Optimizing Geothermal Probe Fields And Groundwater Doublets

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Abstract

Geothermal energy systems require precise sizing to ensure efficiency and sustainability, particularly for probe fields and groundwater doublets. We present two specialized applications developed using COMSOL Multiphysics' Application Builder, leveraging the Heat Transfer and Groundwater Flow modules to address these challenges. These tools, designed by Construire SASU, streamline the design process for geothermal installations, integrating complex thermal and fluid dynamics simulations into user-friendly interfaces suitable for engineers and consultants.

The first application focuses on sizing geothermal probe fields, a critical component of shallow geothermal systems. Built with COMSOL's Heat Transfer module, it solves transient thermal equations using the finite element method.

This application incorporates site-specific geological data (e.g., thermal conductivity, density) and local meteorological conditions to model heat transfer in subsurface environments. Users can define probe configurations (single, double, or triple U-shaped), simulate heat pump and circulation pump performance, and visualize results such as temperature distributions, heat flux, and borehole temperatures. Key features include automated mesh generation, accelerated calculations for long-term simulations (e.g., 20-year hourly response), and compliance with French geothermal regulations. The interface offers intuitive controls, including buttons for geometry setup, mesh refinement, and result animations, enhancing usability. Outputs include model dimensions, mesh quality, and energy consumption metrics (e.g., nominal heating/cooling power, auxiliary energy use). The application is fully validated using COMSOL's solver and is undergoing real-world testing across Construire's projects. It will be publicly available on Construire Sasu website in 2025, with ongoing updates to improve ergonomics and incorporate user feedback.

The second application targets the sizing of groundwater doublets for deep geothermal systems, utilizing COMSOL's Groundwater Flow and Heat Transfer modules. This tool models aquifer dynamics, including Darcy flow and heat transport, to optimize the placement and operation of injection and extraction wells. It accounts for aquifer properties (e.g., permeability, porosity) and thermal interactions between the groundwater and surrounding rock. The application supports transient simulations to predict long-term system performance, ensuring sustainable energy extraction. Like the probe field application, it features an intuitive interface with automated design capabilities, allowing users to input site-specific data and generate optimized doublet configurations. The application is in the final stages of development and is expected to be released on Construire Sasu website by late 2025 or early 2026.

Both applications leverage COMSOL's robust solver capabilities to deliver accurate, scalable solutions for geothermal design. They reduce manual design efforts, enhance regulatory compliance, and provide comprehensive outputs for project reporting. By integrating advanced numerical methods with practical engineering needs, these tools represent a significant advancement in geothermal system design, offering scalable solutions for sustainable energy projects worldwide.

