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Experimental Analysis of Soil Recovery and Heat Interactions with Ground in Slinky Connected Split Air-Conditioning System

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Abstract -In the present research work experimental analysis of soil recovery and heat interaction of slinky ground heat exchanger connected with a split air-conditioning system has been reported. For the analysis a 1.5- ton cooling capacity split air-conditioning system coupled with a slinky type of heat exchanger was deployed at IIT Roorkee campus, India. All the experiments were carried in peak summer conditions during space cooling mode operation. Initially, the heat interaction through the GHX to the ground is analysed throughout the experiments, later once the experiments are over, the ground temperature is monitored to estimate the soil recovery period by circulating water in the GHX. For the present location, several experimental trials were carried out and recorded the soil recovery period for different operating hours. A regression analysis is performed to stablish a correlation between the soil recovery period and the operating hours. The rate of heat rejection to the ground varies from 5 to 8 kW on a typical day in peak summer condition. The ratio of soil recovery and the operating hours is observed to be more than 1 when ground coupled split air-conditioning system is operated from 5 to 12 hours in daytime. Operating the split air-conditioning system for more than 12 hours shows a lesser recovery time as compared to the operating hours due to partial recovery of the ground during lesser cooling load during the nighttime.

***Keywords*:** Ground coupled split-AC; soil recovery period; operating hours, heat injection to the ground.

1. Introduction

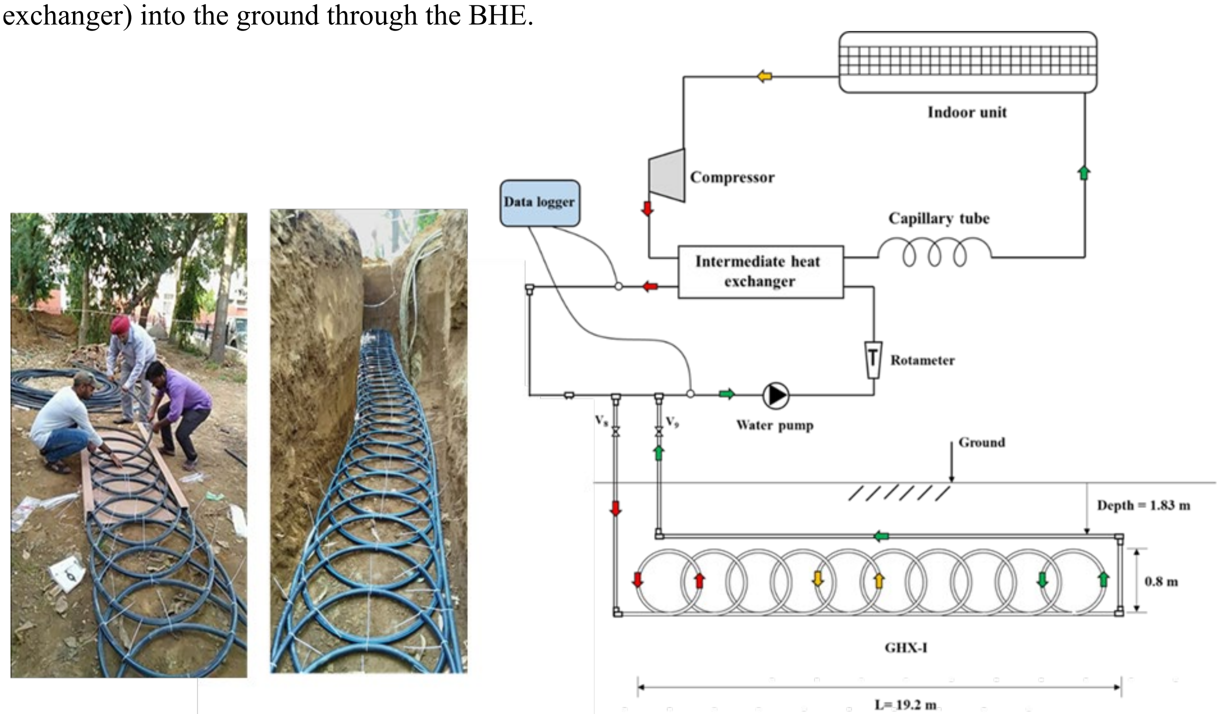
Increased consumption of electricity generated from non-replenishable energy resources for indoor climate control has given rise to severe loss to the environment resulting in global warming and ozone layer depletion. Geothermal energy is one of the renewable types of energy sources which is utilized for space heating/cooling applications. Ground source heat pump (GSHP) system is a renewable type of heating/cooling system that interacts with ground for heat interactions [1]. Larwa et al. [2] carried out experimental and analytical studies on the slinky type of ground heat exchanger (GHX) using ring source model and found good agreement between both the methods. Tang and Nowamooz [3] analysed slinky GHX numerically and suggested to include the ground heat flux and surface temperature while estimating the outlet temperature of GHX. Xiong et al. [4] introduced the analytical solution of ground temperature variation and mean temperature of the tube wall after injecting a constant heat to the ground in slinky GHX. Later, Larwa and Kupiec [5] extended the same model and suggested the correlations for temperature of fluid and pipe. Babak Deghan [6] investigated long-term thermal performance of a vertical spiral ground heat exchanger using numerical and experimental techniques. Results showed that due to thermal interaction between the tubes, reduced spacing between the spiral BHE has resulted in a drop in the performance of the system for long time operation. Esen et al. [7] carried out an experimental analysis and modeling of solar assisted slinky type of ground heat exchanger for horizontal and vertical orientations. It was found that the performance of horizontal configuration was better as compared to the vertical configuration of GHE. As for the modeling of the system was concerned, adaptive neuro-fuzzy interference system (ANFIS) showed better results as compared to artificial neural network (ANN) to forecast the performance of the system.

