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Modelling & Simulation of a Horizontal Ground-Coupled Heat Exchanger to investigate Subsurface Heat Transfer for a Tropical Climate

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ABSTRACT

The main objective of this research was to examine the long-term performance of a horizontal ground heat exchanger for space cooling in Trinidad, West Indies. The COMSOL Multiphysics Finite Element Analysis Simulation Software was used to model, simulate and monitor the effects of heat transfer for a horizontal geothermal heat pump (GHP) system by using in-situ ground data, and as a result, determine the temperature influence on the surrounding soil. Weather data was also used to incorporate thermal effects on the ground since the loops were considered to be shallow at a depth of 1.25 m. The total cooling load for an office of dimensions (3.66 m x 3.66 m x 3.66 m) was calculated to be approximately 2.2 kW and the cooling capacity of the GHP used was 2.3 kW. The minimum length of horizontal ground heat exchangers required was determined. Modelling of heat exchangers was performed and simulations were done for a 12-month period in order to investigate the feasibility of the GHP system for Trinidad and Tobago.

1. INTRODUCTION

The geothermal heat pump (GHP) was modified from the conventional heat pump concept (first developed by Lord Kelvin in 1852) and was implemented by Robert Webber in the late 1940's (Curtis et al 2005). Since the re-introduction of GHPs, application of this technology has been growing exponentially worldwide. GHPs are mainly used for space cooling and space heating, with the option of water heating as an additional benefit/by-product (Coles 2009). GHP systems normally have a higher upfront cost than conventional air-source heat pump systems but are more economically feasible in the long term. Other benefits include the fact that GHPs provide significant reduction of energy usage, require little maintenance, are environmentally friendly and aesthetically pleasing, and administer high levels of comfort (Hepbasli et al 2003).

The Caribbean island of Trinidad, which is located 10.5526° N, 61.3152° W, is the location for this research on GHPs. Together with its twin island Tobago, Trinidad is a tropical island where air-conditioning is needed on a daily basis for indoor comfort. In this study, the underground is used as a heat sink, in light of the fact that Trinidad only experiences the dry season (January to May) and rainy/wet (June to December) season. As Yau and Hasbi (2013) stated in their review on the tropics, climate change has an increasing impact on society, hence the importance of the application of green technologies.

The configurations of the underground pipe can either be horizontal or vertical. Horizontal ground heat exchangers require less land space and trenches are less difficult to excavate than their vertical counterparts. There are many configurations of horizontal ground heat exchangers which exist in the GHP market, including single-loop, double-loop, slinky and serpentine. Due to the complexity involved in modelling horizontal ground heat exchangers due to seasonal variation and the shallow depth of the loops, research has seldom been carried out for this particular layout. Instead, vertical ground heat exchangers are normally modelled (Chiasson 2010). The ground loops account for a large amount of the cost of the GHP system, depending on the length required. Due to this, modelling and simulation of these systems are done prior to implementation, in order to better ensure accurate loop sizing and to therefore test the overall feasibility of the system.

Several factors affect how a GHP system functions: the climate, soil type, subsurface ground temperature, atmospheric temperature, depth of soil cover as well as other soil properties, for instance, thermal conductivity, resistivity, diffusivity and specific heat. An underground temperature survey is essential when assessing GHP applications. Even in tropical regions, underground can possibly be used as a cold source application (Omer 2008). The only known research of practical investigation of GHPs in a tropical country is in Thailand by Takashima et al (2011). The pipes configured in this system are modelled and simulated using relevant data from Trinidad to assess the possibility of using GHPs for space cooling/air-conditioning.

According to Piechowski (1999), the challenge is estimating the heat transfer characteristics of the soil which surrounds the ground heat exchanger (GHE). The pipe consists of fluid, in this case, water which varies in temperature i.e. from inlet to outlet temperature variations. There are many methods used to model GHEs, as stated by Demir et al (2009), but the majority are for vertical systems.

2. SYSTEM CHARACTERISTICS AND DATA ACQUISITION

The virtual room space, which is being analysed in this research, is an office of dimensions 3.66 m x 3.66 m x 3.66 m (i.e. 12 ft x 12 ft x 12 ft), as can been seen in Fig. 1 below. The proposed study site is located on the main campus of the University of the West Indies (UWI), which is where field work was done. Weather data was obtained, and load calculations were done using HVAC (Heating, Ventilation and Air Conditioning) cooling and heating loads software, where electronic equipment and other devices were taken into account in order to increase the accuracy of the final load results. Geophysical data was collected and will be discussed later on. The RETScreen Clean Energy Project Analysis Software was used to predict the required loop length for a particular horizontal heat exchanger pipe configuration.

