Research on Energy Saving Method for IDC CRAC System based on Prediction of Temperature

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***Abstract*—Amid the information era, energy consumption of IDC Computer Room Air Conditioning (CRAC) system is becoming increasingly serious. Thus there is growing concern over energy saving and consumption reduction. Based on the analysis of the energy saving application of the air conditioning system in the present computer room, a new energy saving method of the IDC CRAC system, which presents energy saving decision based on the prediction of temperature, is proposed. Its principle is the collection of CPU utilization reflected the change of equipment working load, the temperature in hot spots and cold area. Then, to build a BP Neural Network model, taking the working load and the temperature in hot spots for the actual input, taking the temperature in a cold area for actual output. The BP Neural Network model can predict the temperature in hot spots of the next, when a set of real-time data into the model. Choosing a reasonable and effective decision-making scheme of the air conditioning system can realize energy saving control. Preliminary simulation results show, through the establishment of BP network model obtain approximation error of training samples and the prediction error of testing samples, both to highlight the advantages of the model. Finally, the distribution of temperature change about CRAC system whole day obtained by simulation shows that the proposed energy-saving method can reduce the energy consumption of IDC, fully embodies the effect of energy saving.**

***Keywords*—IDC; CRAC system; BP Neural Network Model; Forecast of temperature; Energy saving**

I. INTRODUCTION

With the rapid development of information technology and global business, the building and demand of the Internet data center (IDC) computer room are growing and the roll out of the high power density computer and server have raised new challenges on the air conditioning and refrigeration technology. The proportion of power and cooling costs is increasing in the investment of the IT industry, and IDC business boasts high energy consumption. Therefore, how to solve the reasonable running of the IDC CRAC system has become a problem that should be considered in the process of building and using IDC computer room.

A. Features of the Air Conditioning System

The IDC CRAC system mainly serves all types of computers, servers and other equipment which enjoys big Calorific value and high requirement of the humiture in the run, with the following characteristics: 1) with the big cooling load and the small wet load, the indoor air needs to keep humid while removed after heat in the room; 2) all-weather operation, equipment of the room run 24 hours a day. Even in Winters, heat release from the computer room to the outdoor is less than calorific value of equipment, so cool supply is still required [1]; 3) air supply modes of the air conditioning vary, which are mainly under-floor air supplying system and up-supply down-return mode;

In order to ensure normal reliable operation of computers, servers and other high-precision equipment, and the use of IDC room building process must strictly ensure the engine room temperature, humidity and other parameters to obtain precise control. The following provides domestic norms and standards.

TABLE I. DOMESTIC STANDARD "ELECTRONIC INFORMATION SYSTEM ROOM DESIGN SPECIFICATIONS" (GB50174-2008)

Project Level	Level A		Level B
	Summer	***Winter***	***Annual***
Temperature	23±2℃	20±2℃	18-28℃
Humidity	45-65%		40-70%
Temperature variation rate	<5℃/h And no condensation		<10℃/h And no condensation

Note: The environmental conditions refer to the parameters measured at a cold area or the inlet of the equipment, rather than the average parameter of the room or parameters of air conditioner return air.

Extensive use of air-conditioning equipment guarantees effectively the normal operation of equipment in the computer room, but it is the main equipment of power consumption. Therefore, striking a balance between environment-guarantee and energy consumption in the computer room should be taken as an important issue for energy saving work, especially

focusing on air conditioning energy saving [2]. Meanwhile, relevant statistics signify that: while running phases of 24 hours a day for the current IT equipment in the IDC computer room, it is running at a low load of work status some time and at a high load the other. Therefore, it is needed to know the specific working loads of computer room equipment in designing and the effective running time under different conditions.

B. The common energy saving technology of CRAC

Now commonly used energy-saving technologies in the computer room include natural cooling source in the computer room , air conditioning condensers and water cooling system, inverter technology, air-conditioning energy saving additives, CRAC units adaptive control technology, scientific air distribution in CRAC [3] . The natural cooling source uses the outdoor natural cold air to reduce the running duration of the CRAC cooling. Air conditioning condenser and the water-cooling system uses atomized water to realize its cleaning, heat dissipation, cooling and energy saving. Inverter technology adjusts the air conditioning unit operating parameters to save energy, based on the outdoor temperature changes [4]. Air conditioning energy saving additives may work well to prevent oil bubble, oil slick, oil corrosion and other problems caused by long running of the air conditioning. CRAC units adaptive control technology refers to air conditioning operating parameters are set from the manual setting to automatic setting by the computer supervisory control system [5]. Scientific air distribution in CRAC is mainly reflected in the air supply mode of the computer room and rationalizing of air distribution inside the cabinet.

