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A Novel Forecast Method for Air-Conditioning Load of Public Building Considering Accumulated Temperature Effect

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Abstract: It has great significance to estimate the schedulable capacity of air-conditioning load of public building for participating the power network regulation by forecasting the air-conditioning load accurately. A novel forecast method considering the accumulated temperature effect is proposed in this paper based on Elman neural network. Firstly, the starting and ending date for forecast considering the accumulated temperature effect are determined by providing the five day sliding average thermometer algorithm which is usually adopted in aerology research. Then, the effective accumulated temperature of each day is calculated. Finally, take the effective accumulated temperature, temperature and humidity into consideration, the air-conditioning load of public building in the forecast day is acquired by Elman neural network. Simulated results show that the higher forecast accuracy can be achieved by considering the accumulated temperature effect.

Keywords: Air-conditioning load, accumulated temperature effect, Elman neural network, five days moving average temperatures, forecast.

1. INTRODUCTION

With the increase of air-conditioning, the network load shot up in many large and medium-sized cities in China. Taking Nanjing city as an example, temperature of Nanjing continuously remained above in 37 ℃, air-conditioning load sustained increase. On July 29, the maximum of the network load reaches 8.174 million kilowatts, and break through 8 million kilowatts marks. Entering August, due to the rare extreme high temperature weather in the history, the temperatures of Nanjing continue above in 38℃ and air-conditioning load continue to rise. On August 15, the network load of Nanjing reached a new record that high of 8.347 million kilowatts, increased of 10.8% than the highest load of the last year, which mainly caused by the growth of air-conditioning load. Therefore, the accurate air-conditioning load prediction for the control of air conditioning schedulable capacity and the air-conditioning load scheduling has great significance.

2. THE ANALYSIS OF THE ACCUMULATED TEMPERATURE EFFECT

1.1. The accumulated temperature effect

Taking Nanjing as an example, severe heat wave and drought hit in the summer, the accumulated temperature effect plays very significant role in the growth of the air-conditioning load, in which the fundamental reason is that inertia of the human body comfort feeling. Continuous high temperature, even if the temperature has dropped, habitual people perceive as the hot weather; In the case of continuous cool, even if the temperature rise significantly, similar to the hot weather, hot weather is still in the adaptation process, air-conditioning load is still small. The following graphs show the relationship between the accumulated temperature effect and air conditioning load.

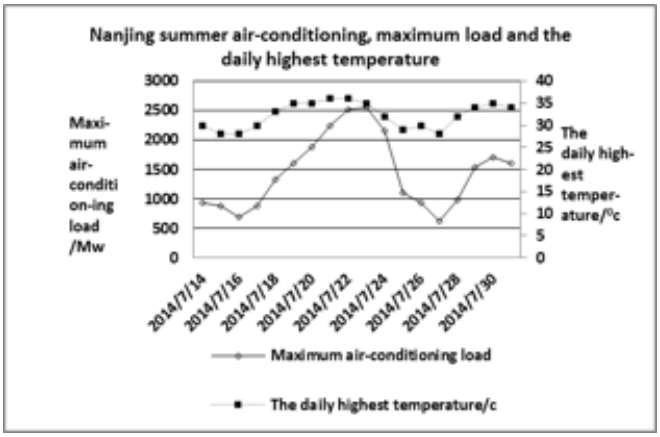

Fig. (1). The relationship between the maximum air-conditioning load and the maximum temperature of Nanjing typical day.

Fig. (**l**) shows the relationship between the maximum air-conditioning load and the maximum temperature of Nanjing typical day from July 14 to 30 of 2014. Air-conditioning is mainly used in summer to decrease temperature, and has the effect on rising temperature in winter. So the network load of April used as a baseline, and daily average load in July month minus the load of April daily to roughly calculate the air-conditioning maximum daily load in July.

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Fig. (**1**) shows that from July 17th to 24th consecutive eight days continues high temperature, and the daily maximum temperature are all above 30℃。From July 21th to 22th, at the highest and lowest temperatures are the same, rainfall, wind speed and wind direction, wind, humidity, air pressure and other meteorological factors under the condition of basic without changing, but average daily air-conditioning load is increased 273.726 MW, which caused by the accumulated temperature effect in the 22th. Accumulated temperature has an effect on the load, especially air-conditioning load, thus the accumulated temperature effect should be fully considered in the forecasting of air-conditioning load.

