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Performance Study of a Hybrid Solar-Assisted Ground-Source Heat Pump System Used for Building Heating and Hot Water Demands

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Abstract

This paper highlights a study for examining the viability and performance of a solar-assisted ground-coupled heat pump (SAGCHP) to meet domestic hot water and heating needs of a typical low-energy residential building covering a total floor area of 100 m^2 under Batna, Algeria, weather conditions. In this study, four different solar-assisted ground source heat pump combinations have been developed and will be simulated numerically using the simulation program TRNSYS. It turned out that a geothermal heat pump system of 7.7 kW, combined with flat solar thermal collectors, is an alternative promoter to achieve the objective of this study. The extreme annual average values of the heat pump coefficient of performance (COP) obtained are 3.48 and 4.55. In the system, with recharging the borehole, the net energy extracted from the ground is decreased by 30.4% compared to the reference case (GSHP). This can reduce the ground thermal imbalance problem.

Keywords: Geothermal energy, Solar assisted ground source heat pump,Solar energy, Thermal performance,TRNSYS.

Nomenclature

COP: Coefficient of performance of the heat pump.
$\mathbf{Q_{heating}}$: Heat pump heating capacity at current conditions.
$\mathbf{P_{hp}}$: Power drawn by the heat pump in heating mode.
$\mathbf{Q_{absorbed}}$: Energy absorbed by the heat pump in heating mode.
$\mathbf{T_{load,in}}$: Temperature of liquid entering the load side of heat pump.
$\mathbf{T_{load,out}}$: Temperature of liquid leaving the load side of heat pump.
$\mathbf{T_{source,in}}$: Temperature of liquid entering the source side of heat pump.
$\mathbf{T_{source,out}}$: Temperature of liquid leaving the source side of heat pump.
$\mathbf{\dot{m}_{load}}$: Mass flow rate of liquid on the load side of the heat pump.
$\mathbf{\dot{m}_{source}}$: Mass flow rate of liquid on the source side of heat pump.
$\mathbf{Cp_{load}}$: Specific heat of liquid on the load side of heat pump.
$\mathbf{Cp_{source}}$: Specific heat of liquid on the source side of heat pump.
$\mathbf{\Delta T}$: The difference between inlet and outlet temperatures of fluid.
$\boldsymbol{\gamma}$: Output signal of control function that is 0 or 1.

Subscripts

TRNSYS: Transient System Simulation program.
SAGSHP: Solar-assisted ground source heat pump.
GSHP: Ground Source Heat Pump.
DHW: Domestic Hot Water.

1. Introduction

Human civilization, industrial development, and improved comfort lifestyles lead to rising building service demands, which directly increase the building's energy consumption. In Algeria, the residential sector is responsible for a large portion of the overall energy consumed. In 2015, the building district's energy consumption was 42.7% of global energy consumption [1]. A large part of the energy consumed is used for space and water heating. These uses are typically supplied by fossil fuels. Obviously, investing in alternative technologies, using cleaner sustainable energy sources in the residential sector, is a key to optimizing the use of this energy. This will guarantee durability and low environmental impacts, considering the great renewable energy potential in the country [2, 3].

A hybrid system consisting of solar collectors and a ground source heat pump (SAGSHP) is the right decision for heating, cooling and DHW. Several research reports are available in the open literature. An overview of the development of GSHP technology, concentrated on GSHP systems and their applications , is presented in [4]. It is reported that GSHP has been increasingly used for building heating and cooling in recent years at an annual rate of increase of 10% to 12%. Several studies have been conducted to examine the industrial

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sector in Jordan [5-12], concentrating on the effectiveness of each renewable energy source. A simulation of the different structures of the SAGSHP system for residential construction was conducted [13]. The findings collected by the TRANSYS software in dynamic operation for ten years show that in this comparative study, for the best scenario for SAGSHP combination, it gives an energy gain of 8.7% compared to GSHP. TRNSYS was used to examine the feasibility of a GSHP hybrid system with solar thermal collectors, in six cities in Canada[14]. They found that the use of GSHP associated with solar thermal represents a good idea to reduce the length of the heat exchanger, which reduces the initial cost for the whole system. A SAGSHP, with reversible flow "known as Geo-Sol", has been studied experimentally and theoretically to meet the energy needs of a 180m^2 dwelling. The modeling is carried out by TRNSYS and the experimental analysis has made it possible to define an optimal layout of the GeoSol process from an economic, technical and environmental point of view[15]. Very recently, the study of the realization of the GSHP started in the city of Tlemcen, Algeria, within the framework of bioclimatic domestic heating[16]. The economic analysis shows that the only sustainable way to be competitive with natural gas is by combining solar collectors and the GSHP. The viability and efficiency of a geothermal heat pump, coupled with a secondary heat source for an office building, are based on the TRNSYS simulation. The results show that this system could solve the problem of cold accumulation in the long term [17]. Previous work such as [18, 19] studied a hybrid system of GSHP and solar collectors using experiments and long-term simulations over 20 years with different control strategies. They found that it was a good option for space heating and DHW. A novel simulation tool for solar-assisted ground-source heat pumps was carried out to examine the influence of solar collectors on improving the efficiency of heat pumps in several locations in Europe (nineteen cities). The result predicted the global COP of the system, which varied from north to south between the values 4.4 and 5.8 for SAGSHP and between 4.3 and 5.1 for GSHP [20]. A different mode of operation of the SAGSHP system in a cold climate was studied, it was found that the shape of the solar thermal collectors should be chosen based on the depth of the borehole and the secondary source used[21]. A theoretical and experimental study of a SAGSHP system was carried out in China. The SAGSHP was alternately operated in solar energy-source heat-pump (SAHP) and GSHP modes. The results showed that heating by the SAGSHP systems was feasible in this area [22].In other research, three different SAGSHP systems with and without the use of phase change materials (PCMs) using TRNSYS software were simulated [23]. It has been shown that the use of PCM reduces the heating load by 40% and that the PVT system consumes the smallest amount of electricity on the grid. Two parallel combined solar and heat pump systems with air-to-water heat pumps were simulated for Chile's residential building for heating demand and DHW[24]. The results show that the overall efficiency of a district heating system for the whole building is in the range of4.64 and 4.88,whereas the efficiency of the DHW is 3.93 for flat plate collectors and 4.27 for evacuated tubes. A different configuration of the SAGSHP system, including direct and indirect expansion (DX, IDX) modes for the provision of energy requirements for a 100 m^2 house in Iran was simulated[25]. The simulation was carried out using TRNSYS with 9 m^2 evacuated tube solar collectors and three borehole's. The results showed that IDX-SAGSHP is the most favorable mode with an overall COP of 3.96.The SAGSHP, carried out in a building of several floors, in a cold climate, is studied and analyzed by[26]. It can be seen that the seasonal energy efficiency of the system has been constant over a decade following a well-coordinated action plan of appropriate regulation. The energy analysis of the SAGSHP, installed at Erzurum, was done by[27]. It can be seen that the COP varied from 3.0 to 3.4 and 2.7 to 3.0 for the heat pump unit and system, respectively. The possibility of generating electricity from geothermal resources and solar heat in Jordan using the Rankine Organic Cycle (ORC) was investigated by[28], and it was found that this cycle, with open-flow solar and geothermal power, was most suitable for generating electricity under the specified site conditions. A presentation of a multi-objective optimization framework based on simulation that takes into account energy efficiency and economic feasibility is carried out by [29]. The framework is designed to identify optimized system configurations that maximize the integrated exploitation of different thermal sources. The annual performances of three typical applications of hybrid source heat pump (HSHP) systems are simulated and compared with conventional single heat source pump systems[30]. The results show that HSHP systems have the potential to achieve year-round energy-efficient operation and adapt to different building demands in various climatic conditions. Some studies focused on the important parameter of ground temperature.[31] proposed a SAGSHP system with graded thermal energy storage (SAGSHP-GTES) for providing DHW to a campus dormitory building in Changsha, After 15 years of operation, with the graded utilization of solar energy in the SAGSHP-GTES system, the soil temperature increased from 18.1 °C to 19.9 °C. A SAGSHP for greenhouse heating with a 50 m U-bend geothermal heat exchanger is suggested[32]. The experimental results highlight that monovalent central heating cannot withstand the heat load of the greenhouse at low ambient temperatures.

