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# "OPTIMIZATION OF GROUND SOURCE HEAT PUMP:A REVIEW"

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***Abstract:*** ***To effectively exploit the heat capacity of the soil a heat-exchanger system has to be constructed. Usually an array of buried pipes running along the length of the building, a nearby field or buried vertically into the ground is utilized. A circulating fluid (water or air) is used in summer to extract heat from the hot environment of the building and dump it into the ground and vice versa in winter. A heat pump may also be coupled to the ground heat exchanger to increase its efficiency. In the literature several calculation models are found for ground heat exchangers. One-dimensional models were devised in the first stages of the system study which were replaced by two- dimensional models during the nineties and three-dimensional systems during the recent years. The present study are further refined and can accept any type of grid geometry that may give greater detail of the temperature variation around the pipes and in the ground.***

***Keywords:*** **- ground heat exchanger; heat pump; vertical heat exchanger; horizontal heat exchanger; renewable energy**

# I. INTRODUCTION

A geothermal heat pump system provides heating and cooling while reducing both energy usage and costs. When government incentives for installation of geothermal systems are utilized to obtain tax credits and accelerated depreciation benefits, the system can realize a lower first cost as well as greater long-term savings. This paper will describe the types of geothermal heat pump system installations and the ways in which Carrier heat pumps can help property owners achieve a faster return on investment.

### 1.1 GEOTHERMAL HEAT PUMP SYSTEMS:

Water source heat pump (WSHP) systems have become a popular choice for commercial buildings where multiple zones of control are desired. The relatively constant temperature of the ground or ground water below the surface is moderate compared to the temperature of the outdoor air, which changes dramatically from season to season. Geothermal heat pump systems use the earth's resources as a heat source and heat sink. A lake, river, well, or the ground itself is used to add or remove heat to maintain an operable water temperature.

Typical designs include vertical loops and horizontal loops. In some applications, water is piped from the ground or lake directly to the water source heat pump. Piping is limited to the amount of pipe required to get the water from the source to the unit.

### 1.2 Horizontal Ground Loop:

This system is used when adequate land area is available and trenching can be accomplished easily. Parallel pipes are laid out in trenches 3 to 6 ft below the ground surface, and then back-filled. Depending on the design, one to six pipes are installed in each trench. Multiple pipe and coiled "spool" configurations are often used to conserve land requirements and reduce overall installed loop costs. See Figure 1.

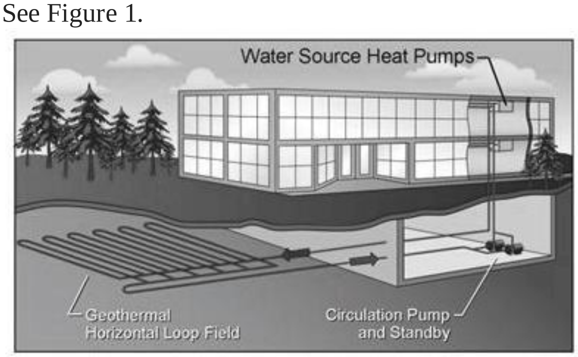


**Figure 1:**Horizontal Closed-loop System, Parallel Piped

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The amount of pipe and the size of the ground loop field are based on ground conditions, heating and cooling requirements of the application, and system design. Trench lengths range from 100 to 400 ft per system ton. Pipes are spaced from 6 to 10 ft apart. The overall land area required ranges from about750 to 1500 ft$^2$ per system ton.

Horizontal designs can use a series or parallel flow path. Series paths offer higher performance per pipe length, but a large pipe size must be used and the pressure drop can become too high.

**1.3 Vertical Ground Loop:**

This design is well suited for retrofit applications when available land area is limited or where landscaping is already complete and minimum disruption of the site is desired. Vertical systems use piping installed in bore holes. Drilling equipment is used to bore small diameter vertical holes. Two pipes joined together with a U-Bend fitting are inserted into the vertical bore holes. The space around the pipe is filled with a grout material. This provides support and also promotes heat exchange between the pipe and the ground. The completed loop is concealed below ground. See Figure 2.

