A Performance Comparison between an Open Source and a Vertical Closed Source Heat Pump System for Residential Heating in the Cold Climate Iran

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ABSTRACT

The investigation presented in this article is aimed at demonstrating the technical and design feasibility of using ground coupled heat pump systems in the cold climate applications for residential heating, where heating load is dominant. An experimental comparison between an open loop ground coupled heat pump system and a vertical closed loop ground coupled heat pump system was shown by focusing on the heating performance. For this purpose, an experimental set-up was constructed. The heating system mainly consists of two different ground heat exchangers, a heat pump, measuring units and a heating space of a house with 65 m^2 located in the building. The heating coefficient of performances of the two ground coupled heat pumps (COP_{HP}, O-C) and the overall system (COP_{sys}, O-C) were obtained to be in the range of 3.2-3.9 for OGCHP and 2.2-4.2 for CGCHP and 3.5-4.2 for OGCHP and 2.5-4.5 for CGCHP respectively. Although significant savings are possible with these heating systems, a substantial investment in equipment and facilities may be required. The experimental results were obtained from November to March in heating seasons of 2010-2011. The results showed that the utilization of the ground coupled heat pump is suitable for residential heating in this region.

1. INTRODUCTION

Buildings are the largest energy-consumer. Buildings are responsible for approximately 40% of total world annual energy consumption, in the form of lighting, heating, cooling and air conditioning (Omer 2008a). Supply hot water and space heating consumptions account for more than 80% of total energy consumption in the buildings.

A ground coupled heat pump (GCHP) system is a renewable energy technology highly efficient for space heating and cooling. This technology relies on the fact that, at depth, the earth has a relatively constant temperature, warmer than the air in winter and cooler than the air in summer. It can transfer heat stored in the Earth into a building during the winter, and transfer heat out of the building during the summer (Omer 2008b).

The main advantage of using geothermal energy is that this renewable energy source can provide power 24 hours a day due to it being constant, without intermittence problems compared to other renewable resources such as wind or solar energy. It is expensive to build a power station but operating costs are low, resulting in low energy costs for suitable sites (Banos et al. 2011).

The ground heat exchanger (GHX) of a GCHP may be categorized as open loop or closed loop cycles. Many factors have an effect in the design of GHX. In the open loop cycle (OLC) (see Figure 1), water is pumped out of the supply well into a low temperature heat exchanger where a part of its thermal potential is used for refrigerant evaporation (Antonijevic and Komatine 2011). Then, the used water is released in a rejection well, which is a second well that returns the water to the ground. No environmental damage is created by open loop wells since the only difference between the water being removed by the supply well and the water being rejected through the discharge well is a slight increase in temperature.

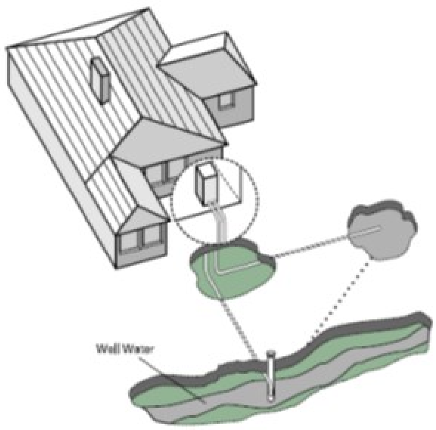

Figure 1: Open loop cycle

The closed loop cycle (CLC) is extracting heat from the ground using a continuous loop of special buried polyethylene pipe (see Figure 2). In this system, a fixed volume of water is circulating through a closed loop of U-shaped pipe buried in the ground. The CLC is an appropriate choice for most suburban homes.

