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INVESTIGATION OF SOLAR ASSISTED HEAT PUMPS' PERFORMANCE IN DIFFERENT CAPACITY

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Abstract: Interest in renewable energy sources is growing when economic values such as air pollution, climate change and external dependency on the environment are considered in the process of depletion of fossil fuels. Despite of energy supply security ensuring thanks to availability of renewable energy resources, they can not respond instantly. Therefore they are used together with non-polluting or electricity sources such as electricity. In this study, the number of planar solar collectors was changed between 2 and 10, and the coverage ratio of the solar energy in the heating system, coefficient of the performance and the performance factor of the system were examined via POLYSUN simulation program.

Keywords: Air source heat pump, planar solar collector, COP, SPF.

Introduction

There are many studies on the heating coefficient of air, earth, water and solar heat pumps. In these studies, system efficiency is investigated experimentally or with the help of simulation based on different parameters. Comprehensive analyzes were made mostly by simulation and the hot water production performance with small power heat pumps was examined by experiments. Solar energy is widely used as an auxiliary system because increasing the size of the system will increase the cost while sizing the heat pump system according to the house heat loss. Abou-Ziyan et al. (1996) studied the traditional heat pump, conventional solar air heater and two series connected solar assisted heat pump system by computer program. R22, R404A and R134A were used as work fluids. The performance characteristics of the heat pump are investigated using different refrigerants, wide range of evaporator temperatures (0-45 ° C), condenser temperature (50-70 ° C) and air flow (1000-2000 kg / h). Compared to the performance of the heat pump for refrigerants, R134A was found to be a better option than R22 for low temperature applications. In addition, the heating efficiency coefficient of the R134A system has increased by 23% compared to R404A. In Cairo, the performance and operating conditions of conventional solar air heater and solar assisted heat pump systems have been evaluated using one year meteorological data. Solar supported heat pump systems (SDIP) have been found to have the best operating characteristics compared to conventional air heaters and conventional heat pump systems. The use of R134A in the system provides a 50% increase in heating coefficient and a reduction in collector area. In addition, the economic analysis shows that SDIP is a cost-effective system, when compared to conventional heat pump and solar air collector, the values are 0.587 and 0.794, respectively. Georgiev (2008) experimentally examined a system with a heat pump and a planar collector. They used the designed experimental setup during the test period to evaluate the COP and system efficiency (η_s). Consecutive results are as follows: COP and η_s have the highest values at lower condenser temperatures and higher evaporator temperatures. Çağlar (2006) used R407C as refrigerant in experiments conducted in Ankara on 8-23 November 2006 using heat pump and vacuum tube collectors. The system efficiency has been experimentally and theoretically examined by placing the evaporator of the heat pump in the storage tank of the evaporator. He has developed a computer simulation program based on mathematical models

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to study the effects of different environmental, design, and operating parameters on system performance. The theoretical results obtained are compared with the experimental results and the mathematical model developed has been tested for compatibility with the experimental results. As a result, he found the maximum heating efficiency coefficient of solar assisted heat pump to be 4.85. According to the second law of thermodynamics, the heating effect coefficient varies between 4.8-27.4%.

Gündüz (2007) studied the working principle of solar energy supported heat pump and system elements in Bilecik province theoretically. She investigated coverage ratio of energy amount from solar collectors for heating system and domestic hot water usage. R134A is used as refrigerant in heat pump. She found that the heat load in the evaporator was 6.04 kW, the electric power of the compressor was 3.84 kW by using the thermodynamic properties of the refrigerant. She found COP of system as 3.1 and indicated additional heater is needed in December, January, February, March, April, May and June. Ceylan (2010) analyzed the heating of a two-story building with solar energy-assisted air-source heat pump. She studied the performance of an air-source heat pump and solar energy in a harsh winter region such as Ankara. The heat loss of the building was calculated as 19.2 kW, the heat pump of 18.5 kW was chosen and the collector of 13.92 m^2 was used. As a result, it compares this system with the natural gas system and calculates that it will save 580.2 m^3 per year.

Açıkgöz (2007) calculated the support of solar energy in a composite energy power system. In the first case, only the heat pump is used to heat and cool the building. In the second case, domestic hot water needed of building is provided with two flat plate collector, and the building is heated with a ground source heat pump. As a third option, twenty five flat plate collectors are added to the heating system to support both use water and heating. Compared these three options and concluded that the use of the collector is more useful for heating hot water. Because meeting the heating needs of the house with the collectors increases the initial investment cost of the system. In this study, the coverage ratio in the system was examined by increasing the solar collector area. First, an air source heat pump at low capacity was selected and the number of solar collectors was increased to investigate the availability of demand. Secondly, the heat pump was selected at a sufficient capacity and the decrease of the thermal energy value given to the system by the heat pump and the solar energy coverage rate were examined as the number of solar collectors was increased. Other parameters examined are consumed electricity, thermal energy from solar energy, coefficient of performance and seasonal performance factor. The difference between this study and the other one is that in Turkey a heating and usage hot water requirement of a villa in Muğla province is analyzed with POLYSUN simulation program.

