Applied Energy 101 (2013) 341–348

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Geothermal heat pump systems: Status review and comparison with other heating options

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ARTICLE INFO

Article history:
Received 6 July 2011
Received in revised form 12 January 2012
Accepted 17 January 2012
Available online 12 February 2012

Keywords:
Heating
Geothermal energy
Heat pump
Thermal energy storage
Efficiency
Economics

ABSTRACT

Heating is a major requirement in many regions, and growing energy demands and pollutant emissions have allowed unconventional heating technologies to be considered, including geothermal. Geothermal heat pumps are reviewed, including heat pump technology, earth connections, current world status and recent developments. Geothermal heat pump technology and conventional heating systems are compared in terms of costs, CO_2 emissions and other parameters. Geothermal heat pump use is economically advantageous when the price of electricity is low. Alternatively geothermal heat pump units have the lowest emissions depending when electricity is produced from a low emitting source.

1. Introduction

A large portion of the global energy supply is used for electricity generation and space heating, with the majority derived from fossil fuels. Fossil fuels are finite resources and their combustion is harmful to the environment, through the emission of greenhouse gases, which contribute to climate change, and other pollutants. Demand for energy is increasing and future fossil fuel shortages are predicted [1]. Hammond [2] argues that fossil fuel depletion along with pollutant emissions and global warming are important factors for sustainable and environmentally benign energy systems. Such concerns have motivated efforts to reduce society's dependence on fossil fuels, by reducing demand and substituting alternative energy sources. Alternative energy resources are sought that are more environmentally benign and economic than conventional fossil fuels.

Beyond fossil fuels, the earth's crust stores an abundant amount of thermal energy. Geothermal energy systems are relatively benign environmentally, with the emissions much lower than for conventional fossil fueled systems [3,4].

Geothermal energy is used in three main ways: electricity generation, direct heating, and indirect heating and cooling via geothermal heat pumps [4]. These three processes use high, medium, and low temperature resources, respectively. High and medium temperature resources are usually the product of thermal flows produced by the molten core of the earth, which collects in areas of water or rock. Low temperature resources are near ambient temperature and are mostly attributable to the solar energy incident on the ground and ambient air.

High and medium temperature thermal resources are often deep within the earth [5], and the depth affects whether they can be exploited economically as drilling and other extraction costs can become high at great depths. Low temperature geothermal resources are abundant and can be extracted and utilized in most locations around the world. Extracting such thermal energy is relatively simple because the depths involved are normally small. Heat pumps extract low temperature thermal energy and raise the temperature to that required for practical use [4]. Geothermal heat pumps can provide an environmentally and economically advantageous option for space heating, and can also be utilized for space cooling.

In this article, we review geothermal heat pump systems and recent developments and compare them with other heating options, with the objective of improving understanding of geothermal heat pump systems and increasing their utilization in appropriate applications.

2. Geothermal heat pumps

Heat pumps can provide heat efficiently and economically with low emissions [6]. The concept of heat pumps has been recognized since the 1800s, and commercial applications have existed for

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doi:10.1016/j.apenergy.2012.01.048

about 60 years. Heat pumps move thermal energy from a lower to higher temperature medium similar to refrigerators [7]. The product of a heat pump is useable heat, usually at a temperature suitable to maintain a comfortable environment within a space. One of the most attractive characteristics of heat pumps is that they transport more thermal energy than the energy required to operate [4,8].

Geothermal heat pumps (GHPs), also referred to as ground source heat pumps (GSHPs), earth energy systems, GeoExchange heat pumps, ground-coupled heat pumps, earth-coupled heat pumps and ground-source systems [9,10], are comprised of three main systems:

- *Geothermal heat pump:* Moves heat between building and ground and modifies its temperature [11].
- *Earth connection:* Facilitates heat extraction from the ground via a heat exchanger loop for use in the heat pump unit [11].
- *Interior heat distribution system:* Conditions and distributes heat throughout the space [11,12].

2.1. Heat pump systems

Heat pumps operate using electricity to drive compressors that provide the necessary work for the concentration and transport of thermal energy [4,8]. Basic heat pumps operate on the vapor-compression refrigeration cycle. The working fluid within the heat pump is usually a refrigerant, with the selection dependent on the overall characteristics and requirements of the GHP system [6,13]. A GHP moves thermal energy between the earth and the heated space by controlling pressure and temperature by means of compression and expansion [4,8,11]. Five major components are incorporated in a heat pump (Fig. 1) [10,11,14]: compressor, expansion valve, reversing valve, and two heat exchangers. There are also various other minor components and accessories such as fans, piping and controls that assist in operation.