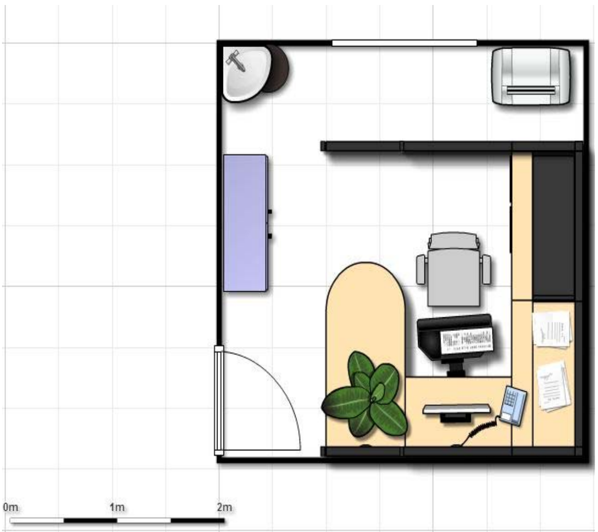

Figure 1: Layout of the proposed office. (Source: Google FloorPlanner).

In this study, the model takes into account the use of high-density polyethylene (HDPE) pipes (outer diameter: 0.032 m) buried 1.25 m below the surface of the ground and in a shaded area. Nevertheless, the effects of weather conditions are simulated. The thermal conductivity, density and specific heat of HDPE are 0.44 W/(m·K), 950 kg/m^3 and 2300 J/(kg·K), respectively (Ma et al 2007).

2.1 Weather Data

Weather data was collected from the DAVIS solar weather station installed on the top floor of the Natural Sciences building, located at the UWI, St. Augustine campus for the period February 2011-January 2012. January 2011 was not included since weather data for that month was not available. Table 1 shows the mean outdoor temperature (in K) during the hours of operation of the GHP unit, the mean outdoor relative humidity (in %), the mean wind velocity (in m/s) and the mean solar radiation (in W/m^2).

Table 1: Mean weather data for Trinidad during a 12 month period.

Mean Out. Temp. K 8am-6pm	Mean Out. Rel. Hum. %	Mean Wind Vel. m/s	Mean Sol. Rad. W/m^2
302.1 (28.9 °C)	79.5	1.1	183.7

The overall mean of the above data sets was used in calculating certain values, such as the heat transfer coefficient (h_s). The value of h_s, for example, was used in the simulation to determine if there are thermal effects on the subsurface due to seasonal variations.

$$h_s = 5.7 + 3.8u \qquad [1]$$

where u is wind velocity (Krarti et al 1995):

$$h_s = 5.7 + 3.8(1.1) = 9.88 \text{ W/m}^2$$

Calculated insolation (I) using surface albedo = 0.25 for grass surface,

$$I = \beta S \qquad [2]$$

where β is (1 – surface albedo) and

S is net horizontal solar radiation

The COMSOL Multiphysics software was used to simulate the effect that Trinidad's weather variation has on the soil depth. Equations [1] and [2] were used in the computer simulation.

2.2 Load Calculation

In order to assess and accurately size the ground loop heat exchanger according to the specifications of the room (office in this case), it is important to evaluate the heating and cooling loads for the office. As a result, the building loads were calculated using the HVAC COMFORTAIR 4.0 software. This software includes a number of variables on which the building load depends. Some of these include the climatic region, building size, orientation in terms of the direction in which the sun rises and sets, its position in relation to the windows, the U-values of the windows, the materials and dimensions of the walls and windows and other factors included in Table 2 showing the summary of heat gains and losses for the office space.

Table 2: Summary of Heat Gains.

Item	Sensible Heat (kW)	Latent Heat (kW)	Total Heat (kW)
Glass solar transmittance	0.10		0.10
Glass conduction	0.05		0.05
Lights	0.03		0.03
Electronic equipment	1.39		1.39
People (1 person)	0.06	0.07	0.14
Appliances	0.07	0.00	0.07
Infiltration	0.03	0.07	0.10
Total Heat Gain	1.73	0.14	1.88
Ventilation Load	0.09	0.24	0.34
Total Cooling Load on Coils and Refrig. Apparatus			2.21

Table 3: Summary of Heat Losses.

Item	Sensible Heat (kW)
Glass	8.18×10^{-3}
Infiltration	9.13×10^{-3}
Ventilation	15.82×10^{-3}
Total Heat Losses	33.13×10^{-3}

The equipment shown in Fig. 1 had the highest total heat value of 1.39 kW. The total cooling load was essential in assessing the most suitable GHP unit for the office. This was done while also taking water heating into consideration, as will be seen later on. For instance, if an assessment was done for a laundromat where a major quantity of hot water is used, there would be a high heating load and a much lower cooling load. This is expected to decrease the length of the GHE significantly, in the event that the pipes are buried even shallower and solar radiation is higher.

2.3 Geophysical Investigation

The MiniSting equipment designed for geological surveys was used to record the results after the electrodes were spaced from North to South (left to right in Fig. 2), 1 m apart. Thermal conductivity is highest in sand (1 – 10,000 Ohm-m) and gravel (100 – 10,000 Ohm-m). From analysis of the 2D resistivity profile, it can be noted that the red and yellow area represent sand and gravel. In the Northern part, the highest resistivity was seen. Thermal resistivity is inversely proportional to thermal conductivity so the higher the resistivity in these areas, the lower the thermal conductivity in the same location. The soil analyzed was also taken from this field.

