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Operating performance in cooling mode of a ground source heat pump of a nearly-zero energy building in the cold region of China

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ABSTRACT

A hybrid ground source heat pump system is utilized to meet the energy demands of the first nearly-zero energy office building located in the cold region of China. The simulation result shows that the heating, cooling and lighting demands of the building could be reduced to 25 kWh/m^2 yr with the utilization of high-performance envelopes and the hybrid renewable energy system. A ground loop consisting of two rectangular fields of 70 borehole heat exchangers is utilized together with the solar energy system to meet the building's energy demand. During the system commissioning phase, from 1 July to 15 August 2014, the inlet and outlet water temperatures of the heat pump unit and boreholes were collected and analysed. The coefficient of performance (COP) of the heat pump unit could reach 5.0 in cooling operation strategy, which satisfies the energy reduction requirement and meets the room temperature standard.

1. Introduction and background

Buildings are the largest consumers of energy. Driven by population increase and economic growth, the global final energy consumption of buildings doubled between 1971 and 2010 to reach 2794 Mtoe. According to the prediction of International Energy Agency, global energy demand from buildings is projected to grow by an additional 838 Mtoe until 2035 compared with 2010 [1]. Reducing the energy consumption in the building sector towards nearly zero and net zero is one of the most important ways to achieve energy reduction and respond to climate change.

The revised Energy Performance of Buildings Directive 2002/91/EC (EPBD) [2] has established several new and strengthened requirements such as the obligation that all new buildings should be nearly-zero energy by the end of 2020. In order to achieve the EU 2020 goal, several research programs and pilot building demonstrations were implemented across the EU. In 2007 the EU CONCERTO Class 1 project commenced, whereby 442 dwellings were designed and constructed as low-energy class 1 houses according to requirements set by the Municipality of Egedal, Denmark. So far, 65 dwellings and 30 single family houses have been constructed with an annual heating demand of 15 kWh/m^2 yr [3], which is a very good result in terms of the energy reduction of new buildings.

Apart from European Union member states, USA issued Executive Order 13514 titled 'Federal Leadership in Environmental, Energy, and Economic Performance' on 5 October 2009, with the goal of achieving zero-net energy in federal government buildings by 2030 [4]. California set the further objective of zero-energy buildings in Executive Order B-18-12 [5]: 'Any proposed new or major renovation of state buildings larger than 10,000 square feet should use clean, on-site power generation; 50% of new facilities beginning design after 2020 to be Zero Net Energy; 100% of new state buildings & major renovations beginning design after 2025 to be ZNE' [6].

Developed countries in Asia also set the goal of zero energy building. On 17 July 2014, the Ministry of Land, Infrastructure and Transport of Korea issued The Action Plan of ZEB Corresponding to Climate Change at the 11th General Meeting of the Presidential Advisory Council on Science and Technology, which is chaired by President Park Geun-Hye. According to the action plan, ZEB for small-scale public buildings such as post offices and schools will be mandatory by 2020, and ZEB will be gradually implemented mandatory in all new buildings from 2025 [7].

Even though there is still discussion about the definition of nearly-zero energy building and other similar terms, such as net zero energy building or zero carbon building and so on [8–12], the

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integration of high-performance envelopes [13–15] and renewable energy systems [16–18] to lower the energy demand and achieve the lowest energy consumption is a clear imperative. The technological and economic features of ground source heat pump systems for heating and cooling have been studied as promising renewable energy system [19,20].

Since 2001, alongside the rapid growth of the economy, nearly half of the world's new building construction is in China, which is more than two billion square metres of new building floor area per year, the total building floor area increased from 807 million m^2 to 2.77 billion m^2 between 2001 and 2011. Residential building area increased from 496 million m^2 to 1.72 billion m^2 and public building area increased from 195 million m^2 to 488 million m^2, the central government has implemented a series of policies to promote building energy efficiency and achieved very good results. However, China has not had a clear goal of nearly-zero energy building until now.

