Research on energy saving of computer rooms in Chinese colleges and universities based on IoT and edge computing technology

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ABSTRACT

To solve the problems of low overall service quality of the university computer room, unstable environment control of the computer room, low adaptive adjustment ability, and high energy consumption. This article takes Chinese universities as an example to analyze university computer room supervision status, use the Internet of Things (IoT) to remotely and automatically monitor the computer room environment and energy consumption, and analyze the amount of data generated by the rapid increase of IoT edge devices. The method and model of edge computing in the computer room energy consumption monitoring system are proposed through research. The monitoring methods of critical parameters such as the computer room's thermal environment and energy consumption are given. Corresponding solutions for computer room management, testing, use, and energy-saving services are given. It provides a brand-new idea for energy saving in colleges and universities and network room security.

1. Introduction

With the continuous development of informatization construction in Chinese universities, the design of network computer rooms has become an important indicator of the development of Chinese universities. In their paper, Fernández-Caramés T M et al. proposed the importance of the Internet of Things, cloud computing, edge computing, and other technologies in constructing university informatization [1]. However, considering the increasing number of network computer rooms in Chinese universities, energy consumption needs to be considered when designing these network computer rooms.

Energy management also plays an important role in smart buildings, with commercial and residential electricity consumption set to increase to 53% by 2035 [2]. The combination of IoT technology and edge computing provides an efficient and effective mechanism for building energy optimization [3].

At present, the electrical equipment in the network computer room of colleges and universities mainly includes the main equipment rectifier, the electric air conditioner, and lighting of the computer room environment, and the serious power consumption of the air conditioner is one of the important reasons for the excessive energy consumption of the computer room [1]. Hayama and Hirofumi analyzed the cooling characteristics of the air conditioning efficiency of the network computer room [4], mainly studied the factors affecting the cooling characteristics of the air conditioner, and established a cooling model. Based on the conclusions of important factors, a new method for evaluating the cooling characteristics of CRAC (Computer Room Air Conditioning) efficiency is also proposed. Dang J et al. studied an optimization strategy based on air conditioning [5]. This optimization control strategy is aimed at the scenario of using smart meters. The smart meter can formulate the power consumption strategy one day in advance, and multiple smart meters can communicate directly. André Jorge et al. The energy consumption monitoring system for large buildings is proposed [6]. The open-source system plays a role in collecting and analyzing energy consumption data. The system is based on the Modbus protocol, and the data is transmitted through the RS485 bus and uploaded to the server through the Internet. The system provides two functions transmitting and storing energy consumption data and reporting system failures.

Sun Wei [7] and others believe that energy-saving and emission reduction in the computer room lack specific plans and objectives, and the situation is not optimistic. In particular, there are many problems in the computer room's fault diagnosis, adaptive adjustment of the environment, and utilization of energy consumption.

1) The university computer room staff's management is not comprehensive about the energy saving of the computer room.
2) The university computer room's equipment hardware is low in evolution, high in energy consumption, and lacks automatic control.
3) Most university computer rooms are still driven by environmental cooling, and air-conditioning equipment also lacks an intelligent monitoring system. Most computer rooms have low cooling efficiency and large cooling energy consumption.
IoT is the product of the rapid development of the modern Internet, aiming at realizing the high-information Internet of Everything. The IoT uses information sensing devices such as radio frequency identification (RFID), sensors, a global positioning system (GPS), laser scanners, etc., to connect the sensor network devices with the Internet by a contractual agreement to exchange information and communicate with each other. Intelligent identification, location, tracking, monitoring, and management [8, 9]. Many researchers are working to discover the potential of IoT to make our world more convenient and comfortable [10]. The Internet of Things is an information carrier based on the traditional telecommunication network, which enables all common physical objects that can be independently addressed to form an interconnected network [11, 12].

The main contributions of this study can be summarized as follows:

(1) A network computer room framework for energy consumption monitoring in colleges and universities based on Internet of Things technology is proposed [12].

(2) A control algorithm for maximizing the energy efficiency utilization rate of air conditioners in network computer rooms in Chinese universities is proposed to improve the energy efficiency utilization rate of air conditioners and the effective control of air conditioners.

(3) Taking Chengde Petroleum College in Hebei Province, China, as an example, the performance of this scheme is evaluated experimentally, and the advantages and disadvantages are analyzed.