II. Neural Network

A. Artificial Neuron model

Biological neurons are the basic units of the nervous system. It is made up of cell body, dendrite and axon. From the viewpoint of Biological Cybernetics, biological neurons can be used as the basic unit of control and information processing [6]. By abstracting process of biological neurons can be formed an artificial neuron model, shown in Fig.1.

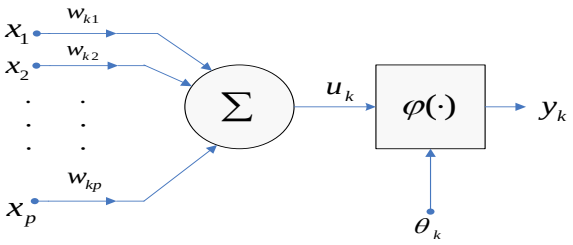

Fig. 1. Artificial Neuron Model

As shown in Figure 1 presents that the artificial neuron model consists of three basic elements, namely, the connection weights, summing unit and activation function. Among them, the connection weights $w_{k1}, w_{k2} \cdots w_{kp}$ corresponding to a biological neuron synapses, the connection strength between each neuron is represented by the weight of the connection weights. Weight values indicate activation of positive representation, inhibition of negative representation. Summing unit means for obtaining a weighted sum of input signals $x_1, x_2 \cdots x_p$. Activation function $\varphi(\cdot)$ plays the role of non-linear mapping, and limits the artificial neural output amplitude to a certain range, generally limited to between (0, 1) or (-1, 1). Activation function generally have several forms, such as a step function, piecewise linear function, Sigmoid type function. In addition, there is a threshold value. At the same time, the role of Figure 1 can be expressed mathematically, as in:

$$u_k = \sum_{j=1}^{p} w_{kj} x_j, y_k = \varphi(u_k - \theta_k) \quad (1)$$

B. Artificial Neural Networks ANN

Artificial neural networks ANN is composed of vast artificial neurons connected broad, which can be used to simulate the structure and function of the brain neural system. Artificial neural networks can be viewed as a directed graph, which use artificial neurons as node, connected by directed weighted arcs. In this directed graph, artificial neuron is a simulation of biological neurons, and the weighted arc is simulation of the axon - synapses - dendrites. The weight of directed arc can indicate the strength of interplay in two artificial neurons.

Artificial neural network is an information processing system consists of a large number of interconnected processing units, which have nonlinear, adaptive characteristics [7]. Artificial neural networks have four basic characteristics: 1) Non-linearity, nonlinearity relationship is a common feature of nature; 2) Non-limiting, a neural network is usually composed of a plurality of neurons connected together widely. Overall behavior of a system depends not only on features of a single neuron, but also on the interaction between the cells; 3) Non-qualitative, artificial neural network have adaptive, self-organizing, self-learning ability. The information processed by neural networks have a variety of changes, at the same time, nonlinear dynamical system are changing; 4) Non-convexity, the evolutionary direction of system under certain conditions will depend on a particular state function. In general, artificial neural network model need to consider the topological structure of the networks, the characteristic of neurons, and the learning rules. Depending on the connection method, artificial neural network can be divided into feed forward networks and feedback networks [8].

In the past ten years, the study of artificial neural networks is deeply, also has made considerable progress. Meanwhile, it has successfully resolved many practical problems which difficult to solve of the modern computer in pattern recognition, intelligent robot, automatic control, predictive estimate, and biological, medical, economic and other fields [9].

C. BP Neural Network

BP (Back Propagation) network has been proposed by D.E.Rumelhart and J.L.McClell in 1986, which use the error back-propagation training algorithm [10]. BP network is a multi-layer feed forward network with hidden layer, solves the learning problems of connection weights in the hidden units of

multi-network. The BP network structure has shown in Fig.2.

