



# Design of Energy Consumption Monitoring System for Group Building Construction Based on Mobile Node

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**Abstract.** Because the nodes in the data transmission network are generally fixed, once there is a problem of node missing or interference, the reliability of data transmission will be reduced, which will affect the performance of the monitoring system. Therefore, a group building construction energy consumption monitoring system based on mobile nodes is designed. First, the system framework including operation layer, decision-making layer and management layer is designed. Secondly, according to the monitoring content of energy consumption data information of large-scale group buildings, the hardware structure of the system is optimized. Finally, through the wireless transmission technology of mobile nodes, the accurate collection and effective transmission of energy consumption in group building construction are carried out, so as to complete the energy consumption monitoring function of the system. Finally, the experiment proves that the energy consumption monitoring system of group building construction based on mobile nodes has high practicability in the practical application process.

**Keywords:** Mobile node · Group Architecture · Building construction · Energy consumption monitoring

## 1 Introduction

With the rapid development of China's economy, the restrictive effect of resources on economic development is becoming increasingly prominent [1]. At present, the proportion of building energy consumption in the total energy consumption of social commodities continues to increase, and the resulting energy shortage will be more prominent. In China, according to the different subjects served by buildings, their energy consumption is divided into rural building energy consumption, urban residential building energy consumption and group building energy consumption. Among them, group building energy consumption accounts for the largest proportion, about 40%. If the energy consumption of various buildings can be monitored and regulated in real time, then the management system and energy-saving measures can be optimized to effectively reduce energy consumption, which will be of great help to create a green and energy-saving environment. At present, there are some problems in the energy consumption of

large group buildings in China at the levels of measurement, transmission and energy conservation supervision. Extensive energy consumption management will cause a lot of energy consumption waste to a certain extent. Energy consumption monitoring and energy conservation management of large group buildings have become the focus of energy conservation and consumption reduction in China [2]. Although China has carried out information-based energy consumption supervision at present, there are many problems of concealment in the process of data reporting in many places due to the low degree of automation of data collection and low degree of management informatization, which directly increases the difficulty of energy consumption data statistics [3]. In order to achieve accurate energy consumption data collection and effective dynamic control of energy consumption, this paper will analyze the energy consumption monitoring system of large-scale group buildings in detail.

## **2 Group Building Construction Energy Consumption Monitoring System**

### **2.1 Hardware Structure of Group Building Construction Energy Consumption Monitoring System**

Mobile node technology is an important aspect of information technology. It is widely used in many fields of modern production and life. It is an indispensable basic technical guarantee for the current smart city construction. In terms of building energy consumption control, mobile node technology can realize multi angle and fine-grained system monitoring and form monitoring information for energy-saving treatment, Provide support for taking necessary energy-saving measures [4]. From the current development of building energy-saving technology in China, there are still many aspects that need to be further improved. Only through continuous optimization and upgrading of technology can a more advanced and perfect energy-saving guarantee system be formed and contribute to the healthy development of the city. Building energy consumption monitoring system refers to the installation of classified and itemized energy consumption measurement devices in buildings and the transmission of technology through the network, It is a general term for hardware and software systems that collect and summarize energy consumption data to information processing equipment in time to realize on-line monitoring and dynamic analysis of building energy consumption [5]. It is further evolved from the building automation system, which can comprehensively monitor the overall energy consumption equipment of the building, and automatically control and optimize the management, so as to achieve high efficiency and energy saving; At the same time, the energy-saving technology with intelligent building as the core is adopted to realize the integrated management of power, air conditioning, lighting and other equipment through networking. Taking the energy management system of medical building as an example, it generally adopts a distributed hierarchical structure, mainly including the decision-making level, management level and operation level. See the figure below for details:

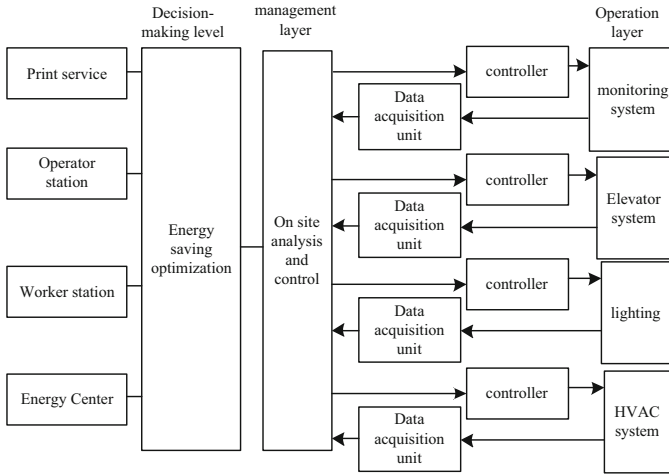


Fig. 1. Energy management system framework

Based on the frame structure of the energy consumption management system shown in Fig. 1, the flow of energy consumption data management is analyzed: first, at the operation layer, the terminal collection instrument automatically collects energy consumption data and reports it to the management layer through the network; At the management level, energy management experts submit the processed data to the decision-making level through data analysis and field analysis. Secondly, at the decision-making level, after the corresponding energy-saving scheme is obtained through relevant optimization methods, the scheme is fed back to the energy management experts; Finally, optimization instructions are generated according to the scheme to control the air conditioning, elevator, lighting, security and other equipment systems on the operation floor through various equipment controllers [6].

The monitoring node is the foundation of the whole building energy consumption monitoring system, with CC2530 chip as the core, supplemented by power consumption detection module, power supply module, alarm module, switch circuit, external memory and other peripheral circuits. The overall structure is shown in Fig. 2.

The internal data system of energy consumption of large group buildings is complex, and there are many energy consuming units. In order to do a good job in the framework of energy consumption monitoring system of large group buildings, it is necessary to control the content of energy consumption monitoring data of large group buildings [7]. According to the requirements of the specific contents of office buildings of state organs and large group buildings issued by China, the monitoring contents of energy consumption data information of large group buildings are shown in Fig. 3.

The energy consumption monitoring system of large-scale group buildings studied is designed in close accordance with the requirements of the software development guide for energy consumption monitoring system of state organ office buildings and large-scale group buildings, which effectively meets the design standards stipulated in China. For the information resources and data layer, it is to achieve the acquisition and transmission