An experimental study on the SAGSHP's efficiency, consuming solar energy during the day and yielding it at night to heat the building, was carried out by[33]. The findings clarify that charging the ground increased the COP by 23% at night. The efficiency of a heating and cooling ground source heat pump is evaluated [34]. It was found that the optimal depth to place a heat pump for cooling and heating is similar for both applications. From a sustainability point of view, the use of GSHP technology has enabled possible energy savings and reduction of CO_2 emissions for a building of 120 m^2 for space heating and cooling in 10 cities in India[35]. It should be noted that the minimum length of an underground heat exchanger is 140 m for heating and cooling. one can also perform multi-objective optimization of SGSHPs with series and parallel topologies to reduce life cycle costs and CO2 emissions[36].A thorough evaluation of the related literature on SAGSHP systems revealed that various studies on technical feasibility, economic viability, in-depth modeling and field testing with many creative concepts had been conducted. In addition, the majority of research requests are conducted on residential structures. The detailed literature review, mentioned above, showed us that many SAGSHP system configurations were evaluated using various approaches. In this work, we developed three SAGHP system design methods that were evaluated using TRNSYS to fulfill the heating and hot water requirements of a residence in a cold region of Algeria (Batna City). The simulation was carried out over a five-year period to observe key factors such as heat extracted from the ground, soil temperature, system consumption, and COP in order to identify the most efficient. The optimal and viable system design is confirmed by its comparison to traditional design in technical, economic and environmental terms.

2. Component model

To simulate and model the systems, we used the dynamic simulation software TRNSYS[37], which represents an adapted and scalable simulation environment in the transient simulations of energy systems. This software has a library of interconnected model components called "TYPE". We develop a typical TRNSYS simulation project by selecting the system components and connecting them according to the strategy chosen for their inputs and outputs. The mathematical models included in this paper are the implanted types in the TRNSYS library. The components taken into account in the study are recorded in Table 1, and the main physical properties used have been presented in Table 2.

Table 1. List of components used for the simulation

Component name	TRNSYS type
Weather data	Type 109-TMY2
Water to Water Heat Pump	Type 668
Flat-plate solar collector	Type 1b
Pumps	Type 3b, Type 656
Storage tank	Type 4a
Ground Heat Exchanger	Type 557a
Tee-Piece	Type 11h
Diverting Valve	Type 647
Ground Temperature	Type 501
Quantity Integrator	Type 24
Multi-zone building model	Type 56b
Printer	Type 25c
Online Plotter	Type 65c
Three-stage room thermostat	Type 8
Controller	Type 2b
Equations	-

Table 2. Main system input parameters used for simulation

Parameter description	Value
solar collector: Type	Flat plate collectors
Total collectors' area	6.6 m^2
Optical efficiency a_0	0.807
Loss coefficient a_1	3.766 $W/(m^2.K)$
Loss coefficient a_2	0.0059 $W/(m^2.K^2)$
Collector slope	36° corresponds to the latitude of Batna city
Water to Water Heat Pump/668 heating power:	7.7 kW in heating mode for an inlet temperature to the condenser of 35 ˚C and an inlet temperature to the evaporator of 0 °C
Storage tank	
Tank volume	0.5 m^3
Fluid specific heat	4.19 kJ/kg.k
Tank loss coefficient	0.833 $(W/m^2.k)$
Ground heat exchanger	
Borehole depth	50 m
Number of boreholes	2
Pipe thermal conductivity	W/m.k
Volume	m^3

2.1. Heat pump

The "type 668" is a simplified water–to–water heat pump model, based on user-supplied data files containing catalog data for providing capacity and power draw of the heat pump as functions of entering load and source temperatures. The COP and output conditions of the heat pump are calculated by the following equations[18]:

The COP of the heat pump in the heating mode can be given by equation (1)

$$COP = \frac{Q_{heating}}{P_{hp}} \quad (1)$$

The amount of energy absorbed from the fluid stream can be defined as:

$$Q_{absorbed} = Q_{heating} - P_{hp} \quad (2)$$

The outlet temperatures of the two liquid streams can be calculated as follows:

$$T_{load,out} = T_{load,in} - \frac{Q_{heating}}{\dot{m}_{load} Cp_{load}} \quad (3)$$

$$T_{source,out} = T_{source,in} - \frac{Q_{absorbed}}{\dot{m}_{source} Cp_{source}} \quad (4)$$

Where COP is the coefficient of performance of the heat pump, Flow rate, heat flux and temperature are given in this order by (m ,Q and T). The terms source, load,in and out correspond , respectively, the ground source side, load side, inlet and outlet of the system cycle.

2.2. Solar thermal collector

The mathematical model used for the flat plate solar collectors (FPCs) efficiency ŋ, is obtained from the relation[38].

$$\eta = \frac{Q_u}{AI_T} = \frac{\dot{m} cp_f (T_{out} - T_{in})}{AI_T} = F_R.(\tau\alpha) - F_R U_L \frac{(T_{out} - T_{in})}{I_T} \quad (5)$$

Here Q_u is the useful energy gain, A is the collector area and I_T is the global radiation incident on the solar collector. $\dot{m}$ is mass flow rate of the fluid, cp_f is the specific heat of the fluid, T_{in} and T_{out} are the inlet and the outlet temperatures of the fluid. F_R is the overall heat removal efficiency factor of the collector. τα is the transmittance of the solar collector. U_L is the overall thermal loss coefficient of the collector. as the heat loss coefficient U_L varies, one can obtain a good relationship using the linear dependence

$$\eta = F_R.(\tau\alpha) - F_R.U_L \frac{(T_{out} - T_{in})}{I_T} - F_R.U_{L/T} \frac{(T_{out} - T_{in})^2}{I_T} \quad (6)$$

Where $U_{L/T}$ is the thermal loss coefficient dependency on temperature.The thermal efficiency is defined by three parameters: $\alpha_0 = F_R.(\tau\alpha)$, $\alpha_1 = F_R.U_L$ and $\alpha_2 = F_R.U_{L/T}$ as

$$\eta = \alpha_0 - \alpha_1 \frac{\Delta T}{I_T} - \alpha_2 \frac{\Delta T^2}{I_T} \quad (7)$$

These parameters are available for collectors tested according to the manufacturer. The FPCs have been modeled using the "Type b1" model.

2.3. Ground heat exchanger

The "type 557" that simulates the ground heat exchangers is the most widely used model in the studies of this type of installation. The program only takes into account borehole's, buried evenly in the ground, in the form of a cylindrical volume determined by equation (8)[25]:

$$V = \pi.n.h.(0.525.s)^2 \quad (8)$$

Where n is the number of the boreholes, h is the borehole depth and, s designs the borehole spacing. Among the most important parameters that should be defined before simulation is the required borehole length (L), which is determined according to equation(9)[15]:

$$L = \frac{q_h R_b + q_y R_y + q_m R_m + q_h R_h}{(T_g + T_p) - \frac{T_{in,ground} + T_{out,ground}}{2}} \quad (9)$$

Where, q_h is the peak hourly ground load, q_m is the highest monthly ground load, and q_y is the yearly average ground load, and the variables R_y, R_m , and R_h represent effective ground thermal resistances for 5 years, 1 month, and 6 hours thermal pulses, R_b is the effective borehole thermal resistance while, T_p is the long-term ground temperature penalty, T_g the undisturbed ground temperature and $(T_{in,ground+}T_{out,ground}/2)$ the average fluid temperature in boreholes. In heating mode, the ground loads are obtained by relation:

$$q_{g,l} = q_{b,l}.\left(1 - \frac{1}{COP}\right) \qquad (10)$$

$q_{g,l}$and $q_{b,l}$ are the ground and the building load respectively.COPrepresents the heat pump performance coefficient.

Understanding the geology and hydrogeology of the underground soil is so essential. The soil of Batna is composed of clay, silt, sand, and gravel in varying amounts[39]. The thermal and geological characteristics of the soil can be summarized as follows:

Thermal conductivity λ=1.5 W/m.k

Specificheat Cp = 1340 J/kg.k)

Thermaldiffusivity $\alpha = 6.219*10^{-7} m^2/s$

2.4. Buildingmodel

To model the thermal behavior of multi-zone buildings, TRNSYS software includes a unit for thermal computation. This unit (Type 56) reads external files containing the building description generated by running the preprocessor TRNBuild coupled with TRNSYS. This building modeling is able to supply a space heating load estimate to determine their appropriate size and assess the functionality of hybrid energy systems in semi-arid climatic conditions. To estimate the heating needs of this load house, internal gains due to people, lighting and appliances were taken into account as well as external charges (e.g. energy benefits due to radiation and ventilation). The case study is a typical 100 m² detached house with a height of 3 m located in Batna, Algeria.The building materials thermophysical properties, used here, determined according to local regulations. DTR C3-2, DTR C3-4[40, 41] are listed in the table 3.

