NWSA-Technological Applied Sciences
ISSN: 1306-3111/1308-7223
NWSA ID: 2014.9.1.2A0084
Status : Original Study
Received: July 2013
Accepted: December 2013
E-Journal of New World Sciences Academy

Onur Özsolak
Cumhuriyet University, onurozsolak@gmail.com, Sivas-Turkey
Mehmet Esen
Fırat University, mesen@firat.edu.tr, Elazığ-Turkey

http://dx.doi.org/10.12739/NWSA.2014.9.1.2A0084

PERFORMANCE INVESTIGATION OF SLINKY HEAT EXCHANGER FOR SOLAR ASSISTED GROUND SOURCE HEAT PUMP

ABSTRACT

In the following study, 12 m^2 test chamber was heated by solar and ground source heat pump under the physical conditions of Elazığ. In order to place slinky heat exchanger pipes, a hole was dug with 1 meter width, 2 meters depth and 15 meters length. Slinky pipes were put horizontally in the hole and water-antifreeze mixture was circulated with the circulating pump in the slinky heat exchanger. The heat taken from the ground was transferred into the environment to be heated through the heat pump. Also the system was operated as solar assisted with the 6 flat-plate solar collectors being placed. Thus, the performance of the operating system could be investigated.

Keywords: Solar Assisted Ground Source Heat Pump, Energy, Slinky Heat Exchanger, Performance Analysis, Heating

SLİNKY ISI DEĞİŞTİRGEÇLİ GÜNEŞ DESTEKLİ TOPRAK KAYNAKLI ISI POMPASININ PERFORMANS ARAŞTIRMASI

ÖZET

Yapılan çalışmada Elazığ iklim şartlarında 12 m^2 alanındaki deney odası güneş ve toprak kaynaklı ısı pompası ile ısıtılmıştır. 1m eninde, 2m derinliğinde ve 15 m uzunluğunda çukur kazılarak slinky toprak ısı değiştirgeci borularını bu çukur içine yatay olarak yerleştirilmiştir. Bir sirkülasyon pompası yardımı ile su-antifriz karışımı yatay slinky toprak ısı değiştirgeci içinde dolaştırılarak topraktan çekilen ısı, ısı pompası vasıtasıyla ısıtılacak ortama verilmiştir. Ayrıca sistem, yerleştirilen 6 adet düzlemsel güneş kollektörü ile güneş destekli olarak çalıştırılarak bu sistemin performansı araştırılmıştır.

Anahtar Kelimeler: Güneş Destekli Toprak Kaynaklı Isı Pompası, Enerji, Slinky Isı Değiştirgeci, Performans Analizi, Isıtma

1. INTRODUCTION (GİRİŞ)

In our day, having been a tendency to increase the rate of consumption of fossil fuels and being limited its reserves brought up to investigate new energy sources. In this context, studies focused on renewable energy sources, especially on solar energy. The convenience of storing of solar energy, transforming into heat energy easily, to be able to use in many fields, the absence of environmental adverse effect, being plentiful and having no owning cost, increase the importance of solar energy as a natural energy source.

The distribution of sunrays on Earth influenced by many factors such as the structure of the area's topography, altitude, seasonal characteristics, and latitude. That's why, the amount of solar radiation falling in each region shows great difference. Although a small amount of solar energy which pruduced in the sun reaches the Earth, it is still more than the consumed energy. However, being limited and intermittented of the density of the energy that reaches the Earth, limits the usage of solar energy. On the other hand, solar energy still maintains its importance as a clean energy source [1].

Located in the solar zone geographical location, Turkey is a country that is appropriate to use solar energy. It was observed that the average total insolation time per annum is 2640 hours (Daily total 7.2 hours), average total radiation 1311kWh/m^2-year (daily average 3.6kWh/m^2)[2].

With such a high solar energy potential, our country is the luckiest country of Europe. The studies about increasing the usage of this potential and studies on heating from the areas of usage continue to rapidly. It is known that the stored solar energy is in low degrees. Heat pump systems were developed in order to transfer this energy that is in low degree to the environment that is in higher degree [1].

There is a strong correlation between energy consumption per capita and pruductivity, life expectancies per capita in a country. World Energy Council have been offering scenarios on different effects of economical growth, technological progressions, environmental protection and international existences in order to provide energy requirements of the future. Between 1990-2050, primary energy consumption will increase by 50% according to result of ecologist scenerio, and according to maximum growth rate scenario it is expected that this rate will be 275%. According to the most ecologist scenario, it is expected that carbon emmissions will decrease down to the levels of the year of 1990, but according to the highest growing scenarios, it is expected to double carbon emmissions [3].