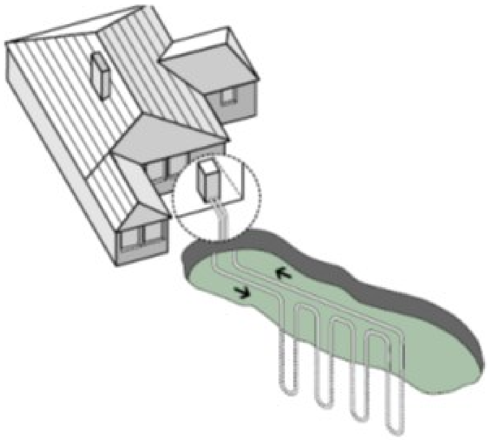

Figure 2: Vertical closed loop cycle

The OLC is used less than the CLC, but may be employed cost-effectively if ground water is plentiful. Local environmental officials should be consulted whenever an OLC is being considered. In some localities, all or parts of the installation may be subject to local ordinances, codes, covenants or licensing requirements.

To choose the optimum system for a suitable installation, several factors have to be considered: geologic conditions need area and utilization on the surface; the supply temperature from underground; heating/cooling load of the building; and the type of space to be heated or cooled. In the design phase, more accurate data for the key parameters for the chosen technology are necessary, to size the ground cycle in such a way that the optimum performance is achieved with minimum cost (Omer 2008b).

The main purpose of this study was to experimentally evaluate the performance of two different loop cycle designs. Tests investigated the difference in the thermal behavior of the loop cycles for heating. An experimental system of GCHP was built in Qom province, Iran, in which two types of ground loop cycles were adopted; one was an OLC, the other was CLC buried in the house ground. The operational performance of these different GCHP systems and the ground temperature field in heating mode were evaluated through the experiments.

Many researchers have investigated the effects of utilizing different closed loop designs in terms of performance and efficiency [12-17], but no researcher has about open loop designs in terms of performance and efficiency.

2. WEATHER DATA

The experimental heat pump systems was established and tested in Qom province having an altitude of 877.4 m and a mild climate in Iran (Qom State Meteorological Station 2011; Iranian Meteorological Organization 2001). In the present study, the temperatures, flow rates, voltages and currents were measured by appropriate instruments explained in Table 1.

Table 1: Hardware used in this study

Quantum	Sensor	Application Scope	Accuracy
Air mass flow	Anemometer	0.8-30 m/sec	±3%
Water mass flow	Rotary meter	0-12 gpm	0.1 gpm
Inlet & outlet water temperature	Type K thermocouple probe	-10°C, +50°C	±0.5%, ±1°C
Inlet & outlet air temperature	Type K thermocouple probe	-10°C, +50°C	±0.5%, ±1°C
Electrical Energy consumption	Power analyzer	100-600 V	±1.2%, ±5V
Outdoor and house air temperatures and humidity	Temperature & Humidity probe	-10°C, +50°C	±3%, ±2°C

3. EXPERIMENTAL SYSTEM

The thermal performance tests were set such that the period of the heat pump operation was the same for all tests. At the beginning of each test, the heat pump would run for 2 hours, so initially the buffer tank would reach the required temperature and to ensure system stability. After this point the heat pump would turn off for 1 hour and then start once more for a further 7 hours.

The experimental results were obtained from November to March in the heating season of 2010-2011. Both of the experimental setups consisted of a heat pump, a brine loop cycle (open or closed), circulation water pumps, fan coil, water tank, a personal computer and control units, a house serving as the heating environment and other auxiliary apparatus. The test method based on ARI 325 and ARI 330 standards for CLC and OLC, respectively (see Figure 3).

