Research Article

Energy-Saving Control Method of Building Central Air Conditioning Based on Genetic Algorithm

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In order to solve the problem of huge energy consumption of building central air conditioning, the water system of building central air conditioning was taken as the research object and the genetic algorithm of energy-saving operation and control of building central air conditioning based on MATLAB was designed, so as to build the energy-saving control system model of central air conditioning. On the one hand, the feasibility of the optimized algorithm to solve the energy-saving problem of central air conditioning was proved through the optimization of genetic algorithm. On the other hand, the energy-saving effect was demonstrated through the operation parameters and the variation of air-conditioning energy consumption before and after the experiment. The feasibility and rationality of genetic algorithm to improve the energy-saving effect of central air conditioning was verified by the comparison of the experiment. The results showed that in the design load range of 30%–70%, the average energy-saving rate of central air-conditioning compressor was 16.8%. The maximum energy-saving efficiency was 37.4%, and the minimum energy-saving efficiency was 15.5%. The average energy-saving rate of water system was 26.8%. Therefore, the genetic algorithm had fast convergence speed and high solving accuracy, which was beneficial to improve the energy-saving ability of central air-conditioning water system.

1. Introduction

At present, with the rapid development of society, energy plays a vital role in social progress and economic development. On the one hand, energy is an important material basis for human survival. On the other hand, it plays an irreplaceable role in promoting the development of national economy [1]. And in the process of economic development of the human, in order to obtain more economic benefits in a short run, overexploitation and unreasonable utilization make humans begin to face the energy crisis, followed by resources waste and environmental pollution. So, a great importance is attached to energy conservation and environmental protection in the world under the background that more and more enterprises attaching importance to energy conservation [2]. As for building energy consumption, energy consumption caused by electricity demand occupies a large proportion, especially for central air-conditioning system, as shown in Figure 1. Therefore, based on the background, the energy-saving control system of central air conditioning based on genetic algorithm was constructed to investigate a more energy-efficient central air-conditioning system of buildings, so as to reduce the massive energy consumption caused by the air-conditioning system [3].

2. Literature Review

In the Western countries, air conditioning was widely used relatively earlier. So, the research on energy-saving methods of air conditioning started earlier, with a long development stage and relatively mature technology [4]. Some scholars investigated the comfort control method of air conditioning in building energy saving in 2000. The problem that how to use optimized control strategies to reduce energy consumption on the premise of ensuring comfort when there is a conflict between energy saving and comfort mainly was investigated [5]. The way that PMV in the air-conditioning...
control system dynamically changes the indoor temperature setting was used to ensure the comfort of the indoor environment and achieve the goal of energy saving. Some scholars focused their research on the monitoring system architecture, which was an Internet-based control, monitoring, heating, ventilation, and air-conditioning system operation scheduling system developed with the significant progress of Internet and computer technology. It was combined with network technology, which had the functions of network control and direct control [6]. The system also included functions to support real-time digital constant temperature control, data acquisition, remote access and control, and optical induction control. And the advanced HVAC energy-saving technology, at that time, was used [7]. The system enabled users to control the operation of the air-conditioning system and quickly identify the fault points of the air-conditioning system through cost-effective energy decisions, so as to minimize system downtime [8].

In 1996, foreign scholars applied genetic algorithm to the optimization of air-conditioning system for the first time. Researches showed that the convergence and robustness of the algorithm could be improved by limiting constraints, providing a solution for optimal operation of air-conditioning [9]. Genetic algorithm was adopted to solve the stability problem of the central air-conditioning system and PID controller was optimized by algorithm, which accelerated the stability of the system and reduced the overshoot [10]. Genetic algorithm was applied to load optimization of chiller. The application analysis results of two cases proved that the optimization algorithm could not only solve the problem of slow convergence speed of predecessors, but also achieve high accuracy in a short time [11]. Air-conditioning system was investigated in double objective optimization problem of genetic algorithm, which could be used to optimize energy use and thermal comfort parameters such as static pressure supply, supply air temperature, air supply carbon dioxide concentrations, or regional temperature range. At the same time, the thermal comfort control daily energy use or daily construction could be satisfied. Compared with the single objective optimization problem, it could be more energy efficient [12].