2. IoT architecture and edge computing model for energy consumption monitoring in network computer rooms in colleges and universities

2.1. The application framework of the IoT in the network computer room of colleges and universities

Figure 1 is a framework diagram of the application of the Internet of Things in colleges and universities. The primary stage of the Internet of Things in universities includes:

- School
- Ministry of Education
- Department of energy
- Edge Computing
- IoT in university computer rooms
- Computer room
- Advanced application of IoT in university computer rooms
  - Big data analysis
  - Remote control
  - fault diagnosis
  - Other monitoring
- Primary application of IoT in university computer rooms
  - Temperature and humidity monitoring
  - Air conditioning monitoring
  - Smart meters
  - Other monitoring
Things in schools includes temperature and humidity monitoring, power detection, power consumption monitoring, etc. The advanced stage includes big data analysis, fault diagnosis, and energy consumption control. The initial stage of the Internet of Things in colleges and universities is to collect various data in the network room. The advanced stage analyzes the data through different analysis methods [13].

Figure 2 shows the three-tier architecture of the Internet of Things system in the university network computer room. Figure 3 is the interaction sequence diagram between the University Internet of Things application framework components. This paper discusses the three-tier architecture of the Internet of Things system in the network computer room of the university.

2.1.1. Perception layer

The sensory layer is the IoT system's nerve terminal, mainly responsible for the information acquisition of the external environment, including sensor units and sensor networks. The sensory layer is also equipped with certain executing agencies accountable for executing downlink commands in the network layer [14]. The sensor unit includes the sensor device and camera module to monitor the computer room's relevant parameters. Sensor networks include self-organizing wireless networks connecting various sensor devices, including short-range wireless transmission technologies such as Zigbee, Bluetooth, infrared, etc. [15]. The actuators include air conditioning, alarm devices, access control devices, and other devices with a certain ability to change the environment.

In this paper, the perception layer is centered on edge devices, which support lightweight data transmission and can be applied to most low-power and resource-constrained embedded devices; at the same time, edge devices are no longer a single data collector but also have certain data analysis capabilities and can complete certain computing tasks at the edge of the network, reducing the computing burden for the cloud platform [16].

2.1.2. Network layer

The network layer is built based on the communication network and is responsible for long-distance data transmission [12]. In this paper, the network layer mainly uses the computer room local WiFi to realize the
been unable to meet the explosive data growth brought about by the high
Simultaneously, the traditional centralized cloud computing platform has
2.2. Edge computing model of IoT in university computer rooms
the wide application of the IoT in various industries.
corresponding interfaces according to users' related needs, and realize
the application of the IoT system. It should serve the users, con
web-side user platform, and so on. The application layer is the purpose of
the users of the University IoT, including the mobile phone-side APP, the
ligent processing of perceptual data. It provides a variety of services for
users of the university computer room. It can realize the intelligent
application of the IoT in the university computer room. Its function is
equivalent to the brain of the IoT. It is mainly responsible for the intel-
processing of perceptual data. It provides a variety of services for
the users of the University IoT, including the mobile phone-side APP, the
web-side user platform, and so on. The application layer is the purpose of
the application of the IoT system. It should serve the users, configure the
corresponding interfaces according to users' related needs, and realize
the wide application of the IoT in various industries.

2.1.3. Application layer
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corresponding interfaces according to users’ related needs, and realize
the wide application of the IoT in various industries.

2.2. Edge computing model of IoT in university computer rooms

A single computer room’s operation will produce a large amount of
data, and multiple distributed computer rooms will produce many data.
Simultaneously, the traditional centralized cloud computing platform has
been unable to meet the explosive data growth brought about by the high
real-time requirements. The computer room's edge equipment connects
the computer room and the users of the computer room through the cloud
and has the edge computing ability [20]. It can use the collected data for
pattern recognition, dimensionality reduction, intelligent processing, and
other functions and directly face computer room users. At present, large
data processing has stepped from the era of centralized processing
centered on cloud computing into the era of edge computing centered on
the interconnection of all things [21]. In the large centralized data pro-
cessing era, more is centralized storage and processing of large data. The
approach is to build cloud computing centers and use cloud computing
centers' supercomputing power to centralize computing and storage

Moreover, real-time data will deploy an edge computing platform
supporting real-time data processing to provide users with many services
or functional interfaces to access the required edge computing services.
Researchers proposed in the literature [22] that the 6G-based Industrial
Network In Box (NIB) has higher energy efficiency, better service quality,
and quality of experience. They are used in IoT and edge computing
applications, especially in the industrial field.