3. Setup and Operation Strategy

3.1. System 1

The basic case is the classic GSHP system consisting: heat pump, vertical borehole heat exchanger (BHE), and distribution system. In the heating mode, a fluid flows through a loop that connects to the ground to absorb its low-grade heat and transfer it to the evaporator. The compressor then increases the refrigerant temperature and pressure. The heat, at a high temperature, thus generated by this compression, is sent to the working fluid, through the condenser, to be transferred to the building via the distribution system. Then the heat gain, required by the building and the DHW, is provided mainly by the heat extracted from the ground and the rest is completed by the compressor of the heat pump. To ensure proper operation of the system, the signal controllers, based on the difference in relative temperatures and the equations combining the control signals are written and activated in the TRNSYS software. Details of the control strategy can be found in section (3.4). Figure 1a shows a schematic representation of this system.

Table 3. Properties of building components

Building component	Structure Component	δ [m]	λ [W/ m. K]	ρ [kg/ m^3]	U [W/m^{2}K]
Floor	1 ceramic product (tiles and slab)	0.02	1.0	1900	
	2 cement mortar	0.02	1.4	2200	1.06
	3 polyurethane	0.05	0.038	27	
	4 reinforced concert	0.10	1.75	2350	
	5 hard stones	0.16	2.4	2400	
Exterior wall	1 cement mortar	0.02	1.4	2200	0.44
	2 hollow brick	0.1	0.48	900	
	3 polystyrene foam	0.05	0.031	40	
	4 hollow brick	0.1	0.48	900	
	5 plasters	0.02	0.35	850	
Roof	1 cement mortar	0.02	1.4	2200	
	2 Polyurethane full	0.16	0.23	830	0.608
	3 plasters	0.02	0.35	850	
Window	Double glazing				2.95

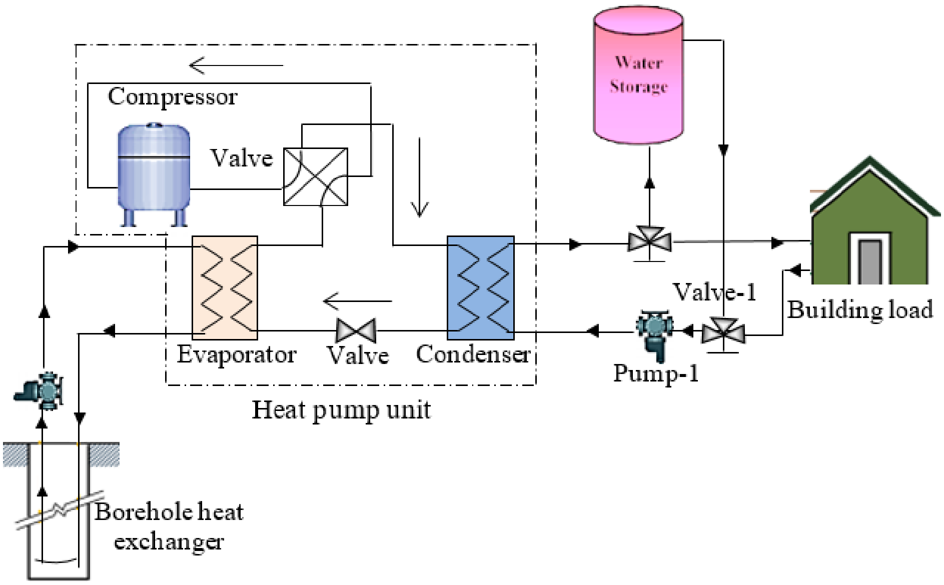

Figure 1.a. Schematic representation of system 1

3.2. System 2

The integration of the solar collector into this first system represents the second system. In this system, in heating mode, the useful energy provided by the solar collectors heats the water coming from the heat pump and enters the storage tank when the temperature of the outlet solar collector is above the average temperature of the storage tank. This mode works according to the second scenario of Razavi [13]; merely, in the proposed system, the added solar energy is used for water heating during the period from March to October. Figure 1b shows a schematic representation of this second system.

3.3. System 3

In this third system scenario, solar collectors are connected to the cold side of a heat pump to preheat the incoming source temperature to heat pump up to 15 °C by adding solar heat to the fluid leaving a ground heat exchanger. This increases the efficiency of the heat pump of the geothermal source. Figure 1c represents the schematic of this system.