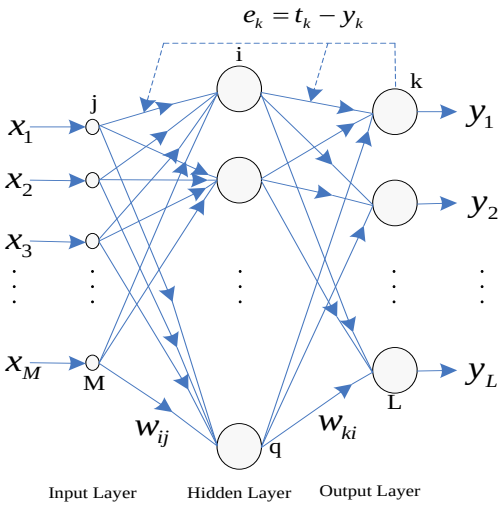

Fig. 2. BP Network Structure

An important feature of neural networks is the ability to acquire knowledge through to learn the environment and improve their performance. So, it can adjust its parameters by using different learning algorithm (such as weight). The basic principle of BP learning algorithm is the gradient steepest descent method; its central idea is that adjusting the weights to make the total error of network becomes a minimum. Also using a gradient search technique, the mean square error between actual output value and expected output value of network is minimized. Network learning is a process that error is spreading backwards while correcting weights.

Figure 2 shows that the network has M input nodes, L output nodes, there are q neurons in hidden layer. Among, x_1 , x_2 , x_3 ... x_M are the actual inputs, y_1 , y_2 ... y_L are the actual outputs, $t_k(k=1,2,...,L)$ are the target outputs, and $e_k(k=1,2,...,L)$ are the output errors.

III. Energy Conservation Design Idea

A. Overall Implementation Process

Based on the analysis of the energy saving application of the air conditioning system in the present computer room, a new energy saving method of the IDC CRAC system, which presents energy saving decision based on the prediction of temperature, is proposed. Design details: First, establishing an experimental test environment, under certain circumstances, is able to better reflect the effectiveness of the design. Second, to confirm the distribution division of the equipment working loads. As the design takes into account the temperature changes caused by different equipment working loads, so it is necessary to classify the device specific working conditions. Third, collecting multiple sets of data is analyzed by BP neural network, achieving the prediction of temperature in hot spots. Through the effective control of the CRAC parameters to achieve energy savings effect. Specific energy-efficient room air conditioning system control process shown in Fig.3.

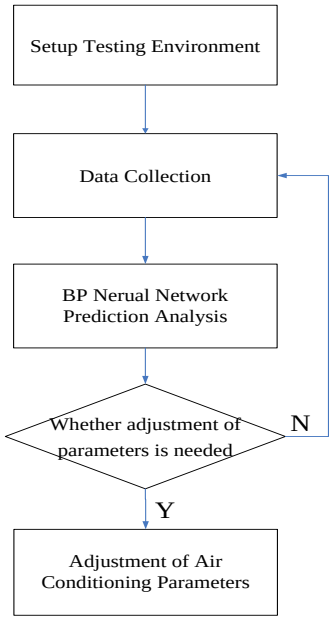

Fig. 3. The Control Process of energy saving in the CRAC system

B. Setup Testing Environment

There are all types of computers, servers and other equipment within the IDC room. Because of the reasonable use of resources, servers and other equipment are placed in a rack / cabinet [11]. Therefore, there are three type of cooling, namely, 1) the cold air enter into the server from the front of the rack / cabinet, the server waste heat discharged from the rear of the rack / cabinet; 2) the cold air enter into the server from the front of the rack / cabinet, the server exhaust heat discharged from the top of the rack / cabinet; 3) the cold air enter into the server from the front of the rack / cabinet, the server exhaust heat discharged from the back and top of rack / cabinet. In this paper, choose the first mode as shown in Fig.4.