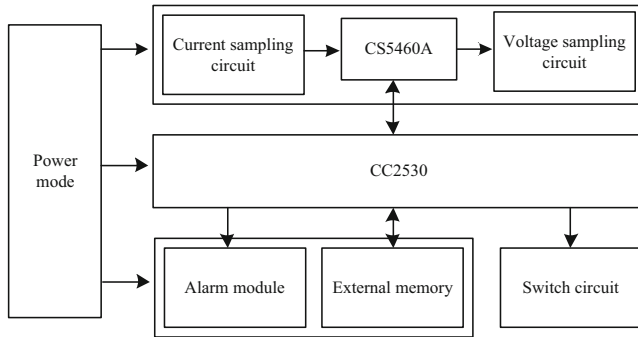


Fig. 2. Overall structure of monitoring node

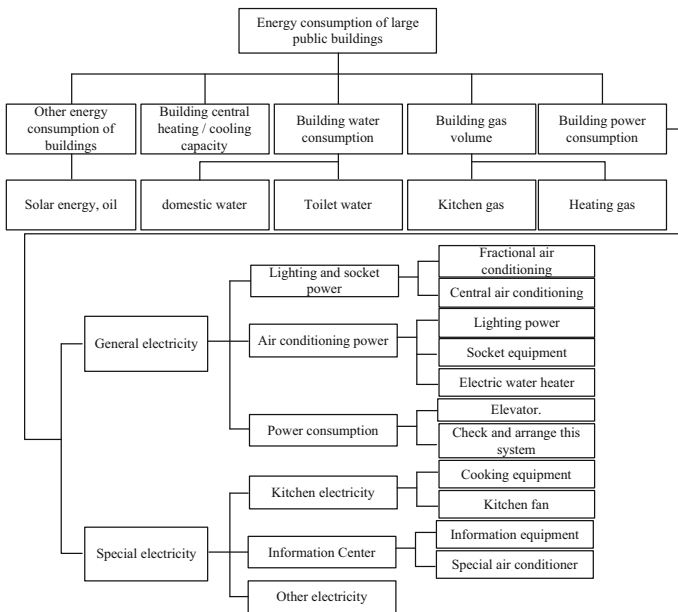


Fig. 3. Energy consumption monitoring data collection content

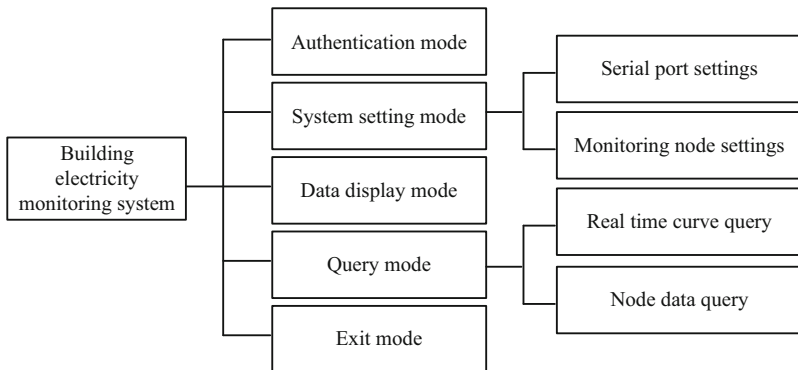
of first-hand energy consumption data information in large group buildings, and classify the collected energy consumption data information [8]. For the application layer, it covers four levels: data and information management, analysis and display, information service and background management, and many contents are covered in different levels. The function of the application layer in the energy consumption monitoring of large group buildings is used for energy consumption data information processing, display and data information monitoring. In the application layer, each function can be regarded as an independent system module. When designing the application layer module, each processing module should be relatively independent to reduce the mutual interference

between each module and pave the way for the subsequent energy consumption data information processing. For the performance layer, it means that different roles in the society can analyze the energy consumption data of large groups of buildings in combination with their own actual needs [9]. It can be seen from the whole networking structure diagram of the building energy consumption monitoring system that the terminal data acquisition equipment of the system completes the networking based on the mobile node. The network includes many terminal sensor collectors and one node collector. The mobile node terminal collection device is defined as an information collection point, and the aggregation collector is the aggregation node. The acquisition node will set the working mode according to various control commands from the sink node. This node is the core of the whole network and plays the actual role of coordinator and gateway. The function realization of the convergence point is to effectively collect the regional network data and transmit it to the data center through the network. The basic structure of the whole energy consumption monitoring system is based on the information collection technology and connected with various energy consumption equipment through nodes. The form of ad hoc network based on wireless network automatically completes the real-time basic data formed by the operation of various energy consuming equipment in the building. Users can monitor the energy consumption of these energy consuming equipment at any time, have a full understanding of the specific situation of energy consumption, and lay a foundation for effectively improving the energy consumption and optimizing the energy-saving measures in the building.

## **2.2 Software Function of Energy Consumption Monitoring System for Group Building Construction**

Large group building energy consumption monitoring is generally controlled and managed with the help of software app. The large group building energy consumption monitoring system software mentioned in this paper covers monitoring terminal, database, data management system, data acquisition system, firewall, communication network, concentrator and building data information acquisition terminal. The energy consumption data information collected by the intelligent building system will be transmitted to the data concentrator to centrally process the energy consumption data information and operation status of the electric energy meter, water meter, cooling meter, gas meter and other energy consumption data information in the building. The concentrator will convert the data information into TCP/IP protocol data packets. The communication network will promote the operation of the data information processing module under the action of the firewall, Transfer relevant energy consumption data information to the database [10]. The energy consumption monitoring system adopts the way of centralized monitoring of real-time data to collect the equipment energy consumption and display the data to users in the form of graphics, statements and figures, so as to realize the functions of energy consumption data collection, query and analysis. At the same time, the operation authority, operation records and fault conditions of the system shall be managed to provide data support for energy conservation and emission reduction and energy safety. This paper analyzes the functional requirements, performance requirements and development technology of the visualization platform of the energy consumption monitoring system. The graphical user interface of the monitoring terminal adopts C++ language

