RESEARCH ON HEAT PIPE AIR-CONDITIONER WITH SOIL HEAT EXCHANGER FOR BASE STATION

by

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The refrigeration system accounts for 40-60% of the total energy consumption of the base station, so an effective energy-saving technology is much needed. This paper proposes a heat pipe air-conditioner with an additional soil heat exchange unit. When the indoor and outdoor temperature difference is small, the indoor heat can be scattered to the soil to achieve energy-saving effect.

Key words: *base station refrigeration, energy saving, heat pipe air-conditioner, soil heat exchanger, control method*

Introduction

In recent years, with the continuous development of the mobile communication technology, the number of base stations in China has seen a rocketing increase, and 2019 saw 5.44 million 4G base stations according to the official data of the three major operators in China. By 2022, the number of 5G base stations in China had reached 2.312 million. With the development of communication technology, 5G has started to be standardized and popularized. The tower company has stepped up the construction of 5G base stations with the construction density at least three times that of 4G base stations, and 5G base stations will be popularized all over China. With the extremely rapid expansion of base stations, however, the energy consumption has also increased sharply and we have to face this intractable problem.

According to incomplete statistics, the annual power consumption of the communication industry is more than 30 billion kWh, and the power consumption of base stations accounts for more than 70% of the total power consumption of mobile communications [1]. The power consumption of the refrigeration system of communication base stations accounts for 40-60% of the total power consumption of communication base stations. Therefore, most of the research on energy-saving technology for communication base stations are related to the air conditioning system [2]. With the further expansion of the communication network and the continuous promotion of energy conservation, it is extremely important to develop a reasonable base station refrigeration system with low energy consumption, which not only helps to save energy, but also improves the competitiveness of enterprises.

Due to historical reasons, telecom operators still used comfortable split air-conditioners for communication base stations, which are improved from household air-conditioners [3]. However, unlike other public buildings, the heating capacity of communica-

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tion equipment in base stations reaches 150-300 W/m^2, which results in high power consumption [4]. The main optimization measure to reduce energy consumption is to use the heat pipe heat exchanger to introduce the outdoor natural cold air-source into the room for refrigeration, so as to minimize the opening time of the air-conditioner [5]. However, the energy-saving efficiency of the heat pipe heat exchanger is not obvious in areas where the annual average outdoor temperature is high, and air conditioning is still needed almost for the whole year round. Based on this point, this paper adopts the method of adding the soil heat exchanger [6-8] on the basis of the heat pipe heat exchanger, in order to achieve energy-saving effect when the outdoor temperature is high.

Heat pipe air conditioning unit with soil heat exchanger

Based on the fact that the heat pipe air-conditioner in the current base station refrigeration cannot effectively cool when the outdoor temperature is high, this paper introduces a heat pipe air-conditioner with a soil heat exchanger and proposes a corresponding control method, which is used to achieve an effective energy-saving effect when the indoor and outdoor temperature difference is small.

Soil heat exchange unit

The heat pipe heat exchanger has the advantages in high heat transfer efficiency and little energy consumption, so the base station mostly adopts the combination of the heat pipe heat exchanger and the air conditioning for refrigeration [9]. However, the heat pipe heat exchanger can only be used in winter or transition season, and the cooling efficiency still needs to be achieved by turning on the air-conditioner at others period. In some areas with high outdoor average temperature all the year round, the energy saving rate of the heat pipe is low, so this paper proposes a heat pipe air-conditioner with a soil heat exchange unit. When the temperature difference inside and outside the room is large, the outdoor unit of heat pipe is used to release the indoor heat to the outside. On the other hand, if the temperature difference inside and outside the room is small, the outdoor unit of heat pipe is used to release the indoor heat to the soil heat exchange unit to replace the mechanical compression air conditioning for refrigeration.

According to the operation principle of the heat pipe air-conditioner with soil heat exchanger, compared with the existing technology, the improved device does not need to use conventional mechanical compression air conditioning when the outdoor temperature of the base station is high. The indoor heat absorbed by the indoor unit of heat pipe is released to the soil heat exchange unit. Because the power consumption of the heat pipe air-conditioner is far lower than that of the conventional mechanical compression air-conditioner, it achieves a good efficiency of energy saving and consumption reduction. When the outdoor temperature of the base station is low, the outside air is directly used to cool the base station, so as to ensure the stable operation of the base station.

