PERFORMANCE ANALYSIS OF A SOLAR-ASSISTED GROUND SOURCE HEAT PUMP SYSTEM IN CLIMATIC CONDITIONS OF TURKEY

by

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In order to contribute to widespread use of RES in Turkey, a solar-assisted ground source heat pump system was modeled using TRNSYS software and simulated for heating and supplying daily hot water to meet the needs of a restaurant in five sample provinces having different climatic conditions. During the simulation, the dining room temperature of the restaurant was kept constant at 22 °C during the winter season and a total of 300 Lph of water (55 °C) was used for 15 minutes four times a day. According to the simulation results, power consumption rates in the solar-assisted ground source heat pump system were determined as about 60% for the heat pump, 16% for heaters, 14% for the ground pump and 8% for fans and other pumps. The highest power consumption, as expected, was obtained for Hakkari Province (6723 kW) in the Eastern Anatolia region, which has a cold climate, while the lowest power consumption was obtained for Izmir Province (2822 kW) in the Aegean region, which has mild climatic conditions. The lowest seasonal performance factor and solar factor values were calculated as 2.27 and 32% for Hakkari and the highest as 2.71 and 56% for Izmir, respectively.

Key words: *solar-assisted ground source heat pump, heating, hot water, simulation, TRNSYS*

Introduction

Primary energy sources in Turkey consist of 28% natural gas, 28% coal, 31% petroleum, and 5% hydraulic energy and other renewable energy sources. Of these, 24% are used in the housing and service sectors [1]. While imported natural gas is used at the ratio of 38.3% in the residential sector, the use of RES is limited. In the hot and humid climatic regions where natural gas is not available, split air conditioning units are used for cooling purposes in summer in addition their use for heating purposes in winter. Moreover, hot water needs in these regions are supplied by using solar energy or electrical heaters. In the cold regions, the houses are heated by fossil fuel boilers, stoves or electrical heaters, while hot water needs are met by using electrical water heaters and fossil fuel stoves. In recent years, land-sourced, lake-sourced, and well-sourced heat pumps have been used in places such as hotels and shopping centers in order to meet hot water demands other than for heating and cooling [2]. The split air conditioners used in particular for heating in warm climatic conditions are not suitable for cold climatic conditions because of decreased performance. Therefore, ground source heat pumps (GSHP)

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are an important alternative for cold regions. Turkey has a great solar energy potential and the use of solar-assisted heat pump (SAGSHP) systems is an important alternative option for more efficient use of RES. However, only a few studies on GSHP systems have been conducted in Turkey [3-7] and only one of them is related to SAGSHP systems [7]. These SAGSHP systems are also known as hybrid systems due to their double sources of heat (soil and Sun). They improve the system performance by increasing the stability of the energy supply and thus have gained attention in comparison with traditional systems [8, 9].

Several studies have been carried out recentlyon improving the efficiency of hybrid energy system use. In order to design an optimum SAGSHP, Yu *et al.* [9] developed three types of performance prediction models considering design factors focused on the thermal storage tank. Razavi *et al.* [10] simulated five different combinations of SAGSHP systems to provide space heating and domestic hot water for a residential building in the city of Zahedan, Iran. Modelling, simulation, and operational control were performed using TRNSYS (Transient System Simulation) software. Wang *et al.* [11] presented a novel hybrid solar GSHP system composed of a GSHP and a SAGSHP used for heating and cooling in an office building and a simulation model was developed in TRNSYS to predict the multi-year performance of this system. Si *et al.* [12] designed a novel SAGSHP for an office building in Beijing for heating, cooling, and production of domestic hot water. The important parameters of the system were optimized using TRNSYS. Emmi *et al.* [13] analyzed SAGSHP systems in cold climates by using TRNSYS to investigate six different locations. Dai *et al.* [14] conducted an experimental study on the influence of operation modes on the heating performance of SAGSHP systems. The characteristics of the SAGSHP systems were investigated under different heating operation modes. Verma and Murugesan [15] analyzed experimentally the performance of a SAGSHP used for daytime storage of solar energy and for space heating at night. Georgiev *et al.* [16] conducted an experimental analysis on a small-sized hybrid installation that included solar collectors and a GSHP. They supported five different modes of operation with emphasis on the charging of the borehole heat exchanger, the heating mode with GSHP and the natural relaxation that followed. They also proposed a methodology for the determination of different system energy efficiencies. Januševičius and Streckienė [17] carried out a simulation study of a SAGSHP using TRNSYS to examine the performance of this system for a near-zero energy building. Li *et al.* [18] investigated the effect of different operation strategies of a combined system on the system performance and soil temperature variation. Three different operational strategies of the combined system were modeled with TRNSYS in the winter season. Nam *et al.* [19] developed a SAGSHP in order to improve the system performance of a GSHP. This SAGSHP was able to maintain the balance of the soil temperature effectively and achieve a higher system performance than the conventional system.