The ecologist and productivity perspective of energy production and consumption of the ground source heat pumps (GSHP) primarily handled by the developing countries. In this regard, the ground source heat pumps are seen to make a significant contribution in better load management for electricity companies, providing lower electricity bills to consumers and a cleaner environment to the society. Increasing the efficacy of a well designed and placed ground source heat pumps, reduces the amount of required energy. Thus, the pollutants caused by this and the other emissions be reduced.

In the following study, these two systems have been operated as solar assisted ground source heat pump by combining solar and ground. There are many experimental and theoretical studies in literature about solar assisted ground source heat pumps.

Tunç et al. [4], made the second law analysis of solar assisted heat pump with a computer similation. 11 different systems were examined and their results were compared. For each system exergetic efficiency or second law efficiency was described. Comparisons were done among different systems, and exergetic efficiency was calculated.

Martin, in 1990, did theoretical and experimental study to examine the influence of parameter conversion, using in the designing of the heat pump system which has horizontal-type one-piped ground heat exchanger (GHE). He developed a computer programme to find out the energy consumption and the performance of 3 tonned heat pump for houses and compared the results with the measurements which is done in two houses in Oklahoma. Furthermore, he made an economic analysis in order to determine the economically optimum design [5].

Reyes et al. [6] had made a theoretical and experimental exergy analysis of solar assisted heat pump for heating. The experimental prototype which works as solar assisted or conventional heat pump, was tested for exergetic efficiency, total system irreversibility and irreversibility of components.

Piechowski [7], in the year of 1999, made simulations to make more accurate of its design and to make easier its calculations of horizontal type GHE’s. This study was done to access the solution easier in higher temperatures like the surface of the soil-pipe and in the places with dense moisture movement. In the analytical study, implicit and explicit methods were used and these two methods were compared. As a result, he argued that implicit formulation is a better method in these kind of studies.

Özgener ve Hepbaşlı [8], were interested in energetic and exergetic modelling of ground source heat pump systems for the system analysis and the performance evaluation.

Esen et al. [9], explained the applicability of artificial neural networks (ANN) in order to predict the performance of an horizontal ground source heat pump system in their studies.

Yang et al. [10], in this examination, explanations comprise about researches and practices related to ground source heat pump made in China and information on patents. Also, the policies related to GSHP were introduced and analyzed.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Heat pumps are known as ever-growing energy conservation systems. To opt for renewable energy sources as a source in heat pumps is extremely important in terms of energy saving and environmental factors. Solar energy has an important potential as renewable energy source in our country. However this energy is limited with daytime and the days when the sky is open. In this respect, it is aimed to gain continuity to the system by adding the heat energy taken from the ground as a second source to heat pump system. With the spreading of these kind of systems, environmental effects will be reduced by providing the usage of energy efficiently.

3. EXPERIMENTAL STUDY (DENEYSEL ÇALIŞMA)

3.1. System Elements (Sistem Elemanları)

A room in Elazığ with a base area (4x3m) of 12m^2 is calculated by considering to be heated with the aim of ground and solar source heat pump. The heat loss of the heating room was measured as 4099W.

The compressor was produced as hermetic type and works with R-22 gas. The qualities of compressor characteristics which is taken from manufacturer company were given below:

Brand : Bristol Hermetic Compressor
Type : H24B24QABHB
Capacity : 5.8kW
Gas : R-22

Engine power: 2190W

As evaporator, a thermal energy storage with an opening top, made of galvanized sheet with a dimension of 50x50x70cm and a thickness of 0.50mm was built and its perimeter was isolated with XPS insulation. Under the storage BK 16x35 model heat exchanger of Buz Çelik(BK) was placed, having a basement of 16.27m^2 and a capacity of 6535kcal/h in which water-antifreeze mixture from the solar collectors are circulating. At the top of this heat-exchanger, one more heat-exchanger which is refrigerant cycle materialised in, with the same brand and capacity was placed without touching each other. Then the storage was provided to circulate by filling with water-antifreeze mixture and by making connection to the ground exchanger. So the manufactured evaporator consisted of two heat exchangers placed in the storage filled with water-antifreeze mixture.

The BK 16x35 model of Buz Çelik, having a basement of 16.27m^2 and a capacity of 6535kcal/h uses air-cooled condenser. In the front side of the condenser, by placing Fantech brand 150W power fan to absorb the inner air, to heat and to send it back to the inner place. With a voltage regulator placing on the fan, circulation number could be changed. The flow rate of the fan is 0.73kg/sec.

In subsoil circulation, one circulation pump was used which transmits water-antifreeze mixture (brine) in GHE(Ground heat-exchanger) to evaporator then send it back to GHE. In also solar energy circulation, one circulation pump was used to circulate water-antifreeze mixture between evaporator and solar collectors. The characteristic of the circulation pump was given below.