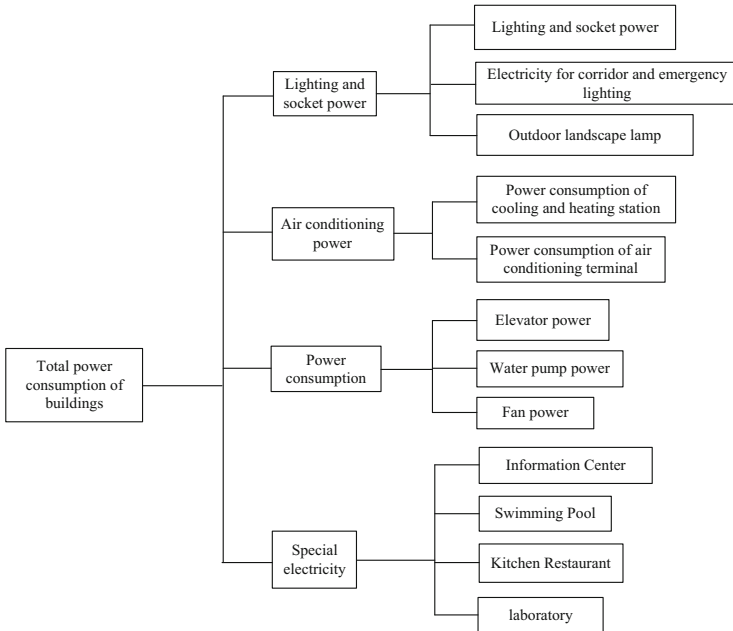
and is designed by using the mobile node development environment. The background uses the embedded database SQLite to realize data management. The overall functional structure is shown in the figure, mainly including authentication, system setting, data display Query and exit five modules. The system setting module is subdivided into serial port setting and monitoring node setting. The query module is also divided into real-time curve query and node data query. The implementation interface and specific description of the main function modules are as follows (Fig. 4).



**Fig. 4.** Overall functional structure of graphical user interface

The data acquisition system manages the building terminal communication protocol in the concentrator and checks the errors in data communication regularly. Carry out relevant data processing for many contents such as data loss and abnormal work, effectively obtain relevant data information in the database, and dynamically monitor, evaluate, analyze, store and display the energy consumption in the building in combination with the energy consumption monitoring indicators set by the system. The monitoring terminal will generally obtain relevant data from the database and obtain the evaluation results for comprehensive analysis and control. The monitoring terminal will analyze the control instructions in combination with the database, data acquisition system, communication network, firewall, concentrator, etc., so as to control the data information status of the acquisition terminal of the building. Due to the different use functions of different buildings, the energy consumption status is also different, even in large buildings, Using different energy consuming equipment, the energy consumption is also different. Therefore, it is necessary to establish a sub item energy consumption data model, so that no matter how different buildings are, the system can use a unified model to realize the comparative analysis of energy consumption of large public buildings. The general itemized energy consumption data model should accurately reflect the energy consumption characteristics of buildings, so that different building energy consumption conditions can be expressed by such a unified model, as shown in Fig. 5.

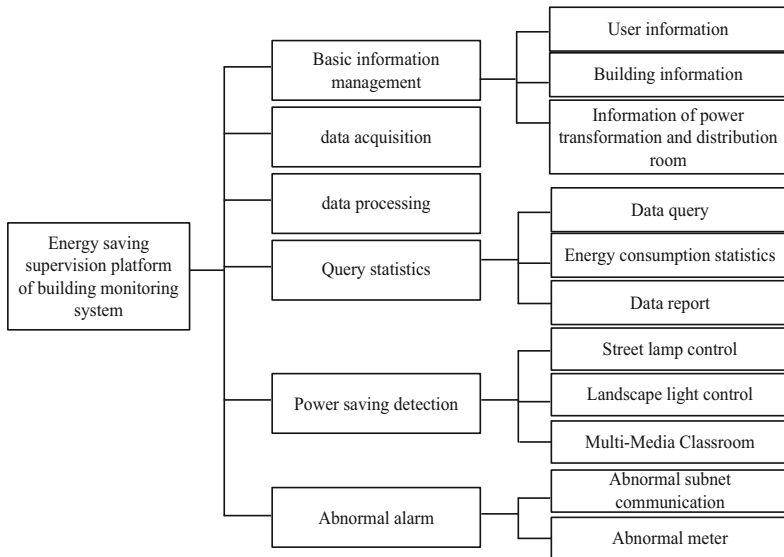
In the actual application of large-scale group building energy consumption monitoring system, it is necessary to introduce the development technology of this software platform in combination with the overall framework and module layered characteristics of the system. With the help of Java, JavaScript and other programming languages for