Material and Methods

Solar energy has been used for heating, hot water production, drying and cooking for centuries. Today it is used for hot water production and heating purposes and has not yet become widespread enough. In this study, coverage ratio of solar energy on heating and domestic hot water is found by means of a simulation program. Analyzes are made with the POLYSUN simulation program, which provides a wide range of functionality for the design and analysis of local energy systems. Correctness of POLYSUN which is simple to use and time-saving are proven with other programs. The correctness of the results for a given zone depends on the availability of real data such as solar energy radiation, humidity, wind and temperature. The meteorological data in the program is provided via the Meteonorm database. Meteonorm is based on measurements from 8055 weather stations around the world. For a given region, the data of the nearest weather station is obtained by interpolation. Another method is to be introduced the meteorological data by us. The simulation is started by inputting the meteorological data, the annual heat requirement of the villa, annual heat loss, usage hot water requirement and location data. Once these values are entered, the appropriate heat pump, tank, flat plate solar collectors and radiator are selected for the heating system. Generated heat values and consumed electricity values for all system parameters are calculated.

The energy requirement of the dwelling was calculated as 16257.3 kWh and it was introduced to the system. POLYSUN, a semi-dynamic simulation program, estimates consumption at intervals of 10 minutes considering the values entered. It is possible that the energy given to the system by the heat pump is large or equal but the low level causes the energy claim to fail. The system model used to meet the villa's thermal energy requirement is shown in Figure 1.

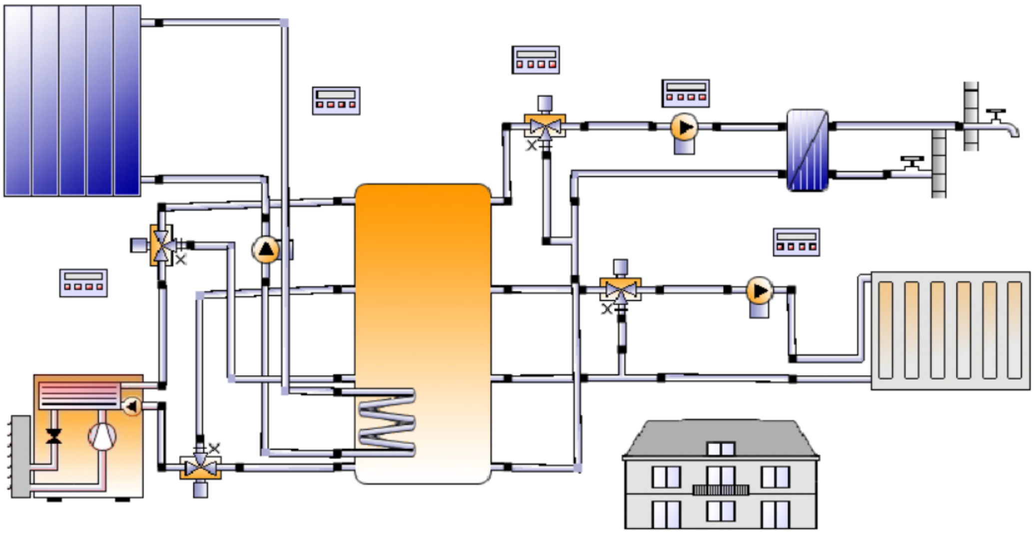


Figure 1. Solar collectors and air-source heat pump assisted heating system (Vela Solaris).

The heat pump capacities were selected as 7.98 kW and 15.34 kW and the number of collectors was 0, 2, 4, 6, 8 and 10, in other words, the parameters were changed between 0-20 m^2 and some parameters were investigated. These parameters are;

- Thermal energy from heat pump,
- Total electricity consumed,
- Thermal energy from solar energy,
- Solar energy's coverage rate,
- Change in the coefficient of performance and seasonal performance factor.

The air data for the Mentese region where the villa is located is taken from the meteorology general management for 2015-2016. It is observed that the average temperature of the outside air does not fall below 5 ^{0}C during the winter season. Wind speed values on an annual basis also create an ideal environment for the use of air source heat pumps. Because high wind speeds at low temperatures interfere with heat transfer in the heat exchanger, making it difficult to absorb heat on the surface of the solar collector by the fluid.

Villa's annual heating energy requirement and heat loss calculations were made using the TS 825 Building Thermal Insulation Rules and TS 2164 Heating System Project Procurement Rules standards. The basic parameters related to the energy consumption of the villas, the amount of thermal energy required for annual heating and hot water preparation, the solar collector used, the storage tank and the circulation pumps are given in Table 1.

Table 1. Basic parameters related to the energy consumption of the villa

		Value	Unit
Heat request	Annual heat demand	16257.3	kWh/year
	Annual domestic hot water demand	1870.3	kWh/ year
	Annual ambient heating request	14387	kWh/ year
Solar collectors	Collector field	2	m^2
	Gross area	1.8	m^2
	Absorbing field	1.8	m^2
	η_0 (laminar)	0.80	
	A1	3	W/m^2K
	A2	0.01	W/m^2K

Table 1.$^{(cont.)}$

Tank	Tank volume	200	lt
	Length	1.2	m
	Thermal conductivity of	0.03	W/(m.K)