1.2. Quantitative analysis of accumulated temperature

In biology, accumulated temperature in climate is accumulated by the average temperature of boundary temperature in every day from the early to the end (including the early day and the end day). Active accumulated temperature is a normal plant development or all of the growing season which is higher than or equal to the biology of the average daily minimum temperature in the total value of the temperature. The effective temperature is that the difference between the temperature and the lowest temperature of biological activity, and the accumulated temperature is known as the effective accumulated temperature [1]. First of all, the effect of accumulated temperature is more obvious and more frequent during the summer than during winter.

The calculation method of effective accumulated temperature is that: firstly calculate the start and finish dates, then calculate effective accumulated temperature during the start date to the finish date. The calculation method of the start date is: a. looking for the date that the average temperature is the first time greater than the boundary temperature from the date in rising stage of temperature; b. putting forward 4 days from the selected date; c. calculating five days moving average temperatures by using formula (1) in five days moving average temperatures with the daily order; d. selecting the five days from the date of the moving average temperature is first greater than the limit temperature from five days moving average temperature in the sequence; e. selecting the average temperature which is first over the date of the boundary temperature from the composition of the 5 moving average temperature of five days, and that date is the start date. The calculation method of the end date is: a. looking for the date that the average temperature is the first time lower than the boundary temperature in cooling phase from daily average temperature; b. put forward four days from the selected date; c. using formula (1) in five days moving average temperatures to calculate the 5 moving average method until the five days moving average temperature is firstly less than the boundary temperature date in daily order; d. selecting the five days moving average temperature is lastly greater than the boundary temperature of the 5 moving average temperature from the moving average temperature of 5 sequence; e. selecting the date that the average temperature is lastly greater than the critical temperature from the composition of the 5 moving average temperature of five days as the deadline. Finally uses the calculation formula of accumulated temperature effect (2) to calculate the accumulated temperature effect from start date to deadline. The accumulated temperature effect is 0 at other dates. Select 25 degrees as the boundary temperature. The accumulated temperature effect is the accumulated of difference between boundary temperature from the average temperature value minus which is greater than the boundary temperature through the temperature from the start to end date. And use the calculation formula of accumulated temperature effect (2) to calculate. Assume that accumulated temperature has effect for N days of one year, and the formula is as equation (2) :

$$T_{mean} = \sum_{j-4}^{j} T_j \Big/ 5 \qquad j \geq 5 \tag{1}$$

$$T_{effect} = \sum \left(T_{N-i} - T_{boundary} \right) \qquad i = 0,1,2,3 \tag{2}$$

T_{N-i} is the $(N-i)$ day moving average temperature of 5. Take the following table as an example in the calculation of accumulated temperature effect. Firstly, calculate the five days moving average temperature in the following table, set the boundary temperature as 25 degrees, and calculate the start date is July 8, and then calculate the accumulated temperature effect.

3. ELMAN NEURAL NETWORK PREDICTION

Elman network is a single hidden layer forward neural network, and it has a lot of hidden layer neurons and weights of hidden layer "threshold" which is randomly generated Elman that has better global search capability and the characteristics of simple and feasible than the traditional gradient learning algorithm (BP algorithm). Compared with SVM, Elman learning is faster and is in often some of the local minimum conditions and can overcome the problem that the traditional gradient vector fitting and the choice of inappropriate, and has better generalization ability. Elman neural network has the advantages which require fewer samples and subsection prediction effect compared with BP neural network. So the paper uses the Elman neural network prediction considering the effect of accumulated temperature to forecast the short-term air-conditioning load of public building. In this paper, the activation function is selected as the sigmoid function. Set as the variable, then the function is $f(u) = 1/1 + e^{-u}$.

In order to avoid the relatively large prediction error which is caused by the relatively great difference between input and output data of network, use the maximum minimum to normalize processing, the function is shown as follows.

$$x_k' = x_k - x_{\min} / x_{\max} - x_{\min} \tag{3}$$

Among them, $x_{\min}$ is the minimum number in the sequence of data; $x_{\max}$ is the maximum value of sequence; x_k is arbitrary data among the sequence; x_k' is the normalized data.

Table 1. Moving temperature and accumulated temperature effect of July, 2014.

