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# Design of real-time data acquisition and regulation algorithm of air-conditioning equipment for grid supply-demand interaction

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ABSTRACT
On the basis of ensuring the balance between supply and demand of the power grid, fully realizing the automatic control of the air conditioning system can make the energy consumption of the air conditioning operation reduce significantly, thus realizing the purpose of energy saving. This paper combines a variety of technologies to establish an intelligent air conditioning measurement and control system, realizes terminal communication through the CoAP protocol, and designs the corresponding system hardware as well as the real-time data acquisition method for air conditioning equipment. Based on the PID principle, the temperature and humidity control strategy of air conditioning equipment based on expert PID is proposed. In order to better ensure the energy-saving control efficiency of air-conditioning equipment, this paper fully considers human thermal comfort and the interaction between supply and demand of the power grid, establishes a comprehensive optimization control model with the objectives of user power consumption and human comfort, and passes through the PSO algorithm in order to obtain the optimal control results. Simulation found that when the initial temperature is lower than the set value, the expert PID control strategy will adaptively realize the air conditioning temperature and humidity adaptive regulation to ensure that the indoor temperature is within a reasonable range. The total power consumption of the grid is reduced by 90.18kW compared with that before optimization, and the maximum value of human comfort evaluation is improved by 11.39%. Relying on the intelligent air conditioning control system, the adaptive control of temperature and humidity can be effectively realized and the indoor air quality can be better ensured, and a reliable control strategy can also be provided to ensure the balance between supply and demand of the power grid.

*Keywords:* air conditioning measurement and control system, CoAP protocol, expert PID, grid supply and demand interaction, PSO algorithm

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## 1. Introduction

During the long time of power system development and exploration, the related parties did not pay high attention to the power supply and demand problems, which made the corresponding power crisis appear in some regions [1]. The development situation of the electric power system mainly covers the following two points. First, the promotion of market-oriented reform, in order to meet the current growing demand for electricity, the power market began to carry out a reform, mainly to increase the means of power supply, change the market business philosophy is the main focus, thus forming a colorful form of transactions, to the future development of the power system paved the way [2-5]. The second is the development of renewable energy, with the increasing consumption of natural resources, a large number of non-renewable energy has been facing the serious problem of depletion, new power generation methods such as wind power generation, light energy generation has gradually come into people's eyes [6-7]. In order to realize the enhancement of power system development, the concept of supply-demand interaction has been proposed to alleviate the pressure on the power system due to various problems [8]. The supply-demand interaction is to balance these power generation methods with the market demand and adjust the supply-demand match between the two parties to achieve the efficient utilization of resources.

With the growing demand for electricity and the limitations of electricity supply capacity, despite the overall adequate supply of electricity, the balance between supply and demand of electricity has become an important issue due to the impact of special circumstances such as extreme weather, growth of electricity load and fuel shortage, which may lead to tight supply of electricity in localized areas during peak hours [9-12]. This requires the power system to have higher flexibility and regulation capability, in which the demand response capability enhancement of air conditioning load has significant optimization effect on the power system [13]. Air conditioning load has seasonal and daily load characteristics, and its peak value is highly coincident with the peak value of grid load, and its regulation is simple, has little impact on users, and accounts for a high proportion of the whole society's electricity consumption, which has a huge potential for regulation [14-16]. There are differences in the air conditioning load characteristics of different user groups, in which the air conditioning load of industrial users accounts for a relatively low proportion of the air conditioning equipment operating state can not be arbitrarily adjusted, the regulation potential is limited. Residential users have large air conditioning loads, and their load peaks have a high degree of overlap with the evening peak of the grid load, but due to the large amount of equipment use, decentralized and stochastic, it is more difficult to regulate and control. Commercial users have a high percentage of air conditioning loads and a huge potential for regulation, which makes them more suitable for participating in demand response [17-19]. To release the potential of air-conditioning load participation in demand response, it is necessary to improve both air-conditioning regulation technology and the mechanism of air-conditioning load participation in demand response. As for air conditioning equipment data collection as air conditioning load regulation to participate in demand response, its data collection faces challenges, such as privacy security and data security, difficulty in integrating data from multiple ends, and limited multimodal data capture [20-21]. To summarize, proposing a multi-source real-time data collection method for solving air conditioning equipment and air conditioning equipment load regulation strategy is the problem that needs to be solved nowadays.

Air conditioning has been commonly found in residential and public buildings nowadays, which greatly improves the quality of people's indoor environment, but its high energy consumption has been a concern. The article establishes an intelligent air conditioning measurement and control system based on modern communication technology by connecting air conditioning with the Internet of Things, realizes data communication through CoAP protocol, and designs the collection method of real-time data of air conditioning equipment. Expert PID control was designed based on the PID principle, and the temperature and humidity control strategy of air conditioning equipment was proposed. On the basis of considering the interaction between supply and demand of the power grid, and taking the user's power consumption and human thermal comfort as the optimization objectives, a comprehensive optimization control model of air conditioning is established, and PSO algorithm is used to optimize it with multiple objectives. In order to verify the effectiveness of the air conditioning regulation algorithm and the intelligent air conditioning control system proposed in this paper, this paper carries out data analysis through simulation experiments, with a view to providing new research ideas for the adaptive control of air conditioning as well as energy-saving control of the power grid.

## 2. Intelligent air conditioning measurement and control system design

The rapid development of the economy and science and technology continue to improve the quality of people's lives, modern buildings in various cities have become the main activities of people's daily work, study and life, and air-conditioning system is undoubtedly one of the most important components of these people's activities. Air conditioning is a large energy-consuming equipment, people enjoy the air conditioning to bring us a comfortable environment at the same time, often ignoring the air conditioning operation consumes a lot of electricity. Therefore, increasing the research on the control of air conditioning system not only conforms to the development of the times, but also has great significance in promoting the energy saving of air conditioning system.

### *2.1. General Architecture and Communication Protocols*

2.1.1. General system architecture. At present, the management and control of air conditioning has become an important part of the building automation system, usually can be realized on the new air conditioner, air conditioning and other major equipment centralized management and control, but the fan coiler and other end equipment is still used in an independent way of control, the control objectives of these end equipment, operating parameters and status of the information has not been included in the air-conditioning system monitoring, while the fan coiler is precisely the air-conditioning system is the highest number of end Equipment, directly affecting the energy consumption of the system. Based on the above status quo, this paper takes modern communication technology as the basis, connects the air conditioner with the Internet of Things, so as to assist in realizing the unified management and control of air conditioning equipment. The air conditioning equipment control system designed in this paper is shown in Figure 1, which aims to provide an effective technical means for energy-saving operation and management of air conditioning systems.