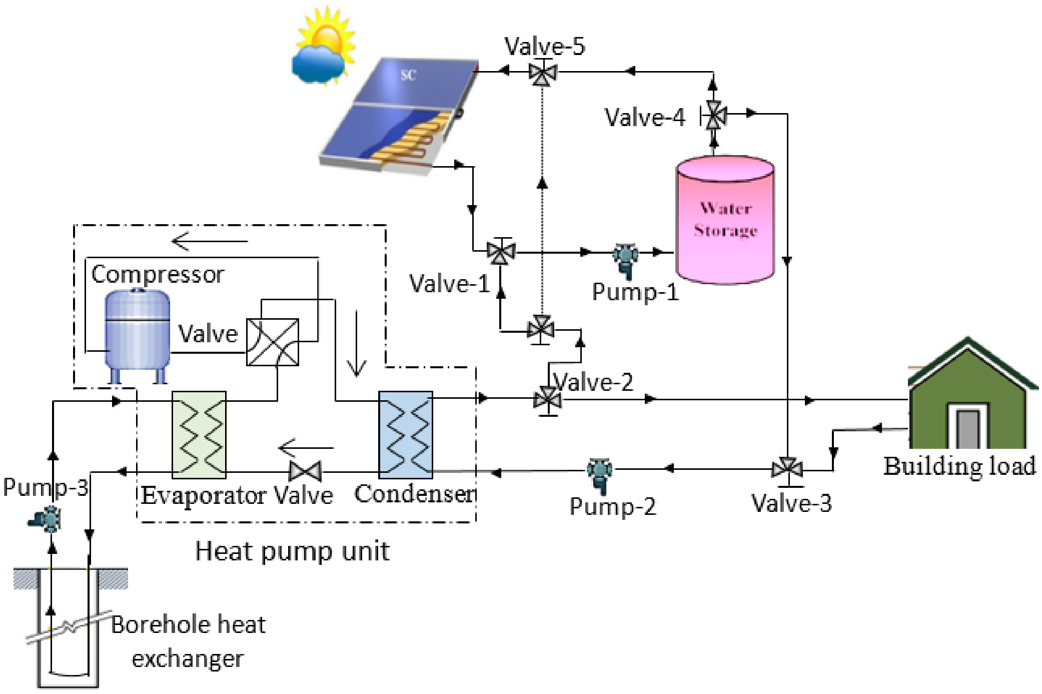

Figure 1.b. Schematic representation of system 2

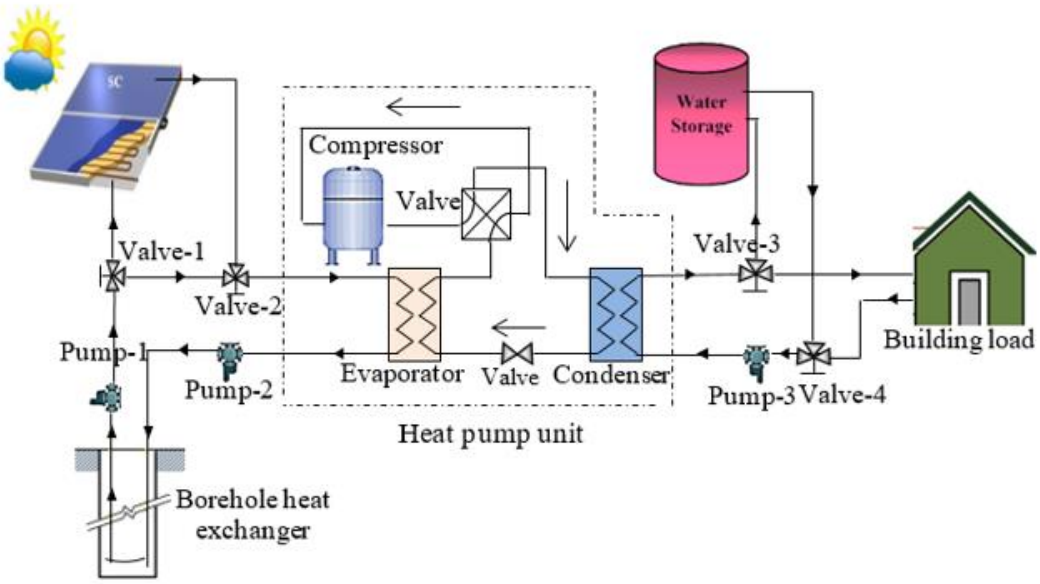

Figure 1.c. Schematic representation of system 3

3.4. System 4

In this system, the operation of the solar collector is directly related to the temperature of the DHW tank. If the outlet solar collector temperature was 10°C above the DHW tank temperature, the circulation pump (Pump 1, fig 1d) operates and the solar collector supplies the tank .The system would continue to operate until the temperature difference falls below 2°C. When the tank temperature reaches its maximum during operation, Pump 1 shuts down. If the output temperature of the solar collector was 2°C above the temperature of the DHW tank that is not at the desired value, all outflow comes from the bottom DHW tank is sent to bypass valve (Valve-1) at GSHP. The regulation guarantees that the total flow sent to the tank if its temperature is lower than that desired in the building and vice versa. In case both charges (DHW tank and building) have not reached the desired temperature, the regulator must activate a solenoid valve (Valve-2, fig. 1 d) so that each of the loads receives the necessary flow rates. The two-input equation blocks, tc and H_C, are connected to the output control signals of the aquastat watching the tank and the thermostatwatching the house. Equation (11) expresses the control function of the bypass valve (valve-2) which determines the fraction of the flow that must flow into the house and into the tank:

$$\text{House\_fraction} = \text{Max}\left(0, (\text{H}_\text{c} - 0.35\ \text{tc})\right) \quad (11)$$

Then

$$\text{Tank\_fraction} = 1 - \text{House\_fraction} \quad (12)$$

The GSHP will only work when the house and the tank are cold and the collector is not able to release energy. The control signals for the heat pump and the circulation pumps (pump-2 and pump-3) are expressed as:

$$\text{On\_heatpump} = \text{Max}(\text{t}_\text{c}, \text{H}_\text{c}) \quad (13)$$

$$\text{On\_pump} = \text{On\_heat pump} \quad (14)$$

In this process, if the tank temperature is above 46°C, the additional solar energy will be transferred to the ground by a vertical heat exchanger. The fluid entering through the bypass valve (valve-3) is directed towards the ground is determined by equation (15) written in the TRNSYS environment:

$$\gamma = gt\ (T_{tank}, 46) \quad (15)$$

This function means that if the temperature of the storage tank is above 46°C, the output and the input control signal of the diverter would be 1. This signify that the fluid entering the diverter valve-3 will go to the ground to recharge it. Figure 1d shows a diagram of this type of system.

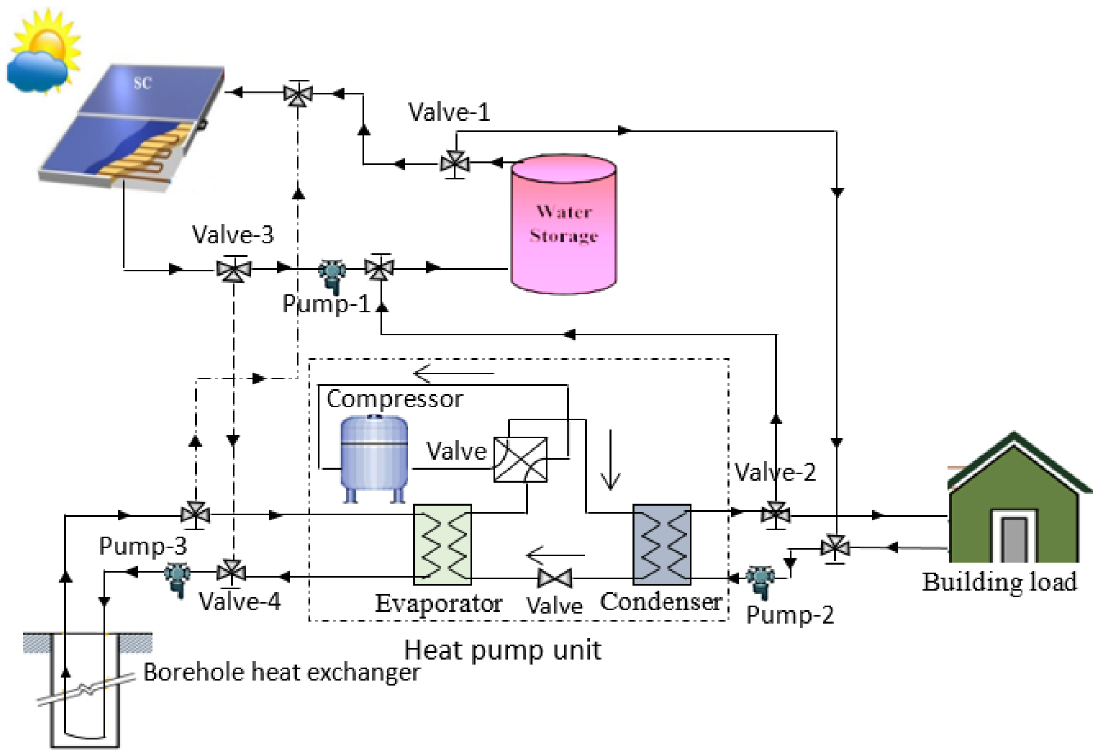

Figure 1.d. Schematic representation of system 4

Figure 1. Schematic representation of the simulated systems.

4. Results and Discussion

In this section, the influence of the main parameters on the functioning of the simulated systems is discussed and compared using the TRNSYS software. The study was carried out over 5 years with a discretization time of 0.125 hours, under the same conditions for the four systems.

4.1. Weatherdata and load characteristics

In our study, we used climate data from the Batna site (35.6°N, 6.2°E) to optimize a heating system design that must meet the needs of the building under the conditions of this site .Summers are hot, dry and mostly clear, while winters are very cold and partly cloudy, and it is dry year round. The ambient temperature ranges between -4°C and 29°C in the winter. The coldest month is January, with an average air temperature of 5.2 °C, the period from November to April. The hot season lasts four months; the hottest month is July, with a 27.6 °C.We use the METEONORM® software to generate the main meteorological data for the site selected for the simulation[42].Figures 2-4show the hourly and monthly ambient temperature and total radiation respectively, while the figure 5 shows the monthly energy demand for the building and domestic hot water. It is clear that the building's highest heating load is between December and January. Peak heating load occurs in January with 15.47 kWh/m^2 at a set point temperature of 20°C.According to Figure 2, the lowest outdoor temperatures are recorded during the same period when solar radiation is weak (solar radiation reaches its highest at the beginning and end of the heating period, and weak radiation is in the middle of the heating period, according to Figure 3). Moreover, due to the greater difference between outdoor and inside temperatures, the peak heating demand occurred at the same time as the bad external circumstances. (as seen in Figures 4 and 5).The total annual energy requirements for space heating indicate consumption of around 57.55kWh/m^2/year and for DHW 3036 kWh /year.

