A Comprehensive Study on the Performance of Geothermal Heat Pump System using R410a Refrigerant

Mubeen Khan[1], Shahid Iqbal[1,*], Ammar ul Hassan Khwaja[1], Jawad Rasheed[1], Hamza Aftab Raja[1], Muhammad Roshan Islam[1], Abdul Ahad[1], Muhammad Yasir[1], Waqas Javid[1], Muhammad Atif Niaz[1]

[1]Department of Mechanical Engineering
Wah Engineering College, University of Wah, Punjab Pakistan
* shahid.iqbal@wecuw.edu.pk

ABSTRACT

The geothermal heat pump is an efficient and cost-effective technology and offer several advantages over traditional air conditioning systems, including high efficiency, low cost and reduced environmental impact. These systems work by circulating a fluid through underground pipes, which either absorb heat from earth or heat release into it, depending upon the environmental conditions. This research presents a comprehensive study that investigates the performance of geothermal heat pump systems using R410a Refrigerant with a horizontal slinky loop ground heat exchanger. The study aims to propose a design of geothermal heat pump system for heating and cooling and experimentally testing of design's feasibility. The design feasibility includes the efficiency, environmental impact and cost-effectiveness of the system. The design of the components of the system was based on the calculated capacity of 1 ton of refrigeration. Experimental investigation revealed that the system effectively maintained a heating temperature of 27°C and a cooling temperature of 20°C.The refrigeration effect and power consumption was determined to be 150.5 kJ/kg and0.7375 kW respectively, while the coefficient of performance (COP) was found to be 4.745. These findings indicating that this system can serve as a substitute for air conditioners in situations where air conditioning is not feasible.

Keywords: Geothermal heat pump, R-410a, Heating and cooling systems, Horizontal slinky loop ground heat exchanger.

1. INTRODUCTION:

Geothermal energy is a local, reliable, and sustainable source of renewable energy and can be generated from the earth's heat. It has wide applications mainly in electricity generation and heating, ventilations and air conditioning systems. Furthermore, its independence from weather conditions allows for nearly continuous heat and power supply year-round [1,2]. The geothermal heat pump is approved as a promising technology for building applications, owing to its remarkable energy efficiency and cost-effectiveness [3]. Geothermal heat pumps utilize shallow geothermal resources, with reliable long-term operation and proper design ensuring sustainability [4,5]. Geothermal heat pumps are better than other systems like air source heat pumps due to lower energy consumption during operation, the utilization of the earth's more stable temperature as an energy source (compared to air), cost-effective design and maintenance, the elimination of the need for additional heating in extremely cold conditions, reduced refrigerant usage, and the flexibility to control temperature remotely from the installation site [6,7]. Geothermal heat pumps are becoming increasingly popular in response to growing energy needs and concerns over pollution emissions. These systems provide economic benefits during periods of low electricity prices and exhibit the lowest emissions when powered by low-emission energy sources [8, 9]. Horizontal geothermal heat pump systems, focusing on cost-effective approaches and analyzing ground heat exchangers. It discusses advantages and disadvantages, discusses economic evaluation methods, and suggests future research [10]. Environmental protection measures involve renewable energy sources, with cities in Europe focusing on sustainable energy development. Geothermal resources, particularly sub geothermal groundwater, provide 6600 Mega Watt of heat energy, with a growth trend of 50 Mega Watt annually. Serbia's energy reconstruction of existing flats could significantly reduce energy consumption through sub geothermal energy and heat pumps [11]. Heat pumps' performance is typically expressed using the Coefficient of Performance (COP), which shows the ratio of energy output to the energy supplied (electricity for components like the compressor and pump) for Ground Source Heat Pumps (GSHP). The COP values for heating and cooling modes are denoted as COPh and COPc, respectively. A typical heat pump achieves a COP of approximately 4, signifying that it generates four units of heating energy for each unit of electrical energy consumed [12-15].

The COP of the heat pump depends on its heating or cooling capacity in relation to the heat supplied. The major advantage of increasing COP is attributable to heat exchange with the ground at a constant temperature, rather than with ambient air at fluctuating temperatures which results into high energy consumption. The purpose of selecting horizontal loop system heat pump is to save cost and improve the efficiency of the pump.