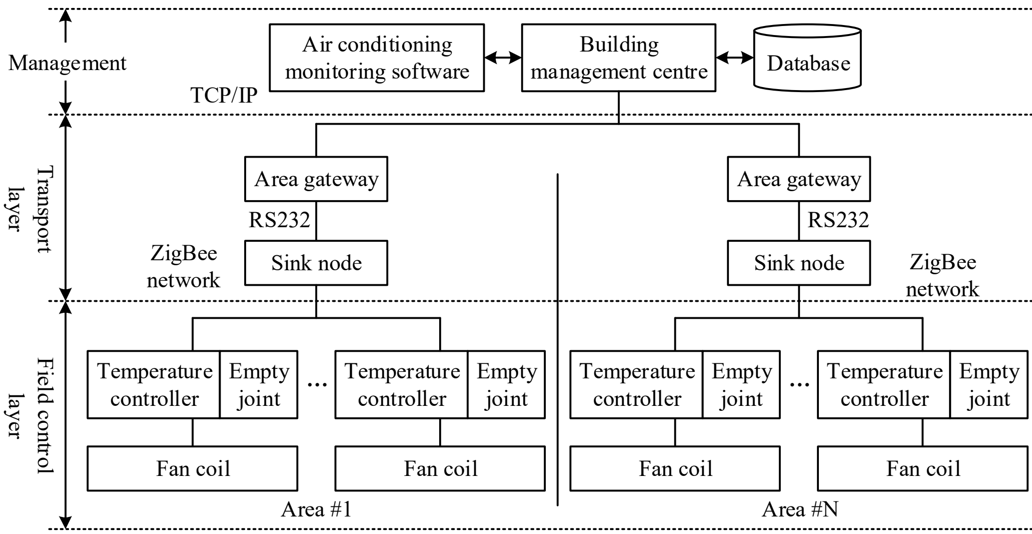



**Fig. 1.** Framework of air-condition system

1) Field control layer. It consists of thermostats, sensors, and fan coils, and is installed in the user's room. The nodes are integrated into the thermostat to collect information on room temperature, human flow and fan coil operation status, and report it to the building management center periodically. The thermostat can not only accept remote control commands to operate the fan coiler and realize the control of the site temperature, but also realize the energy-saving cooling effect of the room and reduce the operational energy consumption of the system based on the detected environmental information and according to the PID temperature algorithm [22].
2) Transmission layer. Realize the convergence of multiple network forms as a data transmission bridge between the management layer and the field control layer. The convergence node establishes a communication network, accepts the data uploaded by the node, transmits it to the regional gateway in RS232 mode, and the gateway realizes protocol conversion and packet sealing, and uploads it to the management center through TCP/IP protocol.
3) Management level. By running the air conditioning monitoring software to complete the data collection and storage and other functions, and statistical analysis of the data, provided to the manager for decision-making reference.

2.1.2. System communication protocols. Among the communication protocols for IoT devices, wireless communication protocols are commonly adopted due to the advantages of easy arrangement and easy expansion. The main reasons for choosing NB-IoT technology in this paper are as follows:

Firstly, the power consumption is very low, which is very suitable for some sensor-based devices. Secondly the cost is low, which is favorable for promotion. Then the coverage is wide and the connection is reliable. Finally, the device is directly connected to the core network, which can eliminate the gateway device that must be in the smart home system using wireless networks such as ZigBee and Wi-Fi. It reduces cost and improves security, and will not cause the entire air conditioning control system to fail due to the gateway not working properly.

Currently there are two application layer communication protocols for IoT scenarios, CoAP and MQTT. MQTT is an instant messaging protocol based on TCP, which is suitable for many-to-many instant messaging scenarios, with the advantage of simpler bidirectional control due to the use of a long TCP connection. However, the disadvantage is the high power consumption, not suitable for battery-powered occasions.CoAP is a UDP-based communication protocol, specifically used for microcontrollers and other resource-constrained devices.The advantage of CoAP over MQTT is that it doesn't need to maintain a long TCP connection, which can extend the life of the battery. In addition, CoAP can be directly accessed to the IoT connection management platform without additional protocol conversion in the gateway, which is more convenient for the development of air conditioning control systems.

## *2.2. System hardware and software design*

2.2.1. System Hardware Design. The hardware circuit of the air-conditioning control system designed in this paper consists of three main parts, i.e. the CPU control module, the Ethernet interface module and the peripheral module.

The CPU module carries out the initialization control of the network chip and the implementation of the CoAP protocol stack, which mainly packages the data to be sent and unpacks and inspects the received data. The data to be sent adds control information layer by layer through the CoAP protocol, and is packaged and transmitted to the network processing module layer by layer. In the choice of microprocessor, DSP or high-speed microcontroller can be used. This improves the transmission speed of the system and enables the system's processing power to be enhanced. The core of the Ethernet interface module is the network controller chip. The peripheral module mainly connects external devices through I/O.

The hardware structure of the system is shown in Figure 2. The main processor is the AT89C55 microcontroller, and the RTL8019AS has a built-in 10BASE-T transceiver, so the circuit of the network interface is relatively simple, and it is connected to the RJ45 interface after being isolated by the isolation transformer HR61101G. 24C64 is used to store the IP address, physical address, and the relevant information of the device. The external RAM provides a cache for data processing. The system provides RS232 interface for system testing and RJ45 interface to connect to Ethernet. The working process is to use the microcontroller to control the various operations of the RTL8019AS, the data flow through the RJ45 interface into the buffer of the network controller. The data stream enters the buffer of the network controller through the RJ45 interface and is then decoded and read into the memory of the microcontroller, which parses and processes the data and then controls the devices on the I/O bus. On the contrary, the microcontroller can also send the status of the devices on the I/O bus to the buffer of the network controller, and then through the RJ45 interface to the LAN, so that the current status of the devices can be observed through the browser on the Internet.

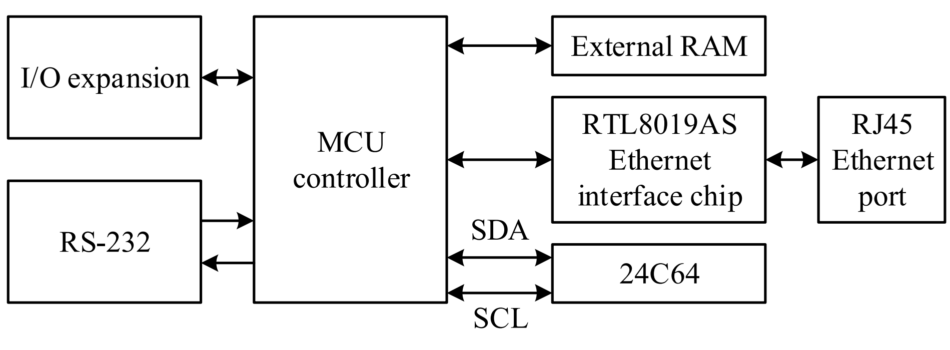



**Fig. 2.** The hardware structure of the system

2.2.2. Air conditioning data collection. The main function of air conditioning is to adjust the environmental state in real time, so that the environment is more suitable for human work and life. In general, the key parameters in the environment are slow and gradual changes, so basically do not need a higher millisecond level of acquisition frequency, the second level of acquisition frequency is basically to meet the needs of daily life. The hardware interface circuit has been designed above, in order to avoid the limitation of application scenarios, all the collection sensors are hooked up to the 485 bus in the role of 485 slave devices, and according to the Modbus protocol, the sensors are used to collect data and update them to the local sensor status registers.

After the system is powered on, system initialization and module initialization are carried out to determine the number and type of sensors currently connected, and then the monitoring timer is turned on with a timing time of 1 s. According to the type of sensors, the timed monitoring status counters are set, and each time the timer times out, the status counters of all the online sensors are increased by 1. The acquisition task is initiated when the status counters of a certain sensor reach the counting threshold. The master control first issues an acquisition command to a sensor on the 485 bus or certain sensors sequentially, waits for the acquisition to be completed, and then issues a convergence command to acquire the acquisition data sequentially from each sensor that has issued an acquisition command and update it to the local sensor status register.

## 3. Energy-saving regulation algorithm for air-conditioning equipment

The booming development of technologies such as the Internet of Things (IoT), cloud computing, 5G mobile communication network and remote monitoring is profoundly influencing the dualization and integration of industrialization and informationization and the transformation and upgrading of the air conditioning industry. The Internet of Things is the Internet of things connected, an important part of the future Internet. Relying on the Internet of Things, the intelligent control of air conditioning equipment can be realized by combining the interaction between supply and demand of the power grid, which can better reduce the energy consumption of air conditioning and also provide help for the stable operation of air conditioning equipment connected to the power grid.

### *3.1. Control algorithms for air-conditioning equipment*

3.1.1. Principles of PID control. PID control is often used in heating rooms equipped with radiators and air conditioners, and mainly contains two parts: the controller and the controlled object. the input of the system in PID control is the difference between the current real-time indoor temperature and the indoor design temperature. u(t) is the signal given by the PID controller to control the inverter pump, and y(t) is the magnitude of the water flow rate of the output of the inverter pump, which serves as an input to control the indoor temperature in the model of the room temperature change. So that the indoor temperature is stabilized at the indoor design temperature, i.e., the reference trajectory r(t). The PID controller, as the core component of PID control, is the basis for realizing temperature control [23].

