Research of University Building’s Electrical Energy Consumption Management Based on IoT & AI

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Abstract. Energy is an important factor in socio-economic development. The level of energy reserves is closely related to the national development, and has a great impact on the national economic development. However, many buildings in university/college, the management of electrical equipment, e.g., lighting and air conditioning is still under the control of students in manual way. According to the published data combined with the often seen phenomenon, the wastage of electrical energy in university/college is serious; and it has become a hot issue. This paper provides a solution to the above challenges in an automatic way through a combined application of technologies like Internet of things, AI, sensors, intelligent control devices and wireless communication technologies. It organized in four sections; the second is a comprehensive literature review after a brief introduction; the third section provides a case of Building Electrical Energy Consumption (BEEC) management and then presents a recommended solution; the future development trend and future work is given in the final part.

Introduction

With the increasing demand for energy resources in the society, countries around the world are paying more and more attention to energy consumption management, and traditional management methods can no longer meet the actual needs. In China, with the rapid development of urbanization, the energy consumption of heating, water and power supply has increased tremendously. According to Chinese statistical data of 2018 issued from the government, the whole country’s energy consumption reached 4.49 billion tons of standard coal in 2017, with an upward trend. Global buildings electrical energy consumption account for 22% and 41% of greenhouse gas emissions, respectively, among which the electrical energy consumption of lighting, air conditioning and other electrical appliances is one of the major factors. Colleges are the main places where student gather and use electricity for a long time. For the sustainable development of society and resources, the problem of building electrical energy management in colleges is becoming more and more urgent. At present, researches in this field mainly focus on BEEC intelligent management support technologies, such as wireless communication technology¹⁻⁴, security system technology⁵⁻⁷, information security technology⁸, IoT( Internet of Things) technology⁹⁻¹⁰ and information fusion technology¹¹. Due to the many types of sensors and communication protocols currently used, the practical application of combining AI technology with BEEC intelligent control application is still limited. With the rapid development of cloud computing and IoT technologies, it is of great practical significance to integrate these advanced technologies and systems in the application of intelligent management of electrical energy consumption in college buildings. To this end, this paper has carried out literature review and analysis of relevant technologies, including common sensor communication technology, intelligent technology and IoT platform technology, etc. among others aiming at assessment of solutions to the problem of BEEC management, provide corresponding technical references for research and development personnel engaged in related work.
Literature Review of the Related Technologies

**IoT Technology**

Building electrical energy consumption management needs to connect equipment information with the network platform through equipment networking technology and methods, relying on computer network systems to achieve integrated management. In such scenario, the application of IoT technology is an effective solution.

The IoT was first proposed by Professor Ashton of the Massachusetts Institute of Technology in 1999 when he researched RFID (Radio Frequency Identification), which is based on the Internet. The ubiquitous network can connect the information of all objects to the Internet through sensors, through the network to manage the physical devices on the network nodes, to realize the intelligent identification and management of distributed equipment.

IoT uses RFID, GPS (Global Positioning System), and other types of sensors as carriers to connect them to physical devices. Through the sensor communication protocol, it connects with the existing Internet to realize physical device information communication with external data, complete physical device management automation, informationization, support object intelligent identification, positioning, location tracking, and operation monitoring, equipment indicator monitoring and forecasting. Therefore, the construction of the IoT requires key technologies such as RFID, sensor, communication and heterogeneous network convergence, high-performance information processing, and has three technical characteristics of comprehensive sensing, reliable transmission and intelligent processing.

IoT architecture can be generally divided into three layers, perception layer, network layer and application layer. Figure 1 illustrates the layers while the functions of each layer are briefly described in the section that follows.

![Architecture diagram of the IoT.](image-url)
Firstly, the perception layer can also be called the “device layer”. This layer is mainly composed of sensing nodes and intelligent sensing devices. It is mainly used to perceive and receive various target physical information, and organizes the information into digital signals according to the protocol, and prepares relevant information of physical device objects for data transmission of the upper layer. The perception layer is composed of information perception layer and object access layer. The information perception layer is mainly composed of hardware, communication protocol, automatic identification algorithm, multimedia information technology and remote sensing control technology. The object access layer is mainly distributed network, self-organizing networking and collaborative information processing technology.

