Enhancing the Performance of Dry Air-Cooled Systems with Wet Geothermal Cooling in Saudi Arabia

Mahmoud Bady1,2, and Nabil A.S. Elminshawy3
1 Mechanical Engineering Department, Islamic University of Medina, Saudi Arabia
2 Mechanical Engineering Department, Assiut University, Assiut 271516, Egypt
3 Mechanical Power Engineering Department, Port-Said University, Egypt

Email: mfbady@yahoo.com

Abstract. Reducing the temperature of the working fluid in the electric generation systems (gas turbine air inlet as well as steam from the steam turbines) requires an effective cooling medium. The present work is a part of a research project conducted in the Islamic University of Madinah, Saudi Arabia, to present reasonable solutions to pre-cool the inflow air to the air-cooled condensers in electric generation systems in KSA, when the ambient air temperature increases above the design air inlet temperature. An extensive amount of measurements has been carried out to investigate the effects of soil parameters on a buried earth-air heat exchanger. Among many parameters, the current research focused on investigating the effects of soil moisture contents and degree of compaction -represented by relative density- on the thermal performance of the buried heat exchanger. Results of the study show that; an average daily basis, a significant induced air temperature drop of 23.5 °C is achieved at the soil moisture content of 30 % and soil compaction of 91.17 %. Furthermore, the effectiveness of considered BEA HE is increased by about 33.34 % when the soil compaction is increased from 26.47 % to 91.17 %.

1. Introduction
The majority of power plants built during the last decade around the world are based on the combined-cycle process for power generation. The new combined-cycle power plants are seen as offering a greater degree of flexibility in the type of cooling system that can be used. Several recently built combined-cycle plants use air-cooled condensers (dry cooling) instead of the traditional condenser/wet cooling system. Still, other plants have hybrid cooling systems.

Kingdom of Saudi Arabia has a long dry summer extending over about seven months, from March to November. The design conditions and the monthly average peak of dry bulb and wet bulb temperatures indicate the hot-dry nature of KSA weather occurs during the hot summer months (April to September) when peak daily temperatures range from 37 to 55 °C. For most of the summer months, the difference between the average DBT and WBT is over 15 oC the relative humidity was between 14.4 % and 20 %. Thus, water cooling condensers (WCC) are expected to perform more efficiently as the sink temperature is lower. In spite of the apparent advantage of the lower power and energy demand of the WCC systems, most of the power plant cooling systems in Saudi Arabia are of the air-cooled types (ACC) type. Due to the shortage of natural and soft water, and rarely rainfall, most of the soft water requirement is satisfied through seawater desalination, which is highly energy intensive. The high cost of water is, therefore, an additional parameter affecting the choice between ACC and WCC systems.
Dry cooling of power plants in Saudi Arabia may be an attractive alternative to wet cooling, particularly where water conservation and environmental protection pose critical sitting issues. However, dry cooling technology may be unable to maintain design plant output during the hottest periods of the year, which are often periods of peak system demand.

Many studies have been carried out to investigate the effects of cooling systems on the cycle performance and energy generation cost. Maulbetsch and DiFilippo [1] stated that the total thermal power plant cost is 5% to 15% higher if dry-cooling instead of wet-cooling is utilized. They also noticed a reduction in the potential annual income may be 1% to 2% that for dry-cooled systems, due to their performance penalties in a hot climatic region. Weifeng et al. [2] stated that the efficiency of the thermal systems utilizing air-cooled condenser is adversely affected when ambient air temperature increases above a certain acceptable nominated temperature. So, the larger the temperature difference between the heat source of the thermal system and the external ambient atmospheric air were simply transferring its exhausted heat to the ambient air directly, the more efficient is the thermal system cooling. Thus, the desirability of lowering the air ambient temperature in the external environment is significant. This consideration gives rise to desirably hybridizing the active air-based units of thermal system alongside with passive techniques (i.e. earth-air heat exchangers) [3].

