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Research on building energy management in HVAC control system for university library

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Abstract

University libraries are usually high energy consuming buildings on campus and the operation efficiency of air conditioning system is still far from satisfactory. Combined with the building automation technology, heating, ventilation and air-conditioning (HVAC) control system for university library buildings has been proposed via fieldbus communication. The analysis of control system from electrical technology field is presented because traditional automatic control design cannot reflect the relationship between air-conditioning automatic control system and electronic devices in detail. Furthermore, since frozen station is one of the largest energy components in air conditioning system, the optimization of cooling water system in frozen station is carried out as an example to explain its electrical principle. The control program of cooling water system is compiled through a Delta WPL software and frequency converter. Building energy management of control system has been proven to reduce energy consumption on campus via the simulation of eQUEST software.

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Keywords: Building energy management; electric technology; HVAC control system; variable cooling water system

1. Introduction

Buildings account for a large portion of energy consumption and carbon dioxide emission. The proportion of campus energy consumption in universities has reached eight percent of the total energy consumption in the society [1]. The library is one of the highest energy consumption buildings on campus, which accounts for 12% of the total energy consumption in university [2]. Since sixty percent of total energy in library is consumed by heating, ventilation

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and air-conditioning (HVAC) [3], many researchers have suggested focusing on HVAC systems to effectively reduce energy consumption and help the Energy Management Department solving practical problems.

The technology of building energy management system (BEMS) is getting sophisticated with time enabling better control over energy consumption and reducing operational cost [4]. In the past few years, distributed control system (DCS) was widely used as a mature technology, but it had difficulty for users to go to each device to check and change its operating parameters [5]. Further, field devices were also hard to set-up and maintain centrally. To solve above problems, fieldbus control system (FCS) has been put forward to reduce system wiring and provide easy system maintenance [6,7]. The interoperability of FCS completely changes the closeness and specificity of DCS control layer. Due to the open interconnection network, database resources can be easily shared with different layers of network. Significant improvements have been seen in the logical algorithm over past few years, such as fuzzy-PID control via fieldbus communication [8].

However, few researches have mentioned the electrical principle and application of the electronic devices to HVAC control system. Intelligent electrical automation is a discipline that studies electrical engineering related to system operation, automatic control, power electronic technology, information processing and computer applications. This purpose of this study is to reveal the internal relation and improve energy efficiency. Based on fieldbus communication, HVAC automatic control system for university library has been proposed in this paper. Taking the example of cooling water system, this study has analyzed the necessity and function of the application for electric automatic control technology. Automatic control program is compiled and simulated through the online running condition of Delta WPL software. Furthermore, total energy consumption of HVAC system in library is analyzed from June to September by eQUEST simulation software.

Nomenclature

AO	automatic operation	FCS	fieldbus control system
AHU	air handing unit	FLN	floor level network
BEMS	building energy management system	MBC	modular building controller
BLN	building level network	MEC	modular equipment controller
CT	cooling tower	MLN	management level network
DDC	direct digital control	MO	manual operation
DCS	distributed control system	PLC	programmable logic controller
EAF	exhaust air fan	RAD	return air duct
ECC	electric control cabinet	SAF	supply air fan
FAU	fresh air unit	VVVF	variable voltage and variable frequency

2. Building description

An intelligent university library in Xian is taken as an example. The maximum of cooling load is 4155.22kW in summer and heat load is 3198.66kW in winter. Magnetic suspension centrifugal frozen unit is used as the cold source, and heat source comes from municipal heating. Considering the function of rooms, the university library has taken two kinds of HVAC systems. The office rooms in this library adopt fresh air unit (FAU) with fan coil, and other rooms including storage rooms and multi-function hall, which own large spaces, adopt full air handing unit (AHU). The details of HVAC system in library can be seen in Table.1.

3. System

Electrical automation has become an indispensable part of building energy management system. This paper mainly discusses the application of electrical automation in intelligent buildings. As advanced intelligent network control and room load change, the design of HVAC control system is based on FCS to realize remote automatic adjustment of air conditioning system operation in university library.