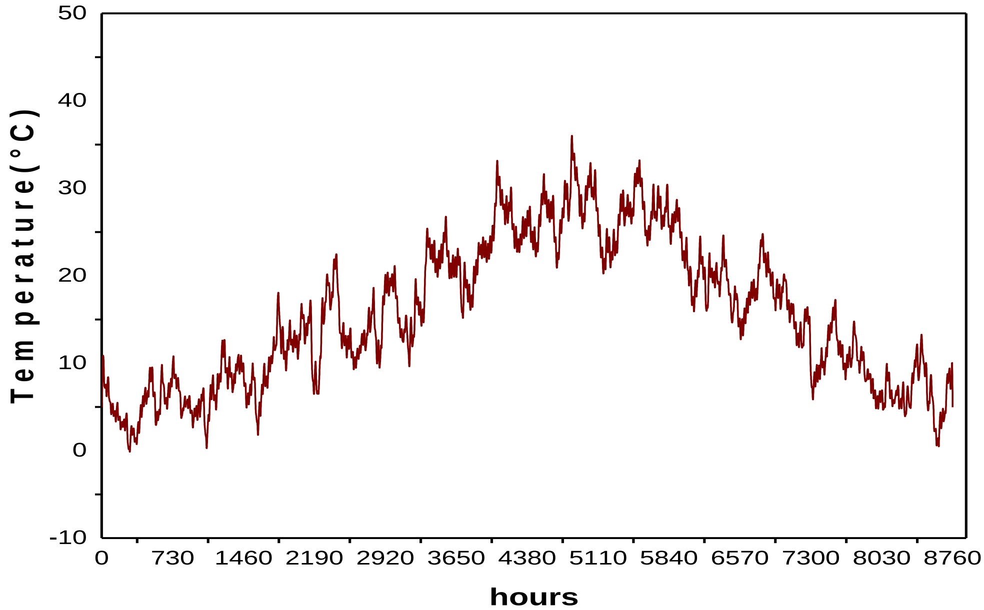

Figure 2. The ambient temperature of Batna.

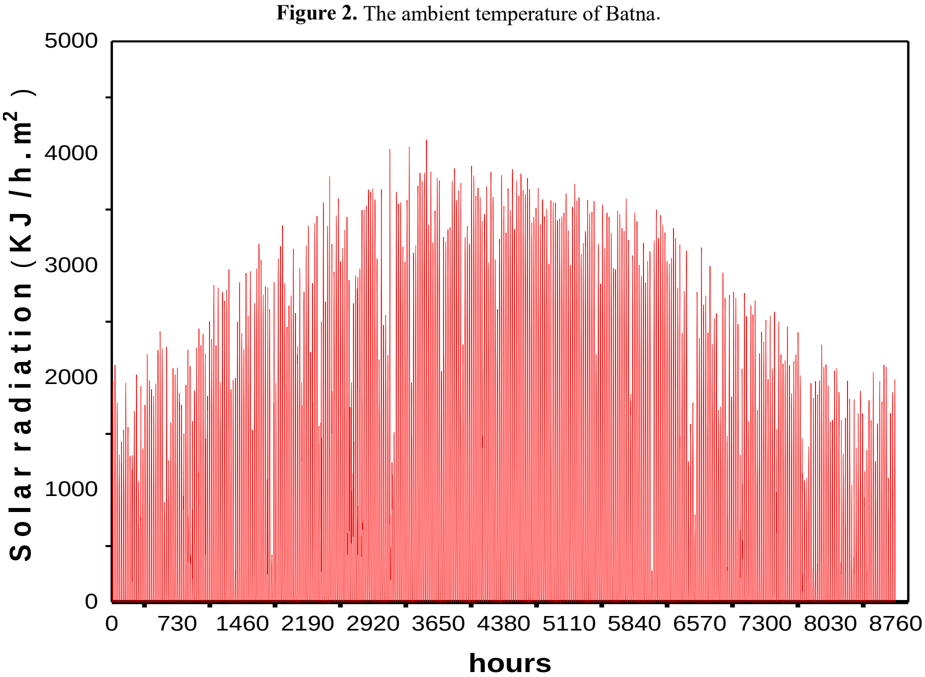

Figure 3. Total radiation on horizontal in Batna'site .

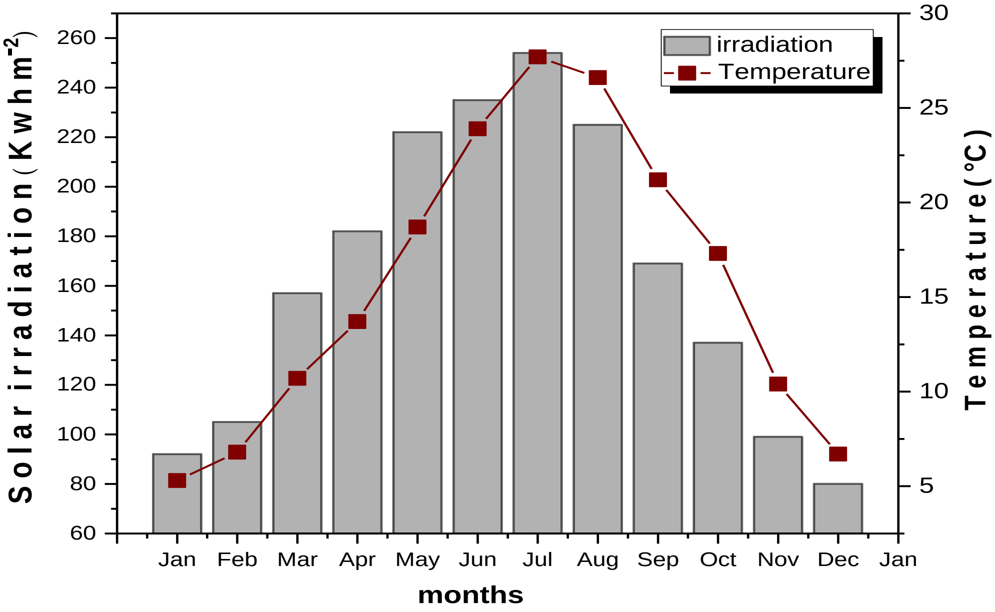

Figure 4. Monthly solar irradiation and average ambient temperature in Batna.

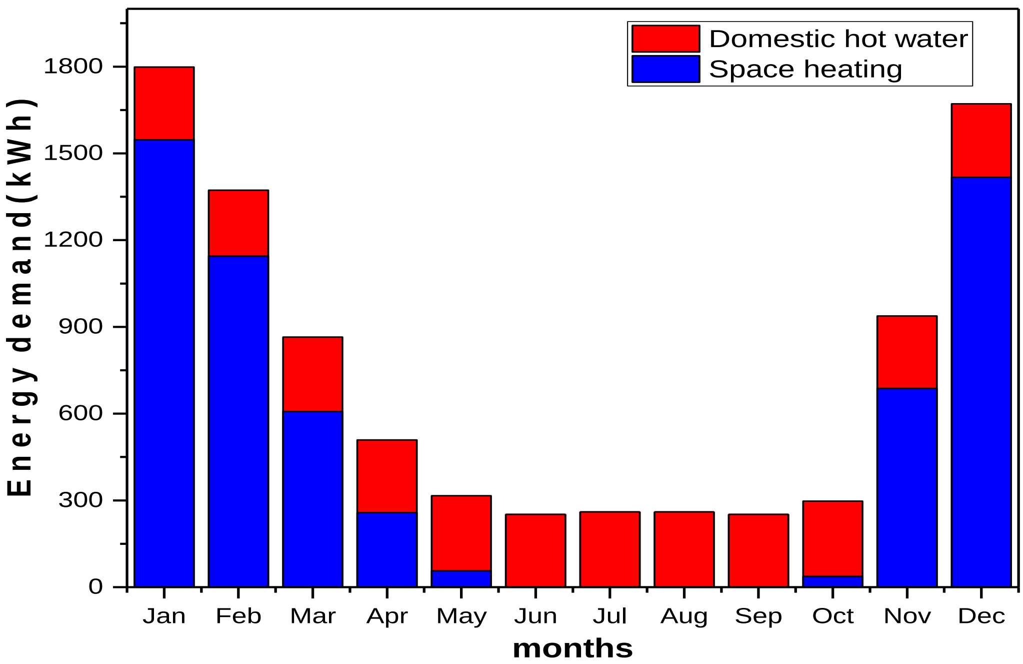

Figure 5. Monthly heating and DHW loads.

4.2. Heat extraction from the ground

As shown in Figure 6, for all systems, in the first two years the decreasein heat extracted from the ground is relatively fast. After this period, the heat extracted from the ground decreases at an increasingly slow rate. When solar heat recharges the borehole, the amount of heat extracted from the ground is reduced by 30.4% in a year in the case of the fourth system compared to the first system. For system 2, the solar heat used for DHW preparation and ground has the possibility of large natural regeneration during the summertime when the heat in the building is not required.