Outdoor ambient atmospheric air is induced into the buried earth-air heat exchanger (BEAHE) before being introduced to the thermal systems for air cooling purpose, rather than being supplied into the thermal systems directly. When air passes through the BEAHE in the summer season, heat is transferred from the air to the soil, the air is then pre-cooled. Due to the delayed thermal response of soil, the temperature of the soil at a few meters under the earth surface is lower than ambient in summer and remains nearly constant at the average annual level [4-8]. The BEAHE utilizes this temperature gradient between atmospheric air and ground for passive cooling by dumping heat into the soil as a natural sink, as a result, the air is pre-cooled by the soil in the summer season. The outlet pre-cooled air from the buried earth-air heat exchanger can be directly employed for enhancing the thermal system cooling. Buried earth-air heat exchangers are eco-friendly and consume almost no energy. Thus power consumption of the vast number of thermal systems can be reduced substantially by hybridizing it with earth air heat exchanger system especially in hot and humid weather conditions where the summer ambient temperature sometimes exceeds 40 °C.

Several configurations for shallow buried earth-air heat exchangers have been proposed as a heat source or sink, two of the most popular configurations are horizontal and spiral coil heat exchangers. Horizontal ground heat exchangers [9, 10] and spiral coil heat exchangers either used directly in the ground or in pile heat exchangers [11, 12]. However, these types of earth-air heat exchangers are more sensitive to atmospheric conditions, and to dynamical behavior of soil moisture contents because they are closely buried to the earth surface. Soil-specific conditions at the site around the BEAHE found to highly impact horizontal earth-air heat exchangers systems designed and performance [13, 14]. In the most recent studies, thermal performance of the earth-air heat exchanger models is always based on heat transfer, without consideration of the soil moisture contents [15, 16]. Only few research works have been accomplished in soil moisture migration caused by buried heat exchangers operation, such as the model designed by Chalhoub et al. [17] to check the effect of soil moisture around the coil was developed. According to a computer simulation by Leong et al [18], the thermal performance of a ground heat exchanger system shows a very sharp decline for dry soil—it is lower by up to 35% with respect to saturated conditions. Alteration of soil moisture content from 12.5% of saturation to complete dryness strongly decreases the ground heat exchanger effectiveness. The soil is usually unsaturated around the buried heat exchanger, in which heat transfer interacts with water transfer in a very complex process. In another investigation by Piechowski [19], the initial value of soil moisture content was significant for accurate simulation or construction of buried heat exchanger. In their experimental investigation that was testing four soil types, an increase in moisture content at a given bulk density increased the thermal conductivity. Furthermore, parameters that affect the thermal conductivity of soil can be controlled externally. Soil density and moisture content are some of these controlled parameters [20].

The main objective of the present research is to investigate experimentally a newly air cooling technique employing geothermal sustainable cooling that will integrate with the traditional cooling or
condensation system that already used with the vast numbers of the thermal system, especially in the summer season. In this study, the ambient air is firstly cooled via a buried heat exchanger which assisted by various soil moisture contents to enhance air cooling by damping the heat of the atmosphere through the soil. The produced pre-cooled atmospheric air will then pass to the traditional thermal cooling systems but with low temperature than the hot air temperatures. The thermal performance of such geothermal wet cooling as a new cooling system will be calculated using two parameters; the soil cooling load and the whole system effectiveness.

2. Experimental setup and measurements

The present study is based on the extraction of heat from the hot ambient air in the summer season and then passes it to the soil beneath the earth surface using the BEAHE.

2.1. Experimental test rig and procedures

To evaluate the performance of BEAHE in various climatic conditions and in order to investigate the effects of different operational parameters, an experimental setup was designed and constructed, as shown in figure 1. The test setup consists of four major modules:

- A primary air simulator including a centrifugal air blower of 0.25 kW equipped with a frequency inverter to adjust air flow rate and electrical heating chamber with thermostat was employed. The electrical heating chamber was used to heat the atmospheric ambient air to the required temperature that represents the actual ambient air in the summer season in Madinah. So, the ambient air with various temperatures and flow rates was supplied to the tubes of the buried heat exchanger. A straighter was provided to achieve airflow uniformity and temperature homogeneity.