Brand : Best Pump
Type : PR 53
Engine power: 370 W

In the testing apparatus, it was used one water meter to measure the flow rate of water-antifreeze mixture circulating in the GHE and one to measure the flow rate of water that goes to solar collectors and totally two water meters having an average rate flow for water 1.5m^3/h produced by Teksan.

Capillary tube was used for throttling valve. It was chosen for its low cost price and being adjustable piece.

For testing set 6 flat plate solar collectors was used having the standard of 90x190cm dimension on the market, and 12 piped with aluminium sheet.

Transferring heat in the ground to heat pump and vice versa can be done by a fluid circulating in ground heat exchanger. Water is a suitable fluid in terms of economic and thermodynamic. However, the fact that its freezing point is 0°C poses a problem in many applications. Especially in the regions where the soil temperature is low, fluids with high freezing points are preferred. Ethylene glycol was added 20% percentage by weight for the fluid which is used in solar and ground parts of the system.

In order to place GHE, a hole 1m wide, 2m deep and 15m long was dug and horizontal slinky GHE was placed in it. In our study, 150m pipe was used in order to provide the necessary heat load. Under the ground 40mm Polyetilen SDR-11 pipe was used as GHE pipe. Polyetilen SDR-11 pipes were taken as 100m coil pipes. In Slinky configuration, it is adjusted as 50 slinky loop and, 25cm distance between each loop and 1m as loop diameter. The pipes are attached by clips which are in specific distances in order to prevent any defect of loops. The formation of slinky configuration out of the hole is shown in Figure 1.

Six pieces of solar collectors were placed on the roof of the building with 38° angle, which was connected to the solar heat exchanger in the evaporator. The energy provided from solar collectors was planned to be given closed cycle to the evaporator. Alo an expansion storage was built on solar collectors. The water-antifreeze mixture in the solar collectors was circulated with 0,2kg/sec flow rate.

Figure 1. The view of slinky pipes [16]
(Şekil 1. Slinky boruların görünümü [16])

In order to complete heat pump system, ground and solar parts must be connected to the heat pump installation. In ground connection, in order to circulate the fluid in ground heat exchanger one circulation pump is used, and also in solar connection in order to circulate the fluid in solar connectors another circulation pump is used, totally two circulation pumps are used.

In the system, in order to adjust the flow rate of the fluid in solar and ground parts valves and in order to measure the flow rate of the fluid 2 pieces of water counters were used. The water-antifreeze mixture coming from solar and ground were connected to heat pump. The water-antifreeze mixture coming from the solar was circulated with closed cycle to heat exchanger in the storage whereas the water-antifreeze mixture coming from the ground was circulated with open cycle to heat exchanger in the storage. Heat pump cycle has worked in closed cycle by the help of heat exchanger in the evaporator. The compressor, condenser, capillary tube and evaporator connections were done compatible with copper pipes using a suitable technique with our own production. Later by filling Freon-22 gas in the heat pump cycle, the system was tested. The heat taken from condenser was sent to the room by a fan replaced on condenser. The general view of the heat pump system was shown in Figure 2.

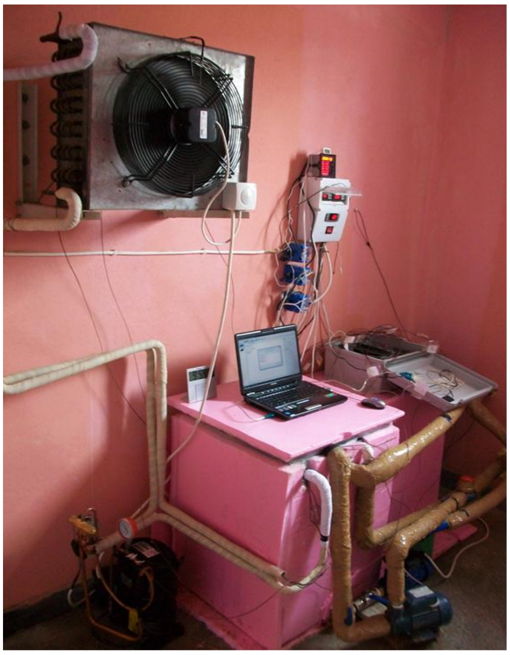

Figure 2. The general view of the heat pump system [16]
(Şekil 2. Isı pompası sisteminin genel görünümü [16])

A digital control device was connected to the system. With Dixell digital thermostat XR0ICX, working and stopping of compressor according to the room and storage temperature, working of the circulation pump in solar collectors or ground heat exchanger were provided. Also, with this device, we had the opportunity to work it according to the intended heat, working heat pump either with solar or ground source or working it with both solar and ground source. The room temperature could be kept on an intended level by the help of this device. The detailed views of solar and ground source heat pump systems in Figure 3. The explanations of the points on diagram were given in Table 1.

