Research on Multi-objective Optimization Method of Central Air Conditioning Air Treatment System Based on NSGA-II

Xue Li¹*, Shujiang Li² and Hongyuan Jiao²

¹Shenyang Wantong Automobile Vocational Training School Co., Ltd
²Shenyang University of Technology, Shenyang, China

*Corresponding author email: 1144746161@qq.com

Abstract. In this paper, the composition, working principle and characteristics of the central air conditioning air treatment system are comprehensively analyzed, the energy consumption equipment of the air treatment system is established, the energy consumption model of the chilled water pump and fan is established, and the sum of the energy consumption models of the pump and fan is used as the air The total energy consumption model of the processing system is given, and the constraint conditions of the objective function are given. The characteristics of the evaluation index PMV describing the application of the human body's cold and hot feeling and the PPD index characterizing the degree of dissatisfaction in the thermal environment are analyzed. The room comfort model with the smallest PPD value is established. Finally, the minimum total energy consumption of the air treatment system and the smallest PPD value are established Established a multi-objective optimization model. The NSGA-II algorithm is used to optimize the established multi-objective function, and the optimal solution set satisfying the two conditions is obtained.

Keywords: Energy saving; PPD index; Multi-objective optimization; NSGA-II.

1. Introduction

The multi-objective optimization of central air conditioning is a comprehensive consideration of economics and human dissatisfaction PPD[1]. It is a practical engineering multi-objective optimization problem to find a series of Pareto optimal solutions that meet the constraints and have the lowest energy consumption of air conditioners and the smallest PPD of human dissatisfaction[2]. The multiple constraints of central air conditioners are non-linear, which makes it difficult for the objective function to quickly converge to the local optimum during the optimization process. The multi-objective optimization algorithm is a group-based random search algorithm, which is suitable for multi-objective optimization of air conditioners[3]. Multi-objective intelligent optimization algorithm to solve the multi-objective optimization problem of central air-conditioning is a hot issue at present, and domestic and foreign scholars have done a lot of research successively[4]. The new NSGA-II algorithm is added to the original NSGA algorithm. The calculation degree and calculation time are far lower than the NSGA algorithm[5]. At the same time, on the basis of the original algorithm, a new operator is introduced to replace the original shared radius. The introduction of a new congestion degree and a new congestion degree comparison operator makes the comparison criteria after non-dominated sorting, the congestion degree is large. Wins. This new calculation standard makes the solution set distribution in the entire solution set domain more uniform, and all solution sets in the quasi-Pareto domain can be extended to Pareto. After the introduction of new operators, the diversity of algorithms has been greatly improved[6].
Based on the advantages of NSGA-II algorithm, a mathematical model for multi-objective optimization of central air conditioning is established. Simulation results show that the NSGA-II algorithm can avoid falling into a local optimum and thus obtain a more uniformly distributed Pareto optimal solution.

2. Multi-objective Optimization of Air Treatment System

2.1. Energy Consumption Model of Central Air Conditioning Air Treatment System
The central air-conditioning air treatment system is a system composed of an Air Handling Unit (AHU), a terminal device, a wind pipe and a room. The air processing unit mixes fresh air and return air according to the corresponding parameters of the air in the air-conditioned room to form a mixed air and transport it to the heat exchange equipment such as the terminal device and the air processing unit. At the same time, the chilled water continuously sends cold capacity to the air processing unit for heat exchange with the mixed air. After the processed mixed air reaches the air supply standard, the room is provided with air through the air supply duct. The structure of the AHU is shown in Figure 1.

![Figure 1. Air-conditioning unit (AHU) structure](image)

Based on the system operation principle and overall energy consumption analysis, it was determined that the main energy consumption equipment of the central air conditioning air treatment system is the chilled water pump and air supply fan[7]. In order to achieve energy saving effects and minimize the total power consumption of the chilled water pump and air supply fan, the mathematical model and total objective function of the chilled water pump, air supply fan are as follows:

\[
P_{\text{pump}} = P_{\text{pump,nom}} \left( d_0 + d_1 \left( \frac{m_w}{m_{w,nom}} \right) + d_2 \left( \frac{m_w}{m_{w,nom}} \right)^2 + d_3 \left( \frac{m_w}{m_{w,nom}} \right)^3 \right) \tag{1}
\]

\[
P_{\text{fan}} = P_{\text{fan,nom}} \left( e_0 + e_1 \left( \frac{m_a}{m_{a,nom}} \right) + e_2 \left( \frac{m_a}{m_{a,nom}} \right)^2 + e_3 \left( \frac{m_a}{m_{a,nom}} \right)^3 \right) \tag{2}
\]