Similar as other countries, ground source heat pump (GSHP) technologies have increasingly attracted attention in different climate zones among all the energy efficiency and renewable energy technologies in China. At the beginning of the twenty-first century, with the establishment of financial incentives and corresponding supportive policies, GSHP systems went through a rapid development phase. In this period, the quantity of GSHP projects and the installed capacity increased rapidly. Compared with 26 million m^2 in 2006, the total floor area of GSHP projects reached 240 million m^2 by the end of 2012 [21]. The performance of ground source heat pump systems in regional applications and in conjunction with underground water has been studied [22,23] but how the system will work alongside nearly-zero energy building has never been researched.

Fig. 1. Outlook of the nearly zero energy building.

Compared with the building energy codes under implementation, the optimum energy-saving rate of office buildings could reach 29.4% in cold regions of China with the utilisation of high-performance building envelopes [24]. Theoretically, if the heating demand and cooling demand were reduced and balanced, GSHP technologies would be the best choice for such offices since they could provide heating and cooling with the same system and balance the underground temperature during long-term operation.

Besides GSHP systems, various renewable energy technologies also have very good result in terms of energy-saving, including medium or high-temperature solar collectors with hot-water absorption chiller, water loop heat pumps, water-cooled VRV, evaporative cooling devices and so on. The objective of China Academy of Building Research (CABR) nearly-zero energy building is reduction of overall cost while consuming minimum energy and combining various technologies to investigate the real performance of innovative technologies. The building discussed in this paper has a rather complex heating and cooling system designed to find the best way to achieve nearly-zero energy (see Section 3.1). During the summer of 2014, only the GSHP system and a small cooling system for meeting rooms were operated; other systems were under-commissioned, so this paper only focuses on the operation result of the ground source heat pump unit.

2. Building characteristics

2.1. Basic information

Starting in 2013, under the umbrella of the U.S. – China Clean Energy Research Center (CERC), experts from China and the United States jointly designed and constructed the nearly-zero energy office building located in CABR. The building was completed in July 2014and started commissioning, operational data have been collected since then.

This is a four-floor office building, as shown in Fig. 1, with a total floor area of 4025 m^2 and occupancy of approximately 180 full-time employees. Depending on requirements, the building are divided into four main functional parts: six meeting rooms accounting for 15% of the total area, several standard offices accounting for 65%, equipment rooms accounting for 5% and stairs and washrooms accounting for 15%. The standard floor areas are shown in Fig. 2.

The energy consumption target of heating, cooling and lighting was 25 kWh/m^2 yr, which was sub-divided into zero use of fossil fuel for heating in winter, cooling energy consumption reduced by 50% in summer and lighting energy consumption reduced by 75% compared with China's existing building energy codes. In order to achieve the nearly-zero energy target in a cold climate, high-performance envelopes are one of the important factors in the

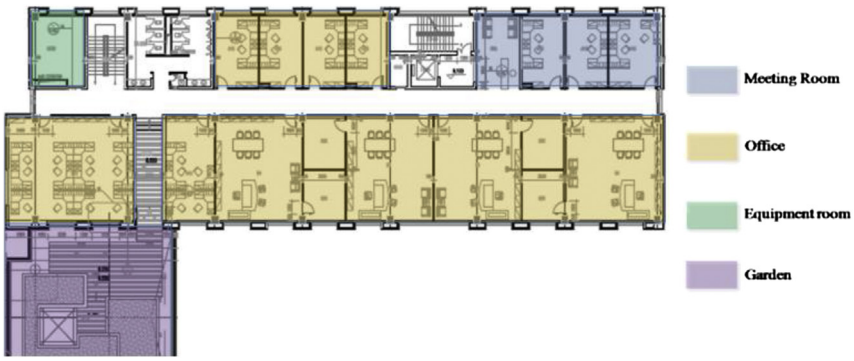

Fig. 2. Standard floor of the building.