The PID control expression is:

$$u(t) = K_p(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d \frac{de(t)}{dt}) \tag{1}$$

where $u(t)$ is the output command of the PD controller, and $e(t)$ represents the difference between the system's current monitored indoor temperature and the indoor design temperature. $K_p, T_i, T_d$ are the proportional, integral, and differential regulation coefficients, respectively.

Proportional adjustment coefficient affects the speed of the system adjustment time, when the room temperature is lower than the set value of $K_p$ value is larger, the system converges to the set value of the shorter the time, but will be in a certain period of time to make the room temperature is higher than or lower than the set value.

The shorter the time for the system to converge to the setpoint, the more likely it is that the room temperature will be above or below the setpoint at some point in time. When the system stabilizes without integration, there may be some difference from the target value, and the size of the integral adjustment factor reflects the sensitivity to system error. Increasing the integral coefficient will make the system operation process error accumulation excessive to produce overshooting phenomenon, and vice versa. It is mainly used to eliminate the static error of the system. Unlike the integral adjustment coefficient, the size of the differential adjustment coefficient reflects the degree of sensitivity to the rate of change of the system error. Increasing the differential adjustment coefficient can reduce the response time of the system to the rate of change of the error, and play a role in weakening the system overshooting, which contributes to the stability of the system. By reasonably adjusting the above three parameters, the performance of the PID temperature control system can be optimized, so that it has a better anti-interference ability in the face of external factors such as temperature interference.

3.1.2. Expert PID control. The temperature control of air conditioning is characterized by hysteresis, nonlinearity, time-varying and so on, so the conventional PID control can not guarantee the control accuracy and stability, and the expected effect is not ideal. The introduction of expert control rules into the conventional PID control makes the air conditioning control system have a certain degree of adaptivity, which makes the air conditioning control system regulate in a more timely manner and with higher precision [24].

$t,d$ are the middle value of the allowable fluctuation range of temperature and humidity set by the system, $t_c,d_c$ are the measured temperature and humidity, $e(t),e(d)$ are the temperature error and humidity error, respectively. The system according to the error value, through the expert PID algorithm to control the fan, pump output frequency of temperature and humidity for independent control. Take the workshop temperature control as an example, there are the following three cases when the expert PID algorithm is used for workshop temperature control.

1) When $|e(t)|>M_1$, and $e(t)\Delta e(t)>0$, the absolute value of the temperature error in the direction of increasing, this time the error is larger, the controller should be implemented to control the role of a stronger, at this time, the PLC controller output is:

$$f(k)=f(k-1)+k_1\left\{k_p[e(t)-e(t-1)]+k_ie(t)+k_d[e(t)-2e(t-1)+e(t-2)]\right\} \tag{2}$$

Where $e(t)$ is the textile workshop temperature error at the current sampling moment, $e(t-1)$ and $e(t-2)$ are the textile workshop temperature errors at the previous and previous two sampling moments, and $\Delta e(t)=e(t)-e(t-1)$ is the amount of change in the textile workshop temperature error at the current sampling moment. $f(k)$ is the current PLC controller output frequency, $f(k-1)$ is the previous moment PLC controller output frequency, $M_1$ is the set error limit, is the proportionality coefficient, $k_i$ is the integral gain, $k_d$ is the differential gain.

2) When $|e(t)|>M_1$, and $e(t)\Delta e(t)<0$, the absolute value of the temperature error in the direction of reduction, which should be reduced to control the role of the PLC controller output at this time:

$$f(k)=f(k-1)+k_2\left\{k_p[e(t)-e(t-1)]+k_ie(t)+k_d[e(t)-2e(t-1)+e(t-2)\right\} \tag{3}$$

3) When $|e(t)|<M_1$, indicating that the absolute value of the workshop temperature error has been smaller, in order to make the system has good steady-state performance to reduce the steady-state error, should be used PI control, at this time, the PLC controller output is:

$$f(k)=f(k-1)+k_p[e(t)-e(t-1)]+k_ie(t) \tag{4}$$

3.1.3. Temperature control strategies. Air conditioning systems ensure indoor comfort by regulating the temperature of the room. Some of these components, such as the pipe network and the cooling and heating source, react relatively slowly to temperature adjustments. This means that when the outdoor temperature, pump flow or water supply temperature changes, the indoor temperature does not immediately adjust accordingly, but takes some time to materialize. Air conditioning systems need to determine how much cooling and heating needs to be provided by the cooling and heating sources based on a number of factors such as indoor and outdoor temperatures, the number of people, and their demand for temperature. This determination takes time and is affected by attenuation and uncertainty in the transfer of heat and cold. As a result of these factors, the response of the system is relatively slow and there is a large lag.

In order to improve the energy efficiency of the air conditioning system, it is necessary to use highly efficient chiller units and apply effective control strategies to improve their operating efficiency. According to the changes in the air conditioning end load and indoor environmental parameters of the building, the automatic control operation of fans, chillers, pumps and other equipment can be optimally adjusted. By installing sensors and other equipment in the piping and equipment, real-time collection of signals is transmitted to the system controller for system operation condition analysis. The air-conditioning system automatically adjusts the frequency of fans and pumps according to the supply and return water temperatures to ensure that each piece of equipment is automatically controlled. The purpose of the control system is not only to save energy by starting and stopping, but also to ensure that the system operates at its optimal state and to guarantee suitable working conditions.

### *3.2. Air-conditioning control under supply-demand interaction*

3.2.1. Evaluation of human thermal comfort. The more widely used thermal comfort evaluation method is PMV-PPD, i.e., mean vote prediction and percentage of dissatisfaction, which has a high prediction accuracy under air-conditioned buildings close to thermal comfort environments, and is suitable for analyzing the overall thermal sensation and thermal comfort of the human body in a steady state environment [25].

The formation of human thermal sensation is closely related to the thermal response of the skin. The thermoreceptors on the surface of the human skin transmit the cold/hot stimulus signals caused by changes in ambient temperature to the central nervous system, and the hypothalamus controls the thermoregulatory properties of the body such as metabolic level, blood flow, muscle activity, and sweating, balancing the amount of heat produced in the body and its exchange of heat with the environment, so as to produce a subjective mental state of the human body that changes dynamically with the environment. At homeostasis, the local thermal sensation of the human body can be expressed as:

$$TS_i = 4\left\{\frac{2}{1+\exp\{-C_1(T_{sk,i}-T_{sk,i,0})-K_1[(T_{sk,i}-T_{sk,0})-(\overline{T}_{sk}-\overline{T}_{sk,0})]\}}-1\right\} \tag{5}$$

where $TS_i$ is the local thermal sensation of each body part, $\overline{T}_{sk,0}$ and $\overline{T}_{sk}$ represent the mean skin temperature setpoints and the mean skin temperatures, respectively, and $T_{ski,0}, T_{sk,i}$ are the local skin base temperatures, respectively, local skin temperature, and $C_1$ and $K_1$ are the coefficients.

When the skin temperature varies dynamically, a dynamic term $TS_{dynamic}$ is introduced into the steady state expression, i.e.:

$$TS_{dynamic} = C_2\frac{dT_{sk,i}}{dt} + C_3\frac{dT_{cr}}{dt} \tag{6}$$

where $C_2, C_3$ are the coefficients and $T_{er}$ is the core temperature. Combined with the above equation, the local thermal sensation model expression for the dynamic thermal environment is obtained as:

$$TS_i = 4\left\{\frac{2}{1+\exp\{-C_1(T_{ik,i}-T_{ik,i,0})-K_1[(T_{ik,i}-T_{ik})-(T_{ik,i,0}-T_{ik,0})]\}}-1\right\} + C_{2_i}\frac{dT_{ik,j}}{dt}+C_{3_i}\frac{dT_c}{dt} \tag{7}$$

The thermal state of different body parts of the human body integrally affects its overall thermal state. According to the Berkeley Thermal Comfort Evaluation Model, the overall thermal comfort of the human body can be quantified and analyzed by local thermal comfort, which is often influenced by its local and overall thermal sensations. It has been shown that the overall human thermal comfort in a non-uniform thermal environment is close to the highest or second highest value of local thermal comfort. When the thermal environment is transient, the expression is:

$$C_{overall} = 0.5(TC_{local,1,\min} + TC_{local,2,\min} + TC_{local,\max}) \tag{8}$$

Where $TC_{local.1.\min}$ and $TC_{local.2.\min}$ are the smallest and the second smallest values in the local thermal comfort, respectively.

