**Heat loss by the Earth, geothermal energy and geothermal heat pumps**

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1. **Introduction –** With the rise of fossil fuel prices and the increased pollution they produce, there has been an increase in research and investment in renewable energy. In this work we discuss geothermal energy and, in particular, the use of geothermal heat pumps.

The direct-use of geothermal energy dates back thousands of years to when people began using hot springs for bathing and cooking. Archeological data show that North American Paleo-Indians, 10,000 years ago, occupied sites around hot springs to recuperate from battle [1]. Historical data show that Romans, Japanese, Turks, Icelanders, Central Europeans and the Maori in New Zealand used geothermal waters for bathing, cooking and space heating. The world’s oldest geothermal district heating system has been operating since the 14th century, in Chaudes-Aigues, France [2]. It is believed that the first geothermal energy use in industry was during the late 18th century near Pisa in Italy. Steam coming from natural vents (and from drilled holes) was used to extract boric acid from hot pools in the area. The first geothermal power plant was installed in the Larderello fields, in 1904, when the steam was successfully used to generate power. In 1980, geothermal heat pumps started gaining popularity in order to reduce heating and cooling costs. Today, geothermal heat plants are operating in 24 countries, with an installed capacity of 10,797.7 MW [3].

1. **Heat loss by the Earth** –The temperature in the Earth’s interior increases with depth. This fact is responsible for the heat flow from the interior to the surface. Heat loss through the Earth’s surface has been calculated using heat flow density values obtained in continents and oceans. Although the number of heat flow data have increased in recent years (38 347 data were used by Davies and Davies,[4]) the data distribution is not uniform and there still exists regions with no data or few data. This requires making interpolations in regions with insufficient data and use of average values in regions with much data. The results obtained for total heat loss range from 30-34 to 47 TW [4-5-6].. Jaupart et al [5], obtained 46 TW for total heat loss, being 32 TW lost in oceanic areas and 14 TW lost in continental regions. The sources for this heat are: Continental heat production (7 TW), mantle heat production (13 TW), core heat loss (8 TW) and mantle cooling (18 TW). The production of heat in the crust and mantle is due to radioactive decay of isotopes of long life. Assuming a constant value for the specific heat of the mantle (1250 J kg-1 K-1), the rate of cooling must be 3.8 X 10-15 K s-1. These power rates are more than double humanity’s current energy consumption from primary sources, but most of this power can not be recoverable.
2. **Geothermal energy** – Geothermal energy is described as clean renewable and sustainable. The word clean is related to the fact that CO2 emissions made by geothermal power plants or by direct use are negligible compared to the emissions associated with fossil fuels. The word renewable is related to the rate of energy recharge. The word sustainable means a provision of energy that meets the needs of the present without compromising the needs of future generations. A replacement for the resource can be found that will allow future generations to use it despite the fact that the resource has been depleted [7].

Geothermal resources are usually classified according to temperature, which varies from an average annual temperature of about 15ºC to values above 300 ºC. In general, resources above 150ºC are used for electric power generation, although power has been generated in Alaska using a 74ºC geothermal resource. Resources below 150ºC are usually used in direct-use projects for heating and cooling. Temperatures in the range 5 to 30ºC can be used with geothermal ground-source heat pumps to provide heating or cooling. According to J. Lund [2], geothermal resources can be classified into: convective hydrothermal resources, geopressured resources, radiogenic resources, hot dry rock resources, and molten rock or magma resources.

Convective hydrothermal resources occur where the Earth’s heat is carried upward by convective circulation of hot water or steam. In vapor dominated systems steam is produced from boiling of deep saline waters in low permeability rocks. The steam from these reservoirs can be exploited to produce electrical energy. Water dominated systems are formed by groundwater circulating to depth and ascending in permeable reservoirs. Surface manifestations of these reservoirs include hot springs, fumaroles, geysers, travertine deposits, chemically altered rocks or no surface manifestations. The Chaves reservoir in northern Portugal is a reservoir of this type.

