Design and Installation of a Direct Exchange Ground Source Heat Pump System

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Abstract:

Ground source heat pump (GSHP) systems are highly efficient, renewable and clean energy technology systems suitable for heating and cooling of residential and commercial buildings. This poster presented a design and an installation of a geothermal system using direct exchange ground source heat pump (DX-GSHP) for a cooling load of 1 ton (3.5 KW). The direct heat exchange system exchange heat with the ground through R22 refrigerant circulating in copper tubes buried at a depth of 5 m in the earth. The direct heat exchange system works on a vapor compression cycle necessitating the use of refrigerant, compressor and throttling devices. The results show that such a system is 70 to 80% more efficient than the conventional cooling systems. The coefficient of performance for this system was 4.5. The effect of using the soil of different thermal conductivities on efficiency of the system has also been investigated as a part of this research work.

Introduction:

Direct exchange ground source heat pump (DX-GSHP) system works on vapor compression cycle. The main components of DX-GSHP are similar to refrigerator units, except for the outdoor heat exchangers, which are buried inside the ground. Research shows that the earth temperature throughout the year remains equal to the average air yearly temperature. Earth, at certain depth, is warmer than air temperature in winter and is cooler than the air temperature in summer. A geothermal heat pump is used to transfer heat to the ground in summer and take out heat from the earth in winter.

Basic Working Principle:

DX-GSHP works on vapor compression cycle. The components of the system includes Compressor, Condenser, Throttling valve, evaporators and a refrigerant of low global warming potential, as shown in Fig. 1. When a refrigerant circulates through copper tubers buried inside the lower temperature earth, the cooling capacity of refrigerant increases, which in return is used in the evaporators for effective cooling.

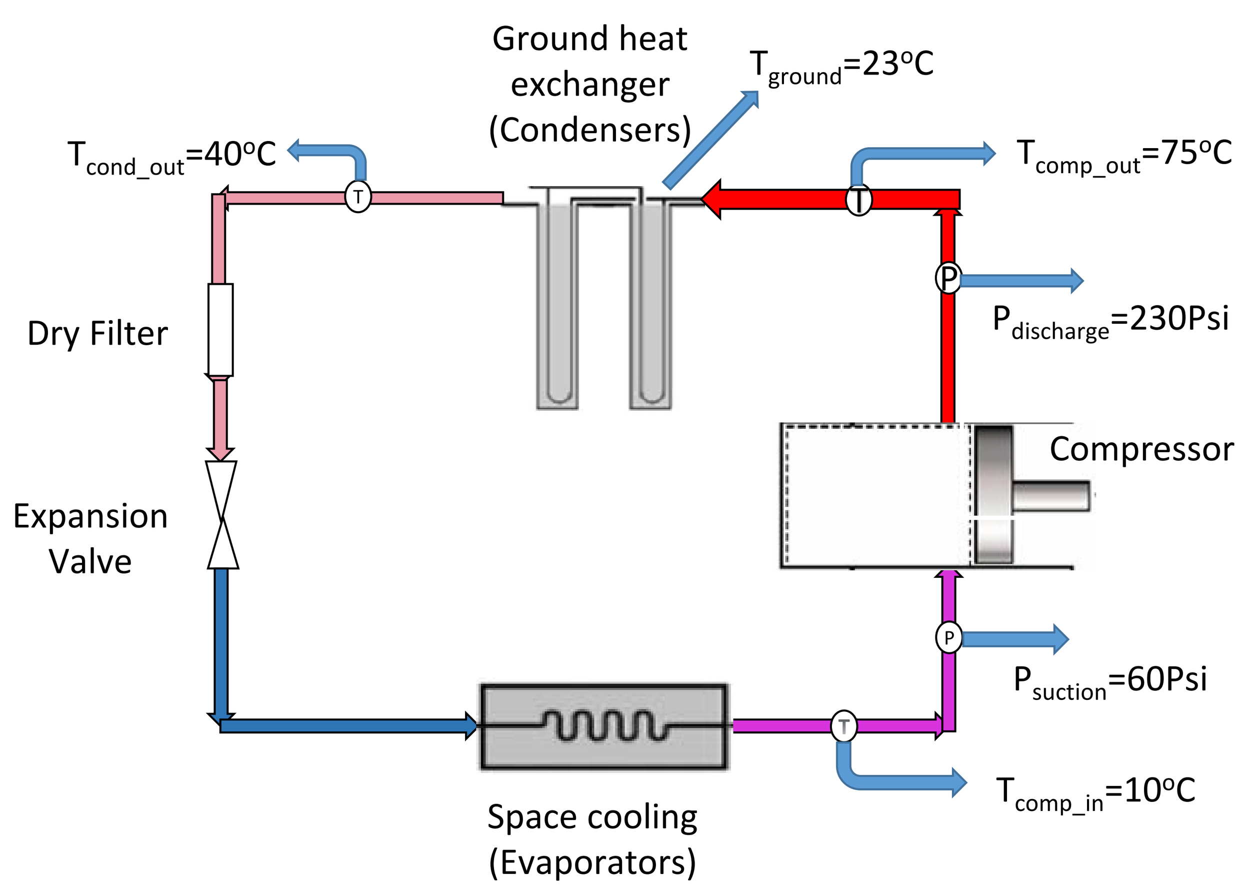

Fig.1 Schematic Diagram

Design and Installation of DX-GSHP:

