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Investigation of an energy pile application and its economic analysis

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Abstract: In this study, the heating and cooling needs of an airplane hangar by integrating a heat pump system into bored piles were investigated. For this purpose, U-type pile heat exchangers were installed inside the piles. 600 bored piles were integrated with heat exchangers depending on the heating requirements of the hangar. Energy calculations were performed for a single pile, and the total amount of energy that could be extracted from the ground was determined. The main goal is to supply cooling and heating for the hangar throughout the year without the use of any additional conventional system. Thus, cost-analysis results for both the heat pump and traditional system using levelized cost method were presented. The study results showed that the annual operating cost $(C_{OM})_{PW}$, total operating cost $(I_{OM})_{PW}$, equivalent annual operating cost (C_{OM}), and total annual cost (C_T) for the present condition reduced by nearly 38.5%, 35%, 35%, and 34% against the conventional system, respectively. The simple payback period was calculated as 1.1 years. Finally, it was seen that using the energy piles can provide the heating and cooling requirements of the hangar throughout the year without any additional conventional system.

Keywords: Ground source heat pump, Energy pile, Pile heat exchanger, Renewable energy.

1. Introduction

The substantial increase in fossil fuel consumption over recent decades has led to the buildup of greenhouse gases, ultimately causing global warming, and giving rise to irregular weather patterns and health issues. To address this, numerous approaches have been explored to reduce global warming. These include enhancing the efficiency of current energy conversion processes through the utilization of effective energy conversion devices, which have minimal or zero environmental impacts. Some examples include fuel cells powered by environmentally friendly fuels like hydrogen, methanol, ethanol, wastewater, etc. Additionally, efforts involve transitioning towards renewable energy sources such as solar, biomass, wind, ocean, and geothermal energy [1,2].

A key solution for global warming and the fossil energy crises is the advancement and use of renewable energy. The benefits of vast reserves and global distribution have drawn more attention to geothermal energy in recent years as a clean and sustainable energy source. As a prominent form of renewable energy, geothermal energy has outstanding benefits such as high sustainability, low emissions, and eco-friendly. Its application varies based on ground temperature, electricity generation, direct heating, and indirect heating/cooling through heat pumps. The utilization of ground source heat pump systems (GSHPs) has grown dramatically in the last few decades all over the world. This is attributed to their low carbon footprint and capacity to gain heat from the ground for building both cooling and heating purposes in various climate conditions. Besides, previous studies have shown that GSHPs are more efficient than HVAC technologies with reduced running costs. Because GSHP units and installation have high capital costs, and are still higher than that of standard systems. However, if governments provide extra incentives, GSHPs may be an affordable alternative solution [3-5].

Although various methods exist for utilizing soil as an energy source, energy piles represent the latest innovation in this field. In unstable foundations, a heat exchange pipe is inserted into a bored pile to reinforce the ground and additionally utilize soil heat. This system is installed at a reasonable cost, making it a desirable option. Therefore, it has become one of the most sought-after cooling and heating systems in recent times. A brief review of some significant research articles about energy piles is presented here. Chen et al. developed a machine learning-based algorithm for COP estimation, an important indicator in GSHPs. A field study was performed for two years on energy pile systems integrated into the heat pump. Study results indicated that the ambient temperature significantly influenced COP performance, while humid-