Systems 1 and 3 are similar, although the latter has the lowest heat extracted from the ground. In these systems, the amount of heat injected into the soil during the summer is much smaller than that extracted by the heat pump during the winter. As a result, the resulting thermal imbalance will decrease the soil temperature; the average soil temperature is seen as an essential indicator for directly assessing the impact of the geothermal imbalance. Figure 7 shows a comparison of the average soil temperature between the different systems over a five-year period. It can be seen that the average soil temperature of system 4 decreased from 14.35°C to 13.22°C. However, this temperature decreased from 13.55°C to 11.68°C for system 1 over the same period.

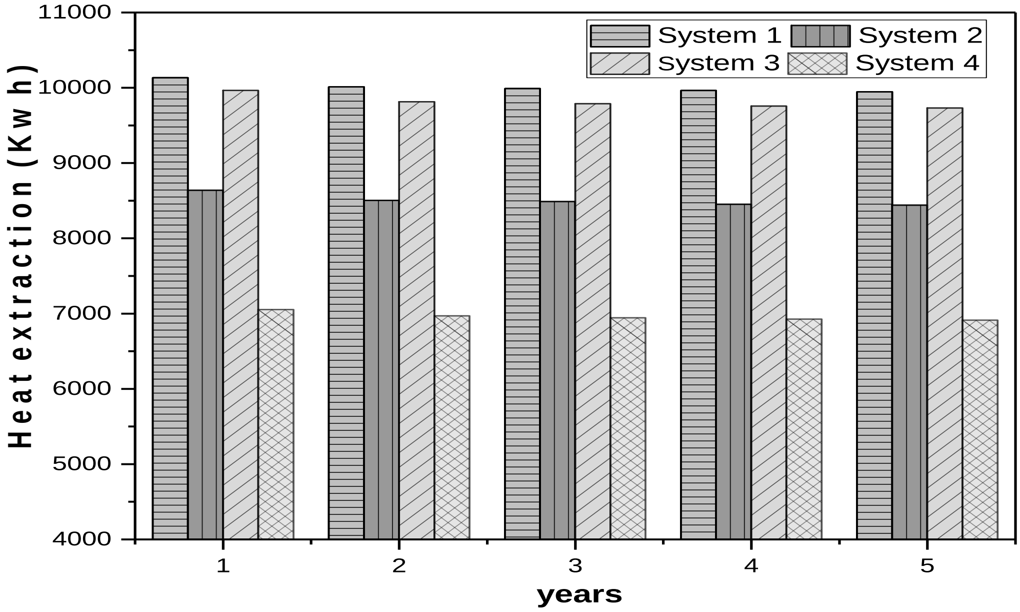

Figure 6. Heat extracted from the ground for the four systems.

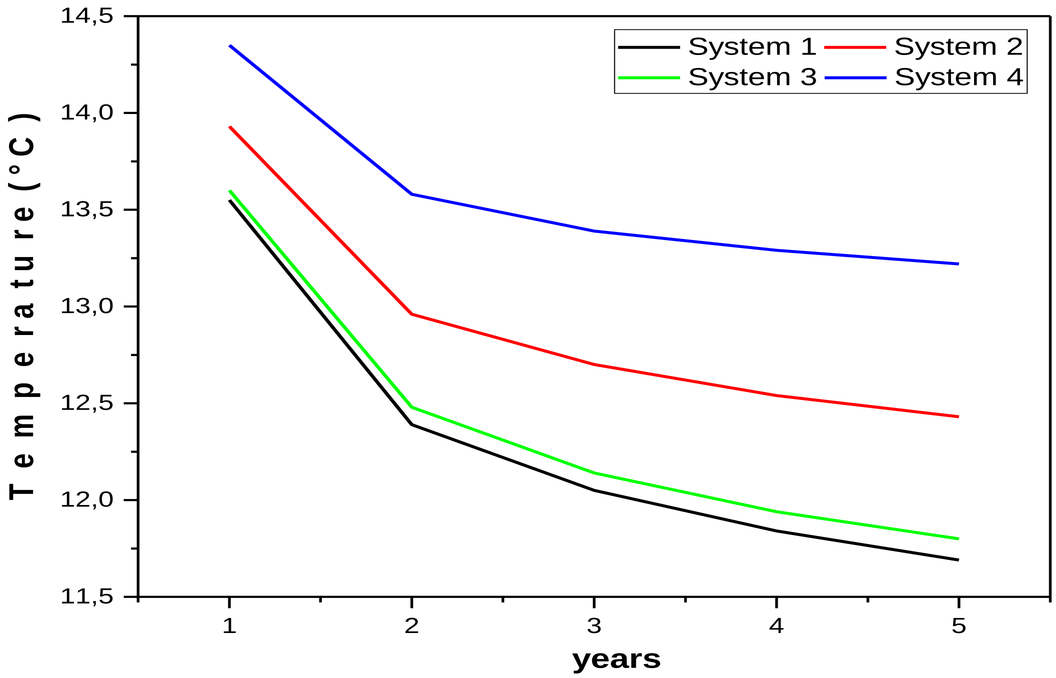

Figure 7. Compare the average soil temperature between different installations

Figure8 shows the heat exchanges with the ground over a year for system 4. As irradiation is low during winter, the solar collectors no longer inject heat into the ground and solar energy is entirely used to heat the water. In seasons when solar energy becomes sufficient, heat is injected into the ground and the resulting energy extracted from the ground will correspond to 9989 kWh, or 99.89 kWh/m. Consequently, we obtain 3067.6 kWh of solar heat injected into the ground, which represents 31% of the energy extracted annually. As a result, the annual imbalance of soil loads is really reduced.

4.3. Electricity Consumption

Figure 9 shows the energy consumption of the simulated systems during 5 years of operation and shows that System 4 consumes less energy since its heat pump, the biggest consumer of power, stops during most of the summer.Thus, the total annual operating time of the heat pump in the SAGSHP system (1608.5 hours) will decrease by 19% compared to the GSHP.

