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Groundwater source heat pump application in the heating system of Tibet Plateau airport

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ABSTRACT

Due to the lack of conventional energy and fragile ecological environment in the Tibet Plateau at an elevation of over 3000 m, renewable energy utilization is of great significance in environment protection and energy conversation. A field measurement of a groundwater source heat pump (GWSHP), a part of a solar assisted GWSHP heating system of an airport in the Tibet Plateau with the side of solar collectors broken down was conducted in this paper. Meanwhile, the indoor thermal environment in the terminal and dormitory heated by radiant floor was measured. The performance, economy of the GWSHP and indoor thermal environment were analyzed. At last, a comparison between the GWSHP and other heat pumps used in this region was made. The results showed that the coefficient of performance (COP) is about 5.0. Compared to conventional heat sources, the performance of the GWSHP is optimal in regard to both energy conservation and economic efficiency. There was a significant difference observed between the thermal environment in the terminal and dormitory. Accordingly, design considerations and regulation measures are recommended to improve the thermal environment. Compared with heat pumps used for heating in the Tibet Plateau so far, the GWSHP in this paper is better.

1. Introduction

There is approximately 2.5% of the earth's land at an altitude over 3000 m, including 1 million square kilometers of the Qinghai-Tibet region in the southwest of China and 330,000 square kilometers of the Andean Plateau in South America. Plateaus and mountains have drawn human populations since the dawn of time, where approximately 500 million individuals currently make their homes. Almost the entirety of Tibet is over 3000 m in altitude, so the region features several unique climatic characteristics such as low atmospheric pressure, strong solar radiation, high atmospheric transparency, wide diurnal temperature range, and small yearly temperature range. In addition to issues with hypoxia faced by Tibetans year-round, the exceptionally cold and dry winters have a serious effect on health and safety. Effectively heating living, working, and public spaces in the Tibet Plateau represents an urgent concern related to the quality of life for Tibetans. Due to the lack of conventional energy resources and the need to protect Tibet's fragile ecological environment [1], the use of traditional coal-fired and oil-fired boilers for heating is restricted throughout the region [2,3]. Tibet is rich in hydraulic resources, terrestrial heat sources, solar energy, and wind energy, however, leaving Tibetans with a wealth of potential alternatives. Tibet has abundant underground water resources that are closely related to surface runoffs, such as rivers and lakes. About 30% of the surface runoffs are supplied by underground water [4].

The heat pump, a system that can upgrade low-grade energy to high-grade energy at the cost of electric energy, has been shown to conserve energy and reduce CO_2 emissions. Different heat pumps can be categorized according to their respective heat sources. There are ground source heat pumps, water source heat pumps, air source heat pumps, and solar energy heat pumps. Numerous researchers around the world have conducted studies on heat pump usage in mountainous regions and plateaus [5]. Ibrahim [5], for example, dynamically simulated the performance of an air source pump water-heater in Lebanon, a mountainous country with over half of its area at elevations above 1000 m; the results showed that the expected monthly average COP varied from 2.9 to 5.0. Bakirci [6] evaluated the performance of a vertical ground-source heat-pump system tailored to climatic conditions in Erzurum, Turkey, which is located in a cold climate at an altitude of 1950 m. The results showed that the average heat-pump COP and total system COP values are approximately 3.0 and 2.6, respectively, in the coldest months of the heating season. The performance of a solar-assisted geothermal heat pump (SAGHP) located in an Alpine ski park at

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2500 m elevation was analyzed via transient simulations in another study; different configurations produced system-level COP values between 3.53 and 3.62 [7].

Heating modes utilized across the Tibet Plateau include passive and active heating. With regards to the former, Huang [8] explored the climate-responsive design of traditional Tibetan dwellings in Lhasa through field measurements to find that passive solutions are effective at improving indoor environments, but cannot provide adaptive thermal comfort without intermittent active sources of heating from a stove or electric heater. Liu [9] made a field measurement of the indoor temperature of a passive solar, two-room house located at nearly 5300 m above sea level in Tibet to find that the indoor temperatures of the bath room and preserve room varied from 5 to 32 °C and 8 to 20 °C, respectively. Wu [10] explored a building heating scheme comprised of a series of solar air collectors and thermally activated building system (TABS) in Lhasa, where a numerical model was built with the finite difference method for TABS and the state-space method for the reference building. Simulation results showed that the indoor air temperature could be maintained at 17–24 °C for 24 h via intermittent TABS operation when the average outdoor air temperature is −3 °C. In 2001, a deep well water source heat pump (WSHP) unit was built into the heating system of a municipal government building in Lhasa, marking the first application of a WSHP in Tibet. WSHPs have since been adopted in several Tibetan building projects, including the PAP Corps office building and military courtyards. Cao [11] studied the deep well WSHP unit + fan coil system in a Tibetan military camp heating system. According to the system's working principles and a comprehensive techno-economic analysis, the operating cost and energy usage of the WSHP system is far lower than that of a traditional oil-fired boiler. To date, there has been no such analysis on the performance of GWSHPs through field measurement in the Tibet Plateau.