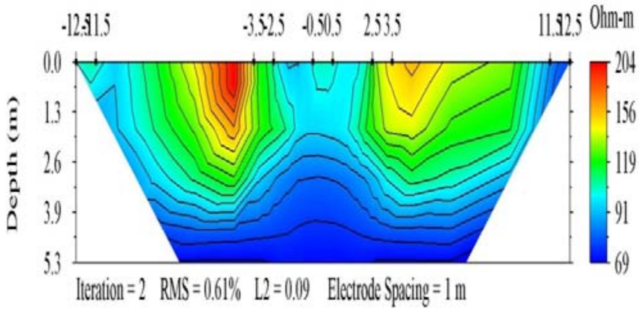

Figure 2: Geological profile obtained on the field.

Geophysical techniques were applied to determine the ground properties at the field behind the Alma Jordan library, on the UWI, St. Augustine campus. Field tests/experiments were conducted and the data analysed. The thermal conductivity, thermal resistivity, volumetric specific heat, thermal diffusivity and temperature of the soil were found using the KD-2 Pro apparatus. It should be noted here that even though the geological survey profile (Fig. 2) showed that the subsurface consists of different soil types, if implementation is practically done, the backfill can be of the same material i.e. uniform. This means that the soil can be homogenous throughout, which is one of the assumptions made in order to decrease the level of difficulty in modelling the heat transfer in the soil.

Soil samples were acquired from the field and analyzed along with using the KD2 Pro equipment to measure soil thermal properties, for verification. Thermal property values were used as a mean of the values obtained for dry season and rainy/wet season on the field.

Table 4: Mean results from the field work done on the field behind the Alma Jordan Library, UWI, St. Augustine.

S m	Seasons (dry & rainy)	K W/(m·K)	C MJ/(m³·K)	T K
1.25	AVG.	0.969	1.938	300.7 (27.5 °C)

where S is depth beneath the earth's surface, K is thermal conductivity, C is specific heat and T is the temperature of the soil.

The soil properties stated above, as well as, density are fundamental in these types of analyses, together with temperature gradient when investigation heat flow in soils (Abu-Hamdeh and Reeder 2000).

The soil temperature was taken in the field using the KD2-Pro thermal properties equipment as well as using thermocouples. The soil temperature at 1.25 m depth which represents the mean soil temperature throughout the year was found to be 300.7 K (27.5 °C). It can be seen from Table 4 that the soil temperature decreases with depth. This follows the pattern of the geothermal gradient for shallow depths. The values used in modelling of the GHE, were for the 1.25 m depth, since the horizontal pipes are simulated at the same level.

2.4 Loop Length Prediction

The table which follows was derived using the RETScreen software. This software originated from the Natural Resources Canada and serves as a prediction tool for clean energy projects. In this research, it was necessary in finding the predicted length of horizontal GHEs required, which tends to vary depending on factors such as the pipe configuration. Without a desuperheater, the predicted loop length was calculated to be 240 m. Since a common practice is to install a water heating system along with a GHP unit and its other components, this system includes a desuperheater (60 x 10^{-3} W), which gave the results below. It should be noted that the configuration of the loops used in the RETScreen software are somewhat different from those used in this research. As a result, the values found in Table 5 are only approximate.

Table 5: Predicted loop length, with desuperheater taken into account (RETScreen Software, courtesy: Natural Resources, Canada.)

HEAT PUMP	UNIT	HEATING	COOLING
Capacity Avg. Load	kW kW	1.60 0.10	2.30 2.15
SITE CONDITIONS		PROJECT LOCATION	CLIMATE DATA LOCATION
Earth temp. Measured at	K (°C) m	300.7 (27.5) 1.25	300.1 (26.9) 0.00
GHE			
Loop Length	m	235	

3. MATHEMATICAL ANALYSIS

This mathematical model considers the pipe and soil properties since this investigation involves heat transfer in the soil over a period of one (1) year.

The assumptions for this mathematical model are as follows:

1) The soil properties are considered uniform throughout
2) There is symmetric heat transfer in the subsurface (Esen et al 2007)
3) The heat transfer process between the air and the soil is convective
4) The distance between the buried pipe and the surface of the ground (i.e. >1 m) is large enough to consider it as farfield. The depth of the buried pipes for this research is 1.25 m
5) The effect of backfill material is negligible
6) The heat transfer in the subsurface in the direction parallel to the GHE is negligible
7) Heat transfer is considered to be axially symmetric close to the pipe wall (Mei 1986).

Since the outer diameter of the pipe is 0.032 m (i.e. < 0.050 m) and the wall of the pipe is 0.003 m (i.e. < 0.032 m), the temperature distribution error is very minimal.