Table 1 The details of HVAC system in library

No	HVAC system	Floor	Service area	The maximum of cooling load in summer (kW)	The maximum of heat load in winter (kW)	Machine Room
1	AHU	G	Hall and corridors	139.74	156.73	G-Room 1#
2	FAU	G	Offices	368.69	363.43	G-Room3#,5#,6#
3	AHU	1st	Reading rooms	571.31	441.21	1st-Room1#,2#,3#,6#
4	FAU	1st	Bookshop and copy shop	42.51	33.88	1st-Room5#
5	AHU	2nd	Multi-function hall and reading room	856	674.19	2nd-Room1#,3#,4#,5#,6#
6	FAU	2nd	Offices	76.42	64.57	2nd-Room2#
7	AHU	3rd	Reading rooms and meeting rooms	833.83	536.21	3rd-Room2#,3#,5#,1#
8	FAU	3rd	Offices and study room	125.44	111.92	3rd-Room6#
9	AHU	4th	Storage rooms and exhibition room	576.50	323.64	4th-Room3#,5#,6#
10	FAU	4th	Study room	95.51	94.04	4th-Room2#
11	AHU	5th	Storage rooms	385.04	398.84	5th-Room1#,3#,4#,6#

3.1 Three-layer bus network architecture

The automatic control system diagram can be seen in figure 1. This BEMS is composed of Siemens APOGEE building control system including insight monitor software, direct digital controllers, sensors and actuators.

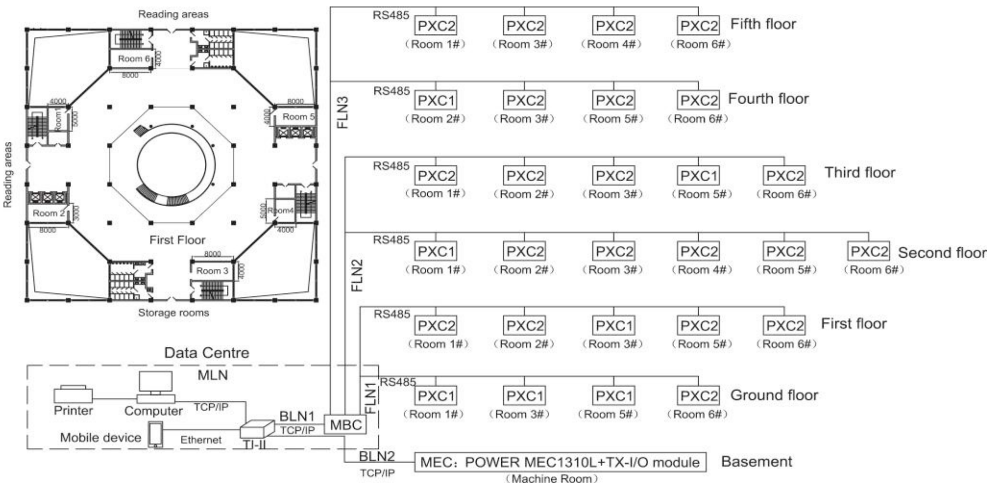
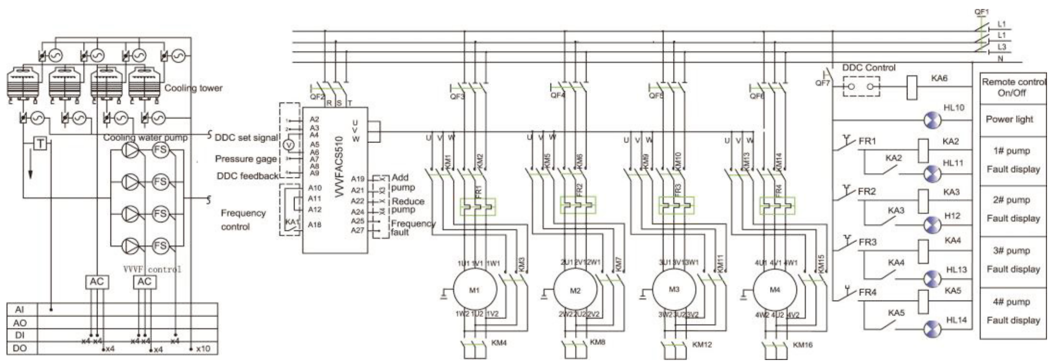