Some scholars designed an energy consumption monitoring platform system based on campus network [13]. The system used interior information acquisition node report information to the specified server which was for monitoring, data statistics and analysis, realizing the GIS map browsing, monitoring, energy consumption statistics and comparison, intelligent decision-making, intelligent alarm, system security management, and other functions. It reduced energy consumption, improved energy efficiency, and provided decision making for campus energy use [14]. On the basis of analyzing the current situation of the central air-conditioning management system, the energy-saving management system of the central air-conditioning was designed and implemented. The system was a system with high extensibility and a good development platform, through which the central air-conditioning equipment could communicate with each other. At the same time, the information could be exchanged with the outside world, realizing the real-time monitoring of parameters such as humidity flow, temperature, pressure, electric in the central air-conditioning system. And it had the function of adopting automatic energy-saving strategy [15]. In recent years, researchers also mixed the genetic algorithm with other algorithms for

![Figure 1: Energy-saving model of central air conditioning.](image)
improvement and applied the improved genetic algorithm to solve the energy-saving optimization operation of central air conditioning [16]. The overheating of evaporator in refrigeration system was optimized by combining genetic algorithm and fuzzy control algorithm. The optimization of improved algorithm showed that compared with traditional proportional integral control, the optimized algorithm made the action of expansion valve more stable [17]. The optimization control strategy of central air-conditioning system based on bee evolutionary genetic algorithm was proposed, which had good optimization control results. Genetic algorithm was integrated into simulated annealing, and an optimal control strategy with good global search ability was proposed [18].

To sum up, both at home and abroad, the research on air-conditioning energy-saving methods was a hot spot and a lot of research results were achieved. From the research content, by using the existing sensor technology, Internet technology, and intelligent control technology, the actual situation of the corresponding energy-saving methods were explored, which were applied in different living and working environment to achieve the goal of air conditioning energy saving. Therefore, according to the existing sensor technology, Internet technology, and intelligent control technology, combined with the actual situation of campus air conditioning and through the design of campus air-conditioning online management system, the corresponding energy-saving algorithm was investigated on the basis of the online management system, in order to achieve the ideal energy-saving effect.

3. Energy-Saving Method of Central Air Conditioning Based on Genetic Algorithm

3.1. Establishing Power Consumption Model. In this research, a functional relationship between air-conditioning energy consumption and indoor and outdoor temperature changes was established. The functional equation of the energy $P_{ij}$ consumed by the $i$ th air conditioner in the $j$ th hour and the current indoor temperature $T_{ij}$, the indoor temperature $T_{ij-1}$ at the last time point and the current outdoor environmental temperature $T_{out,j}$ was as follows.

$$P_{ij} = \frac{T_{ij} - T_{ij-1} - a(T_{out,j} - T_{ij-1})}{\beta_i} \quad i \in \{1, 2, \ldots, n\}, \quad j \in \{1, 2, \ldots, m\}. \quad (1)$$

Assuming that the energy $P_{ij}$ consumed by the $i$ th air conditioner in the $j$ th hour was a certain value, the total energy consumed by all air conditioners in the entire management system in the $j$ th hour was as follows.

$$E_j = \left( \sum_{i=1}^{m} P_{ij} \right) \times 1 \text{ (hour)} = \sum_{i=1}^{m} P_{ij}, \quad (2)$$

$$C_{totalj} = \sum_{j=1}^{n} cE_j^2 = \sum_{i=1}^{m} C_i. \quad (3)$$

The function of total energy consumption of all air conditioners throughout the day was set as quadratic function (3), where $C$ was a constant and its value was related to electricity price and energy consumption. For the $i$ th air conditioner, the total amount of energy consumed in one day was as follows.

$$C_i = c[E_1 P_{i1} + E_2 P_{i2} + \ldots + E_n P_{in}]. \quad (4)$$

It can be seen that the total value of the energy $C_i$ consumed by the $i$ th air conditioner in a day would increase or decrease with the value of the temperature set by the air conditioner $T_{ij}$. According to equation (5), the total value of energy consumed by the $i$ th air conditioner in a day was only related to its own energy consumption and that of the other air conditioners, so, its function could also be expressed as:

$$C_i = \frac{\sum_{j=1}^{n} [(P_{ij} + E_j - P_{ij}) \cdot P_{ij}]}{\sum_{j=1}^{n} P_{ij}} \quad (6)$$