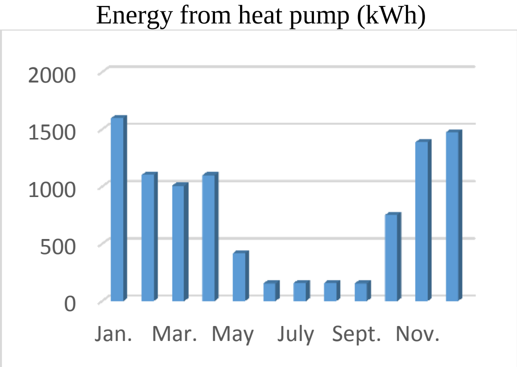
	insulation		
	Insulation thickness	80	mm
Pump (solar)	Flow	1-1000	l/h
	Power	6	kW
Pump (heating and hot water)	Flow	1-1000	l/h
	Power	6	kW

Results and Findings

The heat pump capacity was selected to be 7.98 kW and the coverage ratio of demand was investigated by increasing solar collector fields. The results show that the heat pump capacity is insufficient. Two collectors are sufficient to meet the domestic hot water requirement. The amount of thermal energy given to the system by the heat pump and the electricity consumption values have not changed when more than two collectors are added to the system. The amount of thermal energy supplied by the heat pump and the amount of electricity consumed are shown in Table 2 for systems where zero and two collectors are used. The thermal energy provided by the heat pump are 9468 kWh and 8842 kWh, respectively, depending on the use of 0 and 2 collectors. Amount of electricity consumed for the heating and domestic hot water supply are 3762 kWh and 3616 kWh respectively in case of using 0 and 2 solar collector. Decrease of the thermal energy and electricity consumption is due to solar collectors meet the domestic hot water demand during summer.

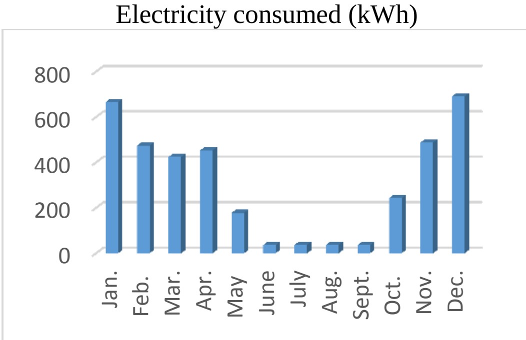
Table 2. Thermal energy and consumed electric energy given to the heating system by the heat pump of 7.98 kW

Energy from heat pump (kWh)

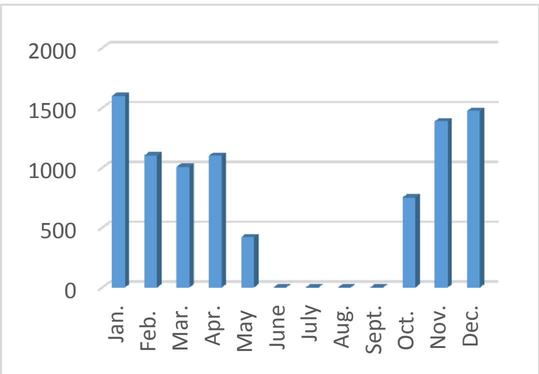


0 collector

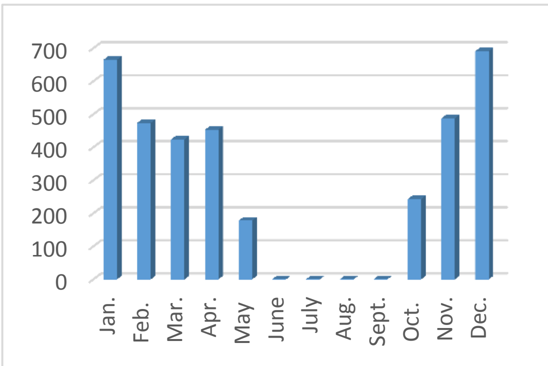
Electricity consumed (kWh)



0 collector



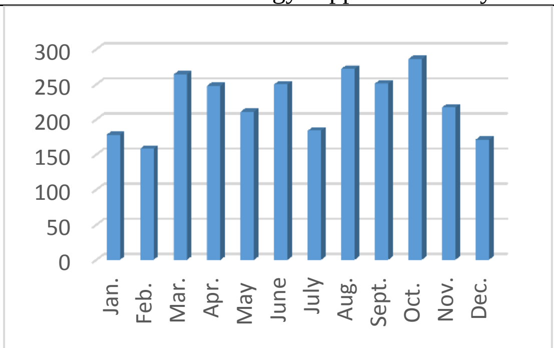
2 collector



2 collector

Heating of villa and hot water demand are provided by solar assisted air source heat pump. The distribution of the thermal energy amount supplied to the system from solar energy by month is shown in Table 3 by adding 2, 4, 6, 8 and 10 solar collectors. In case of adding 2, 4, 6, 8 and 10 solar collectors to the system, the solar thermal energy values provided to the system are 2690 kWh, 3654 kWh, 4176 kWh, 4533 kWh and 4577 kWh respectively.