Fig.1. Library automatic control system diagram

The data transmission adopts three-layer bus network architecture. First, floor level network (FLN) is the basic network in APOGEE system, which can support modular programmable controller, extended module or terminal equipment controller. In this work, PXC1 and PXC2 are used to represent direct digital controller for FAU system and AHU system respectively. Each air handling system in building has the same position relationship in the network and can communicate directly with central station by the MODBUS RS485 remote terminal unit. Point-to-point communication help to ensure high communication rate at the same time [9]. Next, building level network (BLN) supports three building-level networks at the same time and these networks use 24AWG twisted-pair shielding lines to support up to 115kbit/s communication rates. Modular equipment controller (MEC) is applied to the frozen station and modular building controller (MBC) provides gateway functions for distributed network. Because of the open network structure, this system can integrate cold source and air handing unit monitoring. Even equipment system from third party, such as fire safety monitoring, can also be connected to this platform. Furthermore, BLN receives the signals of air conditioning equipment and refrigeration machine from different floors, and then sends them to management level network (MLN). Operators can remote monitor the operating state of equipment all the time via MLN because this management network adopted with TCP/IP protocol and Ethernet to realize the total monitoring of integrated cabling system in library.

3.2 Optimal cooling water control system

The computer networking of electronic devices is designed to monitor and control HVAC system. For example, the MEC controller (Power MEX1310L) with function of supporting point extension module is selected for frozen station in Fig.1. Since the most energy in HVAC system is consumed by frozen station [10-11], this separate controller is used in the system. Traditional design for HVAC automatic control system cannot reflect the connection between electronic devices and frozen station, so we come up with an idea to explore the automatic control system in the aspect of electrical technology field. Cooling water system is taken as an example to explain the electrical control in Fig.2.



(a) Cooling water system (b)Electrical control diagram

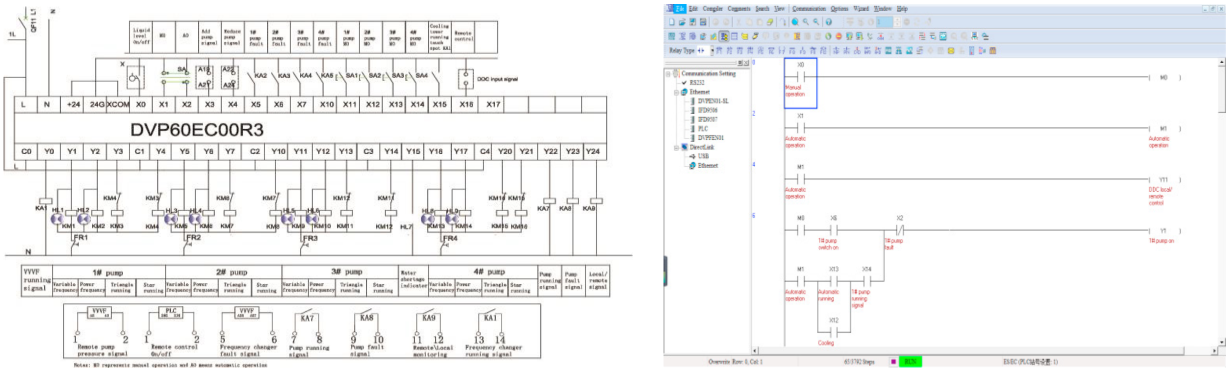
Fig. 2 electrical schematic diagram of cooling water system.