**Fig. 5.** Reference model of electric energy consumption data

program coding design, the data repository is connected with cloud storage technology to ensure the security and huge capacity of energy consumption data information storage. During data information transmission and communication, we should choose a stable RS485 data communication standard to ensure the high-quality operation of stored data information. The campus energy consumption monitoring and management software is divided into six main functional modules: basic information management, data acquisition, data processing, query statistics, energy-saving control and abnormal alarm. Figure 6 shows the structure of energy consumption monitoring and management software.

Collecting energy consumption data of urban group buildings is the first step of energy conservation and emission reduction. The collection can be carried out manually and automatically. The automatic collection of data covers the energy consumption data of subdivisional and classified buildings. It can be monitored and collected in real time through technologies such as mobile nodes, and then automatically transmit these data to the corresponding data processing system, Conduct in-depth analysis to determine the specific energy consumption and lay a data foundation for the next rectification. The alert management page contains three functions: you can set the threshold of relevant



**Fig. 6.** Structure of building energy consumption monitoring and management software

alert items, including alert settings for a certain type of equipment or energy consumption, as well as alert settings for the overall building energy consumption; Display all real-time early warning information to users, and quickly support users to query each kind of early warning information; Support the query and comparison of historical early warning information to facilitate managers to make relevant reference. Early warning management module is an important window for managers to monitor equipment energy consumption. It can help users realize complex real-time data, historical data and preset data comparison and quick operation. The design of early warning interface includes two categories: current alarm and historical alarm. The user (administrator) can edit and refresh the page according to the specific situation. The page can display the equipment name, equipment number, alarm type, alarm status, alarm time, handling opinions, etc. Early warning information includes equipment early warning and energy early warning. Equipment alarm is aimed at abnormal equipment operation, line fault, machine aging, operation error, etc. energy consumption alarm is aimed at the situation that equipment energy consumption exceeds the set threshold of energy consumption. The early warning management module automatically analyzes the collected data, and then matches the early warning threshold information set in the system. When the collected data approaches or exceeds the alarm threshold, the defined early warning information will be automatically generated. Then, the early warning module sends early warning information in the form of Web pop-up, SMS and e-mail to users through the system to timely notify users to detect and maintain the system and eliminate faults. The program logic flow of the early warning management module is shown in Fig. 7.

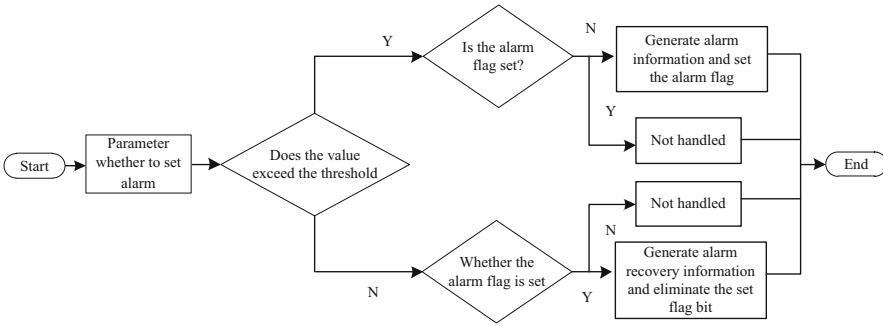


Fig. 7. Design flow of early warning management

At this time, the function of mobile node is to collect the corresponding energy consumption information and directly transmit it to the communication system. The degree of its role determines the monitoring quality and accuracy.