	The Highest Temperature	The Average Daily Temperature	The Moving Average Temperature of 5	The Accumulated Temperature Effect
2014/7/5	22.8	21.4	23.38	/
2014/7/6	28.3	24.2	23.76	/
2014/7/7	29.6	24.9	24.04	/
2014/7/8	30	26.4	24.14	1.4
2014/7/9	31.5	26.8	24.74	3.2
2014/7/10	34.2	29.6	26.38	7.8
2014/7/11	34.4	30.1	27.56	12.9
2014/7/12	28.9	25	27.58	11.5
2014/7/13	27.8	24.8	27.26	11.5
2014/7/14	30.4	26.4	27.18	7.8
2014/7/15	27.9	26.2	26.5	2.6

Finally, the result data of forecast are normalized data, and use the normalization formula (4) for processing to get the air-conditioning load value of the forecast day.

$$x_k = x_{\min} + x_k' \cdot (x_{\max} - x_{\min}) \quad (4)$$

Among them, x_k is arbitrary data for the sequence of data; $x_{\min}$ is the minimum number in a sequence of data; $x_{\max}$ is the maximum value of sequence; x_k' is the normalized data.

In Elman forecasting, put the meteorological data and the air-conditioning load of the data divided into training set and prediction set firstly; Then put the meteorological data and the air-conditioning load data are normalized; Then training the training set data; Finally put the predict daily meteorological data to the trained Elman network to realize the prediction of the air-conditioning load. The Elman prediction process is shown in Fig. (**2**),

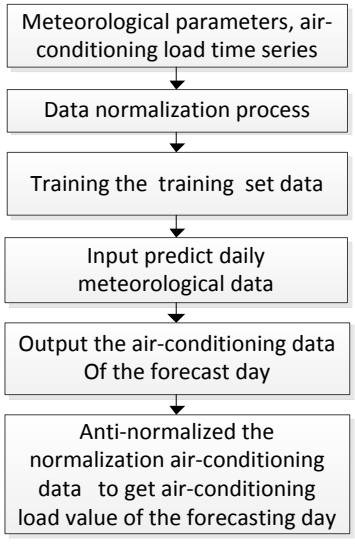

Fig. (2). Elman forecasting process.

4. ANALYSIS OF EXAMPLES

4.1. The Selection of Sample and the Stablish of Model

Choose meteorological data of Nanjing in July 2014 and air-conditioning load of Wanda square of Nanjing in July 2014 as an example. There are the air-conditioning load data among the square daily electricity consumption data per hour in July 2014. And the effect of temperature and accumulated temperature effect is more noticeable in summer, so this article forecast air-conditioning load of public building considering accumulated temperature effect based on Elman neural network.

Firstly, calculate the temperature, humidity and accumulated-temperature effect at daily morning 11:15, 11:30, 11:45, 12:00 according to the meteorological data of Nanjing in July 2014, and calculate the ultra-short air-conditioning load value at daily morning 11:15, 11:30, 11:45, 12:00; Then normalized the above data, and set the normalization date from July 8 to July 29 as the training set to train Elman neural network, for example put the temperature, humidity of the four moments of 11:15, 12:00, 11:30, 11:45 and the day accumulated temperature effect from 1 to 3 as input data, and set a corresponding of the air-conditioning load as a daily output. Train the 2 to 4 until the 27 to 29 as this cycle, making up of 20 groups of circuit training network; Then input the corresponding temperature, humidity of the four moments of 11:15 12:00, 11:30, 11:45 of the 30 day and the accumulated temperature effect of the 30 day to predict 30 four moments of the air-conditioning load values of the normalized data; Finally, anti-normalized the air-conditioning data, and acquire the air-conditioning load value at this four time intervals of the forecasted day.

4.2. Case Studies

Fully considering the meteorological factors and the influence of historical value of air-conditioning load of public building, this example uses the neural network of Elman prediction model of multiple inputs and single output. In this example, use the prediction model of thinking of

Table 2. The temperature, humidity, daily average temperature and effective accumulated temperature of July 14 to 20 in 2014.

Date	Temperature (1115,11:30, 11:45,12:00)	Humidity (1115,11:30, 11:45,12:00)	Daily Average Temperature	Effective Accumulated Temperature
2014/7/14	28;28.3;28.4;28.8;29	74;71; 68;64	26.4	7.8
2014/7/15	27.4;26.9;27;26.5	71; 72;71;74	26.2	2.6
2014/7/16	26.6;26.7;26.6;26.6	82;83;82;80	24.9	2.6
2014/7/17	28.3;28.8;29.1;29.5	79; 78; 77;75	27.3	4.9
2014/7/18	29.9; 30.3; 30.3;30.3	83; 83; 83;83	28.9	7.42
2014/7/19	32.4; 32.9; 32.9;33.5	75; 73; 72;69	30.4	11.6
2014/7/20	34.3;34.4;34.3;34.3	55; 57; 61;60	31.5	18.1

accumulated temperature effect and without considering accumulated-temperature effect of Elman forecasting model in order to highlight the influence of accumulated temperature effect of the air-conditioning load, and contrast, the difference between Elman neural network prediction model of input variables are considered in the accumulated-temperature effect. Parts of the temperature raw data are shown in Table **2**.

