STUDY ON AN ENERGY-SAVING THERMAL MANAGEMENT SYSTEM IN OUTDOOR BASE STATIONS

by

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In order to solve the poor heat dissipation in the outdoor mobile communication base station, especially in summer, high temperature alarm phenomenon occurs frequently, affecting the normal operation of building base band unite, this paper designs an energy-saving and efficient integrated thermal management system, which has achieved good results by applying the combined operation of heat pipe cooling and air conditioning system using the outdoor temperature switching mode. A mobile communication base station in Zhengzhou City was chosen for a pilot application. The measured results showed that the system ran stably, the temperature inside the cabinet was controlled between 12 ℃ and 39 ℃ with no high temperature alarm, the compressor running time was significantly reduced, the power consumption of the air conditioner was significantly reduced, and the annual power saving rate was as high as 58.63%.

Key words: *base band unite, heat pipe, energy-efficient*

Introduction

In recent years, the number of domestic communication base stations increased year by year. By the end of 2021, a total of 1.425 million 5G base stations had been built and put into operation in China, this number was released by 2022 *China Internet Development Report*. China is now the world's largest 5G network, and the 5G world is also the top priority in the other part of the world [1]. According to the China Academy of Information and Communications Technology Report, at the end of June 2022, the total number of mobile communication base stations in China achieved 10.35 million, among which 5G base stations accounted for 17.9%, and 295,000 new 5G base stations were built in the second quarter (also see China Internet Development Report 2022). The increasing number of base stations and the large-scale deployment of 5G base stations will bring huge energy consumption, which means the energy saving of base stations has become one of the hot spots in the field of communications. According to the report, the energy consumption of air conditioning system in base stations accounts for 43% of the total energy consumption. Therefore, reducing the energy consumption of air conditioning in communication base stations has become one of the important ways to save energy.

Practical applications showed that the outdoor communication base station has a high temperature alarm phenomenon in summer, which leads to breakdown of building base band unite, interruption of signal, and serious influence of data transmission. In order to dissi-

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pate the heat, the traditional way is to open the door frequently or for a long time, resulting in the cleanliness of the cabinet below the standard, which further affects the heat dissipation of the equipment, but also for the safety of the operation of the equipment. The filed investigation also found that the air distribution in the base station was unreasonable, and through the data acquisition instrument installed on the site, the operation of the original air conditioning system and the temperature distribution data in the cabinet were analyzed, and it was further found that the air conditioning system of the base station has a long running time and high energy consumption.

At present, research on new energy-saving technologies for base station room air conditioning has been carried out at home and abroad. Wu *et al.* [2] conducted experimental research on separate heat pipe or vapor compression composite air conditioner, and the results showed that, compared with the traditional air conditioning device, the energy saving rate of the test device of the system was between 20% and 55%. In the air conditioning performance experiment of the separated heat pipe machine room, it was found that even in the summer operation test, the running time of the air conditioning compressor of the micro-channel separated heat pipe base station only accounted for 39.1% of the total running time of the base station, and the power saving rate reached at 44.7%, which had a good effect of energy saving and consumption reduction. Yan *et al.* [3] used the CFD method to numerically simulate the indoor air-flow of an energy-saving mobile station that uses mechanical ventilation to dissipate heat, and analyzed the air distribution in the base station, indicating that the improvement of air distribution can reduce the investment consumption of communication base station. Hao [4] comprehensively compared and analyzed the application performance of heat pipes in communication base stations from the perspectives of mathematical theory analysis and calculation, experimental research and simulation analysis, proved that gravity heat pipe heat exchangers can reduce the operating time and operating costs of air conditioning systems, and evaluated the performance of gravity heat pipe exchangers in practical applications at various outdoor temperatures. Zhang *et al.* [5] gave an economic analysis of the gravity heat pipe exchanger, and Ryu and Kwon [6] suggested an energy saving control system using natural air-conditioning.

The energy-saving thermal management system is a hot topic in various fields, Ma *et al.* [7] suggested a passive solar building system, Al-Rabeeah *et al.* [8] suggested a thermal management method for a solar-energy collector, Ma [9] gave an optimal control system for controlling temperature in an office by the fractal variational theory, which is to study the energy conservation in a fractal space [10-12]. Thermal conductivity enhancement [13] is an effective method for the cooling system, and nanofluids were widely used for this purpose [14, 15], the metal nanoparticles have high thermal conductivity, and they can form an effective boundary layer for thermal conduction [16-19].