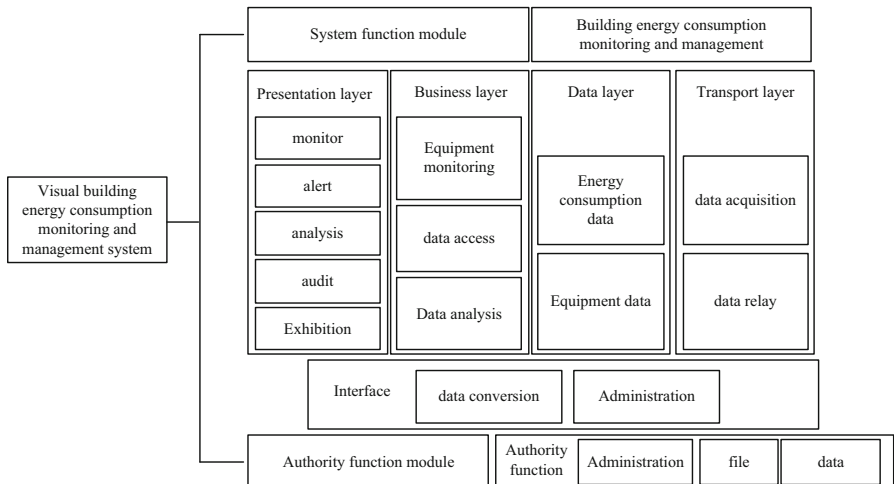
### 2.3 Realization of Energy Consumption Monitoring in Group Building Construction

The functional characteristics of the energy consumption monitoring system developed based on mobile node technology are based on the relevant information collection and transmission of wireless sensor technology. Its network nodes can complete the collection of temperature and other information parameters, and can also connect with various energy consumption devices to automatically collect relevant data based on ad hoc network. Managers can monitor various energy consumption equipment at any time, and diagnose, evaluate and transform energy consumption through corresponding data processing platform. From the current construction situation, the system has been fully applied to the energy consumption measurement and management of many group construction projects in China. Especially for the professional power distribution system of hotels and other buildings, the energy consumption equipment is scattered, and the wireless sensor system based on mobile node technology has greater application advantages. Basic building information, envelope information, indoor personnel activities, indoor environment, outdoor meteorological factors and the operation status of building electromechanical equipment are important factors affecting building energy consumption. The above information is described in the standard data set of building space energy consumption as shown in Table 1.

In practical application, managers can carry out more intelligent management through computer platform. Including access control, lighting, air conditioning, alarm and other energy consumption systems, which can be mixed for networking and share the bus. This construction scheme can save 75% of the construction cost. According to the four principles of demand analysis and system design, combined with the actual functional modules of the energy consumption monitoring and management system, the overall architecture of the energy consumption monitoring and management system is as follows (Fig. 8):

**Table 1.** Classification information of building space unit energy consumption quasi data set

Information classification	Subclass information	Quantity
CPN name	-	1
Essential information	-	1
Structural information	-	1
Personnel information	-	1
Indoor environment information	-	1
Electromechanical equipment information	-	1
Electromechanical equipment information	Lamps and lanterns	28
	Socket	23
	Sun visor	5
	Electrically-operated window	13
	Fan coil unit	5
	VAV air conditioner	5
	Radiator	8
	Fresh air fan	8
	Tap water	1
	Domestic hot water	1
	Gas	2



**Fig. 8.** Overall architecture of energy consumption monitoring and management system

The equipment can complete the linkage function of hardware by using fieldbus, and its operation stability is higher. Because the system platform integrates multiple energy consumption management systems, its operation and application are more convenient and flexible through the management of the software platform. The prediction methods of building energy consumption are mainly divided into two categories: forward model and data-driven model. The former is all kinds of energy consumption simulation software, such as request, Energy Plus, DeST, etc., which is mainly used to optimize the design of buildings and their air conditioning systems; the latter is all kinds of prediction algorithms to simulate and predict their energy consumption with the help of historical data of existing buildings, such as linear regression, artificial neural network, etc. When a node initiates the building energy consumption information summary instruction, such as “building energy consumption summary of a seven storey space unit of a building”, the group intelligent building energy conservation monitoring system establishes a undirected graph  $G(V,E)$  of a seven storey space single  $n$ -node topology of a building based on the automatic topology identification algorithm, in which all CPN nodes in the undirected graph are represented, and  $E$  represents the connection connecting all nodes in the undirected graph. The spanning tree algorithm is adopted to establish the minimum tree with this node as the root node. The collection of building energy consumption can be equivalent to the summation problem. Therefore, the information of building energy consumption is shown in formula (1):