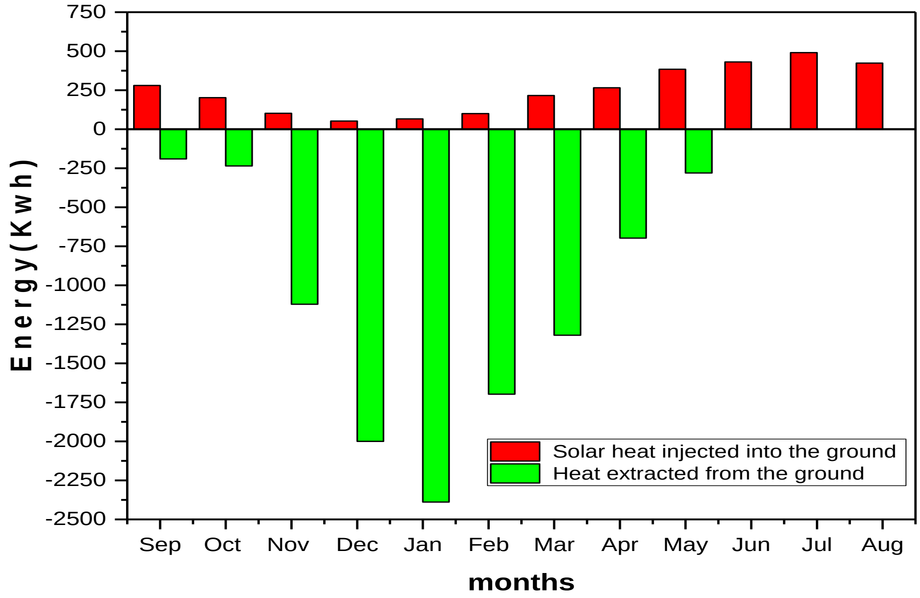

Figure 8. Heat exchanges with the ground during one year for system 4

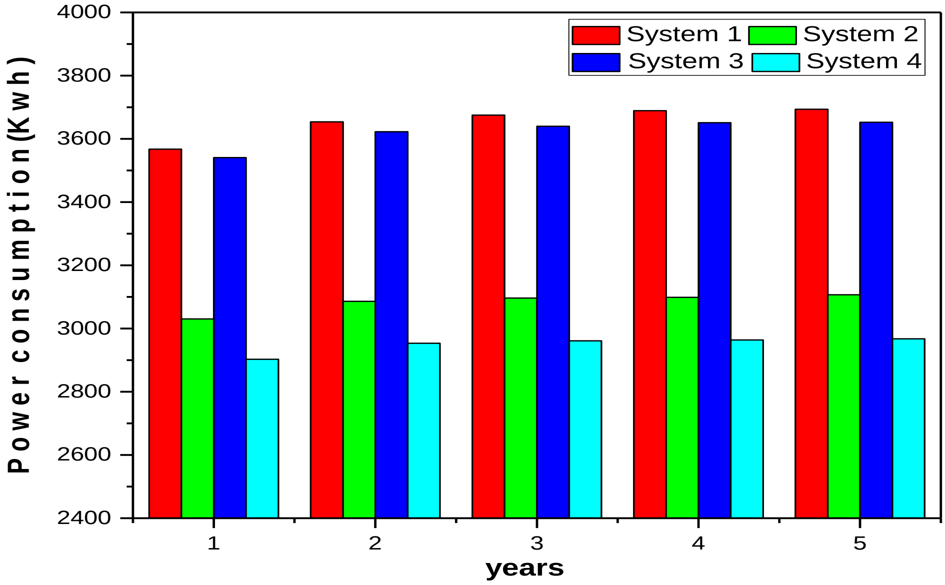

Figure 9. Total power consumptions of different combinations during 5 year

4.4. Coefficient of performance (COP) for the heat pump

The COP of the heat pump for different combinations is shown in figure 10.Systems 2 and 3 have the lowest and highest annual average of COP, respectively. In System 3, the pre-heating of the inlet underground fluid temperature to the evaporator, through the energy of the solar collector, increases the ground source temperature, and therefore the COP of the heat pump increases. In System 1, the GSHP operates during the summer in good condition (see Figure 11), generating high COP records that increase the annual average COP value. For systems 2 and 4, when the heat pump is not running, there is an increase in the ground temperature, but when it starts, the temperature immediately reduces, therefore decreasing the average COP. It is noted that System 2 has the lowest COP compared to System 4. In this system, the deficit can be naturally regenerated from the surroundings and by injecting solar heat. This will help increase the temperature to the evaporator and improve the COP.

To verify the validity of this study model, our results, concerning the space heating, were compared with the experimental results of Ozyurt et al.[43]. Figure 12 shows the evolution of experimental and numerical simulation efficiency coefficients for System 1. The results obtained were compared with those of similar literature for heating water and space on an annual basis. The comparison is summarized in Table 4. For the comparison with the annual data of Kjellsson et al. [19], the COP value is higher than that of this study. This can be attributed to the fact that the Kjellsson study used auxiliary heating devices to power its system and that the extraction from the ground decreased. The comparison of our results with the data of Razavi et al. [13]. shows that our COP (3.56) which is lower than its COP (3.58). This can be attributed to a lower BHE depth. Power consumption was significantly lower than Razavi, due to the addition of the larger solar collector. However, all previous comparative studies should be qualitatively assessed because some operating conditions were different, although similar to those of other studies.

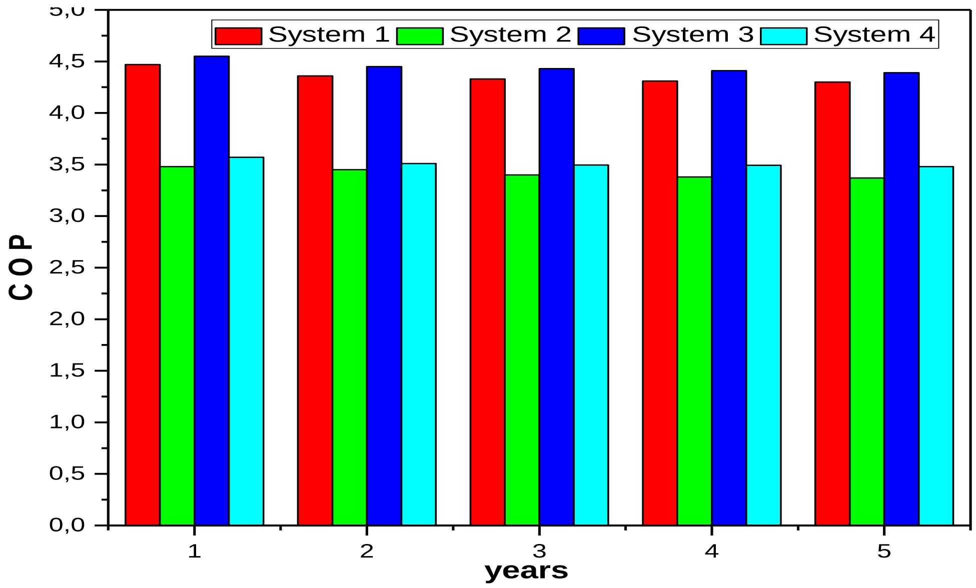

Figure 10. COP for the heat pump for different combinations.

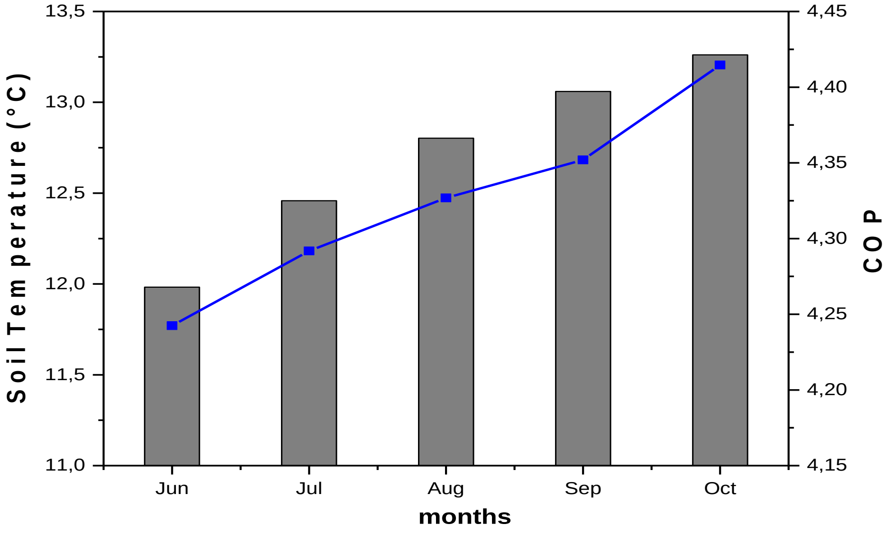

Figure 11. Relationship between COP and soil temperature.

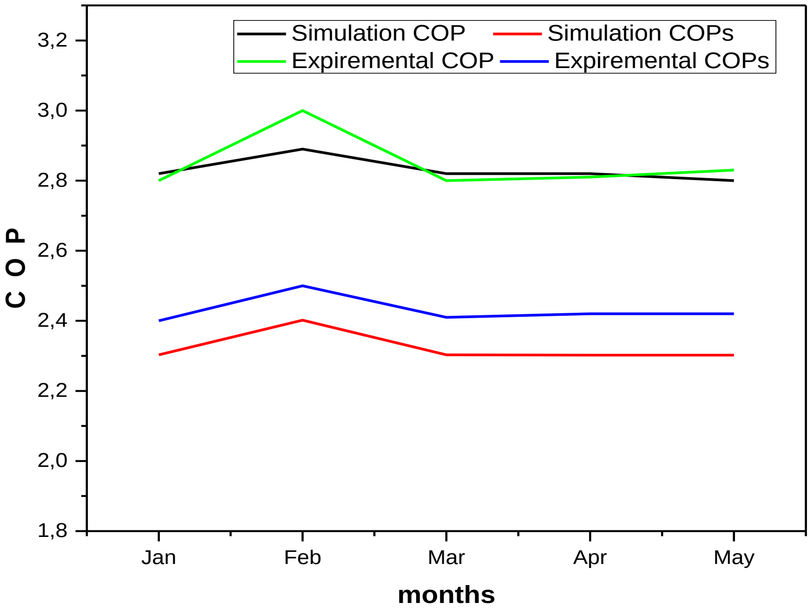

Figure 12. Experimental vs numerical of performance coefficientof heat pump (COP) and overall system (COPs) of system 1

Table 4. Comparison of results with related literature

study	Razavi (3rd scenario)	This study (system 2)	Kjellsson (system 4)
Average soil temperature [°C]	18.4	15.8	7
Depth of GHE [m]	120	100	100
Building type[m^2]	100	100	120
Heat pump nominal heating capacity [kW]	12	7.7	7
Energy consumption [kWh]	~7175	~3031	~8000
Solar collector area [m^2]	3	6.6	10
Mean COP	3.58	3.56	3.7

GSHPs can be considered more efficient than ASHPs because they use a relatively stable underground temperature. Energy use is a variable and essential parameter on which the evaluation of the efficiency of the system depends. The comparison of the monthly energy consumption of GSHP (largest consumer compared to SAGSHP) and ASHP is presented in detail in Table 5 and Figure 13. It is shown that in winter, the energy consumption of GSHP system is about 27% lower than that of ASHP. The highest value is recorded in coldest month (January) with 33.53%, because the temperature at the evaporator of the GSHP system is much higher than that of the ASHP system. In this case the heat pump cycle will operate under pressure conditions and the temperature of higher suction in the compressor, this will lower the consumption of the compressor. Figure 14shows the comparison of the COP of the GSHP systems and the ASHP. It is noted that the overall COP of the GSHP system is 24.8% higher than that of the ASHP system.