In this analysis, the radial temperature distribution for the pipes is examined in order to determine the heat transfer in the soil. Therefore, certain conditions must hold. Firstly, the initial and boundary conditions must be axi-symmetric (i.e. the aspect ratio L/r_2 is sufficiently large in this case). As a result, the temperature gradient along the tangential/longitudinal direction (θ) is ignored. Secondly, the pipe length must be very long in order to neglect the temperature gradient in the axial direction (z) (Muneer at al 2003). Since the pipes in this system are very long, hollow, axi-symmetric cylinders, the system can be considered as one-dimensional. Therefore, the temperature gradient in cylindrical systems is regarded in the radial direction only. It should also be noted that there was no internal heat generation (Incropera et al 2007).

The governing partial differential equation for the heat conduction process in a hollow cylinder (pipe) is as follows:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial}{\partial\theta}\left(k\frac{\partial T}{\partial\theta}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+q=\rho c_p\frac{\partial T}{\partial t} \qquad [3]$$

where r, θ and z represent the radial, tangential/longitudinal and axial coordinates, respectively. T represents the temperature at the boundaries, k, q, ρ and c_p are the thermal conductivity, internal heat generation, density and specific heat of the material, respectively, and t is time.

Considering the radial direction only, (with the exception of the axial and tangential directions), for steady-state conditions,

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)=0 \qquad [4]$$

where, k is initially treated as a variable. In a hollow cylinder, the temperature distribution is a log function of the radial coordinate r. It is assumed that the heat flux at $r = r_1$, q_1 is given (Neumann boundary condition), while the temperature at $r = r_2$ is T_2 (Dirichlet boundary condition).

3.1 Results and Discussion

The simulations were two-dimensional (2D) since axial variation was ignored.

It was found that the pipe/series of pipes buried at 1.25 m below the earth's surface is expected to be affected by the weather (Fig. 3). The temperatures at the top boundary, as well as, the boundary at the base were important in this study. The thermal conductivity, density and specific heat values were included in the analysis. The values obtained as seen in the temperature profile simulated below were compared to some empirical data and had a small margin of error. The annual rainfall rate was not taken into account in the computer analysis but was predicted to have a positive impact on the cooling of the soil, due to the water penetration into the earth. It should also be noted that the field test site in this study is at the base of Trinidad's Northern Range, where there is a higher amount of groundwater.

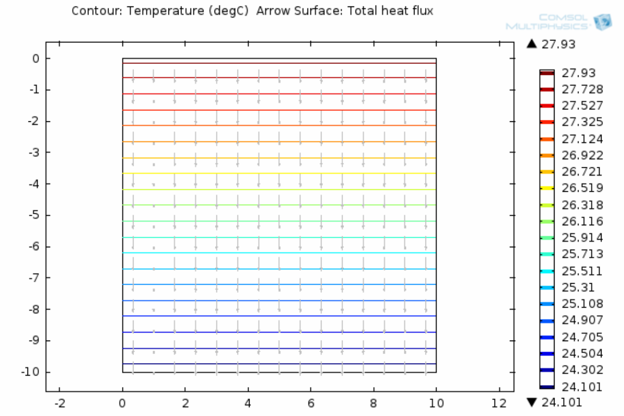

Figure 3: Weather effects on the subsurface simulated on COMSOL Multiphysics.

Fig. 4 shows another representation of the simulation done in Fig. 3. In this stationary study, a temperature profile from 0 m to a depth of 10 m was simulated. With respect to deep geothermal energy, temperature increases with depth. However, this research focuses on a shallow region for a horizontal GHP system in cooling mode and it is expected that as the depth decreases, the temperature also decreases. Not all of the data was available, so an extrapolation had to be done.

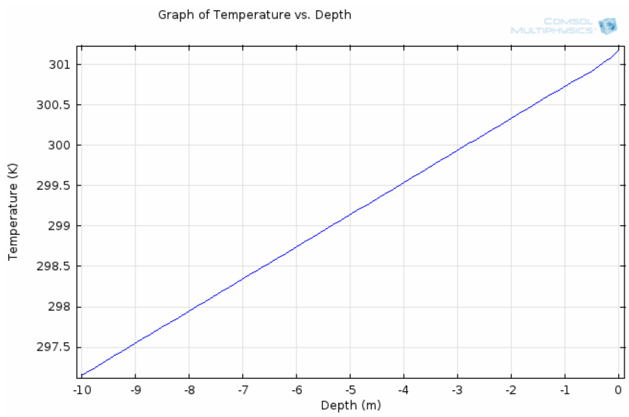

Figure 4: Graph showing how the temperature varies with depth.

The location of the pipe in Fig. 5 is at a depth of 1.25 m. The difference in the temperature distribution of the soil (Fig. 3) and the soil with a pipe buried in it (Fig. 5) was noted. Relevant heat fluxes were applied. This simulation shown in Figs. 5 and 6 were dependent on an estimated heat flux at the pipes. This value was based on assumption 6 made previously. In this analysis, heat transfer is not considered axially, (i.e. along the pipe), but radially.

