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PARAMETERS INFLUENCE ON THE PERFORMANCE OF GROUND HEAT EXCHANGER - A REVIEW

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Abstract
Ground heat exchanger is a significant part of the ground source heat pumps system with environmentfriendly and energy-saving. The coefficient of performance for the ground source heat pump systems is closely associated with the performance of the ground heat exchanger. Some important research development about the ground heat exchanger has been addressed over the last decades. The present term paper work aims to review the previous research on improving the thermal and flow performance of the ground heat exchanger. Various factors like working fluid (gas, antifreeze solution, microencapsulated phase change slurry and nanofluid), turbulence promoter, ground tube (material, structure parameters and optimization tube), backfill materials (conventional type, controlled low strength material and phase change material) and soil field (convention type, frozen soil and groundwater) and others influence the performance of ground heat exchanger. The working fluid, the thermal conductivity of the backfill material and ground water has the greatest impact on increasing the performance compared to other parameters. The composite system is an effective method to enhance the performance of the ground source heat pump systems.

Keywords: Ground heat exchanger, heat pump, composite system, thermal performance, flow performance.

Introduction

Energy is a fundamental problem of the whole world, crucial for developing technology and human progress. With the primary energy consumption increases year by year, renewable energy has become more and more critical. The average ground temperature in the shallow layer maintains stable throughout the year, which is always lower than the summer's air temperature and is higher in winter. The fluctuation of the ground temperature becomes gentle with the depth under the ground surface. The ground temperature would increase with the depth. The soil's temperature gradient is 25 °C km^{-1} at the depth range from 2 to 3 km, and it is 50 °C km^{-1} at depth higher than 3 km.

Geothermal energy is a sort of renewable energy and is the low-grade energy produced by solar radiation or soil decay in the earth's shallow or deep soil, which can be converted into high-grade energy through ground source heat pump (GSHP) systems. In order to reduce air pollution, primary energy consumption and operation cost, the GSHP system becomes increasingly prominent technology, which can be applied in various fields, such as residences, public spaces and industrial parks, especially where the cost is much higher for natural gas than electricity or where natural gas is unavailable. According to the ground depth where the geothermal energy locates, it can be divided into three purposes: power generation (> 4km), direct heating (0.1 – 4km), and direct cooling (> 0.1km)
The ground heat exchangers have been classified as:

1. Horizontal ground heat exchanger
2. Vertical ground heat exchanger
3. Double pipe heat exchanger
4. Direct contact heat exchanger

5. Plate heat exchanger micro channel heat exchanger
6. Spiral tube ground heat exchanger
7. Single pipe ground heat exchanger
8. U-Tube ground heat exchanger
9. Co- axial ground heat exchanger

Parameters, which influence the performance of ground heat exchanger, are:

1. Working fluid (gas, antifreeze solution, microencapsulated phase change slurry and nanofluid.
2. Turbulence promoter, ground tube (material, structure parameters and optimization tube).
3. Backfill materials (conventional type, controlled low strength material and phase change material) and soil field (convention type, frozen soil and groundwater) and others influence the performance of ground heat exchanger.
4. The working fluid, the thermal conductivity of the backfill material.

Literature Review

Zheng. M et. al. [1] presented a three-dimensional unstructured finite volume model for vertical U-tube ground heat exchanger. The model uses Delaunay triangulation method to mesh the cross-section domain of the borefield (borehole field), and consequently may intactly retain the geometric structure in the borehole. The inlet temperature of the ground heat exchanger (GHE) is used as a boundary condition and the inside and outside surfaces of the U-tube pipes are treated as the conjugated interfaces in the domain. A comparison of the model predictions and experimental data shows that the model has good prediction accuracy.

Fossa M. et. al. [2] proposed the thermal analysis of shallow ground heat exchangers with pipes arranged in a helix configuration. The pipes where the carrier fluid is circulated typically embrace a cylindrical volume that is filled by ground or concrete, the latter being the case of the so called geopiles. Other pipes dispositions include conic helices that can be easily inserted in proper excavations. The analysis of the transient thermal behavior of a helix/ground assembly is here carried out according to different approaches, including the exploitation of superposition techniques, the finite element modelling and experiments in a reduced scale mock up. Different geometrical configurations have been taken into account and also the variability of ground and concrete thermal properties have been considered. A detailed description of the experimental set up is provided and the model results have been processed in order to develop suitable 11 temperature response factors (or g-functions) to be employed for predicting the ground heat exchanger behavior in different operating conditions.

