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Experimental investigation on the influence of using a solar assisted geothermal exchange system (SAGES) on the coefficient of performance (COP) of a traditional heat pump case study in Palestine

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Abstract: This study presents an experimental invetigation on the influence of using a solar assisted geothermal-horizontal loop solar assisted heat pump on the performance, this was built using a traditional heat pump. Heat pump performance was tested in four seasons year round operation (heating and cooling).

Palestine, as a developing country, confronts considerable energy issues. In this setting, renewable energy sources provide people renewed hope. Solar and wind energy, as is generally known, are substantial energy sources; however, both forms of energy are intermittent, unpredictable, and expensive to store. The aforementioned reasons make geothermal energy important and worthwhile to examine. The purpose of this research is to test a hybrid solar-assisted horizontal ground loop heat pump (SSHGLHP) in a temperate Mediterranean or semi-arid region. Such systems demonstrate practicality as a prospective and promising source of heating and cooling for residential buildings. The results indicated that the COP of a conventional electric heat pump increased from 3.5-4 to 7 in cooling mode. According to the economic analysis, suchsystems are feasible with a SPBP of 4 years.

Keywords: Solar systems, heat pump, Renewable Energy, cooling systems, heating systems. Geothermal Heat Pump, Building Energy systems, Geothermal Energy, Sustainable Development, Mediterranean Climate.

1. INTRODUCTION

Conventional energy resources, unlike renewable energy resources, are ecologically detrimental, according to (Moatey, P. et al. (2021). Wind and solar energy are sporadic and unpredictable. Palestine suffers from a lack of power and access to energy resources. With today's harsh weather conditions, having control over the environment in both winter and summer has become essential. Because room heating and cooling systems consume a lot of energy. It is now vital to investigate the possibility for new and low-cost HVAC systems. Geothermal energy is one of the most essential ways to save energy since it takes use of the consistent temperature below ground level to provide a better starting for the heat pump rather than the cold weather in winter,and hot weather in summer. It is known in the literature that beyond 2 meters down, the temperature is between 15-17 °C, which is fairly good as a starting point rather than zero or below, which certainly cuts energy expenses and improves system efficiency. The primary goals of this research are to examine the GSHP and its potential in Palestine, as well as to compare the economic and environmental benefits of air source heat pumps with ground source heat pumps.

2. LITERATURE REVIEW

The significance of this article is that it assessed the technical and economic aspects of the combined GSSAHP, as well as the environmental effect of that system in comparison to the traditional system. To the best of our knowledge, only a few publications in the literature documented the horizontal loop geothermal heat pump paired with a solar collector. (Ye-Shuang Xu et al.(2020)) summarized the shallow ground resources heat pumps in China. The author divides the geothermal resource into five areas. He discovered that the (COPs) of the GSHP system were not high, and their utilization rate was still low when compared to other renewable energy resources. For improving the utilization efficiency of SGE, he proposed strategies such as updated technologies, a management system, a feasible evaluation, plan utilization, intelligence environmental effect assessment, and intelligence monitoring. (Y. Al-Douri, (2019)) investigated Saudi Arabia's geothermal energy reserve and potential. The authors proposed prospective geothermal energy applications for future usage and emphasized on keeping a green and clean environment and improving environmental quality. (Yuqing Wang et al, (2020)) evaluated the state of geothermal energy in China and examined the issues he uncovered in laws and regulations, technical progress, financial investment, and environmental protection. He made several suggestions for boosting geothermal energy in China. (Sayed Hamdan et al, (2018)) describes dynamically designing and simulating GSSAHP with five scenarios. The scientists assessed the COP and power consumption, as well as simulated soil temperature for 10 years. They discovered an improvement in