The thermal performance of ground source heat pump system is influenced by the soil recovery period after heat interaction with the ground [8]. A detailed literature review indicates that there are very few research works available focusing on the soil recovery period of slinky coupled ground air-conditioning system. Therefore, the present research work is an attempt to fill this gap by investigating the soil recovery period of the Roorkee ground soil during space cooling mode operation of slinky coupled split air-conditioning system. For this purpose, an experimental set-up of a retrofitted split AC system connected with slinky ground heat exchanger of 1.5-ton cooling capacity was installed at IIT Roorkee campus. The experiments were carried out for different durations for space cooling mode operation in summer conditions. Using the experimental data and the results obtained, a correlation between the operating hours and the soil recovery period is proposed after conducting repeated experiments.

2. System description and experimental set-up

To utilize the geothermal energy at the shallow depth, a slinky type of ground heat exchanger has been deployed under the ground at a depth of 1.83 m from the surface in a trench of 19.2 m long and 0.92 m wide. The installation process of the slinky GHX is shown in Figures 1 (a) & (b). The diameter of each slinky ring is of 0.8 m and total number of rings are 63, additionally 19.2 m length of straight pipe has been utilized to bring the end point of the ring to the main header. Therefore, the total effective length of the slinky GHX is estimated as 158.3 m. Water flow rate in the slinky GHX is controlled by valves V_8 and V_9. To maintain the water circulation in the GHX, a 0.37 kW water pump has been deployed at the inlet of the slinky loop as shown in Figure 1 (c). For water flow measurement in the pipes, a rotameter has been installed at a location where the effect of water turbulence in the flow is not experienced.

To monitor the continuous temperature variation of water in GHX due to heat interaction with the ground, a data acquisition system (DAQ) has been installed at a common point of the GHX. For actual heating/cooling operations of the system, the slinky GHX is connected to an indigenously developed ground coupled split air-conditioning system of 1.5-ton cooling capacity as shown in Figures 1 (c). The water circuit is used to reject heat from the condenser (double pipe heat exchanger) into the ground through the BHE.



(a) (b) (c)

Fig. 1: (a) & (b) Installation of slinky ground heat exchanger (c) 1.5-ton experimental set-up installed at IIT Roorkee

3. Governing equations

3.1 Rate of heat injection into the ground

In cooling mode operation, the total heat removed from the room to be air-conditioned, must be rejected into the ground with the help of the slinky GHE. The heat from the room is taken out by the heat pump and supplied to the water flowing in the GHE, thus making it hot at the inlet of the GHE. When the water flows through the GHE along the depth, heat is transported from water to the ground and by losing heat, the water comes out at a temperature lower than the atmospheric temperature. The expression for the rate of heat rejection into the ground can be written as

$$Q_{rej.} = m_w C_w [\, T_{f,\,in} - T_{f,\,out}] \tag{1}$$

where m_w is the mass flow rate of water (kg/s), C_w is the specific heat capacity of water (kJ/kg K), and T_f is temperature (°C) of water and subscripts in- inlet to the GHE and out - outlet of the GHE.

