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Potential Reduction in Energy and Environmental Pollutants by Solar Assisted Ground Coupled Heat Pump Systems

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ABSTRACT

By the intensive development of industry, harmful greenhouse gas emissions have increased, which has resulted in global warming, climatic changes, and increased fossil fuel cost. For these reasons, the use of renewable energy has been welcomed. Solar assisted ground coupled heat pump systems are one of the important technologies that use renewable energy for residential and industrial heating systems. In these systems, the ground is used as both a heat source and heat sink. In the winter the heat is taken from the ground and is transmitted to the building, and in the summer the heat of the building is transferred to the ground without causing any pollution. Because of the decrease in energy consumption and environmental pollution, it increasingly is favored around the world. In this study the conventional heating systems and solar assisted ground heat coupled heat pump systems are compared from the aspects of CO_2 and SO_2 emission and the energy efficiency. We came to this conclusion that by reducing 30-60 percent of electricity consumption and reducing greenhouse gas emissions by 10-30 percent, it is both economical and friendly to the environment. Ways to extend and increase the efficiency of these systems are also suggested.

1. INTRODUCTION

The pollution of environment caused by fossil fuel burning, the CO_2 emission growth, greenhouse effects and ozone hole widening, recently have led to serious problems causing drastic climate changes and real ecologic troubles. We can look at the problem from two aspects: one of them is because of burning the fuel to produce electricity and the other is because of burning the fuel for heating that these factors directly and indirectly lead to pollution of the atmosphere. Alarming data in the field of fossil energy resource exploitation and environmental pollution have been framed legally, which resulted in the international legislation foundation [1, 2]. In order to reduce the impact of fossil fuel consumption on the environment, the use of renewable energy and the improvement of thermal systems' efficiency offer a viable alternative.

Energy resource reserves, such as the oil, coal and gas ones have been estimated to last no longer than a few dozen decades, which conditions the use and substitution by alternative, namely renewable energy sources [3]. Energy policy mainly depends on governmental policy and their situation in the world.

To decrease the price of the energy resources and to reduce the CO_2 emissions, governments should think of new and renewable energy sources for supplying the residential and industrial heating needs. Conventional heating systems have lower efficiency and emit more CO_2 and NO_x compared with the renewable energy, thus contributing to global warming.

Among the various renewable energy systems, solar assisted ground source heat pump (SAGSHP) systems have been spotlighted as efficient building energy systems, because of the great potential for energy reduction in building air conditioning and reducing CO_2 emissions. In addition, a SAGSHP system occupies less space compared to the other conventional building heating ventilating and air conditioning (HVAC) systems so that the equipment rooms related to HVAC system can be greatly scaled down [4-5].

SAGSHP systems are being considered as a possible solution to reduce primary energy consumption and have often been proposed as a substitute for conventional systems (electric resistances, gas boilers, oil boilers, etc.) to produce domestic hot water (DHW) or space heating (SH) [6]. Currently, the SAGSHP which transforms thermal energy stored in the ground at low temperatures and solar energy into thermal energy at high temperatures and which is suitable for heating purposes.

SAGSHP systems are an important devices that use renewable energy for reducing emissions of gases, such as carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NO_x) and reduce energy consumption. Additionally, the way that the electricity is produced has a great impact on environment pollution.

Blum et al. [10] showed that in Germany, the CO_2 savings for one installed GSHP unit with an average heating demand of 11 kW is at least 1800 kg per year. This avoidance of additional CO_2 emissions, 35% less than with the conventional heating mix such as oil fired boilers and gas furnaces, demonstrates the large potential of such systems in contributing to global CO_2 savings. Other American and European studies found CO_2 savings ranging between 15 and 77%, mainly depending on the primary resource of the supplied electricity for the heat pump and are therefore strongly country-specific [11 & 12]. In most countries, however, CO_2 savings can be achieved with the application of shallow geothermal systems [13].

Omer summarized the benefits of GSHP system. It was concluded that GSHP system were suitable for heating and cooling of buildings and could play a significant role in reducing CO_2 emissions [14].