- A cylindrical truncated drum of 0.5 m diameter with a length of 1.5 m was devoted to containing the selected soil to be tested where the heat exchanger tube was buried. The drum is made of 1.5 mm-thick galvanized steel sheet and aligned horizontally. So, three boreholes were drilled at various depths in the site of Madinah land, at 1, 2 and 3 m from the earth surface.

- The exact soil temperatures were measured in the three various selected depths using cable thermometer. Then, the soil temperature that representing each depth is tested in the lab by filling the truncated drum with the soil collected from the same site around the boreholes and keeps it in a control temperature lab for 24 hrs before each test. This sequence ensures constantly desired soil temperature homogeneity at the beggining of each test that represents each depth. The buried tube was constructed of copper with a length of 1.5 m and a radius of 0.02 m and was aligned at the center of the cylindrical soil drum.

- The experimental investigations were conducted in the hottest month (i.e. July) to evaluate the thermal performance of the considered earth-air heat exchanger for cooling the hot ambient air.

By letting hot ambient air flow through the buried tube, the air temperatures in the earth–air–tube system were measured by multichannel K-type thermocouples with a digital display connected at four various radial positions from the center of the tube. These four equally spaced radial positions are referred to as 0.045, 0.090, 0.135 and 0.180 m from the center of the buried tube. A Kanomax multifunction hot-wire anemometer Model 6501 was used to measure the airflow and temperature at the inlet and outlet of the buried tube. By measuring the ambient air temperatures at the inlet and outlet of the heat exchanger tube at 30 min intervals, hourly cooling potential by BEAHE can be calculated for the various studied working parameters according to the equation:

$$\dot{Q} = \dot{m} c_p (T_{\text{inlet}} - T_{\text{exit}})$$

(1)

The effectiveness of the BEAHE system is given as:

$$\varepsilon = \frac{T_{\text{a,in}} - T_{\text{a,out}}}{T_{\text{a,in}} - T_w}$$

(2)

where $T_w$ is the tube wall temperature at the start of each experiment, $\dot{Q}$ is the cooling potential (W.h), $\dot{m}$ is the air mass flow rate through the tube assembly (kg/s); $c_p$ is the specific heat capacity of air (J/kg. K); $T_{\text{a,in}}$ is the air temperature at the inlet of BEAHE (°C); $T_{\text{a,out}}$ is the air temperature at the outlet of BEAHE (°C).
The current research focused on the effects of soil moisture contents and degree of compaction represented by relative density (DR %) on the thermal performance of buried tube heat exchanger. For the interpretation of the test data, both moisture contents and the degree of compaction of the unsaturated tested soil were controlled. Three moisture contents were prepared; 9.87, 21.3, and 30 %, where each level being tested at three degrees of soil compaction of 26.47, 70.58, and 91.17 %. It should be noted that; it was difficult to prepare indoor soil with a higher degree of compactions, especially at the high water contents. The soil was firstly placed in an oven and allowed to dry for 24 hours and is then left in a dry place before being used, through this process the mass and density of dry soil can be evaluated. According to the required soil moisture content, a fixed mass of the dried soil was thoroughly mixed with the desired amount of water to produce soil with different initial moisture of content.

2.2. Tested Soil Properties
It is expected that the properties of soil affect the performance of the considered earth-to-air tube heat exchanger as natural heat dissipation sink. So, undisturbed natural soil samples collected from the site of Madinah land around the Islamic University campus was subjected to laboratory measurements to determine the bulk density, porosity, and particle size distribution. It is dusty brown poorly graded sand its physical properties according to the current research scope are as follows.