Secondly, the network layer is the middle layer, and its task is network transmission, which transfers the information acquired from the perception layer to the application layer for processing. The transmission layer is established based on the communication network and the Internet. Through the wired transmission and wireless transmission technology, the heterogeneous network is fused to realize the bidirectional transmission. Through network technology, this layer can shield the differences between different physical devices in the perception layer and realize data-centered transmission, storage, query, mining, decision making and analysis.

The top layer is the application layer, which is the layer directly interacting with users in the IoT architecture. This layer supplies the global data management function for the practical application of users, and carries out sensory data analysis, reasoning, decision-making, etc., to achieve the goal of users’ control over various types of objectives.

**Protocols for BEEC Management by IoT**

As shown in figure 2, the IoT technology is applied to connect the physical devices and release the device operation information to the network in real time. Corresponding communication protocols are required to support each link. The following is a brief introduction to the communication protocols that might be used.

Firstly, EPC communication protocol (Electronic Product Code) and RFID communication protocol may be required on the underlying perception layer. With these protocols, parameters and running state data of physical devices can be collected in real time.

Secondly, there are four main kinds of key protocols involved in the network layer, namely short-range non-cellular communication, short-range cellular communication, long-distance cellular communication and wired communication protocol. Among them, short-range non-cellular communication protocols types include Dash7 protocol, NFC technology (Near Field Communication), Bluetooth technology, and IrDA technology (Infrared Data Association), etc. Short-range cellular communication includes ZigBee, WIFI, Z-Wave, Whart, LoRa, etc.
Long-distance cellular communication includes GSM technology (Global System for Mobile Communications), WCDMA technology (Wide Band Code Division Multiple Access), and LTE technology (Long Term Evolution), TD-LTE technology (Time Division Long Term Evolution), NB-IoT technology (Narrow Band Internet of Things), etc. Wired communication has USB, MBUS, RS232, RS485, Ethernet, etc.

Finally, the key protocols at the application layer are: MQTT (Message Queuing Telemetry Transport), AMQP (Advanced Message Queuing Protocol), CoAP (Constrained Application Protocol), XMPP (Extensible Messaging and Presence Protocol), Extensible Communication and Presentation Protocol), DDS (Data Distribution Service), LwM2M (Lightweight M2M), REST/HTTP (Representational State Transfer), SOAP (Simple Object Access Protocol), and Modbus protocol.

In different occasions to choose the appropriate communication protocol, on the one hand, it is necessary to meet the functional and performance requirements of physical hardware, on the other hand, also consider the needs of the operating environment and security, in the process of ensuring reliable information collection and data transmission, the operational performance of the system should be included in the inspection indicators to avoid data loss, illegal outside intrusion, and poor communication.

Application of AI Technology in BEEC Management

AI technology is developed by the mutual integration and promotion of Artificial intelligence and computer technology. AI is mainly used for trend prediction, classification, right and non-judgment of uncertain things. In BEEC management, energy-consuming equipment serves student and related activities. The prediction of building electrical electrical energy consumption mainly includes linear regression, grey prediction, and neural network and support vector machine.

(1) Linear regression prediction algorithm

Multiple regressions technology refers to the change analysis of the variation of two or more independent variables and one dependent variable. A change in a social phenomenon is often constrained and influenced by many factors. Multiple linear regression analysis method is a prediction method using the good linear correlation between dependent variables and independent variables\(^1\).

Literature\(^{22}\) used the multiple linear regression method to establish the electrical energy consumption prediction model of the Spanish bank building. According to the prediction results, the corresponding energy-saving opinions were given; Literature\(^{23}\) first the clustering algorithm is used to classify the data samples, and then the building electrical electrical energy consumption prediction model is obtained by multiple linear regression. The model has high accuracy, but the calculation amount is still large. Although the modeling process of the traditional linear regression model is simple, the corresponding calculation amount is large and the prediction accuracy is not high\(^{24}\).