[3] Koohi-Fayegh et al proposed the Below a certain depth, the ground temperature remains almost unchanged annually. This phenomenon can be exploited by coupling a ground heat exchanger to a heat pump, storing heat in the ground during summer for use in winter. The ground provides a better source/sink for heat than outside air for heat pump efficiency, as it is cooler than the outside air in the summer and warmer in the winter. Through increased efficiency, such systems also help avoid environmental impact. Much attention is now focused on utilizing ground heat pumps for heating and cooling buildings, as well as water heating, refrigeration and other thermal tasks. Modeling such systems is important for understanding, designing and optimizing their performance and characteristics. Several heat transfer models exist for ground heat exchangers, which usually consist of a series of vertical or horizontal underground pipes. Here, an introduction to ground heat exchanger types is provided, analytical and numerical models for heat transfer in vertical heat exchangers are reviewed and compared, recent related developments are described, and design software for vertical ground heat exchangers is discussed.

[4] Emmai, G., et al proposed the popularity of ground source heat pump systems for both heating and cooling has grown significantly over recent years. Ground heat exchangers are usually buried in the ground either vertically in boreholes or horizontally in trenches. Antifreeze fluids in closed-loop systems are commonly used in these plants to protect them from freezing phenomena and also to reduce the total length of the ground exchangers. In fact, the use of antifreeze fluid allows the

system to work below 0 ◦C which implies higher temperature difference between the heat-carrier fluid and the undisturbed ground, consequently the heat flux increases and the total length of the boreholes can be reduced. This study has been set out to investigate three types of layout system: two conventional heat pumps using pure water and water-glycol respectively as the secondary fluid and an innovative heat pump with a flooded evaporator using pure water. The results demonstrated that, for conventional heat pumps with dry evaporator, the use of anti-freeze additives in mild climates is convenient only in grid-shaped borehole fields with a heatingdominant thermal load. In all other cases, the use of pure water decreases the overall operating costs.

[5] Zhnag,y., et al proposed the downhole coaxial heat exchanger (DCHE) geothermal system, which injects and heats working fluids through the annulus and produces them through the insulated inner pipe, is suitable for developing medium deep geothermal resources. The heat extraction performance of a DCHE with different working fluids remains unclear. This paper presents a critical comparison of various working fluids for a DCHE geothermal system. First, a three-dimensional unsteadystate flow and heat transfer model, which includes the DCHE and the neigh bouring formations, was established. Subsequently, a field trial was conducted and the results were utilised to verify the established model. Next, nine working fluids were selected and the datasets of real thermophysical parameters were established for each working fluid. Finally, the suitability of the working fluids under the same working condition were evaluated. The effects of wellbore, reservoir, and fluid parameters were also studied. This paper provides a good guidance for improving the heat extraction performance and reducing the energy consumption of DCHE geothermal systems.

[6] M.Pishkarihmadabad et al proposed the Ground source heat pump, due to high coefficient of performance (COP) and use of low temperature thermal energy source, is one of the best technologies to use renewable energy resources. In this work, at first, a geothermal heat pump for heating with an economizer is simulated, and then the effects of the variations in different parameters such as evaporator pressure, condensation pressure, and intermediate pressure on heat pump and total COP and exergy efficiency are analyzed. Initially, the thermodynamic simulation of the system is performed for different working fluids (R134a, R-12, R152a, R1234yf, and R1234ze(E)) in the EES software programming environment. The COP and exergy efficiency are calculated for different working fluids and obtained optimal values. The best overall coefficient of performance of the system is related to fluid R134a with a value of 3.663 and the best overall exergy efficiency of the system is related to fluid R1234ze(E) with a value of 0.5517. The lowest PCEU value is for fluid R152a with 0.01247$ per kilowatt. It can be concluded that by reducing the evaporator pressure of the cycle, the cost of producing an energy unit will be cheaper and by reducing the middle pressure of the cycle, the cost of producing an energy unit will be more expensive.

[7] Palmer et al proposed the A high-efficiency ground heat exchanger has been developed for use with ground-source heat pumps. The 13 exchanger is made of copper tubing, shaped in the form of a spiral, which can be installed in a vertical borehole backfilled with sand. Thermal performance of a full-scale prototype indicated that this heat exchanger can achieve very high heat extraction rates if subfreezing operating temperatures are used. For most soil types cyclic freezing and thawing is not a problem; however, for the sensitive Leda clay in which the prototype tests were conducted, substantia1 settlement occurred after the first freeze-thaw cycle owing to initial collapse of the soil structure.