It could be translated into:

$$C_i = \sum_{j=1}^{n} [P_{ij}^2 + E_{ij} - P_{ij}] \quad (7)$$

According to equations (1) and (4), the total value of energy $C_i$ consumed by the $i$ th air conditioner in a day could be expressed as the derivative of the current temperature value $T_{ij}$.

$$\frac{dC_i}{dT_{ij}} = \frac{dC_i}{dP_{ij}} \cdot \frac{dP_{ij}}{dT_{ij}} + \frac{dC_i}{dP_{ij+1}} \cdot \frac{dP_{ij+1}}{dT_{ij}} \quad (8)$$

Combining equations (6) and (7), it could be known that:

$$\frac{dC_i}{dT_{ij}} = 2P_{ij} + E_{ij} \quad \Rightarrow \quad P_{ij} = E_j. \quad (9)$$

Based on (1), we could know:

$$\frac{dP_{ij}}{dT_{ij}} = \frac{1}{\beta_i}. \quad (10)$$

Combining equations (8), (9), and (10) and substituting them into (7), it could be obtained:

$$\frac{dC_i}{dT_{ij}} = \frac{P_{ij} + E_j}{\beta_i} - \frac{(1 - \alpha)(P_{ij+1} + E_{j+1})}{\beta_i}. \quad (12)$$
According to (12), we could see that the total value of energy $C_i$ consumed by the $i$th air conditioner in a day would change with the value of the temperature $T_{ij}$ set by the air conditioner.

3.2. Selecting Thermal Comfort Index. Thermal comfort control is a method to control air conditioning by taking the thermal comfort index felt by human body in thermal environment as the control target. As a subjective evaluation standard of human thermal sensation, PMV divides human thermal sensation into seven levels according to different degrees, as shown in Table 1.

In this research, only the influence of air-conditioning setting temperature on PMV value was investigated, while other factors are not investigated for the time being. Then, according to the model of PMV value, MATLAB programming was used to find out the change of PMV value corresponding to different temperature settings in the teaching building of a university campus with time, in order to facilitate the following PMV value to achieve comfort and energy-saving control research. The selected weather data were the average weather data value at the hour from 7:00 to 19:00 in July in summer. The simulation results are shown in Figures 2–6, which corresponded to the indoor set temperature of 25°C to 29°C, respectively, and the variation range and rule of PMV value with time under five different set temperatures. As shown in Figures 2–6, on the one hand, the value of temperature had a great influence on thermal comfort. When the indoor temperature was set at 25°C, the value range of PMV within a day ranged from −0.2 to 0.5. While when the indoor temperature was set at 29°C, the value range of PMV within a day increased from 1.0 to 2.5. On the other hand, even at the same setting temperature and at different time points, indoor thermal comfort fluctuated greatly. These two characteristics clarified the research direction and provided data support for the optimization analysis of genetic algorithm energy-saving method in the research [19].

3.3. Optimization of Air Conditioning Energy-Saving Model by Genetic Algorithm

3.3.1. Initializing the Population. Within the temperature range set above, a certain number of chromosomes were randomly produced and those that did not meet the conditions were eliminated. The size of the initial population

| Hot feeling | Cold | Cool | Slightly cool | Moderate | Slightly warm | Warm | Hot |
|-------------|------|------|---------------|----------|---------------|------|-----|
| PMV value   | −3   | −2   | −1            | 0        | 1             | 2    | 3   |
should be determined according to the actual situation of the problem. Since the integer solution range of the air-conditioning power-consumption model was the set temperature range, which was 5, only 12 hours in a day were controlled and the size of the desired range was 512. So, the initial population size within 100 could meet the optimization conditions, with high efficiency [20].

