0.95 W/m^{2}k, Roof 0.49 W/m^{2}K, Slab 0.71 W/m^{2}K, Glazing 2.97 W/m^{2}K
- Occupied hours：9:00 – 18:00, weekdays
- HVAC：Maintain cooling setpoint temperature 26 °C at occupied hours

System

- Air-cooled chiller
- Stratified chilled water thermal energy storage
- Two fan coil units
- Three fluid to fluid heat exchanger
- Five variable speed pumps

→ **Control variables are mass flow rate of five variable speed pumps**

ANN prediction model

Total four ANN prediction model was made, and the prediction targets of each ANN are ①Room temperature, ②Temperature of top and bottom layer inside the TES, ③Inlet and outlet temperature of chiller,④Energy consumption of chiller

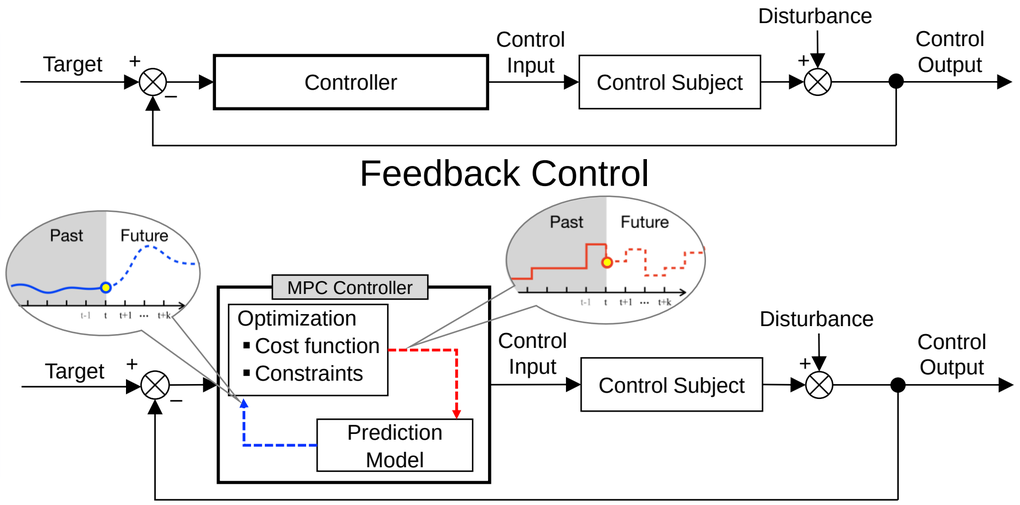

Figure 1. Comparison of feedback control and model predictive control

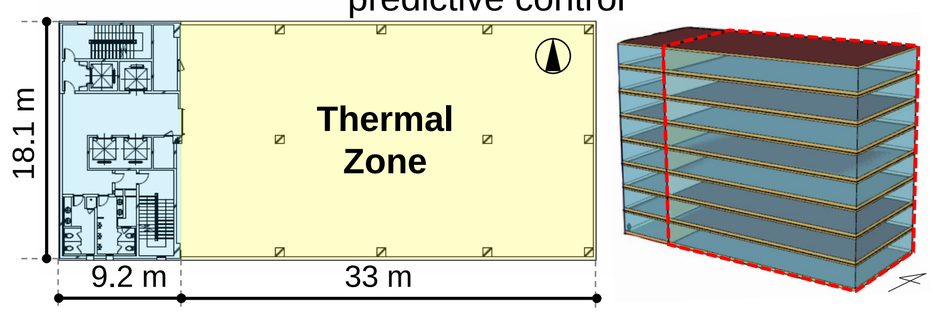

Figure 2. Target building of simulation analysis

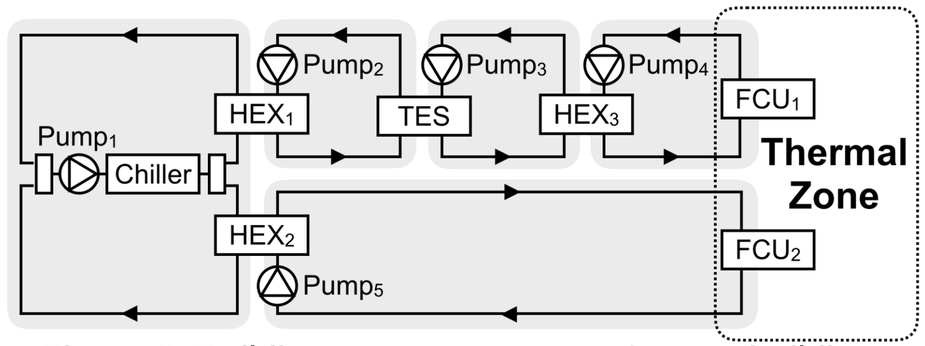

Figure 3. Building energy systems of target building

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Optimization problem

Optimization method：Epsilon constrained differential evolution random jumping(εDE-RJ)

$$J_s = \sum_{t=1}^{t_H=24} \{(C^t_{chiller} + C^t_{Pump}) \cdot P^t\}$$

