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Experimental Performance Analysis of Ground Source Heat Pumps (GSHPs) in Taleghan-Iran

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ABSTRACT

Ground Source Heat Pumps (GSHP) have become one of the most indispensable cooling and heating systems in residential applications since they have higher energy efficiency compared to other conventional alternatives all around the world. In this study, a ground source heat pump system (GSHP) with the heat package unit model of GT018 FHP Manufacturing Co was installed in Taleghan city-Iran. The system set-up included polyethylene U-bend ground heat exchanger pipes, nine drilled wells, and the pipes buried in soil at 15 m depth and in the cooling season of 2013. The system was tested and its performance was reported. In accordance with the meteorological data, the values of humidity variations, air temperature, wells and water temperatures, relative humidity and the system power supply were measured continuously for three months. The results showed that the adoption of GSHP system created a stable room indoor temperature of 25°C to 28°C. Furthermore great energy savings happened in the process and the average COP of 4.76 was achieved for the system that shows a suitable design and installation process.

1. INTRODUCTION

Ground source heat pump systems are known as one of the most environment-friendly systems utilized in the world for the last decades. High initial investment costs limit the installation of these systems. It is undoubtedly acknowledged that the energy costs ascent and the obligation of decreasing greenhouse gases will increase the usage of these systems. Ground heat exchange system and its installation is the most important part of GSHPs costs.

In recent years, many researchers have studied the different aspects of GSHPs. Qing Gao et al. (2009) reviewed the progress of Underground Thermal Energy Storages (UTESs) companioning with GSHP worldwide, and surveyed the development of GSHP and the origination of UTESs. Meanwhile, the basic proposal for development in the future to supply a gap in the field of UTES in China was presented. Karabacak et al. (2011) installed a GSHP system with U-bend pipes in Denizli city –Turkey. They determined the performance coefficients of the heat pump and the system. They also measured the values of solar radiation, external temperature, relative humidity and wind speed and reported the results. Yu et al. (2010, 2011) designed and constructed a constant temperature and humidity air-conditioning system driven by ground source heat pumps in an archive building in China. They measured the rejected heat to the soil and evaluated the energy cost of GSHP and showed that the decrease range of the soil temperature in the middle of two boreholes would reduce with the increase of the distance between two boreholes and suggested an optimal distance between two boreholes in Shanghai. Benli (2011) designed and installed a horizontal closed loop GSHP system with a latent heat thermal storage tank located in Turkey. He showed that the utilization of GSHP-PCM is suitable for greenhouse heating in this district. Zhai and Yang (2011) constructed a GSHP system in Shanghai-China for two years. In their study, the operating cost of the GSHP system was compared to an air source heat pump system. They also analyzed the applications of GSHP systems corresponding to different climatic zones of China. Bansal et al. (2013) devised a new term for evaluating the deterioration in thermal performance of Earth Air Tunnel Heat Exchanger (EATHE) under transient operating conditions in India, experimentally and numerically. and obtained maximum air temperature drop. Pulat et al. (2009) evaluated the performance of a horizontal GSHP by considering various system parameters for winter climatic condition of Bursa, Turkey. They obtained preliminary numerical temperature distribution around GHE pipes and results were compared to conventional heating methods in the economic analysis. Aikins et al. (2012) analyzed the certified heat pump units in the Republic of Korea. They suggested revising the certification standard concerning underground circulation flow rate to save energy and reduce the installation costs of GSHP systems in the Republic of Korea. Michopoulos et al. (2013) installed a GSHP system in Northern Greece over an eight-year operation period. They estimated the performance of the system as well as the Seasonal Energy Efficiency Ratio and compared the results to a conventional heating and cooling system for the building. Yang (2013) investigated the performance characteristics of a vertical U-bend direct-expansion (DX) GSHP with buried copper piping and compared the results to the conventional GCHP (ground coupled heat pump) system in China. Kim et al. (2012) evaluated the performance, temperatures, the relative humidity and the COP of a closed vertical GSHP system installed in Korea. They proved that the ground temperature was almost constant below 10 m in depth. Zhu et al. (2012) compared the deterministic and the probabilistic methods for a GSHP in Pensacola, FL based on Monte Carlo simulation. They tried to find out the data uncertainties impacts on results of their analyses and certified that the GSHP option was more economic than a conventional single zone split system having heat pumps usage, but with a long payback time if incentives were not considered Kim et al. (2013) introduced a new method for verification of the actual operating performance of a GSHP system installed at the KIER site in Korea. They compared the actual performance with the manufacturer's data output including the EWT (entering water temperature), LWT (leaving water temperature), capacity, flow rate, power, and COP (coefficient of performance), based on the ISO standards. Kharseh et al. (2011) calculated the heating and cooling of a reference building for different global warming scenarios in different climates and compared the prime energy required to drive the GSHP system for each scenario and two configurations of ground heat exchangers. Madani et al. (2013) studied and simulated three control methods for a GSHP system based on the climatic conditions in one year. Also, they compared the controlled temperature and the saved energy of these methods with each other.