According to the overall thermal comfort calculation model, relying on the air-conditioning control system to improve the thermal state of the hot discomfort or cold discomfort area can effectively improve the overall thermal comfort of the human body.

3.2.2. Participation of electrical equipment. When the control of air conditioning equipment is carried out, changes in the supply and demand of the power grid will also have an impact on the stability of its control. According to the relationship between air-conditioning equipment power consumption and demand response, household power-using equipment is put into the demand response, and the control demand response model is established with the amount of power-using equipment participation as the target.

It is assumed that there are a total of $K$ types of power-using equipment in each household in the area governed by a substation to participate in the intelligent power demand response, of which the $k$ th type of power-using equipment with a single rated power of $P_{L*k}(k=1,2,\cdots,K)$ is $\beta_k$ units. By detecting the system frequency magnitude, the power deficit of the system can be calculated from the active power-frequency characteristic curve of the system as:

$$P_{vac} = -\alpha\sum_{k=1}^{k} P_{L*k}\frac{f-f_N}{f_m} \tag{9}$$

where $f$ is the grid real-time frequency, $f_N$ is the grid rated frequency, $\alpha$ is the constant factor, and $f_{TH}$ is the frequency response threshold.

The participation of power-using equipment $P_a$ is the sum of the active power adjusted by all power-using equipment participating in the grid frequency friendly response during the time period $t$, i.e:

$$P_a = \sum_{k=1}^{K} x_{k*t}\beta_k P_{L\cdot k} \quad t=1,2,\cdots,T \tag{10}$$

Where $T$ is the total number of time periods, $x_{k\cdot l}$ is the degree of participation in the response of the $k$ th class of power-using equipment in time period $t$, i.e., the proportion of power participating in the response, $0 \le x_{k\cdot l} \le 1$.

When there is a power deficit in the grid, in order to achieve grid frequency stabilization as soon as possible, during the time from the beginning to the end of the participation in demand control, each user should allow as much as possible for the power-using equipment to carry out the demand strategy response, and reduce as much as possible the deviation of the total participation of the power-using equipment from the current power deficit at the grid end, i.e:

$$\min F_1 = | P_a - P_{vac} | \quad t = 1, 2, \cdots, T \tag{11}$$

Its constraints are:

$$0 \le x_{k \cdot l} \le 1 \tag{12}$$

3.2.3. Integrated control strategy. The intelligent control system of air-conditioning equipment needs to fully consider human comfort and energy saving requirements under the interaction of power grid supply and demand when regulating air-conditioning temperature. Based on this, the control strategy considering the interaction of grid supply and demand and human thermal comfort is as follows:

From the comfort index adjustment amount $A_{EQT}$ and energy saving index adjustment amount $cop$ as the two inputs of the air conditioning system controller, with reference to the optimal value of the energy saving index in the demand response model, the controller sends commands to the system by integrating the control parameters of the air conditioning system to get the difference of the control index. The air conditioner gets the instruction to adjust the control object and sends the air with the most suitable temperature into the room to realize the optimization of energy cooperative control.

Figure 3 shows the integrated control framework of human comfort and grid energy efficiency, in which the role of the air conditioning controller is to carry out energy synergistic integrated control of the comfort indicator $A_{EQT}$ and the energy efficiency indicator $cop$.

Therefore, the objective function is:

$$\max f = a \times A_{EQT} + (1 - a) \times cop \tag{13}$$

Where: $A_{EQT}$ takes the value range of [-1~+1], $cop$ takes the value range of the most value interval in the environmental mode experiment, $a \in [0,1]$ is the weight coefficient set according to the operation of the automobile air-conditioning system, which is derived from the particle swarm algorithm. When the air conditioning system is within the comfort range, $a \in [0,1]$ takes a smaller value, when the air conditioning system is not within the comfort range, $a \in [0,1]$ takes a larger value.

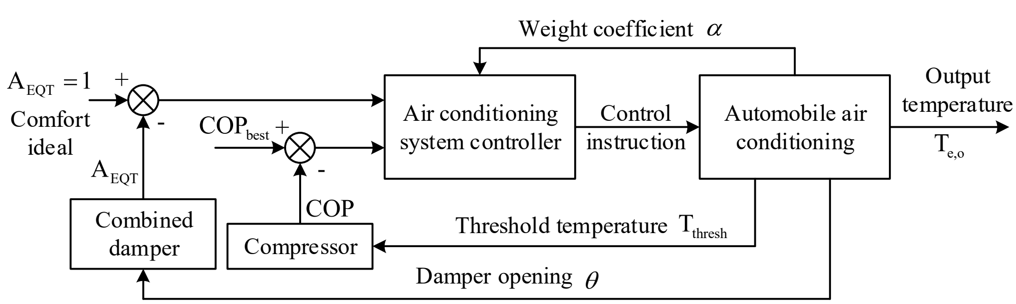



**Fig. 3.** Integrated control framework

For the multi-objective optimal control problem in this paper, Particle Swarm Optimization (PSO) algorithm is used to perform an iterative search for the optimal solution [26]. The steps are as follows:

Step1 Input the initial parameters related to air conditioning.

Step2 Set the number of dimensions, the maximum number of iterations and the number of particles.

Step3 Bring the result obtained in Step1 into the formula of PSO algorithm to get the value of adaptation $\max f$, so that $\max f$ is equal to the position of the current particle $p_{id}^{(t)}$.

Step4 Initialize the position and velocity, calculate the position $p_{id}^{(t)}$ of the first individual optimal particle, and set this $p_{id}^{(t)}$ as the position $p_{gd}^{(t)}$ of the global optimal particle that the population is currently looking for.

Step5 If the current particle fitness value is less than the individual extreme value, update the current individual extreme value.

Step6 If the current particle adaptation value is less than the global extreme value, update the current global extreme value.

Step7 Update the particle velocity vector. I.e:

$$V_{id}{}^{(t+1)} = w \cdot V_{id}{}^{(t)} + c_1 r_1 \cdot (p_{id}{}^{(t)} - X_{id}{}^{(t)}) + c_2 r_2 \cdot (p_{gd}{}^{(t)} - X_{id}{}^{(t)}) i = 1, 2, \ldots, n \tag{14}$$

where $t$ is the current number of cycles, $c_1, c_2$ are the particle weight coefficients, $\omega$ is the inertia weight, $r_1, r_2$ are the uniformly distributed random numbers in (0,1), and $V_{id}, X_{id}$ are the positions of the particles in the first $i$ th dimension and velocity.

Step8 Calculate the fitness value with the updated velocity vector and position vector.

Step9 Repeat Step5 to Step7.

Step10 Judge the number of iterations, output the result if satisfied, otherwise go back to Step7.

The air conditioning system has multi-constraint, discrete and non-linear characteristics, and the particle swarm optimization algorithm is used for this combined optimization problem, which can give full play to the strong adaptability of the intelligent optimization method for solving highly complex problems.

