Characteristic analysis and prediction technology of cooling, heating and power load in energy internet town of Xiongan New Area

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Abstract. Xiongan New Area is another important new area after Shenzhen Special Economic Zone and Shanghai Pudong New Area. According to the development strategy of high-point positioning of the new area, providing safe, reliable, clean and economic modern energy system for Xiongan New Area is one of the important tasks in the construction of the new area. In the process of establishing and optimizing the energy system, reliable data of energy consumption and load characteristics should be obtained first. This paper analyses the types of buildings in the new area and the local climate and meteorological changes, and takes into account the energy consumption of various internal and external factors. Based on this, the different climate conditions of different buildings in a year are discussed. The load characteristics of thermal and cold power are analyzed. Finally, a prediction method of thermal and cold load data considering climate and meteorological information, typical structural parameters of buildings, internal and external disturbances is established.

1. Preface
Xiongan New Area is another important new area with national significance after Shenzhen Special Economic Zone and Shanghai Pudong New Area. The construction of the new area adheres to the development strategy of Xiongan New Area with world vision, international standards, Chinese characteristics and high-point positioning. Traditional energy system structure and energy consumption have brought about imbalance of energy supply and aggravation of environmental pollution to the development of urban agglomerations, which seriously restrict the construction and development of smart cities. With the maturity and landing of distributed energy new technology, multi energy complementarity technology and smart grid technology, the energy internet system established by integrating these technologies through the "Internet +" mode has become the solution to the construction of energy system in Xiongan New Area.

In the establishment of energy system model, load forecasting and analysis of dynamic characteristics are important parts, which can provide a basis for energy output mode and distribution. Through collecting a large number of load data, establishing a database, optimizing energy control model, so as to achieve efficient use of energy [1]. The energy system control model collects a large amount of load data, establishes a database, and optimizes the energy control model, so as to realize...
the efficient use of energy. In practical application, the energy load has the characteristics of diversity and complexity. It needs to take into account the structural characteristics of buildings, the characteristics of human activities, the relevant geographical location and climate change and other factors on the impact of energy load. High load forecasting results will result in waste of energy equipment and resources, and low load forecasting results will lead to insufficient energy supply [2].

Liang Zhecheng et al used temperature and humidity formula and adiabatic saturation theory to calculate the heat transfer inside the building, which provided a method for calculating the heat load of the building [3]. Based on the equivalent temperature difference method and harmonic method, the attenuation and delay time can also be used to calculate the indoor load, which belongs to the quasi-steady state calculation method. With the use of air conditioning and various small household heating and cooling equipment, the indoor load characteristics show a dynamic change, and the response coefficient method is often used to calculate this kind of situation [4]. In annual load forecasting, the daily load forecasting method is often used for indoor heating or refrigeration stable buildings, which is similar to the actual load in high-end buildings [5]. Full-load method estimates the total working time and total consumption of refrigeration or heating equipment for the whole year [6]. With the development of computer technology, there are load forecasting software at home and abroad [7], such as DeST developed by Tsinghua University and Energy Plus software developed by the United States. Based on the classical load calculation principles and formulas, this software can directly and quickly model, and get the change of the cooling and heating load inside the building with the external temperature and building characteristics [8]. Yuan Zhuoxin takes the theoretical equation of load calculation and the characteristics of actual working conditions as boundary conditions, establishes fitting function curve and builds multi-neuron algorithm, then collects load changes under different time and climate conditions for machine learning, continuously improves and corrects model parameters, and obtains accurate model for load forecasting [9].

This paper summarizes and analyses the building and energy consumption characteristics of energy Internet towns in Xiongan New Area. Based on the classical load calculation method, this paper obtains the load consumption of heat and power based on the specific application environment of Xiongan New Area. Finally, a load forecasting model of heat and power based on neural network algorithm is proposed.

2. Characteristic analysis of cooling, heating and power load of energy system in energy internet town of Xiongan New Area

As a new economic development zone, Xiongan New Area compares its functional characteristics with those of buildings in Shanghai Pudong and Shenzhen Special Zones. There are three kinds of energy consumption: residential buildings, commercial office buildings and social public infrastructure.