Table 1. The explanations of the points on diagram
(Tablo 1. Diyagram üzerindeki noktaların açıklamaları)

1	Compressor	8	Sensor measuring storage temperature
2,6	Manometer	11	Sensor measuring room temperature
3	Condenser	26	Sensor measuring collector exit temperature
4	Fan	10	Evaporator
5	Capillary tube	12	Digital thermostat XR0ICX
7,9	Heat exchanger	13	Data Recorder (Data Logger)
14,16,20	Valve	17,22	Water counter
15,21	Circulation pump	27	Energy Analyzer
23	Solar collector	28	Horizontal Slinky Ground Heat Exchanger
24	Expansion Storage		
25	Solarimeter		

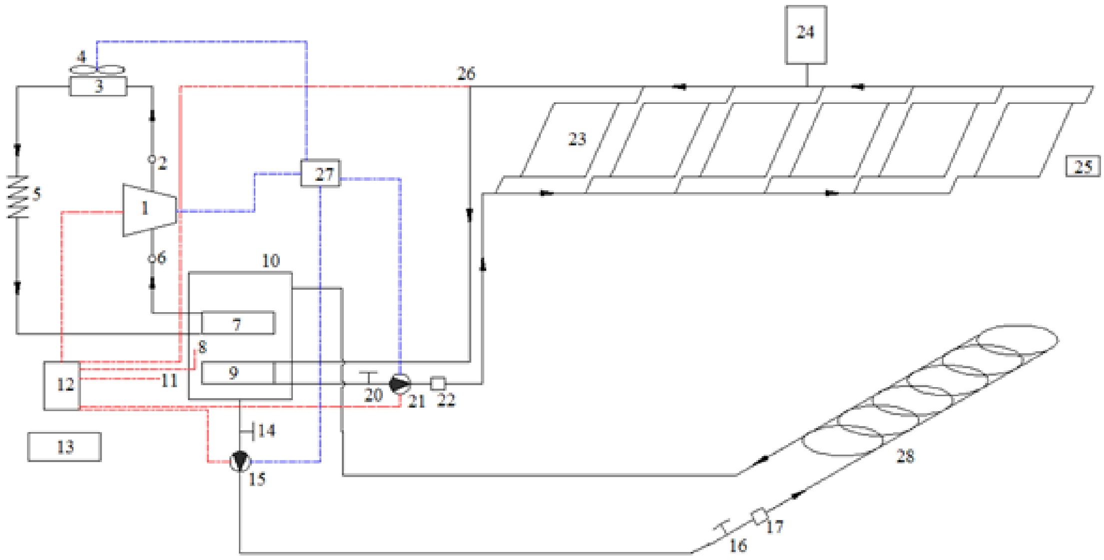

Figure 3. The detailed schematic diagram of Solar and Ground source heat pump system
(Şekil 3. Güneş ve toprak kaynaklı ısı pompası sisteminin ayrıntılı şematik diyagramı)

3.2. Experimental Method (Deneysel Yöntem)

Experiment was done on 12.01.2010. It started at 9.00 and continued up to 17.00. By the help of digital thermostat XR01CX the room temperature was kept on intended value. With the sensor put in the room, the room temperature was stable at 24°C.

Digital thermostat stopped the compressor when the room temperature increased to 24°C whereas it started the compressor when the temperature decreased to 21°C. Also a sensor was connected to heat pump storage and the other one to water-antifreeze turning line and the system was automatically put into operation according to the temperatures at these points. If the temperature in the collector exit increases to 20°C, digital thermostat starts the circulation pump on solar collector line, it stops the one on ground heat exchanger line and operates the system automatically with solar source. In the system the heat taken from ground heat exchangers was given inside by heat pump exchanger. Freon-22 gas was used as a refrigerant in the closed cycle of the heat pump.

The operation of the system can be summarised shortly as: Ground heat is taken by water-antifreeze circulating in heat exchangers, which are placed under the ground, and then given to evaporator. The refrigerant fluid in the form of saturated steam from the evaporator is turned into superheated steam in the compressor by pressing under high pressure and tempature. Later refrigerant fluid the form of superheated steam entering the condenser send its heat to the room with the help of fan on the condenser and then it condenses at constant pressure. Pressure and temperature of saturated liquid form of high-pressure refrigerant evaporator conditions are brought at capillary tubes. As the temperature of the refrigerant fluid in the evaporator is lower than the temperature of the heat source, there is heat transfer from the storage of heat pump to refrigerant fluid at the constant pressure and the refrigerant fluid evaporates. After that cycle starts again and continues like this.