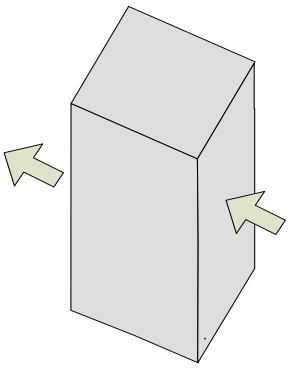

Fig. 4. Type of Cooling

According to the type of cooling, it can put the front area of the regional rack / cabinet known as cold area, the rear area of the regional rack / cabinet known as hot spots. IDC room by the use of the process required to meet the temperature, humidity and other parameters. This paper chooses the domestic standard "electronic information system room design specifications" (GB50174-2008). Control the temperature of cold area within the scope of the class B from 18 ℃ to 28 ℃, and the temperature of the hot spots were measured for

judgment basis to adjust the air conditioning outlet temperature. At the same time, combined with changes in operating conditions of the devices within the IDC room, analyzing the temperature changes caused by different working conditions.

C. The Experimental Data

1) Demarcation of Load

This design need to consider the different temperature variation in the hotspot arise from different conditions of equipment. So the interval division of working condition of equipment is necessary. Generally, heat dissipation of the computer system is mainly because of the electric energy loss, i.e., the electrical power consumption. Combined with the relationship between thermal energy and power distribution, the calculation formula of power consumption used is presented as in:

$$P=K\times C\times F\times VDD^2 \quad (2)$$

Wherein, P is the dynamic power consumption; K a coefficient; C the load capacitance; F the operating frequency and VDD the operating voltage. Thus it can be seen that power consumption of the circuit is mainly determined by such two variables that the operating frequency and the operating voltage [12]. At the same time, the CPU utilization can fully reflect the operational procedure of relevant equipment at some point in time. The paper takes the network video server for the study which is the special equipment for compression, storage and processing of video and audio data. For this type of server, its load is the task request of different video and audio data. When the load of equipment increase or decrease, its CPU utilization will increase or decrease correspondingly. Thus, the CPU utilization can represent working conditions of equipment with different loads. Taking the operating frequency F as the reference amount and the CPU utilization as the collected volume, the congruent relationship between the two can be analyzed so as to represent the different environmental impacts caused by different working conditions of equipment. The data collected are used to draw the corresponding curve through the SPSS statistical analysis software, taking F for normalization processing. The curve is smoothed to remove random fluctuations, which leads to the one shown in Fig.5.

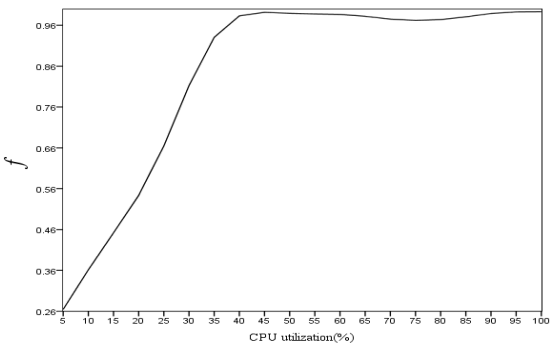

Fig. 5. Corresponding relationship curve between the CPU utilization and the operating frequency

It can be seen from the above curve that when the CPU utilization is in the range of less than 40%, a linear relationship between it and the operating frequency F will be presented, but equipment will work with the highest frequency when the utilization is over 40%. On this basis, working loads can be divided in intervals as shown in Table.2.

TABLE II. DEMARCATION INTERVALS OF LOAD

Working condition NO.	Percentage distribution of loads
1	0-10%
2	10-20%
3	20-30%
4	30-40%
5	40-60%
6	60-80%
7	80-100%

2) Data Collection and Analysis

In the IDC machine room test environment, the paper needs to collect multiple sets of experimental data. The basic constituent element of each set of data contains the hot zone multi-point temperature, cold area multi-point cold area, and equipment working loads. Among them, the data about cold zone multi-point temperature and equipment working loads collected for the current point in time. The corresponding hot zone multi-point temperature value indicates that the temperature collected in the next moment. Each set of test data combined in this form, therefore, the data elements could be used for the actual input in the BP neural network, which include the cold zone multi-point temperature and the equipment working loads. Also, the hot zone multi-point temperature could be used for the actual output in the BP neural network. Analyze the mapping relation between the input and the output, establishing a forecasting model.

In practice, the cold area temperature and the working load enter this model through real-time data collection, so it can get the predicted value of the hotspot temperatures. In order to adjust the temperature of CRAC, observing the predicted value to meet the requirements of the room temperature that completing the energy saving control of the air conditioning system. In summary, the specific data collection and analysis process shown in Fig.6.