1-TPPH-Thermal Power Plant Holding

Although many researches are available about GSHP, a few researches have been done in Iran. In this paper, to develop the usage of GSHP for the sake of residential applications in Iran, a vertical closed loop GSHP system is applied, and the installation process in Taleghan, Alborz, Iran is briefly explained. Utilizing a control system containing a PC, a data logger system, and different sensors installed in different parts of the system, the inlet and outlet temperatures of the pipes, the room temperature, the wells temperatures, the system power and the inside and outside humidity were studied and recorded, experimentally for 3 months. Also, the system COP for the evaluation of the system efficiency was measured and presented.

2. SYSTEM DESCRIPTIONS

Generally the GSHP contains three pipe loops. These loops are presented in Fig. 1 for the heating mode. The first loop is the distribution loop that gets the energy from the refrigerant loop and transfers it to the temperature controlled space (building or room). The second loop is a refrigerant loop and is a sealed loop to transfer energy from a point to another point in the circuit and contains compressor and expansion value. In the heating mode the first loop works as an evaporator and the third loop works as a condenser for the refrigerant loop. The third loop is a ground loop which can be a closed or an open loop. Usually, a closed loop contains water and antifreeze solution which is circulated under the ground absorbing heat from the ground and transferring it to the refrigerant loop in heating mode in winter. Sometimes an extra loop will be added to the original loops to supply domestic hot water.

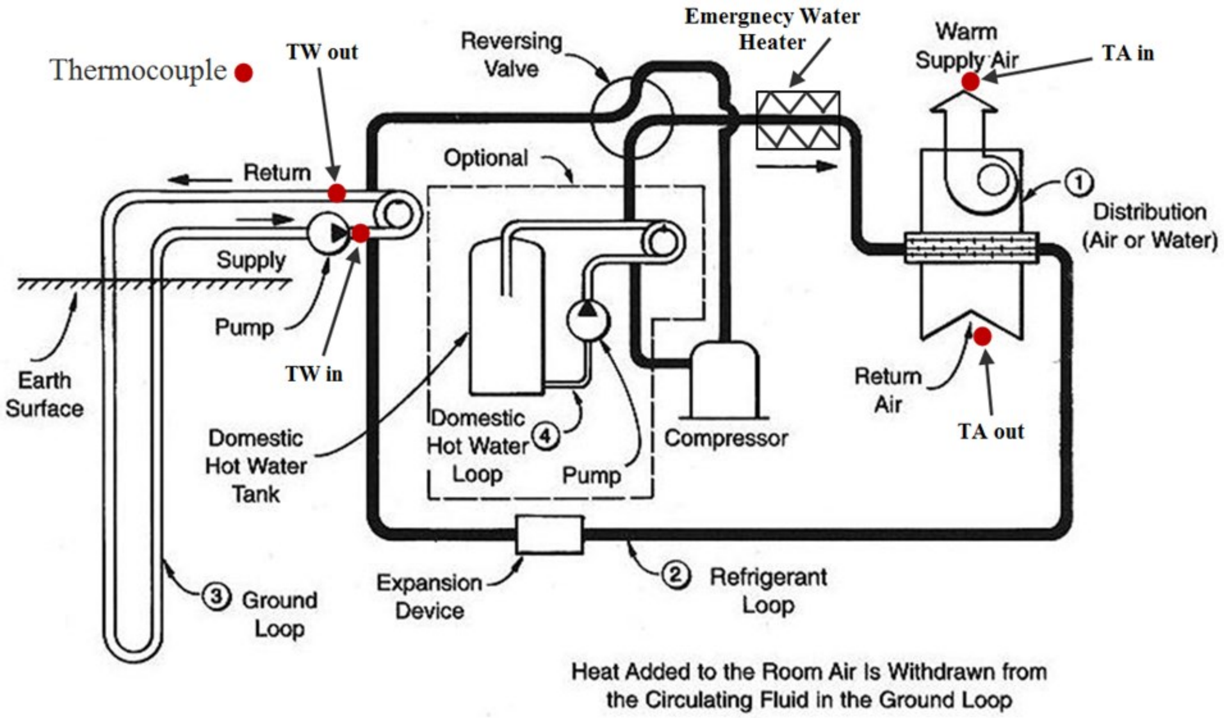

Figure 1: Heat pump loops and operation in heating mode.

