AUTOMATIC STORAGE OF BUILDING THERMAL ENERGY AND HEAT PUMP HEATING BASED ON WIRELESS COMMUNICATION

by

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By means of ZigBee wireless communication technology and heat pump heating technology, the author reduces energy consumption, solve the problem of large energy consumption of building heat pump heating at present. Firstly, the characteristics and applications of ZigBee wireless technology in the system design are adopted, and its protocol stack structure and topology are analyzed, respectively, select your own network structure according to the characteristics of this system. According to its structural characteristics, the overall design of the heat pump wireless control system is designed. Secondly, by installing the heating transmission and distribution system controller, the pressure loss in the system loop is overcome, and the zero differential pressure control point is selected to control the throttling resistance loss of all heat users, start the heating system unit in the building to realize the application of heat pump heating system in the building. Through three experimental tests, the maximum energy consumption of the system in 24 hours application is 9.99 kWh, the minimum energy consumption is 9.53 kWh, and the average energy consumption is 9.7 kWh, the energy consumption in building application is relatively stable, low energy consumption, and good practicability. The adoption of ZigBee wireless communication technology will improve the operation mode of heat pump heating system and improve the automation level and performance of the system.

Key words*: wireless communication, building thermal energy, heat pump heating*

Introduction

As networking and communications technology advances, short-range wireless communications are becoming more and more popular in education and business because they are cost-effective, energy-efficient, and user-friendly. Short-range wireless communication technology is developing rapidly, and currently there are many basic wireless communication technologies: Wireless WLAN technology (Wi-Fi), Bluetooth technology, RFID technology, UWB technology, ZigBee technology*, etc.* The principle of heat pump technology is the old cycle of physics (reverse Carnot cycle), which uses low pressure and low heat to absorb heat from the environment and transfer it to the heating object, which is the most important heating element. The principle of the heat pump is to convert from low energy to high energy using electricity, such as air source heat pump technology, water source heat pump technology, and ground source heat pump technology, which can reduce heating and cooling energy consumption of buildings and provide heating and ventilation reduce environmental pollution in the area. Ac-

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cording to different types of heating equipment, heat pumps can be divided into three types, namely heat pumps, heat pumps and underground heat pumps, fig. 1.

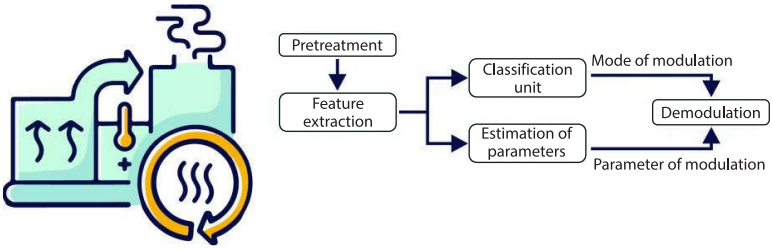

Figure 1. Building thermal energy for wireless communication

Literature review

The operation of the heat pump is a new type of heat, the heat pump has less pollution during operation, more electricity consumption for the fire, easy to use, and other products, and it is important to protect the environment. Those, a heat pump is also known as a ground-water heat pump, and its principle is to extract high temperature water from the ground through the circulation of the pump, and change the low temperature to a high temperature with the input of low energy. But the abundance of groundwater will lead to groundwater depletion and damage to infrastructure. If you want to avoid this problem and have year-round stability, you need to balance the heat from the hot ground in the winter with the heat returning to the hot ground in the summer. Its main control is the control of the heat pump, and the expansion engine is the main part of the heat pump, mainly from the electronic expansion control of the car to the complete control of the room; System research aims to provide comfortable and reliable indoor temperature, and data transmission is via wireless communication technology [1, 2].

Research methods

The ZigBee wireless communication technology and building heat pump control system scheme design

The wireless heat pump heat controller studied by the author adopts ZigBee wireless communication technology, which is the latest development of two-way wireless network technology that can be used in short distance, low power, low cost, low data transmission rate, and it is a technical system. Communications, security and application software developed according to the IEEE802.15.4 wireless standard.