Now the communication base stations in China use the heat pipe heat transfer technology, which affects significantly the cooling efficiency when the natural cold source is used. In order to reduce the air conditioning running time and the energy consumption of communication base stations, this paper adopts an integrated equipment of the heat pipe transfer and the air conditioning system.

Working principle of energy-saving integrated thermal management system

Zhengzhou City is rich in low temperature and cold air sources. In winter and spring and autumn transition seasons, the heat pipe technology is used to cool the equipment in the communication base station by using the outdoor cold source, thereby, greatly reducing the power consumption. Therefore, in the energy-saving integrated thermal management system in this study, the high temperature air in the equipment cabinet is cooled for the first time through the heat exchanger at the evaporation end of the heat pipe, and then the second cooling is carried out through the air conditioning evaporator, and the cooled low temperature air enters the cabinet and exchanges heat with the communication equipment and repeats the cycle. The schematic diagram of the system is shown in fig. 1.

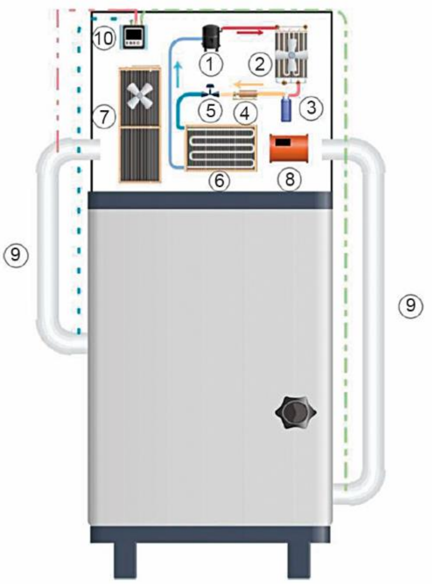

Figure 1. Schematic diagram of an energy-efficient integrated thermal management system; *1 – compressor, 2 – condenser, 3 – reservoir, 4 – filter drier, 5 – expansion valve, 6 – evaporator, 7 – heat pipe, 8 – axial fan, 9 – air duct, and 10 – controller*

The system has two modes: single heat pipe operation and heat pipe + air conditioning combined operation. The heat pipe technology and the traditional steam compression refrigeration technology are integrated to realize the complementary advantages of the two new energy-saving cooling technology. The system has two modes of operation as:

Single heat pipe operation mode. When the indoor air outlet temperature of the base station reaches or exceeds the upper limit of the set temperature, the heat pipe mode operation is turned on, and the air outside the base station is used as a natural cooling source to achieve efficient heat dissipation of the communication base station. When the indoor outlet air temperature is lower than the set temperature, the hot end fan and the supply fan of the heat pipe stopped.

Heat pipe + air conditioner combined operation mode. When the indoor air outlet temperature of the base station reaches or exceeds the upper limit of the set temperature, the heat pipe heat dissipation cannot meet the cooling requirements, and the air conditioning operation mode is started. When the outlet air temperature in the base station reaches or falls below the set temperature lower limit, the air conditioning compressor and condenser fan turned off.

The system was originally installed with a door-mounted air conditioning system and tested in a communication base station in Zhengzhou City. In summer, the system frequently high temperature alarms and even downtime resulted in signal interruption of the system. During the transition season and winter, the door-borne air conditioning system is still on and running for a long time. In the early stage, a data acquisition device is installed for the original air conditioning system to analyze system operation, power consumption and cabinet temperature. Comparing with data collected after installing an energy-saving integrated thermal management system, the improved system is reliable and can guarantee the temperature requirement of the inner space of the base station cabinet. There is no high temperature alarm phenomenon, the power consumption is reduced significantly, and the cleanliness inside the cabinet is improved.

Energy-saving integrated thermal management system on-site installation and test construction

A communication base station in Zhengzhou City was chosen as the test base station with a data collector to collect and analyze current, voltage, air conditioning supply air temperature, air conditioning return air temperature, equipment inlet temperature, equipment return air temperature, and ambient temperature for the original door-borne air conditioning system and energy-saving integrated thermal management system. Detailed data from March 2022 to February 2023 were obtained, and valid data were selected for analysis.

Figure 2 shows the exterior of the installation of an energy-saving integrated thermal management system.

Figure 2. Installation of an energy-saving integrated thermal management system

The energy-saving integrated thermal management system uses heat pipes to dissipate heat and make full use of natural environment for cooling. Double circulation cooling system was adopted, and heat pipe heat dissipation combined with air conditioning system. Reasonably distributing the return air outlet, supplying air accurately, and optimizing the air-flow organization. The wind system adopts closing loop circulation to ensure the cleanliness of the equipment. Using temperature step control, and realizing the transmission of data through Internet of Things, then, the operation of the equipment can be monitored remotely.