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power consumption for GSSAHP and the stand-alone geothermal heat pump, with an 8.7 percent reduction in consumption. They also discovered that the highest yearly mean COP was 3.75. GitiNouri et al. (2019) investigated the optimization of a solar-assisted ground source heat pump system for heating, cooling, and DHW. He ran three configuration simulations for a combined solar-ground source heat pump and discovered that the house temperature, HW storage, and soil were all within the intended range in all cases, as well as a COP of 4 for the Parallel indirect expansion mode. (2019) N. Shah et al. proposed using a solar integrated with GHP and conducted a study comparing six different types of solar integrated GHP based on various factors: photovoltaic system combined with a boiler and a vapor compressor chiller, heating and cooling effect when the photovoltaic system is integrated with a backup boiler, photovoltaic system integrated with a reversible heat pump, solar energy in accordance with a backup boiler, solar energy in accordance with a backup boiler, and integrating the previously combined solar energy and backup boiler to vapor compressor chiller. Finally, solar energy combined with a reversible heat pump is used to provide heating and cooling effects. His goal was to minimize CO2 emissions, and the authors discovered that using geothermal energy may cut emissions from 1.08 tons to roughly 0.05 tons, which is 21 times less than using fossil fuels. The writers of Reference (Corey Blackman et al, (2015) conducted a techno-economic study for solar photovoltaic and solar thermal cooling systems for home renewable energy retrofit. The research was focused on possible energy and cost reductions based on simulated heating and cooling loads in Madrid, Spain. Simple models were utilized to compute the heating and cooling demands, as well as the solar energy contribution to heating and cooling loads. Additionally, given the sorption collector's unique potential to store solar energy thermally and offer cooling at night an analysis has been carried out to find the combined advantage of solar-assisted heating and cooling via photovoltaics during the day and solar sorption at night. The integrated solar-geothermal systems in heating systems were described by (Shah, Manan, et al., 2018). The combined solar-geothermal systems in heating systems were discussed. The authors discovered that ground can be used as a heat source or sink, and that solar photovoltaic can be used to power the system's electrical components such as pumps and the building if excess energy is generated, proving that the system was more feasible than conventional cooling systems powered by electricity. In (Badiei, A. et al., (2020)), the authors conducted a comprehensive review of solar PV assisted heat pump technology advances in the twenty-first century and discovered that integrating Photovoltaic/Thermal collectors with heat pumps for simultaneous heat and power generation improved the COP and reliable operation of systems under severe operating conditions. (Hansani Weeratunge, (2018)), He used a mixed-integer linear programming model to optimize the operating cost of a SAGSHP system based on time-of-use power prices (peak, off-peak). He claims that the system with integrated thermal storage enhanced peak load cutting and reduced operating costs by 7.8%. In Jordan (Aydadi, (2014)) article published on a ground source heat pump for the green restoration of the higher council for science and technology building which was successful and succeeded. Shallow Geothermal Energy Resources for Future Utilization in Jordan (S. Al-Zyoud, 2019) was examined. The author discovered that the water temperature in some fields may reach 68.5 degrees Celsius. There were five different heat source possibilities addressed. She stated that geothermal potential in Jordan is projected to evolve as a result of NS trending Dead Sea Rift activity. She noted that it is critical to evaluate Jordan's geothermal energy potential for future use. (Ismael S Al-Hinti, (2017) produced ground temperature profile measurements and modeling in Zarqa, Jordan for geothermal heat pump applications. With the aid of the data, the author updates a basic semi-empirical model that was constructed to forecast the temperature profile as a function of time, depth, mean ground surface temperature, and soil parameters. Yaqoub Al-Khasawneh (2019) researched ground-source energy uses. Heat Pumps for Residential Buildings in Jordan, the authors proved that a Ground source heat pump is efficient and ecologically beneficial. With a 60 percent yearly savings, the project saved a significant amount of money during its lifetime. Comparisons of ground and air source heat pumps in hot/dry areas are made in the publication (Alshehri, F., Beck, S. o, (2019)).

3. APPARATUS STRUCTURE

The A model for GSSAHP with a capacity of 2.6 kilowatt was designed and produced. The system was planned and installed; the ground loop was sunk into the ground as shown in figure 1, and the condensing unit was immersed in a 175-liter galvanized steel insulated tank measuring 50x50x70 cm. The equipment was outfitted with a 150-liter-per-minute circulating pump and an 8-meter-long Wilo PH123-E head. The ground loop consistedi. The dug hole was 12 meters long, 2.5 meters broad, and 2 meters deep inside the Court figure 1. Pipes were installed in two rows and two layers, with 100 cm between centers. The slinky loops pattern with a distance of 15 cm gap. According to the energy label, the unit was tested before being dismanteled at the plant for a cop of three.

(a)

(b)

Figure 1a: Installed system loops **Figure 1b** condensing unit inside the loop

4. METHODOLOGY

4.1 Method of the experiment

The steps in the procedure are as follows:

1- The air source heat pump was tested before connection to the ground loop.