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ity had a comparatively minimal impact [6]. Mousa et al. conducted a simulation study using the 3-D finite element method to examine the performance of Phase Change Material (PCM) on energy piles. The study revealed that the heat pump COP performance increased up to 5.28% using PCM with high latent heat capacity [7]. Cui and Zhu investigated the whole-year performance of a GSHP with multiple energy piles using a 3-D heat transfer model. The GSHP cooling and heating capabilities were analyzed. The findings of the study revealed that the maximum heating and cooling COPs were 3.63 and 4.73 respectively in the whole season operation period [8]. Carotenuto et al. developed a numerical model to assess the heat transfer performance on energy piles with different configurations. Presented results in the study indicated that the heat transfer performance was increased by up to 42% using concrete with a higher thermal conductivity coefficient [9]. Fadejev et al. researched a review study on energy pile design in geothermal plants. In this study, a high overall system of Seasonal Coefficient of Performance (SCOP) value was higher than 4.5 in properly designed heat pump systems integrated energy piles. However, the impact of convenient design and sizing was demonstrated by SCOP values that were twice as low in some certain case studies [10]. Fadejev and Kurnitski used simulation software to evaluate the performance of the whole building SCOP for cold climate conditions in Finland. Simulation results indicated that utilizing borehole heat exchanger fields and energy piles might yield substantial heat pump SCOP values of up to 5.3 in a commercial hall-type building [11]. Moon and Choi investigated the heating performance characteristics of GSHPs with energy piles and energy slabs. Study findings revealed that the heat pump unit achieved minimum COP values of 4.2 for the energy pile system and 4.5 for the energy slab system [12]. Morrone et al. investigated the technical and economic viability of utilizing geothermal heat pumps (GHPs) with energy piles for cooling and heating in residential houses [13]. Two-story building designed as both an office and residential building was constructed, and friction piles were used on the ground in Sapporo. Four different U-type pile heat exchangers were tested. Heat dissipation rates were calculated for three of these four different heat exchangers, and performance test results were compared. The single U-type pile heat exchanger was selected in terms of economic efficiency and usability [14]. A research project in Austria explored the heat transfer between soil/concrete and the absorber fluid circulating in the pipes, along with a discussion on pile arrangement. The study results indicated that factors such as well resistance and soil shear resistance did not change significantly during the heat drawing from the ground [15]. A case study was conducted to evaluate the application of geothermal energy in heating and cooling systems in Shanghai, China. Several performance tests were then performed to identify the most efficient option among four different pile heat exchangers, and numerical results were compared against experimental data. The W-type heat exchanger was chosen as the preferred model [16]. In another study conducted in Shanghai, average, numerical, and experimental results for W-type and three different U-type configurations of pile heat exchangers for different flow rates were analyzed. It was found that the W-type had 43% more heat dissipation than the U-type [17]. Moel et al. pointed out the technological advantages of energy pile systems. It was stated that the applications of these systems provide significant energy savings [18]. Wood et al. investigated the effect of using a pile system as a heat exchanger in combination with a GSHP for residential heating. The results of the study indicated that the total energy gain from the heat pump throughout the entire heating season was 17.24 MWh [19]. Singh et al. performed an experimental study by designing a small pile in Victoria City, Australia. Based on the study results, if the system were fully implemented in a multi-purpose office building, it would save around $60,000 per year on its energy bills, and reduce 400 tons of CO2 emissions annually [20]. Cui et al. conducted a study to compare spiral-type pile heat exchangers to other heat exchanger types in terms of heat conduction. It was revealed that the spiral-type pile heat exchanger has an advantage in both heat transfer area and flow profile [21]. Suryatriyastuti et al. carried out a simulation study to understand the heat transfer mechanism in the pile system. Parameters related to the heat transfer process in the pile and soil system such as soil temperature, thermal properties of the soil, groundwater flow, and its effect were presented [22]. Amatya et al. performed a study to analyze the axial stresses in the concrete pile because of heating-cooling. In addition, axial thermal load profiles and their effects on the soil around the pile were investigated [23].

In this study, the heating requirement of an airplane hangar built in Istanbul Sabiha Gökçen International Airport was investigated using an energy pile system. U-type pile heat exchangers were installed inside the piles. 600 bored piles were integrated with heat exchangers depending on the heating requirements of the hangar. Energy calculations were performed for a single pile, and the entire potential energy that could be driven from the ground was determined. The main goal is to supply cooling and heating for the hangar throughout the year without the use of any additional conventional system. Therefore, the cooling requirement of the hangar was also considered in the cost analyses. Finally, cost-analysis results are presented for both the conventional and the heat pump integrated energy pile system using the levelized cost method.

2. Material and Methods

2.1. Energy Pile Systems and Operating Principle

In modern high-rise buildings, bored piles are used to strengthen the ground during foundation works on soils with poor bearing properties due to static problems. When pipelines are integrated into these piles to utilize geothermal energy, they are called energy piles. In other words, heat can be extracted from the ground for building heating, and it can be transferred to the ground for building cooling. The pile foundations allow heat to be extracted from the ground to utilize the heat energy stored in summer and winter for heating and cooling purposes in residences using a heat pump.

The use of geothermal energy has become quite widespread in recent years. Geothermal energy varies in depth from 10 to 50 meters in many European countries, with an average soil temperature of 10-15°C. Energy extraction through pile foundations is a relatively new concept. Such a technology can be described as acquiring thermal energy from the ground through heat exchangers that are connected to a building's heat pump. The soil provides heat energy to the building during the winter and takes on the cooling role for the summer season.

Figure 1 depicts the energy pile system and its elements [22]. These systems include three basic cycles. In the first cycle, the soil is used as a heat source for the building's needs in the winter season, and the summer season vice versa, that is, the heat is given to the soil for cooling purposes. The second cycle is where the heat carrier fluid is transferred from the soil to the building via absorbing pipes in the concrete pile. The third cycle is a heating-cooling circuit consisting of closed pipelines embedded in the floors and walls of the building. The amount of energy production depends on the performance coefficient defined for the heat pump. The COP range typically varies between 3.0-6.0. For the best economic energy