In this study, a vertical closed loop GSHP system was installed in Taleghan, Alborz, Iran. The city is famous for its mild sunny summers and cold winters. Its geographical coordinate contains the latitude of 37.2° N and the longitude of 49.24° E. The GSHP is a water-air type which uses water for the ground loop and air for the distribution loop.

The installed GSHP was applied for a 25 m^2 (5m×5m) room as the understudy heating environment. The experimental set up consisted of underground heat exchangers, circulation water pump, circulation water tank, emergency water heater for extreme cold air, compressor, water tank, heating channels that distributed the warm air in greenhouse and controlling system (consisting of a PC, data logger and sensors). Furthermore, GT018 of FHP Manufacturing Co with R-22 (Chlorodifluoromethane—CHClF2) as its refrigerant was used as the heat pump packaged unit. (Fig. 1).

2.1 Pipeline Installation

In order to set up the ground heat exchanger, U-shaped polyethylene pipes (60 mm in internal diameter) buried at 9 wells with the depth of 15 m and the diameter of 80 cm. The distance between each U-shaped pipe was 40 cm to minimize the interference between them. Finally, the remaining parts were installed and the pipes were connected into the pump circulator. Fig. 2 shows the drilled wells and schematic of the installed GSHP pipelines in addition of the heat pump and controlling devices.

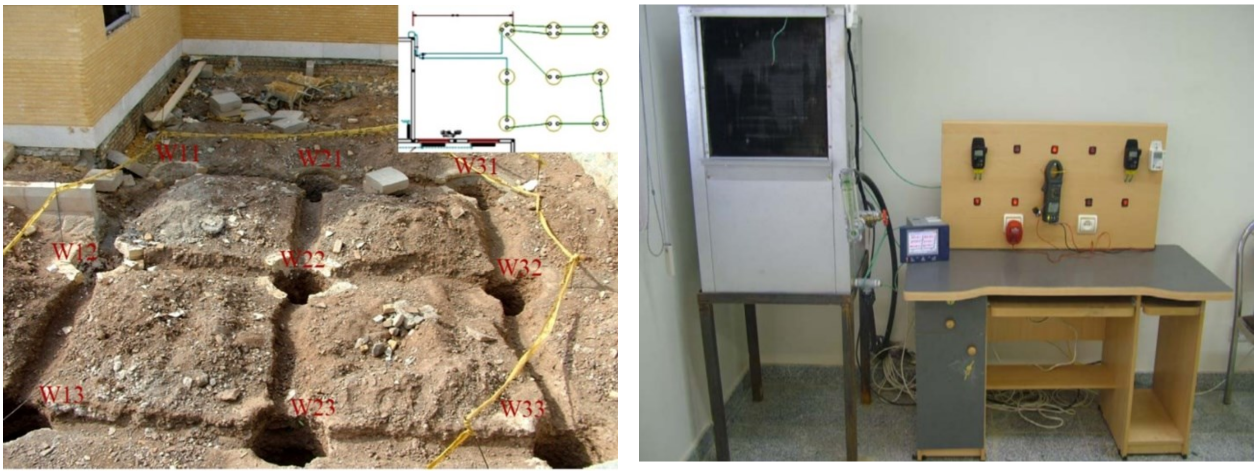

Figure 2: GSHP system which is installed in Taleghan, Iran. Drilled wells and schematic of the installed pipelines (left) and Heat Pump contorting devices and sensors (right).

2.1. Measurements

Considering the above installed GSHP system, the following data was recorded regularly using a 30 min time interval for 3 months:

- The temperature of the water entering and leaving the underground heat exchanger (GHE) using copper-constant thermocouples which were mounted on the unit fluid inlet and outlet lines.
- Measurement of the entering and leaving air temperature.
- Measurement of the 9 wells average temperature.
- Measurement of indoor air temperatures and the humidity using multi-channel digital thermometer.
- Measurement of outdoor air temperatures and the humidity in the southern side by using multi-channel digital thermometer.
- Measurement of the electrical power supply by a data logger.