2. Fabrication of GSSAHP, and testing the thermodynamic characteristics for the refrigerant at inlet-outlet of the evaporator, condenser, compressor, and throttling valve.

3. Operating and testing the system linked to the ground in summer mode, recording all properties as well as water in and out of the ground Tin, total ground temperature Tg, water flow rate, and power consumption.

4. The same attributes were observed when the system was connected to a solar water heater and ground and operated in heating mode. This test was performed on a 2.6 kW split unit sample, and the findings obtained were extrapolated for a 30 kW unit for a conventional dwelling. The economic and environmental assessment was conducted for the 30 kW unit.

4.2 Assumptions

We assumed the following in our study:

1- Adiabatic system with minimal heat loss in the tank or pipelines, isentropic pump and compressor.

2- A average home's heating and cooling load was considered to be 30 kW.

The 3-degree day technique for heating and cooling was used to calculate consumption in both scenarios for heating and cooling as an approximation to real operating conditions and 24 hour operation 90 days of summer and 90 days of winter.

4- Compilation The present value was calculated using a 10% interest rate for 20 years.

5- All estimates were based on an average day derived from real-world data.

5. RESULTS AND DISCUSSION

5.1 Preliminary Experiment

The equipment was tested for confirming COP conformance to the manufacturer label. According to the refrigerant PT diagram, the discharge line temperature was 75°C, which corresponds perfectly to the data for R410a at 364 psig. The evaporator's temperature dropped to -5°C before reaching equilibrium at 0°C. The temperature at the evaporator exit was 12°C. The water temperature climbed from 26°C to 30°C throughout the first three days. The tests were performed on several days between June 12 and August 30, 2020. For the ground loop, the heat rejected in the condenser or heat absorbed from the evaporator was added to the compressor work, or in other words, the heat capacity of water in the tank less heat losses through the tank to the surrounding negligible and adiabatic system. At this point, the load was equal to the capacity, which was defined as the energy produced by the heat pump to raise the temperature of the load, which was water.. The energy that must be dissipated in the ground loop can be calculated by multiplying the water mass in the tank by the specific heat of water times the temperature difference between the initial and final states, which was 5°C, divided by the time period between the initial and final states, which was 2.6kW, to yield the heat pump's capacity of 2.6kW. The highest temperature at the condenser intake was 75°C. The Evaporator air-supplied temperature was 12°C out. The maximum COP refrigeration cooled down to -5°C using the Carnot COP formula, then the temperature change began to attain equilibrium air supplied temperature of 12°C. When the Carnot COP formula is used, the maximum COP is given by (1):

$$COP\ crt = \frac{(\text{Tc in kilven})}{(\text{change in temperarure})} = COP\ crt = \frac{(273+12)}{(75-12)} = 4.5 \qquad (1)$$

The determined COP from the data gathered was =3.34, although the rated COP according to the manufacturer was 3.22 upon cooling with a 3.7% increase. Figure 2 depicts the COP vs temperature differential of the evaporator for a sample test on June 12, 2020.

