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Ground Coupled Heat Pump Design for Tafila Climate

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ABSTRACT

This work represents a theoretical investigation of a ground coupled heat pump system that is used for domestic heating and cooling purposes of a typical residential house in Tafilah-Jordan. The system is designed to provide heating and cooling loads of 7.39, 7.27 KW respectively. The designed system consists of a ground buried heat exchanger (1.5m depth, 6.5m length, and 2.2cm diameter), indoor heat exchanger, and a 2 HP compressor. The system has been analyzed economically and it was found that the ground coupled heat pump system reduces energy consumption and has a payback period for of 1.5 years.

1. Introduction

One of the important requirements in our life is the heating and cooling process, for this purpose many devices and equipment with different types of energy sources are used. One of those is the heat pump, which is a device that can do both operations, heating in winter and cooling in summer. This paper deals with ground coupled heat pump in which we use earth as both heat source and heat sink for both heating and cooling processes of this house. A heat exchanger will be designed and installed at certain depth in the ground to exchange heat during both winter and summer season such that to provide the required heating and cooling loads of the house. A second heat exchanger will be designed and installed inside the house. Furthermore, the compressor and the expansion value will also be designed. Finally, an economic analysis will be carried to study the feasibility of this system by comparing it's cost with other traditional heating or cooling system.

An experimental single family residence has been constructed to demonstrate the feasibility of using an under floor heat exchanger with a ground coupled heat pump system [1]. The system installed integrates waste heat recovery with a heat storage system to provide heating, cooling, and domestic hot water. Unsal and Mazhar [2] used existing standards to compare energy consumption of ground source heat pumps with conventional equipment. This task was undertaken in an attempt to compare the energy

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use and demand characteristics of ground source heat pumps to conventional equipment. A field test of vertical ground coupled heat pump in Alabama was undertaken to determine the acceptability and operational characteristics of vertical ground coupled heat pump in south climates [3]. The system was installed to supply heating and cooling loads of 13 kW and 10 kW respectively. The heat pump operated 10 percent below rated efficiency in cooling and 15 percent below efficiency in heating. However, energy use and demand were substantially reduced.

2. Methodology

In this paper, the design procedure of each component of the system is based on condensing and evaporating temperatures of 38, -5 ◦ C respectively.

2.1 Earth Buried Heat Exchanger

This exchanger will act as an evaporator during heating and a condenser during cooling. The first step was to estimate the variation of earth temperature with depth, the ground temperature at different depth is calculated using the following equation [6].

$$T+T_{mean} = T_{omax}\, e^{-\sqrt{(\pi/\alpha t_o\ )}*X} * [\cos\sqrt{(\pi/\alpha t_o\ )}*X - (2*\pi*t/\ t_o\ )] \quad (1)$$

To sizing of the buried heat exchanger, the area is to be found in order to calculate the length for a given diameter that are required to give the heating or cooling load, using the following equation:

$$Q = U*A*. \quad (2)$$

Where

$$1\backslash U_o = A_o\ /\ h_i A_i + x A_0 / K\ A_m\ , \quad (3)$$

and

$$h = 0.555*\left(\rho_l *(\ \rho_l - \rho_v\ )\ g\ k^3 h_{fg}\ /\ \mu D*\left(T_g - T_w\ \right)\right)^{1/4}. \quad (4)$$

The value of the properties involved in the above correlation is found from table in [7]; then, to find A_o, Ai, A_m and x, the inside and outside diameter of the copper tube are selected to be 2.2 and 2.54 cm respectively.

2.2 Economic Analysis

Cost analysis will investigate the feasibility of the present system after it is being compared with other conventional systems. The estimation of the cost of the present system involves some basic assumptions concerning interest rate, inflation, operations, maintenance and depreciation. These assumptions are:

i. The system is assumed to have only a 20-year life.
ii. Interest rate(r) and inflation rate(i) are taken 8% and 6% respectively.
iii. Operating costs, C_{omr} which include operation, maintenance and repair which taken as 23%.
iv. Scrap value, S, is taken as 10% of the investment.

Present Value of the Cost (PVC) [8, 9]:

$$PVC = I + Comr\,[\,(1+i)/(r-i)\,][1-(\,(1+i)/(1+r)\ )n\,] - S\,(\,(1+i)/(1+r)\,)n. \quad (5)$$

Where I is the investment cost of the system (2000JD) as shown in Table 2, n: life time = 20 years. C_{omr}: 450JD S=200JD, r: discount rate=200JD and i:inflation=120JD. This results in a PVC =2680.5 JD. The PVC of other conventional system (central heating system and conditioning), may be estimated using the same equation in which the investment cost for this system I=4150 JD. PVC =5490 JD, which is higher than that of the heat pump system

The payback period of the system is calculated using the following equation [8, 9]:

$$P(1+1/n)nt = (mA1/j-e)[(1+j/m)mt - (1+e/m)mt] + sv. \quad (6)$$

Substitute the values of the parameters in this equation with sv =0, then t = 1.378, year = 16.5, month is the payback period.