As seen in Fig. 2(a), the cooling water system consists of four cooling towers, four cooling pumps, pressure sensors and water pipes. Having received the signal of cooling tower received in programmable logic controller (PLC), the cooling pumps are automatically regulated by the PID regulation in the frequency converter. Researchers may worry that the decreasing flow of cooling water results in a decrease of refrigeration effect. Actually, the change of cooling water flow does not affect cooling capacity, but passively alters with the change of load. The operation of variable cooling water flow is also a technical measure to adapt to the change of load. Moreover, the air conditioning load varies with season. Considering the special characteristic of university library, most students have their summer vacation in China, so few people go to the library at high temperatures [12]. In low temperature environment, the outlet water temperature of the cooling water will be reduced by the small air conditioning load. In other words, the cooling water is relatively overflowing most of time. Hence, variable flow cooling water system can achieve energy saving.

In Fig. 2(b), electrical schematic diagram of variable flow cooling water system can be divided into three parts, namely frequency converter, four cooling pumps and electric control cabinet (ECC). The frequency converter of type ACS510 is selected to control the number of cooling pump by receiving the given signal from Power MEX1310L and providing feedback through the A7 and A9 ports because energy cannot be effectively managed without closed-loop feedback. The emergency protection of equipment is set by the ports of A25 and A27 ports in the frequency converter.

From the main circuit, the cooling water pumps can be started directly at low frequency by converter. Besides, the star-triangle start control is designed in this study to reduce the impact of start-up current on power grid at power frequency. Furthermore, remote or local monitoring status can be changed by the switching signal of AC contactor KA6. If a user is not in the machine room, the monitoring and control information can also to be sent to the server from a client PC over web or specially appointed mobile device.

The wiring diagram of PLC can be seen in fig.3(a). The controller (DVP60EC00R3) is connected to the frequency converter to realize the remote control of cooling water pumps. The function of fan and pump linkage control is also set in this controller through X15 port. After receiving the running signal from cooling tower, KA1 contact closes, allowing current to pass through a circuit to indicate to the controller that the cooling pump turns on. As shown in fig.3(b), the program of cooling water system is written in the Delta WPL software. Optimal start/stop control is set in this system. Because the opening hours of university library are fixed, the optimal time of day and operating conditions can be calculated for initiating system operation. Based on the online running in the PLC software, the program has been successfully worked and there are no errors exists. Hence, the variable cooling water control system has been proven to provide supervisory control strategies and reduce energy consumption.



(a) Controller's electrical schematic diagram (b) Online running program

Fig.3 Electronic device and program test

3.3 Energy consumption of HVAC system in summer

In the process of energy consumption statistics, the total building energy consumption is divided into energy consumption of cooling machine, cooling water system, chilled water system, cooling tower fan and water pumps. The energy consumption of buildings is calculated by an hourly BIN method in table 2. According to the values of outdoor dry bulb temperature in Xian, the number of hours from 8:00 to 20:00 is counted in the temperature range of 20-37℃. The program has assumed that air conditioning load is proportional to the indoor and outdoor temperature difference for simplifying calculation. Then total energy consumption is accumulated by air conditioning load and equipment energy consumption from sample data. From the table 2, most days are in the condition of load ratio less than 20%, followed by in the range of 20% ~ 40%, but the energy consumption of these two parts is the least.

Table 2 Energy consumption under different loads in summer

Cooling load rate (%)	>80	60<φ≤80	40<φ≤60	20<φ≤40	≤20
Temperature (℃)	t>32	29<t≤32	26<t≤29	23<t≤26	t≤23
Running time (h)	116	168	193	218	293
Number of working machines	4	4	3	2	1
Power of cooling water pump (kW)	120	120	90	60	30
Power of cooling tower (kW)	30	30	22.5	15	7.5
Energy consumption in summer (kWh)	60,796	62,302	48,143	28,015	10,955

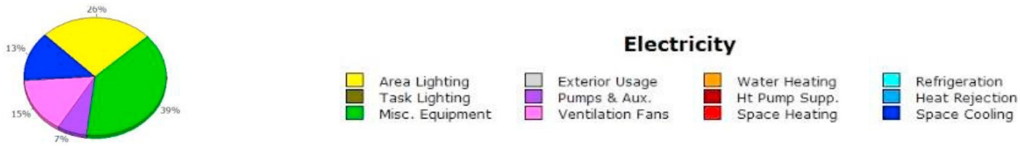


Fig.4 Energy consumption proportion in summer

Total electrical consumption of HVAC system in library is analyzed from June to September. The parameters for occupancy, lighting power, and equipment power are inputted into eQUEST. The simulated energy consumption from the calibrated model is 538,556 kWh in summer and each part of energy consumption is shown in Fig.4. Traditional air conditioning system accounts for 40.6% of total building energy consumption[13], but the energy consumption of this system has decreased to 35% and frozen station constitutes less than 38% of HVAC energy consumption owing to the optimal HVAC automatic control system.