## 4. Verification of energy-saving regulation of air-conditioning equipment

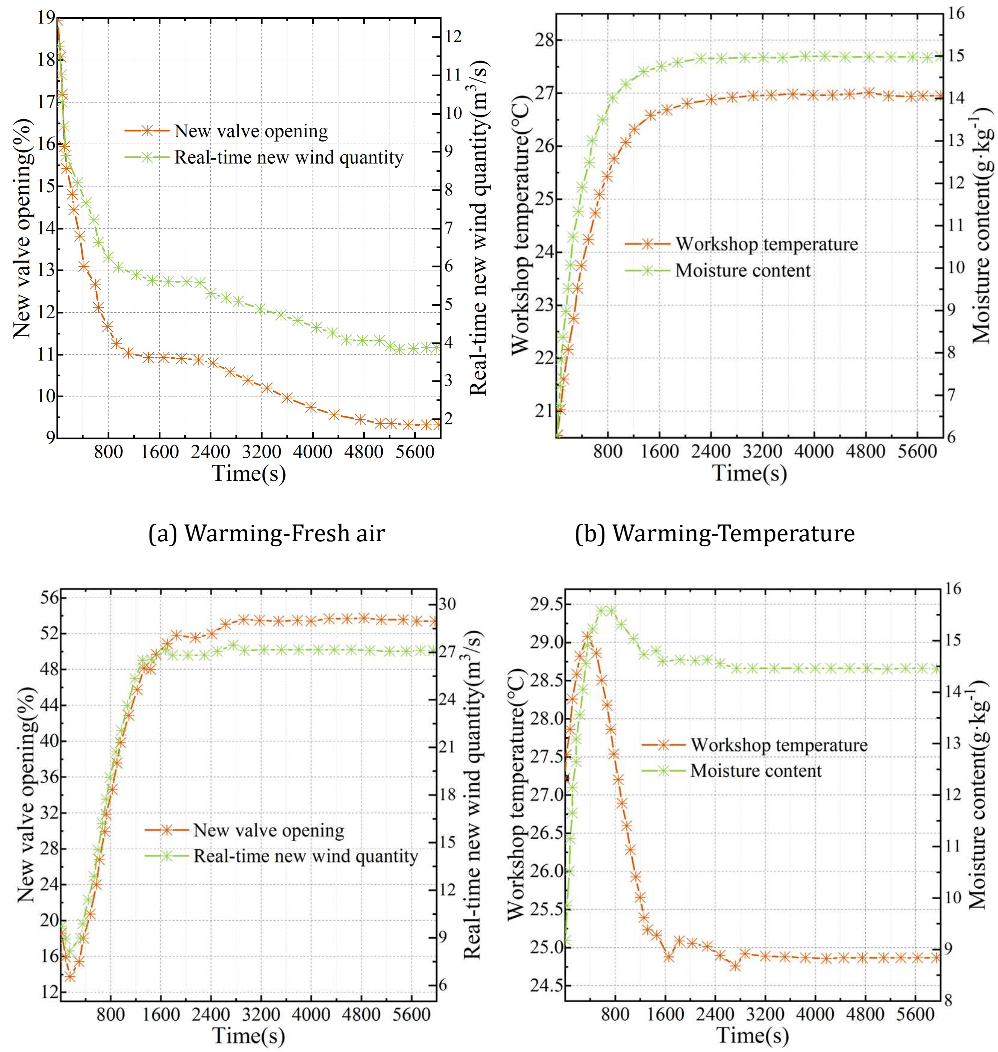
Air conditioning units can filter, heat, cool, humidify, dehumidify and other processes to achieve the desired air temperature and humidity and cleanliness. In the process of air treatment, according to the different requirements of the target temperature and humidity and cleanliness, the treatment of air is completed under the premise of ensuring energy-saving economy and high system operation efficiency. How to effectively satisfy the interactive relationship between supply and demand in the power grid on the basis of a better realization of the precise regulation of the air conditioning system has become an important research direction to reduce the energy consumption of air conditioning.

### *4.1. Effective validation of temperature control*

4.1.1. Fresh air response curve. This section is based on the air conditioning control system given in the previous section, and the temperature and humidity control strategy of the air conditioning system in section 3.1.3 is based on the logical judgment and expert PID control algorithm of the temperature and humidity self-control strategy compiled by Python/PyQt5, and the air conditioning control system is based on the air conditioning control system to further develop the dynamic simulation program for automatic control of air conditioning system. The workshop will set the temperature, relative humidity were 25 ℃, 55%, the initial moment of the new air valve, ground exhaust valve, process exhaust valve opening the same are 19%, the secondary return valve opening for 12%, the pump frequency of 15Hz, the blower frequency of 40Hz.

Temperature control is realized by adjusting the fresh air valve, and the fresh air valve opening is compared with the virtual dew point enthalpy of the workshop and the dew point enthalpy of the machine, and is controlled in real time based on the temperature self-control algorithm of expert PID. Figure 4 shows the fresh air response curve under the temperature and humidity control strategy. Figures 4(a)~(d) represent the change process of fresh air valve opening and real-time fresh air volume, workshop temperature and humidity content over time in the process of air conditioning system warming up and cooling down and humidification, respectively.

At this time, the outdoor fresh air temperature is 20℃, the fresh air humidity is 55%, and the fresh air enthalpy is low. As shown in Fig. 4(a), when the initial temperature of the workshop is lower than the set value, the introduction of new air is reduced and the primary return air is increased to raise the enthalpy of the workshop so that the temperature rises, and the openings of the fresh air valve, the ground exhaust valve and the process exhaust valve are all adjusted automatically from 19% to about 9.3%, and the fresh air volume is gradually reduced from 12.52 $m^3/s$ to 3.95 $m^3/s$. In Fig. 4(b), the isenthalpic humidification is carried out by the spraying room, and the air is mixed with secondary return air and sent into the workshop after spraying. Mixed with the secondary return air and sent to the workshop, the workshop temperature stabilizes from 20.5℃ to about 27.5℃, and the workshop humidity content stabilizes from 6g/kg to 14.11g/kg, which raises the workshop temperature to the set range. In Fig. 4(c), when the initial temperature of the workshop is higher than the set value, more fresh air is introduced to reduce the enthalpy in the workshop by increasing the opening of the fresh air valve to lower the temperature of the workshop, and the openings of the fresh air valve, the ground exhaust valve and the process exhaust valve are all adjusted automatically from 20% to about 54%, and the volume of fresh air is gradually increased from 9.28$m^3/s$ to 27.1$m^3/s$. In Fig. 4(d), the workshop temperature is isothermally humidified through the water spray room, and the sprayed air is mixed with the secondary return air and sent to the spinning workshop, the workshop temperature is stabilized from 29.1℃ to 24.8℃, and the workshop humidity content is stabilized from 9.15g/kg to 14.49g/kg, which reduces the workshop temperature to the set range. Using the temperature control strategy designed based on the expert PID control algorithm in this paper, the temperature adaptive control can be realized according to the external temperature and humidity changes, which effectively ensures that the temperature is within a reasonable range.



