Postprint: Temperature Recovery Performance of Surrounding Soil in Urban Subway Energy Tunnels Under Long-Term Intermittent Operation

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Abstract

Energy underground structure technology holds significant importance for energy conservation and emission reduction in the building sector. Utilizing heat exchange pipes and underground structures as venues for geothermal energy exchange is expected to establish a sustainable energy system serving resilient cities. However, the impact of long-term intermittent operation of energy tunnels on the temperature recovery capacity of surrounding soil has not been adequately studied. This study takes Shenzhen subway tunnels as the research object, employs COMSOL Multiphysics to establish a three-dimensional transient coupled heat transfer model, and systematically analyzes the influence of different lining segment materials (ordinary concrete versus steel fiber reinforced concrete) and operating strategies (constant power versus constant time) on outlet water temperature and surrounding soil temperature recovery performance under long-term intermittent operation mode. The findings reveal: (1) Under intermittent operation, the surrounding environmental temperature does not fully recover; the heating condition causes more pronounced temperature disturbance to the surrounding soil; as the heat exchange system operates, heat accumulates in the soil environment, and this accumulation process primarily concentrates in the initial operation period. (2) When the heat exchange system extracts a fixed amount of heat from the soil, larger heat pump power results in smaller impact on the soil environment and less accumulated energy in the soil. (3) Under cooling conditions, intermittent operation has less influence on the surrounding environmental temperature field, i.e., better temperature recovery, and the heat exchange process under cooling conditions is relatively more efficient than under heating conditions. (4) In constant power operation mode, soil temperature recovery exhibits significant time dependence; under constant power cooling conditions, the variation amplitude of the lowest outlet temperature point during the first five operation cycles is 6.4%-12.5% (power 7.81kW-6.91kW), showing a faster initial recovery trend compared to heating conditions (8.1%-9.6%). (5) In constant time operation mode, steel fiber reinforced concrete segments (thermal conductivity 3.0 W/(m·K)) reduce recovery time to 1.25 hours under cooling conditions, achieving a 34.9% efficiency improvement compared to ordinary concrete (1.92 hours). (6) In constant time intermittent heating condition operation mode, steel fiber reinforced concrete segments (power 5.24 kW) produce a soil temperature rise of 6.97°C (start-stop ratio 16:8), representing a 13.4% reduction compared to ordinary concrete (8.05°C); rational selection of segment materials and intermittent operation start-stop ratio strategies can significantly optimize soil thermal recovery performance.

Full Text

Preamble

Title: Study on the Temperature Recovery Performance of Surrounding Soil in Urban Subway Energy Tunnels Under Long-Term Intermittent Operation

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Abstract: Energy underground structure technology plays a significant role in energy conservation and emission reduction for the building sector. By utilizing heat exchange pipes and underground structures as geothermal energy exchange venues, this approach promises to establish sustainable energy systems for resilient cities. However, the impact of long-term intermittent operation of energy tunnels on the temperature recovery capacity of surrounding soil remains inadequately investigated. This study examines Shenzhen subway tunnels using COMSOL Multiphysics to develop a three-dimensional transient coupled heat transfer model, systematically analyzing how different lining segment materials (ordinary concrete versus steel fiber concrete) and operation strategies (constant power versus constant time) affect outlet water temperature and soil temperature recovery performance under long-term intermittent operation.

The results reveal several key findings. First, ambient temperature fails to fully recover during intermittent operation, with heating modes causing more pronounced thermal disturbance to surrounding soil. Heat accumulation in the soil environment occurs primarily during initial operational stages. Second, when extracting a fixed heat quantity from soil, higher heat pump power reduces environmental impact and accumulated energy. Third, intermittent cooling operation exhibits less impact on the ambient temperature field, demonstrating superior recovery performance and greater efficiency compared to heating. Fourth, soil temperature recovery under constant power mode shows significant time dependence; during constant-power cooling, the minimum outlet temperature variation across the first five cycles ranges from 6.4% to 12.5% (power 7.81–6.91 kW), indicating faster initial recovery than heating modes (8.1%–

9.6%). Fifth, under constant-time mode, steel fiber concrete segments (thermal conductivity 3.0 W/(m · K)) reduce recovery time to 1.25 hours during cooling, representing a 34.9% efficiency improvement over ordinary concrete (1.92 hours). Sixth, during constant-time intermittent heating, steel fiber concrete segments (power 5.24 kW) yield a soil temperature rise of 6.97°C (on-off ratio 16:8), which is 13.4% lower than ordinary concrete (8.05°C). These findings demonstrate that appropriate selection of segment materials and intermittent operation on-off ratio strategies can significantly optimize soil thermal recovery performance.

Keywords: Energy tunnel; Intermittent operation; Numerical simulation; Heat exchange efficiency; Soil heat recovery

Note: Figure translations are in progress. See original paper for figures.