Energy-saving Applications of IoT Intelligent Control Technology in Hospital Central Air Conditioning Systems

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Abstract. With the reform of medical and health care, the energy consumption of central air conditioning in hospital public buildings is increasing, so there is a growing need to strengthen the operational control of central air conditioning to achieve efficient and energy-saving operations. Simultaneously, with the maturity of Internet of Things (IoT) technology, constructing an IoT intelligent control system for energy-saving operation and maintenance of central air conditioning has become an application trend in the energy-saving era. This paper introduces a detailed method of constructing an intelligent control system of central air conditioning by using IoT technology and takes the actual hospital project as an example to use the intelligent control system. Through comparative testing, it is ultimately verified that the energy-saving rate of central air conditioning with IoT intelligent control is over 20%, providing references for energy-saving applications of central air conditioning in large hospital buildings.

Keywords: IoT intelligent control; central air conditioning; hospital; energy saving

1 Introduction

With the increasing energy shortage around the world, all walks of life in China actively respond to the dual-carbon goal of "3060 carbon peaking and carbon neutrality" launched by the state. As a key energy-consuming unit, the large general hospitals' efforts in energy saving and consumption reduction not only reflect the social responsibility of public hospitals but also hold great significance for reducing medical costs and promoting the sustainable development of hospitals. With the continuous development of hospitals, patients' requirements for hospital environmental comfort have increased. While central air conditioning systems meet the comfort requirements of hospital environments, they also consume a significant amount of energy. Therefore, there is considerable energy-saving potential in the operation of central air conditioning systems. With the rapid development of IoT technology, it is imperative to utilize it to build intelligent control for central air conditioning systems and realize energy-saving transformations for their efficient operation. This paper takes the IoT intelligent control energy-saving renovation project of central air conditioning in a Grade IIIA hospital in Shanghai as an example to analyze the intelligent control on energy-saving and discuss the application of IoT intelligent control technology of central air conditioning.

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2 Energy-saving Operation Status of Central Air Conditioning

In public buildings, the energy consumption of central air conditioning systems accounts for about 50% of the total energy consumption [1]. Among them, hospital buildings, due to their special functional requirements, have characteristics such as operating 24 hours a day throughout the year and providing multifunctional services. Their air conditioning energy consumption is higher than that of general public buildings, accounting for 60% or more of the total building energy consumption [2]. As the cold source of the central air conditioning system, there will be some phenomena such as aging of equipment in refrigeration stations, unreasonable human control, and poor maintenance in the actual operation of the air conditioning system, which will lead to a further increase in energy consumption.

The research on energy saving of central air conditioning system operation started from the analysis and statistics of energy consumption data of public buildings at the earliest time. Then, it proceeded with simulation and analysis through the corresponding software construction model [3]. The analysis results are used to select the optimal energy consumption monitoring and control scheme, realize reasonable energy distribution, analysis, and management, help operation and maintenance managers analyze the changing trend of equipment energy consumption, and facilitate timely detection of abnormally high energy consumption equipment [4-5].

At present, the main energy-saving methods of central air conditioning systems include reducing cold/heat load, improving equipment operation efficiency, and optimizing system operation control. By constructing a Building Automation (BA) system, the controller of air conditioning equipment can be regulated more intelligently to achieve energy-saving goals [6-7]. However, in such control, independent control loops for air conditioning units often exist, which are controlled according to the given setpoints, lacking support from a system coupling model support and overall performance optimization. Due to the refrigeration station of central air conditioning being a multivariable, complex, and time-varying system, there are significant nonlinearities, great time delay, and strong coupling relationships among its process elements [8]. Therefore, it is necessary to establish a systematic group control to achieve reasonable and normal operation.

3 IoT Intelligent Control System for Central Air Conditioning

The central air conditioning system (refrigeration condition) is mainly composed of cold source equipment and the transmission and distribution system, which has the characteristics of numerous equipment, complex system operation mechanisms, and great time delay of energy transfer. It is impossible to realize the efficient and stable operation of the central air conditioning system by manual operation and management. However, the IoT intelligent control system can collect and monitor the running state and parameters of the system in real time, analyze, diagnose, and calculate according to the intelligent control strategy model, and ultimately provide the optimized control instructions to assist the overall intelligent management and energy efficiency improvement of the system from cold source equipment to transmission and distribution system.