(2) Grey model prediction algorithm

Grey prediction is to normalize the data, and use the gray theory method to perform an additive transformation on the original data, to realize the prediction of BEEC. The method can determine the width of each hidden node according to the distance between each cluster center. Literature\(^{25}\) the improved grey prediction algorithm is used for BEEC prediction, and the established electrical energy consumption model has better adaptability and high prediction accuracy; Literature\(^{26}\) established a neural network prediction model for BEEC in colleges by analyzing the BEEC data of Columbia University. The model takes the maximum temperature, the minimum temperature and the average temperature as input parameters, which has certain practicability. Literature\(^{27}\) the energy consumption data is grayed out, and then the RBF network training is used to establish a college BEEC prediction model based on GM-RBF neural network. The prediction accuracy is better than the single prediction model. Literature\(^{28}\) the gray theory method is used to analyze the heat transfer process of the building, and the gray model is used to calculate the heat transfer load of the buildings. Literature\(^{29}\) uses the combination of gray theory and Markov chain to predict the electrical energy consumption, and the grey Markov chain prediction model is established. Literature\(^{30}\) proposed a
method to predict the electrical energy consumption of public buildings by using the grey system theory, and established a seasonal grey prediction model. However, when the current method is using to predict the overall temperature regulation electrical energy consumption, it is impossible to predict the change trend of BEEC in different periods, and there is a problem that the building temperature regulation electrical energy consumption prediction deviation is large. It is applicable to the analysis of BEEC with few samples and poor information, but it is not ideal for the prediction results of data samples with high volatility. 

(3) Neural network prediction

Neural network has strong nonlinear fitting ability and has been successfully applied in the field of BEEC predictive analysis research in recent years. Literature the general regression neural network model is used to predict the cooling load of buildings, and the feasibility of the model is verified; Literature considering the factors of building orientation, insulation thickness and transparency, the neural network method is used to predict the building energy consumption, and the backpropagation (BP) neural network energy consumption prediction model is established. The basic function (RBF) neural network has the advantages of fast training speed, global optimization, and generalization ability. It is more concerned by researchers in the field of building energy modeling research; Literature On the basis of investigating 59 buildings, the RBF neural network model was established to realize the prediction of annual electrical electrical energy consumption of residential buildings; Literature analyzed the electrical energy consumption characteristics of public buildings and established the RBF neural network electrical energy consumption prediction model. Although the neural network has good nonlinear fitting ability, its prediction deviation is large when the sample size is small.

(4) Support vector machine prediction

Support Vector Machine (SVM) algorithm was proposed in 1964. It is a training model based on statistical learning theory based on small sample learning problem. This algorithm has a solid mathematical theoretical basis. Its application effectively solves the parameter selection required by neural network training algorithm, easily leads to the local optimal solution, and has good portability. The disadvantages are that the selections of parameters in the algorithm and the type of kernel function have a great influence on its classification effect, and the learning process is a little longer. Therefore, a number of scholars have proposed the Least Squares Support Vector Machines (LS-SVM) algorithm to solve the problem. Its principle is to replace the standard QP problem with a set of linear equations, which reduced the calculation time of the learning process. It is widely used in the prediction of electrical energy consumption of air conditioning systems. However, due to the randomness of LS-SVM parameter selection, it has a great impact on system performance.

Use Case—University BEEC Management Platform and Its Application

University BEEC Management Objects

The teaching building is a place with large electrical energy consumption, and its main electrical energy consumption objects are shown in figure 3. The electrical equipment is basically controlled in manual to turn on/turn off. This kind of control mode completely depends on individuals’ operation, which makes centralized control impossible and management inefficient. At present, there are three adverse phenomena in the electrical energy consumption of colleges: (1) when room no one or very few students, the electrical equipment in the room are still turn on. (2) the management method is that manual to turn on/turn off, often the students left but the lights are turn on.(3) the lighting of the corridor has always been a long-light phenomenon, even in bright daytime and more comfortable temperature, the lights and air conditioners are turn on.
Strategies for BEEC Management for University

In order to solve the problem of manual control of building electrical energy, it is necessary to apply intelligent management strategy to combine automatic control with building electrical energy management, so that the whole system has digital, networked and interactive. The ideal management system should process and analyze data collected by the sensor, combined with user instructions, to achieve the required management functions, and establish a personalized management method that meets the requirements of energy management. According to the demand analysis, the intelligent control strategy of college buildings can be established as shown in Figure 4.
Among them, the main objects of intelligent management of university buildings are laboratory equipment, room lighting, corridor lighting, campus road lighting, air conditioning and other electrical equipment. Therefore, at the bottom of the entire control strategy logic model, data can be collected in real time through infrared sensor, photosensitive sensors, Temperature and humidity sensor, and voice control sensor. In the data transmission layer of the control strategy logical model, mature WIFI protocol is applied to transmit the data packets to the router, and then the data packets are uploaded to the IoT platform and stored after passing through the MQTT protocol. Call the SQL database or API port to predict and analyze its data, and analyze the results of intelligent control terminal equipment.