Table 3. Solar energy supplied to the system in the 7.98 kW heat pump heating system (kWh)



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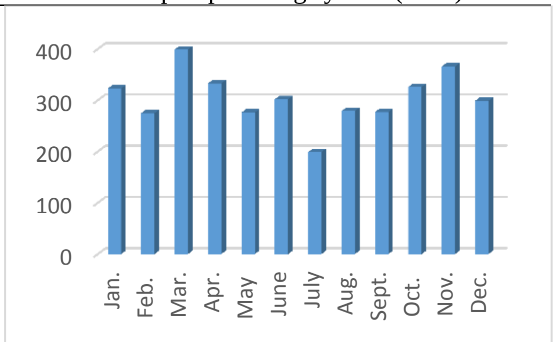
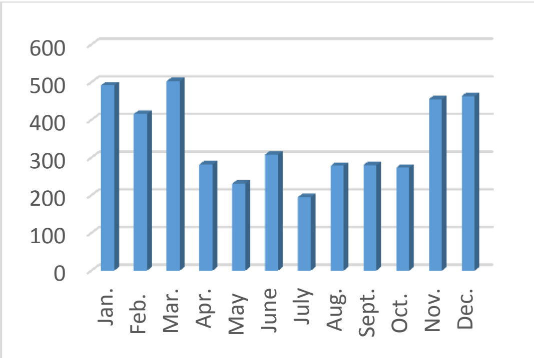
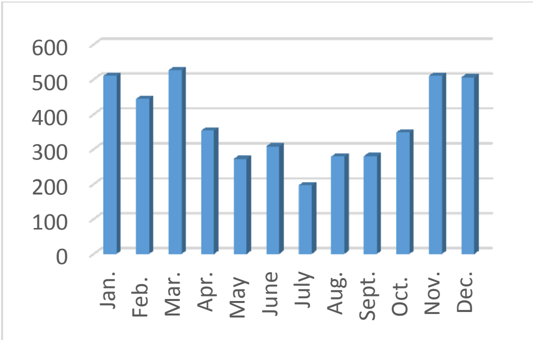


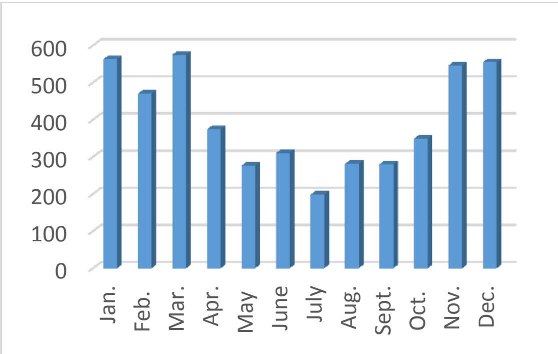
4 collector



6 collector



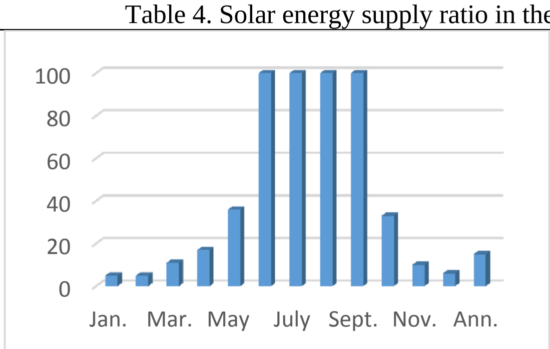
8 collector

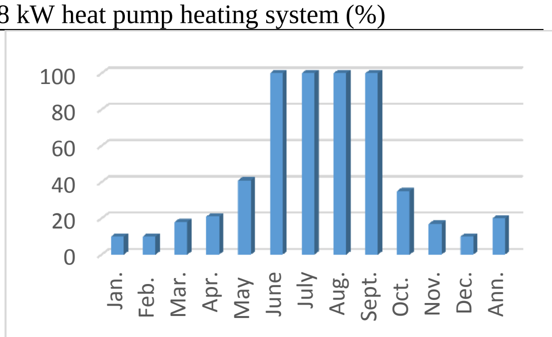


10 collector

Flat plate solar collectors are generally used to meet the usage hot water requirement. It is also used in residential heating. When it can not meet heating requirements unaided, it is operated as hybrid with reliable conventional sources. In this study, collector areas were increased and the situation of demand satisfaction in the system was examined and the distribution according to the month is shown in Table 4. Even if the collector area is 20 m^2, the request can not be met. According to the cases where collector numbers are 2, 4, 6, 8 and 10, the demand coverage percentages in the system are 15%, 20%, 23%, 25% and 26% respectively. In summer period (June-September), the rate of demand coverage is seen as 100% when the use of hot water is only provided by collectors.

Table 4. Solar energy supply ratio in the 7.98 kW heat pump heating system (%)





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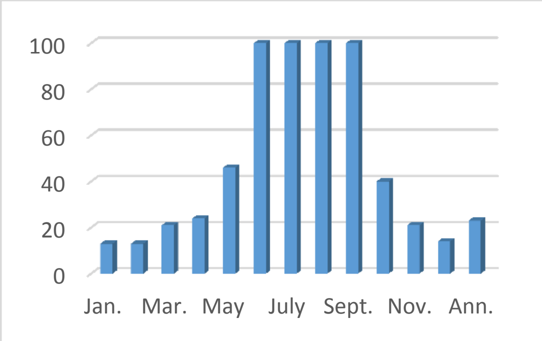