After a review of the aforementioned studies, to the author's knowledge, there have been no other studies on SAGSHP systems that include different climatic regions in Turkey. This paper aimed to propose a sustainable, renewable energy system to heat and supply hot water for a restaurant. To this purpose, the designed SAGSHP was modeled using TRNSYS software and simulated for five sample provinces in Turkey having different climatic conditions.

System description

In this paper, the TRNSYS 17 program was used to simulate and analyze the system. This dynamic simulation program with a modular structure was designed over 30 years ago to model and simulate complex energy systems [20, 21]. Simulations are widely used for general research in the field of heat pumps and to some extent to plan such installations. The advantages include low expenditure of time and cost compared to laboratory or field tests [22]. The TRNSYS is a widely used simulationol and has been applied to validate many studies [22-25]. In addition simulation, it can control subsystems by checking the total energy flows and energy balances, or by following the dynamic process in the system, it can increase the reliability of the simulation [26].

The findings obtained for Istanbul Province climatic conditions as a result of the simulation are presented as graphs, while those for the other provinces are shown in a table format. The regional locations of the provinces examined in this study are given in fig. 1 and their co-ordinates in tab. 1. The climatic conditions of the five regions studied are as follows.

Figure 1. Regions in Turkey and locations of provinces

Table 1. Co-ordinates of provinces in Turkey [22]

Provinces	Regions	Latitude and longitude
Istanbul	Marmara	41° 0 ′ 49.8″ N / 28° 56′ 58.8″ E
Izmir	Aegean	38° 24′ 45.8″ N / 27° 8′ 18.2″ E
Ankara	Central Anatolia	39° 55′ 11.5″ N / 32° 51 ′ 15.4″ E
Trabzon	Black Sea	41° 0′ 18″ N / 39° 43 ′ 37″ E
Hakkari	Eastern Anatolia	37° 34′ 38.7″ N / 43° 44′ 12.4″ E

The coastal areas of the Marmara region connect the Aegean Sea and the Black Sea, have a transitional climate between a temperate Mediterranean climate and a temperate Oceanic climate with warm to hot, moderately dry summers and cool to cold, wet winters. The coastal areas of Turkey bordering the Aegean Sea and the Mediterranean Sea have a Mediterranean climate, with hot, dry summers and mild to cool, wet winters. The coastal areas of Turkey bordering the Black Sea have a temperate oceanic climate with warm, wet summers and cool to cold, wet winters. The Central Anatolian region of the interior of Turkey has a continental climate with sharply contrasting seasons. Winters in the region are especially severe. Since most of the Eastern Anatolia region is far from the sea and has a high altitude, it has a harsh continental climate with long winters and short summers [27].

According to the data obtained from the Turkish State Meteorological Service for the years 1929-2018, annual mean temperatures are 14.4 °C for Istanbul, 17.9 °C for Izmir, 12 °C for Ankara, 14.7 °C for Trabzon, and 10.4 °C for Hakkari [28]. In this designed system, the heat drawn from the soil by a water-to-water heat pump is used to heat the water stored in a tank, fig. 2. For this purpose, a heat exchanger is placed vertically under the ground at a depth of 100 m. The heat transfer from the soil is carried out using a water-antifreeze solution circulated between the heat pump and the ground heat exchanger (GHE) by a pump (ground pump). A mixture of 25% propylene glycol-water is used as the antifreeze solution. The specific heat of the solution is taken as 3974 J/kg°C [29]. The heat pump transfers the heat from the soil to the water inside the tank via a pump (tank pump). The tank is divided into ten layers, with the wa-

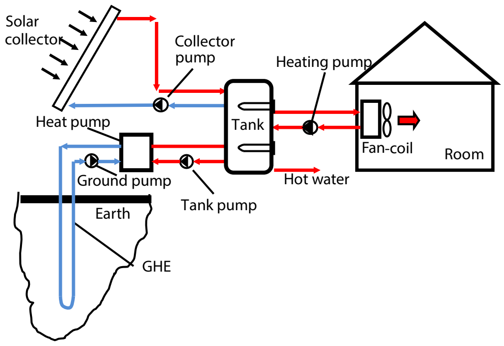

Figure 2. Schematic illustration of a SAGSHP

ter temperature in the upper layer being warmer than that in the lower layers. While the hot water enters the top layer of the tank, the water which is cooler than that in the top layer is sent back to the heat pump from the bottom layer. Two electric heaters with 2 kW capacity and two thermostats are installed in the second and eighth layers of the tank. Hot water is obtained continuously at 55 °C in the tank, which has a volume of 0.35 m^3. This hot water is used in the restaurant as well as for heating the restaurant's dining room in winter.