A tolerance level was chosen based on the appropriate radial temperature distribution from the pipe, as seen in the simulation below. Therefore, when assessing the appropriate spacing between the pipes, the difference in temperature allowed was ± 0.5 K (± 0.5 °C). This means that for proper GHE function, the minimum distance by which the pipes can be separated has to have a temperature difference equal to or within that tolerance. The appropriate pipe spacing was found to be about 3 m apart, since at that point the temperature difference was within the tolerance level.

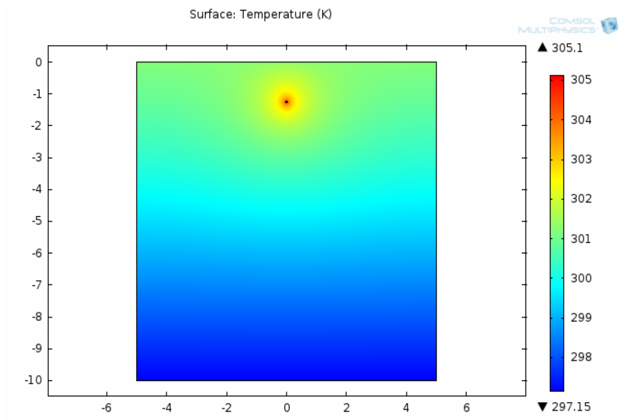

Figure 5: Steady-state study of temperature distribution in the soil to assess pipe spacing.

Two (2) pipes were simulated (Fig. 6) since the RETScreen software which was used to predict the appropriate overall pipe length for T&T's climate, had a 2-pipe configuration already incorporated into it. As a result, the final simulation included 2 pipes buried at a depth of 1.25 m. Fig. 6 also indicates the points (represented by dark red lines) at which the temperature values were analysed. The bright red line shows a depth of 5 m in relation to the points evaluated.

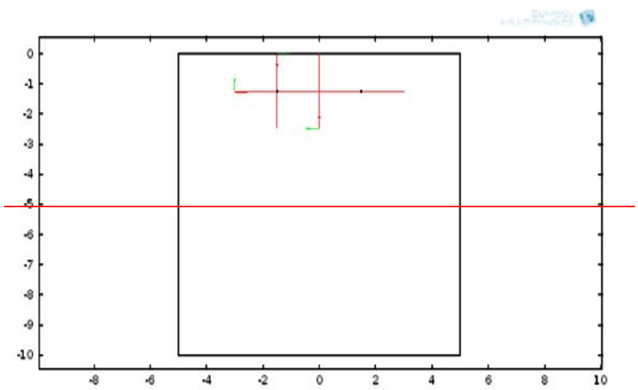

Figure 6: Points representing the positions at which temperature distribution values were taken to be analysed.

For the time-dependent study (Figs. 7, 8 and 9), the ambient temperature for 1 year was included in the simulation package. The following plots are depicted as temperature (in K) as a function of time (in s), not position.

In Analysis 1, the coordinates of the two (2) points at which the temperature variation was noted are (0, 0) and (0, -2.5). This represents the vertical distribution between the 2 pipes. For the 1st month as seen in Fig. 7, the temperature of the soil between both pipes varied from a minimum temperature of approximately 300.4 K (27.2 °C) to about 300.9 K (27.7 ° C). During the 2nd month, with GHP operation due to the weather conditions, the maximum temperature distribution between the coils in the soil was higher than for the previous month, as well as, the 3rd month of heat transfer via the GHE. From the 3rd month to the 6th month, there was a general trend (increasing) as can be seen in Fig. 7.

After approximately 6 months of operation, for the temperature in the subsurface at the points specified for Analysis 1, there was an overall maximum soil temperature of around 301.5 K (28.3 °C). The 7th month showed more temperature variation then the previous months, but its maximum soil temperature with functional GHEs was less than the 8th month. After the 8th month, the soil temperature decreased, which may have been due to the drop in ambient temperature and soil surface. Although in the 8th month of the operational GHE being buried in the soil there was a slight temperature increase, the general trend which followed included decreasing temperature values. This meant that over time, the soil is expected to be cooler at the end of the year temperature (an eventual change from the dry season to the rainy/wet season). The fluctuations in the temperature values are mainly due to the ambient temperature that is heavily influenced by key factors such as rainfall etc.

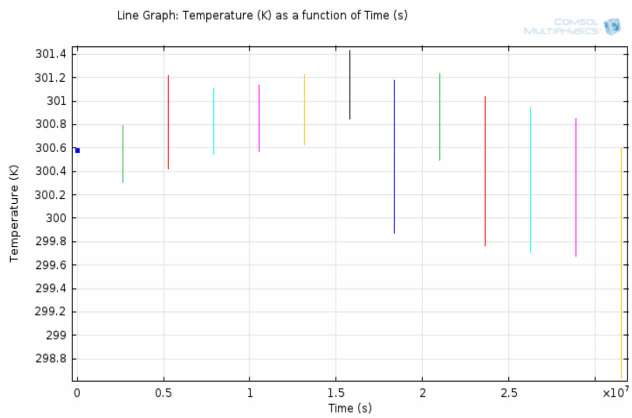

Figure 7: Representation (monthly) of the temperature distribution in the soil with respect to time for Analysis 1 during proposed GHP operation.

