Design and Implementation of an Energy Consumption Data Management System based on B/S Architecture

Xiaoxi Liu*

School of management science and information engineering, JiLin University of Finance and Economics, Changchun, China

*Corresponding author: 1741899460@qq.com

Abstract

With the rapid development of China's economic society, the proportion of building energy consumption has continued to rise. Public buildings hold enormous energy-saving potential, yet existing monitoring systems suffer from issues such as single-functionality and insufficient data integration. This study designs and implements a building energy consumption data management system based on the B/S architecture, adopting a hierarchical framework comprising the perception layer, transmission layer, data layer, and application layer. The system uses intelligent meters to collect real-time multi-type energy consumption data (electricity, water, gas, etc.), employs frameworks like Hadoop and Spark for data cleaning and analysis, and constructs a visual interactive platform based on the Spring Boot+Vue.js technology stack. Integrating core functions such as data collection and verification, multi-dimensional statistical analysis, intelligent early warning, and operation and maintenance work order management, the system achieves all-weather online monitoring and refined management of building energy consumption. This study holds important practical significance for promoting the green and low-carbon transformation of the construction sector.

Keywords

B/S Architecture, Energy Consumption Monitoring System, Data Management, Intelligent Platform.

1. Introduction

With the rapid development of China's economic society, the proportion of building energy consumption in energy and resource consumption has continued to rise. Statistical data shows that in 2020, China's total building area reached 66 billion square meters, of which the public building area was 14 billion square meters; the total energy consumption of public buildings (excluding heating in northern regions) that year reached 346 million tons of standard coal, accounting for 33% of total building energy consumption, and the power consumption was as high as 1,022.1 billion kilowatt-hours. These data indicate that public buildings not only have significant energy consumption growth but also contain huge energy-saving potential[1]. Accurately obtaining building energy consumption data is the basic premise for carrying out energy-saving work. Through statistical analysis of energy consumption data, building energy management departments can fully grasp the building energy consumption status, scientifically formulate energy-saving operation strategies, and provide reliable data support for subsequent energy consumption quota management, energy-saving and low-carbon transformation, and other work. In terms of power consumption monitoring, it is mainly divided into four sub-items: lighting and socket power consumption, air conditioning power consumption, power power consumption, and special power consumption[2].

In recent years, although significant progress has been made in the energy consumption monitoring system for public buildings, problems such as insufficient system awareness and incomplete functions still exist in practical applications. An energy consumption monitoring system refers to a software and hardware integrated system that realizes the functions of online monitoring, data processing, remote transmission, and dynamic analysis of building energy consumption by installing classified and sub-item energy consumption metering devices in buildings and using remote transmission technology to collect energy consumption data in real time. The commonly used software architectures currently are mainly two modes: C/S and B/S[4]. Traditional energy consumption monitoring systems mostly adopt the C/S architecture, i.e., the client/server architecture. This architecture requires the installation of special client software, with most of the computing processing completed on the client side. It is only suitable for local area network environments and has poor flexibility. In contrast, the B/S architecture adopts the browser/server mode, consisting of a presentation layer, an application layer, and a data layer. Users can access the system only through a Web browser without installing additional plugins. The B/S architecture supports wide area network applications, uses open network protocols, has the network characteristics of one-to-many and many-to-many, has low requirements for hardware environments, and performs excellently in data consistency, real-time performance, and traceability[3]. Compared with the C/S architecture, the B/S architecture can realize system access through web pages, with simple and flexible operations, more convenient later maintenance and upgrades, which can effectively reduce development and operation and maintenance costs, and fully meets the actual needs of the energy consumption monitoring system designed in this study.

The existing system platforms generally have the problem of single functions, only being able to realize the display of basic energy consumption data, lacking the collection and analysis of auxiliary information such as building area, equipment operation time, and meteorological data, and having obvious deficiencies in comprehensive data management and in-depth statistics[4]. These defects directly affect the accuracy of the evaluation of the current building energy consumption status and the prediction of energy consumption trends and restrict the efficiency of building energy management departments in formulating scientific energy-saving plans. Therefore, it is imperative to develop an intelligent and modern public building energy consumption monitoring system.