The refrigeration unit of the central air conditioning system is the equipment with the largest energy consumption on the cold source supply side, whose working performance and energy efficiency level directly affect the energy consumption of the central air conditioning systems. With the help of IoT data acquisition means, the performance level of refrigeration capacity, loading rate, and operation efficiency of the unit can be judged. The transmission and distribution system of central air conditioning mainly includes all kinds of pumps, pipeline systems, matched valve components, etc. Grasping all kinds of real-time operation parameters in the transmission and distribution system comprehensively and accurately and regulating the frequency of relevant valves and pumps rationally are not only conducive to reducing the energy consumption of the system but also conducive to improving the operation conditions of the main refrigeration, thus bringing greater energy-saving benefits.

The IoT intelligent control system is mainly divided into three layers, as shown in Figure 1. The first layer is the data sensing layer, including IoT intelligent sensors and various intelligent terminals, which collect real-time operation data in the on-site air conditioning system, communicate with field devices, and upload them to the cloud through the gateway. The second layer is the data processing layer, in which the cloud algorithm program processes and analyzes the data collected by IoT, forms the intelligent centralized control strategy of the system, and then sends it to the gateway, realizing data collection and uploading, algorithm analysis, and intelligent control distribution; the third layer is the application display layer, which interacts with system users through various means such as computer web terminal and mobile APP to realize data viewing, display, and operation control.

The algorithm analysis of the data processing layer and the centralized control strategy directly affect the efficient operation of the air conditioning system, and determine the operation safety and energy consumption level of the cold station system. In the intelligent control system proposed in this paper, the algorithm processing consists of a trinity closed-loop algorithmic structure comprising “load forecasting-AI intelligent control-fault diagnosis”.

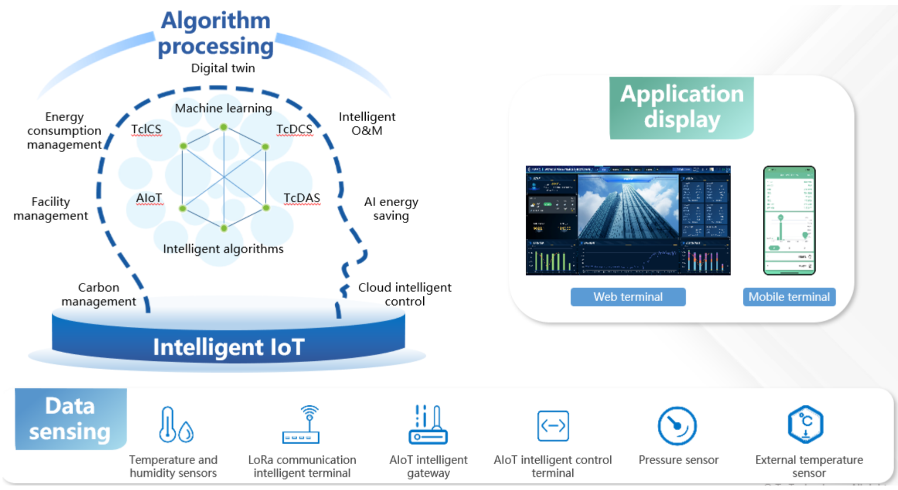

Figure 1 Architecture of IoT intelligent control system

Load forecasting predicts system energy consumption, cold and heat load, and indoor temperature, which is used to assist AI intelligent control algorithms. According to the data collected by the system and the prediction results, AI intelligent control adopts a rule model and algorithm model, which can carry out cloud-edge-terminal collaborative energy-saving control. Fault diagnosis adopts shallow and deep double-layer intelligent diagnosis paths, constructs the equipment fault model, alarms and warns sensors, equipment, and systems, and ensures the safety of intelligent control.

AI intelligent control in the proposed intelligent control system takes into account the advanced nature of system security and algorithm autonomous learning, and the dual-modal architecture it adopts is shown in Figure 2.