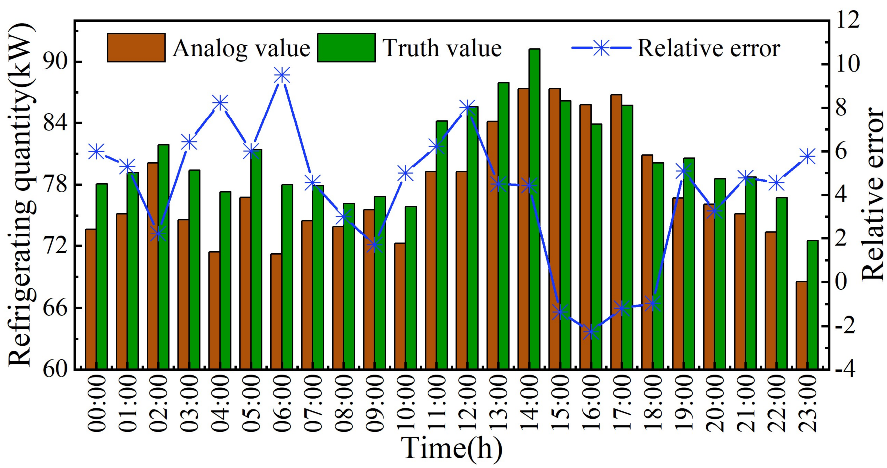

(a) Warming-Fresh air (b) Warming-Temperature

(c) Cooling-Fresh air (d) Cooling-Temperature

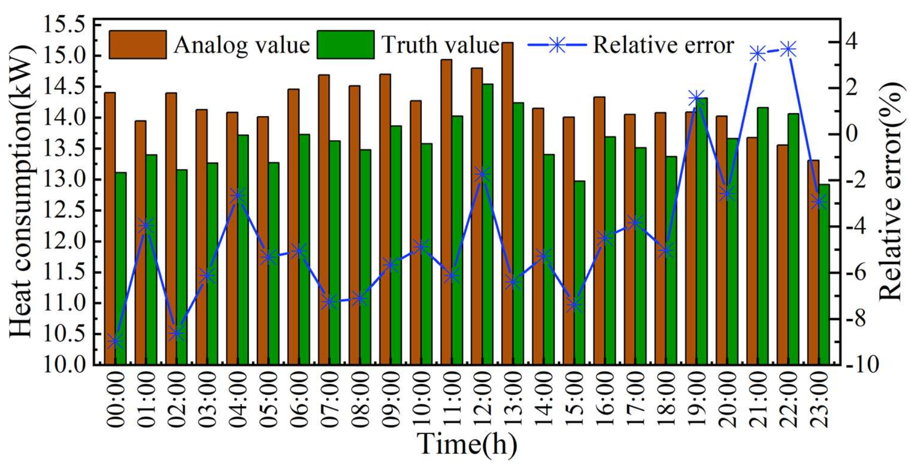
**Fig. 4.** New wind response curve

4.1.2. Simulation of system energy consumption. When relying on expert PID control algorithms for adaptive control of air-conditioning equipment, it is necessary to better ensure that the energy consumption of the air-conditioning system is maintained within a reasonable range under the real-time control of temperature. Based on this, this paper uses the simulated and measured hourly energy/heat consumption of the air-conditioning system on a typical 24-hour day in summer to illustrate the feasibility of the control strategy for reducing the energy consumption of the air-conditioning system. In the use of mathematical models to solve practical problems, the use of numerical solution tools can effectively solve complex real-world problems. In this paper, the simulation tool MATLAB/Simulink is used to build a simulation platform to study the control strategy and operational performance of the air conditioning system. Figure 5 shows the results of the comparison between the hour-by-hour energy consumption simulation values and the measured values, in which Fig. 5(a)~(b) shows the cooling and heat consumption of the air-conditioning system, respectively.

As can be seen from the figure, the relative errors of the hourly cooling and heating energy consumption of the simulated air conditioning system and the actual air conditioning system within 0:00-23:00 on a typical day in summer are all within 10%, and the maximum values of the relative errors of the hourly cooling and heating energy consumption are 9.52% and 8.63%, which indicates that the air conditioning control system designed in this paper can effectively reflect the changes in its energy consumption and has good data collection accuracy for air conditioning energy consumption. At the same time, the model accuracy is further calibrated according to the model energy consumption calibration mean deviation (MBE) index and the coefficient of variation of root mean square error (CV(RMSE)P) proposed in the ASHRAE guideline specification. The MBE of the air-conditioning system's cooling and heating consumption were obtained to be 3.48% and -3.71, respectively, which satisfy the range of ±10% specified in the specification. The CV(RMSE)P of the air-conditioning cooling and heating consumption are 4.37% and 4.89% respectively, which also satisfy the range of <20% specified in the specification. Therefore, through the calibration, it can be proved that the control system has a high accuracy, can truly reflect the energy consumption changes in the air conditioning operation process, and provide a reliable data base for the intelligent control of air conditioning system.




(a) The cooling amount of the air-conditioning system




(b) The heat consumption of the air-conditioning system

**Fig. 5.** Time-by-time energy consumption simulation value and measured value

### *4.2. Air-conditioning control for supply-demand interaction*

4.2.1. Human Thermal Comfort. In order to realize the real-time monitoring of the air temperature and air supply speed around the human body, the temperature and speed monitoring points are set on the surface of each part of the human body, and the real-time change of the monitoring value of each point can be observed through the monitor, and the calculation report of each monitoring point and the calculation report of the average value are created in order to obtain the accurate value of the simulation results. Based on the above human thermal comfort evaluation method, the overall human thermal comfort deviation and the total power of the air conditioning system are calculated under different air supply temperatures and air supply speeds at the air conditioning air supply outlets. Figure 6 shows the variation curve of the overall thermal comfort deviation.

As can be seen from the figure, in the simulation set air supply temperature range, the overall thermal comfort deviation of the human body with the increase in air supply temperature increases first and then decreases, in a certain condition peak, different air supply speed corresponding curve to reach the peak corresponding to the air supply temperature is different, the size of the peak also shows a certain pattern of change, the larger the air supply speed, the corresponding curve of the peak slightly increased, the overall thermal comfort deviation of the human body to reach the peak of the corresponding to the air supply temperature is higher. The larger the air supply speed, the slightly larger the peak value of the corresponding curve, and the higher the air supply temperature when the overall thermal comfort deviation reaches the peak value. The overall thermal comfort deviation obtained from the simulation is always between -0.3 and 0.05, which means that the human body is always outside the thermal comfort zone. When the air supply speed is 4.5 m/s and the air supply temperature is 22°C, the maximum value of the overall thermal comfort deviation in all the simulation results is -0.074. When the air supply temperature is higher (19~25°C), since the indoor temperature and the air temperature around the human body can not reach the requirement of human thermal comfort, the heat dissipation around the human body can be accelerated by increasing the air supply speed, so that the human body's thermal comfort can be improved. Improvement. When the air supply temperature is low (11 ~ 18 ℃), too high air supply speed will lead to the human body surface temperature is too low, the air flow rate is too high, so lower air supply speed of the human body thermal comfort is better. When the air supply temperature is too small (<15 ℃), the air supply speed is unchanged, the overall thermal comfort deviation with the reduction of air supply temperature has a slightly increasing trend, by the human body thermal comfort evaluation index theoretical analysis, the human body head, torso and other parts of the local thermal comfort of the human body, such as a few parts of the overall thermal comfort of the human body has a greater weight, while the hands, feet and other parts of the limbs of the local thermal comfort of the impact of the weight is smaller. Due to the traditional air conditioning system air supply form mainly for the influence of the weight of the larger parts, and too low air conditioning air supply temperature can lead to the overall indoor ambient temperature is low, improve the human body extremities parts of the thermal comfort, so the overall thermal comfort of the human body with the reduction of the air supply temperature on the contrary, the phenomenon of improvement.

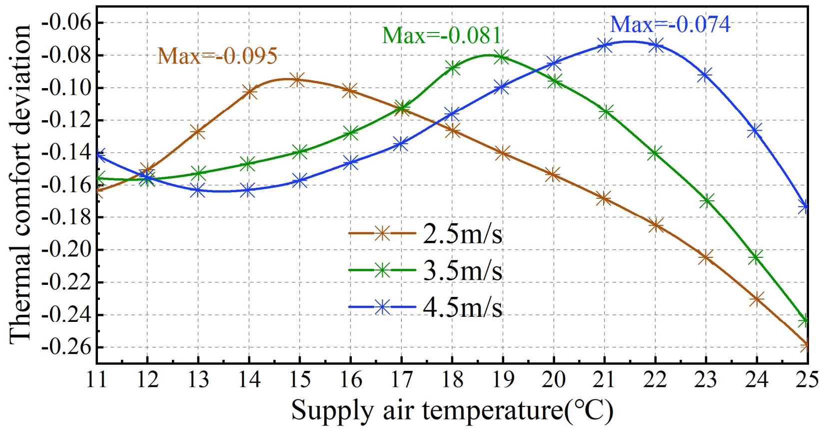



**Fig. 6. Thermal comfort deviation curve**

Figure 7 shows the variation curve of the total power of the air-conditioning system. For the air-conditioning control system, the size of the total power of the air-conditioning system shows monotonous variation with both the air supply temperature and the air supply speed. When the air supply speed is constant, the total power decreases with the increase of air supply temperature, and when the air supply temperature is constant, the total power increases with the increase of air supply speed. If thermal comfort is not considered, the air conditioning can be made more economical by reducing the air supply speed while keeping the air supply temperature constant, or increasing the air supply temperature while keeping the air supply speed constant.