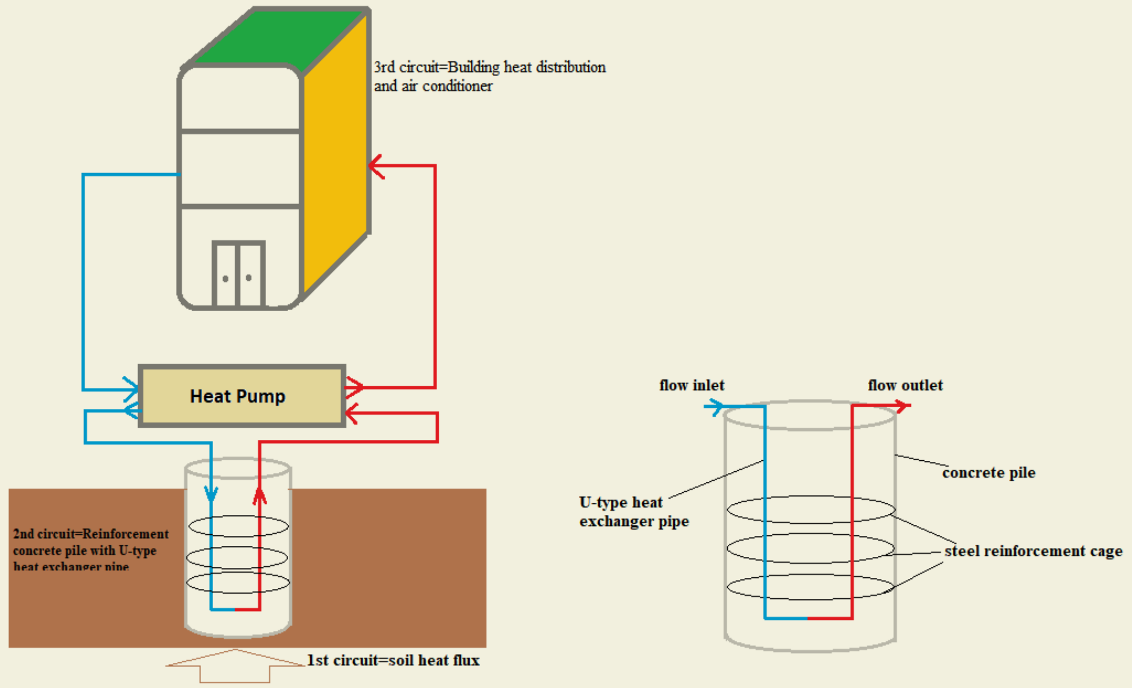

Figure 1. Energy pile cycle and its components

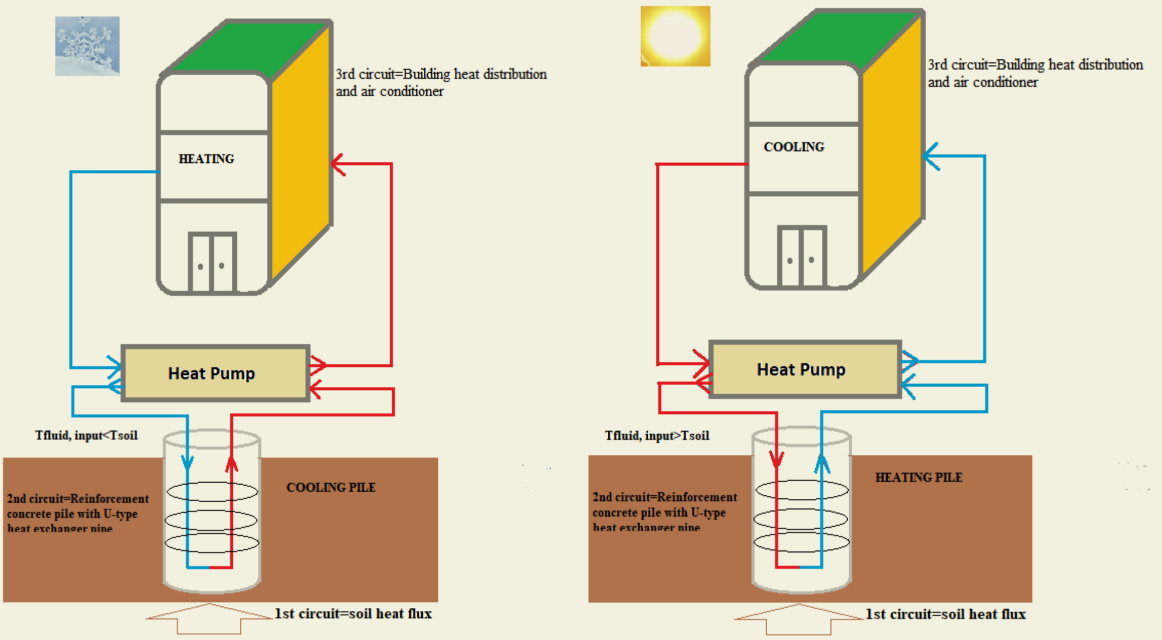

Figure 2. a) Energy extraction b) Energy storage

production, the COP should be 4.0 or above.

