Geothermal energy for heating and cooling in agricultural greenhouses

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Abstract: Geothermal source is a clean technology that is able to use the ground as a thermal sink or heat source. It is one of the energy resources in Iran that can be used with long-term investment. This study provided a new idea for using this energy in heating and cooling of buildings. Two wells were used for heating and cooling with constant temperature of the water in depth of 12 m underground (this temperature is approximately equal to the annual temperature of environment during the year). Water flowed in six speeds: 10, 11.5, 13, 16, 29 and 34 lit min^{-1} using a hydraulic pump from first well, and after passing through radiator, discharged to other well. The outdoor temperature was 9°C, 40°C and 15.5°C -16°C for heating, cooling and well water, respectively. An axial fan was used to passing the air in six speeds: 0.5, 1.1, 2.2, 3.3, 4.4 and 7.4 m s^{-1} through the radiator. The results showed that the use of water from this well could reduce the required power about 25% for heating and could increase the air temperature from 9°C to 25°C. Also, this system could reduce the required power from 38% to 60% for cooling and could decrease the air temperature from 40°C to 25°C.

Keywords: air speed, geothermal source, net energy ratio

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1 Introduction

Considering the importance of energy in development and developing countries, the energy crisis and completion of non-renewable resources, numerous studies and improvements on using of renewable resources in developing and developed countries have been done (Thorsteinsson, 2008; Matek, 2013). Many researches have been conducted in Iran about this fields and almost are focused on water, solar and wind energies. Optimization of fossil fuel energies consumption and using of renewable energy forms are an environmental protection style and a way to exit from energy crisis. Geothermal energy is one of the important renewable energy resources in Iran and other countries. The heat of the Earth is considered infinite; its use is only limited by technology and the associated costs, but the potential is there to provide enough energy to meet the power needs of humankind many times over. Geothermal energy can be used directly or indirectly for industrial processes, electricity generation, cooling tower, agriculture (such as greenhouses), aquaculture and balneology (crop drying, food, timber and industrial process drying), snow melting, heating buildings and hot water for bathing (Lund, 2010; Kagel et al., 2007; Bertani, 2009; Taki et al., 2018). Reduction on cooling and heating electrical energy consumption, prevention of water contamination, and also incredibly easy repair and maintenance are the advantages of geothermal energy (Thain et al., 2006). Geothermal energy can also reduce the production of CO_2 emissions and air pollution on a large scale (Thorsteinsson, 2008) and has economic advantage because of reduced fuel consumption (Bertani, 2012). Recently, geothermal energy has been used in the power generation. For example, the installation power capacity

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in 2010 was about 10715 MW and will be reached to about 11765 MW in 2013 (Ragnarsson, 2005). Also, in 2013, approximately 70 counties in the world, were active in the field of geothermal and predicted the number of countries reached to 76 in 2014 (Ragnarsson, 2005). In Iran, five stations of geothermal pump have installed in Meshkin Shahr, Taleghan, Rasht, Ahvaz and Bandar Abbas and the results showed that this system could decrease more about 50% to 70% of total electric power consumption for cooling (Eslami-Nejad and Bernier, 2011). On the other hand, many researches presented the results of using geothermal sources alone and with other thermal energy systems. Anifantis et al. (2017) presented the results of analyzing the performance of a stand-alone renewable energy system for greenhouse heating on a winter day. The systems consisted of photovoltaic panels connected to an electrolyzer which produced hydrogen by electrolysis and then stored it in a pressure tank during daylight hours. During the night, thanks to a fuel cell, the hydrogen was converted into electricity in order to feed a ground source geothermal heat pump to heat a tunnel greenhouse. The procedure for estimating hourly solar radiation, hydrogen production and consumption for short-term energy storage on a partly cloudy day was also evaluated. The solar energy usability concept, the capacity of energy storage systems and the thermal energy load defined the effective energy management of the system. The overall system efficiency from daylight hours at night, was about 11%. Many researchers use geothermal heat pumps with other thermal systems. Kjellson (2009) proposed a model in which the heated fluid from the collector would be directed to the boreholes after passing through the evaporator of the heat pump. Recharging of boreholes resulted in higher temperature of the soil and lower length of tubes, and heat passing through the evaporator would increase Coefficient of Performance (COP) of the heat pump and decrease the electricity usage of the compressor and also operation periods. Trillat-Berdal et al. (2007) presented different combinations of solar collectors and geothermal heat pump and chose the best model from economical and technical point of view by numerical simulations using TRNSYS software. Using the combination of solar collectors and geothermal heat pumps helps to reduce operating costs in comparison with conventional systems using fossil fuels. Zhao et al. (2009) presented a mathematical model considering in situ resulted for a combined thermal solar collector geothermal heat pump system and after solving the equation considering economical and technical constraints, optimized length of boreholes and total area of collectors were presented. Wang et al. (2008) used 3D dynamic and numerical simulation of the ground and ground heat exchangers in a combined solar collector-geothermal heat pump system and optimized model after considering temperature change and heat recovery of the ground. The results indicated that heat recovery of the ground could increase reliability of the system and also help to improve system economics. The temperature of the ground increased 3°C after one year working of the system and caused long term operation of the combined system. Zhai et al. (2011) compared different systems installed with geothermal heat pumps in a combined system. The results showed that COP for different combinations could be between 3 and 5 and the system combining geothermal heat pump with thermal solar collectors was mostly suitable for heating. Chen et al. (2011) studied a combined geothermal heat pump solar collector model which is used with a heat storage system to supply heat load and domestic hot water required. Results showed that mean annual efficiency for environmental heating increased up to 26% because solar collectors can increase heat stored in the ground and environmental heating was supplied using this energy. Eslami-Nejad and Bernier (2011) studied constant heat transfer in single u-shaped exchangers with two independent circuits which one of them was connected to the heat pump for heating and the others to solar collectors for heat recovery. The results showed that heat recovery of the ground decreased heat extraction from the boreholes, borehole length up to 18% and energy consumed in heat pump up to 3.5% in comparison with system without heat recovery. Using system with two independent circuits could also decrease borehole length up to 33% and energy consumption of the heat pump up to 6.5% in comparison with a single circuit system.

