Study On The Application Of BP Neural Network In The Prediction Of Office Building Energy Consumption

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Abstract. Energy consumption is a big problem that cannot be ignored in the development of the world. Energy consumption of buildings accounts for a large proportion of the total energy consumption. With the development of economy and the improvement of modernization, China's construction industry is in a stage of rapid development. Therefore, under the strong advocacy of China's energy conservation and emission reduction policy and sustainable development strategy, the construction industry must also follow this trend. In the future development, it is inevitable to integrate the environmental protection concept including economy, energy conservation and environmental protection. However, the energy-saving technology on buildings in China lags behind compared with developed countries, so based on the pattern of energy consumption on buildings in China, this paper proposes an application scheme of energy consumption prediction of an office building in South China by using BP neural network, in order to produce an available research direction for the prediction of energy consumption of office buildings, and promote it to other types of buildings, and provide relevant data support for building design. It will reduce the investigation cost of building energy consumption and be able to offer some reference for the relevant standards of controlling building energy consumption.

1. Introduction

The construction industry is in a stage of rapid rise. At the same time, due to population growth, rapid urbanization and social needs, the energy consumption required for services such as lighting, heating, cooling and ventilation in buildings is increasing significantly. According to the analysis of the report, the total operating energy consumption of Chinese buildings in 2017 reached 760 million tce, accounting for 20% of the total energy consumption of the whole society [1]. The situation is the same abroad. For example, in the United States and Europe, the construction industry accounts for 39% and 40% of energy consumption, and 38% and 36% of carbon dioxide emissions, respectively [2]. Reducing building energy consumption is the only way for strategy of sustainable development. However, there are problems in different aspects in the current status of building energy conservation in China. For example, the awareness in energy-saving of building is weak, the building design is unscientific, and the management for energy-saving construction is not standardized, etc. [3]. The technology in predicting building energy consumption is key to improve the energy consumption. It can effectively provide data support during building design and construction, evaluate and optimize design and construction plans, and achieve the purpose of reducing building energy consumption. As
one of the typical public buildings, office buildings can be used as an effective breakthrough in the research of prediction in building energy consumption.

2. Research Status at Home and Abroad

2.1. Research status abroad

In 2015, Nelson Fumo and MA Rafe Biswas used multiple linear regression analysis and quadratic regression analysis to establish models to study the relationship between factors such as time, outdoor dry bulb temperature and solar radiation, and energy consumption of residential buildings. The model is used to predict the TxAIRE research and demonstration house. The results show that the statistical model is a cost-effective method that can reasonably and accurately predict residential energy consumption [4].

In 2017, Subodh Paudel and Mohamed Elmitrib used the algorithm of artificial intelligence based on the support vector machine model while referring to the French residential low-energy building standards (energy consumption, climate data, occupancy and operating conditions). Two modeling methods, "all data" and "relevant data", constructed a prediction model in energy consumption of residential LEB heating. At last they found that compared with the "all data" modeling method ($R^2 = 0.93$, $RMSE = 7.1$), "The "relevant data" modeling method has higher accuracy ($R^2 = 0.98$, $RMSE = 3.4$), and the error is within the acceptable range [5].

The artificial neural network algorithm is used to predict the energy consumption of New Zealand office buildings. The results show that the MLR model with simple input variables can estimate energy consumption within an acceptable error range, which can improve the stability and sustainability of energy consumption in buildings, and the assumptions that form the basis of this study can also be applied to other similar energy management projects [6].

In 2018, Deb Chirag et al. used two models of multiple linear regression and artificial neural network to input 14 variables and iterate 819,150 times to predict the energy consumption of the HVAC system in office buildings with an error of 14.8% [7].

In 2020, a prediction model based on random forest (RF) was proposed. The conclusion shows that in the machine learning (ML) model, the proposed RF model is an available and effective prediction model, which shows good prediction accuracy and superiority to M5P and random tree (RT) model [8].

2.2. Formatting author names

In 2015, Yu Jin, Wang Zhiwei, Wang Cheng and others used DeST energy consumption simulation software to simulate the calculation of an office building in Shenyang to study the relationship between thickness of the insulation layer and energy consumption. Then they analyzed and optimized the model of insulation layer thickness, and got the best value [9].

In 2016, Li Minghai and Liu Min used an artificial fish swarm neural network prediction algorithm to perform a one-month prediction analysis of a university building in Xi’an. The results showed that the algorithm was fast and highly accurate, with an error range up to about 1% [10].

In 2018, Wang Yutong, Pan Yiqun and others proposed an algorithm based on gradient asymptotic regression tree for short-term prediction of building energy consumption. The results show that the algorithm can approximate the optimal solution in a wider range [11].

In 2020, Wang Ru, Song Shuang and others adopted the whale optimization algorithm improved by the complementary set empirical mode decomposition method to predict a large public building in Shanghai. The results show that the hybrid model has good results in energy consumption prediction[12].

In the high-precision and highly robust building energy consumption prediction model, due to the easy utility, practicality, adaptability and high prediction accuracy in the data-driven method, it has been popular in building energy consumption prediction[13]. In addition, data-driven methods are more practical than engineering methods because they provide accurate predictions based on available
data (energy consumption, climate, time, and occupancy), and these data are easily accessible from new buildings through new sensing and communication technologies.

