Factors influencing the performance of near surface ground energy collection and storage systems

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Presentation overview

• Introduction

• Modelling Framework

• Case study: Inter-seasonal heat storage
  • Impact of surface conditions
  • 2D vs 3D
  • Snow / ice cover

• Overall conclusions
Near surface ground energy collection and storage systems

• Energy source / storage / management
  – Ground source heat
  – Shallow energy piles
  – Geothermal energy
  – Passive heating and cooling of buildings

• Infrastructure protection
  – Pavements (e.g. roads, runways)
Factors influencing performance

• Performance highly dependent on:
  – quantity and temporal variation of energy in near-surface soil layer
  – design of the installed system

• Key processes include
  – Transfer of heat between the ground surface and the atmosphere (surface fluxes);
  – Movement of heat within the engineered soil mass
  – Transfer of heat through soil : pipe interface
  – Movement of heat energy within the collector and storage systems
Typical surface fluxes (UK location)

\[ q_G = q_S + q_C + q_E + q_I \]

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Heat flux (W/m²)

-200 -100 0 100 200 300 400
Theoretical formulation - Surface fluxes

• Surface fluxes

\[ -k \frac{dT}{dx} = (1 - \alpha_s)R + \sigma \varepsilon_s (\varepsilon_s T_{a,k}^4 - T_k^4) + h_E (q_a - q_G) + h_C (T_a - T) \]

- Definition of heat transfer coefficients $h_E$ and $h_C$:

• Vegetated soil
  - Canopy cover – Best (1998) and Deardoff (1978)
    - Separate heat balance equation for the canopy surface
Theoretical formulation - Surface fluxes

• Diurnal Shading

  – Diurnal shading factor, $D_s$ to modify the solar radiation term

  $$R_d = RD_s$$

  solar radiation

  $$-k \frac{dT}{dx} = (1 - \alpha_s)R_d + \sigma \varepsilon_G \left( \varepsilon_s T_{a,k}^4 - T_k^4 \right) + h_E (q_a - q_G) + h_C (T_a - T)$$
Case Study: Inter-seasonal Heat Storage in Soils

• Utilises variations in seasonal conditions to allow storage / use of heat.
• Management of various infrastructure assets:
  – Roads
  – Airport stands / buildings
• Main source of heat from surface fluxes and buildings

Scenario 1: Summer
Collection and heat dumping
Case Study: Inter-seasonal Heat Storage in Soils

- Utilises variations in seasonal conditions to allow storage / use of heat.
- Management of various infrastructure assets:
  - Roads
  - Airport stands / buildings
- Main source of heat from surface fluxes and buildings

Scenario 2: Winter
Surface snow / ice management and building heating
Case Study

• Inter-seasonal heat storage demonstration project performed by the Transport Research Laboratory (Carder et al., 2007)

• Two year-long experiment

• Closed loop system
Modelling of heat collection and storage

- Model of the ground and the heat collector / store arrays
  - Standard heat transfer or coupled TH or THM balance eq(s).
  - Surface fluxes, Diurnal shading, Soil-Pipe interface
- 2D or 3D Soil mass + 1D heat transfer within storage and collector pipes
- Validation against field scale tests.
Impact of surface conditions

- Sensor 1  – Pavement (0.01m depth)
  – Variable shading
- Sensor 2  – Soil
  – Vegetation present

Diurnal Shading

![Graph showing temperature over time with shaded areas highlighting peak temperatures.]

Temperature (°C)

13 Sep 12 AM  |  14 Sep 12 AM  |  15 Sep 12 AM  |  16 Sep 12 AM

- Control sensor 2: Soil
- Control sensor 1: Pavement
Impact of Diurnal Shading (2D Model)

Un-shaded

Road surface

Shaded between 12:00 and 15:00
Sensor 2 – Stored Thermal Energy 1D soil column

![Graph showing stored thermal energy over time for different conditions: Experimental, Turbulent, Non-turbulent, and Canopy cover.](image)
Results: Temperature field  2D v 3D

2D End of collection Oct 2006  
3D End of collection Oct 2006

Depth (m)  Length (m)  Temp (°C)
Collection phase

- Numerical
- Experimental

Usage phase

Snow fall

Numerical
Experimental
Conclusions

• Correct assessment of the nature of the heat transfer process occurring on the surface of the soil is of critical importance for the estimation of the amount of energy stored in the ground.

• Of particular importance is the correct representation of low level vegetative canopy cover, diurnal shading and snow/ice cover.

• Thermal properties of the soil mass in the store impact on the ability of the system to store and supply energy efficiently.

• Need to balance additional model complexity with uncertainty related to surface features when moving from 2D to 3D.

• Innovative materials where properties can be controlled could improve efficiency and are currently being investigated.