This study takes the development of a building energy consumption monitoring information management system as the goal and designs and implements an intelligent monitoring platform based on the B/S architecture. The system integrates core functional modules such as data collection and transmission, storage management, real-time processing, and statistical analysis, and can conduct all-round and multi-angle monitoring of the energy consumption data of various buildings in the building complex. By realizing the refined classification statistics and intelligent analysis of energy consumption data, the system significantly improves the automation level of building energy consumption monitoring, constructs a networked and all-weather real-time monitoring system, and provides a scientific and efficient technical support platform for building energy consumption management.

2. System Design

2.1. Overall System Architecture Design

The system adopts a layered architecture design, dividing the system into the Perception Layer, Transmission Layer, Data Layer, and Application Layer, with each layer having clear responsibilities and collaborative operations[5].

(1) Perception Layer: Cmposed of intelligent metering instruments such as smart electricity meters, water meters, and gas meters, it is responsible for real-time collection of energy

consumption data (electricity, water, gas, etc.) in buildings and converting the data into digital signals.

(2) Transmission Layer: Relying on communication technologies such as 4G/5G wireless networks, LoRa, and NB-IoT, it securely and stably transmits the data obtained by the Perception Layer to the Data Layer through data collection gateways.

(3) Data Layer: As the data hub of the system, it uses the MySQL database to store raw energy consumption data and employs big data processing frameworks such as Hadoop and Spark to clean, transform, analyze, and mine the data.

(4) Application Layer: Based on the B/S architecture, it provides users with a visual interactive interface via web browsers to realize functions such as display, query, and statistical analysis of energy consumption data. Data interaction between layers is carried out through standard interfaces to ensure the scalability and compatibility of the system.

2.2. Hardware System Design

As the foundation for data collection and transmission, the stability and reliability of the hardware system directly affect the overall performance of the system.

Intelligent Instrument Selection: Priority is given to devices supporting universal communication protocols such as Modbus and DL/T 645 to ensure interconnection and interoperability between devices from different manufacturers. For example:Smart electricity meters must have functions such as high-precision metering, harmonic analysis, and event recording, and support RS485 or wireless communication.Smart water meters and gas meters must have characteristics such as water resistance, magnetic resistance, and low power consumption to adapt to complex building environments.

Data Collection Gateway: As a key device connecting the Perception Layer and Transmission Layer, it is developed using an embedded Linux system and integrates multiple communication modules. It can simultaneously access multiple types of intelligent instruments, perform preliminary processing and protocol conversion on the collected data. In addition, to ensure the stability of data transmission, the system is equipped with dual communication links, which automatically switch to the backup link when the primary link fails, ensuring no data loss and uninterrupted transmission.

2.3. Software System Design

The software system is developed based on the B/S architecture using the Spring Boot + Vue.js technology stack.Spring Boot framework is used to build backend services, providing data interfaces and business logic processing functions.Vue.js is responsible for front-end page development, realizing dynamic rendering and interaction of user interfaces[6].

To improve system response speed and user experience, Redis caching technology is introduced to cache frequently accessed data; the message queue RabbitMQ is used to handle asynchronous tasks, reduce system pressure, and improve concurrent processing capabilities. The main functional modules are as follows:

(1) Data Collection Module: Responsible for communicating with intelligent instruments, collecting energy consumption data at preset cycles, and sending the data to the Data Layer for storage. At the same time, it performs validity checks on the collected data and eliminates abnormal data.

(2) Data Management Module: Realizes the functions of adding, deleting, modifying, and querying energy consumption data, supports batch import and export of data, and facilitates data backup and migration for users. In addition, this module also provides a data cleaning function to process missing values and error values to ensure data quality.

(3) Statistical Analysis Module: Conducts multi-dimensional statistical analysis of energy consumption data based on user-set conditions such as time range, building type, and energy

consumption categories. It supports generating visual charts such as energy consumption trend charts, comparison charts, and pie charts to intuitively display the distribution and change trends of building energy consumption, providing data support for energy-saving decisions.

(4) Energy Consumption Early Warning Module: Allows users to customize energy consumption thresholds. When real-time energy consumption data exceeds the set threshold, the system automatically triggers an alarm mechanism to notify relevant personnel via SMS, email, and system pop-ups. At the same time, the system records alarm information for subsequent traceability and analysis.

(5) User Management Module: Provides functions such as user registration, login, and permission management. It supports multi-level permission allocation, where users with different roles have different operation permissions to ensure system data security. In addition, the system also has a user log recording function to track user operation behaviors.

2.4. Database Design

The database design follows the principles of high cohesion and low coupling, using the relational database MySQL to store data[7]. According to the functional requirements of the system, the following core data tables are designed:

(1) Building Information Table: Stores basic information about buildings, including building name, floor area, building type, geographical location, etc.