3.3.2. Fitness Function $f(T_i)$ Design. In function model optimization, the individual performance needed to be evaluated by the objective function. The objective function of the model was the formula (4). As the objective function was the solution of minimum value problem and the function values range [10.036, 17.751] was a positive number of fixed intervals, namely, the energy consumption values are obtained, respectively, from the highest and the lowest temperatures in the solution set of the air conditioner. In addition, the indoor comfort condition must be taken into account, namely, the PMV value obtained through the test. Since the value range of PMV was $[-3, 3]$, in order to ensure a comfortable indoor environment as far as possible, the indoor PMV value must be within $[-1, 1]$. Therefore, for the consideration of the above problems, after several tests and analyses, a more appropriate fitness function was defined as:

$$f(T_i) = \frac{2}{(C_i - m) + n \cdot |PMV|}$$  \hspace{1cm} (13)

In the above formula, $m$ and $n$ are two constant parameters, which satisfies:

$$0 \leq m \leq 17, \quad 0 \leq n \leq 17.$$  \hspace{1cm} (14)

And $m$, $n$ values were determined according to test results. $|PMV|$ was the maximum value within 12 hours.

3.4. MATLAB Simulation of the Optimization Model. In the simulation experiment, the meteorological data of July in summer in this region were selected as parameter conditions, including the temperature, humidity, wind speed, average thermal radiation temperature, human activities, and clothing in this region in summer [21]. The outdoor temperature on the day of simulation is shown in Figure 7. The relative humidity was 93%. The wind speed was gentle. The ultraviolet radiation temperature was strong. The energy metabolism of human body was set at 58 W/m². The thermal resistance of clothes was 0.5clo. The simulation setting conditions were as follows. The number of air conditioners in the system $m = 200$ (the simulation of only one air conditioner was analyzed below, and the set temperature values of the other air conditioners were randomly generated values), and the service time of air conditioners in a day was 12 hours, corresponding to the hourly value from 7:00 to 19:00 in a day. The value range of temperature was set as integer value in [25°C, 29°C]. In the model of air-conditioning power consumption, constant values were $\alpha = 0.9$, $\beta = -10$, $C = 0.6$. 

![Figure 5: Variation of PMV with time at 28°C.](image1)

![Figure 6: Variation of PMV with time at 29°C.](image2)

![Figure 7: Temperature forecast for the day.](image3)
Since the value range of parameters m and n were determined, namely $0^\circ \leq m \leq 17$ and $0^\circ < n \leq 17$, there was a certain relationship between the two values. When the value of m increases, the influence of energy-saving effect on the algorithm could be reduced and the influence of thermal comfort index on the algorithm could be increased. The same results happened when n went up. The objective of the research was to ensure that an appropriate thermal comfort index $-1^\circ \leq PMV \leq 1$ achieved the best energy-saving effect as far as possible [22]. Therefore, examples of optimization effects generated when m and n took different values for five times in the test. And the feasibility of the energy-saving method designed in the research was analyzed.

(1) When $m = 1$ and $n = 1$, the simulation results are shown in Table 2 below.
(2) When $m = 4$ and $n = 2$, the simulation results are shown in Table 3 below.
(3) When $m = 6$ and $n = 3$, the simulation results are shown in Table 4 below.
(4) When $m = 8$ and $n = 4$, the simulation results are shown in Table 5 below.
(5) When $m = 10$ and $n = 4$, the simulation results are shown in Table 6 below.

According to the analysis of simulation results in the table above, the following three conclusions could be drawn.

First, the initial population size had a great influence on the algebra of convergence. The larger the population algebra, the faster the convergence. However, the changes of crossover probability Pc, mutation probability Pm, and maximum evolution algebra in appropriate range had little influence on the optimization effect of the algorithm. Therefore, the parameters of the genetic algorithm in the research were set as population size 100, crossover probability Pm 0.5, mutation probability Pm 0.01, and maximum evolution algebra 100 generations.

Second, when the constant parameters m and n in the fitness function formula were set to $m = 1$, $n = 1$ or $m = 4$, $n = 2$ or $m = 6$, $n = 3$, although the better energy effect could be achieved, the indoor thermal comfort index was poor and could not meet the users’ requirements for comfort. So, these three pairs of values were not suitable for use [23]. Comparatively speaking, when the constant parameters m and n were set as $m = 8$, $n = 4$ and $m = 10$, $n = 4$, although the energy-saving effect was relatively poor, it could provide users with a comfortable indoor environment. Therefore, these two pairs of values were in line with the design objective of the air-conditioning energy-saving method in the research, which could be adopted. In the research, the parameters m and n were set to $m = 8$ and $n = 4$.