At present, the wireless communication technologies in the market are mainly WiFi, Bluetooth, IrDA, UWB, and NFC. By comparing the transmission range, rate (bps), working frequency and cost, it fully proves that ZigBee technology has the following significant characteristics and advantages:

– Low data transmission rate: the transmission rate of ZigBee technology is only 10-250 kb/s, mainly used for low rate transmission.
– Low power consumption and power saving: in the low power consumption standby mode of the ZigBee device, the service life of two ordinary No. 5 batteries can reach about six months to two years, which is especially suitable for occasions where battery replacement is inconvenient.
– Low cost: ZigBee has low data transmission rate and simple protocol structure, which can greatly reduce the equipment cost.

– High communication reliability and data security: ZigBee adopts a collision avoidance mechanism called carrier sense multiple address access and collision avoidance (CSMA-CA) to avoid data competition and conflict during transmission. Fully confirmed data transmission mechanism is adopted to ensure the reliability of information transmission. In addition, ZigBee provides data integrity.

The architecture of the ZigBee protocol is based on the IEEE802.15.4 standard, the IEEE802.15.4 standard defines the MAC and PHY layers of the protocol, the ZigBee protocol includes the MAC and PHY layers of IEEE802.15.4 (the standard defines the RF wire radio frequency and communication with adjacent devices), it includes network layer (NWK), application layer and security service layer. Those. The ZigBee protocol is shown in fig. 2.

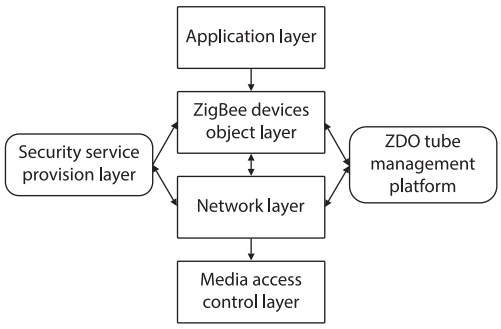

Figure 2. The ZigBee protocol stack framework

The 802.15.4 protocol standard

The IEEE 802.15.4 standard defines only two layers of the OSI standard for low cost wireless private area networks (LR-WPAN), namely the physical (PHY) layer and the data link layer sublayer (MAC). Those, the PHY layer consists of an RF transceiver and a lower control module, and the MAC sublayer provides point-to-point interface services for access to the physical channel at the upper layer [3].

The main purpose of the physical layer (PHY) is to send and receive signals over the network. The PHY layer defines the characteristics that the radio frequency must have, supporting two different radios, *i.e.* 2450 MHz band and 868/915 MHz. Each frequency band provides the number of fixed stations, and data transmission is determined by the choice of operating frequency, 2450 MHz band RF provides 250 kbps data rate, and 16 different, 868 MHz in the 868 MHz band supports one channel with 20 kbps data rate, and 915 MHz supports ten channels with a data rate of 40 kbps. Those, cables all use direct spread spectrum (DSSS) technology, spread spectrum is a technology that extends the spectrum from a narrow frequency to multiple frequencies to achieve transmission, and there are two technologies, direct spread spectrum (DSSS) and frequency hopping spectrum (FHSS).

In wireless LAN, there are two obvious differences between direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS) 121: First, FHSS wireless LAN is less susceptible to interference from external signals than DSSS wireless LAN. This is because FHSS will transmit very short pulse signals in a very wide frequency band, with little interference. The second difference is the network capacity (called broadband), the highest bit of DSSS broadband is 11 Mbps, while the highest frequency bandwidth of FHSS is only 3 Mbps. The transmission speed of DSSS WLAN is much higher than that of FHSS WLAN. The frequency of FHSS transmitting pulse is generally 1MHz, while that of DSSS is 22MHz.

Comparison of characteristics among wireless LAN based on infrared, frequency hopping spread spectrum and direct sequence spread spectrum. As can be seen from tab. 1, although each type of network has its own advantages, the two most decisive factors in wireless LAN – broadband and coverage, which make direct sequence spread spectrum wireless LAN become the most attractive wireless LAN technology. This conclusion is further strengthened by the wireless LAN industry, almost all wireless LAN manufacturers have chosen the direct

sequence spread spectrum technology as the transmission basis of the network, and ZigBee technology is no exception [4, 5].