During the last decade, several investigations have been conducted by researchers in the design, modelling, and testing of heat pump systems. this study includes: (i) experimental evaluation of the performance of a horizontal ground source heat pump system using R-410a as the refrigerant in heating mode, and (ii) theoretical performance evaluation of a system designed with r-410a. This research study also outlines a straightforward procedure for designing the heat pump to achieve temperature rise efficiently while saving energy and costs. Furthermore, this research outlines a straightforward procedure for designing the heat pump to efficiently achieve temperature rise while minimizing energy consumption. As a result, the system exhibits a refrigeration effect of 150.5 kJ/kg with reduced power consumption and an improved coefficient of performance was noted during testing. These findings underscore the system's efficiency in converting electrical energy into heating or cooling capacity while simultaneously saving energy and reducing costs.

2. DESIGN AND FABRICATION

2.1 Selection of Components

The ground-source heat pump comprises three primary components: the heat pump circuit, the ground coil heat exchanger, and the horizontal slinky loop ground heat exchanger. The copper tube used in the system has a 1/2-inch (12.7 mm) diameter and can handle a capacity of approximately 1 ton with R-410a as the refrigerant. The evaporating temperature (suction temperature) is 10˚C, and the condensing temperature is estimated to be approximately 54.4˚C based on the pressure-temperature relationship for R410a. Table 1 represents the specifications of different components for Geothermal heat pump.

Table 1: Specifications of different components of Geothermal heat pump

Components	Specifications
Scroll Compressor with Refrigerant R410a	1x Ton Capacity
Condenser	1 x horsepower
Fan with Condenser	01
Evaporator	4.16 horsepower
Water Reservoir	01
Water Pump	01
Copper Pipe	26 feet
Service Valves	02

The aim of this paper is to develop a geothermal heating and cooling system and assess its feasibility. For testing system all the important data and dimension are given in table 2 and 3.

Table 2: Data collection for a confined space

Dimensions	Room	Window No.01	Window No.02	Door (single)
Length (m)	4.2672	1.920	0.8534	0.8534
Height (m)	4.572	1.859	0.3048	2.0878
Width (m)	3.0784	-	-	
No. of Exhaust			01	
No. of Light			02	
No. of Computers			01	
No. of Printer			01	
Person Occupancy			02	
No. of Fans			01	

Table 3: Dimensions of a confined space

Sr.	Parameter	Values	Sr.	Parameter	Values
1	U for wall	1.79	11	Temperature Difference	24 Co
2	U for roof	1.2	12	Cp	1021.6
3	U for floor	1.3	13	Heat added by computer	50W
4	U for Door-wood	2.32	14	Heat added by printer	40W
5	U for window	6.30	15	Heat added by light	25W
6	SHFG for window	300	16	Heat added by fan	80W
7	SC for window	0.69	17	Heat added by exhaust fan	40W
8	CLF for window	0.65	18	Heat added by chair	0.6W
9	Latent Heat of persons	55w			
10	Sensible heat of persons	75w			

2.2 Load Calculations

2.2.1 Ton of Refrigeration

Q_{north} = U x A x (Ti - To)

Ton of Refrigeration (TR)
= Q (total) / 3.5 x 1.25
TR= 5.374 / 3.5x1.25
TR=1.91 Ton

2.2.2 Refrigeration effect

Refrigerating Effect= h1 – h4
Refrigerating Effect= 425.5 – 275
Refrigerating Effect =150.5 (kj/kg)

2.2.3 Power consumption

P = $\dot{m}$ x (h2 – h1)
P = 0.023(455 – 425.5)
P = 0.7375 kw or 737.5 watt

2.2.4 Coefficient of performance

$$\text{C.O.P} = \frac{N}{w}$$

$$\text{C.O.P} = \frac{3.5\ kw}{0.737.5\ kw}$$

2.2.5 Compression Ratio and Efficiency

The system's compression ratio is 2.5:1, determined by dividing the absolute discharge pressure by the absolute suction pressure. The compressor efficiency is assumed to be 80%.

2.2.6 Heat Rejection and COP of the Refrigeration Cycle

The heat rejection from the system, known as the Heat Rejection (HR), is calculated as 4.14 kW.

2.3 Design Decision

On the basis of the heating and cooling load calculations one-ton geothermal heat pump system is recommended to develop and fabricate one ton capacity geothermal heat pump system. The different components of geothermal heat pump are given in figure 1(a) and (b) respectively.

Figure 1(a): Compressor, water tank and copper pipe for heat pump system.