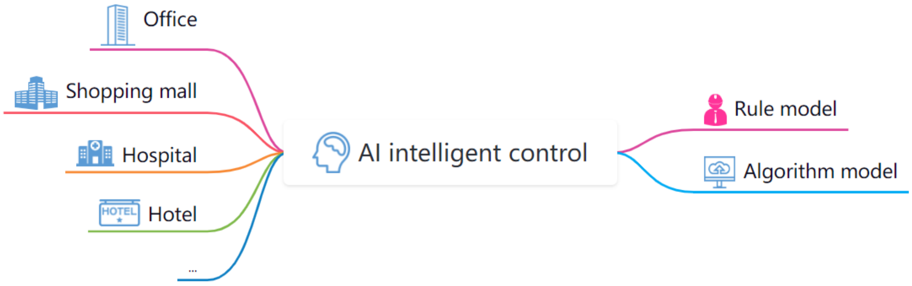

Figure 2 Architecture diagram of AI intelligent control

Among them, the rule model contains hundreds of valuable expert rules in the field of traditional PLC automatic control, which can be specially invoked according to different formats to ensure the stability and rationality of the intelligent control system. The algorithm model uses the powerful computing power of the cloud to learn and optimize the key parameters in the rule model independently according to the actual operation of the central air conditioning system, improving the energy-saving benefits of efficient operation.

The rule model mainly includes temperature control of the main engine, addition and subtraction machine control, variable flow control of the water pump, approximation control of the cooling tower, and so on. The detailed rule model is shown in Figure 3 below. The rule model defines the safe actions, while the conditional parameters between different actions need to be determined by the algorithm model in different application scenarios and working conditions.

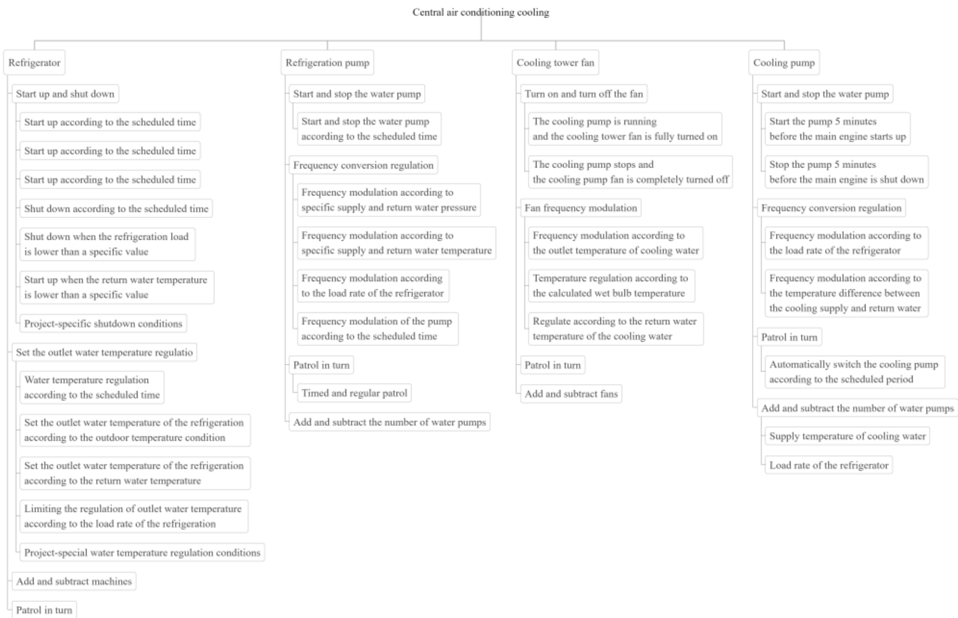

Figure 3 Example of the rule model

4 Case Study

The project case of this paper is a general Grade IIIA hospital in Shanghai, which includes several buildings and shares a refrigeration station. The refrigeration supply covers different functional service areas such as outpatient service, ward, physical examination, purification room, and machine room. The cold sources of central air conditioning are centrifugal chillers and screw chillers, and the auxiliary machines include primary chilled water pumps, secondary chilled water pumps, cooling water pumps, and cooling towers. The detailed list of equipment is shown in Table 1 below, and the refrigeration station supplies nine areas.