In the improved device, the indoor unit of heat pipe includes an evaporator, and the outdoor unit of heat pipe mainly completes the heat dissipation of refrigerant through the double tube condenser. The outer tube of the double tube condenser is connected with the evaporator, and the inner tube is connected with the soil heat exchange unit. When the device is running, the refrigerant in the outer tube of the condenser enters the evaporator and changes the refrigerant from liquid to gaseous in the evaporator by absorbing the indoor heat of the base station. The gaseous refrigerant enters the outer tube of the condenser from the evaporator. When the indoor and outdoor temperature difference is large, it releases heat to the outdoor atmosphere. On the contrary, if the indoor and outdoor temperature difference is small, it releases heat to the inner tube of the condenser. At this time, the refrigerant changes from gaseous to liquid, the inner tube of the condenser transfers the absorbed heat to the soil heat exchange unit to realize heat exchange. In this cycle, the refrigerant continuously takes away the indoor heat of the base station, thereby reducing the indoor temperature of the base station.

The soil heat exchange unit includes a heat dissipation pipe embedded in the soil. The cooling pipe can be buried in the soil outside the base station in a vertical or horizontal manner, and the length and depth of the cooling pipe are determined according to the amount of heat exchange required by the heat pipe air-conditioner in the field. There are also a variety of options for cooling pipes, such as metal cooling pipes, PE pipes, *etc.* The PE pipes refer to polyethylene plastic pipes, which are commonly used materials. They have the characteristics of high temperature resistance, and can withstand the heat released by the outdoor units of heat pipes, and can exchange heat with low-temperature soil. Moreover, they have high strength and corrosion resistance, which can ensure long-term safe and stable use when buried underground [10]. In order to better realize the circulation of cooling water between the cooling pipe and the heat absorption side of the heat pipe outdoor unit, the cooling pipe can be connected to the heat absorption side of the heat pipe outdoor unit through a pressurized conveying device, such as a circulating water pump.

In order to further save energy, when the heat pipe indoor unit in the heat pipe air-conditioner absorbs enough indoor heat, the heat accumulator of the heat recovery device can be added in the soil heat exchange unit to complete the recovery and utilization of the indoor heat. The heat accumulator is connected with a small thermal generator, which can provide power for the power consuming components in the heat pipe air-conditioner, such as the controller. In this way, the heat absorbed from the room can also be better utilized. The process is shown in fig. 1.

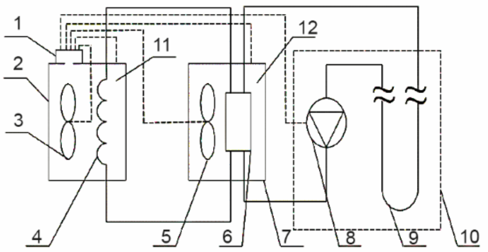

Figure. 1 Structural diagram of heat pipe air-conditioner with soil heat exchanger;
1 – the controller, 2 – the indoor unit of heat pipe, 3 – the first blower, 4 – the evaporator, 5 – the second blower, 6 – the double sleeve condenser, 7 – the outdoor unit of heat pipe, 8 – the pressurized conveying device, 9 – the radiator, 10 – the soil heat exchange unit, 11 – the first temperature sensor, and 12 – the second temperature sensor

Automatic control device process

In order to better control the conversion of refrigeration mode of the device, the corresponding control method is proposed. The additional control module is used to judge and control whether the outdoor unit of the heat pipe releases the indoor heat absorbed by the indoor unit of the heat pipe to the soil heat exchange unit. As can be seen from fig. 1, the control module includes a controller, a first temperature sensor for detecting the indoor temperature and a second temperature sensor for detecting the outdoor temperature. The signal input of the controller is respectively connected with the signals of the first temperature sensor and the second temperature sensor. The signal output of the controller is connected with the soil heat exchange unit.

During the operation of the device, when the controller judges that the temperature difference measured by the two temperature sensors is less than the maximum differential value, the soil heat exchange unit is started up by controlling the opening of the pressurized conveying device connected to the signal output end of the controller, so that the outdoor unit of the heat pipe releases the indoor heat a to the soil heat exchange unit. The specific process is shown in fig. 2.