[8] H.zeng et al proposed the A ground heat exchanger (GHE) is devised for extraction or injection of thermal energy from/into the ground. Bearing strong impact on GHE performance, the borehole thermal resistance is defined by the thermal properties of the construction materials and the arrangement of flow channels of the GHEs. Taking the fluid axial convective heat transfer and thermal ‘‘short-circuiting’’ among U-tube legs into account, a new quasi-three-dimensional model for vertical GHEs is established in this paper, which provides a better understanding of the heat transfer processes in the GHEs. Analytical solutions of the fluid temperature profiles along the borehole depth have been obtained. On this basis analytical expressions of the borehole resistance have been derived for different configurations of single and double U tube boreholes. Then, different borehole configurations and flow

circuit arrangements are assessed in regard to their borehole resistance. Calculations show that the double U-tubes boreholes are superior to those of the single U-tube with reduction in borehole resistance of 30–90%. And double U-tubes in parallel demonstrate better performance.

[9] N.Nailli et al proposed the Due to limited amount of natural resources exploited for heating, and in order to reduce the environmental impact, people should strive to use renewable energy resources. Ambient low-grade energy may be upgraded by the ground heat exchanger (GHE), which exploits the ground thermal inertia for buildings heating and cooling. In this study, analytical performance and experiments analysis of a horizontal ground heat exchanger have been performed. The analytical study, relates to the dimensioning of the heat exchanger, shows that the heat exchanger characteristics are very important for the determination of heat extracted from ground. The experimental results were obtained during the period 30 November to 10 December 2007, in the heating season of the greenhouses. Measurements show that the ground temperature under a certain depth remains relatively constant. To exploit effectively the heat capacity of the ground, a horizontal heat exchanger system has to be constructed and tested in the Center of Research and Technology of Energy.

[10] A. Bidarmaghz et al proposed the design of ground heat exchangers (GHEs) involves the selection of detailed configuration options. However, there is limited understanding of the relative importance of different design choices on performance. This study investigates the effects of different design parameters such as pipe configuration and fluid flow rate on the heat extraction rate, and will be helpful to design a system which is energy efficient and cost effective. Different pipe configurations in vertical grouted boreholes including single U pipe, double U-pipe, and double cross U-pipes for small diameter boreholes, and spiral and multiple U-pipes for larger diameter boreholes, are modelled in detail using state-of-the-art finite element methods. The effects of GHE configurations and fluid flow rate on system efficiency is determined and contrasted. Numerical results indicate that the thermal performance of the system is enhanced by transitioning from laminar to turbulent regime, and by increasing the volume of carrier fluid inside the pipes for a given GHE length (i.e., single versus double pipes). However, in larger diameter boreholes, GHE’s thermal performance does not change significantly for different pipe configurations with similar pipe lengths due to the borehole.

[11] Fujji, H. Et al proposed the Geothermal energy is a sort of renewable energy and is the low-grade energy produced by solar radiation or soil decay in the earth's shallow or deep soil, which can be converted into high-grade energy through ground source heat pump (GSHP) systems. In order to reduce air pollution, primary energy consumption and operation cost, the GSHP system becomes increasingly prominent technology, which can be applied in various fields, such as residences, public spaces and industrial parks, especially where the cost is much higher for natural gas than electricity or where natural gas is unavailable. According to the ground depth where the geothermal energy locates, it can be divided into three purposes: power generation (>4 km), direct heating (0.1–4 km), and direct cooling (>0.1KM).

[12] Badgujar et al proposed the number of Slinky-coil horizontal ground heat exchangers (HGHEs) has been increasing in geothermal heat pump (GHP) systems due to the low initial cost. The performance of the Slinky-coils, however, has not been successfully predicted with good accuracy since the complicated shape of the Slinky-coils is not easy to model either analytically or numerically. To enable this, Fujii et al. (2012) developed a numerical model of Slinky-coils using a simplified grid system with FEM based software. They also demonstrated the validity of the models through the history matching between field test results.

[13] D.Mazur et al proposed this paper provides a literature survey on “Ground Coupled Heat Exchanger Air-Conditioning System”. The study indicates the use of earth as a heat-sink with an aim of controlling global warming and moving towards a greener air-conditioning technology. Measurements show that the ground temperature below a certain depth remains relatively constant (15 °C-20 °C) throughout the year. This is due to the fact that the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases because of the high thermal inertia

of the soil. The difference in temperature between the outside air and the ground can be utilised as a preheating means in winter by a heat exchanger.

[14] H. Fatahian et al proposed the main aim of the study is to identify functioning of a ground, spiral heat exchanger co-functioning with a pressurizing heat pump. The heat pump is connected with a heat battery and works periodically during the heating period. The analysis was made by means of numerical modelling and using the finite element method.