Table 1. Comparison of WLAN

Characteristic	Optical Wireless LAN	DSSS
Whether there is interference	No	Yes
Whether it is disturbed	No	Yes
Power waste	Low	Commonly
Coverage	Line of sight limitation	Wide

The data link layer of IEEE 802.15.4 standard includes two sub layers: Logical link control (LLC) layer and media access control (MAC) layer. The main tasks of MAC layer can be described from three aspects: first, control how a wireless workstation can access to wireless media, since wireless media can be shared by multiple stations, a set of standard programs that can realize access must be available, second, how the workstation is connected to the wireless LAN, and third, how to keep the workstation connected. The MAC sublayer protocols depend on their physical layers and support multiple logical link control standards [6].

The ZigBee equipment type and network method

– Network equipment classification

In ZigBee network, according to functional integrity, network physical devices can be divided into two types, full function devices (FFD) and reduced function devices (RFD): FFD is a node with forwarding and routing capabilities, it has enough storage space to store routing information, and its processing and control capabilities are enhanced accordingly, FFD can be a coordinator or device and communicate with any device. The RFD has small memory and low power consumption, as a source node in the network, it only sends and receives signals and does not act as a repeater or router, RFD cannot act as a coordinator and can only communicate with full-featured devices, it consumes very little resources and storage overhead, that is to say, RFD can only communicate with FFD, while FFD can communicate with RFD and other FFD.

According to the different network functions of the equipment, the nodes in ZigBee network can be divided into three types, namely, central coordinator node, router node and end device node. The ZigBee coordinator must be an FFD device, and a ZigBee network can only have one ZigBee coordinator: A ZigBee router, which is also an FFD device with functions similar to those defined in IEEE802.15.4, but it cannot establish a network, once it enters the network, it can obtain a certain short address space and allow other nodes to join or leave within its communication range. The ZigBee terminal equipment can be either FFD equipment or RFD equipment, it can only communicate with its parent node to obtain network identifier, short address and other related information from its parent node [7, 8].

– Network topology

The ZigBee network has three topologies, namely star structure, mesh structure and tree structure.

The star topology is composed of the central node, namely, the co-ordinator, and other terminal devices directly connected, this network structure has the advantages of simple control, easy fault diagnosis and isolation, and convenient service, however, it also has the following disadvantages: the central node has a heavy burden and is easy to form a bottle neck, and the distributed processing capacity of each node is low. The mesh structure adopts completely peer-to-peer point-to-point communication, a fully functional device node can communicate

with any other node within the communication range, therefore, the route is relatively diverse, it is a highly reliable network with the ability to automatically recover to provide multiple transmission paths, when a few node devices in the network fail, the network can still maintain normal operation. In the tree network structure, the data transmission and information control are realized by using Cluster Tree routing, which enables nodes in the network to achieve good synchronization, facilitate nodes to enter the sleep state regularly, thus reducing power consumption and extending network life, a remarkable feature of this structure is that its network coverage is very large, but the delay of information transmission gradually increases with the increasing coverage, which makes synchronization more and more complex.

This system analyzes the characteristics of ZigBee topology, and selects a reasonable network that directly affects the cost and transmission speed of the network, considering the characteristics of this system, the author chooses a tree network topology with routing nodes [9].

Overall design of wireless heat pump control system

The wireless heat pump heating control system is composed of multiple indoor temperature wireless network nodes and the electric control panel of the heat pump unit, these network nodes can be divided into three categories according to their functions: co-ordinator node, router node and end device. The premise of establishing heat pump wireless network is to select a reasonable network topology, which determines the cost, speed, characteristics and functions of the network. Considering that when the system collects indoor temperature, there are walls or furniture partitions in the room that usually affect the quality of wireless communication, therefore, the author chooses a tree network topology with routing nodes to expand the coverage. The network coordinator device is responsible for the construction, transmission, control and data collection of the entire network 4), and can communicate with the PC through RS485 serial port communication, the PC analyzes and sorts the data sent to the electric control board to assign tasks, and sends control commands to the heat pump unit. Network router node is mainly responsible for path query and data forwarding. The terminal node has no routing function and cannot be accessed by other devices. It is only responsible for receiving indoor temperature data and sending data collected by sensors.