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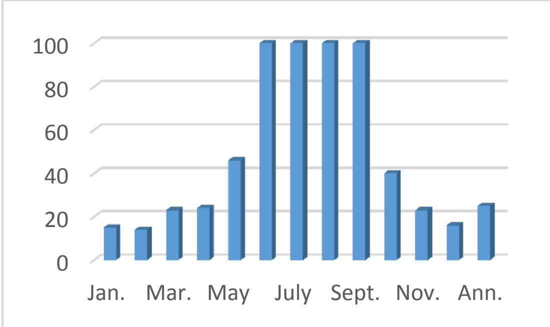
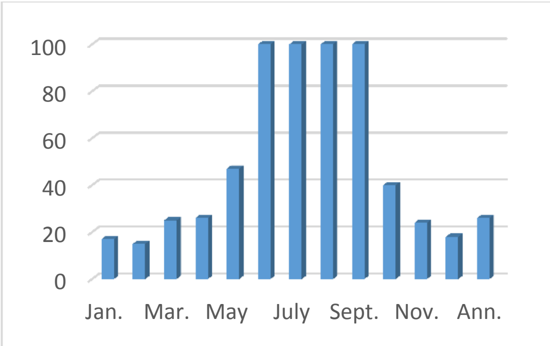


8 collector

6 collector

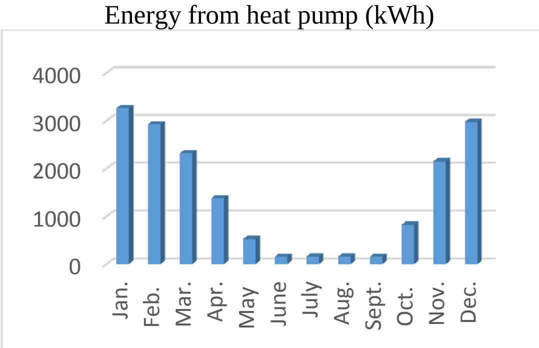


10 collector

The number of solar collectors was changed to 0, 2, 4, 6, 8 and 10 by keeping the heat pump capacity (15.34 kW) constant. The distribution of thermal energy values provided to the system from the heat pump according to the number of collectors is given in Table 5. In the case where the collector is not used, it provides 16965 kWh of thermal energy per year from the heat pump and consumed electric energy is 5669 kWh. It is seen that the most energy consumption is in January and December. When two or more collectors are added to the heating system, the use of domestic hot water in summer is covered by the collector. For this reason, the energy consumption in the summer months is only due to circulation pumps and it is seen to be 1 kWh. When two collectors are added to the system, the thermal energy provided by the heat pump is reduced to 15940 kWh and the total electricity consumed is reduced to 5572 kWh. When four collectors are added to the heating system, the thermal energy provided by the heat pump is reduced to 15168 kWh and the electricity consumed is reduced to 5399 kWh. When six collectors are added to the heating system, the thermal energy provided by the heat pump drops to 14566 kWh and the electricity consumed is reduced to 5282 kWh. When eight collectors are added to the heating system, the thermal energy provided by the heat pump drops to 14299 kWh and the electricity consumed is 5236 kWh. When ten collectors are added to the heating system, the thermal energy provided by the heat pump drops to 14076 kWh and the electricity consumed decreases to 5179 kWh.

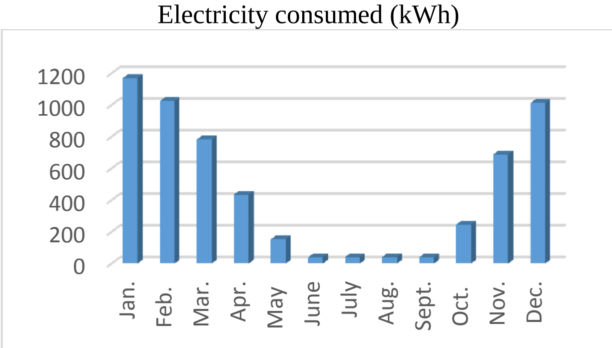
Table 5. Thermal energy and consumed electric energy given to the heating system by the heat pump of 15.34 kW

Energy from heat pump (kWh)

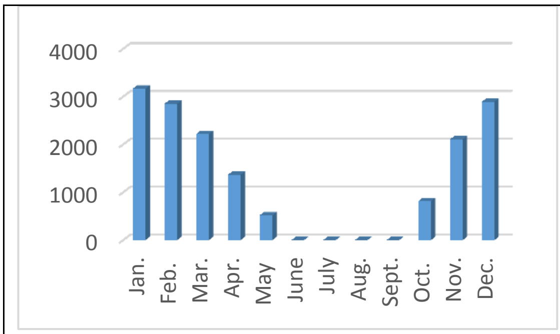


0 collector

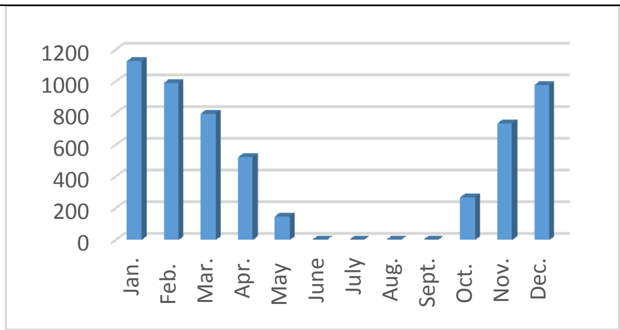
Electricity consumed (kWh)