(2) Device Information Table: Records device numbers, device types, installation locations, communication protocols, and other information of intelligent instruments.

(3) Energy Consumption Data Table: Used to store real-time collected energy consumption data, including collection time, device number, energy consumption type, energy consumption value, etc.

(4) User Information Table: Stores user accounts, passwords, roles, contact information, and other information.

(5) Alarm Information Table: Records the time, alarm type, alarm device, processing status, and other content of energy consumption abnormal alarms. Correlation relationships between data tables are established through foreign keys to ensure data integrity and consistency.

3. Results

As shown in Figure 1, the system achieves centralized integration and dynamic display of multi-type energy data. Through a comprehensive large-screen interface, it real-time presents the overall energy consumption overview of buildings, including core indicators such as total energy consumption of various types, equipment operation status, and operation and maintenance management information. Users can quickly grasp the energy consumption distribution and change trends through visual charts (such as trend charts and comparison charts). At the same time, a real-time alarm information list is integrated to intuitively display the location, type, and processing progress of abnormal events, assisting management personnel in globally controlling the building's energy consumption situation.

As shown in Figure 2, the system constructs a special monitoring module for electrical energy to achieve real-time collection and monitoring of electrical parameters such as voltage, current, power, and electrical energy in each power supply circuit of the building. Through the linkage between the main electrical system diagram and the Geographic Information System (GIS) map, it dynamically displays the operation status of equipment in each circuit (such as on/off and load conditions), and supports time-period (daily/monthly/annual) power consumption trend analysis, load ranking, and power quality evaluation (such as three-phase balance and power factor). At the same time, it integrates an electrical fire early warning function to real-time monitor safety parameters such as residual current and cable temperature, and automatically triggers an alarm in case of abnormalities.