Figure 4 shows the edge computing model of the university computer
room. The network edge devices request content and services from the
cloud center and perform computing tasks, including data preprocessing,
feature extraction, data caching, device management, etc. Therefore, it is
necessary to design better the hardware platform of edge devices and its
key software technologies to meet the edge computing model's reliability
and data security requirements [24]. Simultaneously, the edge settings
also have a certain degree of the user interface, and the processed data
can be directly oriented to users without passing through the cloud.

2.3. Design of IoT energy consumption monitoring system in network
computer room of colleges and universities

Based on the IoT and edge computing, the college computer room's
online monitoring system, as shown in Figure 5, includes energy con-
sumption data collection, thermal environment data acquisition, air
conditioning infrared control system, edge equipment unit, server, and
user application platform, and so on. The electric data acquisition system
realizes the electric energy data collection of the main electrical equip-
ment in the equipment room; the thermal environment data acquisition
system mainly monitors the airflow and temperature of the air condi-
tioning air outlet, the return air inlet, and the rack, and analyzes the
utilization rate of the cold airflow [11]. The edge calculation unit con-

\[\text{Figure 3. Interaction sequence diagram between components of university IoT application framework.}\]

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consumption. Others include flooding, smoke, and data collection for UPS power.

### 2.3.1. Edge device

Edge devices are distributed in each row of cabinets in the computer room, which are the eyes of the monitoring system in the computer room of colleges and universities. The system edge device is divided into two units: the acquisition unit and the calculation unit. The acquisition unit uses the ATMega328P processor, with 14 GPIO interfaces, 6 PWM, and 12-bit ADC interfaces. It is connected to the controller in a serial port through an external module, such as 485 to 232. It can meet most of the requirements by designing external circuits—sensor networks. The collection unit is mainly responsible for collecting energy consumption data, thermal environment data, other data (including sensor data), and air-conditioning infrared control data. The calculation unit uses the BCM2837 core 64-bit ARMv8 processor. At the same time, it is equipped with an embedded Linux system, which can perform certain complex computing tasks while interacting with the server. Upload the calculation result to the cloud server and set the threshold for early warning. The flowchart is shown in Figure 6.

### 2.3.2. Energy consumption data acquisition system

The system is equipped with a three-phase watt-hour meter at the interface of main equipment, air-conditioning system, transmission equipment, DC power cabinet, and other equipment. It is responsible for collecting the power equipment's phase voltage, current, power, and power consumption. The 485 interfaces of the three-phase watt-hour meter are connected to the acquisition unit through the 485-232 external circuit. This part of the protocol is based on Modbus. The watt-hour meter's three input terminals are connected with A, B, and C phases. The two output terminals are connected with the A and B serial lines of the 485 bus, respectively. The acquisition unit can read the ammeter register's electricity data through different instructions under the protocol. Usually, a three-phase ammeter is needed for an electric device. This system collects the data of the main electrical equipment (air conditioning, each row of cabinets, etc.) at a certain sampling frequency. It passes the data into the calculation unit after analyzing the PUE value. The library is uploaded.

### 2.3.3. Thermal environment data acquisition system

The overheating of the computer room is the key problem in the monitoring system of the computer room. The acquisition unit transfers it to the calculation unit through a serial port. The calculation unit calculates SHI and HRI values according to Section 1 and 2 of Section 3.1, uploads them to the cloud server, and sets the alarm threshold.

### 2.3.4. Air conditioning infrared control system

Air conditioning control is the executive mechanism of this system, which receives the control signal from edge equipment, realizes remote control, and controls air conditioning equipment such as air conditioning, doors, and windows according to the control signal. The control system is based on the calculation unit and can perform complex calculation tasks. The calculation unit is connected to the cloud server at a certain sampling frequency. The library is uploaded.
usually represents the utilization rate of cooling. The greater the value, the less energy waste; HRI is the ratio of heat used by cold airflow for cooling server from floor air supply outlet to cold air flow loss heat to outlet. The ratio represents the cooling capacity used for cooling equipment utilization. Ideally, all the cold air flow used for cooling equipment is HRI = 1.

\[
\text{SHI} = \frac{\&Q}{Q + \&Q}
\]

(1)

\[
\text{HRI} = \frac{Q}{Q + \&Q}
\]

(2)

\&Q in Eqs. (1) and (2) is the total heat loss from the cooling airflow in and out; Q is the effective heat loss of the refrigerating gas flow (heat used for cooling equipment).