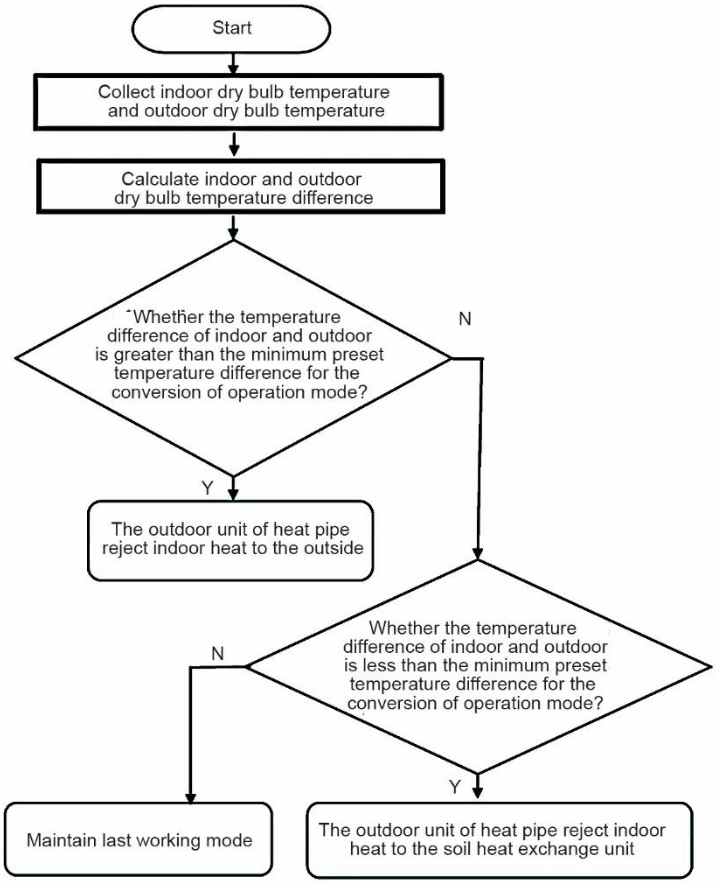

Figure 2. Flow chart of control method of heat pipe air-conditioner with soil heat exchanger

Feasibility analysis of using the device in five major climatic regions in China

Model establishment

In order to analyze the energy-saving effect of heat pipe air-conditioner with soil heat exchanger, the communication base station model is established in the environment of building energy consumption simulation software ENERGYPLUS. The typical base station models established are located in Harbin, Zhengzhou, Shanghai, Guangzhou and Kunming, which are five representative cities in the five major climatic regions of China.

Taking Zhengzhou as an example, the specification of the communication base station model is 4.75 m × 3.8 m × 2.6 m, the wall material is solid clay brick 240 (cement polystyrene board), the thermal conductivity is 0.324 Wm°C, and the thickness is 360 mm. The roof is a non-accessible roof with a thickness of 310 mm and a thermal conductivity of 0.176 W/m°C. The door is a metal frame single-layer solid door with an area of 1.5 m^2.

Feasibility analysis

The base station heating capacity is composed of two parts: the heating capacity of the communication equipment itself and the heat transfer through the enclosure structure. According to the analysis of the experimental results, the calorific value index of base station communication equipment is 490 W/m^2. According to the engineering experience, the calorific value index of base station is 500 W/m^2, and the environmental heat load is 0.1 W/m^2, so the total load of a 20 m^2 base station is 12 kW. Related costs of different refrigeration methods are shown in tab. 1.

Table 1. Related costs of different refrigeration methods

	Air-conditioner	Heat pipe air-conditioner	Heat pipe air-conditioner with soil heat exchanger
Initial investment (RMB)	12200	22300	28700
Operation cost (RMB)	19537.03	8840.38	3816.75

Taking the existing 110000 5G base stations with more than 20 m^2 in Henan Province as an example, compared with a single air-conditioner, using the heat pipe air-conditioner with soil heat exchanger can save 1.73 billion RMB per year, and the static investment payback period is 1.05 years. Compared with the heat pipe air-conditioner, the annual operation cost saved by using this device is 550 million RMB, and the static investment payback period is 1.3 years. It can be seen that the heat pipe air-conditioner with soil heat exchanger has great energy saving potential for either a single air-conditioner or a heat pipe air conditioning refrigeration mode, and has high market application potential.