GHPs for heating operate as follows [12]:

1. Thermal energy is extracted from the earth and transported to the evaporator.
2. Inside the heat pump unit cold refrigerant, in a liquid dominated liquid/vapor state, enters the evaporator. Heat is transferred from the earth connection to the refrigerant and causes the refrigerant to boil and become a low pressure vapor; the temperature increases slightly.
3. The vapor enters an electrically-driven compressor, where the pressure is increased, resulting in a high temperature and high pressure vapor.
4. High temperature vapor enters the condenser. The refrigerant is at a higher temperature than the space, inducing heat transfer from the refrigerant to the building. The refrigerant cools and condenses, yielding a high pressure, high temperature liquid.
5. Hot liquid passes through an expansion valve that reduces its pressure, resulting in a temperature decrease. The refrigerant enters the evaporator to begin another cycle.

Many systems include a cooling mode that removes thermal energy from a space and rejects it to the ground. In the cooling mode, a reversing valve is used to move the fluid in the opposite direction in the cycle. The heat exchangers are reversed, with the earth connection heat exchanger becoming the condenser and the building heat exchanger the evaporator [8,12].

Some systems include a desuperheater (Fig. 1), which is an auxiliary heat exchanger that supplies heat to a hot water tank. Located at the compressor exit it transfers heat from the compressed vapor to water circulating through a hot water tank, reducing or eliminating the energy required for water heating [12].

Merit is usually evaluated in terms of energy efficiency, the ratio of product energy output to driving energy input, in percent. Heat pumps deliver more product heat than the input driving energy, so this definition yields an energy efficiency greater than 100%. To avoid this awkwardness, the term coefficient of performance (COP) is used for heat pumps, defined as the ratio of product thermal energy to input driving energy [9]. COPs for geothermal heat pumps usually range from 3 to 6, with the value dependent on the earth connection setups, system sizes, earth characteristics, installation depths, local climate and other characteristics [10,15].

2.2. Heat distribution systems

The heat distribution system of a GHP system moves heat supplied by the heat pump throughout the space. Two main types of distribution systems exist: water to air and water to water. Water to air systems transfer thermal energy from the ground to air, which is used as the transport medium within the space, while water to water systems use water or another fluid as the heat transfer medium. The most common GHP system in North America is water to air, where an air coil, heated by the heat pump

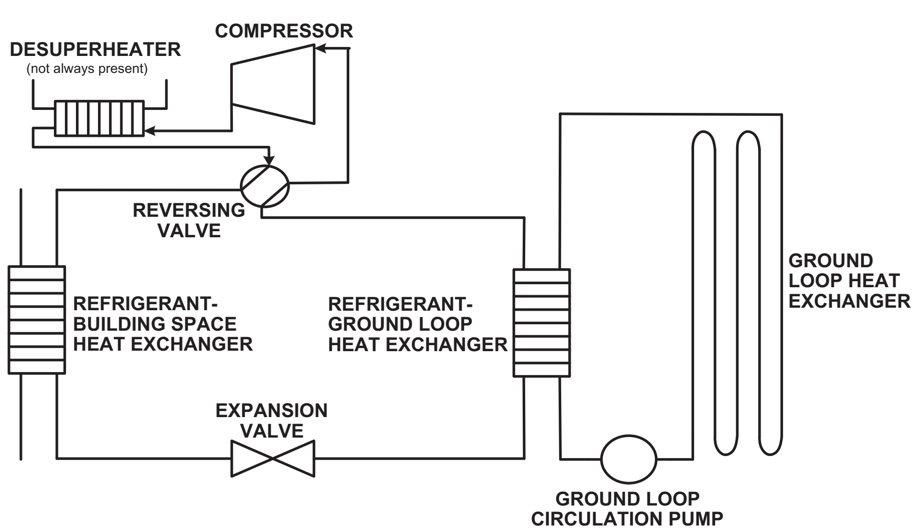

Fig. 1. Basic layout of geothermal heat pump system including desuperheater.