The SAGSHP system was created by adding a solar collector and a pump to circulate water between the tank and the collector to the GSHP system. Unlike the GSHP, the SAGSHP system uses solar energy to heat the water in the tank during the summer months. The hot water in the tank is then sent to a heat exchanger in the room to heat the room via a pump (heating pump), or is withdrawn from the tank for use. The restaurant temperature is kept constant at 22 °C during the winter months, while 300 Lph of water is drawn from the tank for 15 minutes four times a day (6:00 a. m., 8:00 a. m., 20:00 p. m. and 22:00 p. m.).

Simulation conditions and system model

The SAGSHP system modeled with the TRNSYS software was simulated for one year under the same settings for five different climatic conditions in Turkey. In addition, the SAGSHP system was simulated for ten years to examine the change in soil temperature at the end of a long time period. The simulation time step was taken as 0.125 hours. The system model created using TRSNSY software is shown in fig. 3 and components and specifications used in the modelling are given in tab. 2. Here, the Type 927 model was used as a water-to-water heat pump. This model reads an external file prepared by the user, consisting of the load and source

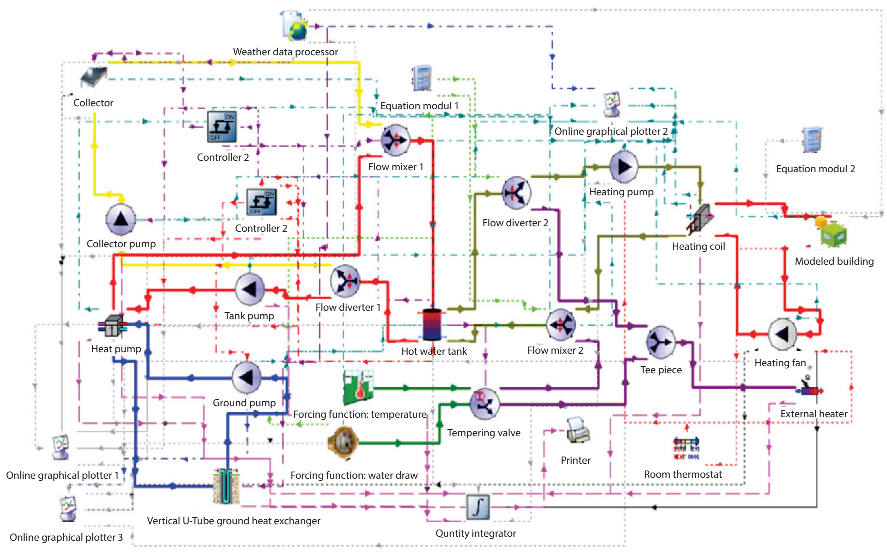

Figure 3. The SAGSHP system model

entering temperatures and power consumption of the heat pump. These data are available in the manufacturer's catalog. The EXW060 water loop heat pump by TRANE, with a nominal heating capacity of 21.73 kW and COP of 4.3 and rated in accordance with ISO 13256-2, was selected for the system [30].

Table 2. Components and specifications used in TRNSYS models

U-values of building (Type 56)		
Roof, wall (outside), wall (inside), floor	0.453, 0.50, 1.387, 0.497	[$Wm^{-2}K^{-1}$]
Heat pump (Type 927)		
Rated heating capacity	21.73	[kW]
Rated heating power	5.05	[kW]
Rated cooling capacity	15.28	[kW]
Rated cooling power	3.89	[kW]
Solar collector (Type 1b)		
Collector area	12	[m^2]
Collector slope	45	[°]
GHE (Type 557a)		
Inner diameter of pipe	13.72	[mm]
Outer diameter of pipe	16.64	[mm]
Center-to-center half distance	25.4	[mm]
Boreholes		
Fill thermal conductivity	1.3	[$Vm^{-1}K^{-1}$]
Number	2	[–]
Depth	100	[m]
Diameter	106	[mm]
Soil		
Thermal conductivity	1.3	[$Wm^{-1}K$–1]
Storage volume	4000	[m^3]
Storage heat capacity	2016	[$kJm^{-3}K^{-1}$]
Pumps (Type 3d)		
Flow rates of ground, heating and tank pumps	1440	[Lh^{-1}]
Flow rate of collector pump	500	[Lh^{-1}]
Power of ground pump	1200	[W]
Powers of heating and tank pumps	60	[W]
Power of collector pump	40	[W]

Control strategy

The heat pump, tank pump and ground pump are controlled by Controller 1. The Controller 1 differential control element (Type 2b) monitors the top layer temperature of the hot water tank (Type 4a) and the water temperature in this layer is maintained at 55 °C. By means of this control element, the top layer temperature of the tank is compared to the average temperature of the tank. If the difference is more than 10 °C, the tank and ground pumps (Type 3d) are activated with the heat pump and they are operated until a difference of 2 °C is achieved. When building heat loss and hot water use are intense, the heat pump alone is not sufficient to increase the water temperature in the tank to 55 °C. In this case, if the water temperature in the second layer falls below 50 °C or the water temperature in the eighth layer falls below 40 °C, electric heaters in the tank are activated to increase the water temperature.