Table 1. List Of air Conditioning System Equipment In Refrigeration Station

Type of equipment	Quantity	Parameter	Remarks
Centrifugal chiller	3	Refrigerating capacity: 4219 kW, power: 707 kW	
Screw chiller	4	Refrigerating capacity: 1164.6 kW, power: 216 kW	
Primary chilled water pump 1	4	Power: 45 kW, flow rate: 520 m³/h, head: 22 m	Without frequency conversion
Primary chilled water pump 2	2	Power: 15 kW, flow rate: 140 m³/h, head: 22 m	Without frequency conversion
Secondary chilled water pump 1	3	Power: 22 kW, flow rate: 180 m³/h, head: 29 m	Area B of the main building (frequency conversion)

Secondary chilled water pump 2	3	Power: 18.5 kW, flow rate: 140 m³/h, head: 26 m	Special needs clinic (frequency conversion)
Secondary chilled water pump 3	3	Power: 30 kW, flow rate: 200 m³/h, head: 32 m	Area A of the main building (frequency conversion)
Secondary chilled water pump 4	3	Power: 22 kW, flow rate: 155 m³/h, head: 32 m	Turnover department (frequency conversion)
Secondary chilled water pump 5	2	Power: 11 kW, flow rate: 70 m³/h, head: 24 m	Constant cooling machine room c (constant frequency)
Secondary chilled water pump 6	3	Power: 30 kW, flow rate: 250 m³/h, head: 29 m	Science and technology building (frequency conversion)
Secondary chilled water pump 7	3	Power: 30 kW, flow rate: 175 m³/h, head: 30 m	Constant cooling purification room (constant frequency)
Secondary chilled water pump 8	3	Power: 11 kW, flow rate: 55 m³/h, head: 28 m	Physical examination center (frequency conversion)
Secondary chilled water pump 9	3	Power: 7.5 kW, flow rate: 35 m³/h, head: 27 m	Inner area of the main building (frequency conversion)
Cooling water pump 1	6	Power: 75 kW, flow rate: 530 m³/h, head: 36.5 m	Four sets with frequency conversion and two sets without frequency conversion
Cooling water pump 2	2	Power: 37 kW, flow rate: 220 m³/h, head: 38 m	Frequency conversion
Cooling tower	7	Power: 11 kW	Without frequency conversion

The main engine, water pump, and other equipment of the refrigerating room are manually operated by relevant engineers according to the experience value, and the overall manual control level is high, but there also exists some problems:

(1) The water supply temperature set by the main engine is relatively constant and cannot be dynamically adjusted according to the real-time load. Although the field engineer will adjust the outlet water temperature of the main engine according to the weather conditions, the adjustment frequency is relatively low.

(2) The variable flow regulation of the water pump is less, and there is a phenomenon of large flow and small temperature difference in the partial load period. Some pumps are equipped with frequency converters but lack sufficient data feedback for recording and analysis. The operation of frequency conversion regulation of pumps by manpower is limited, and the variable flow regulation of pumps is not fully realized. At the same time, some pumps are not equipped with frequency converters and run at power frequency.

(3) The cooling tower does not realize the automatic control operation and regulation of the number of operating units according to the cooling water temperature, which can not make full use of its heat dissipation function, thus affecting the operating load of the refrigerators.

Through the upgrading of the IoT intelligent control system, the digital upgrading of the central air conditioning system of the hospital refrigeration station has been basically realized. After a period of data collection and accumulation and system self-learning, the cloud algorithm program combines an expert model and algorithm model to formulate an optimal control strategy, realizing the intelligent operation of the central air conditioning system.

Through an energy-saving test, the energy-saving benefits of continuous operation for 48 hours under two working conditions (24 hours in the original mode and 24 hours in the intelligent control mode) are compared, and the test data are shown in Table 2.

