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Discussion of a combined solar thermal and ground source heat pump system operation strategy for office heating

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ABSTRACT

Combined operation of solar thermal and ground source heat pump (GSHP) is widely applied in regions with unbalanced cooling and heating demands. The combined system could achieve a better performance if it is well performed. Optimal operation of the combined system is an interesting topic since different systems have their own characteristics in design, site, local resource etc.

The effect of different operation strategies of the combined system to the system performance, soil temperature variation are discussed in this paper. A results discussion of a combined solar thermal and GSHP system for office heating under different operation strategies by simulation is presented firstly, and the real operation of the combined system for a building heating in Beijing, north of China, utilize solar thermal as an assistant system of HP unit is addressed then. Water temperature variation in water tank and the HP unit is plotted and discussed as well, finally, solar thermal energy directly storage into the ground, soil temperature variation in the autumn season is introduced at the end.

A system simulation tool, TRNSYS, is used to model three different operation strategies of the combined system in winter season: solar thermal preheats return water in the condenser side, evaporator side of the HP unit and the combination of the two. The simulation results manifest the system would be more economically efficient if solar thermal preheats return water of condenser side of the HP unit, but the utilization of solar thermal would be maximized if it preheats the return water of the evaporator side of the HP unit.

A real operation of a combined system in winter season in an office building is presented then, in which the operation data in typical days 2014/12/25 to 2014/12/26 are analysed. The data discovers that with the assistant of solar thermal, heat pump could work temporarily, with a COP of 5.2 is found in the day.

1. Introduction

Ground source heat pump system has been widely utilized in public buildings and residential houses for space heating, cooling and domestic hot water. Around 20,000 GSHP units are installed around the world [1] due to its operation convenience, low maintenance price, life circle economic [2] and environmental friendliness. This renewable energy system is also widely installed for various purposes, such as greenhouse [3–5] heating in agriculture, and snow melting projects in municipal engineering [6].

Combined systems of solar thermal and GSHP are also widely applied in cold regions to maintain a sustainable soil temperature in long term operation [7]. It is found that the assistant operation of solar thermal helps to reduce length of HEX at the designing stage, which reduces the initial cost of the whole system [8,9]. By simulation, the performance of a solar assisted ground source heat pump could achieve 4.3-5.1 in a residential building [10].

Heat were collected through solar tube and recharged to the ground through U-tubes as kinds of heat storage were discussed [11–17]. Chen Jinhua [11] analyzed operation pattern of solar-soil compound system, and found that the combined system could ensure the efficiency of the unit, which benefits the recovery of soil temperature. Chen Xi [12] et al. carried out experimental studies on a solar-assisted GSHP for space heating, in which four operation modes were investigated in winter season. The findings suggest that comparing with recharging boreholes, the system performance of the solar thermal energy is more efficient, and thus it is recommended as an alternative source for heat pump. Hanne Thorshaug Andresen [13] has conducted a research located in Shanghai, China, finding that with a solar collector, the electricity usage of the whole system could be reduced by 26.1% and this significant reduction is primarily due to the shortened operation time. Vikas Verma, K et al. [14] also found that with recharging the ground by solar thermal system, COP of the system for space heating in night

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Nomenclature

COP	Coefficient of performance
E_{hp}	Power consumption of HP unit
Q_{hp}	Heat which is provided to the building by HP unit
Q_{sn}	Heat which is provided to the building
Q_{tank}	Heat which is provided to the building by water tank
SCOP	System coefficient of performance
T_{1in}	Temperature of water enter into evaporator side of the HP unit in winter season
T_{1in-1}	Temperature of water which is heated by HEX before enter into evaporator side of the HP unit
T_{1out}	Temperature of water goes out from evaporator side of the HP unit in winter season
T_{2in}	Temperature of water enter into condenser side of the HP unit in winter season
T_{2in-1}	Temperature of water which is heated by HEX before enter into condenser side of the HP unit
T_{2out}	Temperature of water goes out from evaporator side of the HP unit in winter season
T_{bwt}	Temperature of the water in the big water tank
T_{swt}	Temperature of the water in the small water tank

time increased 23% in Indian climate conditions. Dai [15] carried out an experimental study on the performance of a solar assisted ground source heat pump system at different levels of heat. Liu [16] carried out an experimental study on the performance of a combined cooling-heating-power system (CCHP) with GSHP and thermal energy storage (TES) under various loading conditions. They noted that because of the usage of TES and the applying of GSHP, a total improvement of around 15.8% and 37.5% of the cooling and heating capacity has been recorded in the installed CCHP.

Mehmet Esen [17] carried out modelling and experimental performance analysis of solar-assisted ground source heat pump system by different methodologies. Research results shows that the adaptive neuro-fuzzy inference system (ANFIS) is more successful than that of artificial neural network (ANN) for forecasting performance of a solar ground source heat pump. Liu [18] carried out simulation study of feasibility and performance of hybrid ground-source heat pump system for office building and finding that GSHP with auxiliary heat source are easier to retrofit existing buildings than solar assistant GSHP system.

This study gives a brief introduction of the office building and its energy system, being followed by a further discussion of operation strategy of a combined solar thermal and ground source heat pump system with heat storage tank. Solar thermal preheats return water in the condenser side, evaporator side and the combination of the two, which was simulated and analysed by TRNSYS. Real operation of the combined system under season transferring and winter condition in the office building is introduced afterwards. This study reports the conditions of the heat storage system with different water temperatures, demonstrating the combined GSHP system operation performance.

From a heating season's operation data, an average COP of about 4.9 is recorded, and due to this optimized system operation, the GSHP system and indoor air temperature is kept around 24 °C during the whole winter period.

2. System description

Nearly Zero Energy Building (NZEB) of China Academy of Building Research (CABR NZEB) is a 4-floor office building, as shown in Fig. 1 [19,20]. Floor area is 4025 m^2 and occupancy is approximately 180 full-time employees. The building is designed as the first nearly zero energy building in cold climate zone under US-China Clean Energy Research Center (CERC) program. Adhering to the designing principle of "passive building, proactive optimization, economy and pragmatism", the demonstration project integrated cutting-edge building technologies and HVAC systems. It is also an experimental building.

2.1. Energy system

As the first demonstration nearly zero energy building in cold climate zone in northern China, the building is not only an excellent demonstration in building design, technology, but also an academy project, in which many research works related to building energy conservation are carry out in this building.

The CABR NZEB explores the energy saving potential by using highly efficient HVAC system. Underground borehole [21] and solar collectors are used in the geothermal heat pumps and absorption chiller as the primary cooling and heating sources. Schematic diagram of the energy system is shown in Fig. 2.

Fig. 1. North Façade of CABR Nearly Zero Energy Building.