Existing BEEC Management Platform

At present, the building electrical energy-saving control systems have not been recognized by most universities, only a few universities use electrical energy-saving control system. Zhejiang University of Finance and Economics installed “sensors” on each lamp in the classroom, It is controlled by photosensitive sensors and infrared sensors to reduce the frequency of students’ self-study in different classrooms and to promote the concentrated use of classrooms, thus to achieve the purpose of intelligent management of the teaching building; XHU University adopts the method of “regional control of electricity”, which enables students to study by themselves in the designated places of the university to avoid the unnecessary waste of electric energy. Shandong University, Jinan University and other domestic universities have also begun to adopt classroom lighting energy-saving systems to achieve their energy-saving purposes, but the actual effect is not good. South China University of Technology has achieved manual selection, but its electrical energy-saving effect is general, still to be developed and improve[39].

China's intelligent lighting system is still in the early stage of development; as a result, there is still much room for the development of intelligent lighting system in buildings. Foreign countries developed earlier and faster than China, and the current relatively sound electrical energy consumption control systems are shown in table 1.

| System | Characteristics |
|--------|-----------------|
| C-bus system (designed and developed by Clipsal company in Australia) | The open c-bus software interface protocol can be easily connected to the building automatic control system and can be applied to the building electrical energy saving control. Its use of advanced electronic technology, can achieve a variety of lighting control functions; Compared with traditional lighting control technology, it has better energy saving efficiency and cost performance[40]. |
| M-bus wireless intelligent lighting system (UK LITXP intelligent technology company) | Using high-tech communication technology and new technology, through the intelligent system, the lighting equipment in the building can achieve the function of automatic control of lighting brightness, the use of outdoor light intelligent adjustment of brightness, improve the electrical energy saving efficiency in the building. Its energy saving control system meets and reflects the requirements of energy saving, high efficiency, safety and comfort in “green campus”[41]. |
| Siemens building electrical energy saving control system (Siemens ag) | Through centralized intelligent energy management, efficient and innovative energy saving functions, and all the effective interaction between system components and processes and other special functions, with its modern building management function, it can reduce cost, improve building performance, comfort, and can keep dynamic economic balance between sustainable development, in order to achieve higher energy efficiency and economic value [42]. |

Recommended BEEC Management Platform

To change the current situation of increasing electrical energy consumption in colleges, it is necessary to strengthen the intelligent management of electrical energy consumption in colleges as well as the
predictive analysis, so that the electrical energy consumption of colleges can be controlled. In recent
years, domestic and international research on BEEC control in colleges and universities has begun to
receive attention, with the rise of the current IoT and the application of BI technology. Platform
technology and predictive analysis methods have gradually entered the field of buildings. Faced with
the current electrical energy consumption of colleges, it is mainly affected by teaching activities and
seasonal characteristics, the electrical energy consumption in colleges and universities is different and
obviously oscillating.

According to the above analysis, as shown in figure 5, the IoT platform is applied to connect the
router through MQTT protocol, and the bottom layer collects the entity information through the
sensor device. The WIFI LAN is applied to upload data to the router, and the network layer uses
MQTT protocol to upload data to the IoT cloud platform for storage. The electrical energy
consumption of university buildings is predicted by applying the grey theory combined with the
neural network prediction. The predicted results can also intelligently control the underlying
equipment, so as to achieve the purpose of electrical energy saving and electrical energy consumption
reduction of devices. In addition, information can be visualized on the user side or on the mobile APP.

**Conclusion**

Building electrical energy consumption is driven by market demands, many colleges are also striving
for electrical energy-saving. “Electrical Energy Saving” has been listed in the “13th five-year”
Chinese National Development Plan (2016-2020). In the past, most of the researches of the BEEC
focused on independent system control or technology, and lacked the details to the real application.
With the rapid development of computer technology, i.e., IoT technology, artificial intelligence,
information fusion technology and wireless transmission technology etc., the future development can
be seen in the following three aspects:

1. System integration will be the crucial technology in BEEC solution, i.e., lighting, air conditioning,
elevators, other electrical equipment should be connected via IoT and integrated with the security
system. The whole system should run on a set of software/platform to realize the functions, and
further more to making the management more intelligent and convenient.
The new technologies are widely used. With the rapid development of IoT and the related technologies, e.g., sensors, devices, protocols and the IoT middleware, the advanced solution for BEEC will be continuing developed and put in use with the characteristics of easier implementation, extendable, higher data accessing performance etc.