4. Results and discussion

In this section the results of heat interaction of 1.5-ton cooling capacity slinky coupled split air-conditioning system and soil recovery period has been reported in detail. During actual operation of the system in space cooling mode, the heat available inside the room is injected in the ground which leads to a slight increase in ground temperature. Once the heat interaction experiment is over, the circulation pump is kept running to record the inlet and outlet temperature. The mean of these inlet and outlet temperatures, T_m is recorded continuously till it reaches to the initial (beginning of experiment) temperature which indicates the undisturbed ground temperature. The period between turning off the compressor and the time reaching to the undisturbed ground temperature is observed as soil recovery period and is indicated as $T_{reco.}$ All the experiments were carried out in the peak summer season when ambient temperature varies from 24 ºC to 45 ºC.

Figure 2(a) indicates the inlet and outlet temperature variation of the heat transfer fluid (water in this case) running inside the slinky GHX for 8.4 hours of operation. The inlet temperature $T_{f,\,in}$ varies from 27 ºC to 37 ºC in the initial hours of operation up to (3 hours) during moderate ambient temperature and $T_{f,\,in}$ increase up to 39 ºC in peak ambient temperature as shown in Figure 2(a). The outlet temperature $T_{f,\,out.}$ temperature varies from 25.5 ºC to 32 ºC and follows a similar trend as $T_{f,\,in}$. The heat rejection to the ground varies from 4.5 kW to 8.1 kW during the operation as depicted in Figure 2(b). The cycle time operation is found to be more in peak summer season and lesser in moderate summer season as can be seen in Figure 2(b). After operating the system for 8.4 hours, the soil recovery is observed as 9 hours as shown in Figure 2(a).

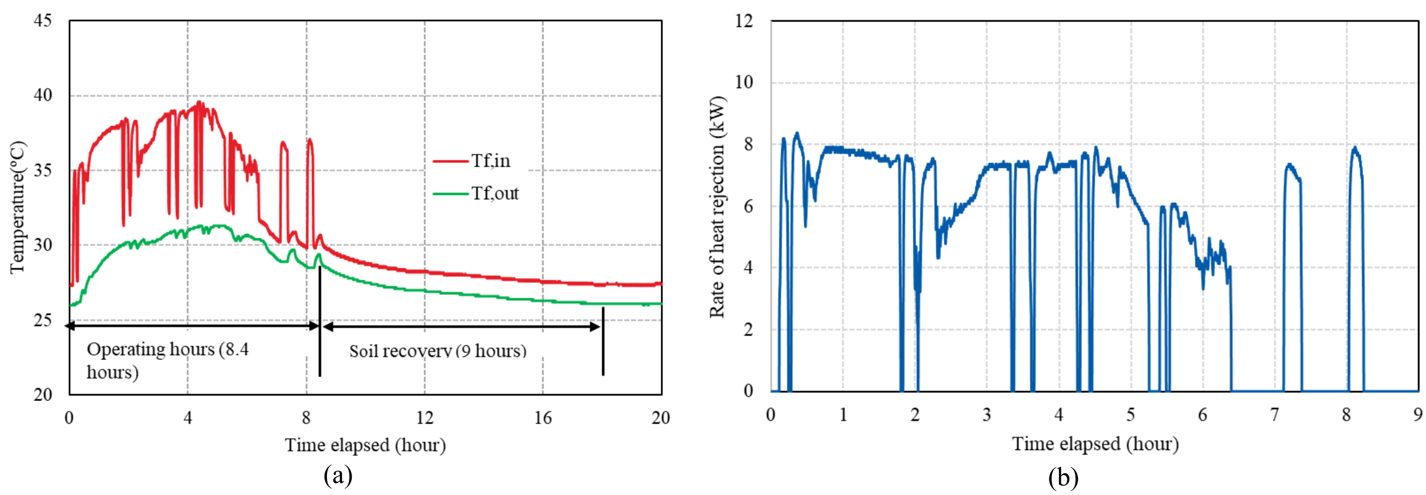


Fig. 2: (a) Variation inlet and outlet temperature of GHX (b) rate of heat rejection in the ground

4.1 Correlation for soil recovery

To correlate the operating time of the slinky coupled split air-conditioning system with the soil recovery of the ground during space cooling operation, several experimental trials were conducted in summer season. Regression analysis has been carried out to get the best correlation between $T_{opr.}$ and the soil recovery period $T_{reco.}$ The operating time and ground recovery duration for some of the experimental trials are shown in Figure 3.