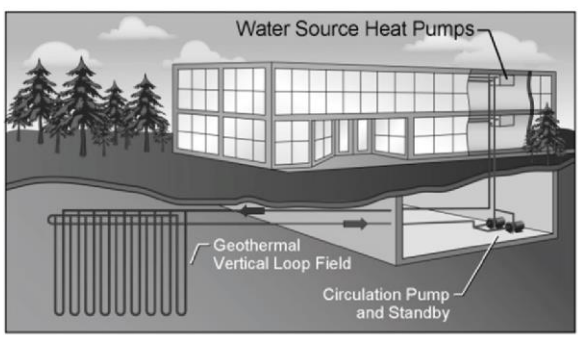


**Figure 2:** Vertical Loop

Bore hole depth ranges from 100 to 300 ft per system ton. Bores should be spaced about 20 ft apart and properly grouted. The land space that is required ranges from 100 to 200 ft$^2$ per system ton. The number of loops required depends on ground conditions, depth of each hole, and load requirements.

**1.4 Surface Water System (Pond or Lake Loop):**

This system, located near a lake or pond, is very economical to install since it requires minimum piping and excavation. The loop can be submerged beneath the water surface. The water serves as the source for absorption and rejection of heat. See Figure 3.

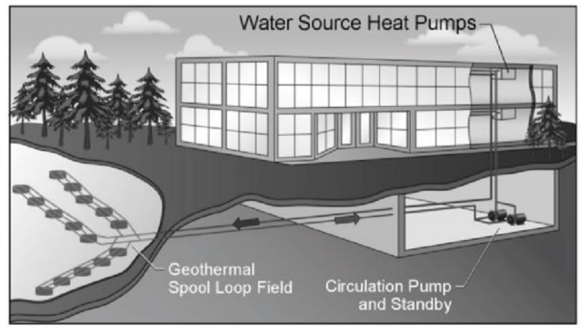


**Figure 3:**Pond and Lake Loops

One popular design uses a spiral loop or “spool.”These designs require less area than straight pipe systems. A pond or lake is attractive as a heat sink because excavation costs are virtually eliminated. Coils or “spooled” mats of pipe can be placed in the pond or lake. A typical residence would require 1/4 to 1/2 acre of water surface at a depth of 8 to 10 ft. The coils should not rest on the bottom of the lake so heat transfer can occur on all sides of the coil.

**1.6 Open Loop System:**

This system is used where good quality ground water is plentiful. In this application, ground water is pumped through supply piping from the well to the building. A well must have enough capacity to deliver a minimum of 1.5 gpm per ton. The water is then pumped back into the ground through a discharge well as it leaves the building. An additional heat exchanger is usually installed between the building water piping system and the ground water piping system. This design limits the amount of piping and excavation required. See Figure 4.

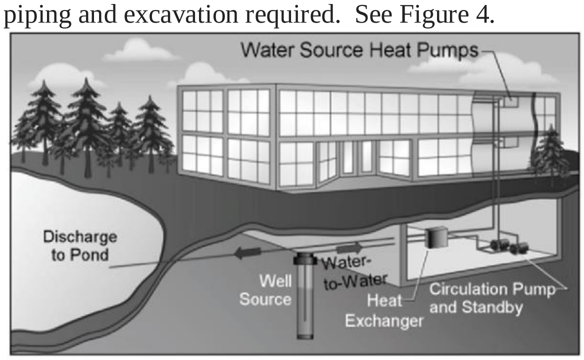


**Figure 4**: Open Loop System

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## II. LITERATURE

**Qingwen Li et. al. [2018] [1]** The latest research on energy piles demonstrates that most scholars are focusing their attention on optimization by designing more efficient heat exchanger coils, analyzing the heat pump matching parameters, and so on. However, after more than 20 years of development, these traditional methods for improving the heat transfer efficiency of energy piles have reached a bottleneck, and a new approach for the continued enhancement of this technology must be investigated. In this study, powdered graphite with high heat transfer characteristics was included in a concrete mix to create graphite concrete piles with enhanced heat transfer characteristics. *e results from theoretical analysis, laboratory testing, and numerical simulation indicate that using graphite to improve the heat transfer efficiency of a concrete material is an efficiency method for enhancing the thermal efficiency of an energy pile system. *e research results also show that the heat transfer coefficient of the concrete exhibits greater improvement when the graphite content is greater than 15% under the same environmental temperature. After studying the performance of the proposed graphite concrete energy pile under deferent environmental temperatures the results indicate that the working efficiency of the energy pile is better in the summer than in the winter. Finally, parameters such as the cast-in pipe configuration and pile spacing are optimized.