2.4 Principle of Working

The geothermal heating and cooling system operate by utilizing the constant temperature of the earth below a certain depth, typically 20-25°c. The efficiency of this system relies on factors such as soil conductivity, thermal inertia, water

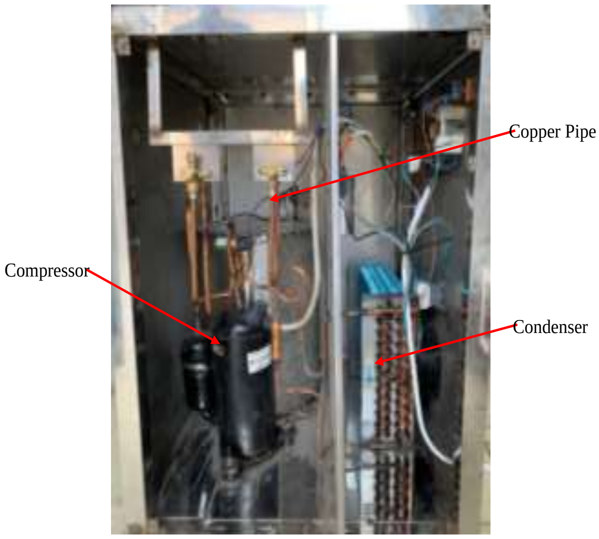

Figure 1(b): Different components of geothermal heat pump system.

retention capacity, and depth, which influence heat transfer with the earth [2 from design paper reference]. Compared to evaporative air coolers and traditional air conditioning systems, geothermal heating systems offer an advantage in that they can extract up to six times the heat energy they consume in electrical energy.

3. RESULTS AND DISCUSSIONS

The geothermal heat pump system operates in both heating and cooling modes. Through the vapor compression refrigeration cycle, the system demonstrated efficient operation in both heating and cooling modes. the refrigeration effect, calculated as the difference in enthalpy between the evaporator and condensed refrigerant, was determined to be 150.5 kj/kg. Power consumption of the system was estimated to be 0.7375 kw (737.5 watts), while the coefficient of performance (cop) was found to be 4.745, sizing of the system components was based on the calculated capacity of 1 ton (3.5 kw). The evaporator required a capacity of 4.16 hp, while the condenser size was determined to be 1 hp.

Figure 2 illustrates the results of a work cycle in in P-H diagrams.

3.1 Heating Mode

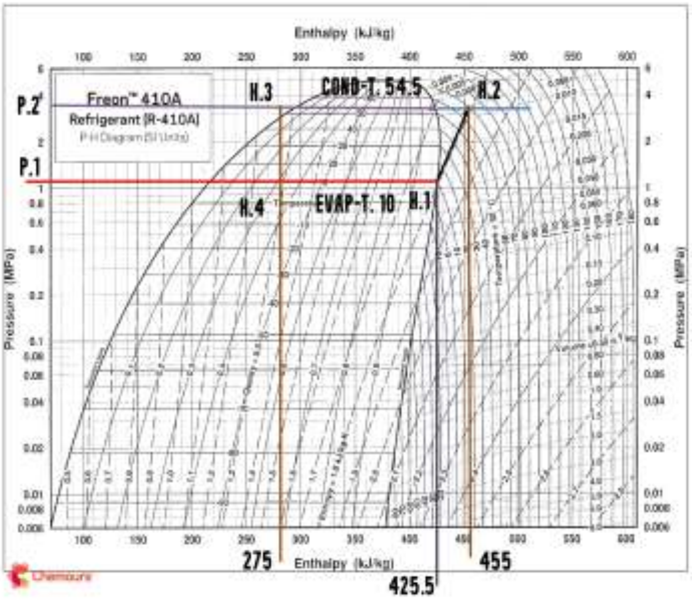

Figure 2: Pressure Enthalpy Chart of refrigerant R410a

The heat pump extracts heat from the ground through the ground heat exchanger using the refrigerant in the evaporator coil. The high-pressure refrigerant then flows to the condenser coil where it transfers its heat to the distribution system (forced air or hydronic) through the condenser. The cooled refrigerant, after transferring heat, is expanded through the expansion valve, which reduces its pressure and temperature. The cycle repeats as the refrigerant flows back to the evaporator coil in the ground heat exchanger.

3.2 Cooling Mode

The heat pump operates in reverse, rejecting heat from the building to the ground. The refrigerant in the evaporator coil absorbs heat from the distribution system. The absorbed heat causes the refrigerant to evaporate. The evaporated refrigerant is compressed by the compressor, raising its temperature and pressure. The high-pressure refrigerant releases heat to the ground through the condenser coil. The refrigerant is expanded through the expansion valve, reducing its pressure and temperature. The cycle continues as the refrigerant returns to the evaporator coil.