Multi-source information fusion and predictive analysis has now entered the era of data explosion, how to make use of the data effective will be the future development trend with the big data technology. As a result, obviously it will be wider used in BEEC.

The future work of the project will develop a prototype for BEEC by FIWARE middleware combined with the BI and big data technologies which will be used to verify the proposed method’s feasibility.

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References
[1] Mengzhen Li. Discussion on the Application of Short-Range Wireless Communication Technology in IoT [J]. Communication World, 2019.26(1):129-130.
[2] Zhiyi Du. Short-Range Wireless Communication Technology and Its Application in Campus [J].Communication World, 2019. 26(1):88-89.
[3] Blake R. (2001) Wireless Communication Technology[M]. 2001.
[4] Ogai H, Bhattacharya B. Experiments of Wireless Transfer Technology for Communication[J]. 2018.
[5] Blake R. Wireless Communication Technology[M].2001.
[6] Pavlopoulos S, Kyriacou E, Berler A, et al. A novel emergency telemedicine system based on wireless communication technology-Ambulance[J]. Information Technology in Biomedicine. IEEE Transactions on, 1998.2(4):261-267.
[7] Pantoli L, Stornelli V, Leuzzi G, et al. On-chip active filter in GaAs technology for Wireless communication systems[J]. Analog Integrated Circuits & Signal Processing, 2018. 96(1):1-7.
[8] Liu L, Xu B. Research on information security technology based on Blockchain [C]// 2018:380-384.
[9] Palade A, Cabrera C, Fan L, et al. Middleware for internet of things: an evaluation in a small scale IoT environment [J]. Journal of Reliable Intelligent Environments, 2018. 1-21.
[10] Wu M, Wu Y, Xiao L, et al. Learning-based synchronous approach from forwarding nodes to reduce the delay for Industrial Internet of Things[J]. Eurasip Journal on Wireless Communications &Networking, 2018(1):10.
[11] Oztekin A. Information fusion-based meta-classification predictive modeling for ETF performance[J]. Information Systems Frontiers, 2018(6):1-16.
[12] S.J. Shellhammer. Auto ID Technology: From Barcodes to Biometrics. IEEE Robotics and Automation Magazine, 1999. 6(1): 4-6.
[13] Ping Zhang, Jie Miao, Zheng Hu, et al. Review of Ubiquitous Network Research. Journal of Beijing University of Posts and Telecommunications, 2010.33(5):1-6.
Shijiang Yang. Research and Implementation of Intelligent Lighting Control System Based on ZigBee and GPRS Technology [D]. Jishou University. 2015.

Jianrao Xue, Wenjun Li, Enqi Wei. Current Situation and Problems of Indoor Air Environment Monitoring Technology [J]. Green Technology, 2016(20):59-60.

Xiaodong Chen. Research on Monitoring and Management Technology of Millet Field Based on Internet of Things. [master's thesis of Shanxi Agricultural University]. Shanxi: Shanxi Agricultural University. 2015.

Zhang. Design of Greenhouse Monitoring System Based on ZigBee. International Conference on Artificial Intelligence, Management Science and Electronic Commerce. IEEE, 2011.3895-3897.

Qia Rong. Application of Internet of Things Technology in the Field of Environmental monitoring [J]. Communication World, 2017. (23):351-352.

Subin Shen, Quli Fan, et al. Research on the Architecture and Related Technology of Internet of Things [J]. Journal of nanjing university of posts and telecommunications, (Natural Science Edition). 2009. 29(06):1-11.

Serbanati A, Segura A S, Oliverau A, et al. Internet of Things Architecture[J].Concept and Solutions for Privacy and Security in the Resolution Infrastructure, eu Project IoT-A, Project Report D, 2013.4.