1.1 Scope, innovations and structure

Based on the above literatures, the aims of this research are using geothermal energy in rural areas with annual water temperature of irrigation wells in rural and industrial areas such as poultry farms. The use of constant temperature of water in wells for heating at winter and cooling at summer seasons and other gains such as no required for drilling wells in most of industrials, greenhouses, animal husbandries and agricultural areas, no required of closed piping systems, heating and cooling with one system, ability of heating and cooling of industrial, greenhouse and animal husbandry farms by direct using of main system exhaust air are very necessary for Iran. So, this research was conducted on the evaluation of well water flow rate and air speed (velocity) for cooling and heating and determination of reduction in required power (RRP) using two wells. Because there is not any similar study in this field in this area, many factors such as well water flow rate required and facilities were evaluated. Section 2 explained the local selection mathematical methods used in this study. In section 3, the results of this research were explained and finally in section 4 total conclusion and some recommendations were examined.

2 Materials and methods

In present research, in order to study on the capability of using subsurface water temperature, a water well of a workstation in Borujerd city, Iran (1670 m height from sea level and average of annual temperature 14.5°C in 33.85796N, 48.745677E latitude and longitude, respectively), was used. The water of well, was pumped to 100 liters volume tank and then passed by different flow rates trough radiators and finally discharged into the second well. For heating system, the outdoor air blown by fan at different velocities to radiators and after getting heat (Heat Exchange) exited from radiators. According to the summer air temperature in Borujerd city (40°C), for cooling system, the air at 40°C (generated by heaters) blown to the radiators and then the cold air was exited. A schematic of different parts of designed system and components arrangement has been shown in Figure 1.

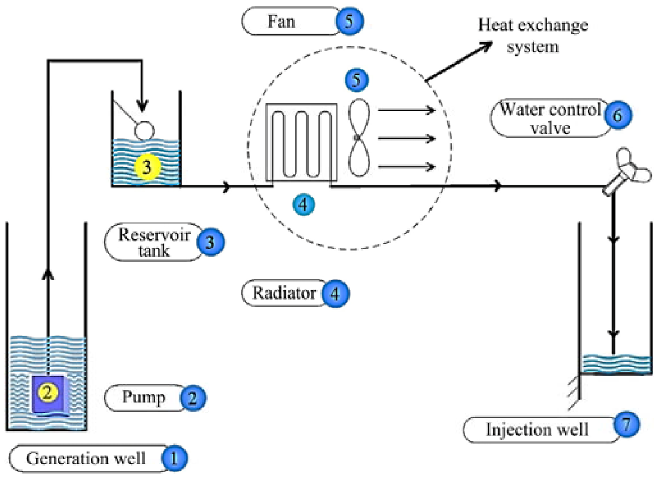


Figure 1 Schematic of designed system for heating and cooling

The continues measurements within the year showed that subsurface water temperature (in 10-12 m depth) was approximately constant (about 16°C) and rainfalls could not make changes on this value even by 1°C. So, the authors decided to use this huge energy resource in Silakhor plain in order to heating and cooling operations. An old well in workshop by 10 m distance from first well (generation well) was used as discharge well (injection well). The temperature of water, was tested by 2 hours pumping water from generation well and observed 16°C constant and then all the required systems were installed on the wells.

A floating 2.2 kW electro pump with 220 V internal voltage, 50 Hz frequency, 1500 rpm rotational speed and 200 lit min^{-1} flow rate (Tavan Tak brand) was used to pumping required water. Then the water, was pumped into a volume tank (100 lit) by a polyethylene tube (2 inch diameter). The tank was insulated by glass wool and had a float controller for maintaining constant level of water. The reserved water, was transferred to a radiator that coupled to a fan horizontally. Radiator had 35×60 cm wind age area with 38 number of horizontal aluminum pipes by cross section area of 25×1 mm, manufactured by Kousesh Radiator Co. The used fan had 40 cm diameter, 75 W electromotor, 220 V input voltage and 1500 rpm rotational speed manufactured by Demanded Co. Voltmeter and ammeter (model Hioki, 600±0.0001 V and 1000±0.001 A) was used to measure the fan and electro pump power consumption. After each experiment replications, water temperature before and after radiator and also air temperature before and after of blowing on radiator vanes were recorded by four thermometers. The output radiator water before discharging to second well (injection well) was controlled to prepare defined flow rates using an adjustable valve. Also, water flow through the radiators was measured by two flow meters model 10 GPM with flow rate of 50±1 lit min^{-1} (Tarahan Tasfiyeh brand). Air speed was measured by air speed meter model Terminator-TAM-618 and air mass flow was calculated by measuring the cross section of air tunnel and air density that extracted from thermodynamic tables.