[15] A. Sharma et al proposed the thermal performance of a ground heat exchanger (GHE) depends on many parameters, particularly the relation of the working fluid, pipe diameter, and fluid velocity. The effect of these parameters on the pressure drop is rarely addressed in the thermal performance calculations. The present study bridges this knowledge gap with the investigation of the thermal performance of a GHE that is supplied with other working fluids than typical air. A 3D computational fluid dynamics simulation of the performance of a GHE has been carried out by using the realizable k-ε turbulence model. The thermal performance of a segment of a GHE system with different pipe diameters at a wide range of Reynolds number (5,000– 50,000) is investigated for different working fluids (air, propylene glycol, and ethylene glycol) which are thermally validated with a 3D model. The numerical results show that ethylene glycol as the working fluid has a higher temperature increment rate comparing are found.

[16] R. Davies et al introduced a portable component model (PCM) of a ground source heat pump system was developed and used as a test case in the creating of a PCM development framework. By developing this framework, new building energy simulation models will be able to be easily integrated into existing simulation software such as Energy Plus and the Modelica Buildings Library. Our model uses a time responsive g-function and numerical methods to simulate ground source heat pumps for single time steps as well as long time scales. We validated our model against GHESim and GLHEPro and found that our model agrees with these two standards within acceptable ranges of error. This allows for development of the PCM framework to have a functional test case for trouble shooting errors during the development process. Future work on this model to include non-uniform time steps would allow it to be used independent on other software as a standalone system.

[17] D. Padwal et al proposed the now a day we all are aware of the increasing price of electricity. So, everyone is moving towards sustainable living. In this case, Earth Tube Heat Exchanger is the best choice for the HVAC facility. In residential buildings more than 40% of the electricity required for heating and cooling purpose. To reduce the burden on the active system we have moved towards a renewable source of energy. Earth Tube Heat Exchanger works the basic principles of a heat transfer and uses geothermal energy as a source of energy. This project presents the results of theoretical calculation and computer simulations (analysis) of Earth Tube Heat Exchanger. By this system, we can achieve full and partial HVAC facilities in the living area. Analysis of the system is done by using solid works. NTU method is used to calculate the length of ETHE and the effect of the velocity on the effectiveness of the ETHE. The experimental setup consisted of a 21 m long aluminium tube buried at a depth 3.5 m and having a diameter of 0.15 m. A 250 W blower is used for transporting the air in an open loop system.

[18] Li. M, et al proposed the heat transfer around vertical ground heat exchanger (GHE) is a common problem for the design and simulation of ground coupled heat pump (GCHP). In this paper, an updated two-region vertical U-tube GHE analytical model, which is fit for system dynamic simulation of GCHP, is proposed and developed. It divides the heat transfer region of GHE into two parts at the boundary of borehole wall, and the two regions are coupled by the temperature of borehole wall. Both steady and transient heat transfer method are used to analyze the heat transfer process inside and outside borehole, respectively.. As for the region inside borehole, considering the variation of fluid temperature along the borehole length and the heat interference between two adjacent legs of U-tube, a quasi-three dimensional steady-state heat transfer analytical model for the borehole is developed based on the element energy conservation.

[19] Weibo Yang et al implement process of the model used in the dynamic simulation of GCHPs is illuminated in detail and the application calculation example for it is also presented. The experimental validation on the model is performed in a solar-geothermal multifunctional heat pump experiment system with two vertical boreholes and each with a 30 m vertical 1 1/4 in nominal diameter HDPE single U-tube GHE, the results indicate that the calculated fluid outlet temperatures of GHE by the model are agreed well with the corresponding test data and the guess relative error is less than 6%.

[20] Weibo yang a, et al introduce this paper investigates the transient heat conduction around the buried spiral coils which could be applied in the ground-coupled heat pump systems with the pile foundation as a geothermal heat exchanger. A transient ring-coil heat source model is developed, and the explicit analytical solutions for the temperature response are derived by means of the Green's function theory and the image method. The influences of the coil pitch and locations are evaluated and discussed according to the solutions. In addition, comparisons between the ring-coil and cylindrical source models give that the improved finite ringcoil source model can accurately describe the heat transfer process of the pile geothermal heat exchanger (PGHE). The analytical solutions may provide a desirable and better tool for the PGHE simulation/design.

[21] P. Cui et al introduce a finite element numerical model has been developed for the simulation of the ground heat exchangers (GHEs) in alternative operation modes over a short time period for ground-coupled heat pump applications. Comparisons between the numerical and analytical results show that the finite line-source model is not capable of modeling the GHEs within a few hours because of the line-source assumption. On the other hand, the experiments with respect to the alternative cooling and heating modes have been undertaken during a short-time period. The comparisons show a reasonable agreement between the numerical and the measured data. The results illustrate that the finite element numerical model can be used to simulate the heat transfer behavior of the GHEs in short time scales instead of the typical finite line-source model. Finally, the variation of the Utube pipe wall temperatures demonstrates that the discontinuous operation mode and the alternative cooling/heating modes can effectively alleviate the heat buildup in the surrounding soil.