3.2. Monitoring of energy consumption in computer rooms

Collecting power consumption data is the precondition for monitoring the energy consumption of the computer room. Conversely, the edge device (gateway) is connected to the intelligent inductance measurement terminal through a 485 bus. This part of communication is based on the Modbus protocol. On the other hand, the data is uploaded to the cloud server through the subscription/publication mode. Unlike traditional cloud computing, edge devices also perform certain computing functions. The collected power data is analyzed on edge devices and uploaded to the cloud server, which reduces the amount of data processing in cloud computing.

As shown in formula (3), the total energy consumption F of the computer room in colleges and universities is composed of the energy consumption of main equipment Q1, the energy consumption of air conditioning system Q2, the transmission equipment Q3, the DC power cabinet Q4, and the other equipment Q5.

\[
F = Q_1 + Q_2 + Q_3 + Q_4 + Q_5
\]

(3)

The main equipment of the computer room includes a WEB server, data server database, data backup server, audit equipment, etc. Transmission equipment includes switches, routers, WIFI equipment, etc. The DC power supply cabinet includes a power supply cabinet and UPS. Other equipment includes temperature sensors, humidity sensors, human body sensors, etc.

The total energy consumption of the university computer room is shown in Table 1. The main equipment energy consumption accounts for 28%, the cooling equipment energy consumption accounts for 48%, the transmission equipment energy consumption accounts for 11%, the DC power cabinet energy consumption accounts for 9%, and the other equipment energy consumption accounts for 4%. Generally, there are two main types of evaluation of the computer room's energy efficiency level: Power Usage Effectiveness (PUE) and the Data Center Infrastructure (DCIE). At present, most of China's computer room energy consumption evaluation index adopts the first type, and its value is formula (4) shows:

| Energy consumption parameters                      | Percentage of energy consumption |
|----------------------------------------------------|---------------------------------|
| Main equipment energy consumption of the computer  | 28%                             |
| room                                               |                                 |
| Air conditioning system energy consumption         | 48%                             |
| Transmission equipment energy consumption          | 11%                             |
| DC power cabinet energy consumption                | 9%                              |
| Energy consumption of other equipment              | 4%                              |

The investigation found that the university computer room follows the traditional computer room pattern, with row racks face to face and different row racks back to back, conducive to convection to form a cold and hot channel. The floor is overhead. The cold airflow enters the cabinet from the air inlet of the movable floor, and the hot air flow flows back from the top of the air conditioner to form the cold and hot air flow organization. In addition to direct temperature and humidity, foreign scholars put forward some evaluation indexes constructed by temperature to evaluate the quality of the data center's thermal environment when studying the computer room's thermal environment. Among them, SHI and HRI are widely used.

SHI is the ratio of heat taken by air-conditioning refrigeration airflow from floor air supply outlet to server cabinet air inlet and outlet, which
Figure 8. System delay at different sampling periods.
the two air conditioners, heat and ventilate with cabinets, walls, windows, etc. The distance between the two air conditioners is different. The cooling effect of the two air conditioners has different impacts on the indoor environment of the computer room, so the weights are also different. The air conditioner 1 in this system is facing the door. Due to the opening and closing of the door, People entering and exiting will bring some heat, so air conditioning 1 has a more significant weight ratio. The decision variable in this mathematical model is the temperature value of the computer room environment. The final control variable is the power consumption of the air conditioning refrigeration system. By controlling the power consumption of the air conditioning refrigeration system, the energy consumption of the entire computer room environment is reduced.

For the above primary symbols reference, see Table 2.

### 4. Performance test

#### 4.1. Packet loss test

The stability judgment of the Internet of Things system is usually manifested in the packet loss phenomenon. The packet loss phenomenon is mainly manifested in three aspects of the system: (1) data loss in the interaction between the acquisition unit and the sensor network; (2) acquisition unit and calculation Data loss in unit serial port mutual transmission; (3) packet loss phenomenon between data transmission between the sensing layer and the network layer. The first two cases are normally closely related to the device's state. When data loss occurs, the data loss judgment can be realized by software, and data retransmission is enabled, so it is not within the scope of this test. This test targets data loss when the edge device's computing unit sends data through the network layer.