Analysis 2 was done for either sides of each of the pipes. The coordinates at the left side of pipe 1 are: (-3, -1.25) and at the right side of pipe 2: (3, -1.25). As can be seen in Fig. 8, the highest subsurface temperature perpendicular to the cross-section of the pipe i.e. heat transfer in the radial direction, was approximately 304.9 K (31.7 °C) during the 6th month of proposed operation. The lowest was during the 12th month with a value of 300 K (26.8 °C). Similarity can be seen here with Analysis 1 since the overall variation in soil temperature showed a general trend comparable to that analysis. The difference noted was that the temperatures on either side of both pipes showed higher temperature values than the vertical representation (from ground surface to 2.5 m depth), since Analysis 2 is in relation to the path of greater heat transfer (radially) from the centre of each pipe.

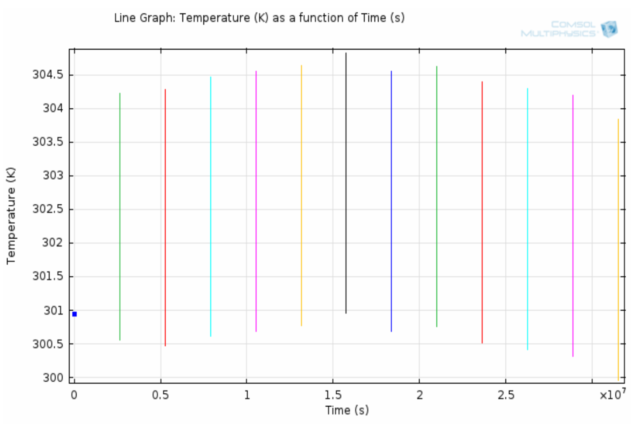

Figure 8: Representation (monthly) of the temperature distribution in the soil with respect to time for Analysis 2 during proposed GHP operation.

A third analysis (Analysis 3) represented temperature values along 2 points at coordinates (-1.5, 0) and (-1.5, -2.5). A line connecting these points were drawn above and below pipe 1 (see Fig. 6), in order to be able to assess the vertical temperature variation in the subsurface, in close proximity to the pipes. The results (Fig. 9) were similar to that of Analysis 2 which was previously discussed.

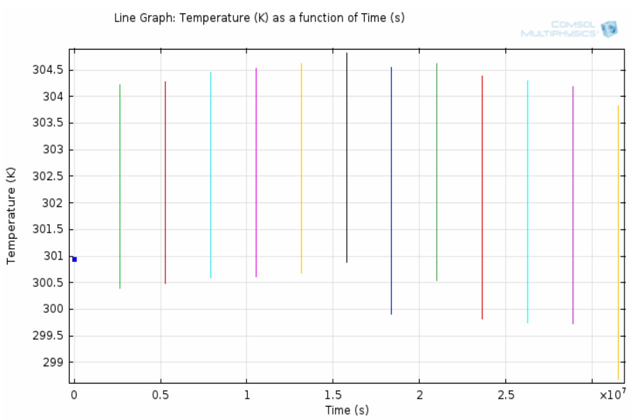

Figure 9: Representation (monthly) of the temperature distribution in the soil with respect to time for Analysis 3 during proposed GHP operation.

When compared to the monthly temperature variation in Fig. 7, the daily temperature distribution for the same coordinates stated in Analysis 1, as seen in Fig. 10, had a higher overall temperature than the former, within the first month. However, it was not indicated in the monthly representation since it was balanced by the overall minimum temperature. The daily temperature values are more accurate since a better representation is shown. The monthly representation is an average of the temperature variation for each month. The maximum temperature noted here was 303 K (29.9 °C), while the minimum soil temperature was 297.8 K (24.7 °C). From Fig. 10, it can be seen that during the first few months, the temperature variation is high, as opposed to the middle of the year. As a result, GHP operation is not recommended during this time. The temperatures of the soil between the pipes were lower and within the tolerance level during certain days of the second half of the year. Consequently, GHP operation may be feasible during this period.

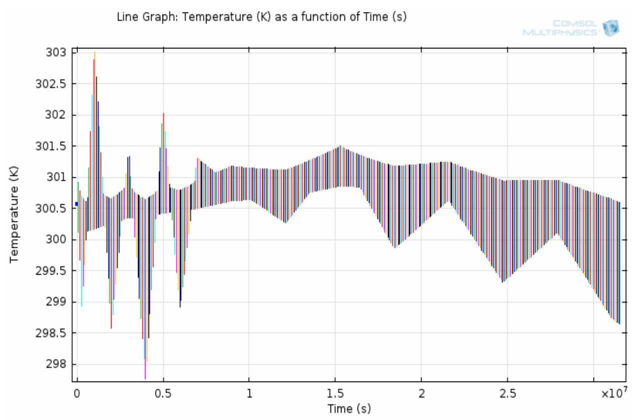

Figure 10: Representation (daily) of the temperature distribution in the soil with respect to time for Analysis 4 during proposed GHP operation.