3. RESULTS AND DISCUSSION

3.1 Recorded Temperature Variations

The recorded temperature data from the sensing units is indicated in Fig. 2. In Fig. 3, Twin is the inlet water temperature from the wells into the heat pump package unit, Twout is the outlet water temperature from the heat pump package unit into the wells, TAin presents the entering air temperature from the heat pump package unit into the designed room space, TAout is the return air temperature to the heat pump package unit from the room, Troom shows the room temperature and Tout is the outside temperature.

As it can be seen in Fig. 3, Tout as an uncontrollable and unstable value and varies during the day and night and has different values ranging from 2 to 15 ˚C. Troom begins from a low value of 7˚C (it means that the room was cool at the beginning of the test and warmed when the GSHP started working). Troom reached to a stable rate ranging from 26 to 28˚C meaning that a suitable range of temperature was achieved. Fig. 3, also illustrates that TAin ranges closely to Troom. It means that the return air temperature is approximately equal to the room temperature because there is only one controlled temperature room and the return air supplies from the room air. During the test, the average temperature of Tout was recorded at 10°C and Tin was 27°C at the same time. The difference means that the GSHP has made a 17°C increase in the room temperature in comparison to Tout. Twout indicates the water temperature that leaved the room and went into the pipelines inside the wells. Twout had a lower range compared to Twin as the room entering water temperature. The difference between the average value of Twout and Twin is approximately 3.5˚C (the difference between the underground and ground temperature). Also, Twout has a low rate of changes compared to the Tout variation. This can be explained through the high specific heat capacity of water. Besides, an unstable variation can generally be seen in Tout, whereas Troom reaches a stable rate (between 25-30°C as favorable temperature for human living. It means that the extracted heat has been correctly transferred into the room.

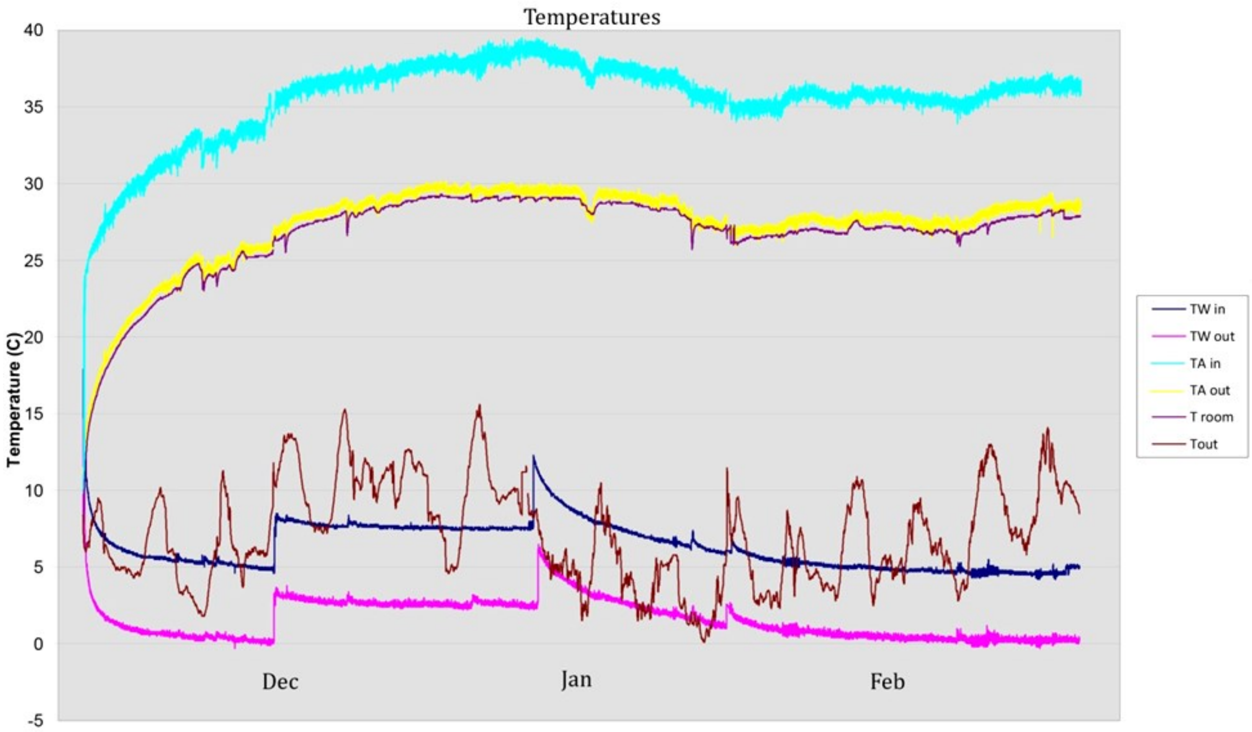

Figure 3: Temperature measurements.