**Shtym A. et. al. [2017] [2]** This paper presents the main types of ground heat exchangers using low-grade geothermal energy; the preference was given to the closed systems. Horizontal and vertical ground heat exchangers were compared; installation of these devices in some consumable pipelines is calculated; the area used by them is estimated; also, the cost of some construction works required for using such an energy source is determined. Basing on the performed analysis, it is obvious that the vertical ground heat exchanger has the advantage over the horizontal one as it is less dependent on seasonal fluctuations of the ambient temperature and solar radiation; also, it does not require a large area.

**Jerzy Wołoszyn et. al. [2017] [3]** The number of installations with ground source heat pumps is steadily increasing. As they involve high investment costs, they require deliberate action and analysis. Research on the influence of design, materials and operating parameters on their coefficient of performance becomes of great importance. In this article the authors propose a new ground source heat pump system with horizontal ground heat exchanger and subsurface irrigation system. In order to examine the possibility of applying the system, the influence of soil moisture content on the heat pump coefficient of performance was investigated in this research. Conducting research on the real object is extremely expensive, so it was decided to conduct simulation studies using the finite element method. The presented results of research confirm that the soil moisture content has the greatest impact on the heat pump system coefficient of performance. The developed ground source heat pump system with subsurface irrigation system allows reducing the length of ground heat exchanger loop.

**Bartomeu Casals et. al. [2017] [4]** The EU-funded CEDRO 4 program has been (and is) implementing several innovative renewable energy systems, among which is a large ground source heat pump (GSHP) project for a Medical Facility in the South of Lebanon. To ensure that GSHP technology's potential in highly utilized facilities is realized in Lebanon, this document provides a guideline on Ground Source Heat Pumps, aiming to be used as a practical manual for designers and installers of geothermal power plants.

**A. Michopoulos et. al. [2016] [5]** This paper presents a feasibility analysis for the installation of ground source heat pump systems in Cyprus. Two reference buildings, a single- and a multi- family one, are designed and analyzed using the Energy Plus software, in order to calculate their energy needs for heating and cooling for the climate conditions of Cyprus, one of the warmest areas in Southern Europe. These energy needs are assumed to be covered by the conventional heating and cooling systems that are most widely used in Cyprus or alternatively by a ground source heat pump system, which consists of a vertical ground heat exchanger and water-to-water heat pumps and is analyzed using an in-house developed and validated code. Primary energy consumption and the resulting CO2 emissions for both the conventional and the alternative systems are calculated and compared. Results show that the installation of the ground source heat pump system achieves in most cases substantial reductions in primary energy use for both types of buildings. As regards carbon emissions, the findings are less clear.

**M. Zacchei [2016] [6]** A detailed and complete analysis has been performed investigating first the most used conventional solutions for heating and cooling of buildings in Europe. It has been found out that the conventional heating and cooling market is very heterogeneous, composed by many different technologies, and characterized by a low level of efficiency for the installed stock: hence there is a relevant need for modernization of existing conventional heating and cooling systems. In this context, geothermal represents a renewable energy source with a very important potential of energy savings (up to 70%), addressing the main EU targets and goals for carbon emissions reduction. An overview of the geothermal solutions currently used for heating/cooling of buildings has been provided: shallow geothermal is the largest type (63%) of geothermal energy used in Europe, but many differences between Member States still exist about actual state of deployment of such renewable energy, mainly due to the availability of incentives and financial support schemes. The more mature markets of geothermal installations are Sweden, Germany, France, Switzerland and Norway, which account for around 70% of all installed capacity of the continent. Market requirements, opportunities and barriers, plus financial models have been deeply analyzed for application of geothermal systems: the main barriers, as lack of available space in built urban environment for installation, different regulations and permits, lack of appropriate financing schemes, high cost of GSHPs and needed certifications respect to alternatives, lack of awareness and knowledge about geothermal systems, can be overcome exploiting opportunities in the market and leveraging on the key success factors of GEOTECH solutions, identifiable in the main following points:

- Less capital-intensive compact equipment
- Reduction of environmental risks, complexity and costs
- Better integration between heat exchange elements during installation
- Maximum use of the foundation structures
- Optimized hybrid solutions integrating the different geothermal systems
- Cost-effective geothermal systems
- Safety enhancement