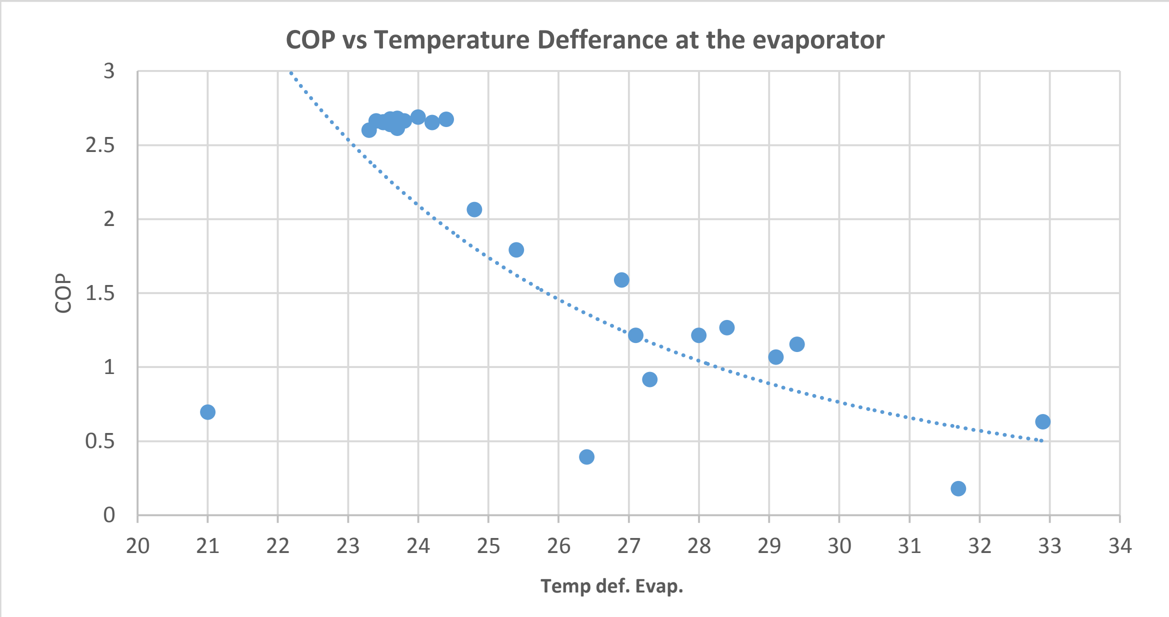

Figure 2: COP versus Temperature Difference at the evaporteor

The compressor power utilized was computed by multiplying the voltage and current by the power factor, which was 0.28 kW at first and increasing to 0.375 kW after an hour.

5.2 Cooling Mode GSHP

Here the System was connected to the ground loop prepared four months before this time to reach equilibrium underground after being disturbed. Data was taken for August and September for the refrigerant properties, water, and ground. Which was on average 17 °C. The Average room temperature during the experiment was 26°C. The temperatures of water entering and leaving the ground source heat exchanger were plotted The water flow through the ground heat exchanger was measured as a function of time. Figure 3 depicts the GSSAHP source minus out temperature at cooling in June 2020, which was 17% higher than air-source HP. Figure 4 depicts the behavior of the heat pump's COP when the work of the circulating pump is ignored. When the work of the circulating pump is calculated, the COP increases in comparison to the literature. Because the refrigerant requires some time to complete the cycle, the energy transferred per unit time from the evaporator to the condenser gradually increases. Another reason is that the energy transferred by the heat pump is a function of time; as time passes, the temperature of the water surrounding the condenser rises, and the energy accumulates and builds up. This means that the heat absorbed in the evaporator, which is a function of time divided by work consumed, will almost certainly behave similarly.