2. Field measurement

2.1. Description of the heating system

Shigatse is located on the north of Himalaya Range in the south bank of the Brahmaputra. It is an alluvial plain at the confluence of the middle of the Brahmaputra and Nianchu rivers which connects to Tibet's capital, Lhasa, in the east, the Himalaya Range in the south, the Ali Plateau in the west, and the northern Tibet Plateau in the north. Its elevation is about 3800 m [12]. The region has a temperate semi-arid plateau monsoon climate with average (annual) temperature of 6.5 °C; the annual temperature range and diurnal range are 18–20 °C and 14–16 °C, respectively [13], and the annual solar radiation received by the area exceeds 6400 MJ/m^2 [14] with a yearly average of 3248 sunshine hours. Solar radiation in Chongqing, which is situated at the same latitude, is only about 3200 MJ/m^2 [15] with 1259.5 h of sunshine, and the annual temperature and diurnal temperature ranges are 39.2 °C and 9.3 °C, respectively [16,17]. Thus, the climate of the area is very different from that of the plain area with the same latitude, showing strong solar radiation and large diurnal temperature range, small yearly temperature range.

As shown in Fig. 1, Xigaze Peace Airport (3783 m elevation) is located in Jiangdang County, Shangzhuzi District, Xigaze City, Tibet Autonomous Region. It has the fifth-highest altitude of all China's airports. Xigaze Peace Airport utilizes a solar-assisted GWSHP heating system. The heat energy center supplies heat to all the buildings comprising the airport at a total heating load of 1200 kW. The heat source of the central heating system is composed of solar thermal collectors on the dormitory building roofs and the heat energy center roofs in addition to two GWSHP units which serve as supplementary heat sources, the rated input power and rated heating capacity of which are 212 kW and 613 kW, respectively. The system employs diurnal storage to make full use of natural energy sources. Fifty percent (volume percentage concentration) ethylene glycol is used as the cycle fluid and is connected to the heating system indirectly. The indoor water-heating system, in winter months, is a closed mechanical circulation loop. The supply and return water temperatures are 50 °C and 40 °C, respectively. Circulating hot water for heating is softened by a full-automatic Na-ion exchanger. Pressurization of both the solar system and heating system is realized by a membrane automatic close-pressure low-level elevated expansion tank with automatic fluid replenishing. A schematic diagram of the system is shown in Fig. 2.

The long-term corrosion by ethylene glycol causes leakage in the circulation loop pipeline of the solar thermal collectors. The solar thermal collector failed during the measurement period, so the whole airport was heated by a GWSHP unit; the unit's operation was controlled according to the return water temperature. Outdoor pipeline bursts occur frequently when the circulating water pump works with variable frequency, so administrative personnel have fixed the circulating water pump frequency at 40 Hz. There was an outdoor pipeline burst from 16:30 to 17:20 during the test which caused the GWSHP to break down momentarily; it was restarted after 17:20 and ran normally through the remainder of the test.

2.2. Outline of site-measurement

The goal of this study was to examine the performance of the GWSHP in a heating system at a typical high-altitude, cold, arid region. The results gathered here may serve as a reference for the design and application of GWSHPs in the Tibet Plateau and other similar areas.

Our research team conducted a field investigation on the heating system at Xigaze Peace Airport on January 27th, 2015, during a sunny, typical winter day. Measured parameters included outdoor meteorological parameters (temperature, relative humidity and solar radiation intensity), flow rate and temperature of the supply and return water on the evaporator and condenser side, power consumption of the water source heat pump and circulating water pump, air temperature (AT), relative humidity (RH), black globe temperature (BGT), and the inner surface temperature (IST) of the building envelopes of the terminal and staff dormitory.

Outdoor solar radiation intensity was tested with a TBQ-2 total solar radiator meter (Jinzhou Yangguang Technologies) at a time interval of 30 min. Indoor and outdoor temperature and RH were measured with a self-recording hygro-thermometer with accuracy of 0.1 °C/0.1% every 5 min. Indoor BGT was tested with a black globe thermometer accurate to 0.3 °C every 5 min. Inner surface temperatures of the envelope were tested manually with a handheld infrared thermometer accurate to 1 °C hourly. Water temperatures on the water intake side and user side were read directly from the water temperature displayer of the GWSHP. Instantaneous power of the heat pump and circulating pump were tested hourly with three-phase power-tongs. Water flows on both sides were measured with an ultrasonic flowmeter with 0.03 m/s accuracy every 1 min (Fig. 3).

3. Results and discussion

3.1. Outdoor meteorological conditions

As shown in Fig. 4, the air was dry throughout the measurement period and there were large differences in temperature and, naturally, solar radiation between day and night. The outdoor temperature changed within the range of −11.21 to 23.18 °C, reaching