The heat that water-antifreeze circulating in ground heat exchanger, takes from the ground is found as below:

$$\dot{Q}_{ghe} = \dot{m}_{wa} C_{p,wa} (T_{wa,i} - T_{wa,o}) \quad (1)$$

Here; $\dot{Q}_{ghe}$ is the heat quantity that water-antifreeze mixture takes from soil (kW), $\dot{m}_{wa}$ is the flow rate of water-antifreeze mixture (kg/s), $C_{p,wa}$ is the specific heat of water-antifreeze mixture (kJ/kgK), $T_{wa,i}$ is the entrance temperature of water-antifreeze mixture to the evaporator (°C), $T_{wa,o}$ is the entrance temperature of water-antifreeze mixture to the soil (°C). If 20% of ethylene glycol is in the water-antifreeze mixture $C_{p,wa}$ can be taken as 3900J/kg°C [11].

The performance coefficient of heat pump (COP_{hp}) and the performance coefficient of the system (COP_{sys}) is found as below:

$$COP_{hp} = \frac{\dot{Q}_{con}}{\dot{W}_{comp}} \quad (2)$$

$$COP_{sys} = \frac{\dot{Q}_{con}}{\dot{W}_{sys}} \quad (3)$$

Here $\dot{Q}_{con}$ shows the heat quantity sent to the room by condenser, $\dot{W}_{comp}$ shows the power that compressor takes from network, $\dot{W}_{sys}$ shows the total power that the system takes from network. $\dot{W}_{sys}$ is calculated as below:

$$\dot{W}_{sys} = \dot{W}_{comp} + \dot{W}_{p} + \dot{W}_{f} \quad (4)$$

$\dot{W}_{p}$ shows the power that circulation pump takes from the network, $\dot{W}_{f}$ shows the power that fan takes from the network. $\dot{Q}_{con}$ the temperature that the condenser send to the room is calculated like this.

$$\dot{Q}_{con} = \dot{m}_{air} C_{p,air} (T_{air,o} - T_{air,i}) \quad (5)$$

Here; $\dot{m}_{air}$ shows the flow rate of air passing through condenser, $C_{p,air}$ shows the specific heat of the air, $T_{air,o}$ shows the exit temperature of air from the condenser and $T_{air,i}$ shows the enterance temperature of air to condenser.

4. FINDINGS AND DISCUSSIONS (BULGULAR VE TARTIŞMALAR)

The system was put into operation with double source that is both ground and solar source. On 12.01.2010 the horizontal ground heat exchanger having a water-antifreeze flow rate of 0.1kg/sec operated as solar source and the performance curves were given between Figure 5 and Figure 8. In Figure 4 the change in solar radiation values according to time was given.

In Figure 5 the change in values of COP_{sys}, COP_{hp} and the heat extraction of soil are given. In the experiment as the maximum values of COP_{sys} and COP_{hp} were calculated respectively as 4.65 and 5.11, the average in a day was calculated respectively as 2.90 ve 3.70. As the heat taken from the ground changed between 3.08-4.01kW, the average in a day was calculated as 3.38kW.

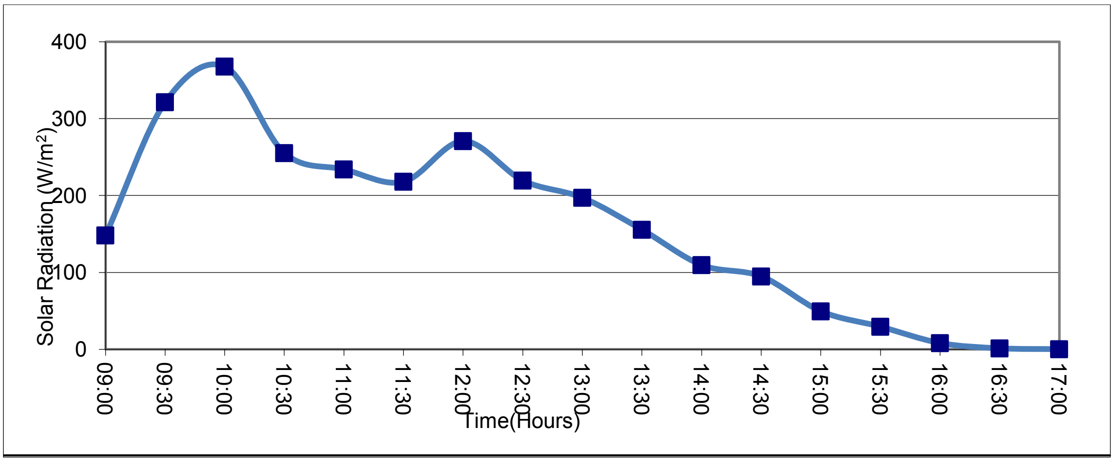

Figure 4. The change in solar radiation values in time
(Şekil 4. güneş ışınımı değerlerinin zamanla değişimi)

The heat taken from the ground changed between 20-26 W/m according to total pipe length, the average in a day was 22 W/m. In a study taken from literature [12], the heat that horizontal ground heat exchangers were 23-33W/m according to pipe length, in another study this value was given as 16-28W/m [13]. In horizontal slinky ground heat exchanger this value was given as 11-25W/m [14].