IV. PRELIMINARY PRACTICES

A. Prediction of Temperature

1) Data Preparation

The simulation experiment can conduct preliminary practices to feasibility of the temperature forecasting and energy saving decisions. Taking the network video server as an example in practice, the sampling frequency is 30 minutes. To find the position of temperature measurement point in the hot and cold zones by determining the initial test time. Collecting multiple sets of data determine the definite value for actual input and actual output in BP neural network. The data form shown in Table.3. In the test data table, the former seven sets of data are used as training samples, and the later two sets of data are used as testing samples of the neural network.

2) Establish BP Neural Network

During the design of BP network, there are several aspects need to be considered ,such as the layer number of network,

the number of neurons in each layer of network , the activation function and learning rate, etc [13].

a) The Layer and The Number of Neurons of Network

In 1989, Robert Hecht-Nielson had proved that the mapping relation of any continuous function can be approximated by a BP network with a hidden layer. A BP network with s-type hidden layer and a linear output layer approach any continuous function with any closed interval.

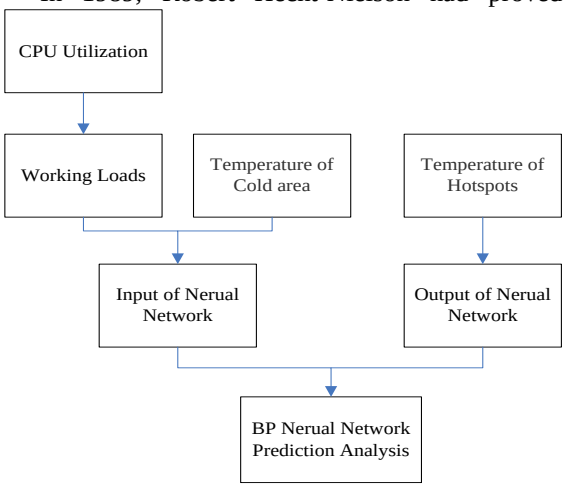

Fig. 6. Data Collection and Analysis

TABLE III. TEST DATA TABLE

Actual Input								**Actual Output**						
Working Load	**The Temperature of Cold Area(℃)**							**The Temperature of Hot Spots (℃)**						
x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y_1	y_2	y_3	y_4	y_5	y_6	y_7
1	21.3	21.5	20.3	20.4	20.9	21.0	20.7	22.0	22.4	21.8	21.4	21.0	21.1	21.9
2	22.0	21.8	20.7	20.9	21.3	21.5	21.1	23.1	22.8	22.5	22.1	22.0	21.7	22.6
3	24.1	23.9	22.1	21.8	23.3	23.0	22.7	25.0	25.2	24.6	24.7	24.0	23.8	24.8
4	24.4	24.7	23.3	23.4	23.7	24.0	23.6	25.8	26.1	25.4	25.1	24.7	25.0	25.3
5	25.6	25.7	24.0	24.4	24.7	25.3	25.0	27.2	27.6	26.8	26.9	26.4	26.7	27.0
6	26.0	25.9	24.8	25.0	25.3	25.6	25.4	30.4	30.1	29.4	29.1	28.8	28.4	29.7
7	27.8	27.5	25.7	25.4	26.3	26.0	25.8	32.5	32.4	31.8	31.4	31.3	30.8	32.0
4	24.6	25.0	23.7	23.2	24.0	24.4	23.9	25.6	26.0	25.3	25.4	25.0	24.8	25.5
6	26.1	26.3	25.0	24.7	25.4	25.6	25.2	30.2	30.5	29.2	29.6	28.7	28.4	29.8

So, a BP network with three-layer accomplishes the map from any n-dimensional space to m-dimensional space [14]. Therefore, increasing the number of hidden layer neurons improve the accuracy of the network.

We should know the number of neurons in input layer and output layer, according the complexity of specific issues.

