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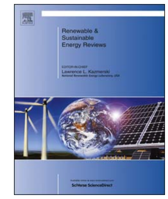

Ground-source pump system for heating and cooling: Review and thermodynamic approach

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ABSTRACT

Ground source heat pump (GSHP) is an innovative and perspective technology able to use the ground as a thermal sink or heat source. If combined with system operating at relatively low temperature, it represents a high efficiency solution for the heating of buildings. Complementarily, during cooling operation it has a good advantage with respect to air-cooled systems, because the ground temperature is stably lower than the outdoor air one. Geothermal heat pump systems are able to reduce the environmental impact of buildings for space heating and cooling by using the ground as an energy renewable source. This paper presents a review on the GSHP systems presenting both a summary of different ground-source typologies of heat pumps and a thermodynamic approach for their modeling. The irreversible thermodynamic approach is here summarized and exposed for a complete GSHPs system. This analytical approach is particularly useful for implementing an optimization design tool for GSHP systems. Recently many works have been published about exergy analysis of these systems. Those works suggest that future lines of development may be considered: a) the optimization based on the transient performance of GSHP systems and not on the sole design condition; b) the integration of irreversible thermodynamic optimization approach into the algorithms of control systems. The diffusion of optimized GSHP systems is essential in order to reduce fossil fuel consumption and CO_2 emissions, complying with the EU's directive.

1. Introduction

On April 23rd, 2009, The European Parliament and the Council adopted the Directive 2009/28/EC on the promotion of the use of energy from renewable sources: it represents the European Union common basis for the promotion of renewable energy [1]. Moreover, economic strategy for the sustainable development suggest both to improve energy efficiency and to introduce a rational use of energy in all the member states of the European Union [2].

Globally, the energy required in buildings for lighting, heating, cooling and air conditioning, is around the 40% of the total world annual consumption, with a considerable environmental impact due to the related CO_2, NO_x and CFCs emissions [3]. Nowadays, heat use for space heating and hot water generation requires around the 80% of the energy demand in houses and utility buildings. Moreover, during the last decades, a considerable increase of the global electrical consumption due to air conditioning demand and the related peak power demand has been pointed out in summer season [4–6]. Consequently, new power plants for electrical energy production are required. Moreover, an increase in the peak electricity cost has been pointed out.

Since 1997, when Montreal Protocol has been approved, governments agreed to phase out refrigerants which potentially destroys stratospheric ozone, to reduce energy consumption, to decrease the rate of energy reserves use and of pollution. Consequently, a renewed interest has increased in cooling and heating technologies in order to reduce their environmental impact [3].

So, buildings can represent a fundamental topic of investigation in order to use its cost effective potential for energy savings, also related to the reduction of green house gas emissions. The fundamental way for building energy consumption reduction for heating, lighting, cooling, ventilation and hot water supply, is to a more accurate energy design buildings [3–7]. Innovative renewable would contribute to preservation of the environment by reducing the emissions at local and global levels. A new theoretical and design approach is required to integrate renewable energies in high performance building [3,8].

Heat pump is a thermal installation which is based on a reverse Carnot thermodynamic cycle which yields thermal energy at a higher temperature. Heat pumps enable the use of ambient heat at useful

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temperature level need electricity or other form of energy to function. The above-mentioned directive could open new opportunities for the diffusion of heat pumps for heating and cooling in buildings. Among the different kinds of heat pumps for heating and cooling of buildings, the ground source heat pumps (GSHP), known also as geothermal heat pump systems or geo-exchange systems, represent a new modern and perspective technology. Indeed, they use the heat stored beneath the earth surface as a thermal sink. GSHPs represent an alternative energy source for buildings heating and cooling applications. The GSHP applications are characterized by their relatively low operative temperatures. Their applications [15,16] can be in one of the three following categories of geothermal energy resources:

1. high-temperature (> 150 °C)} electric power production,
2. intermediate- and low- temperature (< 150 °C) direct-use applications;
3. GSHP applications (< 32 °C).

They can be considered a next future technology for saving primary energy as well as for heating and cooling cost reduction. Their fundamental components are the ground side, the heat pump and the building, designed by taking care of the whole system, such that achieving the most effective operation for a good building comfort [9–14].

During the last years, GSHP have seen a market increase in some European countries among them Sweden and Switzerland are leading since the first 1980s.

This paper wish to review the GSHP systems. They use ground-source as a heat source or sink. To do so, in Section 2 a summary of the GSHP technologies is developed, Section 3 review the ground heat exchanger (GHE) modeling state of the art, in Section 4 the irreversible thermodynamic approach for their modeling is recalled.