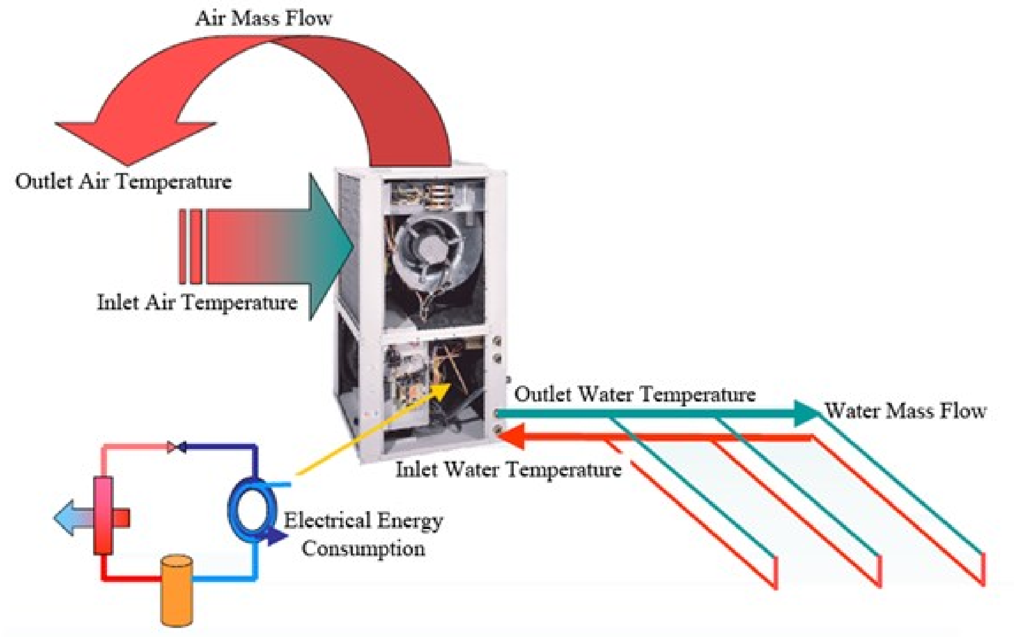

Figure 3: Test heat pump unit

3.1 Vertical closed loop cycle

In order to reduce the pressure drop in the GHX and subsequently reduction of the pump power and reduce the cost of electricity consumption as a result, the combination of several wells had been used. The vertical pipes of the GHX were connected to the supply and return header pipe horizontally near the ground. To avoid thermal interact with each other, the distance between the centers of each well is 5 m. The use of pipe reverse for return header pipes reduces the pressure drop in the system greatly.

A schematic diagram of the constructed experimental system is illustrated in Figure 4. This system mainly consists of three separate circuits as follows; (i) five closed vertical ground heat exchanger was buried with depths of 15 m, (ii) the refrigerant circuit and (iii) the fan coil circuit for heating (air heating). To avoid freezing under the working conditions and during the winter, a 10% by weight ethylene glycol water mixture was prepared. The refrigerant circuit was built on the closed loop copper tubing. The working fluid is R-410. This system was installed in Qom province, Iran (latitude 34:42 longitude 50:51). The ground type encountered on drilling was mostly dry clay and typical thermal conductivity values lie in the range of 0.0102 to 0.0131 kW/m.K. The building examined in this work has a total area of about 65 m^2. The heating load of building is 10.5 kWh (36,000 BTU). The temperatures to be achieved in the building in October are shown in Figure 5.