There are two types of operating in energy piles: one-way operating and seasonal operation mode. In the one-way operating mode, energy flow occurs only in one direction. In seasonal operation mode, the aim is to maintain the thermal balance in the soil. In this mode, heat is extracted from the ground during certain periods, while in other periods, heat is supplied to the ground. The thermal balance of the soil is maintained by both cooling and heating throughout the year. This operating system is preferred for its environmental friendliness in sustaining underground water. Energy extraction and storage are shown in Figure 2.a and Figure 2.b respectively [22].

2.2. Pile Installation

Piles containing steel pipes are usually filled with concrete, and concrete columns are equipped with heat-absorbing pipes using vibroflotation technique. In short, the vibroflotation method is a technique of compacting deep granular soils with vibratory drilling tools. Hence, ground strength increases using this compaction method [24]. In addition to this system, pile heat exchangers are installed. Installation phases for energy pile are illustrated in Figure 3 (a,b,c,d,e,f). First, the reinforcement cage where the pile heat exchanger pipes will be mounted is prepared (Figure 3.a). In the second stage, boreholes are drilled in the area where the piles will be driven (Figure 3.b). In the third stage, heat exchanger pipes are integrated into the prepared reinforcement cage (Figure 3.c). In the fourth stage, the cage is placed inside the casing pipe in the drilled hole. The purpose of the casing pipe is to ensure that the cage is correctly and stably placed in the boreholes (Figure 3.d). In the fifth stage, a funnel is placed over the cage and the borehole is filled with mortar (Figure 3.e). Finally, the casing pipe is removed again, and the pile construction is completed (Figure 3.f). The final state of the energy piles is shown in Figure 4 [25].

2.3. Energy Calculation for Pile Circuit

When the static project of the hangar was studied, it was determined that a total of 1.000 bored piles with a diameter of 80 cm and a length of 25 m were used. The height of the hangar is 32 m. Its length and width are 160 m and

Figure 3. Installation stages of energy pile [25]

Figure 4. Final state of energy piles [25]

180 m, respectively. Underfloor heating was envisaged in the project, and the heat requirement was determined as 1.100 kW. The interior temperature of the hangar was set at 18 °C. In order to meet the heating load of the hangar, it has been suggested to convert 600 bored piles into energy piles. Typically, the distance between the boreholes is taken as 5-7 m in the studies conducted for the vertical GSHPs [26,27]. According to the data in the project, the desired distance between the pile wells is 4 m or more, which is acceptable in terms of heat transfer in the soil. The aim is to extract maximum heat from the energy piles. Therefore, it was decided to use a U-module pipe to achieve the maximum possible energy gain. Since the heat transfers to the piles from the soil, the structure of the soil plays an important role in energy extraction. In practice; first, the lateral surface area (m^2) of the pile is calculated. Then, the energy value that can be extracted from the surface, based on the soil type is multiplied by 10-35 W/m^2. Since the pile diameter is 80 cm and the soil type is slightly moist-clayey, the specific heat capacity is considered 25 W/m^2 in the study [25]. Soil types and specific heat capacity values are listed in Table 1.

Table 1. Soil Types and Specific Heat Capacity [28]

Soil Types	Specific Heat Capacity [W/m²]
Dry, Sandy Soil	10 – 15
Moist, Sandy Soil	15 – 20
Dry, Clayey Soil	20 – 25
Moist, Clayey Soil	25 – 30
Watery Ground (groundwater)	30 – 35

Once the soil type is determined, the energy extracted from the pile can be calculated. The lateral surface area of the pile is determined by

$$A_{pile-lateral} = \pi \cdot D \cdot L_{pile} \tag{1}$$

where D is the pile diameter, and L_{pile} is the pile length. Energy extraction for one pile can be expressed as

$$Q_{pile} = A_{pile-lateral} \cdot \text{Specific Heat Capacity} \tag{2}$$

Four heat exchangers have been installed in each pile. Thus, the energy obtained from each heat exchanger has been calculated as 0.392 kW. The total energy obtained from the energy pile system is determined by

$$Q_{pile,t} = Q_{pile} \cdot n_{pile} \tag{3}$$

where n_{pile} is the number of energy piles used in the system. $Q_{pile,t}$ was found to be 942 kW. This result gives us the maximum amount of energy that can be extracted from the primary circuit, i.e. through the pile heat exchangers [29]. A cross-section view of a pile with heat exchangers is shown in Figure 5.