2.3. Compaction Characteristics
This multidimensional study fuscous on utilizing soil heat dissipation properties which greatly depends on the voids present in the soil. The number of voids present in the soil can be represented by the degree of compaction (relative density). The relationship for determining relative density from void ratio is given by:

\[ DR(\%) = \frac{e_{\text{max}} - e}{e_{\text{max}} - e_{\text{min}}} \times 100 \]  

(3)

where \( e_{\text{max}} \) is the maximum void ratio, \( e_{\text{min}} \) is the minimum void ratio, and \( e \) is the void ratio at given compaction.

The void ratio is calculated on the basis of simple mass-volume relationships. Whereas, maximum and minimum void ratios are determined in laboratory respectively as per ASTM D 4253 and ASTM D 4254. The maximum and minimum void ratio values for Madinah Sand are given in Table 1.

| Parameter | Value |
|-----------|-------|
| \( e_{\text{max}} \) | 0.97 |
| \( e_{\text{min}} \) | 0.63 |
2.4. Compaction Levels for Model Test:
To obtain different bulk densities, the soil was compacted in the truncated drum by a soil compaction hammer. The hammer of an approximate weight 2 kg, was dropped into the soil layer surface inside the drum from a height of approximately 0.30 m. To achieve different levels of bulk density, one used zero drops for the loose soil, 10 drops for the medium soil, and 25 drops for the compacted dense soil. Three compaction levels have been selected for the analysis of heat dissipation properties of the investigated BEAHE. These levels have been abbreviated as T₁, T₂, and T₃. The properties of these levels are summarized in Table 2.

Surface moisture-density gauge Model 3430, manufactured by TROXLER was employed to quickly and precisely measure the compaction level moisture and density of soil and soil bases without using destructive methods. Using direct transmission or backscattered gamma radiation, this gauge measures the density of materials by counting the number of photons emitted by the cesium-137 source.

| Sand Nomenclature | Compaction Level | Specific Gravity | Void Ratio (e) | DR% |
|-------------------|------------------|------------------|----------------|-----|
| T₁                | Loose            | 2.67             | 0.88           | 26.47 |
| T₂                | Medium           | 2.67             | 0.73           | 70.58 |
| T₃                | Dense            | 2.67             | 0.66           | 91.17 |

The daily average improvements in the cooling loads (% Qₐ) across the BEAHE for wet soil with different moisture levels and compaction levels compared with dry soil is an important performance parameter. It can be estimated through the formula:

\[
\% Q_{c-\text{mprovement}} = \frac{Q_{c}\text{wet} - Q_{c}\text{dry}}{Q_{c}\text{dry}} \times 100
\]

2.5. Ground temperature measurements
The mean soil and the ambient air temperatures were measured are shown in figure 2 for the months of June to September in the site around the Islamic University campus at three depths inside the soil: 1, 2 and 3 m. Clearly, the soil temperature decreases significantly beneath the ground surface compares to the ambient dry bulb temperature. It is also seen that, while the mean air ambient temperature fluctuated around 44-49 °C, in the summer months during the day time, the temperature at 1-3 m depth remained virtually constant at 27-29 °C. A maximum difference of about 18 °C was observed between the soil temperature and the dry bulb temperature of the ambient air.

2.6. Uncertainty in the measurements
In the current investigation, the minimum measured values of induced air velocity, air temperature, soil relative density, and soil moisture content are 10 m/s, 20 °C, 26.47 % and 9.87 % respectively. Least count of measuring instruments for induced air velocity, temperature, soil relative density, and soil moisture content are 0.015 m/s, 0.1° C, 10% and 5%, respectively. Therefore, uncertainties in the measurement of induced air velocity, temperature, soil relative density, and soil moisture content are estimated as ± 0.60%, ±0.5%, ±0.37%, and ±0.50% respectively.
3. Results and discussions

Among many factors, the soil relative density and the soil moisture content are selected to study their effects on the proposed heat exchanger performance.