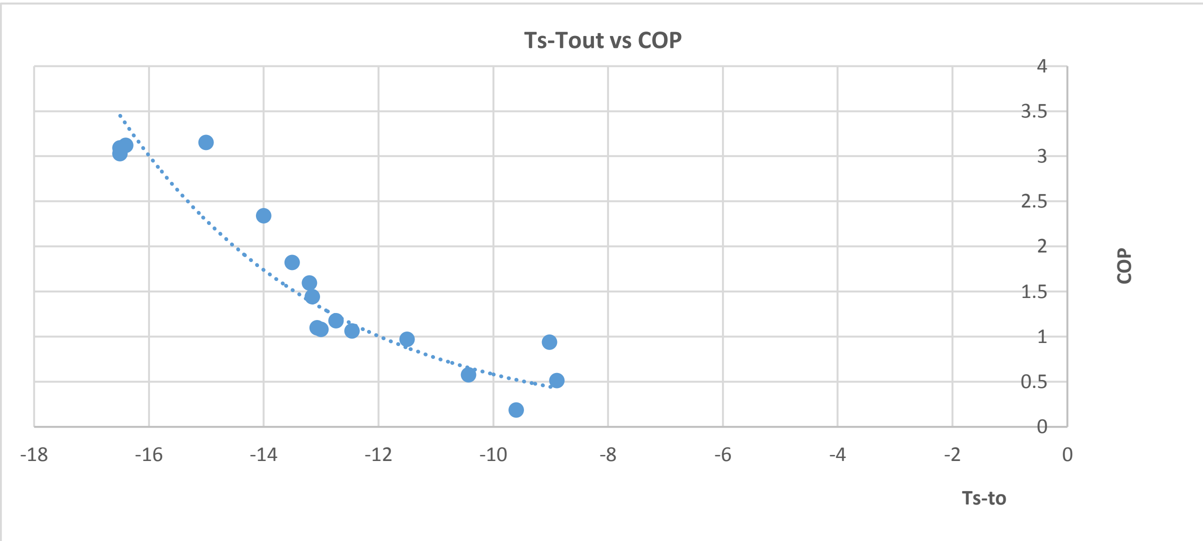

Figure 3: Temperature difference of source and out vs cop cooling GHP

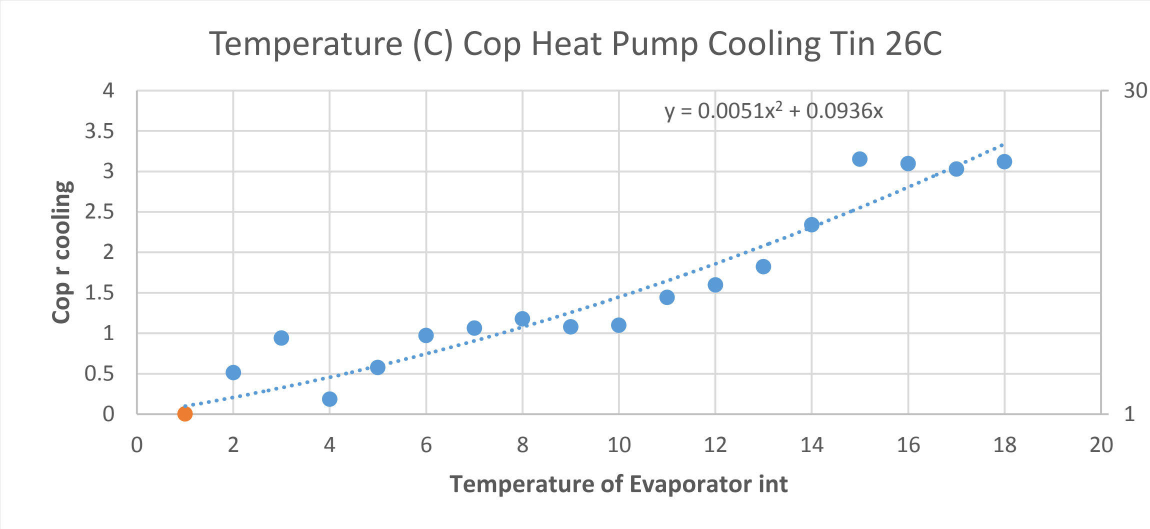

Figure 4: Temperature of evaporator for GSHP vs COP at cooling mood

To be more specific, the heat from the evaporator was calculated from the main equation that defines, so the heat rejected in the condenser was the sum of the heat absorbed in the evaporator and the work done by the compressor. Add the work done by the pump, as shown in (2) and (3):

$$COPh, geo = \frac{Qh}{Wcomp+w\ pump!}\ \ and\ similarly\ for\ cooling \quad (2)$$

$$COPc, geo = \frac{Qc}{Wcomp+w\ pump!} \quad (3)$$

A good COP for geothermal heat pump was obtained by taking the power consumed by the pump and the compressor and 7 neglecting the power consumed by the pump, which was close to 25% of the power consumed by the heat pump due to the oversize of the pump as the pumps available on the market a larger COP could be achieved for smaller pump size. The needed power could be 110 watts less which is negligible compared to compressor power it presents 3% of the power, the COP of the GSSAHP will reach 6. In comparison to the COP tested, the geothermal heat pump was found to be efficient for the following reasons. First, water has a higher heat capacity than air, resulting in more rejected heat and a higher COP. The second was the ground temperature which was at least 15°C in winter less than the ambient temperature improves the heat rejection for the same power input. Third, for extreme outdoor conditions, a larger heat pump was required for the same room as Ta increased. Unlike geothermal heat pumps, where Tg is nearly the same in different areas. The smaller the flow, the better the COP, assuming the water stays in the underground loop for a longer period of time, improving heat exchange.

