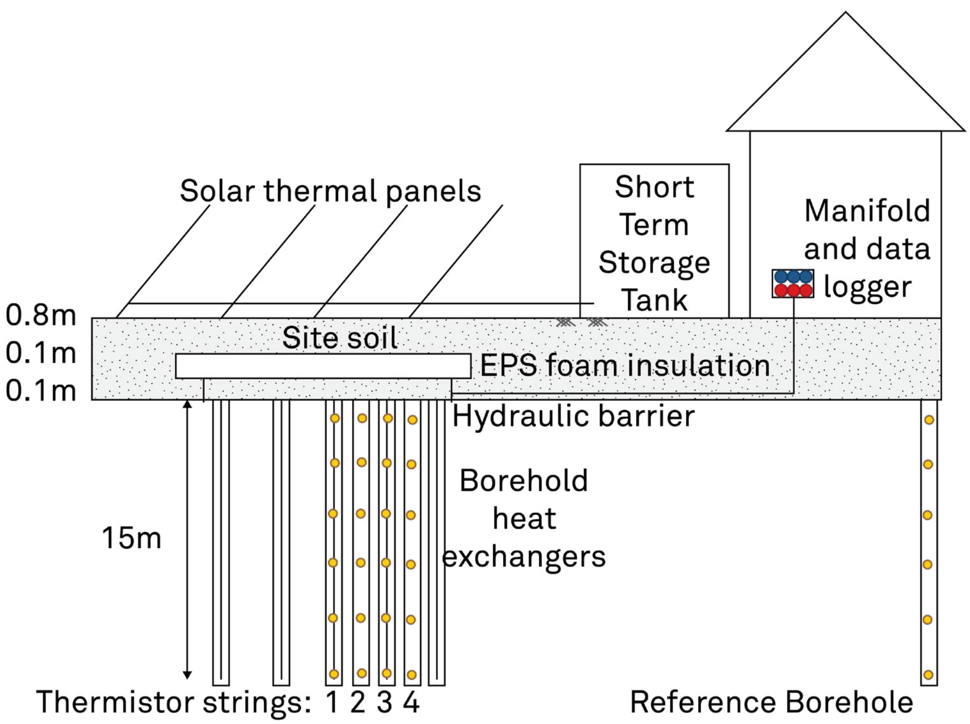
METER
ENVIRONMENT

IMPROVED METHODS SAVE MONEY IN FUTURE BOREHOLE THERMAL ENERGY STORAGE DESIGN

Globally, the gap between energy production and consumption is growing wider. To promote sustainability, University of California San Diego PhD candidate and ASCE GI Sustainability in Geotechnical Engineering committee member, Tugce Baser, Dr. John McCartney, Associate Professor, and their research team, Dr. Ning Lu, Professor at Colorado School of Mines and Dr. Yi Dong, Postdoctoral Researcher at Colorado School of Mines, are working on improving methods for borehole thermal energy storage (BTES), a system which stores solar heat in the soil during the summer months for reuse in homes during the winter. Baser says, “We are running out of finite energy resources. We need to come up with new strategies to use free and renewable energy resources such as solar energy for a sustainable future.”



Baser’s BTES design

HOW IT WORKS

BTES systems are an approach to provide efficient renewable resource-based thermal energy to heat buildings. They are configured to store thermal energy collected from solar thermal panels during the summer and discharge the heat to buildings during the winter. They function by circulating a fluid within a closed-loop pipe network installed in vertical boreholes to inject heat collected from solar thermal panels. During winter, cold fluid is circulated through the heat exchangers to recover the heat from the subsurface and distribute it to the buildings. Baser explains, "The subsurface provides an excellent medium to store this heat due to the relatively lower thermal conductivity and lower specific heat capacity especially when the soil layer is in the vadose zone. Lower thermal properties allow us to concentrate the heat in a specific array and the heat losses to the environment are potentially low. These systems typically include an insulation layer and a hydraulic barrier near the ground surface to reduce heat and vapor losses to the atmosphere."

WHY WE NEED IMPROVED METHODS

Baser and her team are trying to improve the understanding of heat storage mechanisms and evaluate changes in the rate of heat transfer and heat storage in the vadose zone where the soil is unsaturated. The goal of the project is to improve conventional methods by generating models to fit different soil types and situations. She says, "The European community introduced us to the borehole thermal energy storage systems to provide heat specifically for domestic use, but there is still a chance for us to design them more efficiently by having a full understanding of the thermal response of these systems that is specific to the ground material and subsurface conditions. The primary objective of this research is to understand the mechanisms of coupled heat transfer and water flow in unsaturated soil profiles during the heat injection and subsequent heat extraction into these different arrays and different dimensions of borehole heat exchangers."

Baser and her team working on designing numerical models based on finite element method which improve some of the numerical models in the literature used to characterize the thermal response of the systems. The new models add new considerations, such as the heat pipe effect in different soil types. Baser explains, "Because thermal and hydraulic properties of soils are highly coupled and are specific to soils, the thermal response of a BTES system will be different when it is installed in different types of soils. For example, you see the heat pipe effect where there is evaporation and subsequent condensation in fine-grained soils rather than coarse soils because in coarse grain soils the pore characteristics are different. The duration of the heat pipe effect (or convective cycle) is longer in fine grain soils. We conclude that considering coupled heat transfer and water flow in the thermal response of Borehole Thermal Energy Storage system is important."