$$Q = f(x_1, x_2, x_3, \dots, x_n) \quad (1)$$

where,  $x$  represents the data in the standard data set of building energy consumption of corresponding nodes. Accurate building energy consumption data is the basis of building energy consumption data statistics. If abnormal values are mixed into the statistical data, the deviation of corresponding analysis data will increase, and even the chaotic operation of building energy consumption control system will be caused, Therefore, the verification of building energy consumption data is of great significance. Building energy consumption data is based on the law of energy conservation, the law of heat balance and other relevant constraints. There is correlation between several variables of building energy consumption data. Therefore, equality constraints and inequality constraints can be used to check the data:

$$\begin{aligned} h_i(x_i, x_{i1}, x_{i2} \dots x_{im}) &\leq 0 \\ g_i(x_i, x_{i1}, x_{i2} \dots x_{im}) &= 0 \end{aligned} \quad (2)$$

In the building energy efficiency monitoring algorithm based on mobile nodes, the equality constraint is that the sum of the corresponding energy consumption data of each space unit or electromechanical equipment node shall be equal to the monitoring value of the energy consumption data of the area or system node, as shown in formula (3):

$$f(x_n) = f(x_{n1}) + f(x_{n2}) + f(x_{n3}) + \dots + f(x_{nm-1}) \quad (3)$$

The established mobile node combination prediction model belongs to the latter category, and its main modeling steps are as follows for gray processing. Accumulate the original energy consumption data at one time and obtain the accumulation sequence,

so as to weaken the randomness of the original data, highlight the overall development trend and further preprocess the data. Normalize the input and output data in the interval of  $-1$  and  $1$ , and the normalization process is as follows:

$$y = 2 \frac{x}{x_{\max} - x_{\min}} - 1 \quad (4)$$

where:  $x_{\max}$  and  $x_{\min}$  are the maximum and minimum values respectively;  $y$  is the value after pretreatment. In order to evaluate the effectiveness of each model, this paper uses three performance indexes: the absolute value of maximum relative error  $E_{\max}$ , the average relative error  $E_{ave}$  and the root mean square error RMSE to evaluate the prediction accuracy and stability of the three models:

$$E_{\max} = \max \left| \frac{x - x_{\min}}{Y(i) - y} \right| \quad (5)$$

$$E_{ave} = \frac{1}{n} X(i) \sum_{i=1}^n \frac{\tilde{Y}(i) - Y(i)}{x - x_{\min}} \quad (6)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n y(Y(i) - X(i))^2} \quad (7)$$

where,  $n$  is the total number of samples,  $X(i)$  is the predicted value of the  $i$ th series, and  $Y(i)$  is the actual value of the  $i$  series. The calculation results of the above evaluation indexes are shown in Table 2.

**Table 2.** Summary of calculation results of evaluation indexes of each model

Error	GM (1,1) model	Neural network model	Gm-bp combination model
Absolute value of maximum relative error $E_{\max}/\%$	47.32	5.36	0.52
Average relative error $E_{ave}/\%$	7.98	0.98	0.11
Root mean square error RMSE (106)	67.25	2.68	1.65

Building energy consumption prediction is an important functional module of group building energy consumption monitoring system. It is an important source to master the future development trend of energy consumption. Scientific energy consumption prediction is the basis and guarantee for making correct decisions. It has practical guiding significance for formulating building energy-saving operation management measures and carrying out energy-saving transformation. Energy consumption prediction research

is one of the methods to optimize the operation mode of each system of the building. It not only helps to explore the energy-saving focus of new buildings, but also provides an important reference for the energy-saving evaluation and transformation of existing buildings. By formulating artificial energy consumption strategies and carrying out energy-saving planning, building energy conservation can be realized. Taking the widely popularized energy quota, excessive price increase and low reward system as an example, its establishment needs to fully consider the energy consumption level of each building, and the research on energy consumption prediction provides an important basis for formulating the benchmark energy consumption level of buildings. Thus, it provides a strong guarantee for the implementation of the energy quota system.