2.1 Data recording

Data were recorded for heating treatment after system installation in a closed environment by temperature at 9°C, moisture content of 80%, pressure at 620.87 mm Hg and approximately without effective wind, with 2 min time intervals between treatments and also two min for replications intervals. In order to attain identical temperature conditions, the tests were done between 6 AM and 9 AM in the morning. Also, a gasoline burner stove was used for achieving 40°C of environment temperature (average temperature of Borujerd city in July and August between 10 AM to 16 AM) for recording data in cooling treatment part of test. The advantages of using an inverter and three-phase electro pump were safety electro pump start and continuously flow rate control with high precision. For this purpose, a pretest had been done for electric power saving and minimization by suction force of discharged water into injection well using water pour height at 7 m depth. The results showed that 12% required power was saved by reducing the current from 11.1 to 9.8 A. Because no research has been done before in this subject, the water flow rates and test velocities have been chosen empirically regarding to water flow rate and air speed in cooling systems of study region. Also, for cooling treatment, water was transferred to the other construction (15 m away from heating treatment location that cause to reduce the water flow rate for cooling operation). The water flow rates and air speed test levels, temperature and humidity of environment, water temperature for heating and cooling and power consumption of fans and electro motors in considered velocities and water flow rates were examined.

2.2 Systems evaluation

In order to evaluate the system, the power given to the system (heat transfer in heating system) or received power by air (heat transfer in cooling system) or P_{air}, the lost power (heat transfer from water to air in heating process) or taken power (heat transfer from air to water in cooling process) by water or P_w, fans power in different speeds (P_f), electro pump power (P_e), system heating efficiency (η_{sys}), required heating or cooling power for achieve to desired temperature (25°C) (P_{com}), the percent of RRP (which is the ratio of net power received by air to power required for reach to the desired temperature in percent) and net energy ratio or net energy efficiency μ (that explained as ratio of net received power by air in heating system (heat power) or net lost power in cooling system to consumed power or given power to the system (fans and electro pump power) were described and calculated by Equations 1-6. The experimental treatments and their related parameters were listed in Table 1.

Table 1 Treatments and their related parameters

System type	Air speed (m s^{-1})	Air flow rate (m^3 hr^{-1})	Fan consumed power (W)	Water flow rate (lit min^{-1})	Electro pump consumed power (W)	Environment temperature (°C)	Water temperature (°C)	Environment humidity (%)
Heating	0.5	226	19					
	1.1	498	41					
	2.2	995	52	16	175			
	3.3	1493	65	29	330	9	16	80
	4.4	1991	78	34	370			
	4.7	2126	90					
Cooling	3.3	1493	65	10	110			
	4.4	1991	78	11.5	130	40	15.5	80
	4.7	2126	90	13	140			

The power (kW) taken or given from system by air (P_w) for changing the temperature from T_1 to T_2 was calculated by Equation (1) (Ayensu, 1997; Duffie and Beekman, 2013):

$$P_{air} = \dot{m}_a (h_{a2} - h_{a1}) \qquad (1)$$

where, m_a was mass flow rate of air (kg s^{-1}); h_{a1} and h_{a2} were air enthalpy extracted from Psychrometric chart (kJ kg^{-1}) at T_1 and T_2 respectively.

The power (kW) taken or given to system by water (P_w) in order to changing the temperature from T_1 to T_2 was calculated by Equation (2) (Condori and Saravia, 2003):

$$P_w = \dot{m}_w (h_{w2} - h_{w1}) \qquad (2)$$

That m_w was mass flow rate of water (kg s^{-1}), hw_1 and hw_2 were water enthalpy that derived from thermodynamic tables (kJ kg^{-1}) at T_1 and T_2 temperatures, respectively (Sonntag et al., 1998).

Thermal efficiency of system was determined by the ratio of useful thermal power obtained from system to total input thermal power to the system in percentage and was calculated by Equation (3) (Guo et al., 2017):

$$\eta_{sys} = \frac{P_{air}}{P_w} \times 100 \qquad (3)$$

The required power for achieve to the comfort temperature (25°C) (P_{com}) was calculated as Equation 4 (Guo et al., 2017):

$$P_{com} = \dot{m}_a (h_{a2} - 42.91) \qquad (4)$$

where, 42.91 (kJ kg^{-1}) was air enthalpy at 25°C temperature and derived from psychometric charts. The air humidity was reduced from 80% to 28.98% at 25°C temperature.

The percentage of energy required is a percentage of the energy required that supplied by the system (energy received from the air), but in return, some energy is consumed for the pumped water and the fan, which reduces the energy received. The RRP was calculated by Equation (5):

$$RRP = \frac{P_{air} - P_f - P_e}{P_{com}} \times 100 \qquad (5)$$

Net energy ratio indicates the ratio of net received energy to total consumed energy and is a suitable parameter for system and named as net efficiency ratio or net energy efficiency in some references:

$$\mu = \frac{P_{air} - (P_f + P_e)}{P_f + P_e} \qquad (6)$$

Data were entered into Excel spread sheets and analyzed. Then their relevant charts were drawn and best air speed and water flow rates were determined for both systems of heating and cooling.

