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Heat recovery from Internet data centers for space heating based on an integrated air conditioner with thermosyphon

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ABSTRACT

With the rapid increase of Internet data centers (IDCs), a large amount of electricity is consumed for IDCs' cooling, and a considerable amount of heat is exhausted directly into the ambient all year round. On the other hand, to efficiently and cleanly heat the room in cold regions a lot of energy is consumed. In this study, a heat recovery system based on a water-cooled integrated air conditioner with thermosyphon is proposed. To analyze the feasibility and energy performance of the system, a steady-state hourly energy model of the system was developed. The energy performance of a typical system located in Beijing was analyzed, and compared with the most common cooling and heating method in China. The results show that the system can substantially reduce the energy consumption of IDCs for cooling and the energy consumption of buildings for heating simultaneously. It should be an alternative heating system making use of potential heating and natural cooling resources.

1. Introduction

With the development of information and communication technology, especially the boom in the huge amounts of data and cloud computing, the number of the Internet data centers (IDCs) has increased rapidly. According to statistics [1], 430,000 IDCs with about 4,000,000 servers had been built by 2011 in China. Due to the large amount of indoor rejected heat, all-year-round cooling is needed and much energy is consumed by IDCs. In 2011, 70 billion kWh power was consumed by IDCs in China, accounting for 1.5% of the total national electricity consumption. But most of the heat is emitted directly into the ambient by air-conditioning systems.

On the other hand, energy consumption for heating and domestic hot water in cold regions is very high. In the urban areas of north China, heating consumed 163 million ton of standard coal equivalent (tce, 1 tce = 8139 kW h)in 2010 [2], and, with the rapid increase in building areas and improved requirements for the indoor environment, energy consumption for heating and domestic hot water is growing continuously and rapidly. Taking Beijing for example, the total heating area has increased from 540 million m^2 in 2008 to 766 million m^2 in 2013, shown in Fig. 1.

In China, the coal boiler is still most commonly used for heating in cold regions. However, the coal boiler has low energy efficiency as well as high air pollution, and is regarded as one of the main sources of CO_2, SO_2, NO_X and particulate matters, such as PM2.5 and PM10 [3]. Atmospheric haze resulting from PM2.5 and PM10 is becoming an extremely serious issue for China, especially around Beijing [4]. A clean and highly efficient heating method is much anticipated to replace or reduce coal boilers.

Consequently, some renewable-energy heating technologies have recently been proposed, such as air-source heat pumps (ASHPs), and ground source heat pumps (GSHPs). Unfortunately, the ASHP exhibits relatively poor performance and reliability in low outdoor air temperatures [5], although some technologies have been developed in cold climate ASHP [6,7], and the problem of frosting in the evaporator has not been well solved [8]. The GSHP is regarded as a more efficient and stable heating system than the ASHP, and the GSHP has been extensively used for heating in China. Fig. 2 shows the increase in heating areas supplied by GSHP in Beijing from 2000 to 2012. However, the initial investment of GSHP is quite huge. Additionally, after long-term operation, it has been found that the problem of thermal imbalance in cold regions is serious, since the extracted heat from the soil is greater than rejected heat [9], so the performance of GSHP will worsen with the decrease in soil temperature.

To sum up, on the one hand, stable and huge amounts of heat from IDCs are exhausted into the atmosphere by air-conditioning

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Nomenclatures

E	power consumption (kW)
L	load (kW)
Num	number
P	input power (kW)
Q	capacity (kW)
R	energy saving ratio (%)
T	temperature (°C)
W	input power (kW)

Abbreviations

ASHP	air-source heat pump
COP	coefficient of performance
CRAC	computer room air conditioner
GSHP	ground source heat pump
HRHP	heat recovery heat pump
HRS	heat recovery system
IACT	integrated air conditioner with thermosyphon
IDC	Internet data center
PUE	power usage effectiveness
TS	thermosyphon mode
VC	vapor-compression mode

Subscripts

evap	evaporator
cond	condenser
i	in
o	out
r	rated
rej	rejected heat

systems in vain; on the other hand, significant amounts of energy are consumed for space heating in winter and domestic hot water supply for the whole year. In fact, IDCs can be 40 times more energy intensive than a standard office building [10]. If the rejected heat can be used for heating and domestic hot water, not only can much energy be saved, but also some existing problems, such as air pollution from coal boilers, the heat island effect caused by computer room air conditioners (CRACs), and the risk of freezing when the cooling tower is running in the winter, can be alleviated to some extent.