Thirdly, after the constant parameter values of the energy-saving algorithm were determined, the energy-saving effect of the proposed algorithm was deeply analyzed according to the set parameter values. The indoor temperature setting value at the corresponding time point optimized by the genetic algorithm corresponded to the total value of energy consumed in a day (unit: yuan) $C_1 = 12.756$.

The indoor temperature was set at $27^\circ C$ according to the average of the suitable temperature range for human body, which corresponded to the total value of energy consumed in one day (unit: yuan) $C_1 = 13.675$. The randomly generated indoor temperature setting value corresponded to the total value of energy consumed in a day (unit: yuan) $C_1 = 14.286$. The energy consumption of the optimized setting temperature could save about 89% compared with that of the random setting temperature and about 93% compared with that of the average setting temperature range for human body, indicating that the relative thermal comfort of indoor environment was more ideal. Figure 8 is the variation curve of energy consumption value corresponding to each generation in the genetic algorithm simulation. It can be seen from the figure that the model had converged at about the 53rd generation and the optimization effect was obvious.

4. Optimization of Energy-Saving Control System of Central Air Conditioning

4.1. Stability Test of Each Device. The experiment method used to test the stability is as follows.

Start the machine and complete the communication between the upper computer and the equipment to realize the disconnection and frequency regulation equipment. Turn on the cooling tower, cooling water pump, freezing water pump, and compressor in sequence. Set the wind speed gear of the air treatment equipment. Adjust the cooling load of the air conditioner on the experimental bench and maintain the fixed frequency operation of the electrical equipment of the water system. After 30 minutes, the data is monitored and saved through the written data terminal system of the upper computer and the monitored parameters included temperature, flow, head, electric power, etc. The test duration was 10 minutes, and data was read at an interval of 20 seconds.

The fluctuation residuals $v_i$, the sum of squares of fluctuation residuals $\sum v_i^2$, and the experimental standard deviation $s(d)$ introduced by repeatability of experimental data were calculated according to formulae (15)–(17).

$$v_i = (d_i - \bar{d}), \quad (15)$$

$$\sum v_i^2 = v_1^2 + v_2^2 + \ldots + v_n^2. \quad (16)$$

$$s(d) = \sqrt{\frac{\sum v_i^2}{(n - 1)}}. \quad (17)$$

The temperature stability test effect of chilled water cycle is shown in Figure 9. Fan-coil inlet water, fan-coil backwater, evaporator inlet water, AHU (air-treatment unit) outlet water, AHU inlet water in 10 minutes of temperature fluctuation residuals were $0.2^\circ C$, $0.2^\circ C$, $0.3^\circ C$, $0.2^\circ C$, $0.3^\circ C$, respectively. The residual squares of temperature fluctuation were $22.38 \times 10^{-2} C^2$, $20.04 \times 10^{-2} C^2$, $48.86 \times 10^{-2} C^2$, $9.85 \times 10^{-2} C^2$, $14.42 \times 10^{-2} C^2$, respectively. The experimental standard deviations were $0.1^\circ C$, $0.1^\circ C$, $0.2^\circ C$, $0.1^\circ C$, $0.1^\circ C$, respectively.
The stability test effect of water system flow is shown in Figure 10. Figure 10(a) is the cooling water system, Figure 10(b) is the chilled water system. The fluctuation residual difference of cooling water flow and chilled water flow in the 10 minute test was 0.03 m³/h and 0.03 m³/h, respectively. The sum of the squares of fluctuation residual was $26.72 \times 10^{-4}$ M³/m, and $21.81 \times 10^{-4}$ M³/m, respectively. The experimental standard deviations were 0.2 m³/h and 0.2 m³/h, respectively.

The stability test effect of water system head is shown in Figure 11. Figure 11(a) is the cooling water system, Figure 11(b) is the chilled water system. The fluctuation residual difference of cooling water head and chilled water head in the 10 minute test was 0.7 kPa and 0.5 kPa, respectively. The sum of the residual square of head fluctuation was $1.82 \times 10^{-2}$ kPa, and $0.88 \times 10^{-2}$ kPa, respectively. The standard deviations were 0.4 kPa and 0.3 kPa, respectively.

The stability test effect of the compressor electrical power is shown in Figure 12. The residual error of the compressor electrical power fluctuation in the 10 minute test was 5°W. The sum of the residual error squares of the power fluctuation is $200 \times 1^2$. The experimental standard deviation was 4°W.