3 Results and discussion

3.1 Heating system

Figure 2 (a and b) showed the outlet water and air temperatures (T_{wo}) and (T_{ao}) of system at different water and air flow rates in heating system. As it can show, there was no changes in T_{ao} at 29 and 34 lit min^{-1} of water flow rates and it showed the exorbitance of these flow rates for increasing in air temperature. Also, the excess water volume caused no significant changes in air temperature. For each air flow rate, T_{ao} increased with increasing water flow rate from 16 to 29 lit min^{-1} and this increasing temperature decreased at high air flow rate (Figure 2(a)). The reason is that by increasing the water flow rate, there is not enough time for water heat exchanging, and the difference between input and output water temperature is reduced (Figure 2(b)). Also, according to Figure 2, with reducing the air flow rate, air temperature increased. The reason probably is that with decreasing the air flow rate, air molecules have enough time to absorb the heat from the radiator and on the other hand, air molecules have not enough time for heat exchanging in high air flow rate. It should be noted that the input water and air temperatures were 16°C and 9°C, respectively.

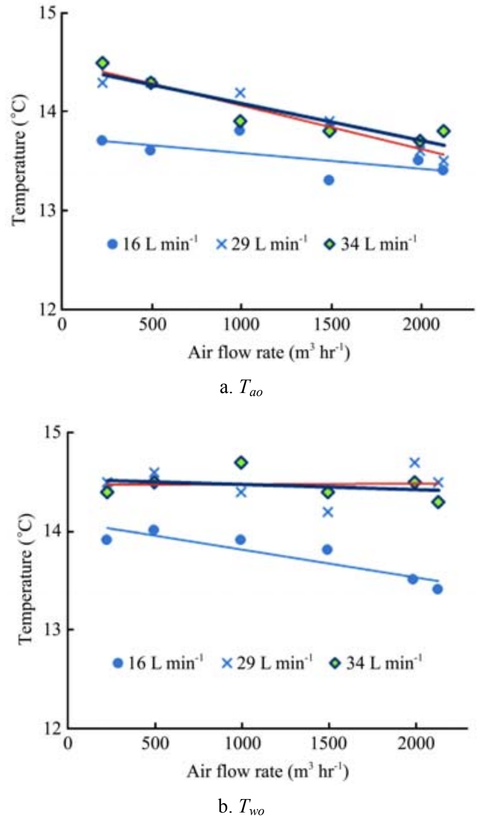


Figure 2 Air and water output temperature changes at different water and air flow rates

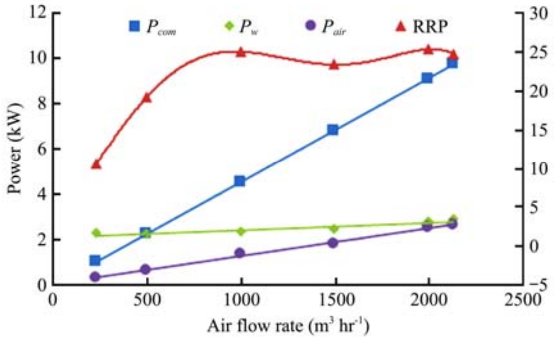
According to Figure 2(b), in all air flow rates, no significant difference was observed in the output water temperatures (29 and 34 lit min^{-1} water flow rate). The reason may be that there is not enough heat exchange by the radiator in the high water flow rate. In each air flow rate, output water temperature was lowest because of having enough time for heat exchanging at the 16 lit min^{-1} water flow rate. Also, at each water flow rates, with increasing air flow rate, the output water temperature decreased and this decrease at the 16 lit min^{-1} water flow rate was more than others. By increasing the air flow rate, air volume (that involved in the heat exchanging) increased and the temperature of output water from the radiator, more reduced.

The changes in required power for achievement to optimal power (P_{com}), percent of RRP, air gain power (P_{air}) and water loose power (P_w) in deferent velocities have been shown in Figure 3. As mentioned before, the power consumption reduction showed the percent of total required power that supplied by water. Basically, P_{com}, P_{air} and RPP increased with the increasing air flow rate while P_w remained constant.

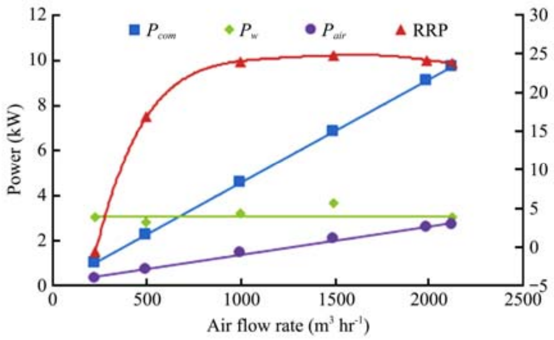
As shown in Figure 3, the amount of P_w at all air flow rate was almost constant (2.3-2.9 kW at the 16 lit min^{-1}, 2.6-3.6 kW at the 16 lit min^{-1} and 3-4 kW at the 16 lit min^{-1} of water flow rate). Also P_w increased by increasing the water flow rate in all the air flow rate and reached from 2.5 kW at the 16 lit min^{-1} to 3.6 kW at the 34 lit min^{-1} of water flow rate. The reason, is exchanging more heat at higher temperatures (close to the water inlet temperature) in higher water flow rate (see Figure 2(b)).

Furthermore, according to the Figure 3, the amount of P_{air} increased at each water flow rate by increasing the air flow rate (the amount of 0.3 kW at the 226 m^3 hr^{-1} air flow rate to 2.9 kW at the 2126 m^3 hr^{-1} air flow rate) because increasing the air mass contacted with the radiator at high air flow rate is predictable. Also, by changing the water flow rate, a significant change wasn't observed in the increasing P_{air}. It is because of the limited capacity of radiators in heat transferring.