Test results and analysis

The operation of the equipment in the transition season, summer and winter environment of the outdoor mobile communication base station was tested. The test results of the equipment cabinet temperature and ambient temperature in the transition season, summer and winter are shown in figs. 3-5, respectively.

In spring, April, the average daily temperature of the outdoor environment ranges from 12.5 °C to 28.2 °C, the average daily temperature of the equipment cabinet is maintained at 22.5~37.8 °C. In Autumn, October, the average daily temperature of the outdoor environment ranges from 10.9 °C to 24.6 °C, and the average daily temperature of the equipment cabinet is maintained at 21.7~35.3 °C.

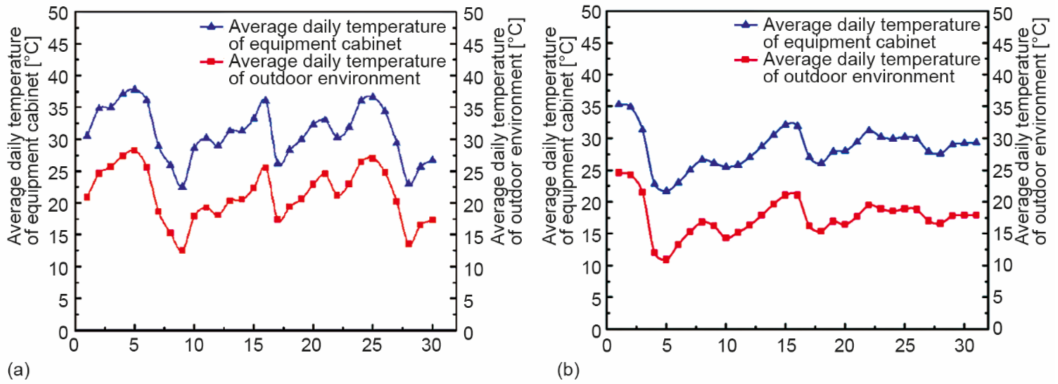

Figure 3. Analysis of equipment cabinet temperature and ambient temperature test results in the transition season; (a) Spring (April) and (b) Autumn (October)

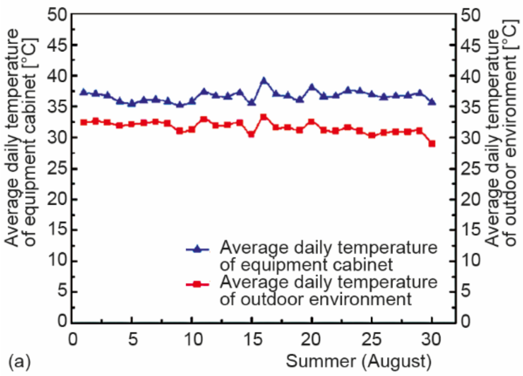

Figure 4 Analysis of equipment cabinet temperature and ambient temperature test results in summer

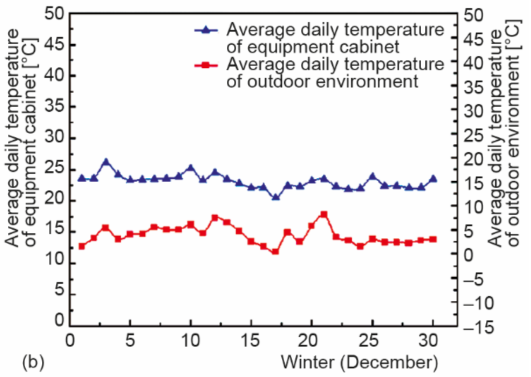

Figure 5 Analysis of equipment cabinet temperature and ambient temperature test results in winter

It can be seen from fig. 4 that the average daily temperature of the outdoor environment in summer, August, ranges from 29 ℃ to 33.3 ℃, and the average daily temperature of the equipment cabinet is maintained at 35.6~39 ℃. And in the case of high outdoor ambient temperature in summer, August, the temperature in the equipment cabinet can also maintain stable.

It can be seen from fig. 5 that in winter, December, the average daily temperature of the outdoor environment is in the range of 0 ℃ to 8.1 ℃, and the average daily temperature of the equipment cabinet is maintained from 20.5 ℃ to 26.1 ℃.

Through the previous analysis of the energy-saving integrated thermal management system for the communication base station, the indoor temperature control of the base station throughout the year conforms to the national standards, the temperature fluctuation in the cabinet is small, and the temperature of the equipment working environment is stable, which can effectively ensure the long-term safe operation of the equipment in the base station cabinet.