5.3 Heating Mode GSHP

The heating mode experiment was carried out between December and January of the year 2021. The heating was done in the reverse cycle. The tests were carried out at an average Ta of 10 °C. During the experiments, the average room temperature was 22 °C. The flow rate of water through the ground heat exchanger was measured at Tg 17 °C, and all other thermodynamic measurements were taken. The power consumed by the pump and compressor was also recorded. The temperature difference between the inlet and outlet of the ground source heat exchanger was 0.5 °C at the start, then increased sharply for half an hour to reach 2.5 °C, and then increased by 0.5 °C for four hours. After that point, the increase stops, and the difference is fixed due to system balance, and the amount of heat absorbed is constantly rejected to ground. Figure 5 depicts the relationship between the heat pump coefficient of COP and time; the COP increases with time due to temperature differences, which increase heat absorption and improve the COP. The COP was raised from 0 to 6. After six hours of operation, the COP increases slightly in steady-state to a maximum of eight. Figures 5 and 6 show similar results. The useful energy which is heat in this experiment is larger because the energy added by the compressor is vital and added to the energy absorbed, and they were summed and delivered to the space. The pump consumed 125 watts, which was included in the COP calculations and is negligible in the plot because the useful power was thirty times the pump power (Yu Jin Nam 1,*, Xin Yang Gao 2).

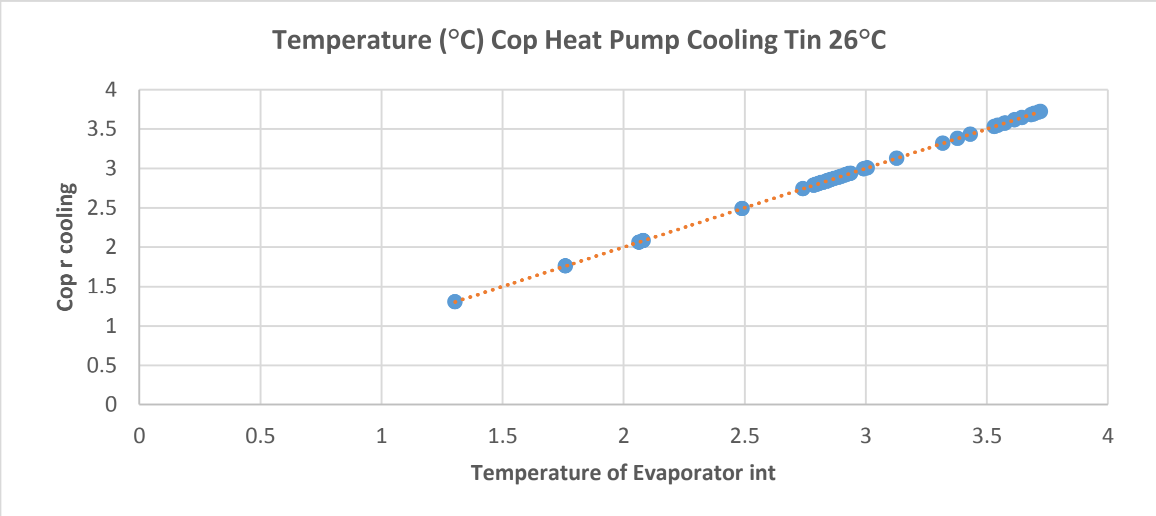

Figure 5: Relation between COP and t temperature of inlet of evaporator heating mode geothermal heat pump