- \(P_{\text{pump}}\) is power consumption of the pump; \(P_{\text{fan}}\) is power consumption of the fan; \(P_{\text{pump,nom}}\) is theoretical power consumption of the pump; \(m_{w,nom}\) is theoretical flow of the pump; \(P_{\text{fan,nom}}\) is theoretical power of the fan; \(m_{a,nom}\) is theoretical flow of the fan; \(m_w\) is Actual chilled water mass flow; \(m_a\) is Actual air mass flow when the fan is running. \(d_0, d_1, d_2, d_3\) is the constant coefficient when the pump is running under...
partial load; \( e_0, e_1, e_2, e_3 \) is the constant coefficient when the fan is running under partial load.

\[
d_0 = e_0 = 0.00153, d_1 = e_1 = 0.0052, d_2 = e_2 = 1.1086, d_3 = e_3 = -0.1164
\]

The overall objective function of the central air conditioning air processing system is:

\[
\min P_{\text{total}} = P_{\text{pump}} + \sum_{k=1}^{n} P_{\text{fan},k}
\]

\[
F_i(x) = \min P_{\text{total}}
\]

2.2. Room Comfort Index PMV-PPD

There are many factors that affect human comfort. Some factors have little effect and cannot be described in detail. Temperature has the greatest effect on human comfort[8]. Therefore, this paper analyzes the PMV index of indoor thermal comfort in detail, and the relationship is as follows:

\[
PMV = (0.303e^{-0.036M} + 0.028) \times L
\]

\[
L = (M - W) - 3.05 \times 10^{-3} \left[5733 - 6.99(M - W) - P_a\right] - 0.0014M (34 - t_a)
\]

\[
-1.7 \times 10^{-5}M (5867 - P_a) - 3.96 \times 10^{-8} f_{cl} \left[ (t_{cl} + 273) - (t_r + 273) \right] - f_{cl} h_c (t_{cl} - t_a)
\]

\[
M \quad \text{is the energy metabolism rate of the human body; } W \quad \text{is mechanical work done by the human body; } P_a \quad \text{is partial pressure of water vapor around the human body; } t_a \quad \text{is Indoor air temperature; } f_{cl} \quad \text{is clothing area coefficient; } t_r \quad \text{is room average radiation temperature; } I_{cl} \quad \text{is clothing thermal resistance; } t_{cl} \quad \text{is Outer surface temperature of clothes; } h_c \quad \text{is Heat transfer coefficient.}
\]

\[
f_{cl} = \begin{cases} 
1.00 + 1.290I_{cl}, I_{cl} \leq 0.078 \\
1.05 + 0.645I_{cl}, I_{cl} > 0.078 
\end{cases}
\]

\[
t_{cl} = 35.7 - 0.0275(M - W)
\]

\[
-I_{cl} \left[ 3.96 \times 10^{-8} f_{cl} \left[ (t_{cl} + 273) - (t_r + 273) \right] + f_{cl} h_c (t_{cl} - t_a) \right]
\]

\[
h_c = \begin{cases} 
2.38(t_{cl} - t_a)^{0.25} & \text{if } 2.38(t_{cl} - t_a)^{0.25} > 12.1\sqrt{V_a} \\
12.1\sqrt{V_a}, & \text{if } 2.38(t_{cl} - t_a)^{0.25} < 12.1\sqrt{V_a}
\end{cases}
\]

\[
V_a \quad \text{is indoor air velocity; } PPD \quad \text{is the degree of dissatisfaction of the indoor staff on the environment, expressed as a percentage, is related to } PMV \text{ as follows:}
\]

\[
PPD = 100 - 95e^{-0.0335PMV^{0.4} + 0.2179PMV^{0.2}}
\]

\[
PMV = 0, \quad PPD = 5\% \quad \text{At this point, the human body is absolutely comfortable. When } PMV \text{ is } [-0.5, 0.5], \text{ corresponding, more than 90\% of people will feel comfortable at this time, indicating that the environment at this time is comfortable. Within the comfortable range, the smaller the } PPD \text{ index, the more comfortable the human body will feel the environment. The objective function of thermal comfort comprehensive evaluation is as follows:}
\]
\[
F_2(x) = \min \text{PPD} = \min f(\text{PMV})
\]

\[
-0.5 \leq \text{PMV} \leq 0.5
\]

\[
\text{PPD} \leq 10\%
\]

Indicators affecting \(\text{PMV}\) and \(\text{PPD}\) include 4 types of environmental changes and 2 types of human changes. In this article, the average room radiant temperature is set to be the same as the indoor temperature\[9\]. When the body's metabolic rate and clothing thermal resistance are constant, the variables together create a comfortable living environment.

