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AN OVERVIEW OF GROUND SOURCE HEAT PUMPS

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ABSTRACT

As a natural consequence of the increase in the world population, energy needs are also increasing dramatically. At the present time natural gas and coal are generally used as energy sources. According to researchers, oil, natural gas and coal reserves will be run out in the near future. Therefore, new and renewable energy is needed to meet the energy needs for our countries. A lot of researchers have been carrying out about field of alternative energy sources. These studies generally; such as solar energy, wind energy, geothermal energy, wave energy and biomass energy. In addition to these energy conversion systems, it was also possible to mention about heat pumps with the features of low energy consumption, high coefficient of performance and environmental friendly.

The presented paper is a study of general description and basic approaches on ground sources heat pumps. Ground source heat pump and history of it were explained. Some explanations were given about Ground Sources Heat Pump Systems such as Working principles, type of it, general view of advantage and disadvantage of it, hybrid type ground sources heat pump systems working principles, zero carbon footprint approach for it and also heat pump investment comparison with other systems.

1. INTRODUCTION

In the early 19th century, Carnot's work and his thesis on the Carnot cycle, which was published in 1824, were the source of the basic principles of the heat pump. The first practical heat pump proposed by William Thomson (later known as Lord Kelvin) demonstrated that refrigeration machines could be used effectively for heating. Thomson suggested that this system would consume less energy than conventional systems. In 1927, work on the installation and testing of an air source heat pump system for space heating and hot water supply in Scotland by Haldane was presented by him in 1930. The first large heat pump system in Europe was commissioned in Zurich in 1938-1939. Water at 60 °C was obtained from the system and the municipal building was heated. The system was organized to provide cooling in summer [1].

Heat pumps are machines that use energy sources such as air, water and soil and heat pumps can be used for heating and cooling in buildings, plants. The ground and water source heat pump carries the heat stored under the earth to the building in winter and the heat inside the building underground in summer. Underground acts as a heat source in winter and a heat sink in summer. Similar situation can be said for air, the atmosphere acts as a heat source in winter and as a heat sink in summer. In order for the heat pump system to work stable, almost uniform, the temperature of this source or sink should not change much during the time. Efficiency of heat pump is depending on whether it is air, water or soil sourced. Air, which is among the heat sources that can be used, is the most preferred heat source because it can be obtained easily. Water can be used as a heat source in environments where it can be obtained, and water has some advantages compared with air source. Ground source heat pumps are the subject of very important projects today and many ground source heat pump projects are carried out in many countries [2].

In the present study, the types of ground source heat pumps, their advantages and disadvantages will be emphasized. Hybrid type ground source heat pumps will be introduced and some studies will be given related to hybrid application. It will also be focused on the applications that can be made to bring the carbon footprint in the use of heat pumps closer to zero. Finally cost of installation and investment costs of GSHP will be compared with conventional systems.

2. ELEMENTS OF GROUND SOURCE HEAT PUMP SYSTEM

Ground source heat pumps provide heating, cooling and humidity control in residential buildings. Moreover, hot water by providing additional heating or replacing conventional hot water generators. It can also be used for

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supply. Three main parts or sub-parts in ground source heat pump systems system exists. These are:

• Soil or ground heat exchangers: Piping arrangements that allow heat exchange by ensuring the contact of the heat carrier fluid and the soil or ground,

• Heat pump: The system that transfers the heat taken from the ground to the building,

• Heat distribution system: The system used to heat or cool the spaces inside the building.

The main parts of the heat pump system for heating mode are given in Figure 1 [3].

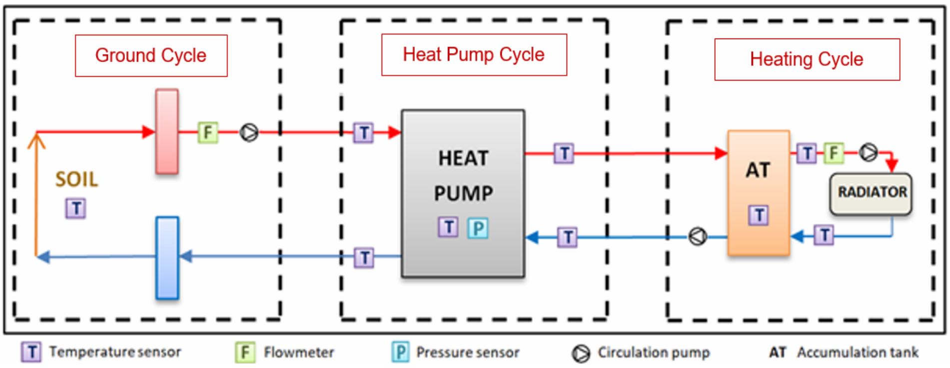

Fig. 1. The main parts of the heat pump system for heating mode [3]