2. SOLAR ASSISTED GROUND SOURCE HEAT PUMP

A schematic diagram of the constructed experimental system is illustrated in Figure 1. This system mainly consists of three separate circuits as follows: (i) the ground coupling circuit with solar collector (brine circuit or water–antifreeze solution circuit), (ii) the refrigerant circuit (or a reversible vapor compression cycle) and (iii) the fan-coil circuit for heating (water circuit). The heat pump transfers the heat between the heating distribution system and the ground. It is the basic building block of the SAGSHP system.

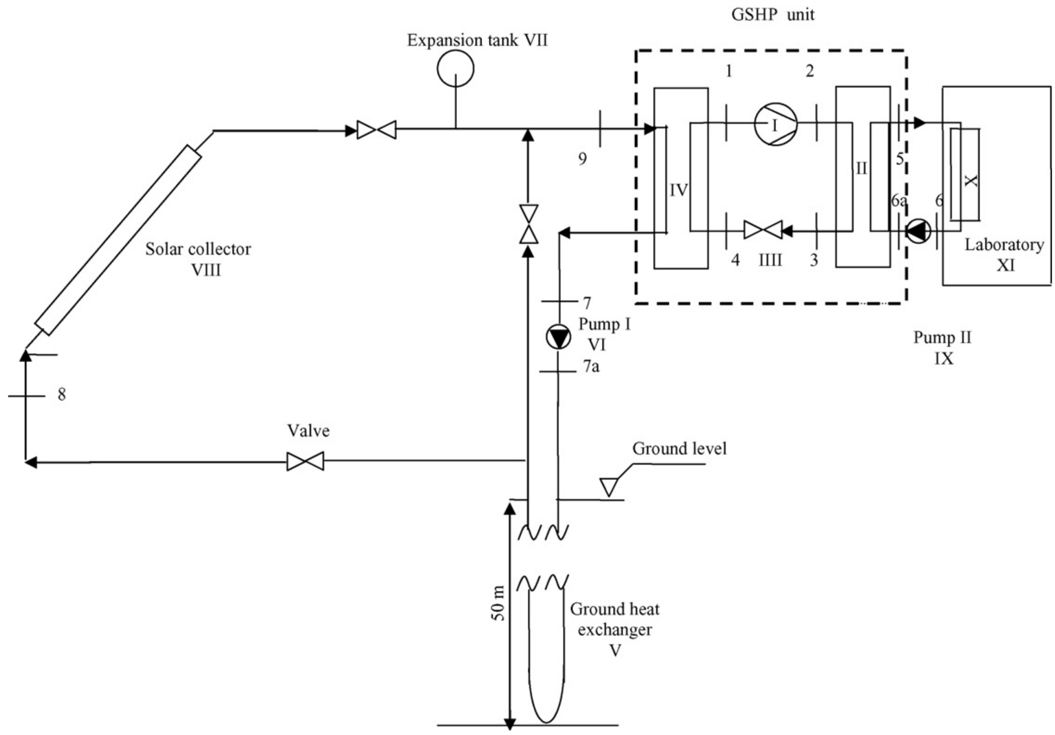

Figure 1: Schematic of the solar assisted ground source heat pump system [7–9].

Conversion from the heating cycle to the cooling cycle is obtained by means of a four-way valve. To avoid freezing the water under the working condition and during the winter, a 10% ethyl glycol mixture by weight was prepared. The closed-loop refrigerant circuit was built with copper tubing. The working fluid is R-22.

A heat pump can save 30%–60% of the electricity used for heating. Heat pumps have both heating and cooling ratings; both in terms of capacity and efficiency. The heat effect delivered by the observed sub-geothermal heat pump heating system is typically 3.2–5.2 times the electrical power input, because SAGSHP moves energy from outside to inside of building (or vice versa).

The power consumption for space heating is calculated based on the population. The population of Iran is taken from the census in 2011and the family size is taken as 4 [18]. In winter conditions, the number of winter days is taken as 60. It is assumed that each family is using only one 2 kW capacity heater for 6 hrs per day and another assumption is that the electric heater is considered to be 100% efficient.

$$Power\ consumption\ by\ using\ electric\ heater = \frac{population}{house\ hold\ size} \times 2 \times 60 \tag{1}$$

$$Power\ consumption\ by\ using\ SAGSHP = \frac{population}{house\ hold\ size} \times \frac{2 \times 60}{COP\ \ SAGSHP} \tag{2}$$

COP in equation (2) is calculated as:

$$COP = \frac{\dot{Q}}{W} \tag{3}$$

where Q and W are heat extracted and power consumption, respectively.