The annual power consumption results of the three cooling methods of the base station simulated by software are as shown in figs. 3-5, taking Zhengzhou as an example.

Calculation method of energy saving efficiency evaluation is:

$$\eta = \frac{N_0 - N_1}{N_0} 100\% \tag{1}$$

where η is the air conditioning energy saving rate, N_0 – the air conditioning power consumption of base stations without energy-saving equipment, and N_1 – the air conditioning power consumption of base stations with energy-saving equipment.

The results of energy consumption analysis are counted as a histogram as shown in fig. 6, which represents the energy consumption of heat pipe air conditioning and heat pipe air conditioning with soil heat exchanger based on the energy consumption of a single air-conditioner.

From the comparison results, it can be seen that the energy-saving rate of heat pipe air-conditioner with soil heat exchanger can reach 61% compared with the single air conditioning refrigeration mode, and it can further save energy on the basis of heat pipe air conditioning combined refrigeration. With the increase of annual average temperature in cities throughout the year, the energy saving effect is gradually enhanced. Especially in some cities located in the southernmost part of China, due to the average temperature of the coldest month in the year is higher than 9 °C, most of the time still depends on air-conditioners for refrigeration, so the effect of applying this design is the most obvious.

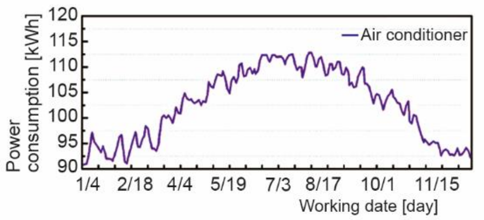

Figure 3. Annual power consumption of single air-conditioner

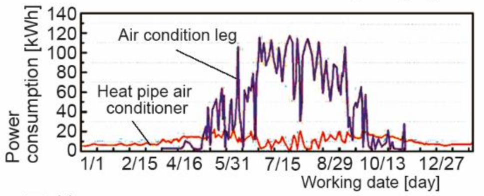

Figure 4. Annual power consumption of heat pipe air-conditioner

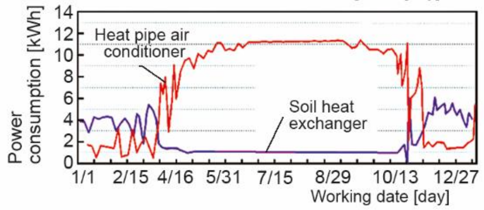

Figure 5. Annual power consumption of heat pipe air-conditioner with soil heat exchanger

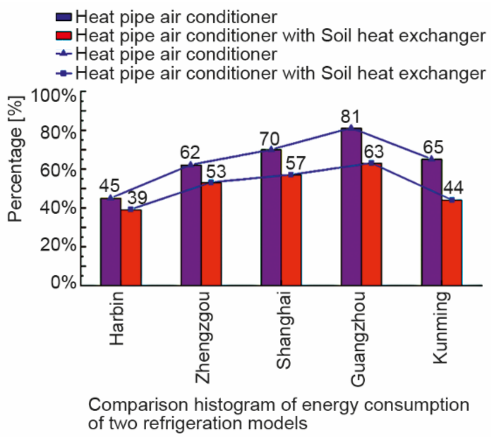

Figure 6. Comparison histogram of energy consumption of three refrigeration modes

Conclusions

- It is an important energy-saving method to use heat pipe air-conditioner and natural cold source to cool the base station, which can release the absorbed indoor heat into the air when the indoor and outdoor temperature difference is large. This also shows that the effect of base station heat pipe is not the same in different regions, and the energy saving effect of heat pipe air-conditioner is not particularly obvious in areas where the average outdoor temperature is high all year round.

- A soil heat exchange unit added on the basis of the original heat pipe air-conditioner can transfer indoor heat to the soil when the working efficiency of the heat pipe heat exchanger is low.
- According to the simulation analysis results of the models established in the typical cities of the five climate regions, it can be seen that the heat pipe air-conditioner with soil heat exchanger has good energy-saving effect in the five climate regions of China, especially in the hot summer and warm winter regions and mild regions. Compared with the energy-saving mode of heat pipe air-conditioner combined refrigeration, the energy-saving rate in Kunming can reach 23.62%, and compared with the energy-saving mode of single air-conditioning refrigeration, the energy-saving rate can reach 61%.

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