3. Discussion of Results

The main objective of this work is to utilize earth as heat source and heat sink for both heating and cooling of a typical house in tafilah. This was achieved by means of heat pump that may be used both in winter and summer seasons. The house selected was a typical one with heating and cooling loads were calculated to be 7.387 kW, and 7.271 kW respectively.

The temperature of the ground was calculated at different depths ranging from 1.25 to 6 m , and the results are shown in Table 1 and Fig 3 , also shown in the Figure the monthly variation of ambient temperature. As indicated in the results, it was found that temperature decrease with depth to a certain value beyond which it almost remains constant. According to Fig 3, it is noted that there is a phase lag between the temperature of the earth surface and the temperature at depth (x) and this phase is approximately one month. In calculating the temperature of the ground, the average monthly temperature of earth surface was used, and this will introduce an error in the results, and to reduce this error the average daily temperature of earth surface over several period were used.

Based on the economical study, it was decided to bury the heat exchanger at a depth of 1.5 m as depth. It was found that a minimum temperature of 11.2 ◦ C occurs in February, and a maximum temperature of 22 C occurs in September as shown in Fig 3. Further, the temperature of earth at that depth is assumed to be uniform and equal to the temperature of the buried heat exchanger surface, and there will be no conduction in the soil around the surface of the heat exchanger. Based on assumed diameter of the exchanger (2.54 cm), the length was calculated to be 5.6 m. The heat exchanger is made of copper material, since this material has a high thermal conductivity. According to calculations shown in Appendix (B), this exchanger gives 8.688 kW when it acts as a condenser and 7.2 kW when it is acts as an evaporator. In order to transport the cooling and heating air to the house, galvanized steel duct was used, with a total area of 30 m^2, Air is forced across the indoor coil through this duct by mean of fan with a power of 0.58 hp , and a rotational speed of 1210 RPM.

According to the economical study which based on local prices, the total initial cost was found to be 2000 JD, and annual operating cost is 450JD, it was found that, heat pump system is more economical than the conventional heating or cooling systems namely; central heating system, split unit system, that are used in Jordan. This is due to its low initial cost in comparison with these other systems; also, its annual operation cost is less than those of the other systems are. In order to control the operation the heat pump ON-OFF controller was used to switch on the heat pump or close it. Further, for the purpose of reverse the cycle from cooling to heating, a four way valve was used.

4. Conclusions

As results of this paper, ground coupled heat pump system may be used efficiently for heating and cooling purpose, and according to the economical study, it was found that heat pump system is more economical than the conventional heating or cooling system. Furthermore, according to the economical study, the heat exchanger was installed at a depth of 1.5 m below the earth surface.

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Nomenclature:

A: Heat transfer area, m^2
A_i: Inside surface area of heat exchanger tube, m^2
A_m: Mean area of heat exchanger tube, m^2
A_o: Outside surface area of heat exchanger tube, m^2
C_{omr}: Operating and maintenance cost, JD.
COP: Coefficient of performance
D: Diameter, m.
h_1 ,h_2: Enthalpy, kJ/kg
h_{fg}: Latent heat, kJ/kg.
h_o: Convection heat transfer coefficient of air, W/m k
h_i: Convection heat transfer coefficient , W/m k.
HRR: Heat rejection ratio
i: Inflation rate, %.
I: Investment includes the cost, JD.
k: Conduction heat transfer coefficient, W/m k
k_f: Conduction heat transfer coefficient of the fluid, W/m k.
L: Length, m.
LMTD: Logarithmic Mean temperature difference, ◦ C.
$\dot{m}$: Mass flow rate, kg/s.
n: Life time of the system, year.
PVC: Present value of money, JD.
P_r: Prandtle number.
Q: Heat transfer rate, W
r Discount rate, %
S: Scrap value, JD
t: Time at any month

t_o: Time period, 1 year
T: Temperature difference at depth x, ◦ c
T_{mean}: Mean temperature of ground surface, ◦ c
T_{omax} : Max. temperature of ground surface, ◦ c
U: Overall heat transfer coefficient, W/m^2 k
v: Velocity, m/s
$V^{\bullet}$: Volumetric flow rate, m^3/s
W_{comp} : Power, W
x: Tube thickness, m
X: Depth, m
ΔP: Pressure loss, Pa
μ: Dynamic viscosity, kg/m s
ν : Kinematic viscosity, m^2/s
ρ_v : Density of vapor phase, kg/m^3
ρ_l : Density of liquid phase, kg/m^3.