For designing DX-GSHP to exchange 3.5KW of heat with the ground with R22 refrigerant, the length of the pipe required for the condensers or copper tubing was calculated by the following equation:

$$L = QR/\Delta T_{lm}$$

where Q is the heat transfer from soil into the refrigerant or vice versa having units Watts. L is the length of copper tubes (condensers) in meters, and R is the heat resistance.

R is equal to:

$$R = R_{convection} + R_{pipe} + R_{soil}$$

$$= \frac{1}{\pi D_i h_r} + \frac{\ln(\frac{D_0}{D_i})}{2\pi k_{pipe}} + \frac{1}{S k_{soil}}$$

where S = shaping factor:

$$\frac{2\pi}{\ln(\frac{2d}{D_o} + \sqrt{\frac{4d^2}{D_o^2} - 1})}$$

where d = depth of pipe underground the surface

D_o = Outer diameter of pipe

h_r is calculated by using forced internal flow equations and

ΔT_{lm} is logarithmic mean temperature difference.

The thermodynamic properties of refrigerant R22 were obtained from TS (Fig. 2) and Ph diagrams (Fig. 3) at specified temperature and pressure.

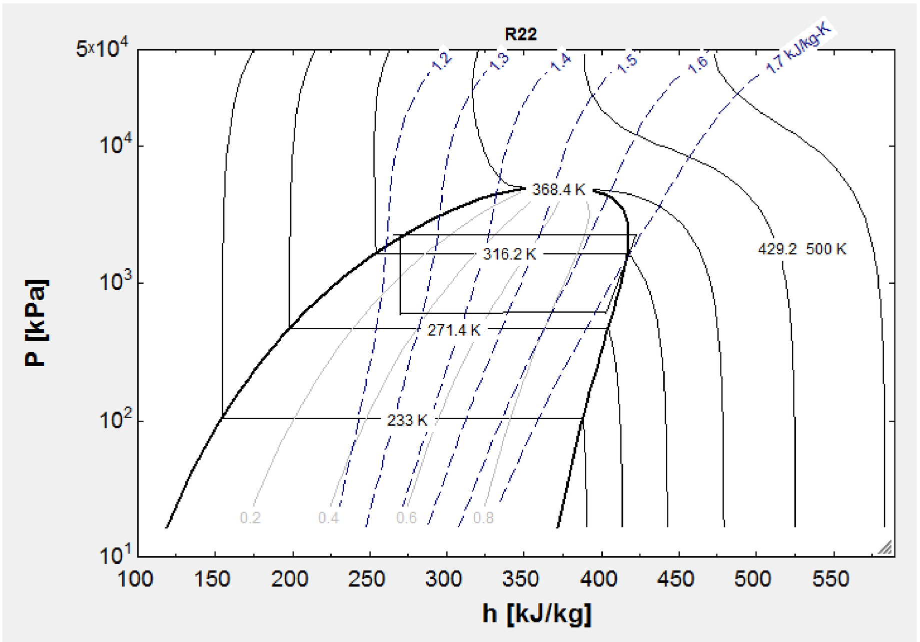

Fig.3 Pressure-enthalpy (Ph) diagram for R22

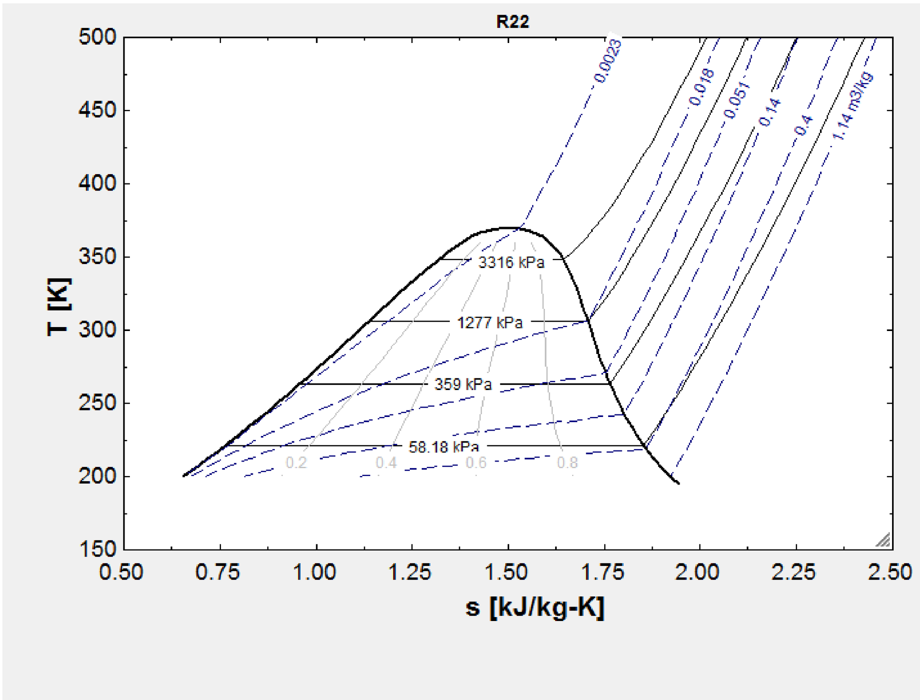

Fig.4 Temperature-entropy (TS) diagram for R22

An experimental DXGSHP system was installed in Islamabad, federal capital of Pakistan. Soils maps were studied to find an area where soil thermal conductivity is high and have a moisture content in it, which increases the heat transfer. With the help of power shovel, the earth was dug up to the depth of 5m of an area of 8 ft x 10 ft. The surface of underground area was for the installation of copper pipes loop. The air temperature or annual ambient temperature of Islamabad is 21.3°C while the average ground temperature of Islamabad is 22.8°C. This is the temperature at the depth of 5 to 10 m.

Fig.5 Ground Temperature

In the horizontal mode of the direct exchange ground source system copper pipes were buried in parallel spaced 0.8 m apart and at a depth of 5m. The spacing between the copper pipes was for minimum thermal interference and need to be optimized. Copper tubes were used as the condensers buried in the earth and connected in parallel with DX heat pump unit. Oxygen acetylene welding was used for joining copper tubes. To enhance the heat transfer, sand bed around the copper tubes was used. The diameter of the copper tubes was 7 mm and its wall thickness was 1mm.

Fig.6 U-loops of copper tubes

Fig.7 Copper tubers

Fig.8 Gas welding

Figure 9 shows the input and output pipes from capillary tubes to the evaporator inside the box and the suction line from evaporator to the compressor.

Fig.9 Fully assembled DX geo thermal system