Based on the above analysis, it could be concluded that the experimental device for energy efficiency of central air-

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**Table 2: Parameter Settings and effects when $m = 1$ and $n = 1$.**

| Population size | Crossover probability $P_c$ | Variation concept $P_a$ | Maximum evolutionary algebra | Convergent algebra (generation) | [PMU] maximum value | Energy consumption value (yuan) |
|-----------------|-----------------------------|-------------------------|-----------------------------|---------------------------------|----------------------|---------------------------------|
| 50              | 0.7                         | 0.02                    | 500                         | 68                              | 2.4                  | 10.148                          |
| 50              | 0.5                         | 0.01                    | 100                         | 63                              | 2.4                  | 10.148                          |
| 100             | 0.5                         | 0.02                    | 100                         | 36                              | 2.4                  | 10.148                          |
| 100             | 0.7                         | 0.02                    | 500                         | 35                              | 2.4                  | 10.148                          |

**Table 3: Parameter Settings and effects when $m = 4$ and $n = 2$.**

| Population size | Crossover probability $P_c$ | Variation concept $P_a$ | Maximum evolutionary algebra | Convergent algebra (generation) | [PMU] maximum value | Energy consumption value (yuan) |
|-----------------|-----------------------------|-------------------------|-----------------------------|---------------------------------|----------------------|---------------------------------|
| 50              | 0.7                         | 0.02                    | 500                         | 73                              | 2.2                  | 10.243                          |
| 50              | 0.5                         | 0.01                    | 100                         | 68                              | 2.2                  | 10.243                          |
| 100             | 0.5                         | 0.02                    | 100                         | 50                              | 2.2                  | 10.243                          |
| 100             | 0.7                         | 0.01                    | 500                         | 53                              | 2.2                  | 10.243                          |

**Table 4: Parameter Settings and effects when $m = 6$ and $n = 3$.**

| Population size | Crossover probability $P_c$ | Variation concept $P_a$ | Maximum evolutionary algebra | Convergent algebra (generation) | [PMU] maximum value | Energy consumption value (yuan) |
|-----------------|-----------------------------|-------------------------|-----------------------------|---------------------------------|----------------------|---------------------------------|
| 50              | 0.7                         | 0.02                    | 500                         | 82                              | 1.7                  | 11.316                          |
| 50              | 0.5                         | 0.01                    | 100                         | 81                              | 1.7                  | 11.316                          |
| 100             | 0.5                         | 0.02                    | 100                         | 43                              | 1.7                  | 11.316                          |
| 100             | 0.7                         | 0.01                    | 500                         | 45                              | 1.7                  | 11.316                          |

**Table 5: Parameter Settings and effects when $m = 8$ and $n = 4$.**

| Population size | Crossover probability $P_c$ | Variation concept $P_a$ | Maximum evolutionary algebra | Convergent algebra (generation) | [PMU] maximum value | Energy consumption value (yuan) |
|-----------------|-----------------------------|-------------------------|-----------------------------|---------------------------------|----------------------|---------------------------------|
| 50              | 0.7                         | 0.02                    | 500                         | 87                              | 0.96                 | 12.756                          |
| 50              | 0.5                         | 0.01                    | 100                         | 84                              | 0.96                 | 12.756                          |
| 100             | 0.5                         | 0.02                    | 100                         | 53                              | 0.96                 | 12.756                          |
| 100             | 0.7                         | 0.01                    | 500                         | 52                              | 0.96                 | 12.756                          |

**Table 6: Parameter Settings and effects when $m = 10$ and $n = 4$.**

| Population size | Crossover probability $P_c$ | Variation concept $P_a$ | Maximum evolutionary algebra | Convergent algebra (generation) | [PMU] maximum value | Energy consumption value (yuan) |
|-----------------|-----------------------------|-------------------------|-----------------------------|---------------------------------|----------------------|---------------------------------|
| 50              | 0.7                         | 0.02                    | 500                         | 89                              | 0.92                 | 12.859                          |
| 50              | 0.5                         | 0.01                    | 100                         | 84                              | 0.92                 | 12.859                          |
| 100             | 0.5                         | 0.02                    | 100                         | 52                              | 0.92                 | 12.859                          |
| 100             | 0.7                         | 0.01                    | 500                         | 55                              | 0.92                 | 12.859                          |
conditioning water system had good stability performance. When the confidence factor was 2, the temperature measurement error introduced by fluctuation was less than 0.2°C, the flow measurement error was less than 0.2 m³/s, the head measurement error was less than 0.4 kPa, and the electric power measurement error was less than 4 W.