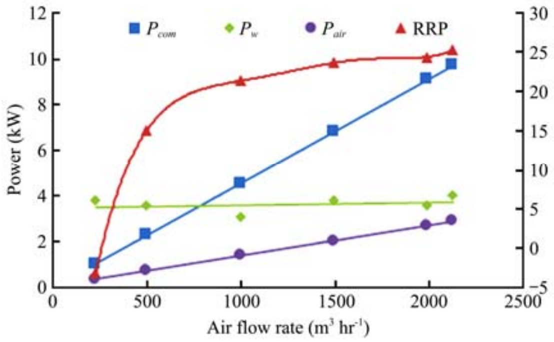
Figure 2 showed that, with increasing in air flow rate, power intaken by air can be increased, but this increase was low compared with the increase in power required. Thus, by increasing the air flow rate, the rate of RRP at all flow rates were reduced and arrived to constant level at air speed more than 3.3 m s^{-1} (1493 m^3 hr^{-1} of air flow rate). The reason is that according to Figure 3, at high air speeds (velocities), the power required (10-7 kW) is very high to compare with the received power by the water (3-2 kW). As it can be seen in Figure 3, by increasing air speed, the difference between obtain power by air and power lost by water was decreased. Also, based on Figure 3, it was clear that RRP at flow rate of 34 lit min^{-1} was more than other flow rates at all of the air speed ranges.



(a) 16 lit min^{-1} flow rate



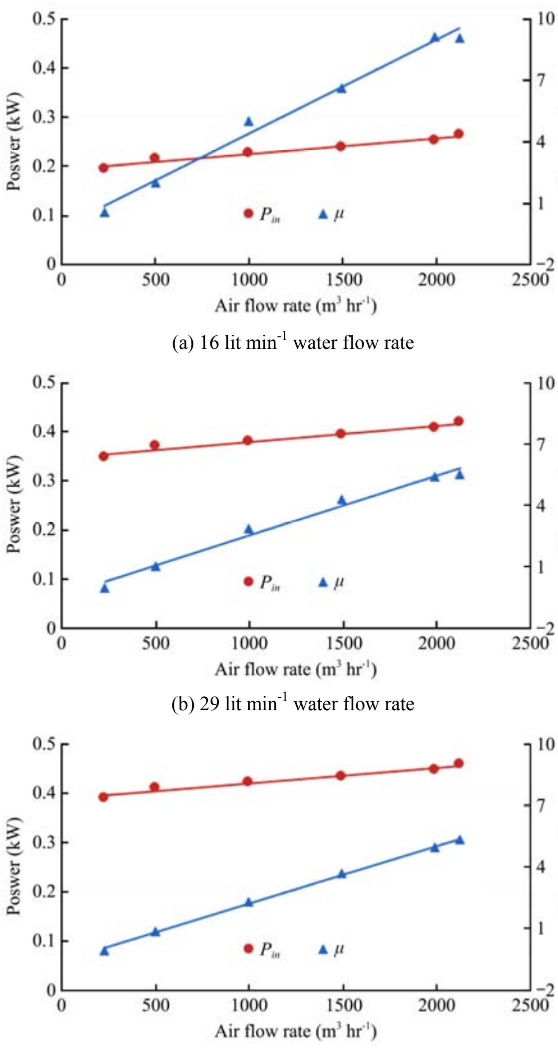
(b) 29 lit min^{-1} flow rate



(c) 34 lit min^{-1} flow rate

Figure 3 Changes in required power (P_{com}), RRP, power received by air (P_{air}) and water loose power (P_w) at different air flow rate in heating system

Figure 4 showed a slight increase in P_{in} with the increasing air flow rate, but its magnitude was higher at higher water flow rates (from 16 to 34 lit min^{-1}). Because the power increased by increasing the fan speed is too small compared with total power (19 W for air speed at 0.5 m s^{-1} to 90 W for air speed at 4 7 m.s^{-1}). Also, Figure 4 showed that, net energy ratio (μ) increased more markedly with increasing air flow rate and showing higher variations and magnitudes at smaller water flow rates. The reason was that low power was consumed at relative flow rate compared to other flow rates that placed at denominator in Equation (4) (according to Table 1, 0.265 kW at flow rate of 16 lit min^{-1} and air flow rate of 2126 m^3 hr^{-1}, 0.42 kW at flow rate of 29 lit min^{-1} and air flow rate of 2126 m^3 hr^{-1}, and 0.46 kW at flow rate of 34 lit min^{-1} and air flow rate of 2126 m^3 hr^{-1}) and increment of air gained power by increasing air speed that placed at numerator (Figure 4). Also, this ratio was very similar for both of 1991 and 2126 m^3.hr^{-1} air flow rate (9.09 versus 9.12) that indicated no more system efficiency at highest air velocities. Changes in net energy



