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A simulation study on heat recovery of data center: A case study in Harbin, China

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ABSTRACT

With the increase in data traffic, high energy consumption of cooling systems in data centers are rising continually and rapidly. Thus planning energy is more and more important to minimize resources consuming. The equipment in data room can produce vast amount of heat which must be removed, and waste heat recovery is an effective means of saving energy. In this paper, a simulation of the annual dynamic air conditioning load of buildings was conducted through Designer's Simulation Toolkit (DeST) to get the cooling and heat load index, and a data center in Harbin was taken as a case study to evaluate the energy-saving effect. The results indicated that the annual cumulative cooling load was far greater than the annual cumulative heat load, so it has great potential for heat recovery. Then a system that made use of waste heat from data rooms to serve subsidiary buildings was proposed. It could fully satisfy the heat demand in data centers when equipment in data rooms all run. Meanwhile, the heat recovery system has a better economic viability when compare with the air source heat pump system. Therefore, using the heat recovery system can improve the energy efficiency and realize the energy saving.

1. Introduction

Energy consumption is one of the most reliable indicators for the development of a country and quality of life [1]. With the rapid development of cloud computing and data storage, the number of data centers is increasing sharply. Generally, the energy consumption in data centers is mainly caused by equipment, air conditioning system, and power system. Among this, the data room is an important part of data center. Lots of waste heat will be generated due to the continuous operation of equipment, which need to be removed to ensure stable operation of equipment. Meanwhile, the subsidiary buildings in the data center also need heating. So it may have a great energy saving effect to make the heat recovery, which can improve energy efficiency of data centers.

Before the energy planning carried out, the heat and cooling load should be analyzed firstly. There are many related researches on the prediction and calculation of building air conditioning load. The research results included various prediction methods, such as regression prediction model, artificial neural network prediction model, and grey theory prediction model and so on. Peng et al. [2] used DeST to simulate the annual hourly energy consumption of an office building. They studied the effects of a variety of thermal performance on the air conditioning load and proposed an effective energy-saving measures. Forrester et al. [3] used the autoregressive integrated moving average (ARIMA) model to predict the energy consumption demand of a commercial building in advance by 4 h, and the forecast time was short. D. Robinson et al. [4] developed a sustainability of urban neighborhoods (SUNtool) for resource flow simulation of urban planning, and the grey-box model was used to predict the hourly thermal energy demand in the region. Oró et al. [5] developed a dynamic energy model of the data center by using TRNSYS, and analyzed the real data center air management system. Kreider et al. [6] used the neural network method to predict the energy consumption of the building air conditioning equipment, and could monitor the operation of the air conditioning system in time. However, the above prediction method is mainly the prediction of the air conditioning load in the next stage of the statistical results of the historical load monitoring data for the built

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Nomenclature

A	area, m^2
COP	Coefficient of Performance
H	humidity
L_{per}	Per capita fresh air volume, m^3/h
PD	Power density, W/m^2
Q	Total load, KW
Q_c	cooling capacity
Q_h	heating capacity
Q_{per}	Per capita heat production, W
q	Load index, W/m^2
q_{nn}	Annual unit area hourly load, W/m^2
$q_{cooling}$	Cooling load index, W/m^2
q_{cum}	Monthly cumulative unit area load, W/m^2
q_{heat}	Heat load index, W/m^2
q_{ven}	Annual unit area load of ventilation, W/m^2
N	Number of people
R	Window-wall Ratio
S	body shape coefficients
T	the temperature, °C
$T_{dry\ bulb}$	the dry-bulb temperature, °C
W	consumed power
W_{per}	Per capita wetting, kg/hr

Subscripts

A	Aboveground
cum	cumulative
equ	equipment
in	indoor
ill	illumination
Max	Maximum
U	Underground

buildings. Before the completion of construction, the air conditioning plan for single building has not been determined, the factors of building internal disturbance are uncertain, in this case, it is difficult to get the accurate load results by using the building dynamic simulation software.