In the SAGSHP system, the Controller 2 differential control element (Type 2b) is used to control the solar cycle. The Controller 2 compares the collector (Type 1b) water outlet temperature to the average tank water temperature. If the temperature difference is over 10 °C, then the collector pump (Type 3d) is activated and operates until the difference is 2 °C. By means of of a collector pump controlled by Controller 2, the water drawn from the bottom layer of the tank is sent to the collector and the water heated in the solar collector is returned to the upper layer of the tank again. The time-dependent forcing function module (Type 14b) enables 300 Lph of water to be drawn from the tank for 15 minutes four times a day (06:00 a. m., 08:00 a. m., 08:00 p. m., and 10:00 p. m.). Besides the domestic hot water withdrawn from the tank, water is supplied at a constant temperature of 15 °C by using the tempering valve (Type 11b). The time-dependent forcing function module (Type 14e) keeps the water temperature constant at 15 °C. In summer, the collector outlet temperature is well above the usage water temperature (55 °C). Therefore, the usage water temperature should be decreased to 55 °C. For this purpose, a portion of the hot water is sent to a tee-piece (Type 11h) to be mixed with cold water coming from the tempering valve, while the other part is sent to the heat exchanger (Type 670) for heating the room by means of the Flow Diverter 2 (Type 11f) placed at the tank outlet. If the hot water temperature is below 55 °C at the tee piece outlet, the external heater (Type 6) is activated and the water temperature is increased to 55 °C. The maximum desired air temperature at the heat exchanger outlet is 50 °C, the heat exchanger efficiency is 50% and the pressure loss is accepted as zero. The dining room air is heated with a fan (Type 112b) with a 6000 kg/h flow rate and 900 W power consumption. The dining room temperature is controlled by the room thermostat (Type 108). The room temperature set value is 22 °C and when it falls to 20 °C, the heating pump (Type 3d) and fan are activated.

Building model features

The building load profile was generated using the TRNBuild interface which was developed as a part of the TRNSYS for multi-zone building simulation [31]. Type 56 models the thermal behavior of a detailed multi-zone building via the TRNBuild software coupled with TRNSYS. Figure 4 gives the architectural plan of the modeled building.

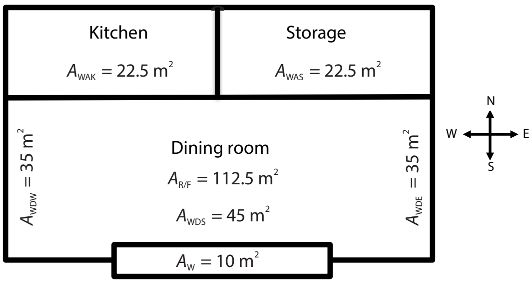

Figure 4. Architectural plan of the restaurant

The building consists of three rooms: the kitchen, store room and dining room. With the SAGSHP system, the dining room temperature is maintained at 22 °C during the winter and, as mentioned before, domestic hot water is supplied at 55 °C. The restaurant has a full occupancy rate between 07:00 a. m. and 10:00 p. m., with the occupancy rates changing on weekdays and at the weekend. As can be seen from tab. 3, the peak occupancy rates occur at 12:00-14:00

and 17:00-22:00 p. m. During these hours, the occupancy rate reaches up to 10-fold in the dining room and 5-fold in the kitchen.

There are various heat gains within the restaurant, both in the dining room and in the kitchen, tab. 4. The kitchen has an air conditioner with a cooling capacity of 13.9 kW and the kitchen temperature is kept constant at 26 °C. The store room is not air-conditioned as it contains only a freezer. The infiltration rate for the kitchen is 0.5 Lph and the infiltration rate for the dining room is calculated by adding 3% of the weekday and weekend occupancy rates to this value.

Table 3. Occupancy of dining room and kitchen

Time interval		Weekday		Weekend	
From	To	Dining room	Kitchen	Dining room	Kitchen
00.00	08.00	0	0	0	0
08.00	10.00	5	2.5	10	5
10.00	12.00	2	1	5	2.5
12.00	14.00	10	5	10	5
14.00	17.00	2	1	4	2
17.00	22.00	10	5	10	5
22.00	24.00	0	0	0	0

Table 4. Heat gain types

	Radiative power [W]	Convective power [W]	Absolute humidity [kgh^{-1}]
Refrigerator	0	417	0
Lights	417	83	0
People	19	42	0.058
Stove	1389	2778	0.1

The lighting heat gain from 07:00 to 22:00 was taken into account in the dining room as two times the occupancy rate. In order to calculate heat gains from the people in the dining room and in the kitchen, the number of people was taken as five times the occupancy rate of the dining room and 0.5 times for the kitchen.