Forecast the short-term load of air-conditioning load by considering the effect of accumulated temperature and without considering the effect of accumulated temperature of Nanjing on July 30, 2014 at morning 11:15; 11:30; 11:45; 12:00. Compared with the results which were shown in Fig. (**3**), the difference between the two models is very large. The error of considering the effect of accumulated temperature is obviously smaller than that without considering the effect of accumulated temperature. The error analysis of Prediction is shown in Table **3**, and there are some errors of considering the effect of accumulated temperature effect model, however, the prediction accuracy of the model obviously improves by considering the effect of accumulated temperature.

In this instance, forecast the total mass of the air-conditioning load of the short-time load of Nanjing Wanda plaza by considering the effect of accumulated temperature based on Elman neural network forecasting method, considering the real-time meteorological factors, especially considering the effect of temperature, humidity, effective accumulated temperature. It can be seen from the simulated results that it provides more stability, maintainability and reusability to the forecast of air-conditioning load, but there is a certain error due to the sample data is slightly less with using a month of data. By contrast this example that considering the accumulated temperature effect and without considering accumulated temperature effect of Elman neural network forecasting method, can prove that the effect of accumulated temperature on air conditioning load is seriously, which is caused by the human body comfort and inertia of human feeling. And in this case, considering the effect of accumulated temperature of Elman prediction method, the error was lower than that without considering the effect of accumulated temperature Elman neural network forecasting method. As a result, the forecasting accuracy obviously improves.

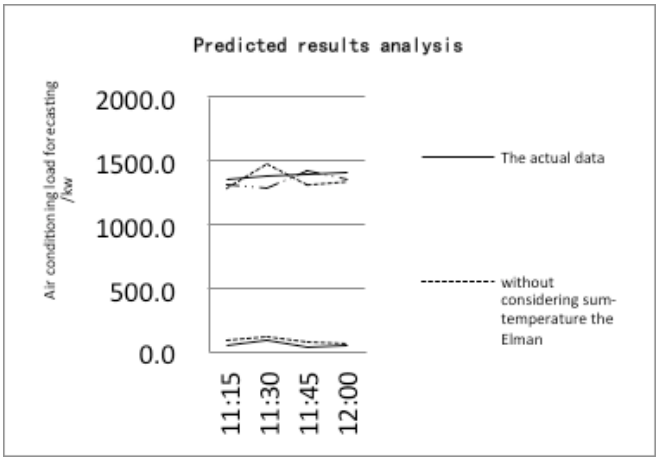

Fig. (3). Analysis results.

There are some errors between the individual simulation results and the actual samples of the history data of the air conditioning load, because the quantity of training sample is relatively small. It can greatly increase the training precision and relatively reduce error, if the training samples were up to a certain number. The more complex the neural network internal relations are and the more sample data have, the more accurate the load forecasting will be and the smaller the deviation will be.

CONCLUSION

This paper proposes a novel forecast method based on Elman neural network model for air-conditioning load of

Table 3. The prediction results 4.

Methods	The Average Error	The Maximum Error	The Minimum Error
without considering accumulated-temperature	5.42%	7.68%	4.37%
considering accumulated-temperature	2.97%	5.56%	2.35%

public building considering accumulated temperature effect. For one thing, this paper makes full use of the effects of meteorological factors on the large scale air-conditioning load, especially temperature. For another, by comparing prediction methods based on various kinds of neural network, the prediction method based on Elman neural network requires fewer sample data but can reach a higher prediction accuracy, which makes it suitable in the process of predicting air-conditioning load of public buildings.

The following conclusions are obtained through the concrete example analysis:

1) Firstly calculate the start and finish date of the effective accumulated temperature by using the five moving average thermometer algorithm of meteorology which is calculated by the 5 moving average temperature of the forecast days in the month, and then can lock the influence of effective accumulated temperature date. and improve the prediction precision;

2) The Elman neural network prediction needs less number of samples than others with the characteristics that the prediction accuracy is higher than others. Considering the effect of the effective accumulated temperature of Elman neural network, the prediction has much higher prediction precision and less prediction error than that without considering the effect of the effective accumulated temperature.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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