Contribution ID: **27** Type: **not specified**

Numerical Simulation of a Ground-Coupled Earth-to-Air Heat Exchanger for Greenhouse Cooling in Humid Tropical Climates

Tuesday, 22 July 2025 12:30 (15 minutes)

The thermal performance of a ground-coupled Earth-to-Air Heat Exchanger (EAHE) system intended to cool greenhouse air in humid tropical environments is examined in this study. To simulate EAHE operation at two burial depths—1 m and 2 m—a three-dimensional computational model was created using SolidWorks and ANSYS 2023R1. In each configuration, a homogeneous, isotropic soil domain was embedded with a network of air-circulating polyvinyl chloride (PVC) pipes. A tetrahedral grid was used to mesh the geometry, yielding more than 4.7 million elements for the 2 m depth and 3.7 million for the 1 m depth. Field measurements of greenhouse air and soil temperature were used to define material properties and boundary conditions, while presumptions like steady-state operation, no-slip conditions, and constant air properties were used. The results of the simulation showed that, although performance varied by depth, the EAHE successfully cooled the inlet air as it passed through the system. The air temperature decreased from 36.7℃ to 30.6℃ at a depth of 2 meters, indicating a more consistent cooling profile throughout the pipe network. The lateral and vertical sections verified progressive cooling, and pre-cooling effects and variable airflow paths were responsible for the variations in cooling intensity across the three channels. The air temperature dropped from 32.5℃ to 30.5℃ in the first pipe sections of the 1 m depth configuration, indicating a more concentrated cooling effect. Interestingly, the horizontal pipe at the top showed the best cooling, probably because it was exposed to air that had already been cooled and because it was farther away from the heat source. The results show that burial depth has a major impact on EAHE systems' cooling effectiveness. While the 1 m depth worked well over shorter distances, especially close to the inlet, the 2 m depth offered more reliable cooling over longer distances. The ground served as an efficient heat sink in both setups, encouraging heat transfer from the moving air. This study provides insights into the best design factors, such as pipe layout and burial depth, for improved thermal performance and validates the potential of EAHE systems for passive greenhouse cooling in humid tropical environments.

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Session Classification: Contributed Talk

Track Classification: Engineering: Mechanical Engineering