**Ioan Sarbu et. al. [2016] [7]** This chapter mainly presents a detailed theoretical study and experimental investigations of ground-source heat pump GSHP technology, concentrating on the ground- coupled heat pump GCHP systems. "General introduction on the GSHPs and its development, and a description of the surface water SWHP, ground-water GWHP, and ground-coupled heat pumps are briefly performed. The most typical simulation and ground thermal response test models for the vertical ground heat exchangers GHEs currently available are summarized. "LSO, a new GWHP using a heat exchanger with special construction, tested in laboratory, is well presented. The second objective of the chapter is to compare the main performance parameters energy efficiency and CO emissions of radiator and radiant floor heating systems connected to a GCHP. These performances were obtained with site measurements in an office room. Furthermore, the thermal comfort for these systems is compared using the "SHR"E Thermal Comfort program. "Additionally, two numerical simulation models of useful thermal energy and the system coefficient of performance COP sys in heating mode are developed using the TRNSYS Transient Systems Simulation software. Finally, the simulations obtained in TRNSYS program are analyzed and compared to experimental measurements.

**Guihong Pei et. al. [2016] [8]** Background: Ground source heat pumps are a building energy conservation tech- unique. The underground buried pipe heat exchanging system of a ground source heat pump

(GSHP) is the basis for the normal operation of an entire heat pump system. Methods: Computational-fluid-dynamics (CFD) numerical simulation software, ANSYS-FLUENT17.0 have been performed the calculations under the working conditions of a continuous and intermittent operation over 7 days on a GSHP with a single- well, single-U and double-U heat exchanger and the impact of single-U and double-U buried heat pipes on the surrounding rock-soil temperature field and the impact of intermittent operation and continuous operation on the outlet water temperature.

**Jeffrey Molavi et. al. [2016] [9]** Geothermal systems are becoming increasingly popular during the surge of green building. However, their popularity is limited by a lack of knowledge and perceived risk associated with a new system. These systems do not pollute the environment because they operate from earth's natural energy and do not alter chemical compounds. Geothermal systems are cheaper in the long run because only equipment that uses combustion requires expensive fuel to operate. These savings counteract the higher price of the equipment installation. Energy conservation also benefits society because there is less damage to the environment. Buildings that are sustainable can be recognized with LEED certification but properties that violate environmental standards can be penalized. Geothermal systems are a good option to improve sustainability because it can improve the quality of the work environment and profitability of business. Moderately sized retail building projects that use them are at an advantage compared to those that do not. This paper provides an in depth study of geothermal system for retails stores in Northeastern United States.

**Minsung Kim et. al. [2015] [10]** Vertical closed-loop groun-source heat pump systems have been installed widely in Korea since they can extract a moderate temperature level of geothermal heat in a relatively small area. For a ground heat exchanger, a vertical closed-loop type with brine circulation is mostly preferred since it is simpler and less harmful to the ground environment. However, it requires a secondary loop between the refrigerant in a heat pump and the brine. By adding a geothermal heat exchanger in the secondary heat exchange loop, circulation pumps should be attached and the temperature difference between refrigerant and ground would be increased, which causes performance degradation. In this paper, performances of direct expansion ground-source heat pump were evaluated mathematically as an alternative to the conventional secondary-loop ground-source heat pump.

**Jimin Kim et. al. [2015] [11]** In order to solve environmental problems such as global warming and resource depletion in the construction industry, interest in new renewable energy (NRE) systems has increased. The ground source heat pump (GSHP) system is the most efficient system among NRE systems. However, since the initial investment cost of the GSHP is quite expensive, a feasibility study needs to be conducted from the life-cycle perspective. Meanwhile, the efficiency of GSHP depends most significantly on the entering water temperature (EWT) of the ground heat exchanger (GHE). Therefore, this study aims to assess the environmental and economic effects of the use of GHE for selecting the optimal GHE. This study was conducted in three steps: (i) establishing the basic information and selecting key factors affecting GHE performances; (ii) making possible alternatives of the GHE installation by considering EWT; and (iii) using life-cycle assessment and life-cycle cost, as well as comprehensive evaluation of the environmental and economic effects on the GHE. These techniques allow for easy and accurate determination of the optimal design of the GHE from the environmental and economic effects in the early design phase. In future research, a multi-objective decision support model for the GSHP will be developed.