2.1. Load characteristics of climatic and meteorological conditions

Xiongan New Area is located in the mid-latitude zone of North China, which belongs to the warm temperate monsoon continental climate, and has four distinct seasons as a whole. The average temperature in March is 4.5 °C, in April is 13.1 °C. The monthly average temperature can be increased by 6-9 °C. In spring, the daytime temperature is high, while the night radiation cooling is strong and the temperature is low. The temperature difference between day and night in spring is relatively large. The difference between day and night in general temperature is 12-14 °C, and the maximum temperature can reach 16.8 °C. In addition, cold air activities in spring are still very frequent. Because of the sharp cooling, there is a "cold in late spring" weather, and the temperature is uncertain, which is easy to form late frost. The climate of Xiongan New Area is hot and rainy in summer. The average temperature of each month is above 24 °C. The extreme maximum temperature usually occurs in June and July. It belongs to the local midsummer and is the hottest month in the whole year. The average temperature is above 26 °C. It shows that the high temperature is persistent and stable, and the
temperature difference between day and night is small. In autumn, the temperature falls back, the temperature is comfortable, and the light is still plentiful. In late autumn, cold air invades from the north. After October, the temperature drops rapidly, and the first frost season often comes in advance. The winter in Xiongan area lasts for more than five months. The days are short and the nights are long. The average temperature in winter is below 0 °C, in January the temperature in plain area is below -4 °C, in mountain area is below -8 °C, the lowest extreme plain temperature is -27.4 °C. Although it is cold and dry in winter, there are more sunny days, and the average daily sunshine is more than 6 hours.

The clear climate characteristics of four seasons make the energy load characteristics reflect their own characteristics with the change of four seasons. When the temperature is low in autumn and winter, the heat load increases. The heat load mainly comes from the geothermal and air conditioning heating of residential and commercial buildings, in which the main heat source comes from geothermal facilities, and air conditioning is the temperature regulation in a small area. In spring and summer, the temperature gradually rises. In April-May, the temperature is pleasant, the geothermal heating stops, the air conditioning usage decreases, and the heat load decreases. From June to the beginning of autumn, the climate is hot and the cold load increases. According to the above analysis, it is necessary to adjust the annual cold and hot supply of energy Internet towns in Xiongan New Area according to the climate and temperature conditions.

2.2. Load characteristics of different building types

Referring to the overall planning of Shanghai Pudong and Shenzhen Central Business District, and according to the planning outline of Xiongan New District, it is known that the main types of buildings in the new area are commercial buildings, office buildings, residential buildings and other cultural and entertainment buildings.

Commercial buildings are generally large-scale entertainment consumption and daily business gathering places. These buildings reflect the comprehensive and diversified features of functions. With the improvement of people's living standard and domestic construction level, a large number of commercial buildings are gathered in the new area. They have higher floors and larger area, which reflects the characteristics of such buildings with high volume rate, high load density and fixed business hours.

Office buildings are mostly composed of various types of individual companies, with large staff flow and population concentration. The overall load is high density, high volume ratio, highly regular load change and relatively fixed time. It is the most regular building in the regional energy system for cooling, heating and power load.

Residential buildings are places of daily life and leisure for residents. The new district is mainly composed of various functional and high-quality residential areas. Residential collocation is composed of villas, foreign houses and middle and high-rise buildings. These types of housing have their own level of volume and load density. The annual load varies steadily with the season and has good adaptability to the energy system.

In addition to the above buildings, the energy consumption of schools, sports, social welfare and cultural facilities is relatively small, but the load changes are unstable due to personnel activities and time, which belong to the larger disturbance factor, and a large amount of data collection is needed to determine its load characteristics.