4.2. Analysis of Energy-Saving Effect of the Optimized Algorithm. After editing and debugging by MATLAB, the designed genetic algorithm was calculated under different load states, and the detailed operation frequency control strategy of each equipment in the central air-conditioning water system was obtained. In the case of low load, the algorithm optimized strategy was to preferentially control the low operating frequency of the compressor and match the frequency of the chilled water pump and the cooling water pump at the same time. When the load increased, the compressor frequency increased and the frequency of chilled water pump and cooling water pump was controlled within a certain range, so as to ensure the high energy efficiency ratio operation of the central air-conditioning water system.

Through the control frequency variation trend of three kinds of equipment under different loads, the thermodynamic principle of the algorithm control strategy could be analyzed more intuitively. With the gradual increase of load, the compressor frequency optimized by the algorithm showed an obvious upward trend, and the operating frequency of chilled water pump and cooling water pump fluctuated to a certain extent during the upward process. This control strategy was explained from the operation principle and thermodynamics of central air conditioning. The power consumption of the compressor accounted for the largest proportion in the power consumption of the whole water system of central air conditioning. At the same time, the compressor had constant torque characteristics and the power consumption of the compressor had a linear correlation with the operation frequency. Therefore, when the system was running under low load, controlling the running frequency of the compressor with constant torque had the most obvious energy-saving effect on the whole system [24]. In this way, sufficient refrigerating capacity could be ensured by adjusting the refrigerant flow rate and the inlet and outlet refrigerant of the compressor could be ensured in a reasonable state to ensure the smooth and efficient operation of the system. When the compressor was running under high load, the low compressor operating frequency could not ensure sufficient refrigerant flow. Therefore, the compressor operating frequency should be increased. Restricted by the flow rate and heat exchange temperature difference, the match of the frequency of chilled water pump and cooling water pump was not a one-way change. In part of the frequency range, the frequency of the pump was reduced. Considering the sacrifice of compressor power consumption, the energy-saving and energy-efficient operation of the whole water system was ensured by reducing the frequency of the pump.

The test data of different cooling load intervals below were investigated to compare the energy-saving effect before and after genetic algorithm optimization. Before optimization, the system was tested under different load conditions in order to maintain power frequency operation. After optimization, according to the control strategy calculated by genetic algorithm, the control of each electrical equipment was analyzed and compared. Figures 13 and 14 showed the flow rate and heat exchange temperature difference of chilled water cycle and cooling water cycle before and after algorithm optimization. Before optimization, frozen water pump and cooling water pump under different load conditions were running power frequency. Flow was a fixed value. The cooling water flow rate in the process of load changes with poor stability, which had nothing to do with refrigeration load changes and was caused by the cooling water stemming. As the experiment progressed, cooling water blockage would
be increased, which could lead to the cooling water flow rate fluctuations. The problem could be greatly reduced by setting up an electronic scale remover or arranging for the periodic removal of cooling water blockages. Before algorithm optimization, as the flow of chilled water system was constant, the increase of air-conditioning load would lead to the increase of temperature difference between supply and return of chilled water, which was approximately proportional. Heat exchange temperature difference of cooling water was also on the rise with the increase of load, but then, frozen water heat exchange temperature difference fluctuated significantly. The reasons for this phenomenon, on the one hand, was due to the cooling water flow rate fluctuations. On the other hand, it was due to the cooling water of the heat exchange effect associated with cooling tower near the parameters of outdoor air. Cooling water was not lower than the lowest temperature of the outdoor air wet-bulb temperature.

By comparing the changes of water circulation flow before and after optimization, it could be seen that the two water circulation flows after optimization were greatly reduced, which proved that the chilled water pump and cooling water pump had great energy-saving space. Combined with Figure 14 water system before and after the optimization of heat exchange temperature difference, it could be found that, the "big flow rate, small temperature difference" of heat exchange phenomenon appeared in the water cycle before optimization. And after optimization, by reducing the water cycle flow, improving the heat exchange temperature difference and improving the heat exchange effect of the water cycle, the energy-saving effect of the whole system was achieved through the water pump of low-frequency low-flow operation.