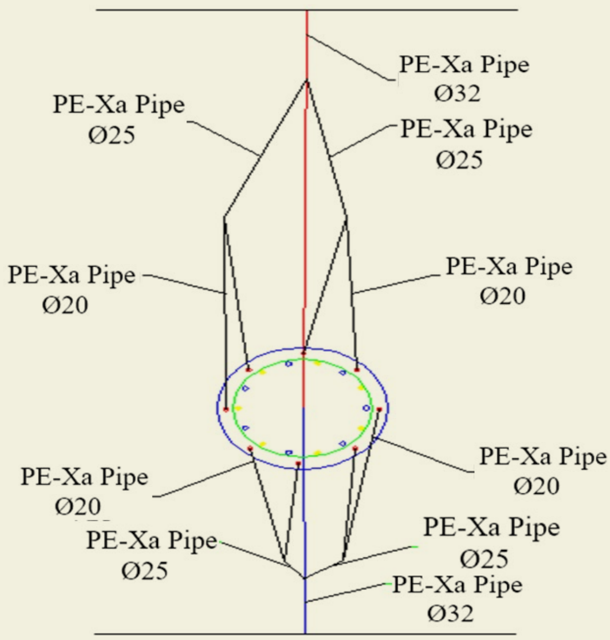

Figure 5. Cross-section view of the pile with heat exchangers [25]

There are four U-type heat exchangers (cross-linked polyethylene, PE-Xa) inside each pile. Pipes having 20 mm diameter are connected to a diameter of 25 mm pipes in pairs. Pipes with a diameter of 25 mm are connected to 32 mm ones. Finally, the pipes with a diameter of 32 mm, which leave from the pile, are attached to the pipe in the collector line. Hence, 20 piles were gathered in one collector. The connection diagram for one collector is illustrated in Figure 6.

There are 6 collectors in the critical line. The last collector is connected to the main line leading to the heat pump. Calculations for collector-1 on the critical line are done similarly. The heating power has been recalculated since 20 energy piles are connected to each collector. The heating power for each collector can be calculated using Equation 4.

$$Q_{collector} = 20 \cdot Q_{pile} \tag{4}$$

Thus, the heating power for collector-1 was found to be

31.4 kW. The COP value of the heat pump used in the system is 3.5. The heat pump capacity can be determined by Equation 5.

$$Q_{capacity} = Q_{pile,t} \cdot \left(\frac{COP}{COP-1}\right) \tag{5}$$

The heat pump capacity was determined as 1,318.8 kW. This value calculated at the heat pump output easily meets the heat loss of the airplane hangar. It was deemed appropriate to use two ground source heat pumps, each with a capacity of 600 kW [25,29].

2.4. Cost Analysis

The initial investment costs and operating costs for the conventional and heat pump integrated energy pile systems were evaluated separately. The amount of total annual energy costs for both systems was obtained using the levelized cost method [30,31].

2.4.1. Initial Investment Costs

While calculating the initial investment cost for the heat pump system, piping and labor, pump, expansion tank, and heat pump device were taken into consideration as system components. For the conventional system, components such as natural gas installation and labor, chimney, chiller, and boiler have been considered [25,29]. Initial investment cost values (I_A) for both systems are shown in Table 2.

2.4.2. Operating Costs

When calculating operating costs, the annual heating energy requirement, annual electricity consumption, and costs are determined based on the operating times throughout the summer and winter seasons for both the traditional and heat pump systems. The results were presented in the discussion section.

Heating cost calculations for the winter season (Heat Pump System):

First, the annual heating energy has been calculated. The operating time of the heat pump for the winter season is 1,440 hours in total for 6 months (October-November-December-January-February-March) with an average of 8