3.1. Effect of soil moisture contents and compaction level on the cooling load:

The effect of soil moisture contents on the temperature drop across the considered BEAHE for various soil relative densities is illustrated in figure 3 through figure 5. Tests were performed for wet soil with three different levels of soil moisture contents of 9.87, 21.3, 30% and compared with dry soil. Since the compaction level of soil is a significant parameter, three soil compaction levels are considered: low, medium, and high compaction with various relative densities of 26.47, 70.58 and 91.17 % respectively. For these set of experiments, the corresponding air flow rate, inlet ambient air temperature and soil temperature were fixed at 0.006 m$^3$/s, 50 °C and 25 ºC, respectively.

It can be noticed that the soil moisture content highly affects the thermal performance of the examined BEAHE. The temperature drop across the considered pre-cooling system increased when the soil moisture content level increased. It is also observed that the thermal performance of the system is clearly improved by increasing the level of soil relative density. As results emphasize, burring the pipes of the investigated heat exchanger in wet soil raises the effectiveness of the BEAHE. Furthermore, burring the pipes of the heat exchanger in a highly compacted soil increases the effectiveness of the BEAHE thermal performance. Accordingly, for the case of induced air with an inlet temperature of 50 °C and air flow rate of 0.006 m$^3$/s, an 18.29 %, 20.34 % and 22.49 % improve in the temperature drop is recorded for soil moisture content 9.87, 21.3 and 30% respectively, for high compacted soil at relative density of 91.17 %. For the case of medium compacted soil with a relative density of 70.58 % and low compacted soil with a relative density of 26.47 % an increase in the temperature drop 15.64, 16.13, and 17.81 % and 13.53, 14.16 and 16.06 % are achieved for soil moisture content 9.87, 21.3 and 30% respectively. On an average daily basis, the temperature drop across the BEAHE increases by 18.29, 20.34 and 22.49 %, when the soil moisture content reached a value of 9.87, 21.3, and 30.0 % respectively, compared to dry soil for high compaction level with soil relative density of 91.17 %.
Figure 3. Effect of soil moisture content on the cooling load at soil relative density of 91.17% (high compaction).

Figure 4. Effect of soil moisture content on the cooling load at soil relative density of 70.58% (medium compaction).

Figure 5. Effect of soil moisture content on the cooling load at soil relative density of 26.47% (low compaction).
Table 3 presents the average daily improvements percentage in the cooling loads ($Q_c\%$) across the BEAHE for wet soil with different moisture levels and compaction levels compared with dry soil. The cooling load is enhanced by 11.74, 23.67 and 36.12% at high soil compaction (DR$\% = 91.17$), by 9.27, 18.87 and 28.39 % at medium compaction (DR$\% = 70.58$), and by 8.01, 16.29 and 25.83 % at low compaction (DR$\% = 26.47$) when the moisture content is raised to 9.87, 21.3 and 30.0 % respectively, compared to dry soil.

| Soil moisture contents (%) | Cooling load across the BEAHE and % enhancement compared to dry soil |
|---------------------------|---------------------------------------------------------------|
|                           | DR$\% = 26.47$ | DR$\% = 70.58$ | DR$\% = 91.17$ |
| dry soil                  | Q$_c$ (W) | Q$_c\%$ | Q$_c$ (W) | Q$_c\%$ | Q$_c$ (W) | Q$_c\%$ |
| 9.87                      | 96.14    | --     | 111.48 | --     | 129.47 | --     |
| 21.3                      | 103.84   | 8.01   | 121.82 | 9.27   | 144.68 | 11.74 |
| 30.0                      | 111.73   | 16.29  | 132.52 | 18.87  | 160.12 | 23.67 |
|                           | 120.98   | 25.83  | 143.14 | 28.39  | 176.23 | 36.12 |