Meanwhile, the data center has a large energy demand. A lot of researchers have been devoted to the utilization of renewable energy, but they are generally limited to the building area. Esen et al. [7] designed and set up a ground source heat pump greenhouse heating system, and investigated the effects of climatic conditions and operating parameters on the system performance. The results indicated that the heating system could be used for greenhouse heating. Rong et al. [8] reviewed the available energy-saving technologies for data centers and provided energy-saving trends for data centers in the future. Ebrahimi et al. [9] discussed the most promising methods and technologies for recovering data center low-grade waste heat, and reviewed some available and developmental low-grade waste heat recovery techniques. Meanwhile, they assessed the suitability and effectiveness of each technology specifically for the reuse of low quality waste heat in data center. They [10] also used the absorption chiller to solve the problem of waste heat recovery in the data center. Lu et al. [11] examined and analyzed different performance metrics for the cooling system and power consumption. However, there was no heat recovery system in the data center. They conducted that the waste heat from the data center could be collected using additional condenser. Zhang et al. [12] proposed a heat recovery system from Internet data centers based on integrated air conditioner, and developed an hourly energy consumption model of heat recovery system. Carbó et al. [13] studied the dynamic behaviors of a liquid cooled data center and developed a dynamic energy model by TRNSYS. Shehabi et al. [14] found that using economizer combined with improved filtration could reduce data center energy demand. Lee et al. [15] proposed a central air circulation system that used a roof ventilation layer and a phase change material (PCM) unit to control thermal load and peak load. They found that natural energy could be used to reduce the energy consumption of indoor temperature control. Cormio et al. [1] proposed a bottom-up energy system optimization model for reducing environmental impact and economical efforts, they combined the primary energy sources exploitation, power and heat generation, emissions and end-use sectors, and the model was also verified by the example of the building area. Dalton et al. [16] conducted a renewable energy planning for the three city of Australia. The power supply scheme was used to combine traditional power generation with photovoltaic generation, and evaluated from three aspects of renewable energy utilization ratio, investment recovery and net present value. Davies et al. [17] proposed a waste heat recovery application in the data center, and considered the possibility of using the waste heat of the data center as the heat source for the regional heating network. Iqbal et al. [18] used Homer to build a system of renewable energy supply for several buildings, and the system consumed no fossil energy and nearly became a near zero energy consumption building. Mourmouris et al. [19] proposed an evaluation framework to promote the use of renewable energy sources. They adopted a multi-criteria decision analysis and developed a multilevel decision-making structure for energy planning and exploitation of renewable energy sources of at the regional level.

A schematic overview of the whole paper was shown in Fig. 1. In this paper, a large data center in Harbin was used as an energy planning research. First, using the general simulation software Designer's Simulation Toolkit (DeST) (developed by Tsinghua University, Beijing, China) [20], the building load characteristics were simulated. Then, the thermal parameters of the building enclosure structure were designed. Meanwhile, the cooling and heat load of the typical buildings in the planning area all the year were simulated, so as to get the cooling and heat load indexes of all buildings in the planning area. In addition, a novel heat recovery system was proposed. The system could realize not only heat recovery but also the shift between space heating in heating season and cooling in non-heating season for subsidiary buildings (office building, teaching & exhibition center, apartment, canteen and fitness center). Additionally, the means of operating the system were introduced to clarify the system in more detail. Finally, the initial investment, operation cost and economic viability of heat recovery system were compared with the ones of air source heat pump system, and the feasibility of the heat recovery system is verified.

2. Model building

2.1. Description of the case study

The project of the data center is located in Harbin City, Hanan industrial district, covers an area of about 870 thousand square meters, construction area of about 630 thousand square meters. The geographic location and architectural effect map of data center was shown in Fig. 2.

In order to facilitate the calculation and analysis, the buildings in