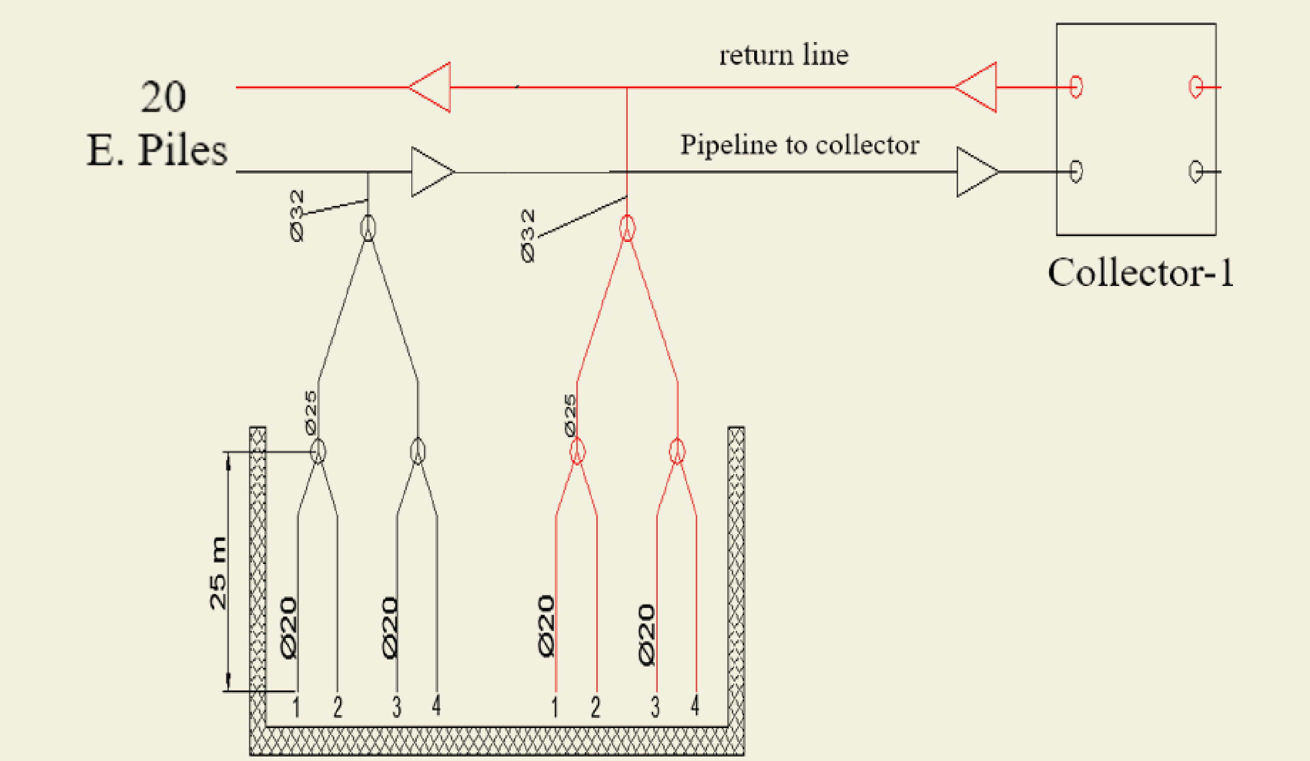

Figure 6. Energy Pile connection diagram with collector [25]

Table 2. Initial investment cost values for heat pump and conventional system

Heat Pump System		Conventional System	
System Components	Price [€]	System Components	Price [€]
Piping and Labor	24,000	Natural Gas Installation and Labor	10,000
Pump	2,000	Chimney	4,500
Expansion Tank	800	Chiller	42,000
Heat Pump (2)	2x35,000	Boiler	20,000
I_A: 96,800 €		I_A: 76,500 €	

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hours per day. The annual heating energy requirement (AHER) for the winter season can be defined as

$$AHER = Q_{HHR} \cdot t_{operating} \quad (6)$$

where Q_{HHR} is the hangar heat requirement. The annual electricity consumption (AEC) is given in Equation 7.

$$AEC = \frac{AHER}{COP} \quad (7)$$

The COP for heating in the winter season is 3.5. The unit price of electricity determined by Turkish Electricity Distribution Corporation (TEDAŞ) is taken as 0.19 €/kWh [32]. The annual heating cost (AHC) can be calculated by using Equation 8.

$$AHC = AEC \cdot \text{Electricity Unit Price} \quad (8)$$

Similarly, the cooling cost was also calculated for the summer season. The average operating time of the heat pump device is 10 hours a day over 6 months (April-May-June-July-August-September) for a total of 1,600 hours. The COP value of the heat pump for the summer season is taken as 6.

The same calculation method was applied to conventional systems. The operating times are the same as those of the heat pump system. The calorific value of natural gas (NGCV) and the gas unit price provided by Istanbul Gas Distribution Corporation (IGDAS) are taken as 8,250 kcal/m^3 and 0.42 €/m^3 [33]. The boiler efficiency was chosen as 0.90. The natural gas requirement over the operation period and its cost were obtained by using the relations given in 9 and 10, respectively.

Heating cost calculations for the winter season:

$$ANGR = \frac{AHER}{NGCV \cdot \eta_{boiler}} \cdot 860 \quad (9)$$

$$AHC = ANGR \cdot \text{Natural Gas Unit Price} \quad (10)$$

In the same way, the cooling cost for the conventional system was calculated. The COP value of Chiller is taken as 2.2.

For a better comparison, the levelized cost method was used to calculate the expenses incurred during the installation and operation of the device by bringing them to a certain reference date [30,31]. The annual cost of initial investment (C_A) is determined by

$$C_A = I_A \cdot DF \quad (11)$$

where DF is the damping factor. DF is calculated by using Equation 12.

$$DF = \frac{(1+i)^n\, i}{(1+i)^n - 1} \quad (12)$$

The total life-cycle period of the system (n) is estimated as 20 years, and the nominal annual interest rate (i) is considered as 3%. The annual operating cost for present conditions $(C_{OM})_{PW}$ covers mainly electricity, fuel costs, and annual maintenance costs (AMC) for the system. $(C_{OM})_{PW}$ is determined by Equation 13.