3. Mathematical Principles

3.1. The mathematical representation of a single neuron
Mcculloch W.S and Pitts W. proposed the neuron M-P model in 1943 [14]. According to this model, we can mathematically express the structure of neurons, as shown in Figure 1.

As shown in Figure 1, the n input signals are weighted and summed and subtracted from the threshold \( b \) to obtain \( u_t \), and \( u_t \) passes through the transfer function \( f(\cdot) \) to obtain the output signal \( y \). \( x_i \) represents the state of the neuron (inhibition or activation) at the input at time t, \( \omega \) represents the strength of the connection between neurons, and \( b \) represents the activation threshold of the neuron [15].

3.2. Mathematical representation of BP neural network
This paper uses a feed-forward neural network, and its training error is back propagation, so it is called BP (Back-Propagation) neural network. Its structure is shown in Figure 2. Derived from the single neuron to the neural network, it can be seen that in the neural network, \( P_k \) is the number of hidden layer nodes of the \( k \)-th layer, \( k = 1, \ldots, l \).

The values before and after the \( k \)-th hidden layer node are:

\[
  u_j' = \sum_{i=1}^{\infty} \omega_{ij} + b_{kj}, \quad u_j = f_k(u_j'), \quad j=1,\ldots,p_k  \tag{1}
\]

The signals before and after the transfer function of the output layer are:

\[
  y_j' = \sum_{i=1}^{p_k} u_i u_{ij} + \omega_{ij}, \quad y_j = f_l(y_j'), \quad j=1,\ldots,p_l  \tag{2}
\]

Figure 2. Basic structure of BP neural network [15].
4. The Realization of Neural Network Model

4.1. Influencing factors of energy consumption in office buildings
With reference to literature [16-19] and the actual situation, 16 input parameters were selected, namely outdoor wind speed, relative humidity, heat transfer coefficient of building exterior wall, heat transfer coefficient of building roof, and heat transfer coefficient of building exterior windows, building window-to-wall area ratio, building shading coefficient, conference room personnel heat disturbance density, office personnel heat disturbance density, aisle personnel heat disturbance density, conference room lighting heat disturbance density, office lighting heat disturbance density, aisle lighting heat disturbance density, thermal disturbance intensity of conference room equipment, thermal disturbance intensity of office equipment, thermal disturbance intensity of other equipment, the output parameter is building energy consumption.

4.2. Data Collection
Field investigations have obtained the architectural parameters of 10 office buildings in a southern city, as shown in Table 1.

4.3. Establishment of Neural Network
Create a workspace in MATLAB 2020a and use the xlsread () function to read the data in the Excel table.
Normalizing data is a commonly used data processing method before using neural networks to make predictions. Now, in order to avoid the large error caused by the magnitude difference between the data of each dimension, the data is converted into numbers between [0,1]. After that, use the fitnet () function to create a neural network with 5 hidden layers.

4.4. Establishment of Neural Network
The first 9 sets of data are used as the training group, and the 10th set is used as the prediction group. Use the train () function to train the neural network. After the training is complete, call the view () function to view the network structure, as shown in Figure 3.
According to the training process, the accuracy value obtained after repeated training of learning reaches 6.99e-12, indicating that the training works well.
4.5. Generalization of the neural network

Input the verification group data into the trained neural network, and use mapminmax() to denormalize the output and observe the results.

The generalization result is 90.75, actually 92.23, and the relative error is calculated to be 1.60%.

5. Comparison Analysis

Enter all 10 sets of data into the network for prediction, and obtain the curve of the prediction result and actual data, as shown in Figure 5. The error histogram is shown in Figure 6. The decline of the mean square error (MSE) with the number of training is shown in Figure 7. The results of residual regression analysis are shown in Figure 8. The above results indicate that the fitting error of the neural network is very small, and the predicted data is very close to the actual data.
6. Tables
The current process of selecting variables to build predictive models is based on human experience or the development of regression models, so it is generally considered to be the most difficult part of the model building process. In the forecasting process of this paper, 16 parameters are selected as input, but there are still some influencing factors that are not taken into account for the complex work of energy consumption forecasting. At the same time, the sensitivity and confidentiality of energy audit data also hinders the correlation between the building under study and energy consumption data, and affects the accuracy of the forecast.

The advantage of the prediction model proposed in this paper is that the error is small, and it is relatively easy to implement with the help of MATLAB 2020a's deep learning toolbox. The model is trained based on the data of 10 groups of office buildings, but the idea of establishing the model in this article is somewhat extensible. It can be applied to other types of building energy consumption prediction work after modification, which provides a referential direction to building energy consumption prediction.

7. Conclusion
Building energy consumption prediction technology is the key to improve building energy consumption. With the help of MATLAB's deep learning toolbox and the training and correction of actual cases, this paper establishes an office building energy consumption prediction model based on BP neural network and proposes a complete application process. In the training process, the model has a good error convergence speed, the final accuracy value reaches 6.99e-12, and the prediction result of the model is in good agreement with the actual data. This result shows that the artificial neural network uses arbitrary functions to make the predicted output continue to approximate the expected output. The “learning” mechanism has strong potential in the application of computers. This data-driven non-traditional mathematical algorithm can solve many existing building problems in energy consumption prediction; at the same time, the feasibility of building energy consumption prediction is also theoretically verified, which provides a certain reference for the development of technology in building energy efficiency.

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