Evolutionary Multi-objective Air-Conditioning Schedule Optimization for Office Buildings

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ABSTRACT

For air-conditioning systems in office buildings, it is crucial to reduce the power consumption while maintaining office workers' thermal comfort. To generate practically feasible temperature setting schedules of air-conditioning systems, we propose an evolutionary multi-objective air-conditioning schedule optimization system for office buildings. In the proposed system, the target building is modeled and simulated by EnergyPlus building simulator which used in the building construction field, and the OMOPSO optimizer is employed to optimize temperature setting schedules. Experimental results show that the proposed system can obtain temperature schedules showing an optimal trade-off between the thermal comfort and the power consumption.

CCS CONCEPTS

• **Applied computing** → **Computer-aided design**; • **Computer systems organization** → *Sensors and actuators*; • **Computing methodologies** → Simulation evaluation;

KEYWORDS

evolutionary multi-objective optimization, particle swarm optimization, air-conditioning control, thermal comfort, predicted mean vote, building energy simulation, EnergyPlus

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1 INTRODUCTION

For office building management, reductions of the energy consumption and the carbon dioxide emission are essential issues. Air-conditioning systems consume approximately 30 percent of the total power consumption in typical office buildings. The air-conditioning control has a large impact on the power reduction, and the concern with an optimal air-conditioning control in office buildings has been growing recently. However, the power reduction on air-conditioning systems generally deteriorates the thermal comfort of office workers. The power consumption is often saved with the sacrifice of workers' comfort in the office building. It is desirable to reduce the power consumption while maintaining the thermal comfort level of the office workers.

For the air-conditioning system optimization, several studies employed simplified mathematical models of the power consumption and the human thermal comfort. However, complex interactions among various elements in the building actually affect to the power consumption and the human thermal comfort. Since it is essential to utilize an accurate simulation of the power consumption and the thermal comfort level, we employ a simulation model constructed by the EnergyPlus software [1] which are widely used in the construction industry and able to precisely simulate the air movement, the thermal environment, and the power consumption.

In this work, we propose a multi-objective air-conditioning schedule optimization system simultaneously optimizing the power consumption and the human thermal comfort by using an office building simulation with EnergyPlus. In the proposed system, we use a particle swarm based optimizer for the multi-objective optimization. Throughout the experiment, we discuss the optimal trade-off of temperature setting schedules between the power consumption and the human thermal comfort.

2 BUILDING SIMULATION

2.1 Office Building Model

The target office building model in this work has eight floors above the ground, the area of total floors is approximately 11,800 $[m^2]$, and a steel-reinforced concrete structure. For the exterior walls, the foamed polystyrene is used as the internal insulation. For the air-conditioning system, a central type with a water-cooled centrifugal chiller with Coefficient Of Performance (COP) = 5.96, the Air Handling Unit (AHU) and the Variable Air Volume (VAV) unit are used. In this work, we use the EnergyPlus software for the energy analysis of the target office building model. As the weather data for the simulation, we use the expanded AMeDAS (Automated Meteorological Data Acquisition System) data on August 21, 1997, in Tokyo, Japan.

2.2 Design Variables

The proposed system optimizes the air-conditioning temperature setting schedule. The design variables are the temperature settings at each hour. The time period to be optimized is set to 5: 00 - 23: 00. That is, the temperature setting can be changed every hour $\mathcal{H} = \{5:00, 6:00, \ldots, 23:00\}$. The design variable vector $\boldsymbol{x}$

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has $|\mathcal{H}| = 18$ elements, and each element x_i $(i \in \mathcal{H})$ indicates the temperature setting at time i. The maximum difference of the temperature settings between continuous two hours are limited to 1 °C or less, i.e., $|x_i - x_{i+1}| \leq 1.0$. Also, the temperature setting has the lower limit $x^{min} = 18$ °C and the upper limit $x^{max} = 30$ °C, i.e., $x^{min} \leq x_i \leq x^{max}$ $(i \in \mathcal{H})$. In this work, the same temperature setting schedule $\boldsymbol{x}$ is applied to all rooms in the building.