Analysis of power saving rate

From the comparison of power consumption in figs. 6-8, it can be seen that the average daily power consumption of the original door-borne air conditioning system in the transition season is 15.97 kWh, the average daily power consumption of the energy-saving integrated thermal management system is 5.08 kWh, and the power saving rate in the transition season is as high as 63.04%. The average daily power consumption of the original door-borne air conditioning system in summer is 16.75 kWh, in the meantime, the average daily power consumption of the energy-saving integrated thermal management system is 8.11 kWh, thus, the summer power saving rate can reach at 52.1%. The average daily power consumption of the original door-borne air conditioning system in winter is 5.7 kWh, and the average daily power consumption of the energy-saving integrated thermal management system is 2.52 kWh, thus, the power saving rate in summer can reach at 56.34%. The measured data show that the annual power saving rate of the energy-saving integrated thermal management system can reach at 58.63%.

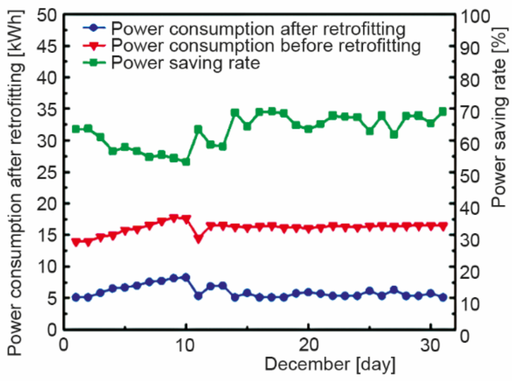

Figure 6. Comparison of electricity consumption during the transition season

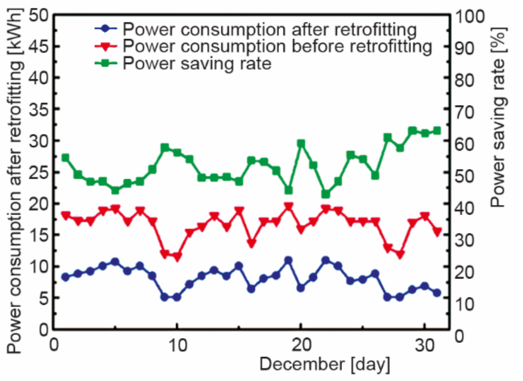

Figure 7. Comparison of summer power consumption

The measured data show that when the ambient temperature is between 2.5 ℃ and 15 ℃, the average start-up times of the original door-borne air conditioning system are up to 27 times a day. After the installation of the energy-saving integrated thermal management system, the compressor starts up six times a day on average, which reduces the operation time of the air conditioning compressor, effectively reduces the power consumption of the base station cooling system, slows down the speed of natural aging of the compressor, improves the use efficiency and service life of the compressor, and might has good economic effect.

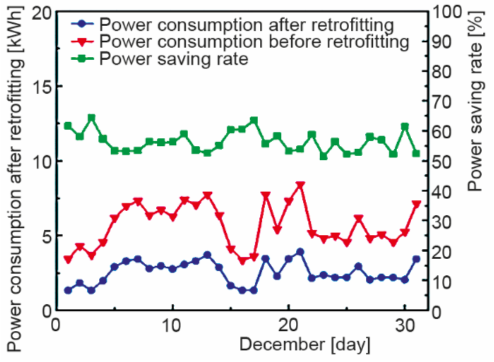

Figure 8. Comparison of electrity consumption in winter

Discussion and conclusion

Reinforcement learning [20] and convolutional neural network [21-25] gave alternative ways to reducing energy consumption of ultra-dense networks with 5G use cases requirements. In this paper, after conducting field tests in Zhengzhou, the energy-saving integrated thermal management system has better use effect than the original door-borne air conditioning system, and the conclusions are as follows.

- The energy-saving integrated thermal management system controls the temperature of the equipment cabinet between 12 ℃ and 39 ℃, which meets the national standard for outdoor communication base stations, thus, there is no high temperature alarm phenomenon, and the use of equipment in the base station cabinet is protected.
- Comparing with the original cabinet door air conditioner, the energy-saving integrated thermal management system has a significant reduction in power consumption, and its average monthly power saving rate in the transition season reaches at 63.04%, its monthly average power saving rate in summer could reach at 52.1%, the average monthly power saving rate in winter could reach at 56.34%, and the annual power saving rate could reach at 58.63%. The energy-saving integrated thermal management system has remarkable energy saving and emission reduction effects and has great applying value.

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