Performance assessment parameters

The solar fraction (SF) and the seasonal performance factor (SPF) are used to characterize the performance of an entire SAGSHP system. The SPF, as calculated according to EN 15450:2007 [32], takes into account the power consumption of the heat pump, circulation pumps (ground, tank, collector and heating pumps), fan, auxiliary heaters to heat output for the space heating and the heat output for domestic hot water preparation:

$$SPF = \frac{\dot{Q}_{\mathrm{SH}} + \dot{Q}_{\mathrm{DHW}}}{\dot{W}_{\mathrm{tot}}} \tag{1}$$

where $\dot{W}_{\mathrm{tot}}$ is the total power consumption and consists of the following components:

$$\dot{W}_{\mathrm{tot}} = \dot{W}_{\mathrm{hp}} + \dot{W}_{\mathrm{pump\_ground}} + \dot{W}_{\mathrm{pump\_tank}} + \dot{W}_{\mathrm{pump\_coll}} + \dot{W}_{\mathrm{pump\_heating}} + \dot{W}_{\mathrm{fan}} + \dot{W}_{\mathrm{tank\_heaters}} + \dot{W}_{\mathrm{ext\_heater}} \tag{2}$$

The SF, as calculated in eq. (3), is the ratio of the total energy load, met by useful solar energy collected by the collectors. The total energy load represents the energy requirements for heating, cooling and/or hot water [33]:

$$SF = \frac{\dot{Q}_{\text{coll}}}{\dot{Q}_{\text{load,total}}} = \frac{\dot{Q}_{\text{coll}}}{\dot{Q}_{\text{SH}} + \dot{Q}_{\text{DHW}}} \tag{3}$$

Performance analysis

Simulation stages are explained in the graphs based on the data obtained for Istanbul as a result of a one-day (24 hours) analysis on the first days of February and July in order to better explain the data complexity. The annual (8760 hours) simulation results obtained for all provinces are presented in the tables at the end of this section. As seen in fig. 5, on the first day of February, the ambient temperature changed between 7 and 9 °C over 24 hours. The heat pump was activated every hour of the day except 12:00-15:00 p. m. When the heat pump was switched on, the source temperature ranged from 1 to 3°C, while the load temperature ranged from 47-58 °C. During this time, the heat pump drew heat from the ground at 10.5-12.5 kW, propelled heat into the tank in the range of 17-18 kW and consumed 4.5-5.5 kW of power.

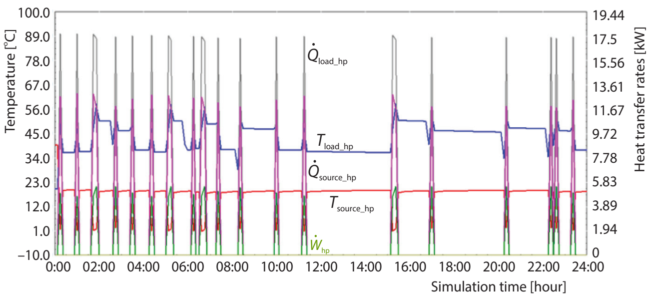

Figure 5. Changes of heat pump parameters in winter

During the simulation, the dining room temperature of the restaurant was kept constant at 22 ºC. As can be seen from fig. 6, when the room temperature dropped to 20 ºC, the fan was activated along with the heat pump. Since only the temperature was controlled in the room, the relative humidity of the room decreased to 25% when the compressor was switched on, while the relative humidity was up to 80% when it was not active. The collector outlet temperature increased to 30 °C between 12:00 p. m. and 16:00 p. m., but since it was lower than the average water temperature in the tank, the collector pump was not switched on. As soon as the water temperature in the tank fell below 55 °C, the heat pump was activated and the water temperature increased when the heat pump was switched on. Furthermore, due to high heat loss, the heat pump was switched on very frequently during the night.