3.2 Well Temperatures

The well temperatures were also measured. Fig. 4 demonstrates the average wels temperatures during the test period. Temperature measurement sensors were installed at three different heights of each well that made the wells average temperatures recordable.

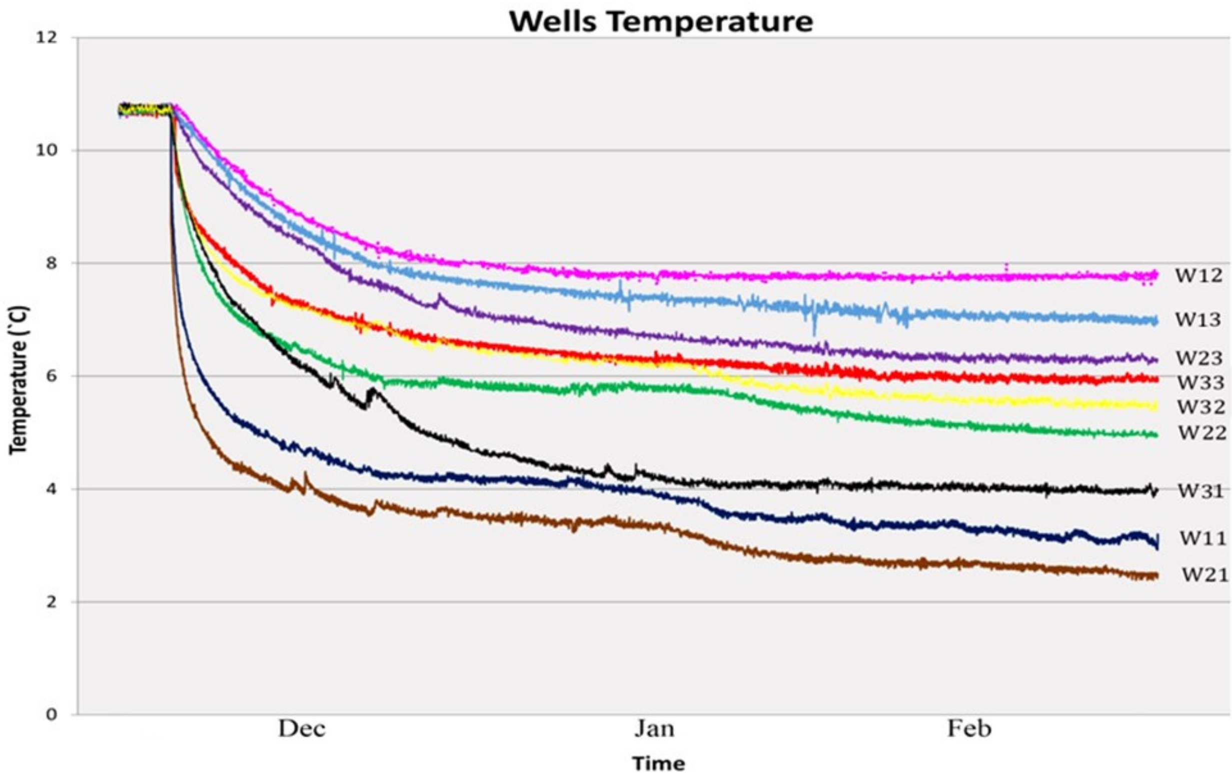

Figure 4: Well temperatures.

Considering the water cycle in the wells, the circulating water enters the wells (here we mention the phrase "well" instead of "pipeline inside the well" for summarizing) with a low temperature and absorbs the heat from the ground which can be considered as a higher energy source. This phenomenon increases the temperature of the water. It means that, the first well should experience a temperature change sooner and more steeply compared to the other wells. Well 21 was the first well in which the water cycle was started, therefore, the curve has dropped faster than the other wells. However, due to the increase of water temperature, the circulating fluid would flow to the next well with a higher rate. Thus, the next curve should be at a higher level in comparison to the previous well curve. The trend can be clearly seen in Fig. 4.

3.3 Room Humidity Variations

The room humidity is shown in Fig. 5. After around 15 days, the room humidity decreased from 60% to less than 30%. However, it eventually reaches a fluctuation between 20 to 30%. Based on the fluctuation rate, the results show that humidity was also achieved to a suitable range for a human being.