Saving in electricity = Electricity consumed by electric heater - Electricity consumed by SAGSHP (4)

SAGSHP systems may be more expensive to install than some natural gas, oil or electric heating units, but they are very competitive with any type of conventional heating system. For this reason, heat pumps are most attractive for the applications requiring heating. Furthermore, their annual operating costs are lower than other conventional heating systems. The primary energy efficiency and CO2 emissions for the conventional heating systems and SAGSHP systems have been given in the Table 1.

Table 1: Comparison of different heating systems

System	Primary energy efficiency (%)	CO_2 emissions ($kgCO_2$/kWh heat)
Oil fired boiler	60-65	0.45-0.48
Gas fired boiler	70-80	0.26-0.31
Condensing gas boiler + low temperature system	100	0.21
Electrical heating	36	0.9
Conventional electricity + GSHP	120-160	0.27-0.20
SAGSHP	300-400	0.00

Figure 2 shows that GSHP and SAGSHP systems save a significant amount of operational cost compared with conventional HVAC. But perhaps more importantly, the plot also shows that energy (and water) cost of SAGSHP systems are quite similar to that of GSHP systems.

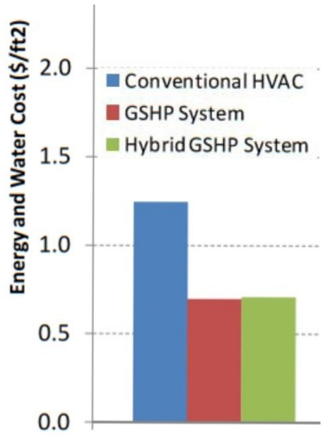

Figure 2: Energy and water cost of SAGHSHP as compared with GSHP and conventional HVAC systems.

Though the GSHP systems cost significantly more, the hybrid approach mitigates this increase, while maintaining much of the operational savings (see figure 3).

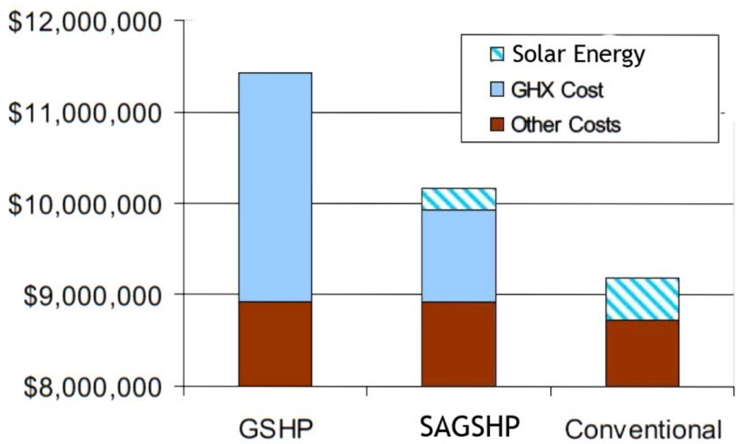

Figure 3: First cost by component for system options (US$).

3. GLOBAL WARMING

Heat pumps can significantly reduce primary energy use for building heating and cooling. Heat pumps utilize renewable or solar energy stored in the ground near the surface (ground source). The renewable component (70%) displaces the need for primary fuels, which, when burned, produce GHG systems and contribute to global warming.

SAGSHP equipment is widely available all over the world. The equipment is competitive on a life-cycle cost basis with those systems examined, particularly in those markets where air conditioning is desired. There is unlikely to be a larger mitigating effect on the resulting global warming impact of buildings from any other current market available single technology than from SAGSHP system.

4. ENVIRONMENTAL POLLUTION GASES

By the intensive development of industry and the growing impact of anthropogenic processes, the intensity of the harmful gas emission has increased, which has resulted in global warming and climatic changes. Carbon dioxide (CO_2) is one of the most essential greenhouse gases originating from anthropogenic impact, mainly by fossil fuel burning.