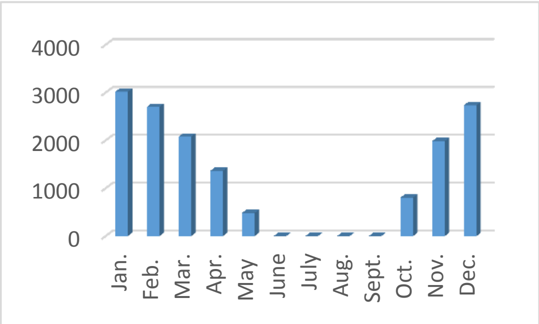
0 collector



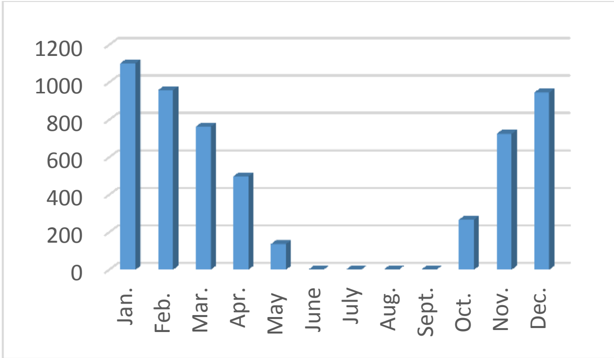
2 collector



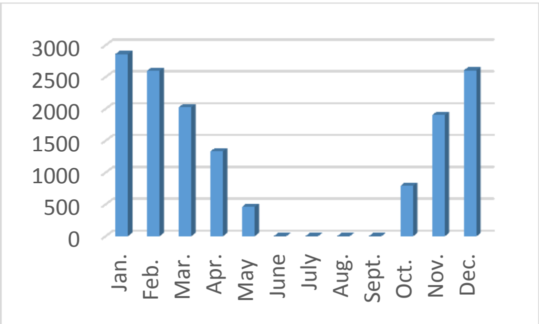
2 collector



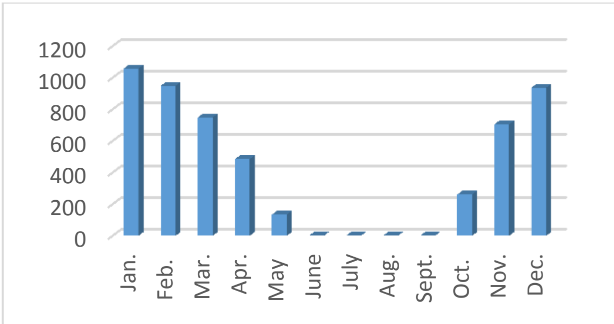
4 collector



4 collector

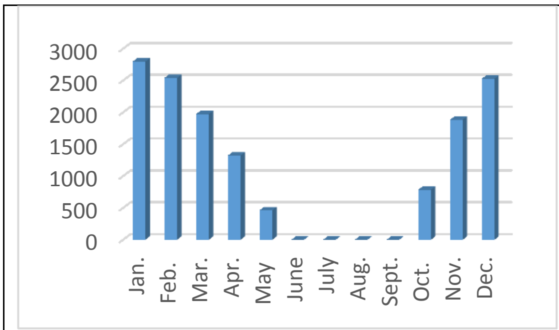


6 collector



6 collector

Table 5. (cont.)



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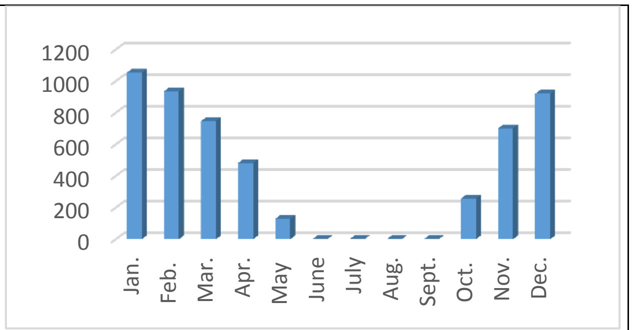

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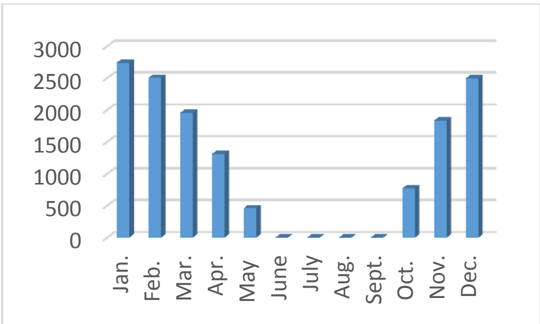
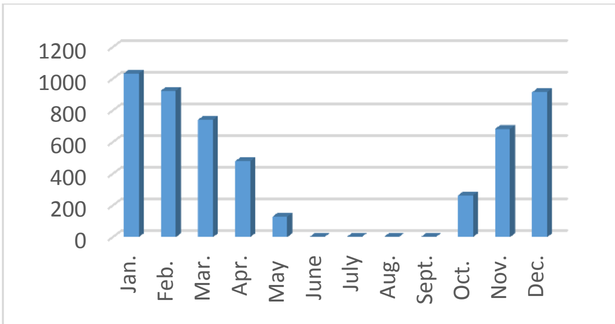