3. TYPE OF GROUND SOURCES HEAT PUMPS

Heat pumps can serve in a very wide area. It can be divided into two as Buildings and Industrial Enterprises. Although heat pumps in buildings are more common, the use of heat pumps in industry is increasing day by day. The point where the thermal energy is taken is called the heat source and the heat pumps are named according to these sources. These sources are called as, air, water and soil. The use of soil as a heat source is more expensive than the other energy source systems (air and water). The system consisting of pipes buried under the ground is called a ground heat exchanger. With the help of these pipes, the soil's energy is transferred to the heat-carrying fluid or the waste heat of the cycle is transferred from the heat carrying fluid to the soil.

In systems based on the fact that the soil is a major energy source to the heat exchangers placed in the soil, the soil temperature varies less than the air and water. Two different types of ground heat exchangers are used in ground-source heat pump applications that are vertical and horizontal applications [4].

Fig. 2. Horizontal ground heat exchanger [6]

Horizontal heat exchangers

Figure 2 shows an example to horizontal heat exchanger system. Horizontal ground heat exchangers consist of heat exchanger pipes buried in trenches at a depth of between 0.8 m and 2.0 m. They require a relatively large surface area which should not be built over and should preferably not be sealed from rain, so are most suitable for applications such as private houses, rural houses, schools and sports facilities etc. They require that the ground should be free from large boulders [5].

Vertical heat exchangers

Vertical ground heat exchangers as shown in Figure 3, also referred to as borehole heat exchanges, are utilized in situations where the available land area is limited. Compared to horizontal ground heat exchangers, they require less piping and pumping energy, albeit they generally come with higher costs. These heat exchangers can be installed in various soil and rock types, with the exception of alluvial gravels with low thermal conductivity. However, caution must be exercised in areas with mine workings, as they may not be suitable in such locations.

Vertical ground heat exchangers are applicable for a wide range of building types, from individual houses to large commercial buildings that utilize extensive ground heat exchanger arrays. The configuration of the ground heat exchanger pipe typically involves a single or double U-tube inserted in a vertical borehole. Alternatively, a concentric pipe may also be used. In suitable soft ground conditions, direct hydraulic pushing or ramming methods can be employed for installation, though the overall depth of the ground heat exchanger will be limited.

The depth of an individual vertical ground heat exchanger depends on the specific ground conditions and can vary from 15 meters to a maximum practical depth of approximately 200 meters. Typically, the borehole diameter ranges from 100 mm to 150 mm [5].

Fig. 3. Vertical ground heat exchanger [6]

In the study conducted by Benli [4], monthly average COP_{sys} values were obtained as 2.7-3.3 and 2.9-3.5 for horizontal ground heat exchanger and vertical ground heat exchanger respectively. Considering this study, it can be said that the coefficients of performance are relatively high in vertical applications.

4. ADVANTAGES AND DISADVANTAGES OF GROUND SOURCE HEAT PUMPS

Advantages:

• GSHPs have lower carbon emissions and greenhouse gas emissions. Therefore, they are environmentally friendly.

• GSHPs exchange heat with the underground soil. The soil temperature is almost constant throughout the year, so that the heat pump operates stable throughout the year.

• GSHPs have a longer lifespan when compared to many conventional HVAC systems. The ground loop tubes can survive for decades and heat pump units typically have an average lifespan of 20 years.

• GSHPs have lower operating costs due to their efficiency in energy utilization. GSHPs can provide significant reductions in electricity bills compared to conventional heating and cooling systems.

• Compared to conventional heating and cooling systems which use fossil fuels, GSHPs reduce greenhouse gas emissions. By using renewable energy sources, they help reduce carbon footprints and halt climate change.

Disadvantages:

• GSHPs usually has high initial installation cost.

• GSHP design and installation must be of high quality. Otherwise, system performance may fall below of expectations.

• GSHPs need enough land to build the ground loop.

• The installation and maintenance of ground source heat pump systems can be a complex process requiring expertise and experience.

• Some soils have application difficulties due to unknown soil map.

5. HYBRID GROUND SOURCE HEAT PUMP SYSTEM

A hybrid ground source heat pump system combines both renewable and fossil fuel energy sources to provide energy to a property. This installation consists of two basic components: a heat pump and a conventional system that works with gas, oil or LPG. The primary objective of hybrid ground source heat pump systems is to improve the cost efficiency of ground source heat pump installations. While these systems can significantly reduce energy consumption in areas where it is required, the initial high cost associated with the installation of the ground heat exchanger can be a drawback. It is widely recognised that hybrid systems use established technologies such as cooling towers or boilers to manage some of the highest heating or cooling demands. However, these hybrid systems have encountered technical obstacles that initially prevented their adoption. The incorporation of this additional component into the heating and cooling configuration adds additional complexity. Figure 4 show the schematic view of hybrid ground source heat pump system [7].