Experiment

Installation of heating transmission and distribution system controller

The heating pipe network of the central heating system is an important structure connecting heat sources and heat users, the pipe diameter, friction ratio and the size of the resistance pump in the pipe-line determine the selection of the circulating water pump head. The circulating water pump provides the power to circulate the system, overcomes the pressure loss in the system loop, and conducts heat exchange through the plate heat exchanger. The water and electricity calculation of the heating system:

$$H = \frac{q}{o(l_i - l_h)} \times 3500 = \frac{0.72q}{l_i - l_h} \tag{1}$$

where H [th^{-1}] is the flow parameter of each pipe section in the pipe network, q [W] – the heat load designed according to the heat user, o [°C] – the specific heat of water in the heating hot water pipe-line system, and l [°C] – the temperature difference between supply and return water in the pipe-line system.

Select zero differential pressure control point

In the traditional distributed variable frequency heating system, the point where the supply and return water pressures are equal is generally defined as the zero pressure difference control point. The optimal zero differential pressure control point is selected to make the system achieve the best heating effect with the minimum energy consumption of power transmission and distribution. The critical point of zero pressure difference refers to that when the water supply and return pressure pipe-lines of the system intersect at a specific point of the main heating pipe, the power provided by the pump can overcome the resistance loss depression of the branch pipe. The operation of the heating transmission and distribution system consumes the least energy, which can meet the heating demand. However, it is difficult to find the critical point of zero pressure difference in practical projects, and the approximate position of the critical point can only be determined through the analysis of the hydraulic diagram. The specific zero differential pressure control point is located at the user's pump parameters, as shown in tab. 2 [10].

Table 2. Water pump with zero differential pressure control point at the user

Project	Main circulating pump	Hot user branch 5 pump	Hot user branch 6 pump
Head [m]	16	3.5	7
Flow [th^{-1}]	360	85	66
Power [kW]	28	0.7	2

The system architecture of the building is customized based on the requirements of the perception layer, network layer and application layer of the IoT. The wireless communication identification layer consists of various sensors and 2-D barcode labels. In order to minimize the energy consumption of power transmission and distribution, an optimal zero differential pressure control point is selected without throttling resistance loss.

Check all kinds of heating system units before opening safety devices and relays are rated as set measure and operate normally. In indirect solar water heating in the system, considering the flow resistance and heat transfer efficiency, this kind of heat exchanger needs to be combined with a hot water storage tank, so we decide to choose coil heat exchanger, should choose copper tube:

$$R_{si} = \frac{Q_z}{\varepsilon M_{si} t_o} \tag{2}$$

where R_{si} [m^2] is a heat exchanger for a centralized heating system area, Q – the heat system and water tank exchange. Thermal parameter value: ε – the scale modification parameter value of heat exchanger, M_{si} [kWh] – the heat loss of water tank, and t_o [MPa] – the coil pressure loss of the heat exchanger. When it runs, first test each device whether there is noise, field controller whether automatic control can be realized, the start-stop delay of each device is if no, it can be automated. Based on weather effects, design heat storage must be considered in heat storage system. passing water temperature to store and release heat. Water is good the fluidity and heat transfer, and the price is low, have phase For lower coefficient of thermal expansion and viscosity. Therefore, this item Mesh using water as heat storage medium.

Analysis of heating effect data

Example analysis

A building under construction in the suburb is selected as the object of the heating test effect analysis. The building area is 1615.94 m^2, facing north and south, with four floors, three floors above the ground and a height of 3 m. Lay heating pipes on each floor of the building.

Before construction, check whether the antifreeze, buried pipe length and position, and water temperature difference of the buried pipe heat exchanger conform to the qualification appraisal of the project, and issue the appraisal report. The specific pump parameters of the test bench are shown in tab. 3.

Table 3. Parameters of water pump of test bench

Location of water pump	Flow [m]	Head [m]	Power
Main circulating pump	9	26	760
Hot consumer pump	0.073	8	70

Heating effect

The energy efficiency of various heating systems mainly refers to the thermal efficiency of the heating system, which is an important indicator of whether the heating system can save energy. After using the building thermal energy heat pump heating system, the actual heating area is 1255 m^2. The heat transfer coefficient of the external wall of the building is 0.63 W/mK, and the external wall is insulated with 65 mm foam polystyrene board. The scheme has been optimized according to the application characteristics of the building and the surrounding environment. The most intuitive indicator in the energy saving analysis of the heating system is the comprehensive energy consumption of the system, in order to detect the comprehensive energy consumption of the building thermal energy heat pump heating system, each test system is set to run for 24 hours, respectively, and the experimental data are counted and the experimental results are analyzed, as shown in tab. 4.