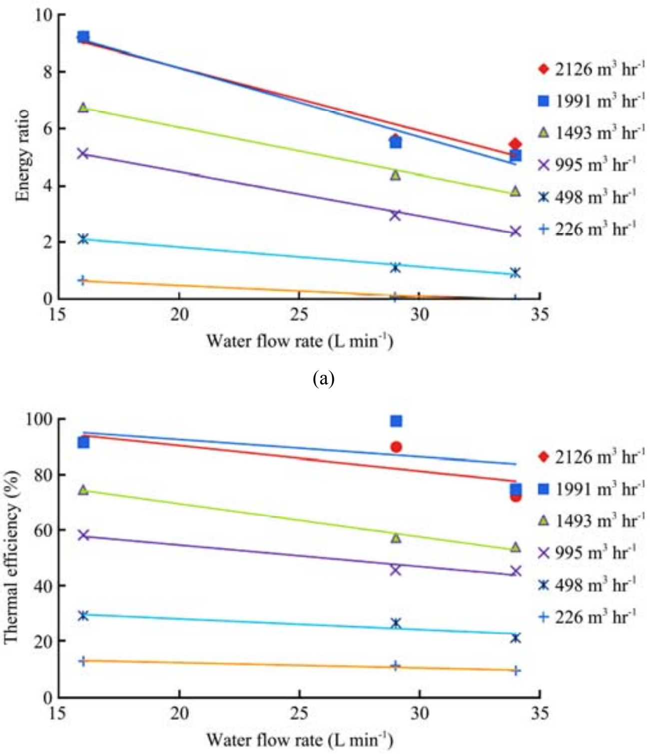
(a) 16 lit min^{-1} water flow rate

(b) 29 lit min^{-1} water flow rate

(c) 34 lit min^{-1} water

Figure 4 Changes in P_{in} and net energy ratio (μ) at different air flow rate (velocities) in heating system

ratio (a) and thermal efficiency (b) of heating system at the six air flow rate proportional to different water flow rates were shown in Figure 5. According to Figure 5a, in all air flow rate, by increasing input water flow rate, net energy ratio was reduced and also net energy ratio was increased by increasing in air flow rate and the maximum amount of net energy ratio obtained at flow rates of 16 lit min^{-1} and air flow rate of 1991 and 2126 m^3 hr^{-1}. It indicated that air flow rate increment more than 1991 m^3 hr^{-1}, had no effect on net energy ratio at low flow rates and also according to this Figure, slope of charts increased with increasing air speed.



(a)

(b)

Figure 5 Changes in a: net energy ratio and b: thermal efficiency of system at different air and water flow rates during heating process

On the other hand, according to Figure 5(b), the system thermal efficiency was reduced by increasing water flow rate at all of the air velocities. The reason of this reduction can be explained that water flow rate increment caused to reduce thermal efficiency because of the increasing input power. Also, thermal efficiency increased with the increasing air flow rate up to 1991 m^3 hr^{-1} and this increase in higher speeds decreased, so that a certain difference between 1991 and 2126 m^3 hr^{-1} of air flow rate at the 16 lit min^{-1} water flow rate. This indicated that the effect of the changing in water flow rate on the thermal efficiency was greater than the effect of increasing in air speed (air flow rate) because of high heat capacity of water compared to air.

According to Figures 3 to 5, we can conclude that the best air flow rate for using in geothermal water wells energy for heating systems is about 1800-2200 m^3 hr^{-1} (4-5 m s^{-1}) and the best water flow rate is 16 lit min^{-1} or less, which increases the thermal efficiency of the system, net energy ratio and the energy intake by air. Although, increasing in air speed can enhance the required power, and causes to maximum power of water used. Also, reduction of air flow rate, increases the duration of heating. Therefore, using the low speed of air is not desirable.

3.2 Cooling system

The output air (T_{ao}) and water (T_{wo}) temperature changes at different water flow rates (13, 11.5 and 10 lit min^{-1}) were shown in Figure 6. This figure showed that with increasing the air flow rate in the all water flow rates, output air temperature (T_{ao}) decreased and with closer to the desired temperature (25^{o}C). Also, the lowest output air temperature was obtained at the 13 lit min^{-1} water flow rate and 2126 m^3 hr^{-1} (4.7 m s^{-1}) air flow rate. It indicated that air flow rate more than 2200 m^3 hr^{-1} (5 m s^{-1}) could be necessary for cooling system.

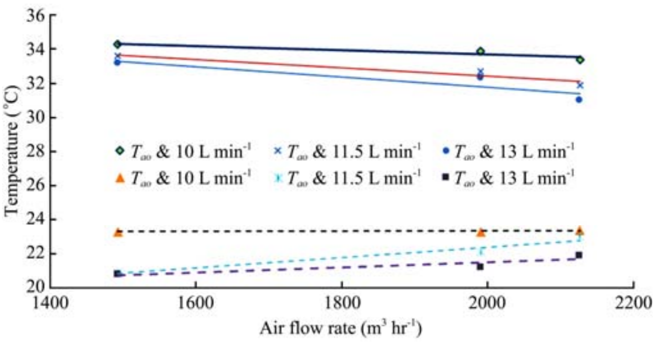
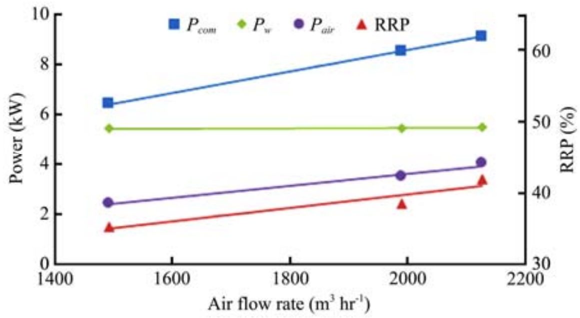