[22] C. K. Lee et al introduce a modified model for a borehole ground heat exchanger borefield (BHE) of a ground-source heat pump (GSHP) system was developed based on a three-dimensional finite difference scheme which could cater for multiple ground layers and an inhomogeneous groundwater flow in the soil. The model was validated using FLUENT for a single borehole based on a constant load along the effective length of the borehole with good agreement. The present model was then used to investigate the effect of the groundwater table on the performance of the BHE. It was found that with the borehole partially-submerged in groundwater flow, the borehole specific load along the borehole depth became stratified, the extent of which depended on the various parameter values. The borehole thermal resistance also varied with the relative groundwater table and the groundwater flow velocity. The trends of the fluid temperature leaving a borehole were quite different between the situations when the borehole was partiallysubmerged in groundwater flow and the case with a full groundwater flow. This meant that the use of an effective groundwater flow velocity to account for the groundwater table effect in a full-groundwaterflow BHE model could be erroneous, particularly for simulation of a large BHE.

[23] Ping Cui a,b,c, et al proposed the Existing analytical solutions for thermal analysis of ground source heat pump (GSHP) systems evaluate temperature change in the carrier-fluid and the surrounding ground in the production period of a single borehole heat exchanger (BHE) only if a continuous heat load is assigned. In the present study, we modified the Green's function, which is the solution of heat conduction/advection/dispersion equation in porous media, for discontinuous heat extraction by analytically convoluting rectangular function or pulses in time domain both for single and multi-BHEs field. The adapted analytical models for discontinuous heat extraction are verified with numerical finite element code. The comparison results agree well with numerical results both for conduction and advection dominated heat transfer systems, and analytical solutions provide significantly shorter runtime compared to numerical simulations (approx. 1500 times shorter).

Furthermore, we investigated the sustainability and recovery aspects of GSHP systems by using proposed analytical models under different hydro-geological conditions. According to the engineering guideline VDI 4640, a linear relationship between thermal conductivity of the ground and the sustainable heat extraction rate is demonstrated for multi-BHEs.

[24] Seicuk Erol 1 et al proposed the Several models are available in literature to simulate ground heat exchangers. In this paper an approach based on electrical analogy is presented, for this reason named CaRM (CApacity Resistance Model). In some cases several information are needed during design: both the borehole and the surrounding ground are affected by thermal exchange. The model here presented allows to consider the fluid flow pattern along the classical vertical ground heat exchangers as a single U-tube, a double U-tube or coaxial pipes. Besides, ground temperature at different distances from borehole are calculated, taking into account also the thermal interference between more boreholes. Starting from the supply temperature to the heat exchanger, the outlet fluid temperature is calculated and the ground temperature in each node, step by step. The model has been validated by means of a commercial software based on the finite differences method. Further comparisons have been carried out against data from a ground thermal response test and from the survey of an office building equipped with a ground coupled heat pump and vertical double U-tube heat exchangers. The agreement of results validates the model here presented.

[25] Michele De Carli et al proposed the Freezing of soil around ground heat exchangers (GHE) is a common problem for a ground coupled heat pump (GCHP) operated in the cold district, which will affect the underground soil temperature variation and its heat transfer performance. In this paper, a two-dimensional model for heat transfer with freezing-thawing phase change in soil around GHE is developed and numerically analyzed by apparent heat capacity method. The influences of soil freezing, soil water content, and soil type on soil temperature variations and long term underground thermal imbalance of GCHP with GHE array are investigated. The results indicate that the soil freezing can lessen the soil temperature drop and thus increase the temperature difference between the fluid inside GHE and far-field soil. This helps to shorten the GHE design length and cut down the initial system cost. The soil freezing characteristics are mostly affected by the soil thermal diffusivity. From the view of the ability in delaying soil temperature drop, the sandstone is preferable to sand, and sand is better than clay. Additionally, increasing water content can reduce the drop degree and speed of the soil temperature, as well as, accordingly alleviate the underground thermal imbalance of GCHP.

[26] Weibo Yang a, et al proposed the improvement to the thermal resistance capacity model (TRCM) used to model borehole heat exchangers is presented. Here, the original model is extended to integrate the thermal capacities of the heat carrier fluid and pipe and to better account for the spacing between the pipes. Model results are compared to results provided by numerical models and show very good agreement. It is shown that the improved model brings a significant improvement for short times over the original model, allowing a rapid computation of the temperature response function at virtually any time and distance from a single borehole.