Hybrid Ground Source heat pump can also be defined as systems that work by taking the electrical energy required for compressor from the PV panel. Figure 5 shows an example for hybrid type ground source heat pump system.

In weather conditions with high solar radiation, the electrical power required by the heat pump is generated by the PV panel. If the electricity generated by the PV panel is more than the heat pump needs, the extra part can be stored or, if possible, sold to the power grid. Inconditions where electricity generation is low, the heat pump can meet part of its electricity needs from the grid. Thus, the needs can be met uninterruptedly in all conditions.

Hybrid ground source heat pump and PV panel systems offer an effective solution for sustainable energy use and provide environmentally friendly energy use. It also reduces dependence on the electricity grid.

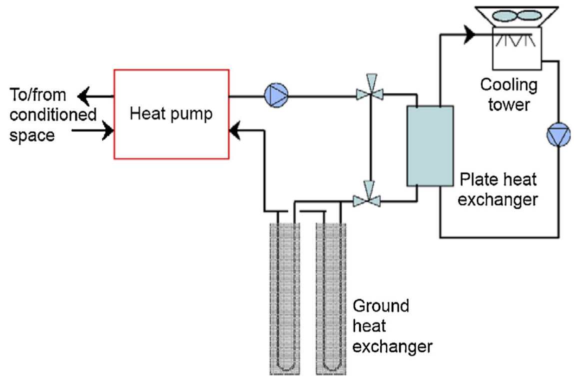

Fig. 4. Schematic view of hybrid ground source heat pump system [7]

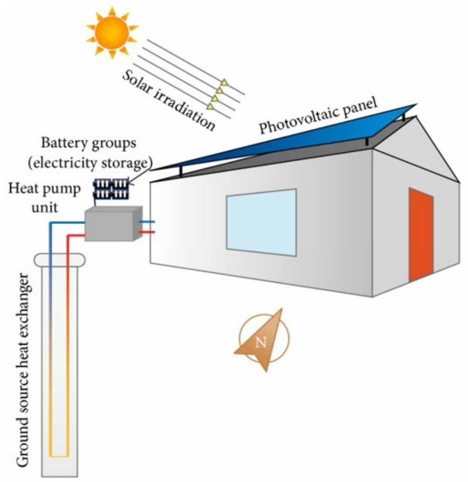

Fig. 5. An example view to hybrid type ground sources heat pump system [8]

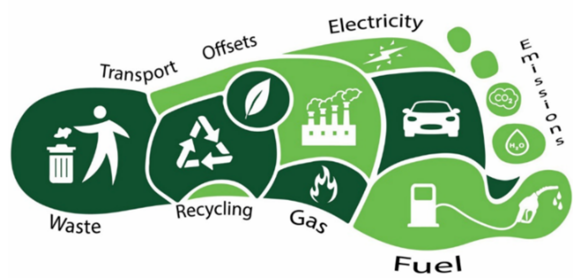

Fig. 6. Illustration of carbon footprint [9]

6. LOWER CARBON FOOTPRINT FOR GROUND SOURCES HEAT PUMP

Figure 6 shows an illustration of carbon footprint. The carbon footprint explains the amount of all greenhouse gases (CO_2), including carbon dioxide, emitted into the atmosphere by our activities and consumptions in daily life, in tons equivalent. In a simpler language, it can also be called the numerical equivalent of the destruction we cause to nature. Many factors, from transportation to the heaters we burn for heating, the food we cook and even the electricity we consume, have an impact on the formation of carbon footprints.

The use of renewable energy sources instead of fossil fuels is very important in terms of reducing net carbon emissions and climate change. Therefore, the use of renewable energy sources and low carbon emission technologies should be given priority. Wind energy, solar energy, hydroelectric energy, geothermal energy, cogeneration systems, heat pumps and heat recovery units are among these sources and technologies [10].

The term zero carbon heating describes heating methods that do not generate carbon emissions in the energy generation and heating processes. Traditional heating methods generally use fossil fuels (natural gas and coal). The use of these fuels plays a role in climate change and environmental problems by causing carbon emissions and greenhouse gas emissions. However, renewable energy sources are used in zero carbon heating systems. There is no carbon emission in obtaining energy from renewable energy sources.

Ground source heat pumps take energy from the soil and electricity is consumed for the operation of the system. If the electricity consumed is obtained from renewable energy sources, carbon emissions will not occur from these systems. Thus, the system will have reached net zero carbon emission.