$$Minimize\ J_s(\dot{m}_{p1}, \dot{m}_{p2}, \dot{m}_{p3}, \dot{m}_{p4}, \dot{m}_{p5})$$

Subject to

$$T_{zone} \leq 26\ °C\ at\ 09:00 \sim 18:00$$

$$\dot{m}_{p1}, \dot{m}_{p2} \leq 10.86\ (kg/s)\ , \dot{m}_{p3}, \dot{m}_{p4}, \dot{m}_{p5} \leq 8.22\ (kg/s)$$

$$C^t_{Pump}\ (kWh) = 0.2555 \cdot \dot{m}^t{}_{pump}$$

(1) J_s：Objective function
t_H：Prediction horizon (=24 hours)
t_C：Control horizon (=1 hour)
(2) $C^t_{chiller}$：Energy consumption of chiller at t timestep (kWh)
(3) C^t_{pump}：Energy consumption of pump at t timestep (kWh)
(4) P^t：Electricity price at t timestep (yen/kWh)
(5) $\dot{m}^t{}_p$：Mass flow rate of pump at t timestep (kg/s)
T_{zone}：Room temperature (°C)

Condition of case study

Case study was conducted to compare RBC and MPC scheme. In RBC scheme, TES is fully charged with 10.86 kg/s at unoccupied hours and discharged with 8.22 kg/s at occupied hours, then chiller operates when charged heat amount of TES is not enough to handle the zone cooling load.

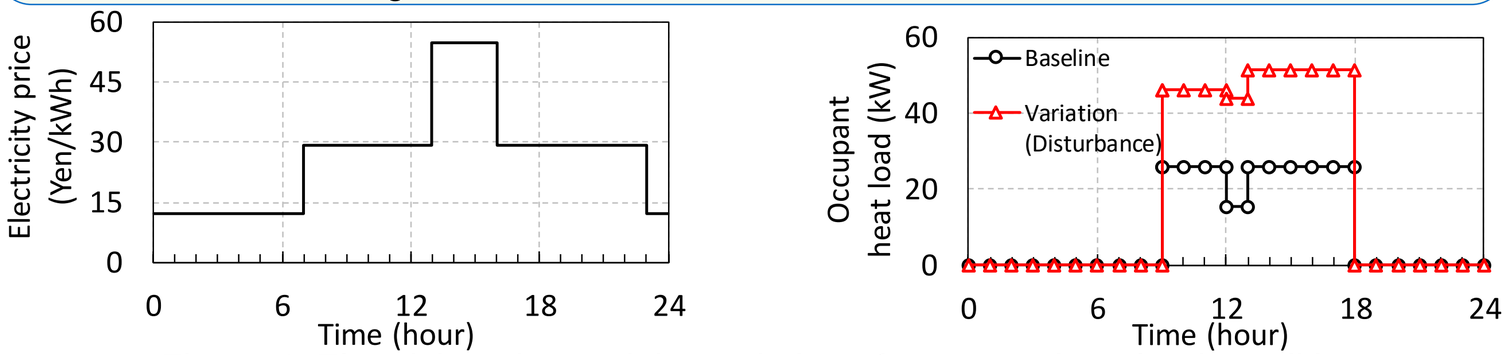

Figure 4. Electricity price and the variation of occupant heat load condition

Case	Control scheme	Disturbance of occupant heat load	Remarks
RBC_Base	RBC	×	-
RBC_Base_Var	RBC	○	Operated with RBC_Base case's pump mass flow rate
RBC_Var	RBC	○	-
MPC_Var	MPC	○	-