Design Parameters:

The results were based on the following design parameters.
1 TR or 3.5 KW of heat exchange in the condensers
Entering refrigerant temperature (Compressor out temp) = 76°C
Refrigerants Flow Rate: 0.02kg/s
Soil Data:

- Thermal Conductivity = 2.07W/m-k
- Ground Temperature= 22.8°C

Pipe Data:

- Thermal conductivity = 399W/m-k
- Pipe inside Diameter = 7mm
- Pipe thickness =1mm
- Pipe Depth = 5m

Testing and Results:

To test how effectively the DX-GSHP system worked, a comparison was done between the conventional AC system and a DX-GSHP. A demonstration box of size 4 ft × 4 ft ×5 ft was used for both systems. An indoor unit was installed in the demonstration box and both systems were run at times when atmospheric temperatures were almost the same. Table 1 shows that DX-GSHP system takes almost half the time to cool the demonstration box than the AC system takes.

Table 1: Test Results in real time.

	Time	Ambient Temperature	Box Temperature	Target Temperature	Time Taken
AC System	8:10AM	30	50	18	7 mins
DX-GSHP System	8:05AM	32	50	18	3mins 40 secs
AC System	12:00PM	40	40	18	11 mins
DX-GSHP System	12:00PM	40	40	18	6 mins
AC System	2:08PM	45	44	45	12 min 15 secs
DX-GSHP System	2:15PM	45	43	45	7mins

Conclusion:

Testing of the system confirmed that nearly all design parameters were met and surpassed. The system was able to obtain the desired result. This research tests the actual performance of DX-GSHPs in earth for space cooling. This design of the DX-GSHP system is reliable and effective on a small scale. The coefficient of performance of this system came out to be 4.5 while that of Split AC system is from 2.5 to 3 . The heat transfer rate of the ground heat exchangers (GHE) is 3.5kw. The spacing between the GHEs or the copper pipes is of 0.8 m, for less interference in heat transfer process. We also concluded that the material used for backfilling and the ground temperature determines the performance of the DX-GSHP system.

Future Work:

Further studies will be performed to increase the system efficiency. Future work will be focused on study the effect of different refrigerants on system's overall efficiency. Moreover, future work includes the study of thermal effect of the underground pipes with different refrigerant, mass flow rates and operating conditions. Spacing between the pipes to decrease the thermal interference will also be part of future work, and how it affects system's efficiency. The GSHP system performance will be simulated and optimized with a computational fluid dynamics (CFD) approach.

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