7. INVESTMENT AND INSTALLATION COST COMPARISON

In a study [11], the installation cost of Heat Pump and Gas Boiler Systems in the same single-family home investigated by researchers. The total cost of the Heat Pump Heating System is 9372 EUR; the total cost of the Gas Boiler Heating System is 1100 EUR.

There is a sum for investment and operating expenses in the first year. Due to operating costs, expenses will increase over the coming years. The total costs for the Gas Boiler System are 2.61 times greater than those for the Heat Pump System per ten years [11].

The Table 1 presents a comparison of the anticipated expenses for each system over a 10-year period (assuming the same operating costs each year) [11].

Table 1 *Comparison of expenses of the gas boiler system and heat pump system [11]*

	Operating cost per year									
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year
Boiler investment 1 100 EUR	4835.1	8570.2	12305.3	16040.4	19775.5	23510.6	27245.7	30980.8	34715.9	38451
HP investment 9 372 EUR	9866.9	10361.8	10856.7	11351.6	11846.5	12341.4	12836.3	13331.2	13826.1	14321

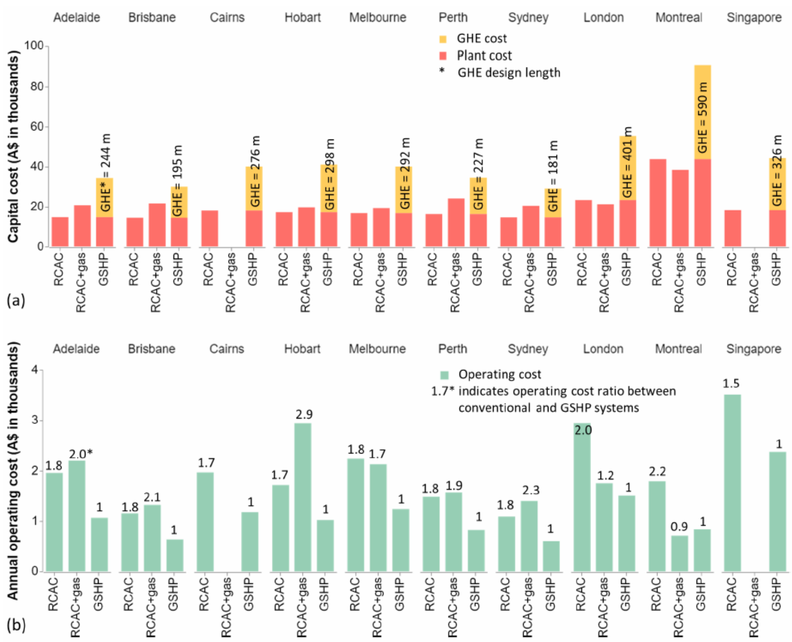

Fig. 7. a) Capital costs and b) annual operating costs in A$ for the 10 cities considered [12]

In another study [12], the costs of GSHP and conventional systems were compared under various climatic conditions. According to Figure 7a, over a 20-year lifespan, the cost of installation and maintenance of GSHP systems was reported to be higher than conventional systems. A large part of the costs of GSHPs is due to the installation of Ground Heat Exchangers (GHEs), which involves the drilling of boreholes.

In Australia, people used to install two separate systems because gas used to be much cheaper than electricity. For this reason, buildings in Australia often have two systems for heating and cooling. Looking at Figure 7a, something interesting is that the total costs for GSHP and reverse cycle air conditioners (RCAC) systems are similar, even though the full GSHP setup costs twice as much as the RCAC system. This happens because RCAC systems have a shorter lifespan and need replacement. So, the costs shown here include buying two 10 kW RCAC units to cover 20 years, which matches the cost of getting one 10 kW GSHP system for the same 20-year period [12].

The operating costs of the same study illustrated in Figure 7b exclusively encompass the power consumption of GSHP units, omitting the relatively minor energy usage of circulation pumps for smaller systems. The operational expenses associated with GSHP systems exhibit a range spanning from approximately A$600 to A$2,400 annually, contingent upon the geographic location (Figure 7b). In comparison to the array of examined heating and cooling alternatives, GSHP systems boast the lowest operational costs owing to their inherent efficiency [12].

8. CONCLUSION

Ground Source Heat Pumps are energy efficient space for application of heating and cooling systems. These systems have higher average coefficients of performance, low carbon emissions compared to other systems.

In the present study, general view of Ground source heat pump, the types of ground source heat pumps (vertical and horizontal), their advantages and disadvantages were presented. Hybrid type ground source heat pump was defined and advantages of them also was discussed. Zero or nearly zero carbon footprint term was explained for heat pump systems. The initial investment and operating costs of GSHP were compared with conventional systemsby using the studies obtained from the literature. Although the installation cost of GSHP is higher, the operating cost is lower.

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