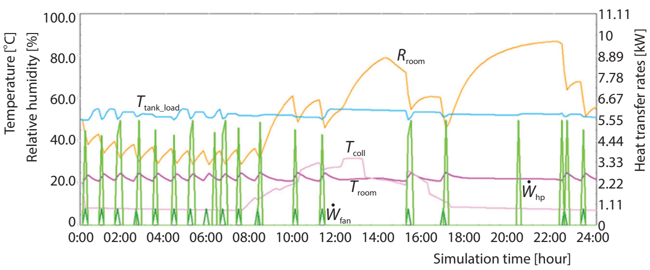

Figure 6. Changes of room temperature and relative humidity in winter

As seen from fig. 7, 300 kg/h of water was drawn from the hot water storage tank for 15 minutes four times during the day, at 8:00 a. m., 10:00 a. m., 08:00 p. m., and 10:00 p. m. When the heat pump was not sufficient to raise the tank water temperature to 55 °C, electric heaters in the tank were activated four times during the night and in the daytime only once. Consequently, the water temperature in the eighth layer fell below 40 °C, as seen in fig. 7, and the electric heaters in the tank were activated to increase the water temperature. When the water temperature was below 55 °C, the external heater was switched on in order to increase the water temperature to 55 °C during the water draw, even though the heat pumps and heaters in the tank were activated. Unlike the GSHP system, the SAGSHP system utilizes solar energy to heat the water in the tank during the summer months. In the first 24 hours of July, the heat pump was switched on frequently from midnight to 06:00 a.m., but did not run between 06:00 a. m. and 12 p. m., fig. 8. Meanwhile, the heaters inside and outside of the tank were activated only twice, at 00: 00-02:00 p. m. and at 06:00 and 08:00 a. m., respectively. The reason for this was the use of solar energy to heat the water in the tank. Figure 8 shows that the solar energy was activated between 07:00 a. m. and 16:00 p. m., the collector pump was activated and the water temperature in the tank was close to 100 ºC.

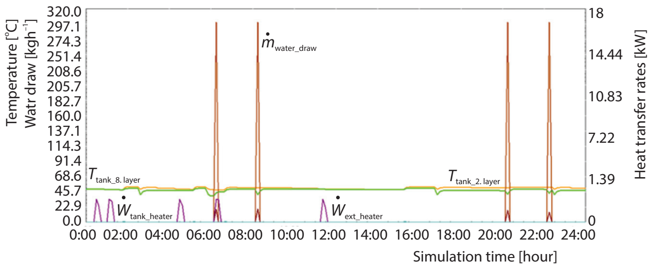

Figure 7. Water draw and activity of heaters in winter (February)

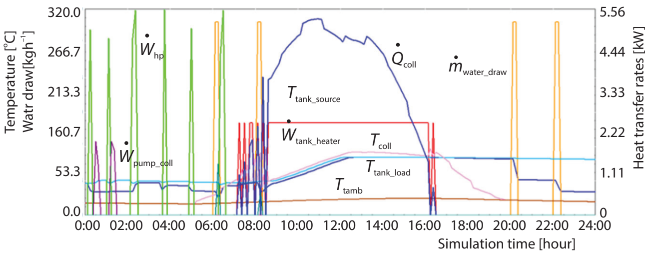

Figure 8. Activity of collector pump and heaters in summer (July)

During the simulation, it was observed that the average soil temperature remained constant at about 20 ºC on the first day of February. As seen from fig. 9, the average heat transfer rate in the ground was found to be as much as the amount of heat drawn by the heat pump. The temperature of the antifreeze-water mixture entering the GHE was in the range of about 1-2.5° C, while the GHE outlet temperature was in the range of 8.5-10 °C.

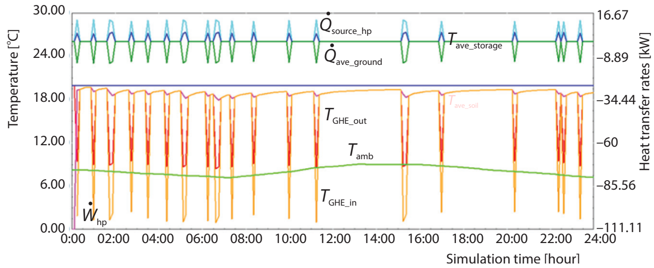

Figure 9. Change of parameters in soil and GHE in winter

In order to see how the soil temperature was affected, a 10 year time simulation was performed for the climatic conditions of Istanbul on the SAGSHP system. As a result of the 10 year simulation, a decrease was ob-

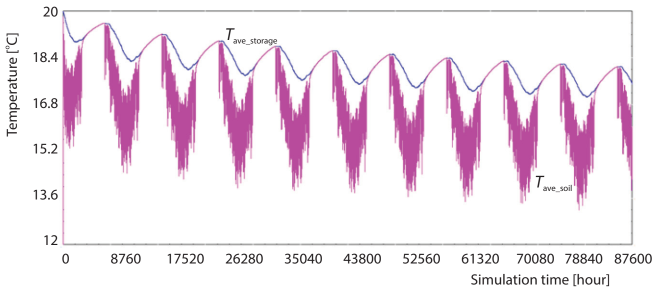

Figure 10. The 10 year time simulation for İstanbul

served in the average soil temperature values. During the first five years, the drop in the average soil temperature was 1.31 °C, while this value was 0.57 °C for the last five years. As seen from fig. 10, the average soil temperature near the boreholes dropped from 15.8-13.5 °C at the end of ten years. The temperature decrease in the ten-year period can be considered as small, and these results are also consistent with the literature [17, 29].