### 3 Analysis of Experimental Results

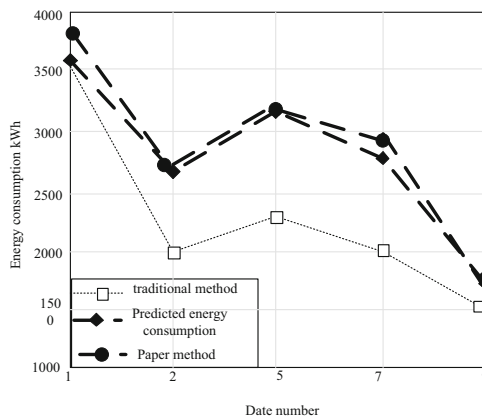
Collect the energy consumption data of group buildings as the sample data of this experiment. The group data types include municipal buildings, library buildings, hospital buildings, supermarket buildings and office buildings. The energy consumption of the above group buildings is large, which can meet the requirements of this experiment. The construction energy consumption data of the above group buildings will be collected for 6 months with an interval of 5 min.

Since the core of the operating system and the design interface are completely separated, a graphical window framework should be set before each operation. The graphical window standard in the embedded environment is realized by windows 10. Because the embedded system is developed by the system, the embedded system also has compatibility properties. According to the hardware design, connect all software functions, download the software to the embedded system, and connect the temperature sensor with the fuzzy controller through the serial interface, so as to build the experimental environment and complete the experimental verification. Before the experimental acceptance, the building structure shall be inspected to ensure the safety of building energy consumption monitoring. The traditional detection method shall be compared with the building temperature loss detection results of the system designed in this paper. The results are shown in Table 3.

**Table 3.** Comparison results of two methods on building energy consumption detection rate

Typhoon series	Traditional system	Paper system
10	32%	85%
15	39%	92%
20	45%	90%
25	35%	89%
30	42%	87%
35	50%	82%
40	55%	90%

Further, take the group building m as an example. The total construction area of the building is about 30000 square meters, with 3 floors underground, mainly parking garage and equipment room, 1–3 floors above the ground are commercial, and there are 6 towers above 3 floors. The building energy consumption monitoring system is equipped with 197 intelligent instruments. During operation, the building energy consumption monitoring system has the following problems: firstly, the system energy consumption monitoring can only realize the itemized measurement of building energy consumption and only display the total itemized energy consumption data. Secondly, the system can only realize the collection and transmission of energy consumption data, and can not realize building energy conservation control and building energy efficiency analysis. Finally, the naming of energy consumption collection points is inaccurate, The user cannot accurately judge the position of the monitoring point. Each data is predicted 20 times, and the average value is taken as the prediction result to predict the energy consumption in the last ten days. The comparison between predicted energy consumption and measured energy consumption is shown in Fig. 9.



**Fig. 9.** Comparison between predicted energy consumption and measured energy consumption

Based on the analysis of the above comparison test results, it is not difficult to find that compared with the traditional methods, the operation effect of the monitoring system of this method is obviously better, and is closer to the actual value, which fully meets the research requirements.

## 4 Concluding Remarks

To sum up, there is a very broad development space for the current energy-saving design of group buildings in China. Various advanced energy-saving and monitoring technologies are used in the energy consumption management of urban group buildings, which can fully ensure the quality and efficiency of relevant management. The successful application of mobile node technology in building energy consumption monitoring system effectively improves the operation efficiency of the whole monitoring system, which is

very necessary to optimize and improve. The continuous upgrading of mobile node technology itself also provides more weapons and tools for building energy conservation, and increases the research on relevant aspects. This is the basic work that must be done carefully, and it is a very important attempt to expand the application depth of mobile node technology.

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