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Review

General review of ground-source heat pump systems for heating and cooling of buildings

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ABSTRACT

A large number of ground-source heat pumps (GSHP) systems have been used in residential and commercial buildings throughout the world due to the attractive advantages of high energy and environmental performances. The GSHPs are proven renewable energy technology for space heating and cooling. This paper provides a detailed literature review of the GSHP systems, and their recent advances. The operation principle and energy efficiency of a heat pump are defined first. Then, a general introduction on the GSHPs and its development, and a detailed description of the surface water (SWHP), ground-water (GWHP), and ground-couplet (GCHP) heat pumps are performed. The most typical simulation and ground thermal response test models for the vertical ground heat exchangers currently available are summarized including the heat transfer processes outside and inside the boreholes. Also, some information about a new GWHP using a heat exchanger with special construction, and the possibility to obtain the better energy efficiency with combined heating and cooling by GCHP are presented. The various hybrid GCHP systems for cooling or heating-dominated buildings are well described. Finally, the energy, economic and environmental performance of a closed-loop GCHP system is also briefly reviewed. It is found that the GSHP technology can be used both in cold and hot weather areas and the energy saving potential is significant.

Contents

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1. Introduction

Economical strategy of a sustainable development imposes certainly to promote efficiency and a rational energy use in buildings as the major energy consumer in Romania and the other member states of the European Union (EU). Buildings represent the biggest and most cost effective potential for energy savings. Also, studies have shown that saving energy is the most cost effective method to reduce green house gas emissions (GHG).

At present heat use is responsible for almost 80% of the energy demand in houses and utility buildings for space heating and hot water generation, whereas the energy demand for cooling is growing year after year.

In order to realize the ambitious goals for the reduction of fossil primary energy consumption and the related CO_2 emissions to reach the targets of the Kyoto-protocol besides improved energy efficiency the use of renewable energy in the existing building stock have to be addressed in the near future.

On 17 December 2008, the European Parliament adopted the Renewable Energy Directive. It establishes a common framework for the promotion of energy from renewable sources. This directive opens up a major opportunity for further use of heat pumps for heating and cooling of new and existing buildings. Heat pumps enable the use of ambient heat at useful temperature level need electricity or other energy form to function.

The amount of ambient energy E_{res}, captured by heat pumps to be considered renewable energy, shall be calculated in accordance with the following equation [1]:

$$E_{res} = E_U \left(1 - \frac{1}{SPF}\right) \quad (1)$$

where E_U is the estimated total usable thermal energy delivered by heat pumps; SPF is the estimated seasonal performance factor for these heat pumps.

Only heat pumps for which SPF > 1.15/η shall be taken into account, where η is the ratio between total gross production of electricity and the primary energy consumption for electricity production. For EU-countries average η = 0.4. Meaning that minimum value of seasonal performance factor should be SPF > 2.875.

Ground source heat pump (GSHP) systems use the ground as a heat source/sink to provide space heating and cooling as well as domestic hot-water. The GSHP technology can offer higher energy efficiency for air-conditioning compared to conventional air-conditioning (A/C) systems because the underground environment provides higher temperature for heating and lower temperature for cooling and experiences less temperature fluctuation than ambient air temperature change.

The first known record of the concept of using the ground as heat source for a heat pump was found in a Swiss patent issued in 1912 [2]. Thus, the research associated with the GSHP systems has been undertaken for nearly a century. The first surge of interest in the GSHP technology began in both North America and Europe after World War Two and lasted until the early 1950s when gas and oil became widely used as heating fuels. At that time, the basic analytical theory for the heat conduction of the GSHP system was proposed by Ingersoll and Plass [3], which served as a basis for development of some of the later design programmes.

The next period of intense activity on the GSHPs started in North America and Europe in 1970s after the first oil crisis, with an emphasis on experimental investigation. In the ensuing two decades, considerable efforts were made to establish the installation standard and develop design methods for vertical-borehole system [4–6].

To date, the GSHP systems have been widely used in both residential and commercial buildings. It is estimated that the GSHP system installations have grown continuously on a global basis with the range from 10% to 30% annually in recent years [7].

This paper mainly presents a detailed literature review of GSHP technology, concentrating on the ground-coupled heat pump (GCHP) systems. Initially, are defined the operation principle and energy efficiency of a heat pump. Thus, a detailed description on GSHPs and its development are performed, the most typical simulation models of the vertical ground heat exchangers currently available are summarized, and a new ground-water heat pump (GWHP) using a heat exchanger with special construction, tested in laboratory and the possibility to obtain the better energy efficiency with combined heating and cooling by GCHP are well presented. Finally, the energy, economic and environmental performances of a closed-loop GCHP system and the advanced engineering applications of hybrid GCHP systems are also briefly reviewed.

2. Operation principle of a heat pump

Heat pump is a thermal installation which is based on a reverse Carnot thermodynamic cycle (consumes drive energy and produces a thermal effect).

Any heat pump moves (pumps) the heat E_S from a source with low temperature t_s to a source with high temperature t_u consuming the drive energy E_D.

• Heat source can be:

- a gas or air (outdoor air, warm-air from process of ventilation, hot-gases from industrial processes);
- a liquid called generic water: surface water (river, lake, sea), ground-water, discharged hot-water (domestic, technologic, and recirculated in cooling towers);
- soil, with the advantage of accessibility.

• *Heat consumer*. The heat pump yields thermal energy at a higher temperature, depending on the application of heat consumer. This energy can be used to:

- space heating; heat pump heating who will be related to low temperature heating systems: radiant panels (floor, wall, ceiling, floor-ceiling), warm-air, or convective systems;
- water heating (pools, domestic and technologic hot-water);

It is recommended that the heat consumer to be associated with a cold consumer. This can be performed with either a reversible (heating–cooling) or a double effect system. In a cooling mode, a heat pump operates exactly like a central air-conditioning.

• *Drive energy*. Heat pumps can be use to drive different energy forms:

- electrical energy (electro-compressor);
- mechanical energy (mechanical compression with expansion turbines);
- thermo-mechanical energy (steam ejector system);
- thermal energy (absorption cycle);
- thermo-electrical energy (Péltier effect).

The GSHPs are those with electro-compressor. The process of elevating low temperature heat to over 38 °C and transferring it indoors involves a cycle of evaporation, compression, condensation and expansion (Fig. 1). A non-CFC refrigerant is used as the heat-transfer medium, which circulates within the heat pump.