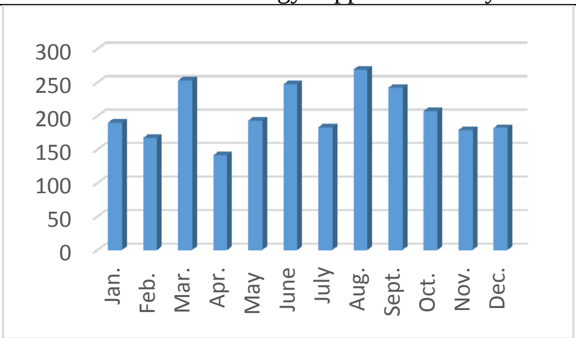
10 collector



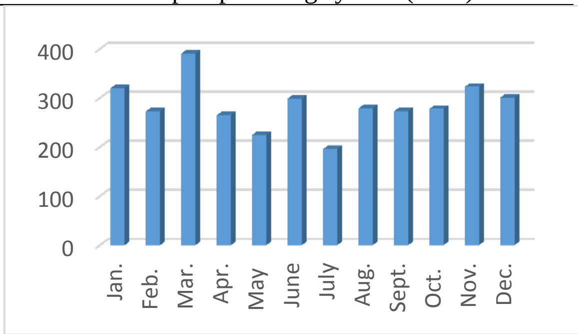
10 collector

The change of the energy given to the system depending on the solar collector area is given in Table 6 monthly. The amounts of solar energy given to the system according to the 2, 4, 6, 8 and 10 collector additions to the heating system are 2453 kWh, 3423 kWh, 4095 kWh, 4396 kWh and 4630 kWh.

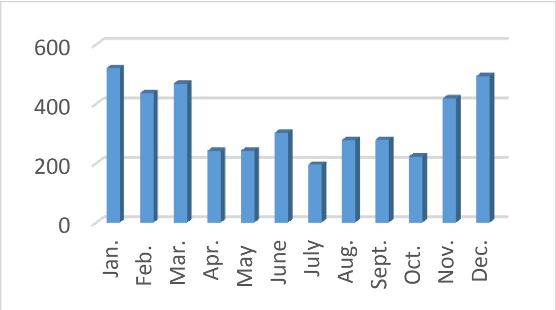
Table 6. Solar energy supplied to the system in the 15.34 kW heat pump heating system (kWh)



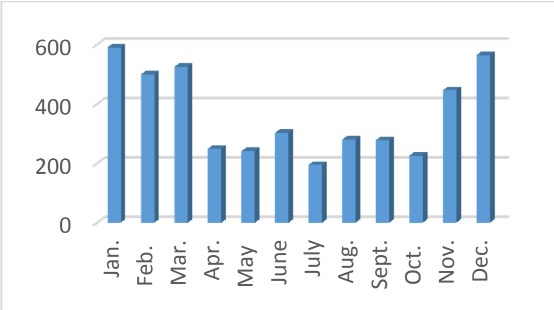
2 collector



4 collector

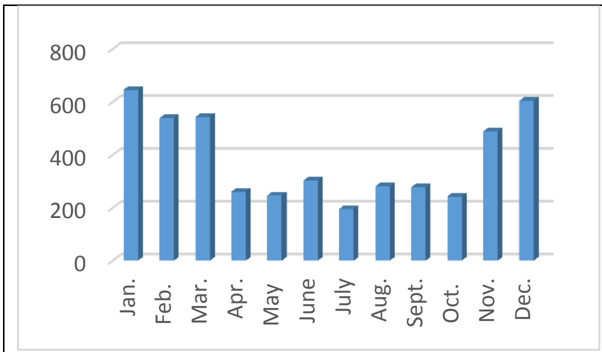


6 collector



8 collector

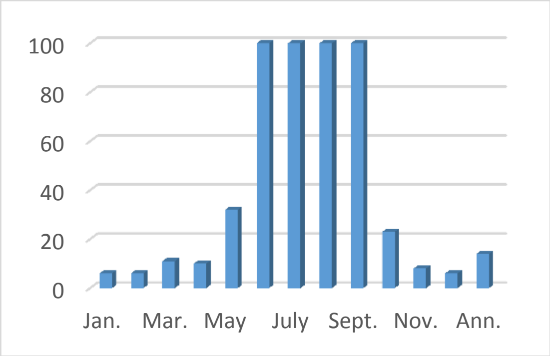
Table 6.(cont.)



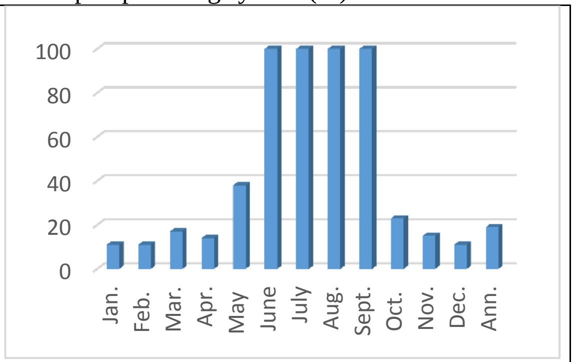
10 collector

When a 15.34 kW heat pump is used in the heating system, coverage ratio of solar energy is shown in Table 7 according to collector area. In summer period (June-September), coverage ratio of solar energy is seen to be 100% since all domestic hot water need is provided by collectors. When two collectors are added to the heating system, the demand coverage ratio of the system is 14%. It seems that even in the coldest periods such as December and January, 6% of the energy demand is met. When four collectors are added, the demand coverage ratio of the system is 19% annually, and is 11% in December and January. When six collectors are added, the request coverage ratio of the system is 23% and is 16% in December and January respectively. When eight collectors are added, the demand coverage ratio of the system is 24%, and is 18% in December and January respectively. When ten collectors are added, the request coverage rate in the system is 26%. Even in the coldest periods, such as December and January, the energy demand seems to meet 20% and 19%, respectively.