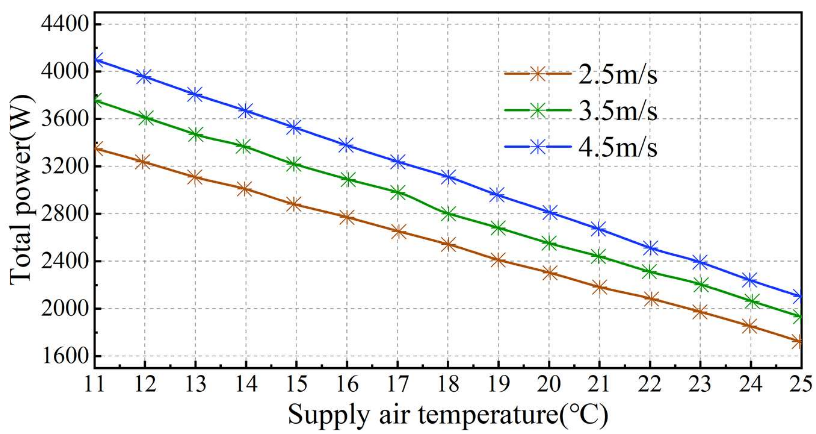
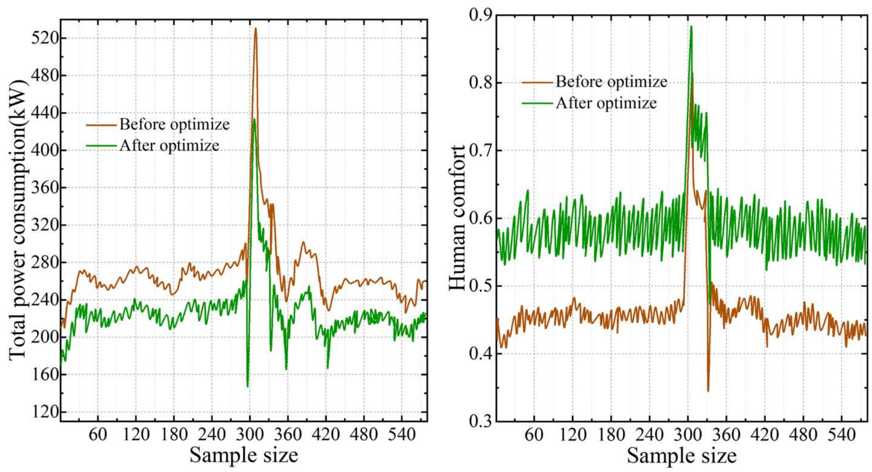



**Fig. 7.** The total power curve of the air conditioner

4.2.2. Model optimization results. Based on the consideration of the interaction between supply and demand of the power grid, this paper establishes a multi-objective optimization model from the human comfort and energy saving of the power grid. For the model, this paper applies the PSO algorithm to solve it. Numerical optimization experiments are carried out using the data from 8 a.m. to 18 p.m. on a typical summer day in a neighborhood as an example. The comparison results of grid power consumption and human comfort before and after optimization are shown in Fig. 8, where Fig. 8(a)~(b) shows the changes of total grid power consumption and human comfort, respectively.

From the figure, it can be seen that the total power consumption of the grid can be up to 528.71kW before optimization, and in the optimal control model considering human comfort and the interaction between supply and demand of the grid, its total power consumption of the grid is up to 438.53kW, which is reduced by 17.06% compared with that of the pre-optimization. In addition, from the results of human comfort evaluation, the maximum value of human comfort evaluation before and after optimization differs by 11.39%. The introduction of the optimization control model designed in this paper makes the energy consumption of the air-conditioning equipment significantly lower than that before optimization, and the human comfort is significantly improved, so the optimization effect is obvious. Therefore, the optimization control model designed in this paper can achieve the maximum degree of optimization control based on the consideration of human comfort and the interaction between supply and demand of the power grid to better ensure the energy consumption of air conditioning as well as the stability of the power grid.




(a) Total power consumption (b) Human comfort

**Fig. 8.** Model optimization results

### *4.3. Testing of air-conditioning control systems*

4.3.1. Testing of air-conditioning controls. Comprehensive analysis of the above shows that the air conditioning equipment control algorithm designed in this paper has strong temperature adaptive control capability, and can also carry out optimized control on the basis of both human comfort and grid energy saving. Applied to the intelligent air conditioning measurement and control system constructed in the previous section, it can significantly enhance the control level of air conditioning equipment. In this section, in order to verify the effectiveness of the intelligent air conditioning measurement and control system designed in the previous section, the air conditioning intelligent control test is carried out.

In the air conditioning control process, the success rate of receiving commands from air conditioning equipment is taken as the test index. For the air conditioning control commands, this paper mainly selects the commands such as high and low wind speed, up and down, left and right wind sweep, temperature increase and decrease, open and close, and wind speed automatic. Relying on the intelligent client to control the air conditioning, each instruction is tested to send and receive 60 times, and the number of times the instruction is successfully received is recorded. Table 1 shows the test results of intelligent air conditioning control success rate.

From the test results of the intelligent air conditioning control success rate, it can be seen that the air conditioning intelligent measurement and control system designed in this paper has a high success rate of air conditioning control, and can basically send the air conditioning control commands to the gateway to receive them accurately and without error within a short distance. Relying on this control system can achieve the goal of high accuracy of air conditioning control, basically able to meet the user's air conditioning control needs.

**Table 1.** Test results of the success rate of air conditioning control

| Instruction | Success | Test | Instruction | Success | Test |
|---|---|---|---|---|---|
| Low wind speed | 100.00% | 60 | Medium wind speed | 96.14% | 60 |
| High wind speed | 94.58% | 60 | Velocity speed | 100.00% | 60 |
| Up and down Windswept | 98.72% | 60 | Right and left Windswept | 99.06% | 60 |
| Temperature adds | 100.00% | 60 | Temperature reduces | 100.00% | 60 |
| Open | 100.00% | 60 | Close | 100.00% | 60 |

4.3.2. Changes in CO2 concentration. In order to verify the control effect of the intelligent air conditioning control system, it is now applied to the demonstration project of intelligent air conditioning fresh air system, through the analysis of the indoor air quality of the project, to verify the actual control effect of the intelligent air conditioning control system. Taking the air conditioning equipment of an office building as an example, the experiment time is the working time of a weekday, and the indoor office staff is relatively fixed. A total of four areas (A, B, C, D) were selected as the air conditioning control experimental area, and the indoor CO2 concentration in each area was 860 ppm, 840 ppm, 850 ppm and 830 ppm, with a set value of 820 ppm. The traditional air conditioning control system was selected as a comparison to validate the effect of air conditioning control in case of fluctuations in indoor CO2 concentration caused by changes in indoor personnel, by changing the indoor CO2 concentration, and by changing the indoor CO2 concentration. The air conditioning control effect is simulated by changing the set value of indoor CO2 concentration to simulate the dynamic process of indoor personnel change.

Figure 9 shows the CO2 concentration changes of different air conditioning control systems, where Figures 9(a)~(d) show the CO2 concentration changes of regions A, B, C, and D, respectively. Table 2 shows the mean value, mean deviation, and the maximum value of CO2 concentration in each region.