The heat pump heating is more efficient than all heating systems based on direct combustion of fossil fuels: recent studies [15, 16 and 17] have confirmed the CO_2 emission reductions of up to 80% by implementation of ground source heat pump heating in residential, commercial and institutional buildings. SAGSHP systems are housed entirely within the building and underground. They are quiet, pollution free and do not detract from the surrounding landscape. They produce low or no greenhouse gas (GHG) emissions. SAGSHP systems do not create heat through combustion; they simply move solar heat that is stored in soil or water from one place to another.

Governments and energy planners prefer geothermal energy technology because it is an environmentally benign technology, with no emissions or harmful exhaust. The geothermal energy industry was the first to move away from damaging chlorofluorocarbons (CFCs). Although geothermal energy units require electricity to operate the components, a high COP means that geothermal energy systems provide a significant reduction in the level of CO_2, SO_2 and NO_x emissions [18].

A heat pump requires an additional power to achieve a satisfactory temperature in the system. In most cases, a heat pump requires electrical energy in order to operate, upon which CO_2 emission quantity depends on the type of energy source used to generate electrical energy (if renewable energy sources are used for electrical energy generation, there are no CO_2 emissions). The mean CO_2 emission rate in Iran is assessed to be 677.826 g CO_2/kWh. SO_2 emissions are 3.058 g SO_2/kWh and NO_x emissions are 2.55 g NO_x/kWh [19]. With an adequate system, a seasonal coefficient of performance of 4.0 can be achieved in the heating regime. The results have shown that SAGSHP system using electrical energy to operate reduce the CO_2 emissions by 45% in relation to oil boilers and by 33% in relation to gas boilers.

$$CO_2 \; Emission \; by \; the \; use \; of \; electric \; heater = heating \; demand \times \frac{operating \; hours}{year} \times \frac{emission \; intensity \; of \; energy \; source}{kWh}$$

$$CO_2 \; Emission \; by \; the \; use \; of \; SAGSHP = heating \; demand \times \frac{operating \; hours}{year} \times \frac{emission \; intensity \; of \; energy \; source}{kWh}$$

Saving in CO_2emission =CO_2emission by the use of electric heater - CO_2emission by the use of SAGSHP (8)

The comparison of CO_2 emissions from geothermal energy plants in relation to the plants using fossil fuel is given in Figure 4. The values of CO_2 emissionS for coal, oil, and natural gas have been calculated on the basis of data taken from the energy deputy of the energy ministry of Iran. The total potential of CO_2 emissions reduction by using geothermal heat pumps is estimated at 1.2 million tons a year or 6% of overall global emissions (nowadays it is estimated that the use of renewable energy resources could reduce global carbon dioxide emission by 10%, which will appear in energy production until the year 2020). The CO_2 emission out of low temperature geothermal water can be assessed as the nonexistent one, namely it ranges within the scope of 0–1 g CO_2/kWh.

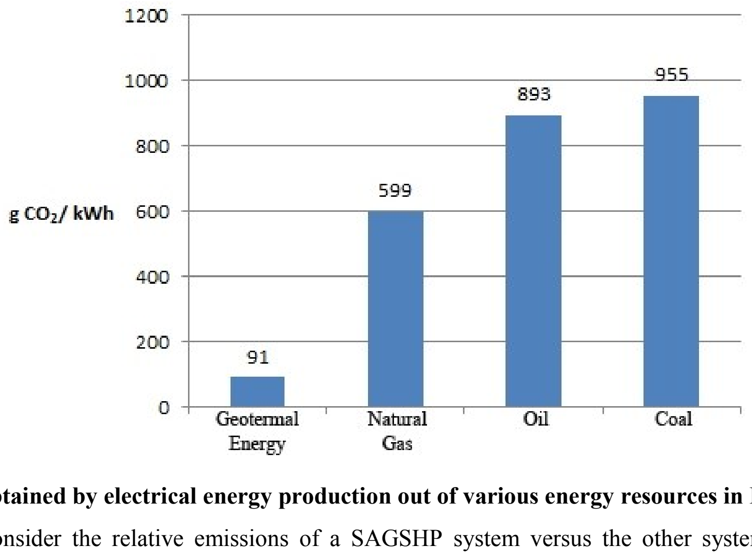

Figure 4: CO_2 emission obtained by electrical energy production out of various energy resources in Iran [19].