The temperature drop across the BEAHE noticeably increases with increasing the soil moisture content of the soil around the considered heat exchanger. One possible explanation for this behavior is that the thermal conductivity of granular soils was observed to increase rapidly with an increase in moisture content due to the increase of replacing air porosity with water. Indeed, the dependence of thermal conductivity on moisture content has been documented by many soil science and engineering laboratory studies. This significantly increases the thermal conductivity of granular soil and the energy fluxes becomes greater since the thermal conductivity of water is 25 times larger than air. Therefore, the current results clearly demonstrate that always a high soil moisture content and soil relative density are recommended for realizing better pre-cooling effects from the BEAHE system. Furthermore, the high cooling capacity is achieved for highly moisturized compacted soil, compared to the soil with medium and low moisturized compaction levels. This is because a highly moisturized compacted soil conducts more heat due to low porosity/voids and therefore, results in high induced air temperature drop ($\Delta T$) across the BEAHE which consequently increases the cooling capacity of the system.

**3.2. Effect of soil moisture content and soil compaction on the BEAHE effectiveness**

In this section, the effectiveness of the considered BEAHE system is determined for various levels of soil moisture content and soil compaction. Figures 6 through 8 illustrate the effect of soil moisture content and soil compaction on the effectiveness of BEAHE. The effectiveness of the studied BEAHE is clearly improved by increasing both soil moisture content and compaction. The daily improvement percentage in the BEAHE effectiveness when the system buried in soil with moisture content level of 9.87 %, 21.3 %, and 30 % compared to dry soil are: 29.84 % for high compaction, 20.28 % for medium compaction, and 13.20 % for low compaction. Furthermore, system effectiveness is increased by 33.34 % when the soil compaction is increased from 26.47 % to 91.17 %.
Figure 6. Effect of soil moisture content on the BEAHE effectiveness for high compaction soil.

Figure 7. Effect of soil moisture content on the BEAHE effectiveness for medium compaction soil.

Figure 8. Effect of soil moisture content on the BEAHE effectiveness for low compaction soil.
From the above set of results, it can be observed that the effectiveness of the studied BEAHE is highly improved when its pipe buried in a dense soil with high moisture content. Since relatively dense soil with high moisture content is always associated with a low air gap and consequently high wet solid skeleton. Accordingly, for this case, the surrounding moisturized soil thermal of conductivity is more likely to raise and consequently offer a high rate of heat extraction by conduction between the pipe surface and the soil as well as between the subsequent layers of the surrounding soil.

4. Conclusions
The following can be concluded from this experimental investigation:
1. On an average daily basis, a significant induced air temperature drop of 23.5 °C is achieved at the soil moisture content of 30 % and high soil compaction of 91.17 %.
2. The induced air temperature drop across BEAHE is improved by about 18.29 %, 20.34 % and 22.49 % for soil moisture content of 9.87, 21.3 and 30 %, respectively for high compacted soil at a relative density of 91.17 %.
3. On an average daily basis, the temperature drop across the BEAHE increases by 18.29, 20.34 and 22.49 when the soil moisture content reached the value of 9.87, 21.3, and 30 % as compared to dry soil for high compaction level with soil relative density of 91.17 %.
4. The cooling load is enhanced by 11.74, 23.67 and 36.12% at high soil compaction (DR % = 91.17), by 9.27, 18.87 and 28.39 % at medium compaction (DR % = 70.58), by 8.01, 16.29 and 25.83 % at low compaction (DR % = 26.47) when the moisture content is raised to 9.87, 21.3 and 30 % respectively as compared to dry soil.
5. The daily average improvement of BEAHE system effectiveness when the system buried in soil with moisture content level of 9.87%, 21.3%, and 30% compared to dry soil is 29.84% for high compaction, 20.28% for medium compaction, and 13.20% for low compaction.
6. Furthermore, the effectiveness of considered BEAHE is increased by about 33.34% when the soil compaction is increased from 26.47% to 91.17%.
7. The maximum system effectiveness of 0.823, 0.651 and 0.581 corresponding soil compaction of 91.17, 70.58 and 26.47% respectively, are achieved at a soil moisture content level of 30%.