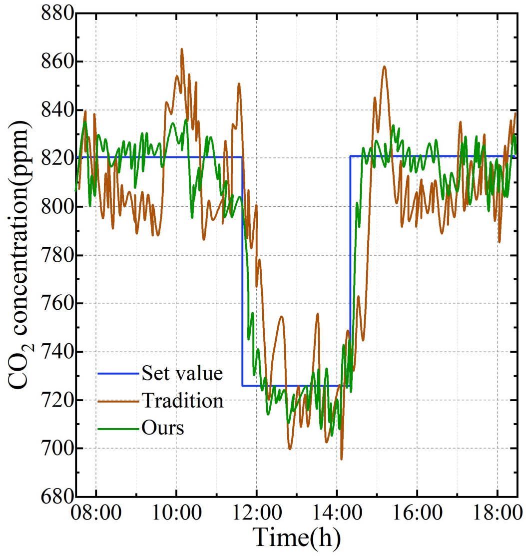
Combining the data distribution of the charts, the following conclusions are drawn:

1) The average values of CO2 concentration corresponding to the four regions of the two air conditioning control systems are similar, and the difference between the mean values of CO2 concentration in each region is about 6-8 ppm, and the maximum deviation is in region D. The difference between the average values of CO2 concentration of the two air conditioning control systems is 1.02%, which indicates that the two air conditioning control systems have the same control effect on indoor CO2 concentration.

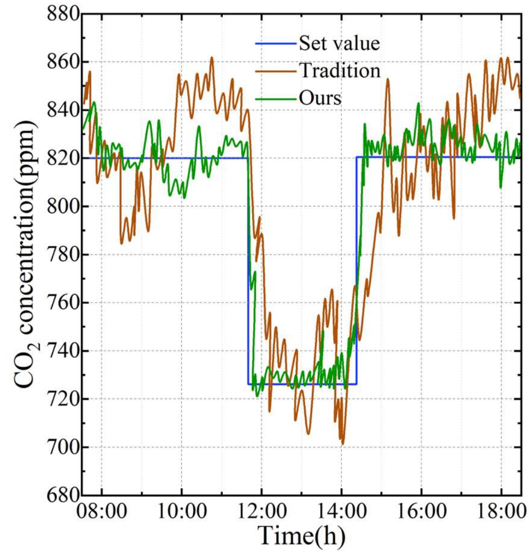
2) The maximum value of CO2 concentration in the four areas corresponding to the traditional air conditioning control system is higher than the method in this paper, and the maximum value is area A. The traditional system is 32 ppm higher than the system in this paper, and the relative set value is 44 ppm higher. the minimum value of CO2 concentration in the four areas corresponding to the traditional air conditioning control system is lower than the system in this paper, and the minimum value is area A, and the value is 18 ppm lower than the system in this paper. By comparison the minimum values of CO2 concentration corresponding to the two systems, it can be seen that the CO2 concentration corresponding to the conventional air conditioning control system deviates from the set value to a greater extent.

3) The mean values of the deviations of the CO2 concentrations in the four regions corresponding to the traditional air conditioning control system from their set values are higher than those of this paper's system, and the mean value of the deviations of the CO2 concentrations in region B corresponding to the traditional air conditioning control system is twice as high as that of this paper's system. This shows that the intelligent air conditioning control system designed in this paper has a better control effect, and the indoor CO2 concentration control effect is more stable.

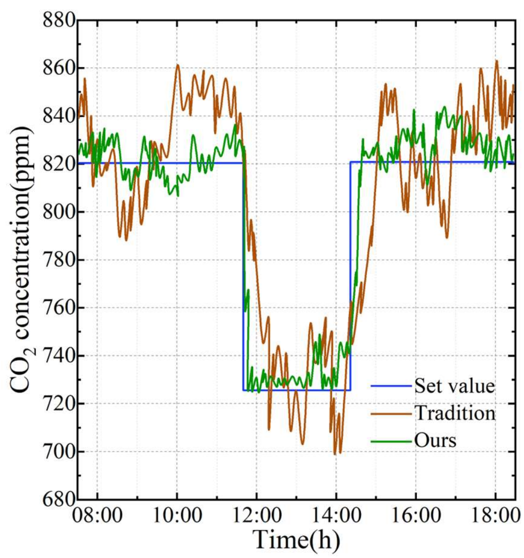
In summary, it can be seen that both methods can quickly make adjustments to meet the indoor air quality when the set value of indoor CO2 concentration changes, and both can maintain the indoor CO2 concentration at its set value. Among them, the control effect of the intelligent air conditioning control system designed in this paper is more stable.



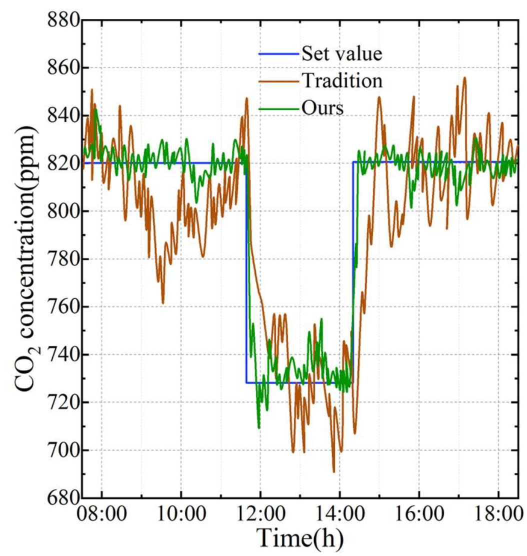

(a) Region A




(b) Region B




(c) Region C




(d) Region D

**Fig. 9.** Variation of CO2 concentration in each region

**Table 2.** Indoor CO2 concentration under different control system

| CO2 concentration | Region A | | Region B | |
|---|---|---|---|---|
| | Tradition | Ours | Tradition | Ours |
| Means/ppm | 792 | 786 | 795 | 788 |
| Max/ppm | 864 | 832 | 861 | 843 |
| Min/ppm | 682 | 709 | 699 | 721 |
| Deviation mean/ppm | 24 | 16 | 30 | 15 |
| CO2 concentration | Region C | | Region D | |
| | Tradition | Ours | Tradition | Ours |
| Means/ppm | 791 | 785 | 782 | 790 |
| Max/ppm | 862 | 841 | 857 | 842 |
| Min/ppm | 700 | 725 | 689 | 710 |
| Deviation mean/ppm | 23 | 12 | 24 | 14 |

## 5. Conclusion

This paper proposes an intelligent measurement and control system for air-conditioning equipment, introduces an expert PID algorithm to realize the adaptive regulation of air-conditioning temperature and humidity, establishes a comprehensive optimization control model based on the consideration of the interaction between the human body's thermal comfort and the power grid's supply and demand, and solves the problem through the PSO algorithm. For the effectiveness of the method in this paper, the validation analysis is carried out through simulation experiments. When the initial temperature is lower than the set value, the expert PID control strategy will reduce the introduction of fresh air and increase the primary return air to increase the temperature, the openings of the fresh air valve, the ground exhaust valve and the process exhaust valve are automatically adjusted from 19% to about 9.3%, and the fresh air volume is gradually reduced from $12.52m^3/s$ to $3.95m^3/s$, which can fully ensure the indoor temperature within a reasonable range. Based on the integrated optimization control model, the total power consumption of the grid is reduced by 17.06% compared with the pre-optimization period, and the maximum value of human comfort evaluation is improved by 11.39%. The mean value of CO2 concentration deviation in the corresponding area of the traditional air conditioning control system is twice as much as that of the system in this paper. In conclusion, relying on the real-time data collected from the air conditioning equipment, combined with the expert PID control algorithm and the comprehensive control optimization model, it is possible to meet the demand for human thermal comfort and reduce the total power consumption of the power grid on the basis of ensuring adaptive control of the air conditioning temperature, which provides a new research idea for energy-saving control of air conditioning.

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