 The sediments that fill the sedimentary basins have thermal conductivity values lower than those of the surrounding rocks. This produces high temperatures and sometimes high heat flow values. Geothermal gradients in these regions can be over 30ºC/km.

Geopressured resources occur in sedimentary basins where deeply buried fluids contained in permeable sedimentary rocks are warmed by their great burial depth. The fluids are confined by surrounding impermeable rocks and are subject to a much greater pressure than hydrostatic.

Radiogenic resources can be found in regions with granitic intrusions are near the surface. Due to the radioactive decay of uranium, thorium and potassium, the geothermal gradient in the region can be high, providing hot water. This type of resource occurs in Northern Alentejo and in the Beiras regions but is not explored.

Hot dry rock resources are defined as heat stored in rocks from which energy can not be extracted by natural hot water or steam. The local depths of these reservoirs are within 10 km from the surface. The hot rocks have few pore spaces or fractures, little water and low interconnected permeability. In order to extract the heat, experimental projects have fractured the rock by hydraulic pressure, then cold water descends through a well from the surface to the reservoir where heat is extracted from the rock and hot water returns to the surface through another well. Geothermal production wells are commonly more than 2km, but rarely much more than 3 km deep at present [8]. Experimental projects are currently underway in Australia (Paralana and Cooper basin), in France (Soultz-sous-Forêt), in Germany (Landau), in Japan (Ogachi), in the United Kingdom (United Downs, Redruth and Eden Project), and in the USA (Desert Peak, the Geysers and at Bend, Oregon). At Basel, in Switzerland, the project was cancelled due to induced seismicity.

Molten rock or magma resources have been drilled in Hawaii experimentally to extract heat energy directly from molten rock. The heat was used in a space heating system for over 10 years but now has been shut down due to cooling of the surrounding rock.

**3.1 Electricity production -** Geothermal power plants depend on the temperature of the reservoir and the type of fluids involved.

Dry steam plants are the simplest and oldest design. They directly use geothermal steam at temperatures of 150ºC or more [8]. The steam is piped directly from dry steam wells or after separation from wet wells through a turbine that drives an electrical generator. Subsequently it is led to a condenser where vacuum conditions are maintained by cooling water.

Flash steam power plants pull deep, high-pressure hot water into lower-pressure tanks and use the resulting flashed steam to drive turbines. They require fluid temperatures of at least 180ºC, usually more. They are the most common type of plant in operation in regions with hot fluids.

Binary cycle power plants (organic Rankine Cycle) have been gaining popularity in recent years. They utilize geothermal fluids at lower temperatures than conventional plants, in the range of 74 – 170ºC. They use a secondary working fluid, usually an organic fluid that has a low boiling point and high vapor pressure at low temperatures, compared with steam. The fluid passes through a turbine in a similar way as steam in conventional cycles. Binary plants are usually constructed in small modular units of up to a few MWe capacity which are linked together. Kalina is a relatively new binary fluid cycle that utilizes a water-ammonia mixture as working fluid to allow more efficient power production. Binary cycle plants are the plants used in hot dry rock reservoirs projects.

The efficiency of geothermal utilization is enhanced considerably by co-generation plants, compared with conventional geothermal plants. A cogeneration plant produces both electricity and hot water which can be used for district heating as well as other direct uses.

**3.2 Direct uses –** Direct use ofgeothermal fluids is primarily for direct heating and cooling .In 2005 [9], the main types of direct applications of geothermal energy were space heating (including 32% due to geothermal heat pumps), bathing and swimming (including balneology) 30%, horticulture (greenhouses and soil heating) 8%, industry 4% and aquaculture 4%.

Space heating, of which more than 80% are district heating, is among the most important direct uses of geothermal energy. The preferred water temperature for delivery, in space heating, is in the range of 60-90ºC and the return water temperature is in the range of 25-40ºC.