5. References
[1] Maulbetsch J and DiFilippo M 2006, Cost and Value of Water Use at Combined-Cycle Power Plants, California Energy Commission, PIER Energy-Related Environmental Research, CEC-500-2006-034.
[2] Weifeng H, Dong H, Chen Y, Wenhao P, and Yiping D 2014, Mechanism of the air temperature rise at the forced draught fan inlets in an air-cooled steam condenser, Appl. Therm. Eng. 71, 355-63.
[3] Soni S, Pandey M, and Bartaria V 2015, Ground coupled heat exchangers: a review and applications, Renew. Sustain. Energy Rev. 47, 83–92.
[4] Fard A, M H, Gholami A, and Khojastehpour M 2011, Evaluation of an earth-to-air heat exchanger for the north-east of Iran with semi-arid climate. International Journal of Green Energy, 8(4), 499-510.
[5] Santamouris M, et al. 1995, Use of buried pipes for energy conservation in cooling of agricultural greenhouses. Solar Energy, 55(2), 111-124.
[6] Bhardwaj S, and Bansal N 1981, Temperature distribution inside ground for various surface conditions, Building and Environment, 10 (3) 183–192.
[7] Jacovides C, Mihalakakou G, Santamouris M, and Lewis J, On the ground temperature profile for passive cooling applications in building, Solar Energy 57 (3), (1996) 167–175.
[8] Bisoniya T, Kumar A, and Baredar P 2014, Cooling potential evaluation of earth–air heat exchanger system for summer season, Int J Eng Tech Res 2 (4), 309–316
[9] Philippe M, Bernier M, Marchio D, and Lopez S 2011, A semi-analytical model for serpentine horizontal ground heat exchangers, HVAC & R Res. 17 (6) 1044-1058.
[10] Congedo P, Colangelo G, and Starace G, CFD simulations of horizontal ground heat exchangers: a comparison among different configurations, Appl. Therm. Eng. 33e34 (2012) 24-32.
[11] Cui P, Li X, Man Y, and Fang Z 2011, Heat transfer analysis of pile geothermal heat exchangers with spiral coils, Appl. Energy 88 4113-4119.
[12] Park S, Sung C, Chauchois A, and Choi H 2015, Constructability and heat exchange efficiency of large diameter cast-in-place energy piles with various configurations of heat exchange pipe, Appl. Therm. Eng. 90, 1061-1071.
[13] Naylor S, Ellett K, and Gustin A 2015, Spatiotemporal variability of ground thermal properties in glacial sediments and implications for horizontal ground heat exchanger design, Renew. Energy 81 21-30.
[14] Wu R, Tinjum J, and Likos W, Coupled thermal conductivity dry out curve and soil-water characteristic curve in modelling of shallow horizontal geothermal ground loops, Geo tech Geol Eng. 33 (2015) 193-205.
[15] Sanaye S, and Niroomand B 2010, Ground coupled heat pump: thermal-economic modeling and optimization, Energy Convers. Manage. 512600–2612.
[16] Wu Y, Gan G, Verhoef A, Luigi P, et al. 2010, Experimental measurement and numerical simulation of horizontal-coupled slinky ground source heat exchangers, Appl. Therm. Eng. 30 2574–2583.
[17] Chalhoub M, Bernier M, Coquet Y, and Philippe M 2017, A simple heat and moisture transfer model to predict ground temperature for shallow ground heat exchangers, Renew. Energy 103 295-307.
[18] Leong W, Tarnawski V and Aittomaki A 1998, Effect of soil type and moisture content on ground heat pump performance Int J. Refrig. 21 (8), pp. 595–606.
[19] Piechowski M 1999, Heat and mass transfer model of a ground heat exchanger: theoretical development, Int. J. Energy Res. 23 571–588.
[20] Abu-Hamdeh N, Khdair A, and Reeder R 2001, A comparison of two methods used to evaluate thermal conductivity for some soil, International J. of Heat and Mass Transfer 44, 1073-1078.

Acknowledgment
The authors would like to acknowledge the research deanship at the Islamic University of Medina, Saudi Arabia, for providing a fund to conduct this research work.