The annual sample data obtained as a result of the simulation for Istanbul is presented in tab. 5. The results obtained for all provinces are presented as graphs in figs. 11 and 12. As expected, the highest power was consumed by the heat pump. However, the power values consumed by the heaters and the ground pump are not to be underestimated. The reason for the high power consumption of the heat pump was due to the inadequacy of the selected heat pump, and the reason for the high power consumption of the ground pump was due to the high power consumption of the selected pump when circulating water in the GHE placed at a depth of 100 m. According to the simulation results for the five different provincial climatic conditions, as expected, the highest power consumption was 6723 kW for Hakkari, while the lowest power consumption was 2822 kW for Izmir. The lowest SPF and SF ratios were obtained for Hakkari Province at 2.27 and 32%, respectively, while the highest were 2.71 and 56% for Izmir.

Table 5. Annual simulation results for Istanbul

Energy consumptions rates [kWh per year]		Ratio [%]	Heat transfer rates [kWh per year]	
$\dot{W}_{hp}$	2200.71	59.67	$\dot{Q}_{load\_hp}$	7296.75
$\dot{W}_{tank\_heaters}$	532.88	14.45	$\dot{Q}_{source\_hp}$	5096.04
$\dot{W}_{extr\_heater}$	25.83	1.70	$\dot{Q}_{ave\_storage}$	–5053.04
$\dot{W}_{pmp\_tank}$	516.60	0.70	$\dot{Q}_{Sun}$	3517.65
$\dot{W}_{pump\_ground}$	62.80	14.01	$\dot{Q}_{load\_tank}$	9490.48
$\dot{W}_{pump\_coll}$	49.20	1.33	$\dot{Q}_{source\_tank}$	10732.23
$\dot{W}_{pump\_heating}$	18.77	0.51	$\dot{Q}_{loss\_tank}$	1205.41
$\dot{W}_{fan}$	281.59	7.63	$\dot{Q}_{SH}$	7249.99
$\dot{W}_{tot}$	3688.39	100	$\dot{Q}_{DHW}$	1035.08

Finally, the data obtained in this study were compared to the experimental study of Dai *et al.,* [14] for hourly water heating only and to the simulation study of Razavi *et al.* [10] for both water and space heating annually. The comparison is summarized in the tab. 6. In the case of the hourly comparison with Dai *et al.,* [14] our COP_{sys} (2.55) was less than the COP of the compared system (2.98). Our lower value can be attributed to smaller storage tank volume. In addition, in this study, hot water drawn from the tank was used for both space heating and hot water needs. In the case of the comparison with the annual data of Razavi *et al.,* [10], the lower COP value of this study can be attributed to lower tank volume and lower GHE depth. The energy consumption of this study was considerably lower than that of Razavi's simulation, which can be explained by the four-fold larger solar collector. However, all the previous comparisons must be evaluated qualitatively since some operating conditions were different, although they were similar to those of other studies.