Table 5. The COP and power consumption of the GSHP and ASHP

	Overall power consumption (kWh)			Overall COP	
M	GSHP	ASHP	% Saving	GSHP	ASHP
Oct	80	101.34	21.06	3.89	2.90
Nov	340	455.05	25.28	3.84	2.85
Dec	675	908.00	25.66	3.67	2.77
Jan	778	1170.45	33.53	3.61	2.45
Feb	644	864.08	25.47	3.56	2.74
Mar	440	574.34	23.39	3.62	2.85
Apr	237	310.59	23.69	3.72	2.87
May	97	121.92	20.44	3.77	2.93
Overall	3291	4505.80	26.96	3.71	2.79

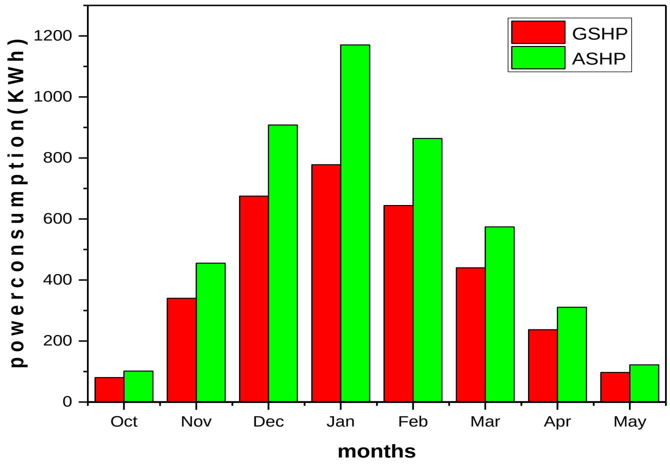

Figure 13. Comparison of the power consumption for the GSHP and the ASHP

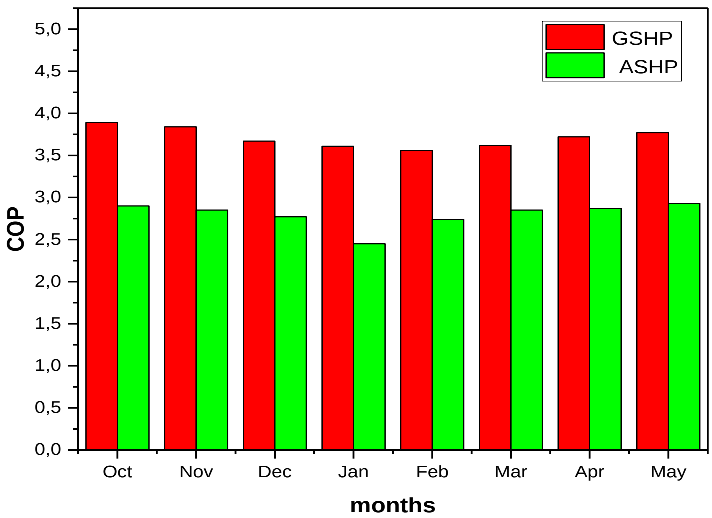

Figure 14. Comparison of the COP for the GSHP and the ASHP

4.5. Economic and Environmental aspects

We conducted an economic analysis of the Air Heat Pump System (ASHPS), Natural Gas Space Heating System (NGSH), GSHP and SAGHP to determine the viable choice between these systems. Initial costs are the sum of the costs of the GSHP system, including installation of the ground loop, heat pump, piping, pump and control systems. BHE's installation cost is the largest contributor to GSHP's cost premium (30% of total cost.) They include labor and materials for drilling, grout, horizontal trench and head pipes. For each system, the initial and operating costs were determined by the market and electricity prices of the Algerian company. In this study, the cost of BHE is assumed to be $29/m. As shown in Figure 15, the initial costs of SAGSHP and GHSP are significantly higher than those of the other two systems. This is mainly due to the investment costs of the heat pump and the ground connection. In contrast, we compare carbon dioxide (CO2) emissions for heating systems stressing the importance of CO2 emissions through its impact on climate change as greenhouse gases. Table 6 shows the total costs, energy consumption and CO2 emissions from the use of heating systems. It is clear that the SAGSHP offers the greatest emission reductions compared to the other three systems in terms of low energy consumption, making it one of the most environmentally beneficial applications.

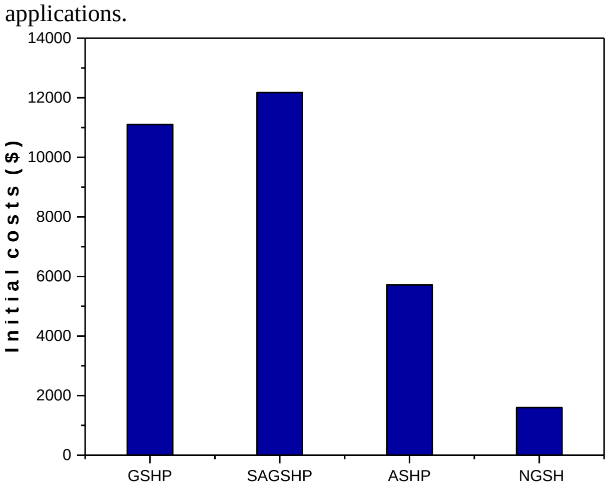

Table 6. Economic comparison among different systems

system	Total Costs ($)	Energy consumption (KWh)	CO_2 emissions (kg)
NGSH	1737	11273	6177.6
ASHP	5868.62	4820.1	2400.9
GSHP	11239	3567.4	1776.5
SAGSHP	12285.2	2902.8	1445.61

5. Conclusions

In this paper, various SAGSHP scenarios to cover both the heating needs of a 100 m^2area and provide domestic heat water in the climatic conditions of the city of Batna, Algeria have been used. Using the TRNSYS software, the simulation was carried out according to the impacts of the key parameters on the performance of the system studied. Focusing on the results, the main benefits of combining thermal collectors with a geothermal heat pump system to supply space heating are:

- Reduction of electricity uptake of the heat pump by decreasing the operation time of the heat pump and recharging the borehole.
- Increasing the overall performance of the system.
- Keeping the ground temperature at stable values and reducing the net heat extraction during the long term of operation.
- Diminution of the use of conventional energy sources and their environmental effects

The main conclusions that may be drawn from the present paper are as follows:

- Depending on the use count of the soil heat source, use of solar thermal systems is an appropriate solution to reduce the heat extraction from the ground, as we can see in system 4, which has a reduction of energy extracted from the ground of 30.4% compared to system 1. On the other hand, system 4 has the possibility to minimize the temperature decrease in ground after a long-term operation, which means that the system uses ground source efficiently
- The least power consumption was recorded in system 4, with a reduction of 18.6% compared to the stand-alone heat pump system. In parallel, the highest annual average heat pump COP belongs to system 3 at 4.55 where the minimum value is recorded as 3.48 in system 2
- The obtained results showed that SAGSHP systems can provide a good solution for heating and domestic hot water with good performance compared to GSHP systems, which could not provide heat supply for domestic hot water and space heating on some days in winter.

The perspectives of this study are numerous and concern in particular the optimization of configurations and control systems in order to increase their performance. This optimization must take place through a simulation of the SAGSHP systems, the results of which must meet both heating, cooling, and DHW demands.

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