According to total hole length, the heat taken from the ground changed betweeen 220-286W/m, the average in a day was calculated as 241W/m. In a study taken from literature [15], the heat value that 1.4m depth, 1.2m feet horizontal slinky ground heat exchanger taken from the ground according to hole length was calculated as 42.5-158.4W/m.

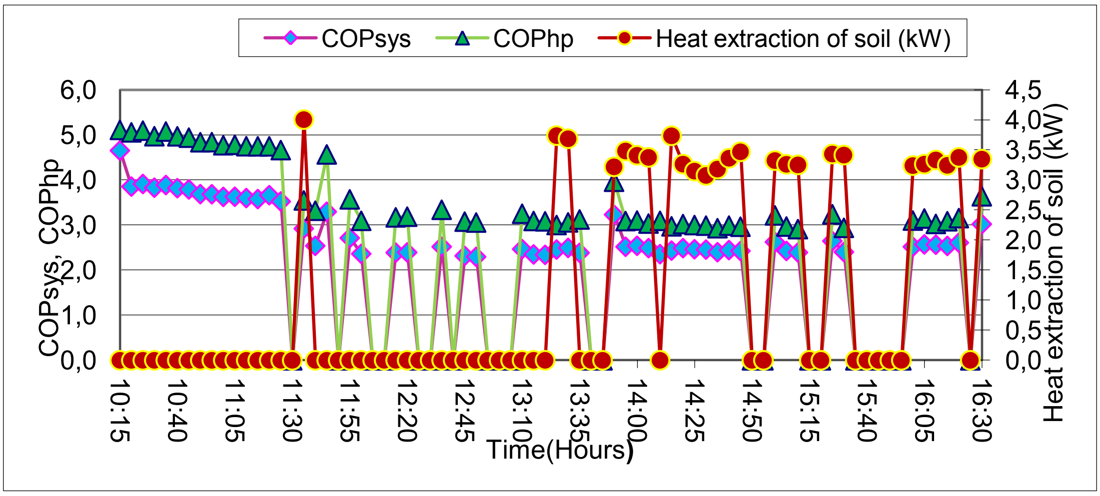

Figure 5. The change of COP_{sys}, COP_{hp} and the heat extraction of soil in time
(Şekil 5. COP_{sis}, $COP_{ıp}$ ve topraktan çekilen ısı miktarının zamanla değişimi)

In Figure 6 the temperatures change of $T_{air,i}$, $T_{air,o}$ and heat pump storage temperature (T_s) in time, in Figure 7 the temperature change of $T_{wa,i}$, $T_{wa,o}$ and ambient temperature (T_a) in time and in Figure 8 the temperature change in horizontal slinky ground heat exchanger hole are given. As the maximum difference between the going and coming heat of water-antifreeze mixture in a day was 10.27°C, in $T_{wa,i}$ temperature reached to 12.86°C. As the maximum difference between the entering and exiting air in condenser was 12.47°C, an average in a day was calculated as 8.49°C.

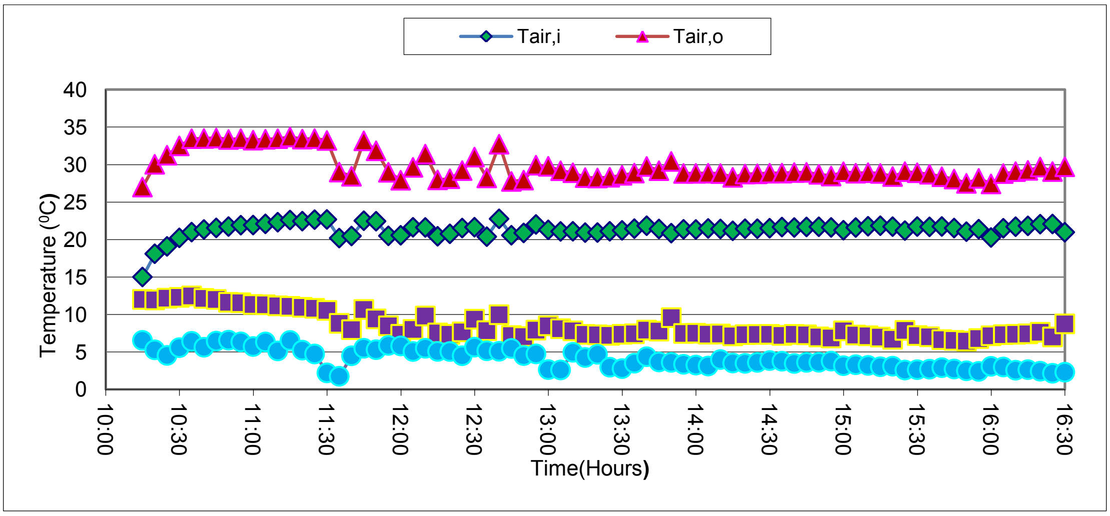

Figure 6. $T_{air,i}$, $T_{air,o}$ and temperature of storage in time
(Şekil 6. $T_{h,g}$, $T_{h,ç}$ ve depo sıcaklığının zamanla değişimi)