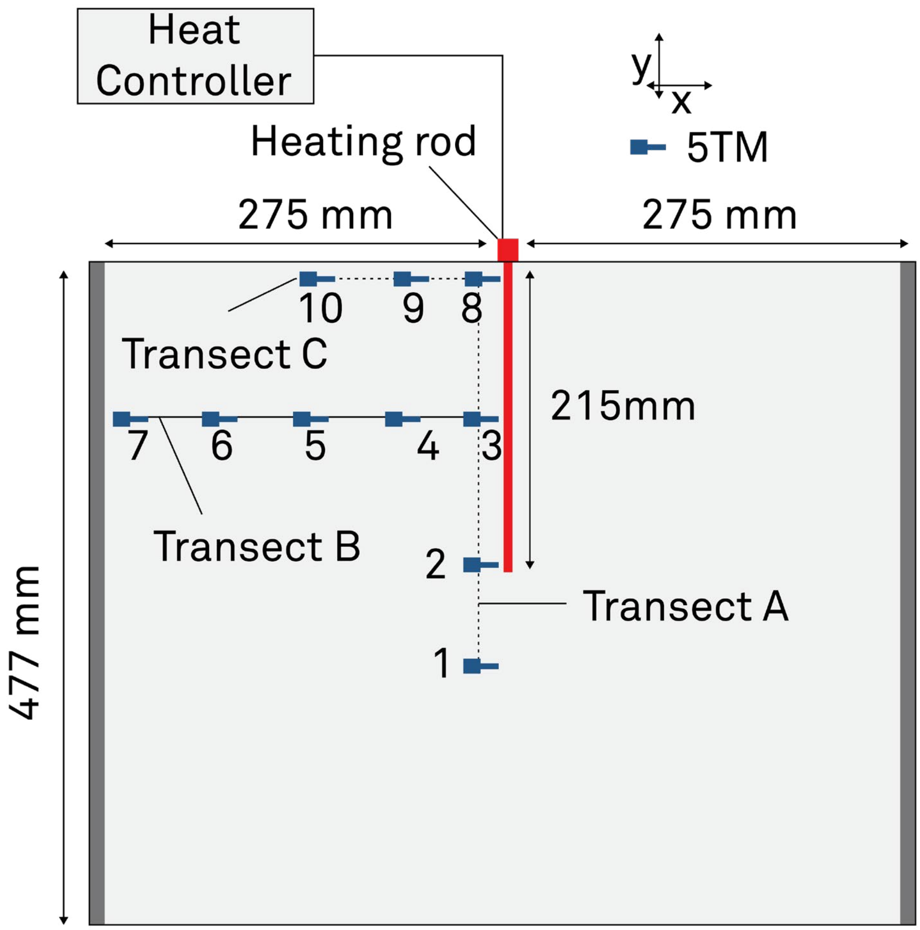
EXPERIMENTS IN THE FIELD AND IN THE LAB HELP VERIFY THE NEW MODELS

To fully understand heat transfer mechanisms and water flow in unsaturated soils, the research team installed two different SBTS systems at different scales, one in Golden, Colorado School of Mines campus, and the other at the UC San Diego research campus. Baser says, "The subsurface characteristics of both sites are different, and this gives us the opportunity to investigate the impact of the different soil layers on the thermal response experimentally in a full scale. In addition, the scales of each Borehole Thermal Energy Storage system are different, and we also apply different heat injection rates. We have used these data to further validate our coupled heat transfer and water flow model so that we can use it for design purposes."

TEMPOS thermal properties analyzer

Baser started with laboratory heating experiments, in which soil in a large tank is heated by heat exchangers. She installed METER soil moisture sensors to measure volumetric water content and the temperature and then used the METER thermal properties analyzer to monitor thermal properties during heating experiments to characterize the coupled thermo-hydraulic relationships. For the field experiments, the team uses METER soil moisture sensors equipped with temperature sensors and the thermal properties analyzer to monitor subsurface temperature fluctuation because during the summertime the air temperature is higher, thus ambient air temperature fluctuation and penetration may become significant.

Baser also uses thermistor strings that include six thermistors at different depths and thermistor pipe plugs, voltage input modules, and flow meters. She says, "Thermistor pipe plugs and flow meters are used in the manifold to monitor the inlet and outlet fluid temperatures and flow rates in each loop to calculate heat transfer rate into the ground. Flow meters were installed to control flow in each loop because you don't want to over or underload the borehole loops. The amount of energy that you collect from the solar loop and the amount of energy that you inject into the ground can be used to define the efficiency of the system." Baser says thermistor strings help monitor the ground temperature during the summer heat loading at different depths. They're also used to monitor borehole wall temperature over time. The team installed one thermistor string 9 meters away from the heat storage array to see if far field is affected by the heat transfer within the array.



Soil moisture sensor locations

THE NEW MODELS WILL SAVE MONEY

Baser says building numerical models and solving them was very complicated and time consuming, but they've had good results. She explains, "We've recently proved, both experimentally and numerically, that considering coupled thermal and hydraulic relationships are very important for thermal response analysis. Thus, our recommendation is that it's fine to use the analytical models and user-friendly numerical models that consider constant thermal properties in the design analyses for saturated soils. However, in unsaturated soils, there is a very high possibility that the contribution of heat transfer evaporation and condensation would be missing and the Borehole Thermal Energy Storage system would be oversized, costing a significant amount of money. When dealing with soils in the vadose zone, coupled thermo-hydraulic constitutive relationships in the modeling efforts need to be considered."

You can learn more about Tugce Baser's research here.

Discover METER soil moisture sensors and thermal properties analyzer