[27] Philippe pasquier et al proposed the ground-source heat pump systems are highly efficient and energy saving. Its main disadvantage is a significantly higher installation cost compared to conventional systems. The length of the ground heat exchanger (GHX) piping, consequently, the first cost, depends on several factors; one key factor is the undisturbed ground temperature estimations. Xing and Spitler model was developed which provides a new set of ground temperature results for GHX design. There are two common methods in United States to be used for ground temperature estimations - ASHRAE Handbook method and ASHRAE district heating manual method. This paper presents the impact of Xing and Spitler model development on the horizontal ground heat exchanger (HGHX) design. An analytical HGHX simulation tool is developed. 12 geographically diverse sites in United States are chosen for the case study. Three different HGHX configurations are investigated. For each site, HGHX design length using the Xing and Spitler model estimated ground temperatures as inputs are compared to design results based on measured ground temperatures; the calculated HGHX design length percentage error are within ±18.9%. The calculated HGHX design length percentage

error using the ASHRAE Handbooks results and ASHRAE district heating manual results are within ±38.3% and ±57.7% respectively.

[28] Spitler Liheng li introduce this paper presents a new cylindrical source heat transfer model for simulating the influence of the thermal properties difference between the borehole and pile ground heat exchangers and the surrounding soil directly. Based on the energy conservation law, the model proposes a heat transfer equation that heat transfers from the heat source to both sides, and the analytic solution in Cartesian coordinate system is obtained via Laplace transform and inverse transformation. Because special cases of the analytical solution can be deduced to the classical models, the proposed model can be considered a unified model of the classical ones. The heat transfer analysis using this model shows that the thermal properties of the materials inside and outside the heat source have a greater impact on the initial period of heat transfer. Furthermore, the proposed model enables more accurate energy consumption analysis and energy pile design. Base on the model, to improve the heat transfer efficiency, the following measures can be adopted for the materials inside and outside the heat source. The moisture content of the soil outside the heat source can be increased, optimally keeping the soil saturated. Inside the heat source, on the premise of satisfying the requirements of mechanical properties, the thermal conductivity can be increased, whereas the volumetric heat capacity and diameter can be decreased.

[29] Jun Yanga et al proposed the Ground-source heat pump systems are increasingly popular for providing single-family home heating in Nordic countries. As the density of installations increase, questions sometimes arise as to the influence of new systems on existing systems. These questions cannot be readily answered, as design and simulation techniques developed over the last 35 years have focused on analysis of individual systems without regard to the influences of other systems. Response factor models of ground heat exchangers utilize pre-computed response functions known as g-functions. These g-functions give the response of the ground heat exchanger (non-dimensionalized temperature) to the past and current heat rejection or extraction of the ground heat exchanger. We might call this a "self-g-function.

[30] S.Matt et al proposed the building sector consumes much energy either for cooling or heating and is associated to greenhouse gas emissions. To meet energy and environmental challenges, the use of ground-to-air heat exchangers for preheating and cooling buildings has recently received considerable attention. They provide substantial energy savings and contribute to the improvement of thermal comfort in buildings. For these systems, the ground temperature plays the main role. The present work aims to investigate numerically the influence of the nature of soil on the thermal behavior of the ground-to-air heat exchanger used for building passive cooling. We have taken into account in this work the influence of the soil nature by considering three types of dry soil: clay soil, sandy-clay soil and sandy soil. The mixed convection equations governing the heat transfers in the earth-to-air heat exchanger have been presented and discretized using the finite difference method with an Alternate Direction Implicit (ADI) scheme. The resulting algebraic equations are then solved using the algorithm of Thomas combined with an iterative Gauss-Seidel procedure. The results show that the flow is dominated by forced convection. The examination of the sensitivity of the model to the type of soil shows that the distributions of contours of streamlines, isotherms, isovalues of moisture are less affected by the variations of the nature of soil through the variation of the diffusivity of the soil. However, it is observed that the temperature values obtained for the clay soil are higher while the sandy soil shows lower temperature values. The values of the ground-to-air heat exchanger efficiency are only slightly influenced by the nature of the soil. Nevertheless, we note a slightly better efficiency for the sandy soil than for the sandy-clayey silt and clayey soils. This result shows that a sandy soil would be more suitable for geothermal system installations.