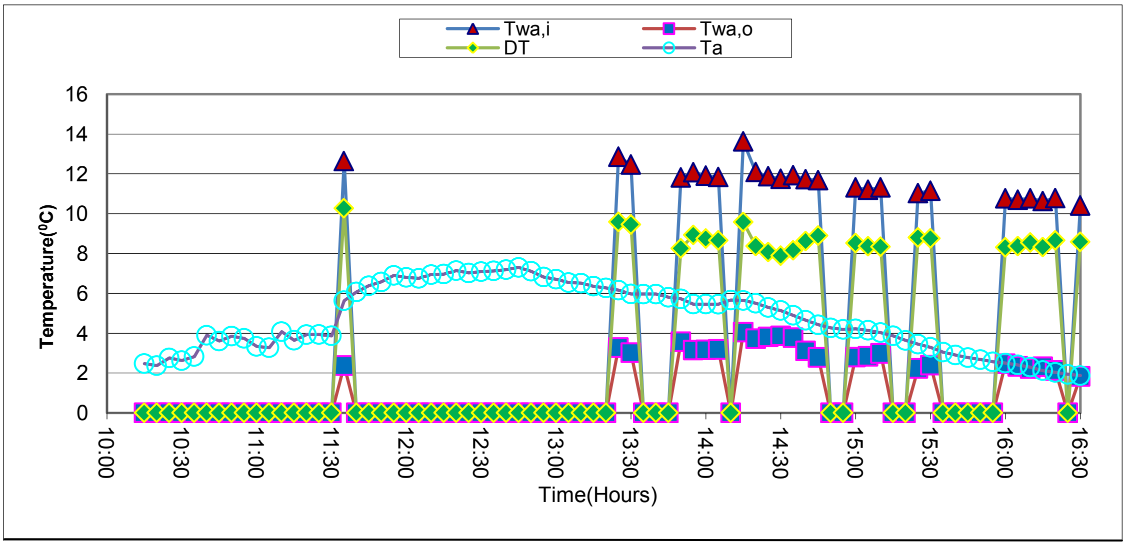

Figure 7. Temperature changes of $T_{wa,i}$, $T_{wa,o}$ and T_a in time
(Şekil 7. $T_{sa,g}$, $T_{sa,ç}$ ve $T_ç$ sıcaklıklarının zamanla değişimi)

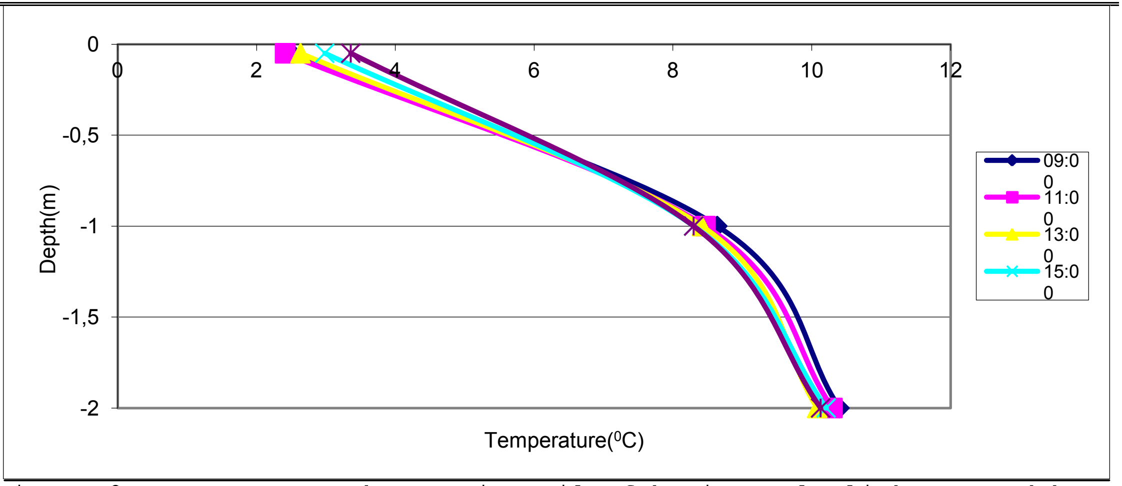

Figure 8. Temperature changes in soil of horizontal slinky ground heat exchanger hole
(Şekil 8. Yatay slinky toprak ısı değiştirgeci çukurundaki toprak sıcaklıklarının değişimi)

5. CONCLUSION AND SUGGESTIONS (SONUÇ VE ÖNERİLER)

A solar assisted horizontal slinky ground heat exchanger heat pump was put into operation in the established system. In this manner, the performance of the system was searched and energy analysis of the system was obtained.