**Marco Bortoloni et. al. [2015] [12]** Ground-source heat pumps are a reliable technology and may represent an efficient and cost-effective option for space heating and cooling, when the investment for ground heat exchangers is reasonable. New advanced ground exchangers have been recently proposed, showing high performances also in shallow ground; their shape has not yet been investigated in literature. In the present study, an analytical solution based on the line source method is applied for sizing a novel shape. This so-called at-panel shape is assumed to be an equivalent slinky-coil having the same heat transfer surface per unit of trench length. As overall benchmarks, two other configurations of straight pipes disposed vertically and horizontally have been sized; all devices are supposed to work in a four lined geothermal field. The building heating requirement has been evaluated assuming a simplified lumped system and three different climate zones, defined by 2,000, 2,500 and 3,000 degree days. Then, a 2D finite-element model has been implemented to solve the transient heat conduction problem in the ground. The results of the analytical formulation and numerical simulations have been compared in terms of average temperature at the wall surface of the heat exchanger. The design minimum temperature considered by the analytical method in sizing the two straight pipe configurations and the flat-panel is accurately reproduced.

**Jae-Ki Byun et. al. [2013] [13]** In the present study, a fuel cell driven ground source heat pump (GSHP) system is applied in a community building and heat pump system performance is analyzed by computational methods. Conduction heat transfer between the brine pipe and ground is analyzed by TEACH code in order to predict the performance of the heat pump system. The predicted coefficient of performance (COP) of the heat pump system and the energy cost were compared with the variation of the location of the objective building, the water saturation rate of the soil, and the driven powers of the heat pump system. Compared to the late-night electricity driven system, a significant reduction of energy cost can be accomplished by employing the fuel cell driven heat pump system. This is due to the low cost of electricity production of the fuel cell system and to the application of the recovered waste heat generated during the electricity production process to the heating of the community building.

**C.S.A. Chong et. al. [2014] [14]** The heat pump market in the UK has grown rapidly over the last few years. Performance analyses of vertical ground-loop heat exchanger configurations have been widely carried out using both numerical modeling and experiments. However, research findings and design recommendations on horizontal slinky-loop and vertical slinky-loop heat exchangers are far fewer compared with those for vertical ground-loop heat exchanger configurations, especially where the long-term operation of the systems is concerned. The paper presents the results obtained from a numerical simulation for the horizontal slinky- loop and vertical slinky-loop heat exchangers of a ground-source heat pump system. A three-dimensional numerical heat transfer model was developed to study the thermal performance of various heat exchanger configurations. The influence of the loop pitch (loop spacing) and the depth of a vertical slinky-loop installation were investigated and the thermal performance and excavation work required for the horizontal and vertical slinky-loop heat exchangers were compared. The influence of the installation depth for vertical slinky-loop configurations was also investigated. The results of this study show that the influence of the installation depth of the vertical slinky-loop heat exchanger on the thermal performance of the system is small. The maximum difference in the thermal performance between the vertical and horizontal slinky-loop heat exchangers with the same loop diameter and loop pitch is less than 5%.

**Jason Meyer et. al. [2011] [15]** While ground-source heat pump (GSHP) technology for space heating and cooling is well established, with widespread implementation across the U.S., information and experience specific to the practicality of using it in cold climates is limited. In Alaska, the use of GSHPs for residential and commercial space heating is uncommon, though several high-profile GSHP installations have occurred, which indicates a broader interest among homeowners, businesses, and government entities to explore this alternative space-heating method. Within the U.S., the South has the highest percentage of GSHP installations (35%), followed by the Midwest (34%), the Northeast (20%), and the West (11%) (Lund, Gawell, Boyd, & Jennejohn, 2010). Ground-source heat pumps in the U.S. are typically sized for the cooling load (Navigant Consulting, Inc., 2009). This sizing is in contrast to GSHPs in Alaska and other northern areas, where the capacity of a GSHP is determined by the heating load of the building. Furthermore, in cold climates, it is probable that a GSHP will be used only

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for heating, unlike more moderate climates, where the ground is used for both heat extraction (space heating) and rejection (space cooling). This difference presents two disadvantages for GSHP efficiency in cold climates: heat is being extracted from relatively cold ground and is not being balanced by heat rejection used for space cooling.