3. Constraints

Set the variable range according to the experimental platform, ensure that all ranges are within the effective range, and follow the principle of energy conservation:

\[
m_{w,\text{min}} \leq m_w \leq m_{w,\text{max}}
\]

\[
m_{a,\text{min}} \leq m_{a,k} \leq m_{a,\text{max}}
\]

\[
Q_{\text{AHU},k} = c \frac{m_{c,k}}{c_s} \left( T_{\text{air},k} - T_{\text{chow},k} \right) \quad (k = 1, \cdots, n)
\]

\[
-0.5 \leq \text{PMV} \leq 0.5
\]

\[
\text{PPD} \leq 10\%
\]

4. NSGA-II Algorithm Description

NSGA-II algorithm steps\[10\]: (1) Set the algorithm parameters: population size, initialize the population, initialize the population size, the number of iterations, the probability operator parameters, and the hybrid crossover operator parameters. (2) An individual is randomly generated as a parent population. (3) When the number of iterations, the parent population is selected by probability, mixed and mutated, and the offspring population is generated. (4) Combine the parent population and the new population, and perform a fast non-dominated sort on the new population. (5) Use the elite strategy to select a good individual from the new population as the new parent population. (6) Probability selection, mixing crossover and mutation operations are performed on new generations to generate new offspring populations. (7) If the current number of iterations is not less than the maximum number of iterations, the algorithm ends, otherwise, proceed to step 4.

5. Algorithms to Solve Multi-objective Optimization Problems

Set the population size to 100 and the inertia factor weight to be set. The maximum number of iterations of the learning factor is 100, 200, 500, and 1,000 for four simulations. The simulation results are shown in Figure 2.
Figure 2. NSGA-II algorithm Pareto surface

The above simulation result graph represents the application of the multi-objective optimization algorithm to the multi-objective optimization problem of the central air conditioning air processing system, and the distribution of the Pareto optimal solution set on the target space. In the figure, the abscissa represents the thermal comfort index PPD/%; the ordinate represents the total energy consumption of the central air conditioning /w.

6. Summary

This paper makes a comprehensive analysis of the central air-conditioning air treatment system, and gives the total energy consumption model of the air treatment system, including chilled water pump energy consumption and air supply fan energy consumption. According to the data of the laboratory related equipment and the relevant information of the central air conditioning system, the relevant operating parameters in the central air conditioning energy consumption model are set, and the evaluation index PMV, which represents the thermal sensation of the human body, and the PPD index, which represents the degree of dissatisfaction with the thermal environment, are applied. To describe the comfort of the room, a minimum PPD evaluation model is established, and the PPD constraint range is set. Finally, a multi-objective optimization model is established with the minimum total energy consumption of the air treatment system and the minimum PPD. According to the equipment of the experimental platform, the value range of the optimization variables is set, and the multi-objective optimal solution set of the air treatment system is found within the constraint interval of all variables.

References
[1] Wu Weiwei, Fan Dongye, Zhu Wenping, Liu Xuan, Yan Xiuru. A Summary of Research on
Optimized Operation of Central Air Conditioning System [J]. Building Thermal Energy Ventilation and Air Conditioning, 2019, 38 (07): 37-41 + 19.

[2] Meng Qinglong, Yan Xiuying. Simulation study on optimal control of cooling capacity of surface cooler in air conditioning system [J]. Journal of System Simulation, 2015, 27 (06): 1368-1373.

[3] Sun Jianmei, Liu Yunzhao. Effect of air supply method on indoor comfort of an office building [J]. Journal of Civil Engineering and Management, 2015, 32 (04): 15-19.

[4] Q.P. Ha, V. Vakiloroaya. Modeling and optimal control of an energy-efficient hybrid solar air conditioning system[J]. Automation in Construction, 2015, 49.

[5] Zhongjun Zhang, Yufeng Zhang, Adnan Khan. Thermal comfort of people in a super high-rise building with central air-conditioning system in the hot-humid area of China[J]. Energy & Buildings, 2020, 209.

[6] Li Sanyi, Li Wenjing, Qiao Junfei. A density-based local search NSGA2 algorithm [J]. Control and Decision, 2018, 33 (01): 60-66.

[7] Wang Yanbing, Xu Hongyan, Guo Jun. Adaptive non-dominated sorting genetic algorithm [J]. Control and Decision, 2018, 33 (12): 2191-2196.

[8] Wang Qingsong, Xie Xingsheng, Zhou Dalai. An Improved Nondominated Sorting Genetic Algorithm [J]. Information Technology and Network Security, 2019, 38 (05): 28-32 + 36.

[9] A.C.Y. Yuen, T.B.Y. Chen, C. Wang, W. Wei, I. Kabir, J.B. Vargas, Q.N. Chan, S. Kook, G.H. Yeoh. Utilising genetic algorithm to optimise pyrolysis kinetics for fire modelling and characterisation of chitosan/graphene oxide polyurethane composites[J]. Composites Part B, 2020, 182.

[10] Xiupeng Wei, Andrew Kusiak, Mingyang Li, Fan Tang, Yaohui Zeng. Multi-objective optimization of the HVAC (heating, ventilation, and air conditioning) system performance[J]. Energy, 2015, 83.