$$(C_{OM})_{PW} = AOC + MC \quad (13)$$

The average maintenance costs for the heat pump system, boiler, and chiller are determined to be 200 €/year, 600 €/year and 400 €/year, respectively. The total operating cost for present conditions $(I_{OM})_{PW}$ is expressed as

$$(I_{OM})_{PW} = (C_{OM})_{PW} \frac{1}{(i-e_f)} \left[1 - (1+e_f)^n (1+i)^{-n}\right] \quad (14)$$

where e_f is the escalation rate. When calculating $(I_{OM})_{PW}$, the future annual escalation rate (e_f) is taken as 2.5% for natural gas, and 4% for electricity [31]. Therefore, the boiler and chiller were evaluated separately for the conventional system. Equivalent annual operating cost and total annual cost relations are given in Equation 15 and 16, respectively.

$$C_{OM} = (I_{OM})_{PW} \cdot DF \quad (15)$$

$$C_T = C_A + C_{OM} \quad (16)$$

Finally, the simple payback period for the system can be determined by using Equation 17.

$$\text{Payback Time} = \frac{(I_A)_{\text{Heat Pump}}}{(C_{OM})_{PW,\text{Conventional}} - (C_{OM})_{PW,\text{Heat Pump}}} \quad (17)$$

3. Results and Discussion

First, the soil type was determined. Then the energy extracted from the pile was calculated. Since the energy obtained from each pile heat exchanger is determined as 0.392 kW, the calculated heating power for one pile or pile circuit is 1.57 kW. Each collector line has twenty piles. Thus, the heating capacity for each collector in the critical line was found to be 31.40 kW. The heating powers of pile heat exchangers and collectors for each line are given in Table 3.

Calculations were carried out for other collectors. The distance between each collector is 15 m. The main pipeline to heat pump which is connected to collector-6 is 50 m. The energy pile installation diagram for ciritical line is shown in Figure 7.

Table 3. Heating powers for pile heat exchangers and collector lines

	Pile Circuit	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6 (Connected to mainline)
Line Length [m]	25	40	15	15	15	15	50
Heating Power [kW]	1.57	31.40	62.80	94.20	125.60	157	188.40

Table 4. Annual operating costs for heat pumps and conventional system

Heat Pump System			Conventional System		
Heating Cost [€/year]	Cooling Cost [€/year]	Annual Operating Cost [€/year]	Heating Cost-Boiler[€/year]	Cooling Cost-Chiller[€/year]	Annual Operating Cost [€/year]
85,988.5	55,733.3	141,721.8	77,056	152,000	229,056

Table 5. All cost results for heat pump and conventional system

System Type	I_A [€]	C_A[€/year]	$(C_{OM})_{PW}$ [€/year]	$(I_{OM})_{PW}$ [€]	C_{OM}[€/year]	C_T[€/year]
Heat Pump	96,800	6,505	141,922	3,025,372	203,305	209,810
Conventional	76,500	5,140	230,056	4,689,065	315,105	320,245