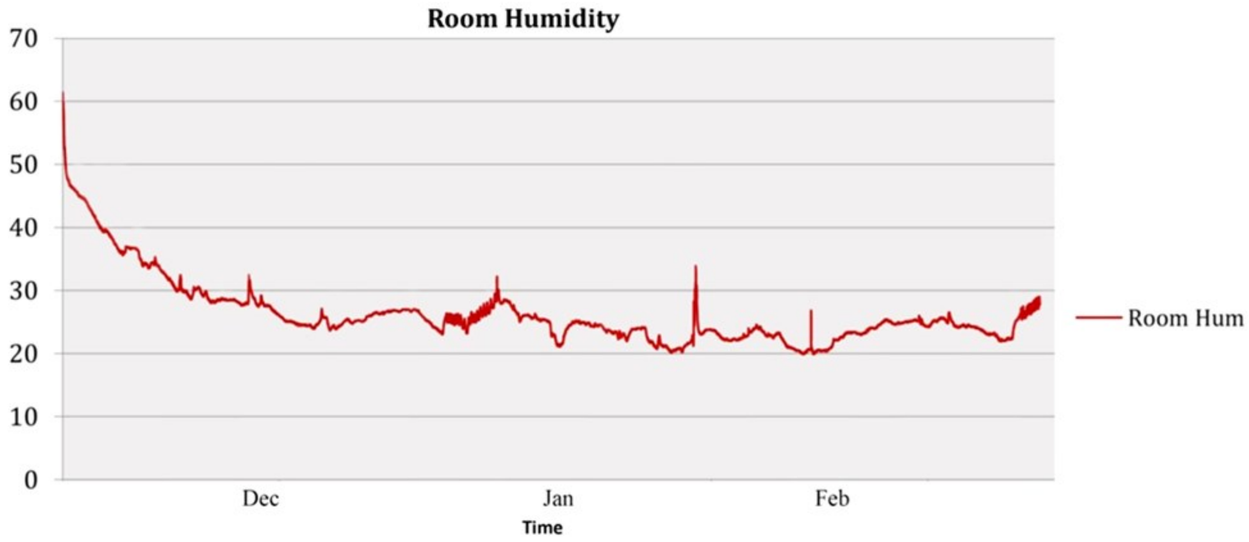

Figure 5: Room humidity variations.

3.4 Energy Efficiency Evaluation

The power supplied for the system was also recorded and the results are shown in Fig. 6. As can be seen in Fig. 6, the reported values were similarly recorded as the previous items. By neglecting the small rates of changes, the system has consumed a constant power value.

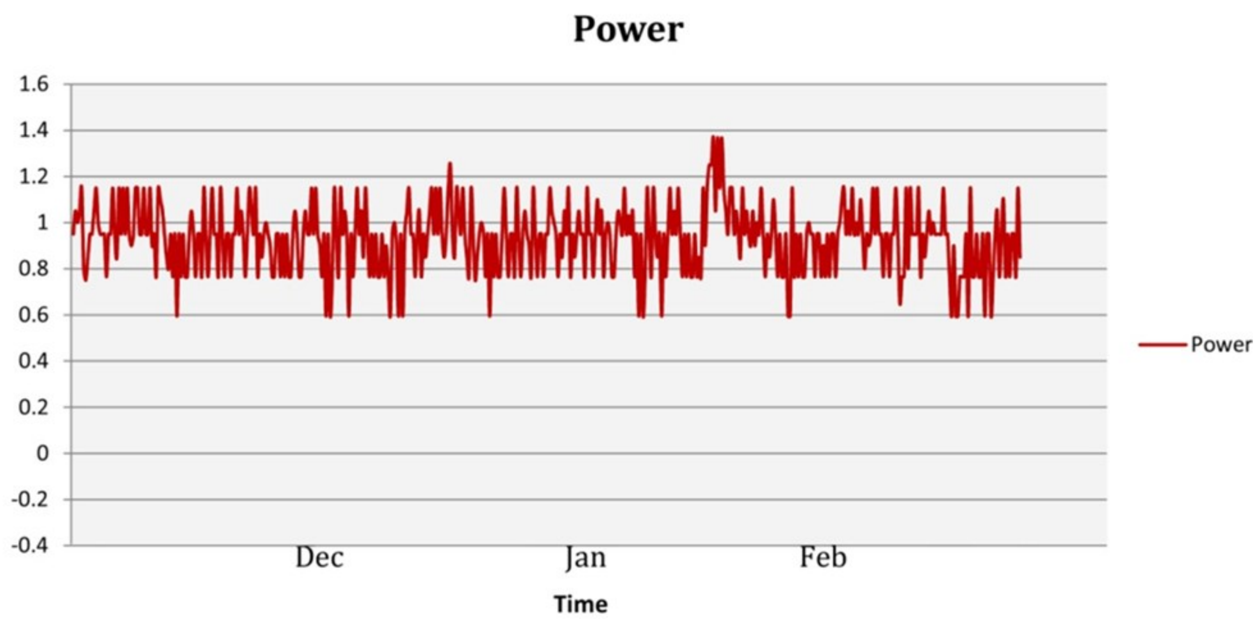

Figure 6: Power supply variations diagram (in kW).

