Research on Energy Control System of Office Building Based on the BIM and BP Neural Network Technology

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Abstract. As the proportion of building energy consumption in the total energy consumption continues to increase, more and more countries pay attention to the prediction analysis and operation control of building energy consumption. In this paper, an office building energy management and control system based on the building information modeling (BIM) and back-propagation neural network (BPNN) technology is proposed. Firstly, the BPNN algorithm is used to predict the energy consumption of the building, and then the model predictive control (MPC) method is employed to search the optimal control parameters to realize the energy saving of air-conditioning system and other equipment. In addition, the office building environment model is established through the BIM technology, which can real-time display the operating conditions of equipment and more visually control the equipment in the office building. The experimental results show that the system can satisfy the comfort level and significantly reduce the energy consumption.

1. Introduction
With the acceleration of urbanization and the improvement of people's living quality, the proportion of building energy consumption in China has risen to 40%. To fully dig the influence factors of public building energy consumption and establish the corresponding forecast model is beneficial to comprehensively analyze and evaluate the current situation and development changes, and provide effective basis for the implementation of public building energy saving renovation plan. In this paper, the building information modeling (BIM) and back-propagation neural network (BPNN) technology based office building energy control system is proposed. Under the condition of satisfying personnel comfort, this system can guide the construction equipment operation into the energy-saving optimization mode and obtain the actual building operation process data information. Combined with BIM model to display real-time operating conditions of equipment and other equipment, the equipment in office buildings can be more visually controlled.
2. Establishment of the BIM model

2.1. Introduction to BIM Technology
BIM is a data model for 3D digital description of building entities and functional characteristics. The data, process and resources in different stages of the whole life cycle of a building can be combined to realize the simulation, analysis and prediction of the building environment, equipment operation and maintenance, energy consumption and other aspects [1]. BIM is characterized by simulation, visualization, coordination and other functions [2].

In this paper, BIM technology is applied in the operation and maintenance stage of buildings, which is deeply integrated with the intelligent energy management and control system of office buildings to realize the precise positioning of electromechanical equipment in buildings, display the running status of equipment in real time, and provide accurate navigation for the work of maintenance personnel.

2.2. Establishment of BIM model
In this paper, the Revit series of software developed by the AutoCAD company is used for modeling research [3]. Through radio frequency identification (RFID) and other technologies, all the equipment in the building will be collected on the BIM platform for control. On the one hand, the operation status of the device is understood; on the other hand, remote control is carried out [4].

The component ID is unique during the construction of BIM model, and the RFID tag recorded by the equipment is also unique when the collection equipment is input into the database. Based on this feature, the two are forcibly bound one-to-one, so that the component ID of the model can be found out by querying the RFID tag of the device, and then fast roaming and positioning can be achieved. In addition, we can click the model component in the model page to view the data information of the corresponding collection device and issue the optimization control instruction with the collection information [5]. The association relationship between the BIM model and electromechanical equipment is shown in figure 1.

![BIM model and electromechanical equipment correlation diagram.](image)

3. The overall architecture of the system
This paper mainly studies the energy prediction and control of office buildings. The overall architecture of the system is shown in figure 2, which mainly includes the device layer, network transmission layer and application layer. All kinds of data in the device layer are firstly connected to the reading and writing devices through the RFID antenna, and then transmitted to the location database and security information database in the application layer through the network layer through RS-485 and Modbus. The client side views the BIM and location information fusion database through the information integration platform of the intelligent management system. It is more convenient for the users to understand the environmental data information and the real-time running state of the equipment. The system can also predict and control terminal equipment according to the BPNN algorithm to realize energy saving optimization [6~8].
4. Model predictive control based on the BPNN

4.1. Neural network prediction model of building energy consumption

In this paper, a multi-layer BP network is utilized to simulate the building energy consumption. According to the investigation and analysis, there are many variable factors affecting the energy consumption of public buildings, such as indoor and outdoor environmental factors and people's activities, which all have a certain impact on the energy consumption of public buildings. If various factors are taken into account when determining the structure of the prediction model, the system will be too complex and huge, the network learning time will be too long, and it is easy to fall into the local minimum. Therefore, only the main influencing factors such as temperature and humidity, light intensity and power consumption are considered in this paper. The classical BP learning algorithm is mainly divided into the input layer, the hidden layer and the output layer. The gradient descent method is adopted to determine the initial weight and the hidden layer function. The input parameters can be calculated by the hidden layer to get the output value, and then the weight of the network needs to be adjusted until the training goal is reached. The working flow chart of the neural network is shown in figure 3.