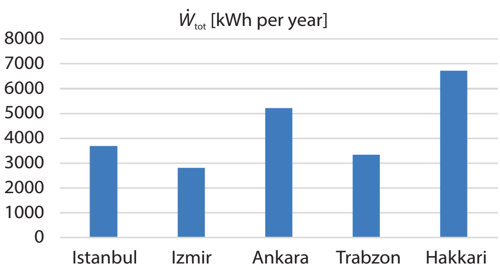

Figure 11. The SAGSHP system total power consumption for different provinces

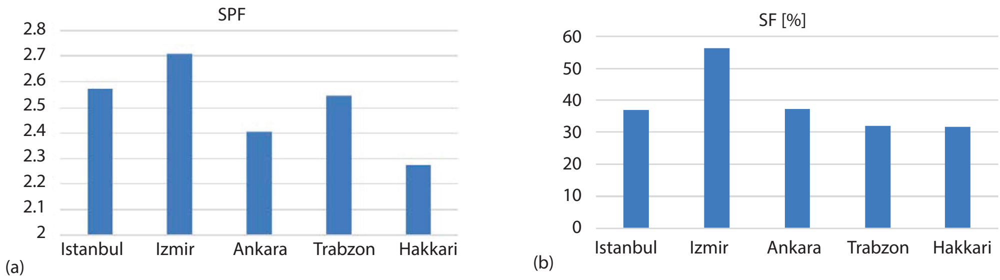

Figure 12. The SAGSHP system values for different provinces; (a) SPF, (b) SF

Table 6. Comparision of results with related literature

Study	Mean temperature	Depth of GHE [m]	Average soil temperature [° C]	Tank volume [m^3]	Building type	Heat pump nominal heating capacity [kW]	Solar collector area [m^2]	Energy consumption [kWh]	Mean COP
[14] (experimental) Dalian, China	–7.5 °C	75	13.8	1	Only water heating in tank	19.7	10.38	–	2.98 (system)
This study (simulation) Hakkari, Turkey	–4.6 °C (January)	100	20	0.35	Water heating and space heating	21.73	12	2.2 (for one hour)	2.55 (system)
[10] (simulation) Zahedan, Iran	18.3 °C (Annual)	120	18.4	1	100 m^2 house	12	3	~7175 (3rd scenario)	3.58 (heat pump)
This study (simulation) Izmir, Turkey	17.9 °C (Annual)	100	20	0.35	112.5 m^2 restaurant	21.73	12	2822	3.34 (heat pump)

Conclusion

In order to contribute to the widespread use of RES in Turkey, a SAGSHP system was simulated for heating and supplying daily hot water needs for a restaurant. Using TRNSYS software, the simulation was performed for five provinces of Turkey, all having different climatic conditions. According to the results obtained, as expected, the highest annual energy consumption was found for Hakkari Province, which has the coldest climate. This value was 2.38 times higher than the energy consumption value for Izmir Province, which has the warmest climate of the studied provinces. Solar energy supplied 56% of the energy consumed by the SAGSHP system in Izmir and 32% in Hakkari. Thus, solar assistance is an important concept in support of GSHP systems for all the studied provinces. The SAGSHP system is important in terms of replacing fossil fuel utilities, reducing fossil fuel usage and using renewable energy resources more efficiently. Therefore, in our country, which has a high solar energy potential, the use of such systems should be encouraged in order to expand the use of renewable energy systems.

Nomenclature

A – area, [m^2]
$\dot{Q}_{ave\_storage}$ – average heat transfer rates in ground storage tank, [kWh]
$\dot{Q}_{cool}$ – rate of useful energy gain by the solar collector fluid, [kWh]
$\dot{Q}_{DHV}$ – heat output for domestic hot water preparation, [kWh]
$\dot{Q}_{load\_hp}$ – rejected heat transfer rate of heat pump, [kWh]
$\dot{Q}_{source\_hp}$ – extracted heat transfer rate of heat pump, [kWh]
$\dot{Q}_{load\_tank}$ – rate at which energy is removed from the tank to supply the load, [kWh]
$\dot{Q}_{loss\_tank}$ – rate of thermal energy loss from tank to the environment, [kWh]
$\dot{Q}_{source\_tank}$ – rate of energy transfer from the heat source to the storage tank, [kWh]
$\dot{Q}_{SH}$ – heat output for space heating, [kWh]
$\dot{m}_{water\_draw}$ – amount of water drawn, [kgh^{-1}]
R_{room} – room relative humidity, [%]
T_{amb} – ambient temperature, [ºC]
T_{ave_soil} – average soil temperature near boreholes, [ºC]
$T_{ave\_storage}$ – average temperature of the ground storage tank, [ºC]
T_{coll} – collector water outlet temperature, [ºC]
T_{GHE_in} – water temperature entering the ground heat exchanger, [ºC]
T_{GHE_out} – water temperature leaving from the ground heat exchanger, [ºC]
T_{load_hp} – heat pump load temperature, [ºC]
T_{room} – room temperature, [ºC]
T_{source_hp} – heat pump source temperature, [ºC]
T_{tank_load} – tank top layer temperature, [ºC]
T_{tank_source} – tank bottom layer temperature, [ºC]
$\dot{W}_{ext\_heater}$ – power consumption of the external heater, [kWh]
$\dot{W}_{fan}$ – fan power consumption, [kWh]
$\dot{W}_{hp}$ – heat pump power consumption, [kWh]
$\dot{W}_{tot}$ – total power consumption, [kWh]
$\dot{W}_{tank\_heater}$ – total power consumption of auxiliary heaters inside the tank, [kWh]
$\dot{W}_{pump\_ground}$ – power consumption of ground pump, [kWh]
$\dot{W}_{pump\_tank}$ – power consumption of tank pump, [kWh]
$\dot{W}_{pump\_coll}$ – power consumption of collector pump, [kWh]
$\dot{W}_{pump\_heating}$ – power consumption of heating pump, [kWh]

Subscripts

WAK – wall adjacent kitchen
WAS – wall adjacent store room
R/F – roof/floor
WDW – western wall of the dining room
WDE – eastern wall of the dining room
WDS – southern wall of the dining room

Acronyms

SF – solar fraction, [%]
SPF – seasonal performance factor of the system

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