The edge device uses the local WiFi network in the equipment room to test the data loss under different data acquisition frequencies. The edge device publishes 1000 times and uses 500 bytes of data as the publishing unit to perform statistics on packet loss. As shown in Figure 7, when the acquisition frequency is within 1 ms, the packet loss phenomenon is serious, and the packet loss rate is about 15%. The system transmission is better when the acquisition frequency is between 1 ms and 40 ms, and the packet loss rate is stable at 1.6%. Fluctuation and fluctuations are irregular; when the acquisition frequency rises to 80 ms, the packet loss phenomenon decreases from 2.1% to 0 with the acquisition frequency; when the acquisition frequency reaches 80 ms, the data transmission between the sensing and network layers is no packet loss. With certain stability, it can satisfy most applications.

### 4.2. Delay test

The real-time nature of data transmission is the key to the performance of IoT systems. It is mainly manifested in three aspects: (1) the data transmission delay of the sensor network; (2) the transmission delay between the acquisition unit and the computing unit; (3) the transmission delay between the sensing layer and the application layer. The first type of delay is related to the state of the sensing device itself. The second edge device's serial port transmission has no delay, and the delay is associated with the device itself. Therefore, the transmission delays of the first two are not within the scope of this test. It is mainly tested for the third case to test the network transmission performance of the edge device of the sensing layer.

Under different sampling periods, the edge devices to send data from 2000 byte and 100 times repeated trials take average delay, due to the time synchronization problem perception layer and application layer, the edge of test equipment to assume the role of the application layer interface at the same time, namely in the release test data at the same time as the application layer to subscribe to the news topics, it can test data from published to the application layer users receive delay. The transmission delay under different sampling cycles is shown in Figure 8. The maximum delay of the system is 35 ms, the minimum delay is 26 ms, the average delay is 30.43 ms, and the delay standard deviation is 3.3813 ms. The system has no delay and has a high real-time performance.

#### 4.3. Response time test

This paper selects two data formats for testing: (1) XML data exchange format widely used in traditional network computer rooms [27]. (2) JSON data encapsulation format selected for this solution.

This paper tests the transmission efficiency and data parsing efficiency of the two data formats for the same number of data. It takes the monitoring data of each sensor and equipment in the network computer room as the experimental data sample. 10 seconds for data acquisition. The time of one data transmission is from the time the terminal starts collecting to the time when the client receives the data; the time for one data parsing is from the time when the data is transmitted to the client to the end of the parsing, which is displayed on the WEB interface, which is a parsing process. The marked time stamp the transmission and parsing time, and 5 tests are done. The numbers of data are 200, 400, 1000, 1600, and 2000. The comparison of data transmission time is shown in Table 3, and the comparison of data parsing time is shown in Table 4.

### 4.4. Security test

This paper evaluates the security performance of the data transmission protocol through the following indicators: (1) data encryption; (2) data integrity calculation; (3) data authenticity verification; (4) data source verification; (5) transmission delay verification; (6) protocol standard compliance. The comparison of protocol standards is shown in Table 5. The comparison of transmission delay is shown in Table 6.
4.4. Research on transmission protocol

This scheme puts forward higher requirements on the selection of transmission protocol. In addition to high transmission efficiency, the integrity and accuracy of data transmission should also be considered. Through the investigation, we learned that the two commonly used remote transmission protocols in the current computer room environmental monitoring system are HTTP protocol based on TCP protocol and MQTT protocol. The differences between the two protocols in protocol standards are shown in Table 5.

By comparing the protocol standards of HTTP and MQTT, it can be seen that MQTT, as a high real-time lightweight transmission protocol based on the publish-subscribe mechanism, can adapt to unstable networks, low power consumption, and support a large number of customer connections. The differences in protocol standards also determine the differences in protocol transmission performance. Therefore, performance testing experiments were performed on the two transmission protocols in the computer room environment. This scheme finally chooses the MQTT remote transmission protocol through comparison and analysis and comprehensively considering various factors. The experimental conditions are as follows: The testing environment is built in the computer room of the university, and the experiments are carried out in the WIFI network environment to compare the response time of the HTTP protocol and the MQTT protocol. With throughput, the test sample is 200 times, and the performance comparison results of the transmission protocol are shown in Table 6.

The statistical results in Table 6 show that in terms of real-time performance, the average response time of MQTT is lower than that of HTTP, and the real-time performance is better; in terms of throughput, the throughput of the MQTT protocol is greater than that of HTTP protocol, and the transmission efficiency is high; data integrity MQTT The packet loss rate of the protocol is lower than that of the HTTP protocol.