2. Ground-source heat pumps technologies

In this section, a brief description of the present GSHP technologies is developed. The design and the relative cost of the system is affected by the geological properties, the subsurface temperatures, the thermal and the hydrological properties of the site. Consequently, system performance depends on the uncertainty in design input parameters, with particular regards to the temperature and thermal properties of the source. The GSHP systems general scheme is represented in Fig. 1. It is composed by [15,16]:

1. The load side with an air-water or a water-water loop in relation to the application considered;
2. The refrigerant loop of the water source heat pump;
3. The ground loop in which water exchanges heat with the refrigerant and the earth.

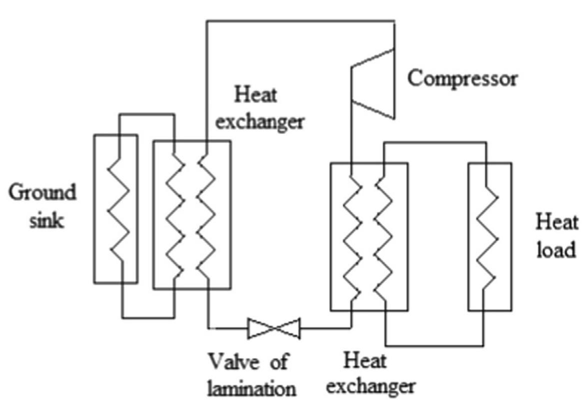

Fig. 1. General design of GSPS.

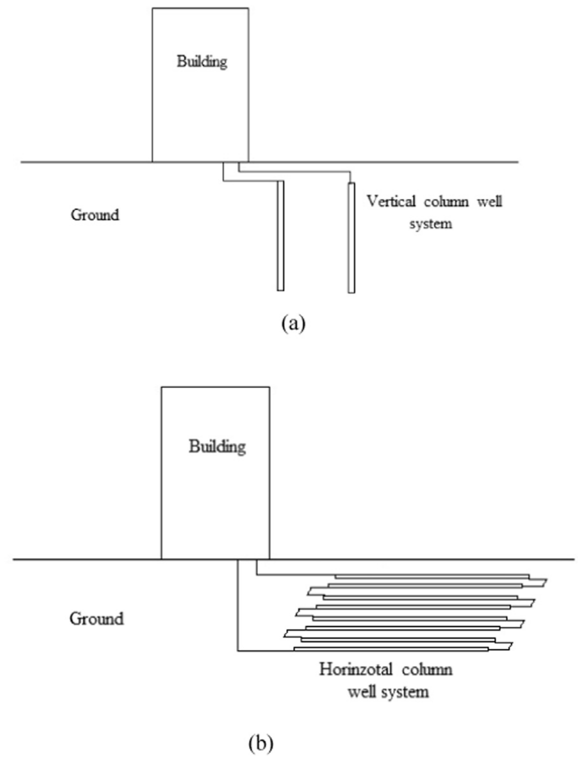

Fig. 2. Geometric well systems.

The system absorb heat at a low temperature level and reject it to a higher temperature level [15,16]. The GSHPs use the thermal energy stored in the earth through two main different geometries of the circuits, vertical or horizontal heat exchange systems buried in the ground, as represented in Fig. 2. The system can work both as a refrigerator and as a heating system, with the possibility of obtaining a dual-mode GSHP systems by using a reversing valve to switch between heating and cooling modes, by reversing the refrigerant flow direction. In relation to the technology used, the GSHP systems can be classified in four categories [8]:

1. GWHP, ground-water heat pump systems, also known as open-loop systems, are the original type of GSHP system, first installed in the late 1940 s [11]. They are vertical GWHP systems, which involve wells and well pumps in order to supply ground water to a heat pump or directly to the applications. The used ground water is discharged to a suitable receptor. Designing is based on the knowledge of some conditions related to the ground-water availability and its chemical quality. They are interesting systems for their low cost, simplicity in realization and small amount of ground area necessary. Disadvantages and problems are related to the possible limited availability and poor chemical quality and to ground water withdrawal and re-injection;
2. GCHP, ground-coupled heat pump systems, known as closed-loop GSHP systems [17]. They were developed during the 1970 s with the advantage of overtaking the problems related to the ground water quality and availability. Moreover, they uses less pumping energy than the previous systems because of the less elevation required [18]. In these systems, heat rejection and extraction is obtained by a high-density polyethylene pipe heat exchanger buried in vertical boreholes (Fig. 2a) or horizontal trenches (Fig. 2b). This fluid used can be water or an antifreeze solution. In the case of vertical borehole GCHP systems, the ground heat exchanger can be composed of (30.5–120 m)-deep and (76–127 mm)-diameter boreholes, backfilled with a material that prevents contamination of ground water, and with a (19–38 mm)-diameter U-shaped pipe through