[31] N.Kokou et al proposed the Ground source heat pumps are a sustainable way to provide building heating and cooling due to their efficient use of near-constant ground temperatures as mediums for heat exchange. Conventional in-ground heat exchangers are limited by the large size of required borehole field installations and the high economic costs, therefore the pairing of in-ground

structural helical piles with these heat exchangers offers a system of geothermal heating and cooling which can be more accessible and lower cost than traditional equipment. In this research, a novel helical steel pile was modelled using a 3-D numerical model and finite element analysis. This model was first validated with experimental data from a double-tube pile, with 24-hr transient operation outlet temperatures accurate within 3%. Finally, the steady state heat exchange rate per unit area was calculated, with the new helical steel pile geometry yielding an increase of 8.6 W/m, 13.2 W/m, and 16.2 W/m (for 2 L/min, 4 L/min, and 8 L/min flowrates respectively) over the validation model.

[32] R. Sarah et al proposed the weather of the United Arab Emirates region poses a considerable challenge in terms of the extreme summers where average ambient temperature exceeds 45 ºC. The extreme summers result in greater power consumption by the air conditioning systems widely used in the region, the continual increase in energy demand and greenhouse gas emissions decree for efficient use of renewable energy resources. Thus there a is growing necessity to improve the geo-thermal techniques in order to cut-down on power consumption for refrigeration and air conditioning applications. The Vertical Looping Method was employed in the implementation of direct exchange ground source heat exchanger. This paper presents the experimental results on the performance of the system with medium as still air, water and sand. The experimental result shows that the highest coefficient of performance of 3.72 achieved when the bore hole is filled with water. Keywords: Ground Source, Heat Exchanger, Vertical Looping, Condenser, Air Conditioner.

[33] S. V. Kota Reddy et al proposed the heat pump-coupled borehole heat exchanger (BHE) systems ("Ground coupled" or "Geothermal heat pumps") are ideally suited to tap the ubiquitous shallow geothermal resources. Traditionally, geothermal direct use aims to use the heat content of formation fluids, if present. The heat content of the rock matrix is generally higher; this heat is the target of shallow resource used. The thermal load of the BHE depends mainly on the thermal conductivity of the surrounding ground. The heat transfer from the ground to the BHE is by conduction, i.e. there are no formation fluids produced. Experimental and theoretical investigations prove that BHE/HP systems, if properly designed, operate reliably on the long term without negative environmental effects.

[34] J. Walter et al proposed, in recent years, various researchers have studied the performance of Solar Assisted Ground Source Heat Pump (SAGSHP) systems using borehole heat exchangers. However, the research conducted has been limited to conventional boreholes (30m to 150m depth), which are expensive and not suitable for the small housing sector. This paper reports an experimental analysis of a shallow SAGSHP system with inter-seasonal storage. The system, installed in Leicester UK, consists of seven photovoltaic-thermal (PVT) collectors connected in series with an array of 16 shallow boreholes (1.5 meters depth). Data regarding the energy fluxes involved in the soil-based thermal store have been monitored and analysed for one year. The results show that the shallow soil is able to serve as a storage medium to cover the heating demands of a near zero energy domestic building. However, it was noticed that in addition to the solar heat captured and stored in the soil, the system covers part of the heating demand from heat extracted from the soil surrounding the thermal store. During winter, the lowest temperature reached by the soil so far is 2 °C. Hence, no freezing problems have occurred in the soil. An analysis of the temperature variation of the ground storage under the system operation is shown.

[35] J. Wrigh et al introduce a portable component model (PCM) of a ground source heat pump system was developed and used as a test case in the creating of a PCM development framework. By developing this framework, new building energy simulation models will be able to be easily integrated into existing simulation software such as EnergyPlus and the Modelica Buildings Library. Our model uses a time responsive g-function and numerical methods to simulate ground source heat pumps for single time steps as well as long time scales. We validated our model against GHESim and GLHEPro and found that our model agrees with these two standards within acceptable ranges of error. This allows for development of the PCM framework to have a functional test case for trouble shooting errors during

the development process. Future work on this model to include non-uniform time steps would allow it to be used independent on other software as a standalone system.

[36] Rayn Davies et al introduce a new finite-difference model of heat transfer inside a shallow coaxial ground heat exchanger and in the surrounding layered soil is presented, taking into account the freezing of ground moisture. Three modes of heat exchanger operation are numerically simulated: stationary mode, transient mode and controlled mode. In the stationary mode, estimates of the sensitivity of the heat carrier fluid outlet temperature to changes in the heat exchanger parameters are calculated. In all modes, close attention is paid to demonstrating the difference in the results at a negative temperature of the fluid, calculated with and without taking into account the freezing of ground moisture. It is shown that this difference, caused by the zero-curtain effect, can range from 10% in the stationary mode to 35% in the control mode.