Table 4. Energy consumption of heat pump heating system kWh

Water pump position	1st test	Test 2	3rd test
Main circulating pump	2.4	2.5	2.6
User 1	1.14	1.20	1.02
User 2	1.17	1.24	1.01
User 3	1.25	1.27	1.03
User 4	1.31	1.35	1.10
User 5	1.26	1.31	1.69
User 6	1.05	1.12	1.08
Total	9.58	9.99	9.53

According to the data in tab. 4, the first test of the system in this paper consumes 9.58 kWh in total for the first test in 24 hours. For the second test, the total energy consumption is 9.99 kWh. The total energy consumption of the third test is 9.53 kWh. It can be seen that the comprehensive energy consumption of the building heat pump heating system designed in this paper is relatively low, which provides a reference basis for the heat pump heating system in buildings.

Taking the building heat pump heating system as the research object, the application of heat pump heating system in buildings is studied. The heat pump heating system designed in this paper uses the advanced plate heat exchanger for heat exchange in winter, and the vertical buried pipe underground exchanger to transmit the heat exchange of the ground pump unit to the room. Through the analysis of experimental data, the total energy consumption of the system in 24 hours in practical application is about 9.7 kWh. The comprehensive energy consumption is low and practical, reflecting the characteristics of green energy conservation of buildings [11].

Conclusion

Heat pump technology is a new type of heating device, which has the advantages of high efficiency, cleaning, safety and convenience, under the current energy situation and environmental requirements, it has very high application value and broad prospects for promotion. The application of wireless sensor network in building heat pump heating, it brings great convenience to improve the traditional heating mode and improves the intelligent level of traditional heating. The adoption of ZigBee wireless communication technology, improve the operation mode of heat pump heating system, and improve the automation level and performance of the system.

References

[1] Park, H., *et al*., Method and Apparatus for Reporting Channel State Information in a Wireless, *Communication System*, *20* (2020), 13, 0094392
[2] Jassim, A. K., *et al*., Microstrip Patch Antenna with Metamaterial Using Superstrate Technique for Wireless Communication, *Bulletin of Electrical Engineering and Informatics*, *10* (2020), 4, 26
[3] Nasir, N., *et al*., A Study on Different Slot Position for Designing Dual Band Microstrip Antenna for 5G Wireless Communication, IOP Conference Series: *Materials Science and Engineering*, *1176* (2021), 1, 012014
[4] Wang, A., *et al*., Wireless Communication Applications of the Variable Inclination Continuous Transverse Stub Array for ku-Band Applications, *IET Microwaves Antennas and Propagation*, *36* (2021), 6, 12
[5] Eid, M., *et al*., High Modulated Soliton Power Propagation Interaction with Optical Fiber and Optical Wireless Communication Channels, *Indonesian Journal of Electrical Engineering and Computer Science*, *56* (2021), 3, 49
[6] Padhy, S. P., *et al*., Performance Enhancement of Relays Used for Next Generation Wireless Communication Networks, *International Journal of Informatics and Communication Technology (IJ-ICT)*, *10* (2021), 1, 27
[7] Zhao, M. M., *et al*., Exploiting Amplitude Control in Intelligent Reflecting Surface Aided Wireless Communication with Imperfect CSI, *IEEE Transactions on Communications*, *42* (2021), 61, 15
[8] Mathur, H., *et al*., A Novel Precoded Digitized OFDM Based Noma System for Future Wireless Communication, Optik: Zeitschrift fur Licht- und Elektronenoptik: Journal for Light-and Electronoptic, *25* (2022), 259, 1259
[9] Zhu, C.,.et al., Exergy Analysis of Phase-Change Heat-Storage Coupled Solar Heat Pump Heating System, *Materials*, *14* (2021), 19, 5552
[10] Korichi, S., *et al.*, The Thermal Behavior of a Novel Wall Radiator Panel Coupled with Horizontal Ground Source Heat Pump Heating System: Improve Indoor Environment to Reduce the Airborne Transmission of Infectious Diseases, *Renewable Energy and Environmental Sustainability*, 5 (2020), 1, 11
[11] Wang, W., *et al.*, Performance Improvement of Air-Source Heat Pump Heating System with Variable Water Temperature Difference, *Applied Thermal Engineering: Design, Processes, Equipment, Economics*, *210* (2022), 118366

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