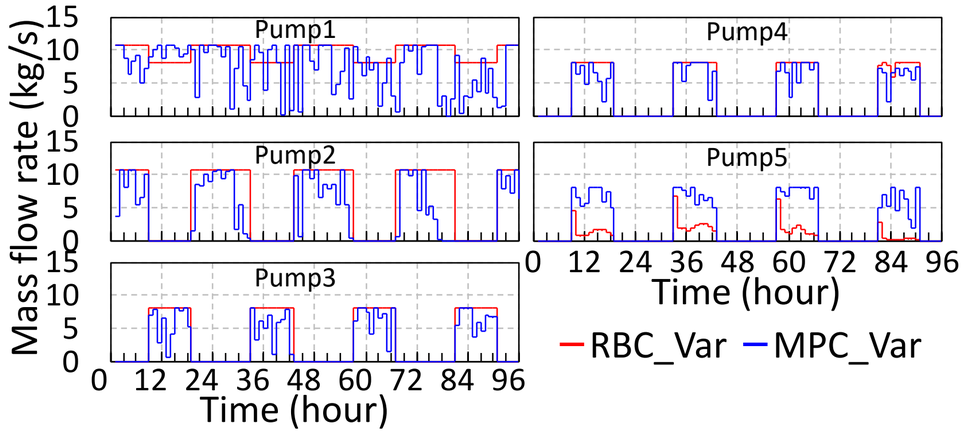

Figure 5. Comparison of mass flow rate of the pumps

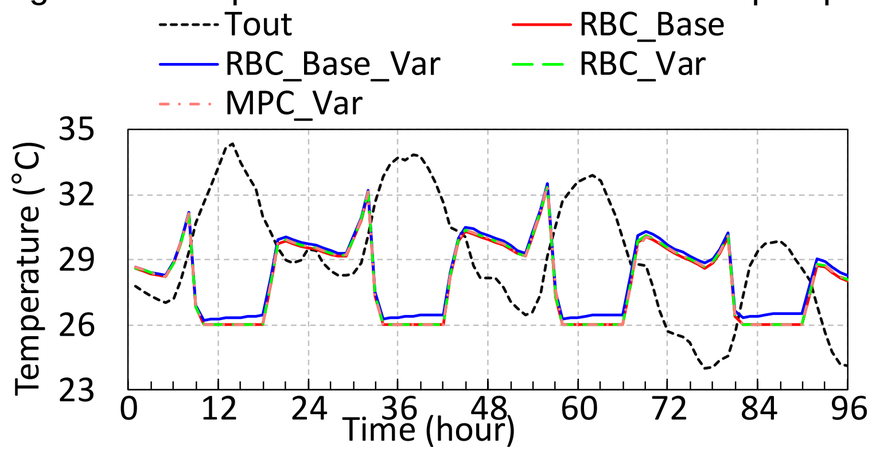

Figure 6. Comparison of room temperature

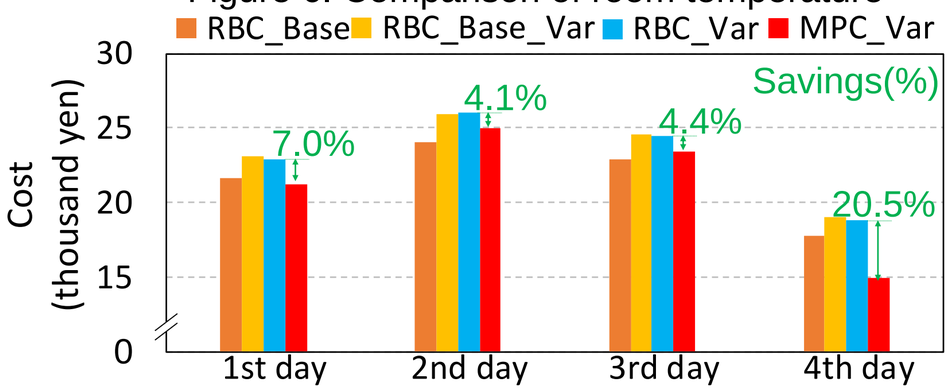

Figure 7. Comparison of operation cost

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