**MICHAŁ WAJMAN [2011] [16]** Nowadays, Ground Source Heat Pumps (GSHPs) are more frequently acting as a main or the only device covering the building heat/cool demand. The most efficient way to extract/dissipate the low-temperature heat from/to the ground is by means of Borehole Heat Exchanger (BHE). In this Master of Science Thesis various aspects related to this technology are studied, focused on summarizing the possibilities of installing this technology in Poland. Borehole drilling methods used in Poland and Sweden are analyzed and the most proper and economical ones according to Polish geological structure are proposed. Approximately for 80 % of Poland the ground should be penetrated with Mud Rotary Drilling, while for the rest 20 % DTH Air or Water driven hammer should be used. Solutions of Thermal Insulated Leg (TIL) Borehole Heat Exchanger cooperation with mechanical ventilation system are proposed and simple preliminary estimations show higher Coefficient of Performance (COP) in comparison to normal, common situation, where standard U-pipe BHE works. The possibility of using a new product (Energy Capsule - EC) in Polish conditions is surveyed, found hard to prosper at Polish market according to its high costs. Profitability of Ground Source Heat Pumps with Borehole Heat Exchanger in different geological regions of Poland is investigated. After conducted simulations it occurred that Polish lowland regions are cheaper in exploited, while uplands regions are less expensive at investment level. Finally, the most efficient BHE conception from those currently available at market as well as recently in- vented is suggested. Annular coaxial BHE in a form of Energy Capsule seems to be the most beneficial from all designs taken into account during performed simulations because of its low price and good thermal properties.

**Matthew James Swenka [2008] [17]** The objective of this study was to evaluate residential ground-source heat pumps throughout the state of Iowa and use that information to develop educational opportunities for prospective ground-source heat pump owners. The ground-source heat pumps were evaluated based on performance, efficiency, and economics. The study was limited to similar homes throughout the state of Iowa, recent constructions and vertically or horizontally configured loops. Energy audits were conducted for each home to obtain building characteristics. Using the characteristics, heating and cooling loads were estimated for each home. Utilizing the heating and cooling loads along with utility bill and weather information, performance data were calculated for each home. The energy analyses showed that cooling loads are not accurately tracked using this method as a result of occupant schedules. The heating load performance showed that there is a negligible difference between the performance of a vertical and horizontal loop system. The economic analysis evaluated the cost difference between using a ground-source heat pump and natural gas furnace. The analysis showed that a significant amount of money could be saved during the heating season when using a ground-source heat pump.

**Georgios Florides et. al. [2004] [18]** The temperature distribution in the ground is distinguished in three zones. The Surface zone, which reaches a depth of about 1m, the Shallow zone extending at a maximum depth of 20 m, and the Deep zone, where the ground temperature remains nearly constant throughout the year. To effectively exploit the heat capacity of the soil a heat-exchanger system has to be constructed. Usually an array of buried pipes running along the length of the building, a nearby field or buried vertically into the ground is utilized. A circulating fluid (water or air) is used in summer to extract heat from the hot environment of the building and dump it into the ground and vice versa in winter. A heat pump may also be coupled to the ground heat exchanger to increase its efficiency. In the literature several calculation models are found for ground heat exchangers. One-dimensional models were devised in the first stages of the system study which were replaced by two- dimensional models during the nineties and three-dimensional systems during the recent years. The present models are further refined and can accept any type of grid geometry that may give greater detail of the temperature variation around the pipes and in the ground. Monitoring programs have been set-up to test various prototype constructions with satisfactory results.

## III. CONCLUSION

In this paper various types of earth heat exchangers are described. Earth heat exchangers are used to exploit effectively the heat capacity of the soil and commonly they are coupled to heat pumps for increasing their efficiency. One, two and three-dimensional models can be found in the literature that simulate the heat transfer process. Simulation models may be used successfully for sizing and predicting the thermal performance of ground heat exchangers. These exchangers usually supply more heating and cooling energy than the primary energy they use for power input for the fan or pump. There are no studies undertaken so far related to the efficiency and cost estimation of ground heat exchangers systems in Cyprus and it is of interest to examine such systems in this environment.

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