In order to improve the accuracy of network training, it can use a hidden layer, increasing the number of neurons in the hidden layer, to achieve such design. In the specific design, the number of neurons in the hidden layer is ensured by empirical formula. General empirical formula used to determine the number of neurons in the hidden layer, as in:

$$n_1 = \sqrt{n+m} + a \quad (3)$$

$$n_1 = \log 2^n \quad (4)$$

Wherein, n_1 is the number of neurons in hidden layer, n is the number of neurons in input layer, m is the number of neurons in output layer, a is a constant between 1 and 10. By Table.3, during the design process, n have set for 8, m have set for 7. By using the equation 3, the paper have selected 5 for the initial number of neurons in the hidden layer, and then training the network to find the right number of neurons in the final.

b) The Learning of BP network

After determining the structure of BP network, it needs to learn and correct threshold value and weight value of the network, in order to realize the mapping relationship between the input and the output [15]. The main contents of this article are that to establish and implement the neural network forecasting model about temperature of the hot zone. Mainly, in the simulation the paper have used the neural network toolbox offered by MATLAB software to program the model.

For the content of this paper, select the improved elastic gradient descent algorithm. In the elastic gradient descent algorithm, when occurs the oscillation of the training, the variation of the weight will reduce. After several iterations, the variation of the weight will increase when the weight change in one direction. A large number of practical applications proved that the elastic gradient descent algorithm is very effective. In MATLAB neural network toolbox, the training function of elastic gradient descent algorithm is the Function trainrp.

3) Analysis

During the network training, in order to ensure the data for the same order of magnitude, firstly, it have pretreated the data of input and output in the neural network. So it can speed up the training of the network. The transfer function established in the neural network model is based on the S-type function, its input range as [0, 1] is best [16]. Therefore, the algorithms used in the paper should take the data normalized to [0, 1].Suppose $X_{\max}$ is the maximum value of the original data elements in the same column of the table, $X_{\min}$ is the minimum value, X and X_i are the normalized data before and after, and the normalization function , as in:

$$X_i = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \quad (5)$$

In summary, there is a BP neural network model that could predict the temperature of hot zone in IDC room. Using the MATLAB software conducted the simulation experiments of the design. BP network training effect can be obtained by simulation, as shown in Fig.7.

Through several simulation experiments, to compare multiple sets of training data, this study found that for the purpose of BP network needs to have a S-type hidden layer and a linear output layer, the hidden layer contains five neurons, the linear output layer contains seven neurons. Meanwhile, the training function of network is trainrp. After the completion of training for the network, we need to model the training samples approximation error, as shown in Fig.8. In order to test the effect of the model, using the test samples in the table to test the model that calculate the prediction error of the output, as shown in Fig.9.

As shown in Figure 8 and Figure 9, seven groups approximation error value of training samples can be kept at 0.2 or less, and even 5-set error values below 0.1, indicating that BP network model better reflects the direct relationship between input and output . Meanwhile, two groups prediction error value of test sample can be kept between 0.1235 and 0.1240.

Through the establishment, training and testing of the above-mentioned BP network model, when there are sets of data of equipment working load and sets of data of cold zone temperature as input data into the model that can predict the temperature of hot spots in next time. The next time improve energy conservation control of CRAC systems.