The calculation formula for the energy saving amount and energy saving rate is as follows.

$$E_s = E_r - E_a \quad (1)$$

$$\eta = (E_s / E_r) \times 100\% \quad (2)$$

where:

E_s–energy saving amount, kWh;

E_r–power consumption in original mode, kWh;

E_a–power consumption in intelligent control mode, kWh;

η–energy saving rate, %.

Table 2. Comparative Data Of Intelligent Control On energy Saving

Working condition	**Mode**	**Centrifuge**	**Screw machine**	**Refrigeration pump**	**Cooling pump**	**Cooling tower**	**Total consumption**
Case 1	Power consumption in original mode (kWh)	18, 334	48	7, 614	4, 629	2, 988	33, 613
	Power consumption in intelligent control mode (kWh)	14, 040	48	5, 438	2, 867	3, 136	25, 529
	Energy saving amount (kWh)	4, 294	0	2, 176	1, 762	-148	8, 084
	Energy saving rate (%)	23.42	0.00	28.58	38.06	-4.95	**24.05**
Case 2	Power consumption in original mode (kWh)	9, 274	2, 478	5, 582	3, 559	2, 748	23, 641
	Power consumption in intelligent control mode (kWh)	7, 816	2, 004	4, 201	1, 661	2, 586	18, 268
	Energy saving amount (kWh)	1, 458	474	1, 381	1, 898	162	5, 373
	Energy saving rate (%)	15.72	19.13	24.74	53.33	5.90	**22.73**

Case 1 is a comparative working condition in September when the temperature is relatively high and the cooling demand is large. It runs with a large-capacity centrifuge for cooling and supplies nine secondary pump areas all day. Case 2 is a comparative working condition in October, and the temperature is relatively low. Except for two normally cold areas, which are cooled 24 hours a day, the other areas will stop cooling at night. Therefore, the centrifuge is used for cooling during the day and the screw machine is used at night.

In this project case, the original power frequency cooling pump is changed into a frequency conversion pump, and the frequency converter is regulated by intelligent control, so the single energy saving rate of the cooling pump is the highest in the above working conditions. The energy saving rate of the cooling tower in Case 1 in the above table is negative, which means that the cooling tower is used more in intelligent control mode, making full use of the heat dissipation effect of the cooling tower and reducing the return water temperature of cooling water, as shown in Figure 4. Under manual control, the water temperature changes widely, basically at 23-28℃, while the temperature under intelligent control remains relatively stable, ranging from 23℃ to 26℃.

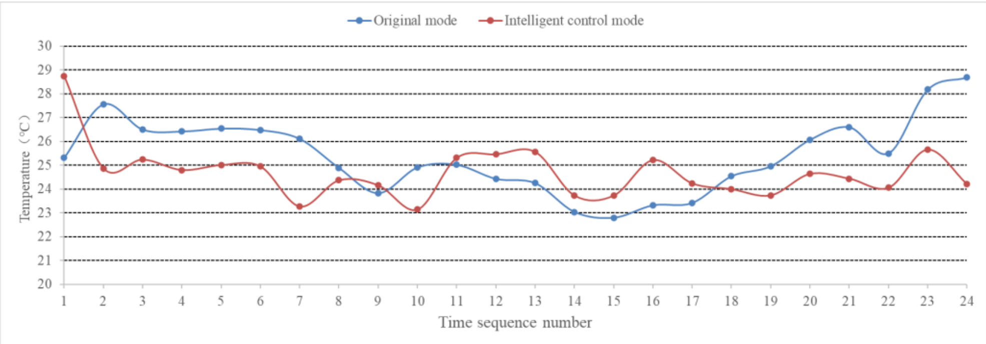

Figure 4 Hourly cooling water return temperature in Case 1 under original mode and intelligent control mode