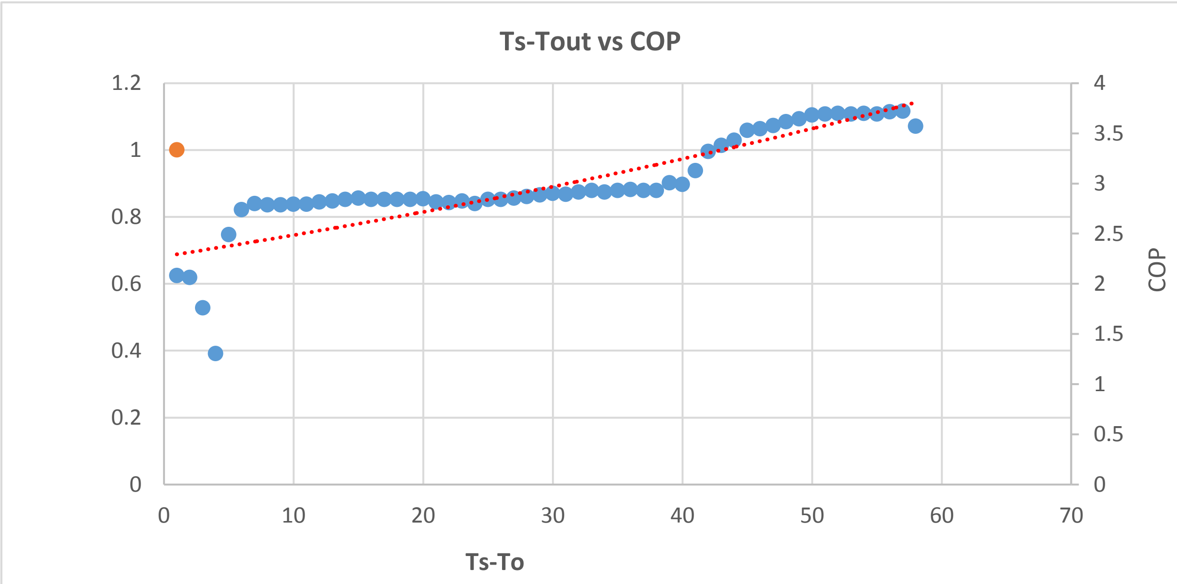

Figure 6: Relation between COP and temperature difference of geothermal loop

The higher the temperature of the source the lower the COP in cooling but in heating the lower the temperature source the higher the performance. This means that adding a solar water heated system to the system during the heating season improves performance and results in a COP of 9, as shown in figure 6.

5.4 Combined FPSC and HGSHP experiment

Finally, the heat pump was connected to an FPSC, and the same data were collected. The test was carried out in February. The system was disconnected from the ground and connected to an FPSC with standard dimensions (190x90 cm) and 9 galvanized steel columns insulated with polyurethane. Calculating the heat transfer coefficient will be the same for heating mode, the average temperature between the inlet and outlet of the ground loop on 24-8-2020 at steady-state was Ta=2.25, Tb=1.61, LMTD=1.92, and UA=1.35, giving the highest COP for all tests, which is logical for many reasons, including: Because water was the working fluid in the ground loop and the refrigerant was in a liquid state in the condenser, the heat transfer coefficient was higher, Furthermore, the heat transfer coefficient was higher in the refrigerant's condensation state (Baruah, 2017).

To calculate the needed area of SWH:

$$Q = V x \rho x C p x \Delta T \tag{4}$$

Vis the installed pump's volumetric flow rate, is the density of water, Cp =4.190 KJ/kg°C, and T is the temperature difference required for maximum COP. At a temperature difference of 5 degrees Celsius, the COP was 9. Lower temperature differences result in lower Qh and thus lower COP, while higher temperature differences result in higher COP.

6. ANALYSIS OF GEOTHERMAL HEAT PUMP

When compared to conventional systems, geo-exchange systems save 30-70% in heating costs and 20-50% in cooling costs, according to the United States Environmental Protection Agency (Home Inspection Standards of Practice, (2018)). Geo-exchange systems require far less maintenance than conventional systems, resulting in significant cost savings. They are built to last for decades in addition to being highly reliable. An economic analysis must be performed between a conventional system for heating and cooling and a geothermal heat pump, with a load of 30 kW assumed for an average household (Geothermal Heating & Cooling - Geothermal Energy Heat Pumps (2010). In Palestine, the tariff for each kWh of electricity is currently 0.50 IL/kWh for the first 160 kW, 0535 IL/kWh for 161-250 kWh, 0.617 IL for the 251-600 kW, and 0.66 IL for the 401-600 kWh; after 600 kWh, the tariff is 0.73 ILFor diesel, the average November 2021 diesel cost is 5.49 IL per liter, which equates to 6.86 IL per kilogram [19]. Each kilogram of gas pumped by the company at the wholesale price costs 5.41 IL (Fuel prices in Palestine,2021) According to the manufacturer, the air source heat pump has a COP of 3.5. The electricity consumption is 10 kW per hour. In the best case, the Cop for the Solar Assisted Heat (Melis Sutman et al, 2019) Pump was 7. Table (1). (1).