4. CONCLUSION

This study presents a detailed analysis of a geothermal heat pump system utilizing a horizontal slinky loop ground heat exchanger using R410a as a refrigerant. The system design and calculations were based on the given data, which included an evaporating temperature of 10°c, suction pressure of 12 bar, discharge pressure of 30 bar, compression ratio of 2.5:1, and compressor efficiency of 80%. The geothermal heat pump system with a horizontal slinky loop ground heat exchanger offers an environmentally-friendly and efficient solution for heating and cooling applications. The system leverages the constant ground temperature, resulting in high energy efficiency and reduced operating costs compared to traditional HVAC systems. The system can provide both heating and cooling, as well as domestic hot water, making it a comprehensive solution for year-round comfort. The calculated refrigeration effect, power consumption, cop, and sizing of system components was 150.5 (kj/kg), 0.7375 kW, 4.745 and 1 ton (3.5 kW) respectively, indicating the system's capability to provide reliable and sustainable heating and cooling.

REFERENCES

[1] **Soltani, M., Kashkooli, F.M., Dehghani-Sanij, A.R., Kazemi, A.R., Bordbar, N., Farshchi, M.J., Elmi, M., Gharali, K. and Dusseault, M.B., 2019**. A comprehensive study of geothermal heating and cooling

systems. Sustainable Cities and Society, 44, pp.793-818.

[2] **Alshehri, F., Beck, S., Ingham, D., Ma, L. and Pourkashanian, M., 2021.** Sensitivity analysis of a vertical geothermal heat pump system in a hot dry climate. Renewable Energy, 178, pp.785-801.

[3] **Cui, Y., Zhu, J., Twaha, S., Chu, J., Bai, H., Huang, K., Chen, X., Zoras, S. and Soleimani, Z., 2019.** Techno-economic assessment of the horizontal geothermal heat pump systems: A comprehensive review. Energy Conversion and Management, 191, pp.208-236.

[4] **Rybach, L. and Eugster, W.J., 2010.** Sustainability aspects of geothermal heat pump operation, with experience from Switzerland. Geothermics, 39(4), pp.365-369.

[5] **Self, S.J., Reddy, B.V. and Rosen, M.A., 2013.** Geothermal heat pump systems: Status review and comparison with other heating options. Applied energy, 101, pp.341-348.

[6] **Javaani, N., Ansari, A. and Moradian, H.**, Design and Installation of the First Geothermal Heat Pump in Iran.

[7] **Yari, M. and Javani, N., 2007.** Performance assessment of a horizontal-coil geothermal heat pump. International journal of energy research, 31(3), pp.288-299.

[8] **Self, S.J., Reddy, B.V. and Rosen, M.A., 2013.** Geothermal heat pump systems: Status review and comparison with other heating options. Applied energy, 101, pp.341-348.

[9] **Chua, K.J., Chou, S.K. and Yang, W.M., 2010.** Advances in heat pump systems: A review. Applied energy, 87(12), pp.3611-3624.

[10] **Cui, Y., Zhu, J., Twaha, S., Chu, J., Bai, H., Huang, K., Chen, X., Zoras, S. and Soleimani, Z., 2019.** Techno-economic assessment of the horizontal geothermal heat pump systems: A comprehensive review. Energy Conversion and Management, 191, pp.208-236.

[11] **Milenić, D., Vasiljević, P. and Vranješ, A., 2010.** Criteria for use of groundwater as renewable energy source in geothermal heat pump systems for building heating/cooling purposes. Energy and Buildings, 42(5), pp.649-657.

[12] **Wu, Y., Gan, G., Verhoef, A., Vidale, P.L. and Gonzalez, R.G., 2010.** Experimental measurement and numerical simulation of horizontal-coupled slinky ground source heat exchangers. Applied Thermal Engineering, 30(16), pp.2574-2583.

[13] **Ozgener, O. and Hepbasli, A., 2007.** Modeling and performance evaluation of ground source (geothermal) heat pump systems. Energy and Buildings, 39(1), pp.66-75.

[14] **Bi, Y., Wang, X., Liu, Y., Zhang, H. and Chen, L., 2009.** Comprehensive exergy analysis of a ground-source heat pump system for both building heating and cooling modes. Applied Energy, 86(12), pp.2560-2565.

[15] **Selamat, S., Miyara, A. and Kariya, K., 2016.** Numerical study of horizontal ground heat exchangers for design optimization. Renewable energy, 95, pp.561-573.