It is also found that the heat transfer temperature difference of chilled water is different under different loads. Heat exchange temperature difference under partial load was low, which may be bound by the safe operation of the pump
condition. Water pump speed was lower than the critical value and the requirements of the heat load could not be met by reducing the pump frequency. There were also some points where the temperature difference of water circulation heat exchange was greater than 5.0°C, which proved that under this load point, a “large temperature difference” heat exchange by reducing the frequency of chilled water pump had obvious energy-saving effect on the system. Evaporation and condensation pressure of refrigeration cycle were important evaluation parameters for energy efficiency of refrigeration cycle. Increasing evaporation pressure and decreasing condensation pressure was beneficial to efficient operation of refrigeration cycle. Figure 15 shows the changes of evaporation pressure and condensation pressure in the refrigeration cycle before and after genetic algorithm optimization. Through comparison, it was found that the evaporation pressure of the refrigeration cycle was improved to some extent under different load conditions, but the change trend of condensation pressure was not obvious.

Before the algorithm optimization, the system was in power frequency operation state. And both equipment and water system were in a low energy efficiency working state. The total electric power of the central air-conditioning water system was above 2.0 KW. The water system energy...
efficiency before and after the algorithm optimization was compared, as shown in Figure 16.

Before optimization, the electric power of the system remained constant. With the increase of the load, the energy efficiency ratio of the system also increased. The relationship was approximately positive. After the algorithm was optimized, the energy efficiency ratio trend of the system also increased with the increase of load and the average energy efficiency ratio increased about 26.8%. The energy efficiency ratio of the optimized system was relatively low. On the one hand, considering the actual operating background, most of the air conditioners only met the requirements of 50%~70% of the designed load. In this research, only 30%~70% of the designed load was taken as the research object. The energy efficiency ratio of the system was rising with the increase of the load rate. Therefore, the experimental effect did not reach the maximum energy efficiency ratio that the device could achieve. At the same time, the operation of the actual device was limited by the heat exchange effect of evaporator and condenser, the energy efficiency of the operation of the device was lower than the energy efficiency ratio that could be achieved theoretically [25]. It could be seen that the energy efficiency of the system and equipment decreased gradually as the load increased. In the design load range of 30% to 70%, the average energy-saving rate of the compressor was 16.8%. The average energy-saving rate of the chilled water pump was 51.0%. The average energy-saving rate of the cooling water pump was 55.0%. The maximum energy-saving rate of central air-conditioning water system was 37.4%, and the minimum energy-saving rate was 15.5%. The average energy-saving rate was 26.8%.

5. Conclusion

To sum up, the operation characteristics of central air-conditioning water system was analyzed in this research, and the fact that using artificial optimization algorithm was the key to solve the energy-saving operation of the system was pointed out. Based on the analysis of genetic algorithm to solve the optimization problem, the energy-saving operation algorithm of central air-conditioning water system was designed, including setting the encoding and decoding mode and fitness function; setting the population size, selection, variation and crossover probability, designing algorithm operator and determining the optimization process, etc., The algorithm was realized based on MATLAB software. In the research, first, the rationality of the algorithm design was verified through convergence analysis and the optimal control strategy of the algorithm from the perspective of air-conditioning operation principle was explained. The variation of flow rate and temperature difference of heat exchange between chilled water and cooling water, evaporation temperature and condensation temperature of refrigeration cycle optimized by genetic algorithm under different cooling load conditions were investigated experimentally. In the design load range of 30%~70%, the variation of operating parameters and energy efficiency of the system before and after genetic algorithm optimization was investigated. Experiment results showed that genetic algorithm had energy-saving effect on water system of central air conditioning. In the design load range of 30% to 70%, the average energy-saving rate of the compressor was 16.8%. The average energy-saving rate of the chilled water pump was 51.0%. The average energy-saving rate of the cooling water pump was 55.0%. The maximum energy-saving rate of central air-conditioning water system was 37.4%, and the minimum energy-saving rate was 15.5%. The average energy-saving rate was 26.8%.

Data Availability

The labeled dataset used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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