[37] G.P. Vasilyeva et al proposed the Ground-Source Heat Pumps (GSHPs) are a clean alternative to traditional space heating and cooling technologies. GSHPs take advantage of relatively constant ground temperatures as a medium for heat exchange, in contrast to the use of highly variable air temperatures. Conventional systems use a heat pump paired with a borehole heat exchanger to exchange heat with the ground. Widespread use of these systems has been impeded by high initial costs and low short-term return on investment. Helical steel piles (HSP) are structural elements that are drilled into the soil to provide support to buildings. With only minor modifications, these structures have shown promise as a viable alternative to the use of the conventional borehole heat exchanger. At present, there is little understanding of the functionality and the optimal design of HSPs as heat exchangers under different soil properties such as heterogeneity, porosity and saturation content. Therefore, the focus of this paper is to investigate the performance of HSPs under different heterogeneous soil conditions using numerical analysis. This paper presents the results of a numerical study of HSP performance under varying moisture contents.

[38] Geoffrey et al proposed the objective of this paper is to compare the required length and performance of ground heat exchangers as well as heat pump energy consumption for fixed and variable speed ground-source heat pumps. In the first part of the paper, a physics-based model of a water-to-water heat pump is briefly presented. This model is incorporated in TRNSYS simulations using a performance map where variable speed operation is handled through a linear relationship linking the COP to the percentage of the full capacity being used. The ground heat exchanger is modeled using a thermal resistance and capacitance approach to account for borehole thermal capacity. Simulations are performed on a typical residential building located in a cold climate (Montréal, Canada) and equipped with either a fixed or variable speed groud-source heat pump. Results are obtained for eight cases with: variable or fixed speed operation (VSC or FSC), with or without consideration of borehole thermal capacity (TC or NTC), and with annual heating needs covered at 90% or 100% by the heat pump. The differences in the required borehole length between the TC and NTC cases are relatively small. The smallest required borehole length is for the FSC-90%- TC case (180 m) and the longest is for the VSC-100%-TC case (250 m). The VSC-100% case has the largest seasonal Performance factor (SPF) at 4.14 and the FSC-90% case has the lowest at 3.11.

[39] A horizontal ground heat exchanger has been applied as a simpler sustainability measure in buildings compared to its vertical counterpart, making it more suitable for residential application. A lack of contextual scientific findings within the specific construction culture has precluded its widespread application in the developing world. In this study, an experimental and simulation investigation was carried out on the thermal performance of an air-based horizontal groundcoupled heat exchanger buried 3 m below the ground. The study was performed in the tropical climate of Mauritius with a focus on space cooling. The ground temperature and air temperature inside the pipeline at several locations of the installation was measured. A CFD simulation model was developed and calibrated against the experimental data, which allowed further analyses on the influence of system parameters on performance. The study allowed to confirm the performance of the technology for application as a sustainability measure in the local construction industry and to identify practical

challenge that need to be addressed. A drop in temperature of up to 5°C was achieved at 2.3 m/s and 8°C at 4 m/s. The latter result holds promise to achieve thermal comfort by achieving indoor air temperature of 27 °C or lower when ambient air is at 33-34°C during typical summer periods.

[40] Ground-heat transfer is tightly coupled with soilmoisture transfer. The coupling is threefold: heat is transferred by thermal conduction and by moisture transfer; the thermal properties of soil are strong functions of the moisture content; and moisture phase change includes latent heat effects and changes in thermal and hydraulic properties. A heat and moisture transfer model was developed to study the ground-coupled heat and moisture transfer from buildings. The model also includes detailed considerations of the atmospheric boundary conditions, including precipitation. Solutions for the soil temperature distribution are obtained using a finite element procedure. The model compared well with the seasonal variation of measured ground temperatures.

III. Conclusion

- First, several sensitivity coefficients of parameters and uncertainties occurring in in-situ tests are examined in depth.
- Starting from an analytical heat transfer model of borehole ground heat exchangers, sensitivity coefficients for single U-tube ground heat exchangers are of analytical forms. The sensitivity analysis provides some general and new guidelines for mitigating the influence of testing uncertainties.
- Next, Monte Carlo simulation is performed to evaluate reliability of two powerful minimization algorithms, the Levenberg–Marquardt method and a trust region method subject to bounds.
- The Monte Carlo simulation shows that if thermal diffusivity of soil is an estimated parameter, the Levenberg–Marquardt method may result in unreliable results, and its performance depends strongly on the quality of the initial guessed values.
- In contrast, the interior trust region method considered in this paper can produce more reliable results, and its performance depends on the range of input parameters bounds.
- Finally, feasibility of the highlighted methodology is illustrated by applying it to two real in-situ thermal response tests

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