Figures used in the abstract

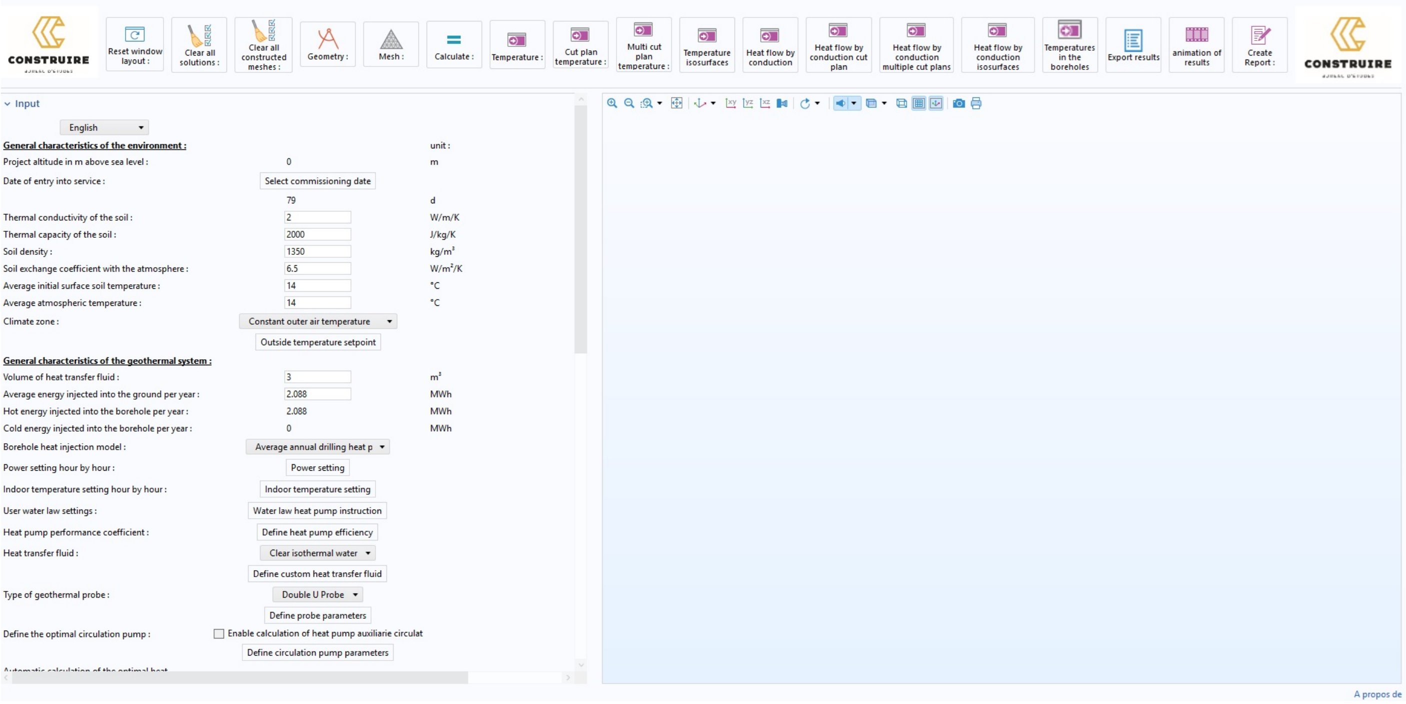

Figure 1 : This screenshot showcases the user interface of a geothermal probe field sizing application, developed with COMSOL Multiphysics' Application Builder. Featuring input fields for soil properties, probe types (e.g., double U), and heat pump settings, it enab

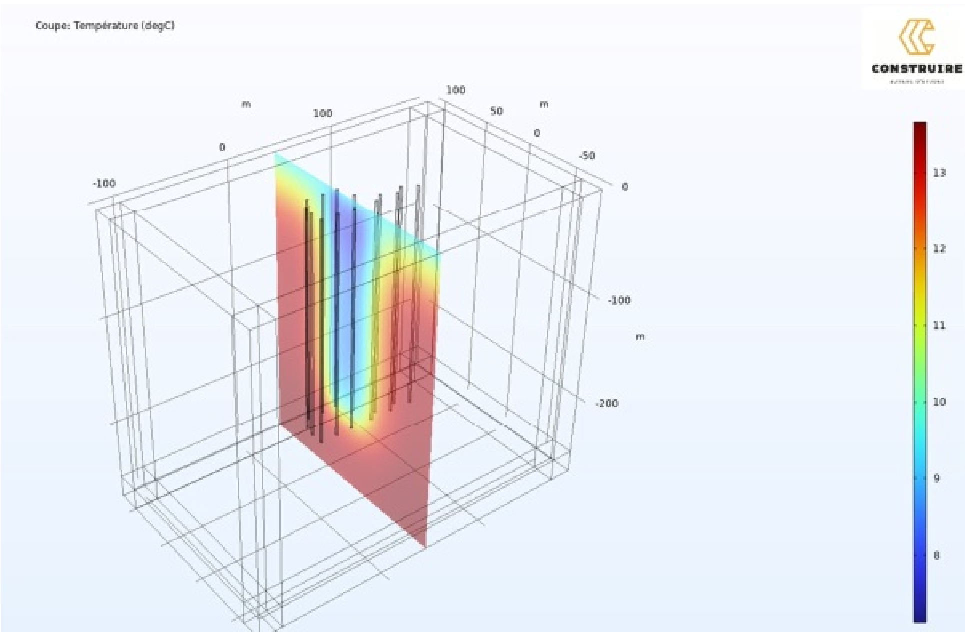

Figure 2 : This image presents a 3D temperature cross-section from a geothermal probe field simulation, developed using COMSOL Multiphysics' Heat Transfer and other modules. The color gradient (8–13°C) illustrates thermal distribution around double U-shaped probes,

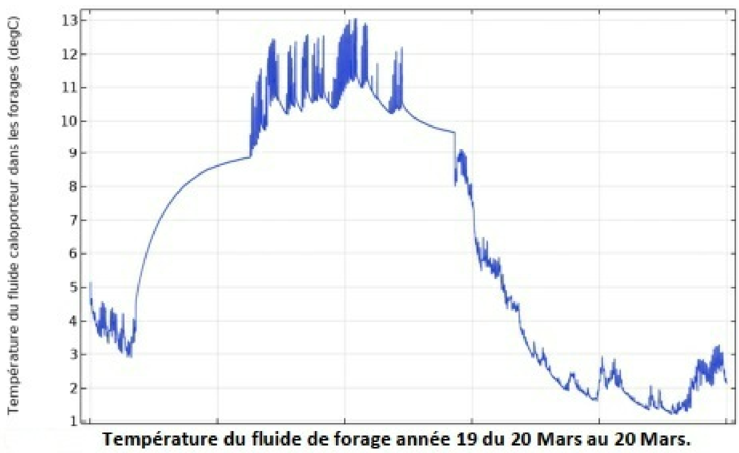

Figure 3 : This graph depicts the fluid temperature in boreholes over 1 year (March 20– March 20) after 19 years of client usage of the probe field, simulated with the geothermal probe field application built on COMSOL Multiphysics. Fluctuations (6–12°C) demonstrate