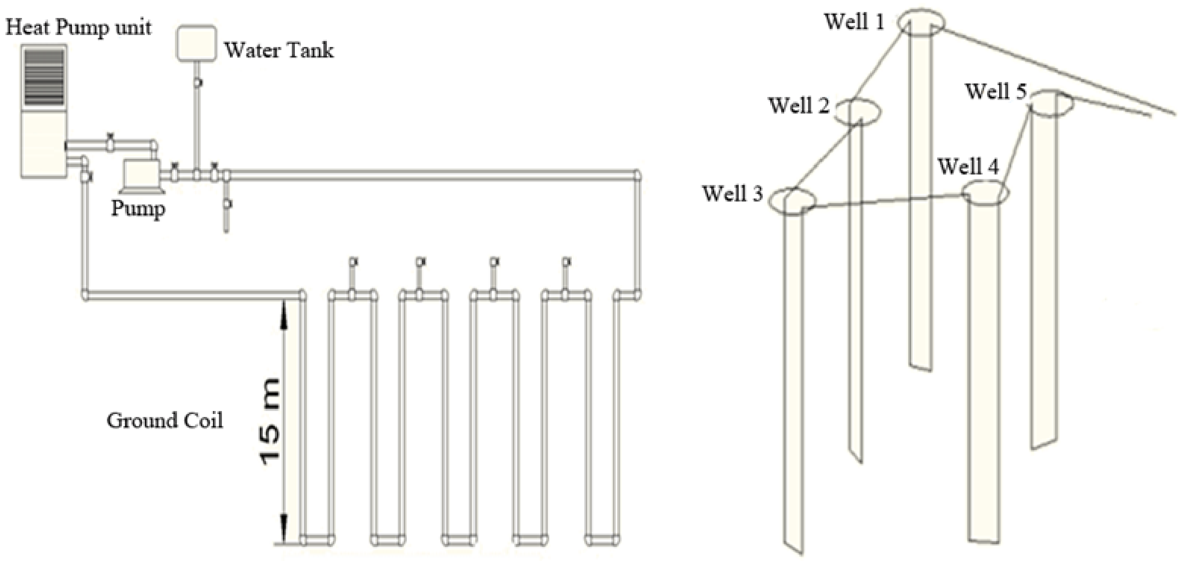

Figure 4: Schematic diagram of constructed experimental GCHP system with vertical closed loop cycle

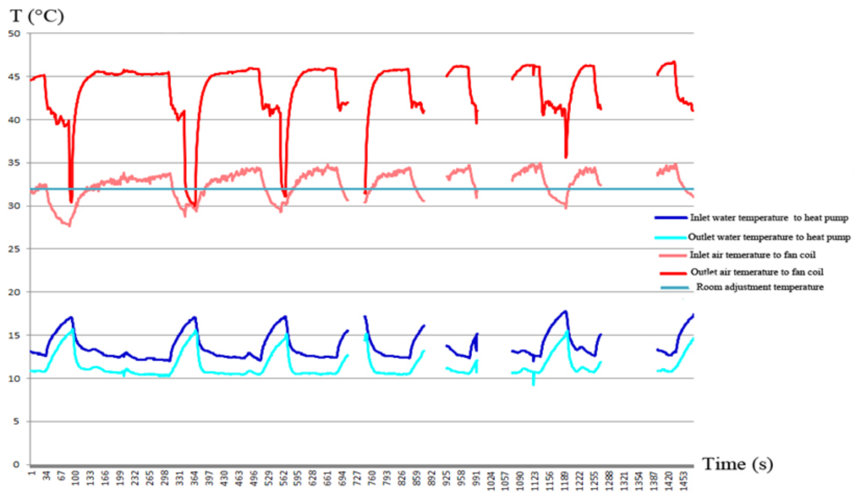

Figure 5: Temperatures to be achieved in the building in the CLC

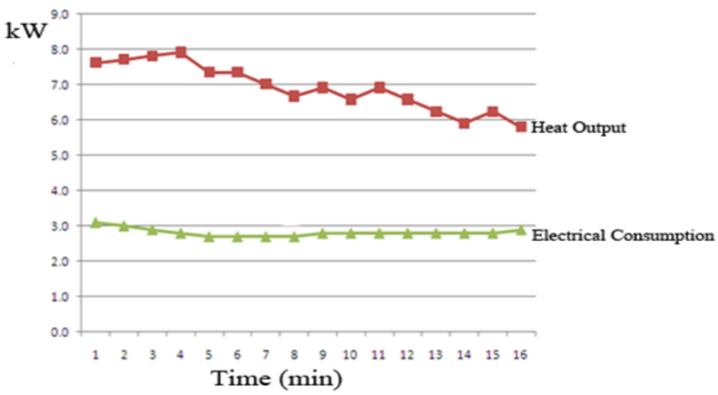

Figure 6: Output heat from the ground and power consumption in the closed loop cy

3.2 Open loop cycle

A schematic diagram of constructed experimental system is shown in Figure 7. This system mainly consists of three separate circuits as follows; (i) two well was buried with depths of 3.5 m, (ii) the refrigerant circuit and (iii) the fan coil circuit. The main characteristics of the elements of groundwater heat pump systems are given in Table 1. The refrigerant circuit was built on the closed loop copper tubing. The working fluid is R-410. This system was installed in Qom province, Iran (latitude 34:42 longitude 50:51). The building examined in this work has a total area of about 65 m^2. The heating load of building is 10.5 kWh (36,000 BTU). Temperatures to be achieved in the building in October are shown in Figure 8.