4. Conclusion

Building energy management of HVAC control system has been carried out in a university library. The objectives of BEMS are the improvement of occupant comfort, the efficient operation of building systems and the reduction in energy consumption and operating costs. APOGEE building automatic control system is adopted in library to realize the remote monitoring function of central station to each sub-station through MODBUS-TCP/IP and Ethernet/IP protocol. From the field of electrical technology, variable cooling water system is taken as example to show the function of optimal start/off control, emergency protection and linkage control via the closed-loop feedback system in the frequency converter and programmable logic controller. Supervisory control strategies have been proven to reduce energy consumption on campus and the application of electric automatic control technology greatly improves the performance of refrigeration and air-conditioning equipment.

References

[1] H.W. Tan, X.U. Yu, H.C. Lin and H.U. Cheng. Research on Building Campus Energy Management. Building Energy & Environment, 29 (1) (2010), pp: 36-40.

[2] B. Gao, H.W. Tan and Y.C. Song. Campus Building Energy Consumption: Taking one Comprehensive University as Example. Building Energy Efficiency, 39 (2011), pp: 41- 44.

[3] M. Hassan, A. Amrin, S. Sarip, G.Y. Khawaja and A. Grader. Simulation of Operational Faults of Heating, Ventilation and Air Conditioning Systems Compromising Energy Consumption for Abu Dhabi Future Schools (ADFS). International Journal of Engineering Research and Reviews, 4 (2016), pp: 97-106.

[4] T. Nikolaou, D. Kolokotsa, and G. Stavrakakis. Review on methodologies for energy benchmarking, rating and classification of buildings. Advances in Building Energy Research, 5 (2011), pp: 53-70.

[5] J.E. Luntz and W. Messner. A distributed control system for flexible materials handling. IEEE Control Systems, 17 (1997), pp :22-28.

[6] W. Pratt. Evaluating fieldbus networks: Choose the right tool for the job (2003).

[7] S. Kolla, D. Border and E. Mayer. Fieldbus networks for control system implementations. Electrical Insulation Conference and Electrical Manufacturing & Coil Winding Technology Conference, (2003).

[8] I.C. Franco, F.V.D. Silva, A.M.F. Fileti and M.R. Menezes. Implementation and tuning of a FUZZY-PID control system via fieldbus communication. Process Control, 3 (2017), pp: 0889-0898.

[9] T.B. Hartman. Direct Digital Controls for HVAC Systems. McGraw-Hill, Inc. (1993) New York, NY, USA.

[10] X. Du, X. Qi and M. Ai. The analysis of the energy efficiency of refrigeration stations in HVAC. 2009 IEEE International Conference on Automation and Logistics. (2009), pp:175-180.

[11] X.H. Yang, Z. Lu, Q.S. Bai, Q.L. Zhang, L.W. Jin and J.Y. Yan. Thermal performance of a shell-and-tube latent heat thermal energy storage unit: Role of annular fins, Applied Energy. 202 (2017), pp:558-570.

[12] Q.W. Jiang, X.Z. Meng, Y.H. Liu, J.B. Chen and M. Zhao. Measurement and Evaluation on Air Quality of the University Library with HVAC System, 4th International Conference on Building Energy & Environment, (2018) Melbourne Australia.

[13] Y. Wang and A. Li. Survey on energy consumption status and field test of temperature and humidity for public buildings in Xi'an in summer, Heating Ventilating & Air Conditioning, 58 (2009), pp:76-80.