In this section the effect of operating hours of the split air-conditioning system on soil recovery of the ground during actual operation of the split air-conditioning system has been discussed. Using regression analysis, the best curve fit is obtained for the relationship between the soil recovery, $T_{reco.}$ and the operating hours, $T_{opr.}$ of the system. In cooling mode operation, several experiments were conducted between 2020 and 2023 and the best results were chosen for the analysis. Figure 3 shows the variation of the Mean temperature, T_m (t) of inlet and outlet of GHX and the soil recovery period, $T_{reco.}$ on the selected day. From Figure 3(a) it is observed that for shorter duration of operational time, the soil recovery duration is less and the ratio of $T_{reco.}$ and $T_{opr.}$ is less than 1.

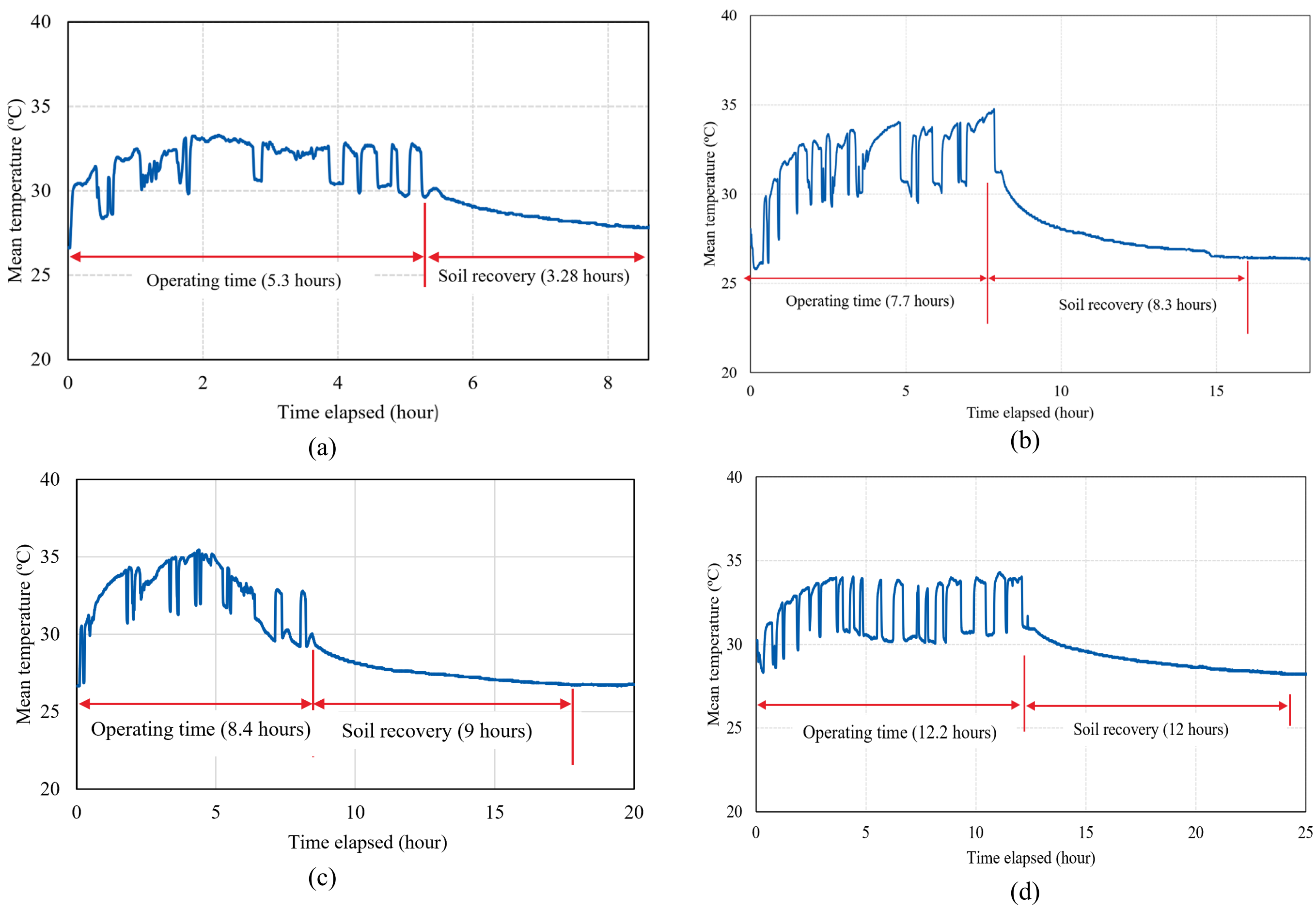


Fig. 3: Variation of mean temperature of inlet and outlet of water in GHX, indicating soil recovery period after operating the system (a) 5.3 hours (b) 7.7 hours (c) 8.4 hours and (d) 12.2 hours