Table (1) economic study for different systems compared to the GSSAHP using present value and SPBP

System	**GSSAHP**	**ASHP**	**Diesel Heating**	**Cooling +Heating**
Equipment Capacity (KW)	**30**	30	36	
Unit price initial cost (US$)	**18,000**	10,000	12,000	
Excavation cost (US$)	**10,000**	---	---	
Piping and installation	**12,000**	----	----	
Total first cost	**40,000**	10,000	14,000	**24,000**
Power consumption Kwh	**4.3**	10	1	11
Efficiency or COP	**7**	3.3	80%	
Total Lifetime of system	**20**	20	20	**20**
Total utility cost $/season cycle	**1,972**	6,703	102	**6805**
Total power consumption $	**39,440**	134,060	20,40	**136,100**
Fuel Consumption kg/h	**----**	-----	8,003	**8,003**
Total life time operating cost	**43,384**	147,466	162,100	**309,566**
Annual Maintenance cost $	**1000**	1000	500	**1500**
Total annual operating and main. cost	**2972**	7703	8,605	**16,308**
PV of annual cost of heating	**25,302**	65,510	77,516	**143,026**
Total life time cost at pv($)	**65,302**	75,510	91,516	**167,026**
Saving of each system from the diesel +A\C systems lifetime($)	**101,724**	------	--------	**0**
$PBP = \frac{K2 - K1}{(E+M)_1 - (E+M)_2}$	**(40k-24k) \(5.944-16.308k) =1.6 year**	(40k-10k) \9.462 = 3.2 years		

PBP= Simple pay-back period, K= capital investment, E annual Energy cost, M=annual maintenance cost 1 system considered, 2= alternative system

7. CARBON FOOTPRINT LIFE CYCLE ASSESSMENT

Calculating a carbon footprint that conforms to this definition is difficult due to the large amount of data required. According to the United Nations, the carbon footprint is a subset of the ecological footprint, and the carbon footprint for each of the energy sources will be used for calculations for the footprint of each system compared in the systems used in our study. Using the above values for a comparison of conventional heat pump, geothermal heat pump, diesel heating system, see table (2) below. The efficiency of various systems used and the resulting energy conservation as a result of increased efficiency, which will reduce operating costs and emissions. Using the emissions per unit consumed and the annual consumption based on the system efficiency and rating as shown in table (2), the results showed that using a geothermal solar assisted heat pump saved around 1857 tons of CO_2 per year. Taking into account the large number of systems installed and the heating load, which constitutes the vast majority of the load in Palestine, this will demonstrate the significant savings in both energy and emissions that can be achieved by using the solar-assisted geothermal heat pump, as well as the added value of having no outdoor units, a long life, and less heat rejected to the outside.

Table.2 Carbon footprint for compared systems.

Method	**AS HP**	**GSSAHP**	**Diesel**	**Total Emmtions (AC +heating)**
Rating of equipment	30 kW	30kw	36 kW	
Consumption kwh \kg	8.5	4.2	5	
Co_2 emmitions per unit generated kwhr or kg	0.53	0.52	3.33	
Annual operating units kg or kw)	15,406	12,766	27,412	
Total tons per year	8165.2	6638.3	91,282	
Lifetime years	20	20	20	
$Co_2$for life cycle tons	163	132	1,825	1,989

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8. CONCLUSION

The findings revealed a promising potential for solar-assisted heat pumps in Palestine, owing to the constant temperature of the ground throughout the year and the use of the sun on sunny days. In comparison to other countries in the reign, the expected energy savings assume a shift to this type of heat. The cooling efficiency COP was 5. As the potential for solar radiation is greater, the heating results COP were around 4. The solar water heater integrated ground source heat pump had a COP of 7. Improved inverter technology in the pump and compressor will undoubtedly improve the system because the COP will be higher anyway, resulting in lower cost and more environmentally friendly systems. The GSSAHP was far more cost effective than installing two systems, one for cooling and one for heating, because there is no cooling without using at least an air source heat pump. With a simple payback period of 1.5 to 3.2 years when compared to heating and cooling with an air source heat pump, despite the high cost of excavation and installation. Larger savings are expected for larger systems. Considering that 57% of Palestine's energy bill is residential, and one-third of this energy is used for heating or water heating. It will be worthwhile to consider renewable resources such as GSSAHP, which is one of the best-known systems ever known, as well as the availability of solar energy most of the year and the ease of utilizing horizontal rather than vertical lops, which are less expensive and easier. Environmentally, the system has reduced CO2 emissions by 1826 tons.

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