2.3 Objective functions

To evaluate the human thermal comfort of a temperature setting schedule $\boldsymbol{x}$, we use the Predicted Mean Vote (PMV) values during the working time between 6:00 and 22:00. The evaluation timings are $\mathcal{T}_1 = \{6:00, 6:10, \ldots, 21:50, 22:00\}$. The first objective function for the thermal comfort is formulated as follows:

$$\text{Minimize} \quad f_1(\boldsymbol{x}) = \frac{1}{|\mathcal{T}_1|} \sum_{t \in \mathcal{T}_1} |PMV(\boldsymbol{x}, t)|, \tag{1}$$

where, $PMV(\boldsymbol{x}, t)$ is the PMV value at time t calculated by EnergyPlus with the air-conditioning temperature schedule $\boldsymbol{x}$. Since too uncomfortable schedules with a large PMV value cannot be accepted, in this work we involve a constraint condition in the optimization problem. The feasible schedule $\boldsymbol{x}$ is

$$\text{Subject to} \quad |PMV(\boldsymbol{x}, t)| \leq 0.5 \quad (\forall t \in \mathcal{T}_1). \tag{2}$$

For infeasible schedules not satisfying the above constraint, the following constraint violation value is minimized.

$$V(\boldsymbol{x}) = \frac{1}{|\mathcal{T}_1|} \sum_{t \in \mathcal{T}_1} PMV_v(\boldsymbol{x}, t), \tag{3}$$

where,

$$PMV_v(\boldsymbol{x}, t) = \begin{cases} 0 \quad , & \text{If } |PMV(\boldsymbol{x}, t)| \leq 0.5, \\ |PMV(\boldsymbol{x}, t)|, & \text{Otherwise.} \end{cases} \tag{4}$$

To evaluate the power consumption of a temperature setting schedule $\boldsymbol{x}$, we use the *Air System Electric Energy* (ASEE) values obtained by the EnergyPlus simulation. The evaluation timings are $\mathcal{T}_2 = \{0:00, 0:10, \ldots, 23:50, 24:00\}$. The second objective function for the power consumption is formulated as follows:

$$\text{Minimize} \quad f_2(\boldsymbol{x}) = \sum_{t \in \mathcal{T}_2} ASEE(\boldsymbol{x}, t), \tag{5}$$

where, $ASEE(\boldsymbol{x}, t)$ is the electric power consumption of the air-conditioning system at time t calculated by EnergyPlus with the air-conditioning temperature schedule $\boldsymbol{x}$.

3 RESULTS AND DISCUSSION

To simultaneously optimize the human thermal comfort and the power consumption in the air-conditioning scheduling problem, we employ a Multi-Objective Particle Swarm Optimization algorithm, OMOPSO [2], as one of the representative multi-objective optimizers for solving problems with continuous variables. For the weight and random values of OMOPSO, we use the same setting used in [2]. The number of particles is set to 100, and the total number of generations is set to 100.

Fig. 1 shows solutions (air-conditioning schedules) obtained by the proposed system at the final generation in the objective space. The horizontal axis indicates the thermal comfort index to be minimized. The vertical axis indicates the power consumption of the air-conditioning system to be minimized.

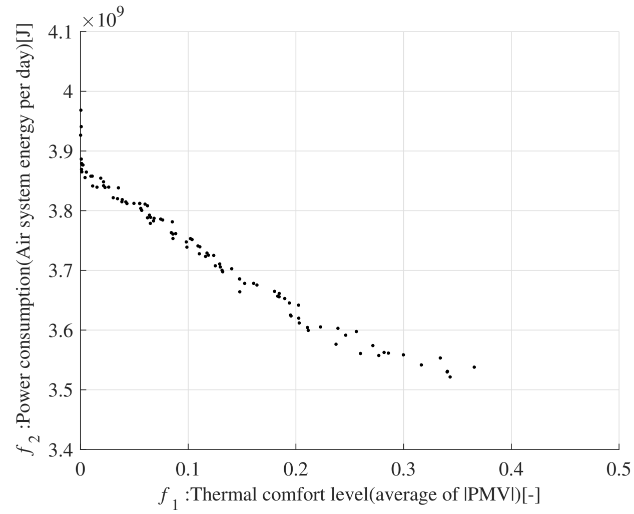

Figure 1: The thermal comfort and the power consumption of the obtained temperature setting schedules

From the result, we can see that the thermal comfort level of all schedules obtained by the proposed system is less than 0.5, and feasible schedules satisfying **Eq. (2)** are obtained. Furthermore, we can see that the proposed system can obtain many candidate schedules with better thermal comfort levels less than 0.1. The result shows the dynamic schedules considering both the power consumption and the thermal comfort can be found by the proposed system using OMOPSO.

4 CONCLUSIONS

In this work, we proposed the evolutionary multi-objective air-conditioning schedule optimization system for office buildings. In the proposed system, the target building was modeled and simulated by EnergyPlus which is one of the practical simulators used in the building construction field. To obtain the temperature setting schedules which dynamically change the temperature setting over time, the proposed system used OMOPSO to simultaneously optimize the thermal comfort and the power consumption of the air-conditioning system in the building. Experimental results showed that the proposed system could obtain dynamically changing temperature schedules.

As future works, we will consider more objectives and treat a many-objective optimization problem in the system involving a decision making procedure.

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