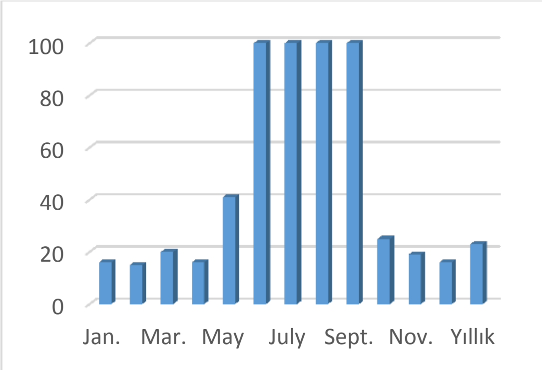
7. Solar energy supply ratio in 15.34 kW heat pump heating system (%)



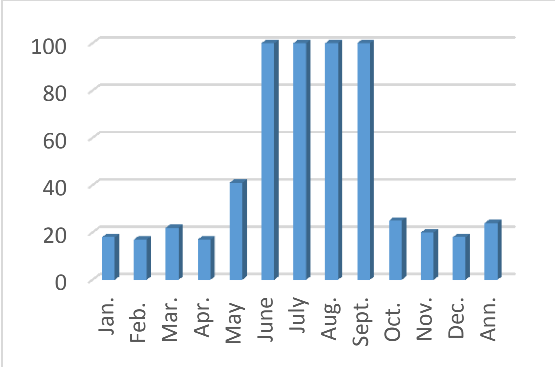
2 collector



4 collector

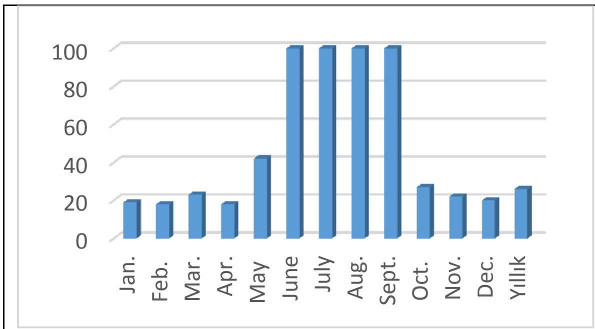


6 collector



8 collector

Table 7.(cont.)



10 collector

Simulations show that as the area of the planar solar collectors increase, the performance factor of the system increases but the coefficient of heating effect decreases, and the results are shown in Table 8. The use of the heat pump at two different capacities has been examined and a case study has been carried out by increasing the number of collectors for the times when the 7.98 kW heat pump alone failed to meet the demand. While the COP (coefficient of performance) of the heat pump decreased from 2.59 to 2.52, the seasonal performance factor (SPF) of the system increased from 2.52 to 3.29. Since solar energy is primarily used when solar energy is available, there has been a decrease in the operating hours of the heat pump. Since the tank volume is 200 litres, it is obligatory to use a heat pump for the evening hours.

Table 8. Change of the SPF and COP according to solar collector area.

	Solar collector area (m^2)	SPF	COP	Operating hours (yearly)
7.98 kW	0	2.52	2.59	3466
	4	2.73	2.52	2942
	8	3.02	2.52	2652
	12	3.15	2.52	2530
	16	3.22	2.52	2469
	20	3.29	2.52	2480

	Solar collector area (m^2)	SPF	COP	Operating hours (yearly)

15.34 kW	0	2.99	3.03	5615
	4	3.04	2.9	2804
	8	3.17	2.85	2643
	12	3.24	2.8	2562
	16	3.27	2.77	2434
	20	3.3	2.76	2427

The other heat pump has a capacity of 15.34 kW and can meet the demand for thermal energy alone. Looking at the annual operating hours, it seems that it gives more energy to the system than the other. While the COP decreased from 3.03 to 2.77, the SPF of the system increased from 2.99 to 3.27.

Results

The heat pump capacity and the number of solar collectors are changed and the thermal energy provided by the heat pump, the electricity consumed, the solar energy given to the system, the solar energy coverage, change of the COP and change of the SPF have been examined. It is not a viable solution to increase the number of collectors when the demand can not be met by the heat pump alone. The performance factor of the system has increased because the amount of electricity consumed decreases as the number of collectors increases. Heat pumps operate at high efficiency with high evaporator and low condenser temperature. As a result, the tank temperature increased due to the increase in the collector area and the heating effect coefficient of the heat pump decreased. It was also observed that the working hours of the heat pump decreased depending on the collector area. When the SPF according to the heat pump capacities were examined, it is seen that it changes between 2.52-3.29 for 7.98 kW and 2.99-3.30 for 15.34 kW. When the COP according to the heat pump capacity were examined, 2.59-2.52 for 7.98 kW and 3.03-2.76 for 15.34 kW decreased. Provide with the domestic hot water usage with solar collectors has reduced electricity consumption. In the summer period, all of the domestic hot water need is met by collectors and electricity is used for water circulation only. If it is considered that the entire energy requirement of the house is to be covered by collectors, a large volume tank should be selected for thermal storage and a separate tank for heat pump should be used. Increasing the number of collectors not only increases the cost of initial installation but also causes difficulty in implementation in apartment buildings.

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