It is therefore useful to consider the relative emissions of a SAGSHP system versus the other system options. We began by researching emissions factors to use in the calculation. Emission factors vary by region due to differences in electric generation, fuel mix, and other electricity supply-side factors. We used these factors to compare emissions across the same system option that were in the economic analysis. Emissions saving for carbon dioxide, the primary greenhouse gas, are shown in Figure 5. Both SAGSHP and GSHP systems result in a similarly high level of carbon dioxide savings.

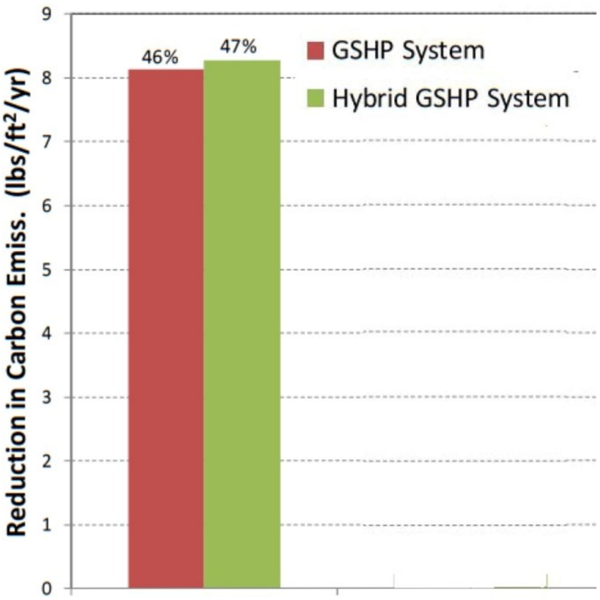

Figure 5: Carbon dioxide emission saving for SAGSHP system and GSHP system. As compared with conventional HVAC

5. CONCLUSIONS AND SUGGESTIONS

Based on the aforementioned statements by reducing 30-60 percent of electricity consumption and reducing 10-30 percent environmental pollution gases, SAGSHP systems are both economical and environmentally friendly.

The positive environmental effects are maximized in case of complete substitution of old, low efficiency, highly polluting central heating of buildings or housing blocks, and the exclusion of local fossil fuel energy sources. The installation in urban surroundings is simple, without major space requirements and building interventions.

The following conclusions can also be drawn from this study:

- Heat pumps offer the most energy efficient way to provide heating and cooling in many applications, because they can use renewable heat sources in our surroundings.
- Heat pump systems are environmentally friendly. The initial costs of the heat pump systems are higher, but they have low operating, maintenance, and life cycle costs and a longer life expectancy than most conventional systems.
- SAGSHP systems present tremendous environmental benefits when compared to the conventional systems. In addition to not exhausting natural resources, their main advantage is, in most cases, total absence of almost any air emissions or waste products. Therefore, these systems can be used to minimize environmental impacts and emissions.
- These systems provide a new and clean way of heating buildings in the world. They make use of renewable energy stored in the ground, providing one of the most energy-efficient ways of heating buildings. They are particularly appropriate for low environmental impact projects.

Since the beginning of the 21st century, the application of SAGSHP systems has been growing rapidly. However, there are also some challenges. The following suggestions are provided in order to overcome these encumbrances and promote the market growth of SAGSHP systems. Implementing SAGSHP systems is one of the promising efforts to reduce fossil fuel consumption and CO_2 emissions.

- Strengthen the technical cooperation on SAGSHP research, including domestic and international cooperation, to reduce repetitive work;
- Increase support for R&D on SAGSHP, including domestic and international partnerships;
- Technical guidelines, contractor certifications, quality awards, etc. should be put in place to protect the industry and the consumers against poor quality and insufficient longevity of ground source heat pump systems;
- To avoid more investment and to forecast the coefficient of the performance and also to design the SAGSHP systems based on the heating needs of the building, it is better to prepare a technical and economic model.

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Nomenclature

CO_2	Carbon dioxide
SO_2	Sulphur dioxide
NO_x	Nitrogen Oxides
GSHP	Ground Source Heat Pump
HVAC	Heating Ventilating and Air Conditioning
DHW	Domestic Hot Water
SAGSHP	Solar Assisted Ground Source Heat Pump
SH	Space Heating
GHG	Greenhouse Gas
CFCs	chlorofluorocarbons