Haihong Li, Xuesong Gong, Zhi Tong. Application of multiple linear regression Prediction model in prediction of rural domestic waste production[J]. Southwest Agricultural Journal, 2010. 23(4):1325-1328.

Aranda A, Germán Ferreira, M.D. Mainar-Toledo, et al. Multiple regression models to predict the annual energy consumption in the Spanish banking sector [J]. Energy and Buildings, 2012. 49 (3):80-87.

Guichun Fang, Xiaoyan Chen. Research on Forecast Model of Building Energy Consumption in Colleges and Universities in Fujian Province [J]. Energy Conservation, 2014.33 (1):45-49.

Yuedong Lin, Qiaoling Xu, Dong Chen. Building Energy Consumption Prediction Based on PCA-Elman Neural Network [J]. Intelligent Building Electrical Technology, 2016(4):5-8.

Rong Chen, Linzhi zhong, Chao Zhao, et al. Research on Building Electrical Energy Consumption Prediction Based on Improved Gray Model [J]. Journal of Fuzhou University: Natural Science Edition, 2013.41 (5):903-908.

Escrivá-Escrivá G, Álvarez-Bel C, Roldán-Blay C, et al. New artificial neural network prediction method for electrical consumption forecasting based on building end-uses [J]. Energy and Buildings, 2011.43(11): 3112-3119.

Chao Zhao, Siming Lin, Qiaoling Xu. (2014) Prediction of Building Electrical Energy Consumption in Universities Based on GM-RBF Neural Network [J]. Journal of Nanjing University of Science and Technology, 2014.38(01):48-53.

Wenbin H, Ben H, Changzhi Y. Building thermal process analysis with grey system method[J].Building and Environment, 2002.37(6):599-605.

Kumar U, Jain V. Time series models (Grey-Markov, Grey model with Rolling Mechanism and singular spec-trum analysis) to forecast energy consumption in India[J]. Energy,2010.35(4): 1709-1716.
[30] Wei Zhang. Research on Energy Consumption Monitoring in the Field of Public Building Energy Conservation Based on Seasonal Grey Prediction Theory [D]. College of Electrical and Automation, Hebei University of Technology. 2011.

[31] Anstett M, Kreider J F. Application of neural networking models to predict energy use [J]. Transactions—American Society of Heating Refrigerating and Air Conditioning Engineers, 1993;99:505-510.

[32] Neto A H, Fiorelli F A S. Comparison between detailed model simulation and artificial Neural network for fore-casting building energy consumption [J]. Energy and Buildings, 2008;40 (12):2169-2176.

[33] Ekici B B, Aksoy U T. (2009) Prediction of building energy consumption by using artificial neural networks [J]. Advances in Engineering Software, 2009;40(5):356-362.

[34] Li Q, Ren P, Meng Q. Prediction model of annual energy consumption of residential buildings [A]. Proceedings of the Advances in Energy Engineering (ICAEE) [C]. Washington DC, USA: IEEE. 2010.

[35] Dan Xiao. Research and system development of data mining methods for energy consumption analysis of public buildings [D]. Chongqing: College of Automation, Chongqing University. 2012.

[36] Jiecai Pei, Zhihua Li, Weicong Ding. Fault Diagnosis of Analog Circuit Based on Hybrid Kernel Function PSO-SVM [J]. Computers and Modernization, 2017(1):41-45.

[37] Wang Z, Yan M. Online adaptive least squares support vector machine and its Application In utility boiler combustion optimization systems [J]. Journal of Process Control, 2011;21(7):1040-1048.

[38] Xuejin Gao, Longxiao Fu, Cuixia Wu, et al. Energy Consumption Prediction Model of LS-SVM Subway Station Air Conditioning System Based on ISOA [J]. Computer and Modernization, 2018;278(10):40-47.

[39] Gan Guo. Building Energy Saving Control System Based on Wireless Communication [D]. Huaqiao University. 2016.

[40] Yunzhou Zhang, Chengdong Wu, Liang Jin, et al. Design of Intelligent Lighting Control System Based on C-Bus [J]. Control Engineering, 2008;15(2):182-184.

[41] Peng Wang. Application of M-BUS in AMR System of Smart Grid [D]. Shandong University. 2012.

[42] Jianhua Zhu, Jun Wang. Central Air-Conditioning Billing System Based on Siemens Building Automation System [J]. Informatization Research, 2004. 30(5):74-76.