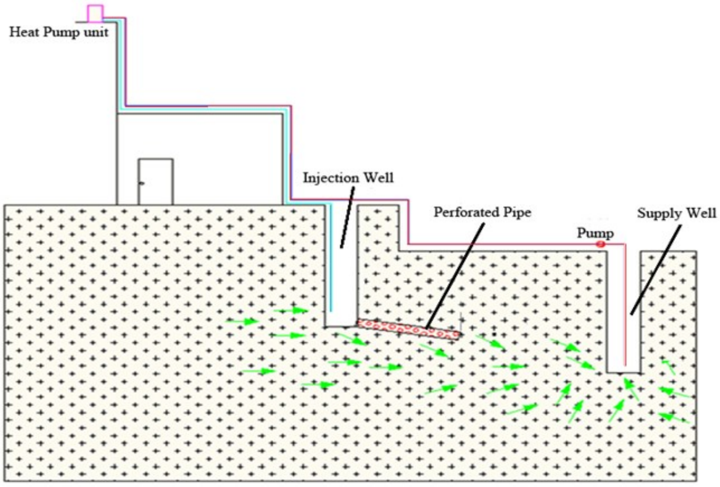

Figure 7: Schematic diagram of constructed experimental GCHP system with open loop cycle

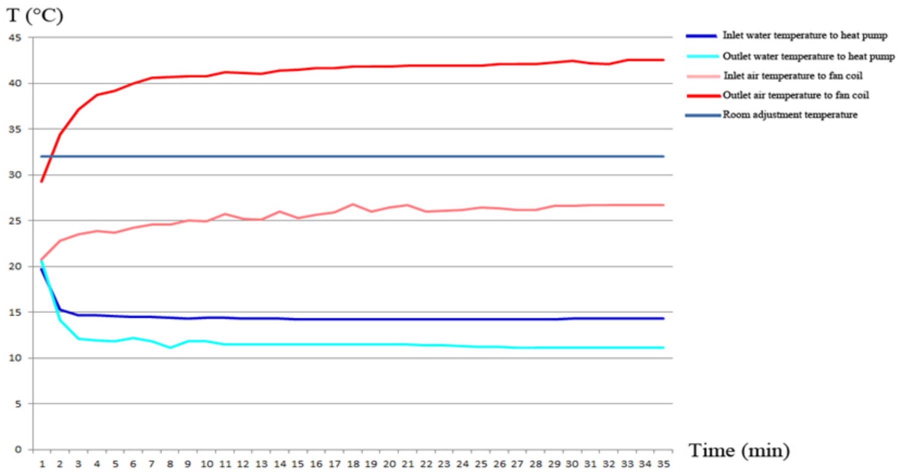

Figure 8: Temperatures to be achieved in the building in the OL

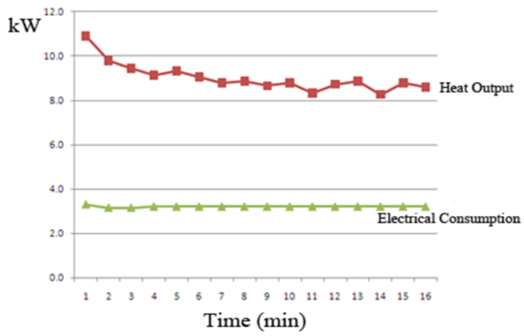

Figure 9: Output heat from the ground and power consumption in the open loop cycle

4. RESULTS AND DISCUSSION

The heat output from the heat pump is determined by operation times and the temperature lift across the condenser. Figures 6 & 9 shows how the heat output varies for both loops across the range of operation times. It is clearly seen that the heat output for both loops falls with increasing operation time and as predicted by the reduction in thermal performance of the evaporator. It is apparent that the heat output of the system, when used with the closed loop is lower than when used with the open loop.