Geothermal heat pumps performance can be measured by their efficiency, called Coefficient of Performance (COP) which strongly depends on the quality of GSHPs installation and design: from as low as 2 for air source heat pumps in unfavorable conditions, up to 4 for an unassisted GSHP, and up to 7.8 for well-designed GSHP system (Carnot cycle).

COP can be derived from recorded results and the related equations. The equation used for evaluating the COP in this paper is as below

COP = power output / power input (1)

Considering the inlet power of GT018 GSHP as 1.2 KW (from the heat pump datasheet), and the average value of 14000 recorded data of the power supplied in Fig. 6, the output power will be:

Power output = power inlet –power supplied (2)

Upon applying Eq. (1) and Eq. (2), COP can be calculated and presented. Fig. 7 shows the COP of the installed GSHP.

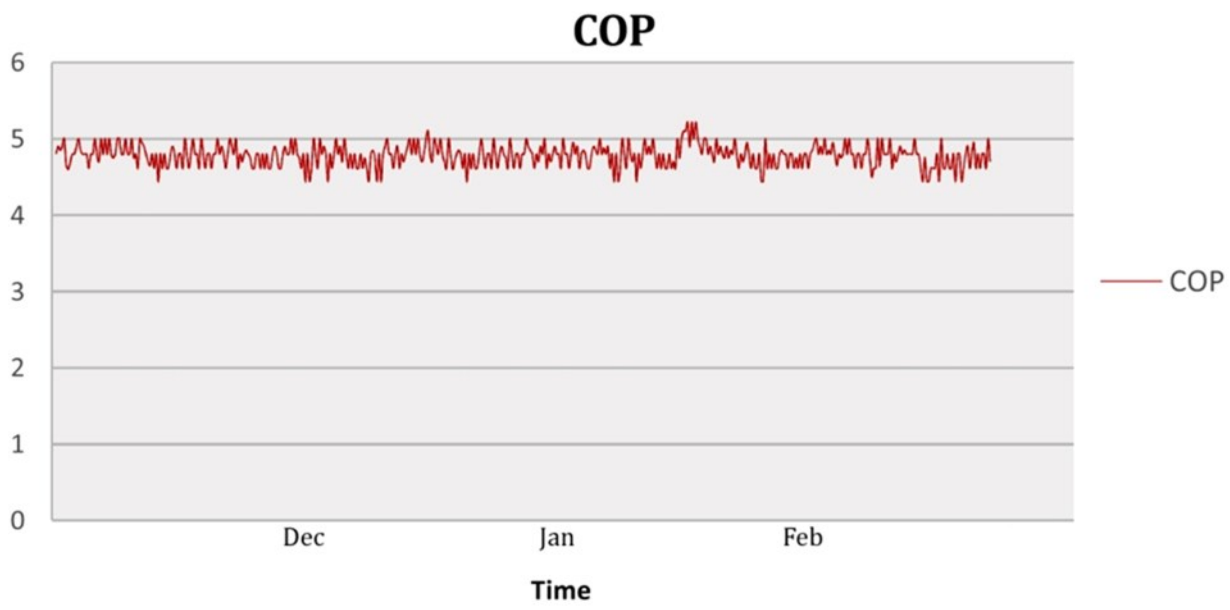

Figure 7: COP of the installed GSHP.

Fig.7 shows that COP has an average value of 4.76 (with the maximum value of 5.71 and minimum of 4.13). The average value shows that the current GSHP has been installed and performed well with an acceptable efficiency which noticeably reveals that GSHPs are one of the best and affordable heating/cooling systems.

4. CONCLUSION

A vertical closed loop GSHP was installed in a cold season in Taleghan, Alborz, Iran. For this purpose, 9 wells with the depth of 15 m and the diameter of 80 cm were drilled and U-shaped polyethylene buried in the wells. Water, as the system heat exchanger fluid, was circulated through the pipelines in the wells. The system was applied to heat up a 25 m^2 test space. In this study, the inlet and outlet water temperature from/to the wells, the entering and leaving air temperature from/to the heat pump package unit, the room temperature and humidity, and also the outside temperature were recorded permanently for 3 months.

