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Experimental investigation and economic analysis of gravity heat pipe exchanger applied in communication base station

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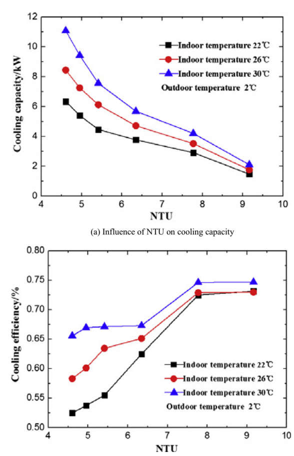
HIGHLIGHTS

- NTU affects the cooling capacity and efficiency of the heat pipe exchanger.
- Gravity heat pipe exchanger is promising for cooling communication base station.
- Gravity heat pipe exchanger reduces operating time and cost of air conditioner.
- Energy saving achieved by gravity heat pipe exchanger is significant.
- Electricity-saving rate ranking: Kunming, Harbin, Xi'an, Shanghai and Guangzhou.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper proposes a gravity heat pipe exchanger used for cooling the communication base station to replace the traditional air conditioning system during winter and transition seasons. Tests were conducted on a commercial available gravity heat pipe exchanger. The experiment was performed to study the effects of the air flow rate and temperature on the cooling capacity, the heat transfer unit number (NTU) and cooling efficiency of the heat pipe exchanger. The results showed that the larger the air flow rate, the smaller the NTU and the larger the cooling capacity. Based on the analysis of the experimental data, it proved that the gravity heat pipe exchanger could reduce running time and operating cost of air conditioning system. According to the practical applications, the yearly cooling loads of a typical communication base station were further calculated for five typical cities which represent the five climatic zones of China. The results validated that the energy saving by using the gravity heat pipe exchanger is significant. The highest annual electricity-saving rate is achieved by Kunming, about 48.6%, while the lowest annual electricity-saving rate is obtained in Guangzhou, about 18.7% among the five climatic zones. The fitted correlation of cooling capacity in term of outdoor temperature is generic to evaluate approximately the performance of applying the gravity heat pipe exchanger in the actual applications subject to various outdoor temperatures.

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Nomenclature

A_h	heat transfer area of heat pipe exchanger (m^2)
a	indication error of instrument
COP	coefficient of performance of the air conditioning
C_p	specific heat at constant pressure
F_b	area of building envelope (m^2)
G_{min}	minimum of indoor and outdoor air flow rate (kg/s)
K_b	heat transfer coefficient of building envelope (W/(m^2 K))
K_h	heat transfer coefficient of heat pipe exchanger (W/(m^2 K))
m_{min}	minimum air flow rate between indoor and outdoor (kg/s)
m_s	indoor air flow rate (kg/s)
NTU	heat transfer unit number of heat pipe exchanger
P_f	the power of the fan (kW)
Q	cooling capacity (kW)
Q_1	heat transfer through building (kW)
Q_2	heat release through equipment(kW)
Q_3	lighting and human body heat Dissipation (kW)
Q_c	heat release of communication cabinets (kW)
Q_E	cooling capacity of heat pipe exchanger (kW)
Q_a	cooling load undertaken by air conditioning (kW)
Q_{actual}	actual cooling capacity (kW)
Q_b	heat release of battery pack (kW)
Q_h	cooling load undertaken by heat pipe exchanger (kW)
Q_{max}	maximum theoretical cooling capacity (kW)
Q_s	heat release of switch power (kW)
Q_t	heat release of transmission equipment (kW)
t_1	indoor air inlet temperature (°C)
t_2	indoor air outlet temperature (°C)
t_3	outdoor air inlet temperature (°C)
t_N	designed indoor air temperature (°C)
t_w	outdoor air dry bulb temperature (°C)
U_B	standard uncertainty of instrument
U	standard uncertainty
v	wind speed (m^3/s)
W_a	electricity consumption of air conditioning (kW)
W_h	electricity consumption of heat pipe exchanger (kW)

Greek symbol

ε	cooling efficiency (%)

1. Introduction

Communication base station is an important part of communication system. It is of large number, large quantity of heat, long-time cooling season and large quantity of energy consumption [1]. The internal environment factors, such as temperature, humidity and cleanliness, affect the operation reliability and service lifespan of the communication equipment [2]. The cooling of communication base station has emerged as a significant challenge with the rapid increase of IT equipment. The consumption of communication base station includes four aspects, namely, communication equipment, air conditioning system, distribution system and auxiliary components. The consumption of air conditioning system occupies about 43% of the total energy consumption, which is the largest part except the main equipment energy consumption [3]. Therefore, reducing the energy consumption of air conditioning system is a key approach to saving energy for communication base station.

Since 1970, heat pipe exchangers have been extensively applied in many industries including HVAC systems. Hayama and Nakao [4] and Hong-Koo et al. [5] studied the effects of the parameters and the way of supply air on the communication base station. They reported that the change of velocity has more obvious effect than that of temperature on energy saving, and under air supply system could improve the temperature distribution to obtain a good energy saving effect. Al-Rabghi [6] and Wang and Xu [7] used outdoor air for cooling, which can decrease 30% energy consumption of air conditioning system. El-Baky and Mohamed [8] stated that the incoming fresh air could be cooled down by the application of heat pipe exchanger between two streams of fresh and return air in an air conditioning system. Firouzfar et al. [9] established that the application of methanol-silver nanofluid as the working fluid in a two-phase thermosyphon heat exchanger saves energy by 9–31% for cooling and 18–100% for reheating the air supply stream in an air conditioning system. In addition, China Mobile and Tsinghua University [10] developed a system of separated heat pipe, which can save 80% energy compared with air conditioning system.

Communication base station is a special building which dissipates heat almost all year round [11]. The air conditioning system used in the communication base station would have large operating energy consumption. The existed methods of energy saving include variable-frequency technology, self-adaptive control technique of the air conditioning [12], water treatment technology of the air conditioning, cooling technology using natural cold source [13], energy saving technology of new refrigerant [14], absorption refrigeration utilizing waste heat in data centers [15], harmonic treatment technology [16] and so on. The use of natural cold source is one of the most appropriate and promising approach applied to the communication base station. The principle is that when outdoor air temperature is lower than indoor air temperature to a certain extent, the outdoor air as cold source takes away the heat from communication base station. The purpose of cooling communication base station could be achieved without air conditioning system. Using outdoor cold air for cooling base station is able to save a great amount of power consumption of air conditioning system during the winter and transition season. This cooling technology has alternative processes, i.e., direct fresh air cooling and isolated air heat exchanger systems [17,18].

The gravity heat pipe is a promising heat transfer component with high thermal conductivity [19,20]. It has been proved to have a comparatively high heat transfer capability with a very small temperature difference between the heat source and heat sink [21]. Moreover, it possesses excellent isothermal property, compact structure and small flow resistance. Hence it has been widely applied in the thermal industry [22].

The gravity heat pipe can be divided into three sections: the evaporation, condensation and adiabatic sections [23]. Evaporation section is the one end where the working fluid absorbs heat from the heat source to evaporate. Condensation section is the other end where the working fluid condenses to release heat to the heat sink. Adiabatic section is heat transmission channel in the middle of the heat pipe. Compared with the conventional heat pipe, the gravity heat pipe does not have the wick, resulting in simple production and low cost. Because of its reliable working performance, the heat pipe is adopted to the communication base station to investigate its energy saving in this paper.

The gravity heat pipe exchanger uses the outdoor cold air for cooling the communication base station. When outdoor air temperature is lower than 18 °C, indoor heat is discharged to outdoor

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