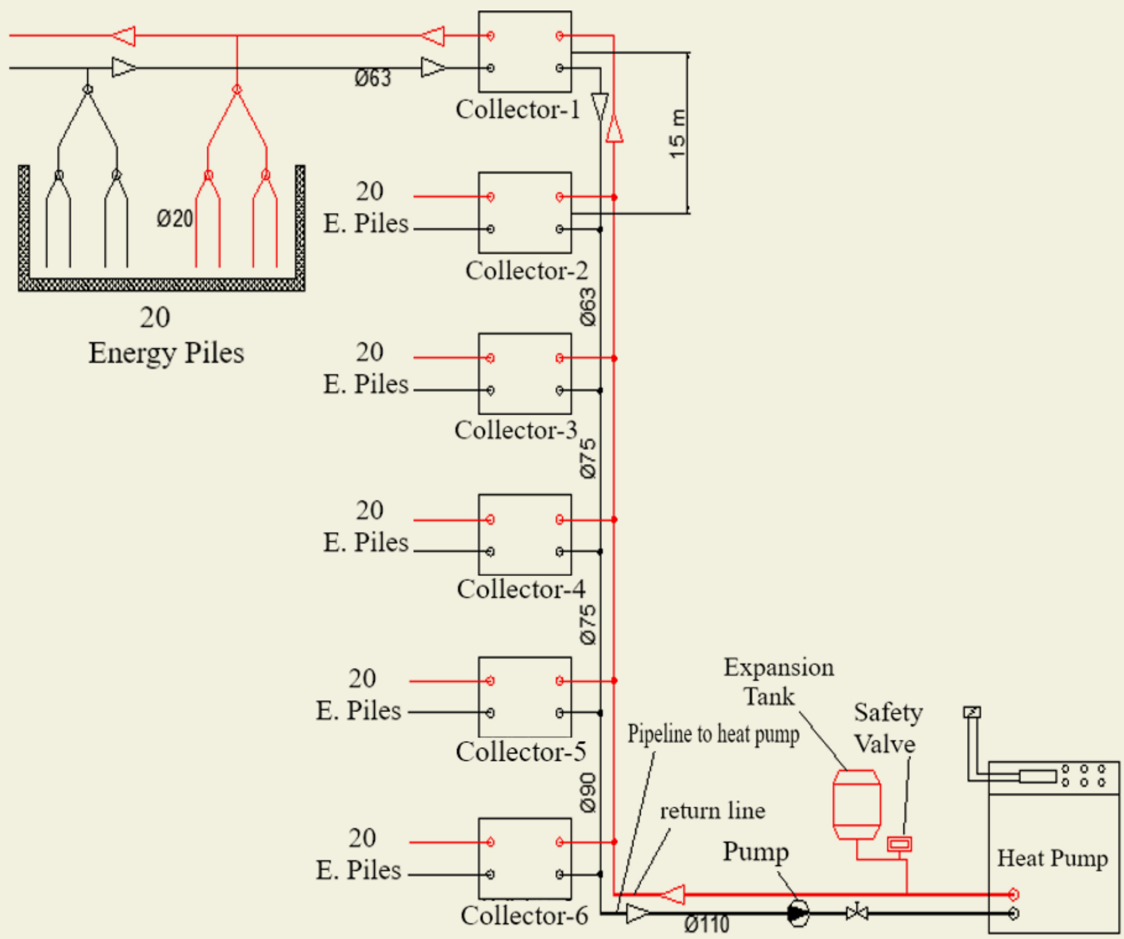

Figure 7. Energy pile installation for critical line [25]

Operating cost calculations were considered separately for heat pump and conventional system. When the heat pump system was used for the pile application, it was seen that the annual operating costs almost decreased by %40 compared to the conventional system. The annual operating costs (AOC) for both systems are given in Table 4.

For a better comparison, the costs incurred during the installation and operation of the devices have been evaluated using levelized cost method. Thus, C_A, $(C_{OM})_{PW}$, $(I_{OM})_{PW}$, C_{OM} and C_T were calculated for present condition. Based on the final cost results, it was shown that the $(C_{OM})_{PW}$, $(I_{OM})_{PW}$, C_{OM} and C_T decreased by approximately 38.5%, 35%, 35% and 34% compared to conventional system, respectively. Finally, simple payback period was calculated as 1.1 years. All cost results for heat pump and conventional systems were presented in Table 5.

4. Conclusion

In this study, it was aimed to heat an airplane hangar at Sabiha Gökçen Airport using energy piles. Depending on the static project of the hangar and the heat requirement, U-type heat exchangers were integrated into the bored piles. Underfloor heating was envisaged for the hangar, and the heat requirement was determined as 1,100 kW. It was suggested to convert 600 bored piles into energy piles. First, energy extraction for one pile was calculated. Then the total energy gain from the system was obtained. The energy drawn from each pile, and total primary circuit

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was calculated as 1.57 kW and 942 kW, respectively. The initial investment costs and operating costs for the heat pump and the conventional systems were calculated. The calculations performed for the heating and cooling season were carried out separately. Similar procedure was applied for cooling season as well. Finally, levelized cost method was used to perform cost analysis for both heat pump and conventional system. Results are presented as follows:

- When the heat pump system was used for the pile application, it was shown that the annual operating costs nearly decreased by %40 compared to conventional system.
- Cost analysis results for the heat pump and conventional systems have been found as: 6,505 and 5,140 €/year for annual cost of initial investment, 141,922 and 230,056 €/year for operating costs, 3,025,372 and 4,689,065 € for total annual operating costs, 203,305 and 315,105 €/year for equivalent annual operating costs for present condition.
- Based on the cost analysis results, it was seen that the $(C_{OM})_{PW}$, $(I_{OM})_{PW}$, C_{OM} and C_T decreased by approximately 38.5%, 35%, 35% and 34% compared to conventional system, respectively.
- Simple payback period has been calculated as 1.1 years. The critical point here is that the initial investment cost values obtained for both systems are close to each other. It might be explained by the fact that there is no additional drilling cost in energy piles. Therefore, the system amortized itself in a short time.

As a result, the heating and cooling needs of the hangar can be met throughout the year using the energy pile system without any additional conventional system.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Nomenclature

GSHP	Ground Source Heat Pump
COP	Coefficient of Performance
I_A	Initial Investment Cost
AHER	Annual Heating Energy Requirement
AEC	Annual Electricity Consumption
AHC	Annual Heating Cost
ANGR	Annual Natural Gas Requirement
AOC	Annual Operating Cost
MC	Maintenance Cost
DF	Damping Factor
C_A	Annual Cost of Initial Investment
$(C_{OM})_{PW}$	Annual Operating Cost for Present Condition
$(I_{OM})_{PW}$	Total Operating Cost for Present Condition
C_{OM}	Equivalent Annual Operating Cost
C_T	Total Annual Cost

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