The plot in Fig. 11 has the same general trend to that seen in Fig. 8. However, a better representation is given in the former. Analysis 5 for the horizontal temperature variation at the sides of the pipes would therefore be similar to that of Analysis 2. There was not much difference between Figs. 8 and 11 when compared to Fig. 8 since that analysis included temperature values at the ground surface, which is influenced by the ambient temperature and other climatic factors. Analyses 5 and 6 include temperature variations within the subsurface of the earth and are less influenced by the climatic factors, although they still are. Temperature difference in the ground is mainly due to the GHEs in this case.

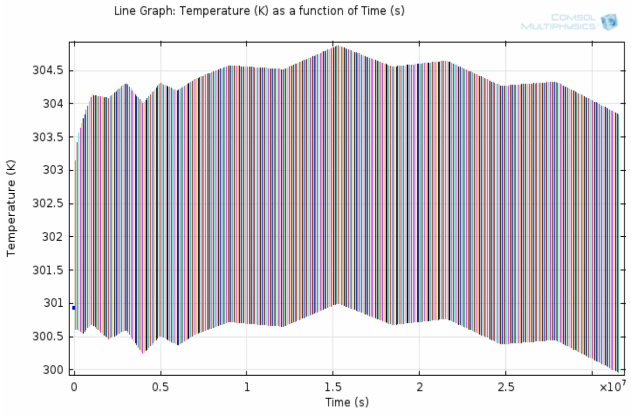

Figure 11: Representation (daily) of the temperature distribution in the soil with respect to time for Analysis 5 during proposed GHP operation.

Fig. 12 has a similar general trend when compared to Fig. 9, with the exception of the first 2 months. Due to the drastic fluctuations in the temperature variations during that period, Analysis 3 varies from Analysis 6 to some extent. The fluctuations were perhaps due to the same rationale as Analysis 4 since ground surface temperature change was also included. The following months are similar to that of Fig. 9. Here, the minimum and maximum soil temperature values were approximately 297.8 K (24.7 °C) and 304.9 K (31.8 °C), respectively. The latter value was the same as in Analysis 3.

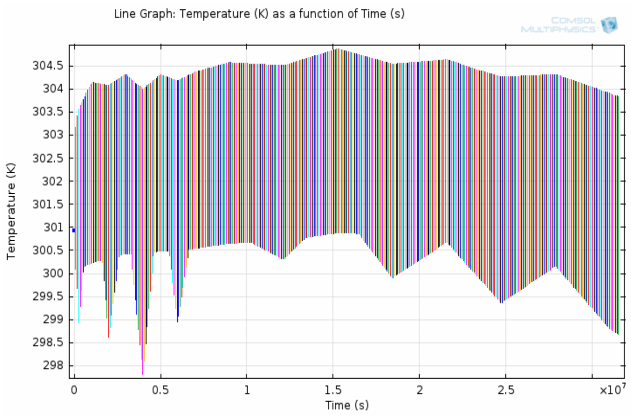

Figure 12: Representation (daily) of the temperature distribution in the soil with respect to time for Analysis 6 during proposed GHP operation.

4. CONCLUSIONS

The meteorological data which had an effect on the surface of the ground were taken into account in this model. The wind speed and ambient temperature values were very important in the computer simulations since they influence the convective heat transfer coefficient as well as the temperature of the underground soil. Analyses were done on a large scale (monthly) as well as small scale (daily). Since the minimum temperatures for each month in Analysis 1 ranges from 298.7 K to 301.5 K, this may indicate feasible GHP operation after a 1 year period since these values are mostly within the tolerance level. A more important consideration than the results of Analysis 1 is the temperature variation around the pipes, as seen in Analyses 2 and 3. GHP operation is expected during certain days of the year as seen in Figs. 10, 11 and 12. Since the maximum temperature at the proposed depth throughout the 12 months was approximately 304.9 K and the minimum was about 300 K in Analyses 2 and 3, this indicates that GHP operation may not be feasible at specific times.

Daily representations were done to further examine the results obtained. The daily temperature plots gave a better representation of the subsurface variation than the monthly temperature plots. From Analysis 4, it is concluded that since the temperature variation is high and not within the tolerance level during the first few months, GHP operation may not be recommended during this time. The temperatures of the soil between the pipes were lower and within the tolerance level during certain days of the last half of the year. Consequently, GHP operation may be feasible during this period. For Analysis 5, the trend was similar to the monthly temperature plot. As a result, the conclusion is similar to that of Analysis 2. With respect to Analysis 6, there was not much divergence in the plot when compared to Analysis 3, therefore the same conclusion holds for both.