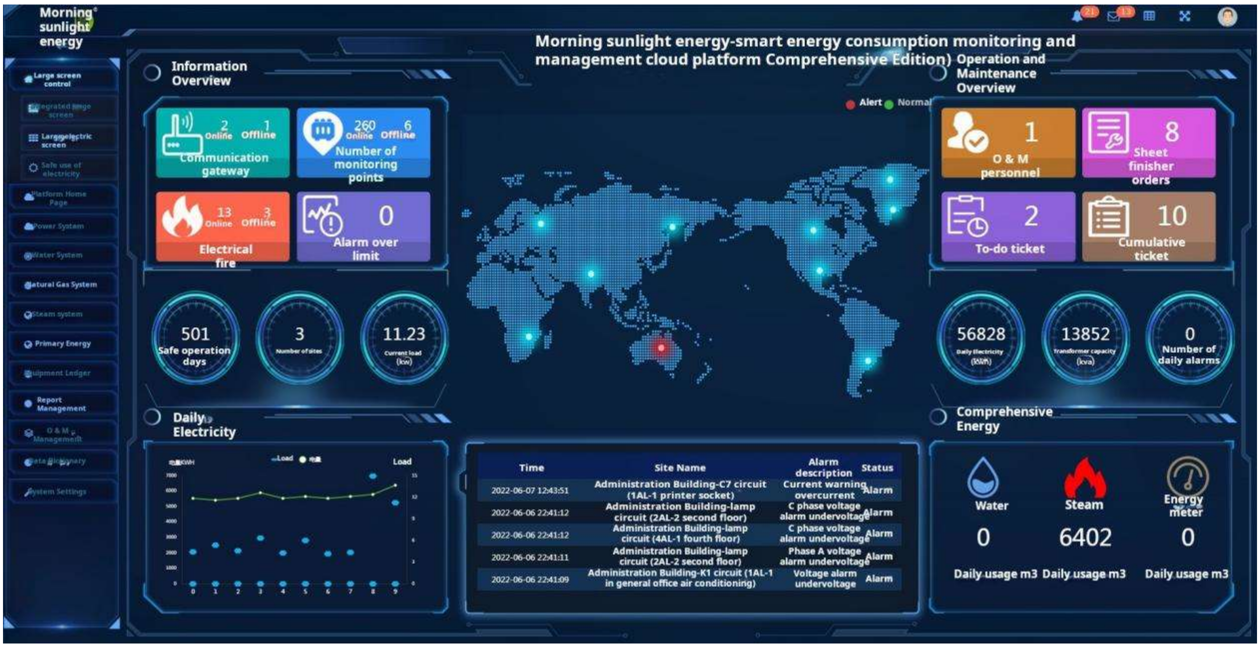

Figure 1. Neural network structure

Figure 2. Power Monitoring Interface

As shown in Figure 3, the system deploys a special monitoring module for natural gas energy to real-time obtain parameters such as instantaneous flow, cumulative consumption, pressure, and temperature of gas pipelines, and supports energy consumption data statistics by site or equipment dimension. Through comparative analysis of historical data on gas consumption patterns, it identifies high-energy-consuming equipment or abnormal consumption periods, while providing data reports and trend charts to provide a basis for gas equipment operation and maintenance, energy consumption optimization, and cost accounting.

Figure 3. Natural Gas Monitoring Interface

As shown in Figure 4, the system supports full-process monitoring of water resource consumption, real-time collecting data such as instantaneous flow, cumulative water consumption, pressure, and water temperature of the water supply network, and can generate water consumption trend curves and analyze peak water consumption periods. It has a leakage detection and alarm function, which identifies pipeline leaks and other issues through abnormal fluctuations in flow, while providing a water consumption data report export function to assist management personnel in formulating water-saving strategies and pipeline maintenance plans.

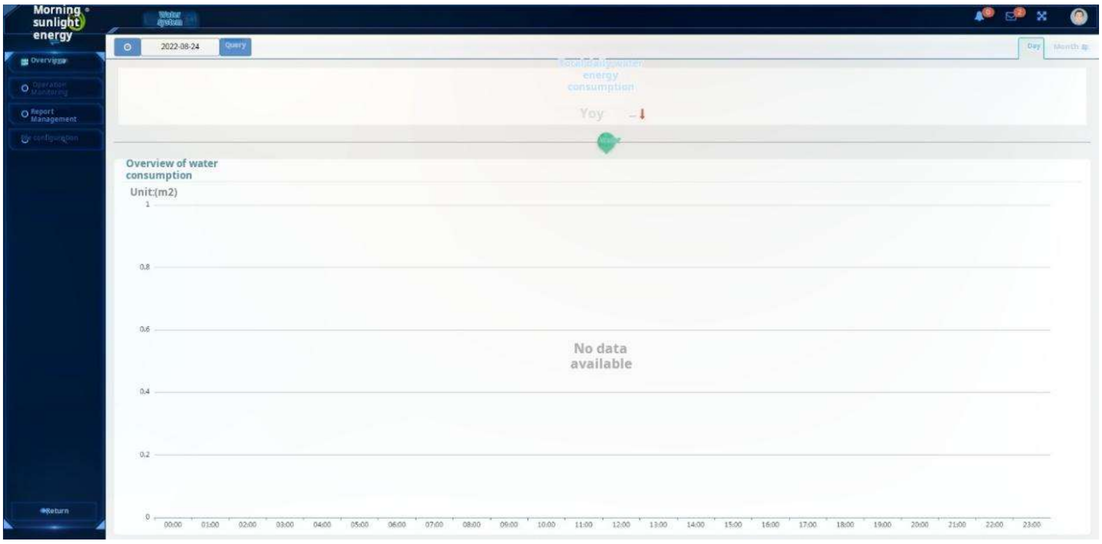

Figure 4. Water Consumption Monitoring Interface

Through the coordination of comprehensive data visualization and energy-type-specific monitoring functions, the system achieves comprehensive perception and refined management of building energy consumption. Starting from core energy sources such as electricity, water, and natural gas, combined with visual display and intelligent analysis, it effectively improves the transparency of energy consumption data and management efficiency, providing technical support for building energy-saving renovations, safe operation, and decision-making.

4. Conclusion

This study designs and implements a building energy consumption data management system based on the B/S architecture. Through a hierarchical framework, the system integrates multi-energy data collection, transmission, analysis, and visualization functions, establishing a real-time monitoring and intelligent early warning system covering energy types such as electricity, water, and natural gas. The system enables centralized display of energy consumption data, multi-dimensional analysis, and closed-loop management of abnormal events, effectively addressing the issues of single-functionality and delayed data processing in traditional systems. It significantly enhances the automation level and management efficiency of building energy consumption monitoring, providing scientific and efficient technical support for energy-saving decision-making, equipment operation and maintenance, and safety assurance in public buildings. In the future, the system can further integrate AI algorithms and renewable energy technologies to deepen application scenarios.

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