Because the refrigeration station system needs to supply nine areas, the pipeline system is complex, and the pumps in each area are manually regulated, resulting in the phenomenon of pipeline hydraulic imbalance. The return water temperature in the constant cooling area (machine room and purification room) is higher than that in other areas, as shown in Figure 5. The time in the figure is from 12:00 on the first day to 12:00 on the second day. The return water temperature in each area ranges from 11℃ to 14℃, and the regional temperature difference is above 4℃ at night. The temperature of the constant cooling purification room during the day is about 2℃ higher than that in other areas. To ensure the cooling of this purified operating room, it is necessary to increase the output of the refrigerator, which leads to the high load operation of the centrifuge and even the need to open other refrigerators. Through the control of an intelligent control algorithm program, the frequency conversion operation of pumps in each area is reasonably controlled, which basically achieves the hydraulic balance of pipelines in each area and ensures that the frozen water supply in each area is similar. The return water temperature in 9 areas under intelligent control operation is shown in Figure 6. Except for the large temperature difference in each area in 6 hours at night, the temperature difference in each area is basically within 2℃ for the rest of the time, which ensures the cold supply of the purified operating room under the condition of low load operation of centrifuges. Therefore, intelligent control regulation directly affects the energy consumption of the refrigeration pump and the main engine, possessing high energy-saving benefits.

Through the comparison and verification of two different working conditions, it can be observed that the energy-saving rate of central air conditioning refrigeration station operation regulation based on IoT intelligent control system is over 20%, revealing considerable energy-saving benefits.

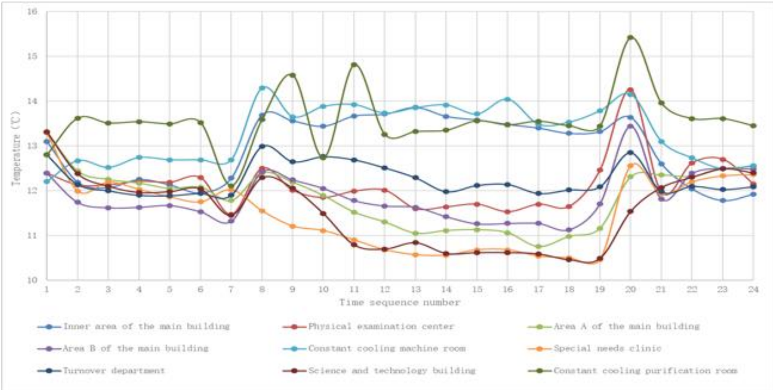

Figure 5 Return water temperature of 9 cooling areas under Case 1 original mode operation

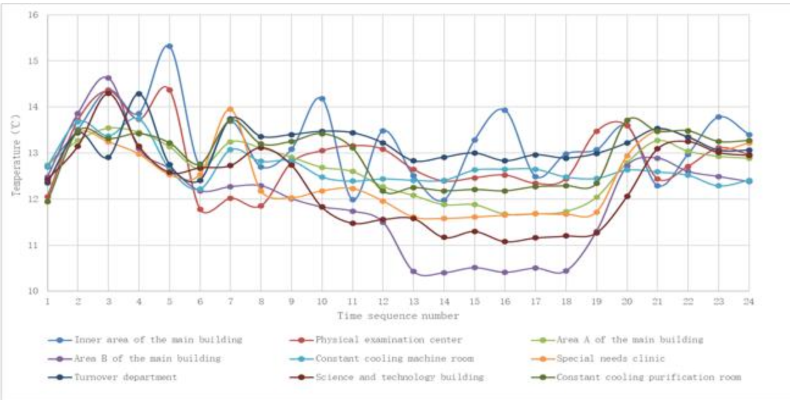

Figure 6 Return water temperature of 9 cooling areas under Case 1 intelligent control mode operation

5 Conclusion

Through using the algorithm program of the IoT intelligent control system, the overall operation of the system can be fully considered to jointly control multiple devices, which improves the comprehensive analysis ability of multiple influencing factors in the operation control of the central air conditioning system, obtains a more optimized operation control strategy, and realizes the coordination and consistent balance between the operation performance and the energy-saving effects.

The hospital has constructed a central air conditioning intelligent system based on IoT, which can realize the effective application of big data, cloud computing, and artificial intelligence in the hospital scene, making energy interconnected, orderly and controllable, safe and intelligent, meeting the need of China's medical system reform and energy revolution, and also meeting the requirements of construction and development of intelligent hospitals and smart cities.

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