Water temperature leaving the heating package unit showed a lower rate of changes compared to the outside temperature variation which was explained due to the high specific heat capacity of water.

The results showed that the uncontrolled outside temperature with the range of 2-15°C was reached into a controllable and steady room temperature of 26-28°C which is a demandable temperature for living. For this 18°C approximate increase of the room temperature, the system power supply was also reported.

The average temperatures of all 9 drilled wells were also recorded and reported. According to the results, the water temperature increased as it circulated through the wells. The difference of input and output temperatures of the nine wells was 4.4°C averagely. Besides, the fluctuation of the room humidity was also recorded. In the diagram, the room humidity decreased from 60% to less than 30% (between 20 to 30%) within 15 days. Moreover, considering the power supply results, the COP of the system was calculated and the average of 4.76 was achieved. Achieving the average COP of higher than 4 for the current GSHP system showed that an indispensable design and installation was performed which means that the system has a positive effect on the energy saving.

REFERENCES

A. Michopoulos, T. Zachariadis, N. Kyriakis. (2013). Operation characteristics and experience of a ground source heat pump system with a vertical ground heat exchanger, Energy 51, 349-357.

ErhanPulat, SalihCoskun, KursatUnlu, NurettinYamankaradeniz. (200). Experimental study of horizontal ground source heat pump performance for mild climate in Turkey, Energy 34, 1284–1295.

Euiyoung Kim, Jaekeun Lee, Youngman Jeong, Yujin Hwang, Sangheon Lee, Naehyun Park. (2012). Performance evaluation under the actual operating condition of a vertical ground source heat pump system in a school building, Energy and Buildings 50, 1–6.

HatefMadani, Joachim Claesson, Per Lundqvist. (2013), A descriptive and comparative analysis of three common control techniques for an on/off controlled Ground Source Heat Pump (GSHP) system, Energy and Buildings 65, 1-9.

HuseyinBenli, (2011). Energetic performance analysis of a ground-source heat pump system with latent heat storage for a greenhouse heating, Energy Conversion and Management 52, 581–589.

Jiyoung Kim, JeaChul Jang, EunChul Kang, Ki Chang Chang, EuyJoon Lee, Yongchan Kim. (2013). Verification study of a GSHP system Manufacturer data based modeling, Renewable Energy 54, 55-62.

Kojo Atta Aikins, Jong Min Choi, (2012). Current status of the performance of GSHP (ground source heat pump) units in the Republic of Korea, Energy 47.77-82.

MohamadKharseh, LobnaAltorkmany, Bo Nordell. (2011), Global warming's impact on the performance of GSHP, Renewable Energy 36, 1485-1491.

Qing Gao, Ming Li, Ming Yu, Jeffrey D. Spitler, Y.Y., Yan, (2009). Review of development from GSHP to UTES in China and other countries, Renewable and Sustainable Energy Reviews 13, 1383–1394.

RasimKarabacak, SengulGuvenAcar, HalilKumsar, Ali Gokgoz, Mustafa Kaya, YahyaTulek. (2011). Experimental investigation of the cooling performance of a ground source heat pump system in Denizli, Turkey, International Journal of Refrigeration 34, 454-465.

VikasBansal, RohitMisra, Ghanshyam Das Agarwal, JyotirmayMathur, (2013). Derating Factor new concept for evaluating thermal performance of earth air tunnel heat exchanger: A transient CFD analysis", Applied Energy 102, 418–426.

Wei Yang. (2013). Experimental performance analysis of a direct-expansion ground source heat pump in Xiangtan, China, Energy 59, 334-339.

X.Q. Zhai, Y. Yang, (2011). Experience on the application of a ground source heat pump system in an archives building, Energy and Buildings 43, 3263–3270.

X. Yu, X.Q. Zhai, R.Z. Wang. (2010). Design and performance of a constant temperature and humidity air-conditioning system driven by ground source heat pumps in winter, Energy Conversion and Management 51, 2162–2168.

X. Yu, R.Z. Wang, X.Q. Zhai, (2011). Year round experimental study on a constant temperature and humidity air-conditioning system driven by ground source heat pump, Energy 36, 1309-1318.

Yimin Zhu, Yong Tao, RambodRayegan. (2012). A comparison of deterministic and probabilistic life cycle cost analyses of ground source heat pump (GSHP) applications in hot and humid climate, Energy and Buildings 55, 312–321.