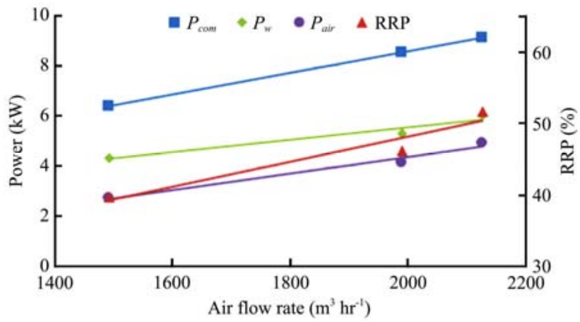
Figure 6 Water and air temperature changes during cooling process

According to Figure 6, in any water flow rate, output water temperature (T_{wo}) increased by increasing the air flow rate and the intensity of this increasing (slope) increased at the high water flow rate. Also, it showed that at higher air velocities, water temperature would increase up to 20^{o}C. Generally, higher air speed and water flow rates were required for achieving to desired air temperature (25^{o}C) in cooling system.

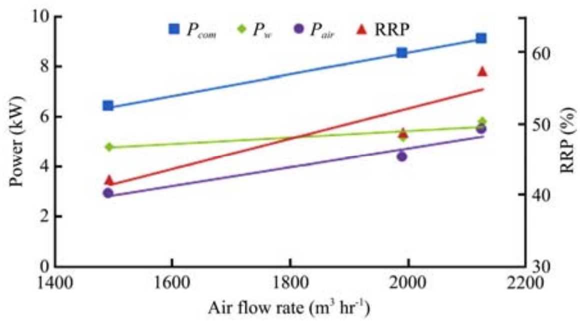
Required cooling power (P_{com}), air loose power (P_{air}), power absorbed by water (P_w) and percent of RRP at different flow rates and air velocities were shown in Figure 7. As it can be seen, four variables increased with the increasing air flow rate or air speed. Additionally, the results showed that RRP increased with the increasing air flow rate. Both of RRP and P_{com} increased by increasing air speed and water flow rate which indicated that by increasing the air flow rate, larger proportion of required power for cooling was provided by water. According to Figure 7, it is clear that increasing the air speed, will cause to increase the power absorbed by water from air (P_w).



(a) 10 lit min^{-1}



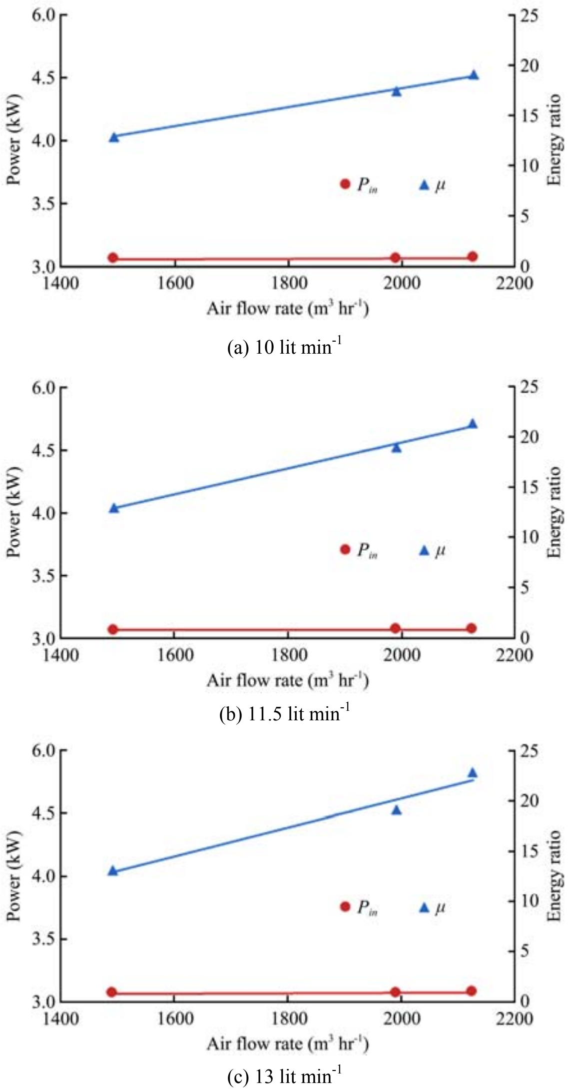
(b) 11.5 lit min^{-1}



(c) 13 lit min^{-1}

Figure 7 Changes in required cooling power (P_{com}), air loose power (P_{air}), power absorbed by water (P_w) and percent of *RRP* at different air flow rate and water flow rates of cooling system

Figure 8 showed the changes of total input power (P_{in}) and net energy ratio μ at different air and water flow rates. It showed that by increasing the air flow rate, net energy ratio (μ) increased at all three water flow rates and indicated that higher fraction amount of required cooling power prepared by water. Figures 7 and 8 show that with increasing air flow rate, changes in P_{air} compared with P_{in} will increase. Generally, for achieve to best cooling performance, the air flow rate should be at higher rates in order to transfer more heat (power) from air to water.