Open loop distribution systems are used for private use and for district heating. Geothermal water is used directly for heating and the spent water from the radiators is discharged at the surface to waste. This type of system is only used when the water quality is good and recharge into the geothermal system is adequate. More commonly closed loop (double pipe) systems are used. In this case, heat exchangers are used to transfer heat from the geothermal water to a closed loop that circulates heated freshwater through the radiators. This is often needed because of the chemical composition of the geothermal waters. The spent water is disposed of into wells that are called reinjection wells.

1. **Geothermal heat pumps** –Geothermal heat pumps are similar to ordinary heat pumps, but instead of using heat found in the outside air of the building, they use heat from the Earth to provide heating, air conditioning and, in most cases, hot water. In winter, they move the heat from the Earth to the buildings. In summer, they pull the heat from the buildings and discharge it into the ground. The ground source heat pumps comprise a wide variety of systems that may use ground water, ground, or surface water as heat sources or sinks.

 Geothermal heat pumps are the fastest growing applications of geothermal energy in the world today**.** They can be used everywhere and use a well established technology, utilizing the energy stored in the Earth’s interior. The temperature at a certain depth in the ground remains constant throughout the year and the ground capacitance is regarded as a passive means of heating and cooling of buildings. To exploit effectively the heat capacity of the ground, a heat-exchanger system has to be constructed. A heat pump may also be coupled to the ground heat exchanger to increase its efficiency.

There are two general types of ground heat exchangers: open and closed [10]. In an open system, the ground may be used directly to heat or cool a medium that may itself be used for space heating or cooling. Also, the ground may be used indirectly with the aid of a heat carrier medium that is circulated in a closed system. The loop of the heat exchanger is made of a material that is extraordinarily durable but allows heat to pass through efficiently. The fluid in the loop is water or an environmentally safe antifreeze solution. The length of the loop depends upon a number of factors, such as the type of loop configuration, the house heating and air conditioning load, soil conditions, local climate , etc.

In open systems, ambient air passes through tubes buried in the ground for preheating or pre-cooling and then the air is heated or cooled by a conventional air conditioning unit before entering the building. In a similar way, the water of a water-bearing layer may be used. In most cases two wells are required, one for extracting water from the soil and one for injecting it back into the water-bearing layer.

In the closed systems, heat exchangers are located underground, either in horizontal, vertical or oblique positions, and a heat carrier medium is circulated within the heat exchanger, transferring the heat from the ground to a heat pump or vice-versa. A typical horizontal loop, placed at 1-2m depth, is 35 – 60 m long per kW of heating or cooling capacity. Horizontal ground loops are the easiest to install while the building is under construction. Vertical heat exchangers or borehole heat exchangers are widely used when there is a need to install sufficient heat exchange capacity under a confined surface area. In a standard borehole (50-250 m deep in typical applications), plastic pipes are installed, and the space between the pipe and the hole is filled with an appropriate material to ensure good contact between the pipe and the undisturbed ground and reduce thermal resistance. Vertical loops are generally more expensive to install but require less piping than horizontal loops because the earth deeper down is cooler in summer and warmer in winter, compared to the ambient temperatures.

Several types of borehole heat exchangers were tested and are used widely. They are classified in two types: U-pipes, consisting of a pair of straight pipes, connected with a U-turn at the bottom, or concentric or coaxial pipes, with one straight pipe inside a larger diameter pipe or joint in complex configurations.

We can say that geothermal heat pumps can be a near future present day means of using the heat from the ground to cool or warm the buildings, in cold or hot weather conditions.

Geothermal heat pumps are environmental benign and represent a large potential for reduction of CO2 emissions. The heat pump needs auxiliary power to achieve the temperature rise needed in the system. The results show that the electrical driven heat pump reduces CO2 emissions by 45% compared with an oil boiler and 33% compared with a gas fired boiler. In most cases it is possible to use solar energy to give the power needed. In these cases, there are no emissions associated with the system.

According to the report,” Global Geothermal Power and Heat Pump Market Outlook (2010-2015)”, Europe is the current geothermal market world leader, followed by the Americas and Asia. Geothermal direct use will double globally in the next five years while global geothermal electricity capacity will grow to 19,200 MW.

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