After operating the split air-conditioning system up to 12 hours, the soil recovery period $T_{reco.}$ is observed to be more as compared to the operating hours and the ratio of $T_{reco.}$ and $T_{opr.}$ becomes slightly more than 1. On increasing the duration of operation up to 12 hours, the soil recovery time decreases because after 12 hours of operation, the cooling load decreases in the nighttime and the system operates at part load condition with comparatively longer idle time between each cycle of operation. In the longer idle time, the thermal load on the BHEs becomes zero and the ground soil tries to regain its original thermal state. This partial ground recovery continues at nighttime when cooling load becomes less due to low ambient temperature as can be seen in Figures 3(d).

After analyzing all the temperature plot of soil recovery, a regression analysis has been carried out to find the best relationship between the soil recovery $T_{reco.}$ and operating hours $T_{opr.}$. Figure 4 shows the normal and regression fitted curve of the soil recovery period with operating time. The regression analysis reveals that the soil recovery follows a logarithmic path with respect to the operating hours of the split air-conditioining system. The best fit trend variation of the the soil recovery is presented as Eq. (2) with $R^2 = 0.97$ and is depicted in Figure 4. From the linear regression fitting, the best best fitting correlation is found as

$$T_{reco.} = 9.6\ln(T_{opr.}) - 11.95 \quad (2)$$

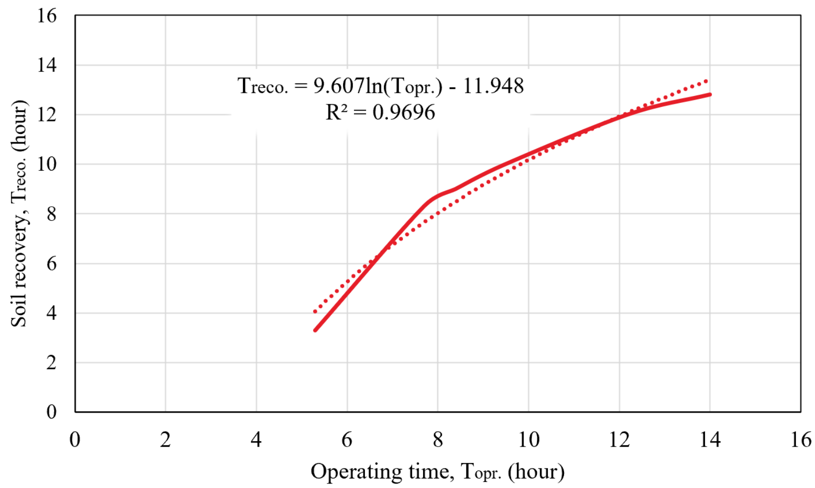


Fig. 4: Curve fitting of between operating hours and the soil recovery period

4. Conclusions

In the present analysis soil recovery period and heat interaction for slinky type ground heat exchanger coupled with a 1.5-ton cooling capacity split air-conditioning system has been studied in detail for peak summer season. Initially, the thermal interaction of borehole heat exchangers with the ground has been analyzed in detail. Then soil recovery analysis using mean temperature of inlet and outlet GHX temperatures is carried out. Lastly, a best-fitted correlation between the soil recovery and the operating hours has been proposed. After a detailed analysis of the results obtained, the following research findings are identified:

1. The rate of heat rejection to the ground is more and varies from 5 kW to 8.2 kW for initial 4 hours of operation due to more cooling load at higher ambient temperature and in subsequent hours the rate of heat rejection decreases due to decrease in cooling load at lower ambient temperature.
2. The soil recovery period for shorter duration up to 5 hours of operation is less as compared to the operating hours. However, the ratio of soil recovery period to the operating hours is found to be less than 1 when split air-conditioning system is operated from 5 hours to 12 hours.
3. Operating the split air-conditioning system for more than 12 hours shows lesser soil recovery period as compared to the operating hours due to partial recovery of temperature at nighttime due to lesser cooling load demand.
4. The soil recovery follows a logarithmic curve with respect to the operating hours for peak summer conditions.

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