Since the differences in the minimum and maximum monthly and daily temperatures are higher for Analyses 2, 3, 5 and 6, the application of the GHP is not feasible for the entire year. The decision to implement the system is also highly dependent on the economical factor, as well as, if the GHE is buried in a shaded area (perhaps by tree cover as on the proposed field located behind the Alma Jordan library, UWI, St. Augustine). This would increase the performance of the GHP system. The analyses above were done based on 24 hour meteorological data obtained. However, the operation of the GHP system is for an office occupied during daylight hours. Therefore, heat will not be transferred during the 24 hours. It is a possibility that if implemented, the subsurface can be cooled during times in which the GHP is non-operational.

It is suggested that the GHP systems should be tested for water heating on a larger scale, for instance, laundromats in the tropics. It may greatly reduce the length of the GHE buried underground if the subsurface temperature is sufficient. A high amount of water at high temperatures is needed in laundromats. If it is also more economical than the conventional method, this should be further studied. Research on groundwater heat pumps (GWHPs) for this region is recommended, particularly at the base of the Northern Range, where there is increased groundwater capacity. This could positively influence the cooling of the subsurface and in turn aid in the applicability of GHPs for space cooling in Trinidad. The large industries can possibly benefit immensely from such an investment.

REFERENCES

Abu-Hamdeh, N. H. and Reeder, R. C.: Soil Thermal Conductivity Effects of Density, Moisture, Salt Concentration and Organic Matter, *Soil Science Society of America Journal*, **64**, (2000), 1285-1290.

Chiasson, A.: Modeling Horizontal Ground Heat Exchangers in Geothermal Heat Pump Systems, *Proceedings of the COMSOL Conference 2010*, Boston, U.S.A., (2010), 1-5.

Coles, C.A.: Review of Geothermal Heating and Cooling of Buildings, *Proceedings of the 2nd Climate Change Technology Conference 2009,* Hamilton, Ontario, Canada, (2009), paper #103, 1-12.

Curtis, R., J. Lund, Sanner, B., Rybach, L. and Hellström, G.: Ground source heat Pumps – Geothermal Energy for Anyone, Anywhere: Current Worldwide Activity, *Proceedings of the World Geothermal Congress 2005,* Antalya, Turkey, (2005), 1-9.

Demir, H., Koyun, A. and Temir, G.: Heat transfer of horizontal parallel pipe ground heat exchanger and experimental verification, *Applied Thermal Engineering*, **29**, Istanbul, (2009), 224-233.

Esen, H., Inalli, M. and Esen, M.: Numerical and experimental analysis of a horizontal ground-coupled heat pump system, *Building and Environment*, **42**, Elazig, (2007), 1126-1134.

Google Floorplanner, 2007, http://floorplanner.com

Hepbasli A., Akdemir, O. and Hancioglu, E.: Experimental Study of a Closed Loop Vertical Ground Source Heat Pump, *Energy Conversion and Management*, **44**, Izmir, (2003), 527-548.

Incropera, F., DeWitt, D.P., Bergman, T. L. and Levine, A. S.: Fundamentals of Heat and Mass Transfer, *John Wiley & Sons*, (2007).

Krarti. M., Lopez-Alonzo, C., Claridge D. E. and Kreider, J. F.: Analytical Model to Predict Annual Soil Surface Temperature Variation, *Journal of Solar Energy Engineering*, **117**, (1995), 91-99.

Ma, C. F., Gu, Z. X. and Wu, Y. T.: Numerical Study of Heat Transfer of a Single U-Tube in Vertical Ground-Coupled Heat Pump Systems, (2007), http://energy.bjut.edu.cn/picture/article/200/c6/9f/2dc20a93432299ba704252e899ad/197a8c11-3333-4771-8b61-297b0ab187e5.pdf.

Mei, V.C.: Theoretical Heat Pump Ground Coil Analysis with Variable Ground Farfield Boundary Conditions, *Energy Division, Oak Ridge National Laboratory*, **32**, (1986), 1211-1215.

Muneer, T., Kubie, J. and Grassie, T.: Heat Transfer – A problem solving approach, *Taylor & Francis Group*, New York and London, (2003).

Natural Resources, Canada: RETScreen Software, 1998, (http://www.retscreen.net)

Omer, A.: Ground-source heat pumps systems and applications, *Renewable and Sustainable Energy Reviews*, **12**, Nottingham, (2008), 344–371.

Piechowski, M.: Heat and Mass Transfer Model of a Ground Heat Exchanger: Theoretical Development, *International Journal of Energy Research*, **23**, Melbourne, (1999), 571-588.

Takashima, I., Yasukawa, K., Uchida, Y., Yoshioka, M. and Won-In, K.: A Geothermal Heat Pump System in Bangkok, Thailand, *Proceedings of the 9th Asian Geothermal Symposium 2011*, Bangkok, Thailand, (2011), 96-101.

Yau, Y.H. and Hasbi, S.: A review of climate change impacts on commercial buildings and their technical services in the tropics, *Renewable and Sustainable Energy Reviews*, **18**, Kuala Lumpar, (2013), 430-441.