It is clear from Figure 6 for the CLC system that the maximum $T_{o,g}$ throughout the heating season was approximately 16.5°C and the average is 13.6°C, while the minimum was about 10.3°C. The outdoor air and the ground temperatures were recorded as the mean values of -3.0 and 7.8°C, respectively. The variations of $T_{o,g}$, T_o and T_g during of the heating season for the OLC system are given in figure 8. It can be seen that the trends of $T_{o,g}$, T_o and T_g are different than those shown in figure 5. The maximum value of $T_{o,g}$ over the six month period was approximately 15.2°C, the average being 14.9°C, while the minimum value was approximately 14.7°C. The outdoor air and the ground temperatures were found as the mean values of -3.0 and 11.4°C, respectively. The difference between the average values of $T_{o,g,clc}$ and $T_{o,g,olc}$ were determined as 1.3°C. The average temperature difference between the inlet and outlet of the CLC and OLC were obtained to be about 3 and 2.9°C, respectively. Figure 5 shows the variation of $T_{o,g}$, $T_{i,g}$, T_g, T_o and T_i when CLC is used.

The house temperature was set to a range of 16°C by using a digital thermostat. The compressor and circulating pump work in this temperature range. When the house temperature exceeds 16°C, only the condenser fan works, and therefore, the house temperature decreases again. When the house temperature decreases below 16°C, the compressor and circulating pump starts functioning again. As the compressor and circulating pump run, the outlet and inlet water-antifreeze solution temperature drastically drops. However, the above mentioned solution temperatures increase when they do not work. Figure 8 indicates the variation of T_o, T_i, T_g, $T_{o,g}$ and $T_{i,g}$ when OLC is used. Figure 6 depicts the variation of heat output and the electrical consumption of the CLC systems. Figure 9 shows the variation of heat output and the electrical consumption of the OLC systems. The mean values of COP_{sys} for the CLC and OLC were obtained as 2.2-2.8 and 2.8-3.4 respectively. These coefficients of performance are low due to poor design of the system, when compared to the values of the commercially available systems having COP values for heating 3-5.25.

5. CONCLUSIONS

The performance of an open loop and vertical closed loop for a ground coupled heat-pump systems were investigated experimentally. The experimental results indicate that the average $COP_{sys,clc}$ and $COP_{sys,olc}$ values are approximately 2.2-2.8 and 2.8-3.4 in the coldest months of the heating season, respectively. The open loop design has the potential to reduce drilling cost and make installation on site easier; the open loop in its current form is seen to add performance benefit against the conventional closed loop design.

The results of the study have allowed us to draw the following conclusions about the operation of both cycles:

(a) The heat output of the CLC system is lower than OLC system but electrical consumption of the OLC system is lower than CLC system.

(b) Heat pumps offer the most energy efficient way to provide heating in many applications, because they can use renewable heat sources in our surroundings.

(c) 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. Their overall economic benefit depends primarily on the relative costs of electricity and fuels, which are highly variable over time and across the world. In addition, heat-pump systems provide heating and hot water production.

(d) These systems provide a new and clean way of heating houses. They make use of renewable energy stored in the ground, providing one of the most energy efficient ways of heating houses. GSHPs are suitable for heating of houses and so could play a significant role in reducing CO_2 emissions.

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NOMENCLATURE

COP	heating coefficient of performance, (-)	***Subscript***

$\dot{m}$	mass flow rate, (kg/s)
$\dot{Q}$	rate of heat transfer, (W)
T	temperature, (°C)
W	power consumption, (W)

Abreviations

CGCHP	Closed ground coupled heat pump
OGCHP	Open ground coupled heat pump
GCHP	ground coupled heat pump
C	closed
CLC	closed loop cycle
fc	condenser fan-coil
g	ground
GHX	ground heat exchanger
HP	heat pump
i	inlet, (inside)
m	meter
o	outlet, open
OLC	open loop cycle
rg	refrigerant (R-22)
sys	system