4.2. Optimal control

Based on the established BIM model, this paper analyzes the influencing factors of energy consumption of one office, observes the energy consumption of the office through energy consumption simulation analysis, and selects the optimal system operation scheme. The design of this scheme mainly analyze building energy consumption according to the changes of indoor and outdoor factors, equipment running time and other aspects of the various systems, and obtain the optimal building operation strategy to achieve both energy saving and high comfort.

Since BPNN modeling can approach arbitrary nonlinear functions with high accuracy, it is not necessary to have a deep understanding of the internal mechanism of the controlled object, and only the input, output and hidden layer parameters are needed to determine. Therefore, BPNN is applied to
model predictive control (MPC), which is a closed-loop optimal control strategy based on model including three elements: predictive model, rolling optimization and feedback control. The control flow of a classic MPC is shown in figure 4. Where $y_{sp}$ represents the set output of the system, $y_r$ represents the reference trajectory, $u$ represents the input, $y$ represents the actual output, $y_m$ represents the model output, and $y_c$ represents the predicted output.

![Figure 3. Flow chart of the BPNN.](image)

![Figure 4. The control flow chart of the MPC.](image)

The MPC optimization algorithm has strong robustness, relatively less computation, high precision, and achieves the control goal of low energy consumption and high comfort. The low energy
consumption control mode that meets the requirements of building operation energy saving and personnel comfort has been realized, and the operation process information of the actual building has been obtained. Combined with the BIM model, the real-time operation status of equipment and other equipment has been displayed, so as to control the equipment in the office building more visually [9].

5. Simulation Experiments

5.1. BIM simulation design and energy consumption simulation of office building
In this paper, the first floor area of an office building is taken as the simulation experiment object, and it is drawn according to the basic building drawing information. In the BIM model, the running state and energy consumption of the equipment can be checked in real time. The BIM model establishment process and rendering effect of the office building are shown as follows:

![BIM model of the office building.](image)

Air conditioning system plays a decisive role in the energy consumption of office buildings, accounting for about 40%. Therefore, in the energy consumption simulation analysis, this paper takes the air conditioning system as an example to obtain the reference value of energy consumption analysis of the air conditioning system (negative number represents the cooling load, positive number represents the heat load) and the monthly cumulative reference value of energy consumption, as shown in figure 6 and 7 below.

![Figure 6. Reference value of energy consumption analysis of air conditioning system.](image)

![Figure 7. Monthly accumulative reference value of energy consumption.](image)
5.2. Matlab platform design program for simulation, and analysis of the results

(1) The energy consumption value was predicted according to the historical data. The illumination, indoor temperature and the number of people in the office were taken as the input, and the actual indoor average temperature was taken as the output. 5000 sets of data were used for training and 1000 sets of data were selected for verification.

(2) Set neural network parameters: the training times of the network epochs were set as 100 times, the accuracy goal of training was set as 1E-3, the learning rate LR was set as 0.05, and other attributes were set as default values.

(3) It was necessary to normalize the forecast data, then output the predictive results, and reverse normalize the output results.

(4) Result analysis showed that the network reached the optimal state through 515 times of repeated learning training, and the accuracy value was 9.78e-08, and the training was completed. The process of error decline is shown in figure 8, which represents the decrease of mean square error (MSE) with the number of training times. The distribution results of residual normal test are shown in figure 9. The distribution of test results showed that the data had a high coincidence degree.

Taking the operation of air conditioning system as an example, indoor temperature control effect diagrams in summer and winter are shown in figure 10 and figure 11 respectively. The horizontal axis denotes the simulated time step, that is, one step is equal to one minute; the vertical axis is the temperature value, the unit is °C. The optimized control system runs from 8 a.m. to 7 p.m. It can be seen from the two figures that, under the optimized control mode, the indoor temperature is basically kept at the appropriate temperature in the daytime, and the indoor temperature control effect is better. After work, the air conditioning system stops operating and the indoor temperature gradually drops. Comparison of monthly power consumption before and after system optimization control is depicted in figure 12. According to the comparative results, it can be concluded that, after optimized control, the energy consumption is significantly reduced and the requirements are met.
6. Conclusion
The influencing factors of building energy consumption are very complex, that are difficult to be fully reflected in a model. Therefore, the BPNN prediction model established in this paper only considers the inherent characteristics of buildings. While the effects of regional differences, climate differences and different building types on building energy consumption are not considered. To sum up, in order to conduct in-depth research and analysis on office building energy consumption, it is necessary to accumulate more and more comprehensive data resources as the research basis. In the near future, with the continuous accumulation of company data, the model can be continuously improved and trained to improve the accuracy and robustness of the model, so as to provide better reference for the improvement of the energy efficiency of office buildings.

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