4.5. Transmission network selection test

It is also important to select a high-speed and efficient transmission network for this scheme. During the experimental test, the experiment was carried out under the same conditions and in the same environment, and the WIFI network, 4G network, and 5G network were selected. And compared the upload speed, the scope of application, network transmission stability, and respective costs of the three network transmission methods and obtained the results shown in Table 7.

Through the performance comparison of the three transmission networks in Table 7, it can be seen that the upload speed, the breadth of the applicable range, and the transmission stability of the WIFI network and the 5G network under the same conditions meet the requirements of this scheme. However, considering the lower cost of the WIFI network, the WIFI network scheme is selected in the design and implementation of this system to realize data transmission.

5. Discuss evaluation

5.1. Comparison of energy consumption before and after monitoring

Table 8 shows the main data monitored by the Chengde Petroleum College Computer Room IoT Energy Consumption Monitoring System, and the values are average. It can be seen from the preliminary test that the remote monitoring of the energy consumption of the computer room of Chengde Petroleum College has been realized, which can increase the energy efficiency of the computer room by 10%–20%. Reference [28] proposes a novel adaptive battery-aware algorithm (ABA), which utilizes the charges up to their maximum limit and recovers unused ones. The proposed ABA adopts this recovery effect to enhance energy efficiency, battery lifetime, throughput, and reliability. Reference [29] Propose the Adaptive Energy Optimization Algorithm (AEOA). It can be used in the network computer room to reduce energy consumption.

5.2. Energy saving effect analysis

Compare the electricity consumption and charges of the network computer room of Chengde Petroleum College before and after the system was used in 2020–2021, as shown in Table 9. Comparative data shows that the computer room's power consumption from January to December 2021 will be reduced by 15%–27% every month compared with the same period in 2020.

5.3. Advantages and disadvantages of analysis

Table 10 compares the energy consumption monitoring of the traditional university network computer room and the energy consumption monitoring of the university computer room based on the Internet of Things and edge technology. The computer room energy consumption monitoring system based on the Internet of Things and edge computing technology has energy-saving, energy-saving, and emission reduction effects, equipment safety analysis, data standardization, operation and maintenance costs, and monitoring objects.

Energy-saving awareness in China is generally not high. The scale of energy-saving institutions is small, and the technical strength is weak,
especially in the computer room of colleges and universities. Colleges and universities have enormous demands from energy consumption analysis to energy-saving computer room reconstruction, design, and maintenance. The Internet of Things and edge computing energy consumption monitoring systems of university computer rooms can provide data foundations for energy-saving institutions through open application layer user interfaces by analyzing university computer rooms’ energy consumption. The situation targeted the implementation of relevant control measures and created an energy-efficient computer room.

6. Conclusion

This paper summarizes and analyzes the reasons for the high energy consumption of computer rooms in colleges and universities in my country and proposes a framework for monitoring the energy consumption of network computer rooms in Chinese colleges and universities. And the monitoring method of the data of the computer room environment and energy consumption is given. Taking Chengde Petroleum College as an example, the air conditioner’s energy consumption is controlled by not changing the existing equipment in the computer room, using the mathematical model of air conditioning energy consumption control. The energy efficiency utilization rate of the computer room air conditioner is improved, and the waste of energy consumption is effectively reduced. The stability and advantages of this scheme are verified through performance tests. Currently, this paper only analyzes the energy consumption that may be caused by cooling and does not consider other energy consumption factors. In the follow-up research, we will continue to improve and optimize.

Declarations

Author contribution statement

Jia Qu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

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Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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Table 10. Advantages and disadvantages of analysis.

| Method            | Energy Consumption Monitoring of University Network Computer Room | Energy consumption monitoring of computer rooms in colleges based on the Internet of Things and edge computing technology |
|-------------------|------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| The basis for energy saving | No                                                               | Yes                                                               |
| Energy-saving and emission reduction effect | Poor                                                            | Good                                                             |
| Equipment safety analysis         | No                                                               | Yes                                                               |
| Data standardization          | No                                                               | Yes                                                               |
| Network resource consumption    | High                                                              | Low                                                               |
| Operation and maintenance cost  | High                                                              | Low                                                               |
| Monitoring object             | Little                                                            | More                                                              |
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