Some important results that were obtained in this study were summarized as items below:

In the experiment as the maximum COP_{sys} and COP_{hp} values of the system was calculated respectively as 4.65 and 5.11, an average in a day was calculated respectively as 2.90 and 3.70.

The heat quantity taken from the ground changed between 3.08-4.01kW, an average in a day was calculated as 3.38kW.

According to total pipe length the heat taken from the ground changed between 20-26W/m, an average in a day was calculated as 22kW/m.

According to total hole length the heat taken from the ground changed between 220-286W/m, an average in a day was calculated as 241W/m.

The more the tempature of water-antifreeze mixture increased entering the evaporator, the higher COP_{sys} was obtained.

In those kind of system, use of solar and ground together will be a logical approach. A decrease in load on ground heat exchanger can be provided by operating the system with solar assisted and with this a decrease can also be provided in ground heat exchanger cost by reducing the length of ground heat exchanger.

As a result, it is clear that solar assisted ground source heat exchanger systems will be both economically and environmentally useful in our country. Because of their reducing potential in energy consumption and emmissins of greenhouse gases, it is certain that these systems will continuously draw attention.

REFERENCES (KAYNAKLAR)

1. Utlu, Z., (1999). The design of heat pump assisted by a solar system in the conditions of İzmir. MSc. Thesis. İzmir: Ege University Institute of Science.
2. Akpınar, A., Kömürcü, M.İ., and Filiz, M.H., (2008). Türkiye'nin enerji kaynakları ve çevre, sürdürülebilir kalkınma ve temiz

enerji kaynakları, VII. National Clean Energy Symposiums, UTES' 2008, İstanbul, 17-19 December, pp: 12-24.
3. Özgener, L., (2005). Exergoeconomic analysis of geothermal district heating systems. PhD. Thesis. İzmir: Ege University Institute of Science.
4. Tunç, M., Uysal, M., and Özmen, A., (1988). Exergy analysis of solar-assisted heat pump systems. Applied Energy, 29, pp: 1-16.
5. Esen, H., (2007). Investigation of seasonal behaviour of a vertical ground source heat pump used in residential air conditioning systems. PhD. Thesis. Elazığ: Fırat University Institute of Science.
6. Reyes, E.T., Nunez, M.P., and De G, J.C., (1998). Exergy analysis and optimization of a solar-assisted heat pump. Energy, 23, 4, pp: 337-344.
7. Piechowski, M., (1999). Heat and mass transfer model of a ground heat exchanger: theoretical development. International Journal of Energy Research, 23, pp: 571-88.
8. Ozgener, O. and Hepbasli, A., (2007). Modeling and performance evaluation of ground source (geothermal) heat pump systems. Energy and Buildings, 39, pp: 66–75. (doi:10.1016/j.enbuild.2006.04.019)
9. Esen, H., Inalli, M., Sengur, A., and Esen, M., (2008). Performance prediction of a ground-coupled heat pump system using artificial neural Networks. Expert Systems with Applications, 35, pp: 1940–1948. (doi:10.1016/j.eswa.2007.08.081)
10. Yang, W., Zhou, J., Xu, W., and Zhang, G., (2010). Current status of ground-source heat pumps in China. Energy Policy, 38, pp: 323–332.(doi:10.1016/j.enpol.2009.09.021)
11. Altuntop, N., (2005). Güneş enerjisi tesisatlarında antifriz olarak etilen ve propilen glikol kullanımının incelenmesi. Tesisat Mühendisliği Dergisi, 86, pp: 31-38.
12. National Rural Electric Cooperative Association, Oklahoma State University and International Ground Source Heat Pump Association, (1988). Closed-loop / ground-source heat pump systems: Installation guide, NRECA Research Project 86-1, Oklahoma State University, Stillwater, Oklahoma.
13. Florides, G. and Kalogirou, S., (2007). Ground heat exchangers-A review of systems, models and applications. Renewable Energy, 32, pp: 2461–2478.(doi:10.1016/j.renene.2006.12.014)
14. Doherty, P.S., Al-Huthaili, S., Riffat, S.B., and Abodahab, N., (2004). Ground source heat pump–description and preliminary results of the Eco House system. Applied Thermal Engineering, 24, pp: 2627–2641. (doi:10.1016/j.applthermaleng.2004.04.007)
15. 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. (doi:10.1016/j.applthermaleng.2010.07.008)
16. Özsolak, O., (2011). Investigation of using solar and ground source heat pump system for residential heating in Elazığ. PhD. Thesis. Elazığ: Fırat University Institute of Science.