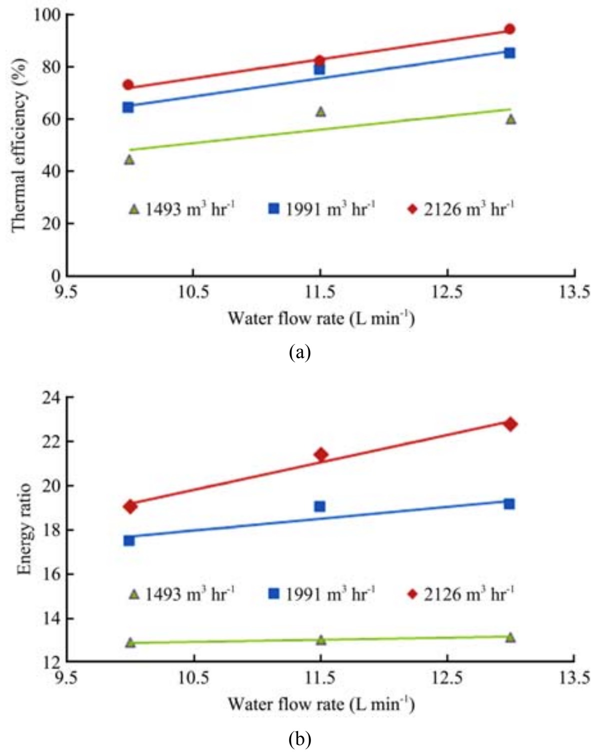
(a) 10 lit min-1

(b) 11.5 lit min-1

(c) 13 lit min-1

Figure 8 Changes in input power (P_{in}) and net energy ratio (μ) at different air and water flow rates of cooling system

The changes of thermal efficiency and net energy ratio for all three air speeds at the water flow rates were shown in Figure 9. As seen in Figure 9a, thermal efficiency and energy ratio increased with increasing flow rate at any flow rates and also increased with air flow rate at any water flow rate. The maximum thermal efficiency (94.2%) was obtained at 2126 m^3 hr^{-1} of air flow rate and 13 lit min^{-1} of water flow rate. By referring to Figure 7, it seemed that higher power can exchange between air and water by increasing water flow rate and thus increase the efficiency of system. Regarding to Figure 6, by decreasing air speed, the temperature difference between air and water was reduced and therefore there was not good heat transfer between the hot air and water in the radiator and finally the thermal efficiency of the system was reduced.



(a)

(b)

Figure 9 Changes in system thermal efficiency and net energy ratio (a and b) at different water flow rates

The results of Figure 9(b) showed that net energy ratio was increased by increasing air speed and water flow rate. The minimum value of net energy ratio was 12.9 at 12 lit min^{-1} water flow rate and 1493 m^3 hr^{-1} air flow rate. These results are predictable because the energy consumption will increase by increasing in air speed and water flow rate (Table 1) and it is negligible in compared with the received energy by the air at different speeds and flow rates.

According to Figures 6 to 9, it can be concluded that the best air flow for using the well water for cooling is 2000 to 2200 m^3 h^{-1} and the best water discharge is 11.5 to 13 lit min^{-1}, which causes increasing in thermal efficiency of the system, the net energy ratio, net power ratio to the power consumption and the power output from the air. However, according to Figures 8 and 9(b), increasing in water flow from 11.5 to 13 lit min^{-1} caused a slight increase in the energy ratio (μ) in lower air flow, but according to Figures 9 and 5, the RRP, the energy ratio (μ) and thermal efficiency of the system (η_{sys}) increased with the increasing air velocity. The reason is that the power required for increasing air velocity is low compared to the water that transferred (the power exchanged with water), and increasing in air velocity makes it possible to use the maximum energy available in the air. Also, reducing the speed can reduce the airflow and, as a result, changes in temperature in a specific volume (in the room or in any area), which is not desirable.

4 Conclusions

Based on the results of this research, the following conclusions were given:

1. Using of 34 lit min^{-1} of groundwater with 16°C temperature for heating was caused 5.5^{o}C increasing in the air temperature in 226 m^3 hr^{-1} of air flow rate.

2. Application of groundwater for heating operation could reduce the *RRP* to 25.29%. Also value of net energy ratio indicated that using this potential clean power for heating system can produce about nine times higher useful power than conventional system. Finally, highest system thermal efficiency were achieved by 92.09% at 16 lit min^{-1} water flow rate and 2126 m^3 hr^{-1} air speed. So for heating operation by this system, best air and water flow rates were evaluated about 1991 m^3 hr^{-1} and about 16 lit min^{-1}, respectively.

3. Using of 13 lit min^{-1} of groundwater with 15.5°C temperature for cooling operation caused 9^{o}C decreasing in the air temperature at the 2126 m^3 hr^{-1} of air flow rate. This system can reduce required power about 35.26% to 57.49%. Additionally, net energy ratio increased from 12.89 to 22.8.

4. The goal of this study was using the groundwater for heating and cooling operations. So, the consumed power by water pumping was separated from consumed cooling or heating power. Generally speaking, it can be concluded that water of well could be used for home heating and cooling even used only for these two operations. Moreover, cooling system has better thermal and power efficiencies compared to the heating system.

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Nomenclature		Subscripts	
P_{air}	The power given to the system or received by air (kW)	i, in	Inlet
P_{com}	Required heating or cooling power (kW) for achieve to desired temperature (25^{o}C)	air, a	Air
P_f	Fans power in different speeds (kW)	f	Fan
P_w	The lost or taken power by water (kW)	e	Electro pump
RRP	Reduction in required power (%)	sys	System
T	Temperature (^{o}C)	1	Initial
$\dot{m}$	Mass flow rate (kg s^{-1}),	2	Final
Greek symbols		w	Water
η	Heating efficiency	o	Outlet
μ	Net energy ratio or net energy efficiency		

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