In fact, the idea of heat recovery from IDCs has been proposed for a long time, and the exhausted heat from IDCs has been utilized by various methods. Ward et al. [11] drew high-temperature waste air from a containerized IDC to supply heating directly to a nearby greenhouse, and developed a model based on environmental opportunistic computing. Haywood et al. [10] tried to capture high-temperature water (e.g. 60–90 °C) from the CPUs of each server blade, to energize an absorption chiller, and analyzed the thermodynamic feasibility of the system. The results showed that the PUE (power usage effectiveness) of the IDC can be less than 1 with this technology. Similarly, Harman [12] analyzed the feasibility of a system which captures high-temperature water from CPUs (e.g. 70–90 °C) to drive an ejector heat pump. More commonly, several researchers and companies [13–15] have utilized the heat of the condensation of water-cooled CRACs or chillers to supply heating for other buildings, such as office buildings, swimming pools, and greenhouses.

In summary, there are three categories of reuse of the waste heat in IDCs: (1) drawing the high-temperature air to supply heating directly, which is simple and convenient, but cannot recover large-scale heat over a long distance; (2) capturing water of sufficiently high temperature from the CPUs to drive other units, which shows great energy-saving potential, but is also extremely challenging in practical applications; (3) utilizing the heat in the cooling water of CRACs to supply heat, which is a practical method and has been applied in some projects. However, in most of the existing projects, traditional vapor-compression CRACs are usually used to supply cooling for IDCs all year round. In this way, waste heat is reused, but the energy consumption of CRACs is still high, which is not helpful for the lower PUE of an IDC. Consequently, is it possible to utilize natural cooling technologies in heat recovery systems to reduce simultaneously the energy consumption of refrigerating and heating?

Recently in fact, various natural cooling technologies have been proposed for IDCs, such as a waterside economizer [16], an airside economizer [17], a thermosyphon heat exchanger [18], and so on. However, these natural cooling technologies will increase investment, installation space, and maintenance. Han et al. [19] developed an air-cooled integrated air conditioner with thermosyphon (IACT), used in a telecommunications base station, which combines vapor compression with thermosyphon in one device and can make full use of natural cooling sources with little additional investment. Experiments and analysis showed that this technology could realize stable and great energy savings in different climates [20].

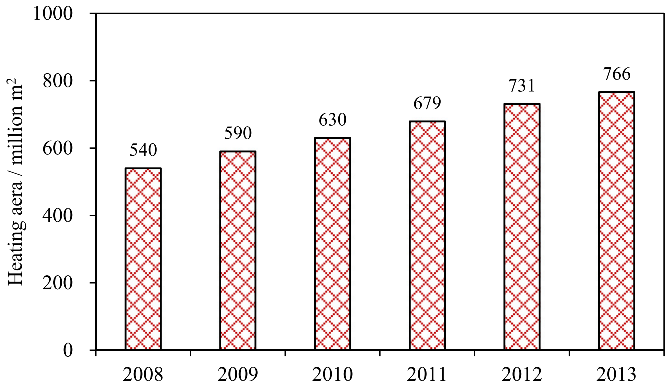

Fig. 1. Total heating area in Beijing.

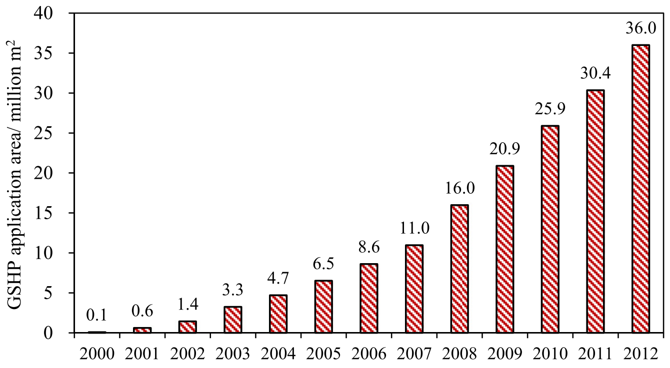

Fig. 2. Heating area by GSHP in Beijing.