3. Establishment of heat and power load forecasting model for energy system in Xiongan Energy Internet Town

3.1. Cold and heat load forecasting

The annual hourly load of typical commercial, office and residential buildings is simulated by using DeST software. The calculation formula of hourly load of regional buildings is shown in Formula 3-1.
In the formula: \( Q_t \) is the hourly total load in the area; \( q_{it} \) is the hourly load per unit area of class \( I \) buildings; \( s_i \) is the total area of class \( i \) buildings in the area; \( n_i \) is the coefficients of simultaneous use of class \( i \) buildings in the area. According to the relevant design manual, the usage coefficients of commercial and office areas are 0.7-0.77, residential buildings are 0.49-0.55 and other areas are 0.65-0.7.

\[
Q_t = \sum_{i=1}^{m} n_i q_{it} s_i
\]

\[
n_i = \frac{\text{Maximum Cold/Heat Load of Buildings Superposed at a Time}}{\text{Calculated Daily Maximum Cold/Heat Load of Buildings}}
\]

3.2. Power load forecasting

The commonly used methods of building electric load calculation are unit index method, demand coefficient method and load density method. Among them, the power load calculation formula of unit index method is shown in Formula 3-3.

\[
S = KN / 1000
\]

In the formula: \( S \) is the apparent power; \( K \) is the unit index; \( N \) is the area of the building. The main types of buildings involved in the planning of Xiongan New District are apartments, hotels, office buildings, commerce, sports centers, schools, hospitals, etc. The electric load estimation indexes are shown in Table 1. After establishing the model, we can obtain the actual energy consumption data, record the change rule of load with time, optimize the unit index, and finally obtain the actual power load, also known as the dynamic index method.

| Building category | Electricity load index (W/m²) |
|-------------------|-------------------------------|
| Commercial buildings | 40-80                         |
| Office building   | 60-120                        |
| Residential building | 30-70                       |
| Hospital          | 30-70                         |
| School            | 20-40                         |
| Sports center     | 40-70                         |

3.3. Establishment of load forecasting model for cooling, heating and power plants

The influence factors of building load characteristics are studied, and then the load forecasting model is established as follows. The first step is to determine the use of the building. The second step is to get the operating conditions of the building on the day and in the month under variable working conditions, including the use time and mode. According to the load proportion of refrigeration and heating and other electricity parts in different use time, the actual load situation can be obtained. Finally, according to the data of building's own attributes, the coupling of dynamic and self-owned attributes is carried out to establish the final cooling and heating load. This method is usually used to deal with the multi-factor solution to a certain problem, but the interaction among the factors in the model is difficult to couple and predict. In this paper, the idea of artificial neural network is used to establish the model of the initial cooling and heating load. In the later stage, the initial data of the model are collected continuously during the operation of the small town, and the incentive function is optimized continuously to obtain the self-adaptive load forecasting model. The process of model building is shown in Figure 1.

The structure of multi-factor input and multi-output neural network is adopted. The structure of multi-factor input and multi-output neural network is adopted. The input parameters include the building characteristics, the state of refrigeration and heating equipment, operation status of equipment, weather and climate and other external and internal factors, as shown in X1-Xr in Figure 2. After
calculating the signal transmission between neurons, that is, the excitation function between each neuron is processed. The connection between any two neurons is expressed by the weighted value $w$ of the signal between nodes as the influence weight of many factors, which couples many factors of the cooling and heating load. In the later period of learning and optimization, the incentive function and weight are constantly adjusted according to the dynamic characteristics of load.

Figure 1. Schemes of mathematical simulation model for load forecasting.

Next, an artificial neural network model with multi-factor influence is established based on a predicted value in the thermal and cooling load forecasting, and the practical application process of the model is introduced. Finally, the optimal selection of input parameters of the neural network is realized by combining a large number of data mining.

In practical forecasting, it is often necessary to record the data samples of an object, such as the daily use of an air conditioner in a building in January, i.e. Sample A. At the same time, it is necessary to evaluate the fluctuation value of the sample or the error value in the model. Sample selection and discretization are based on the principle of information gain. Assuming that $N$ is the total number of samples in a measurement activity, the sample data are divided into $m$ different categories according to the characteristics of factors. The data set is divided into $k$ subsets by different values of samples, in which the number of samples of class $i$ in the $j$th subset is expressed by $N_{ij}$. The total entropy value is expressed by the following Formula 3-4:

$$E(A) = \sum_{j=1}^{k} \left( \frac{(N_{1j} + \cdots + N_{mj})}{N} \right) I(N_{1j}, \ldots, N_{mj})$$  \hspace{1cm} 3-4$$