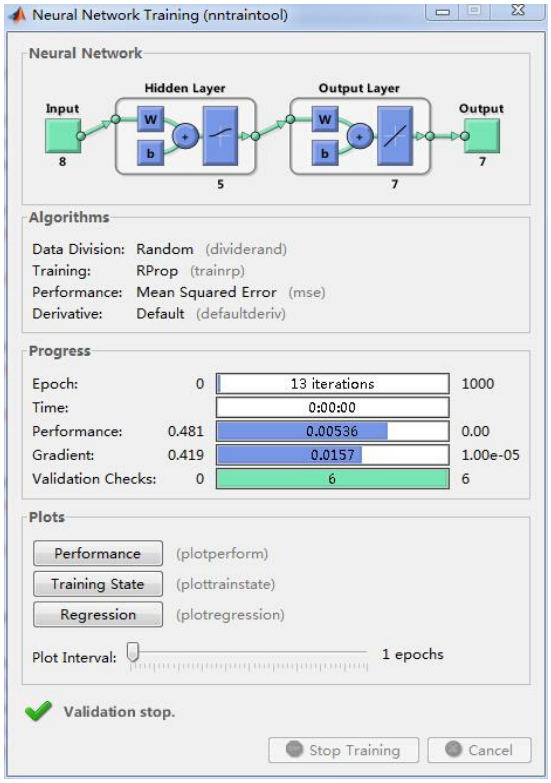

Fig. 7. Training effect of BP network

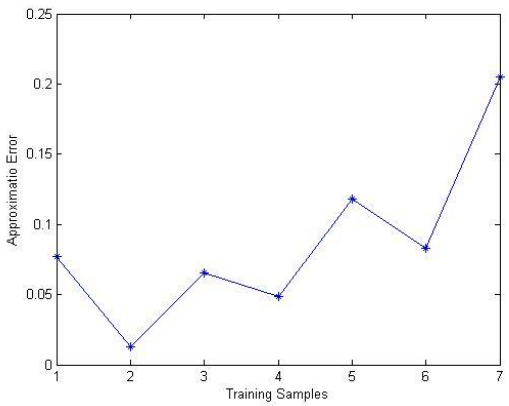

Fig. 8. Approximation Error of Training Samples

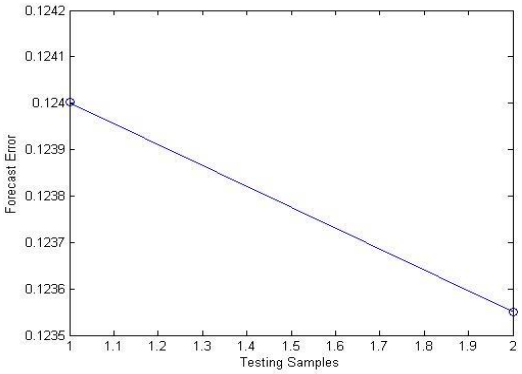

Fig. 9. Forecast Error of Testing Samples

B. Energy Saving

In order to reflect the energy saving of paper design, this article assumed two cases: 1 .Throughout the day, to keep the air temperature of CRAC unchanged at 20 ℃; 2. Combining the BP network model, the output data of the temperature of hot spots predicted by the model adjust the air temperature of CRAC.

According to the domestic selection criteria GB50174-2008, firstly, the air temperature of CRAC was adjusted to 28 ℃, and then collected the data of working load and cold zone temperature to predict hot spots temperature in next time, finally achieve energy efficiency goals. By means of software, it can map out the changes in air temperature throughout the day, as shown in Fig.10.

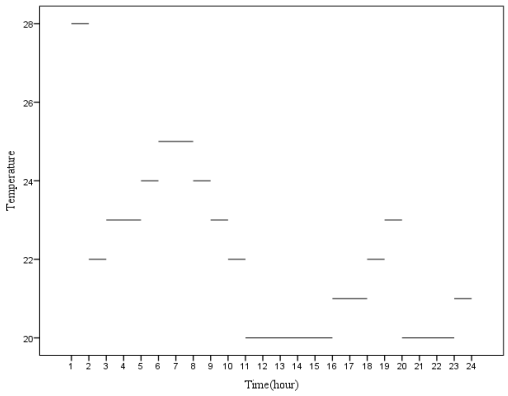

Fig. 10. Temperature of CRAC System

From Figure 10, the air temperature is constantly changing. Combining different energy consumption caused by different air conditioning temperature, to some extent, the design scheme proposed in this paper can reduce the energy consumption of the cost of IDC.

V. CONCLUSION

The energy consumption of the IDC CARAC system accounts for a large proportion in that of the computer room, so it is needed to reconstruct energy saving of the CRAC system. From the perspective of service objects of the air conditioning system, temperature changes are primarily caused by the all-day changing working conditions of computer room equipment. Understanding and grasp to the running status of equipment can produce a more effective energy saving method to achieve the goal by adjusting air conditioning operating parameters.

In this paper, CPU utilization for the reference data to represent the working conditions of the equipment, while collecting multiple sets of real-time temperature of hot and cold zones. The equipment working load and the cold zone temperature act as the actual input and the hot zone temperature act as the actual output establish a BP network model. Through a set of real-time input data, it predicted the temperature of the hot zone the next time that as a data basis to adjust air temperature of CRAC systems. Feasibility of the research method proposed is analyzed by simulated experiment and results show that the BP network model can well determine the mapping relationship between input and output. Also, the value of approximation error and prediction error are able to show that the design proposed method has achieved the purpose of the experiment better.

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