For the $j$th subset, $(N_{1j}, N_{2j}, \ldots, N_{mj})$ indicates the expected amount of information:

$$I(N_{1j}, \ldots, N_{mj}) = -\sum_{j=1}^{m} P_j \log P_j$$  \hspace{1cm} 3-5$$

In the formula, the probability that the size of subset $j$ belongs to subset $i$ is represented by $P_{ij}$, then the information gain of $A$ is expressed as:

$$G(A) = I(N_j) - E(A)$$  \hspace{1cm} 3-6$$

The higher the information gain, the greater the relationship between the representation and the final load. By applying this principle, the main parameters affecting the total load of cooling, heating and power can be selected. In the multi factor fuzzy problem, the single neuron model is as follows:

$$y_i = f(\text{net}_i) = f \left( \sum_{j=1}^{n} w_{ij} x_j - b_i \right)$$  \hspace{1cm} 3-7$$
In the formula, $X_i$ is the input, $Y_i$ is the output of the neural network, $W_{ij}$ is the weight, $B_i$ is the threshold of the neural network, and $f$ is the transfer function.

The upper output of the multilayer neural network serves as the input of the next one, and each layer contains more than one neuron. In this model, feedforward network is used to calculate the load, that is, the objective of learning and forecasting is the actual energy load value.

The weights and thresholds of neural networks are used to initialize random functions. Then calibrate along the negative gradient direction. The process is as follows:

1. Calculating the Error of Output Node

   $$E_n = \frac{1}{n} \sum_{n} (t_n - y_n)^2$$

   In the formula, the expected output of the neural network is $t_n$ and $y_n$ is the output of the ganglion point.

2. Calibration weights

   $$w_{ij} = (n+1) = w_{ij}(n) + \Delta w_{ij} = w_{ij}(n) + \eta \frac{\partial E_j}{\partial w_{ij}}$$

3. Calibration threshold with the same method as (2)

4. Repeat the above steps until convergence.

When using the model in practice, the more samples collected, the better. 70% of them can be used to learn training samples, and the other 30% can be used to correct the results of the neural network. Different gradient algorithms can be used in the learning of the neural network model to obtain the error values under different algorithms, so as to optimize the accuracy error and operation speed, and to obtain the neural network model under different conditions of use.

In the load forecasting of the energy system in Xiongan New Area, the influence of load can be divided into three aspects: cooling, heating and power. Three last-level neural networks are established. Then, meteorological climate, building characteristics and various internal and external factors are introduced as the input layer of the layered neural network, and the excitation function and distribution weights are established. The obtained neural network algorithm can realize self-correction of model parameters and model optimization in the process of early load forecasting and after putting into use.

4. Conclusions

Xiongan New Area is a strategic need under the development of the new era. The rapid development of smart city technology has contributed to the full use of high and new technologies in planning of the new area. When establishing energy system in Xiongan New Area, more efficient and energy-saving solutions should be explored. The work done in this paper is as follows.

1. The climate change of local temperature in one year is analyzed. It is pointed out that the four seasons of climate change have a significant impact on residents' living habits and building usage. Thermoelectric load has a strong correlation with climate change. When the temperature is low in autumn and winter, the heating load increases, and the air conditioning is used as the temperature regulation in a small area. In spring, the temperature gradually rises, the heating load reduces and the air conditioning usage decreases. The summer climate is hot, and the cold load of central air conditioning increases.

2. The functionality of the buildings in the new area determines the characteristics of their loads. Commercial buildings have high load density, high volume ratio, stable load change and relatively fixed time. Residential buildings of different properties have their own level of volume rate and load density, and the annual load varies steadily with the season, so they have better adaptability to the energy system.

3. A multi-input two-layer neural network algorithm is proposed to predict the time-varying electric, cold and heat loads, which take into account climate and meteorology, typical structural parameters of buildings, internal and external disturbances.
Because the new area is still in the planning state, the actual use of building information is not clear. The parameters in the initial learning period of the neural network mainly come from empirical formulas and industry standards, and the predicted results are not precise enough. However, with the introduction of the new district construction plan, the model parameters will be determined step by step, the number of machine learning samples will increase, and the prediction will gradually be accurate.

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