Modeling
Horizontal Ground Heat Exchangers in Geothermal Heat Pump Systems

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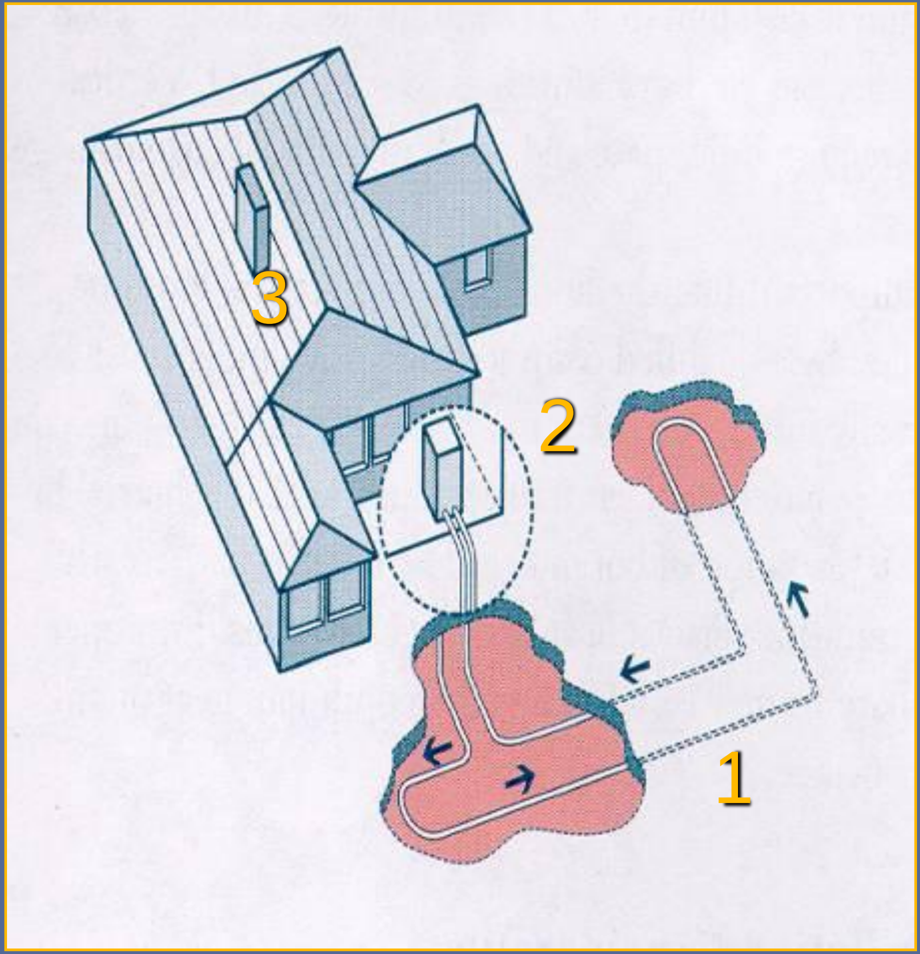
Presentation Outline

- Background
- Model implementation in COMSOL
- Results

Background: Horizontal Ground Heat Exchanger (GHX)

1. Earth connection
   - Closed-loop (vertical or horizontal)
   - Open-loop (well-to-well)
2. Water-source heat pump
3. Interior heating/ cooling distribution subsystem
   - Forced air
   - Radiant



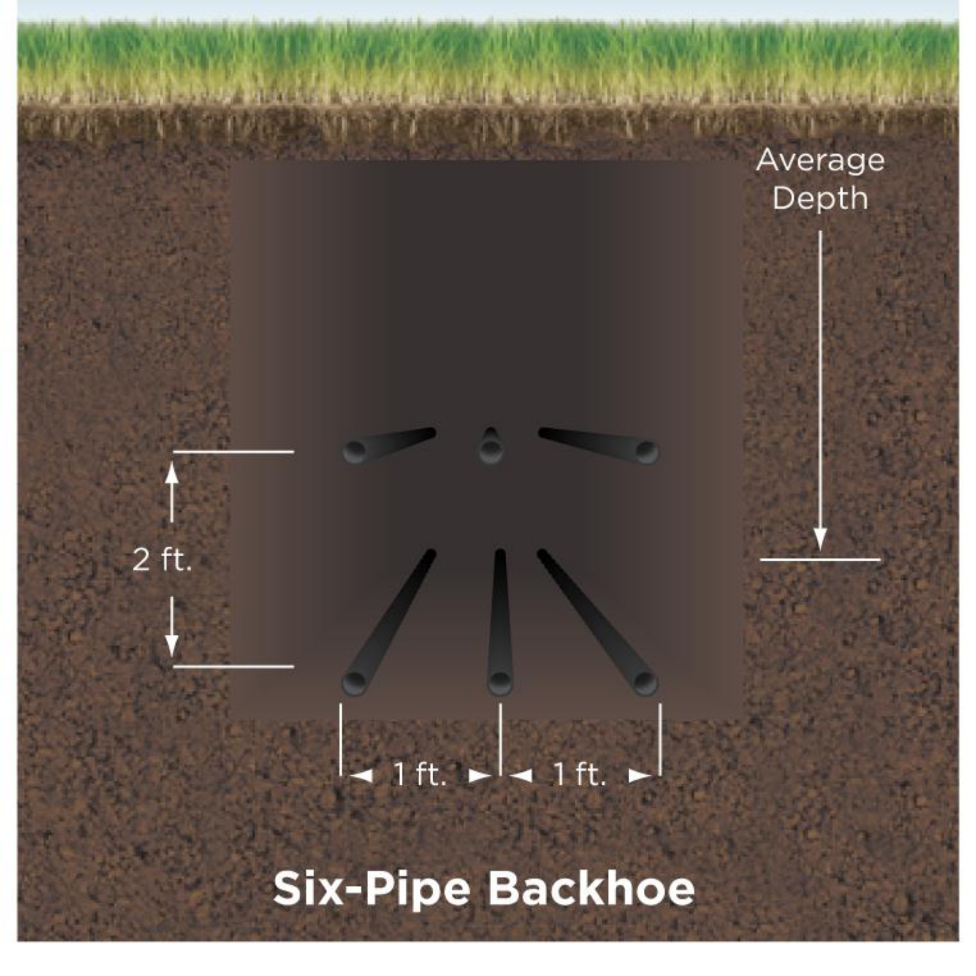
Background: Horizontal Ground Heat Exchanger (GHX)

- Relatively simple to install
- Difficult to model
  - Proximity to ground surface (transient boundary condition)
  - Effects of rain, snow, subsurface water migration
  - Thermal interference of adjacent trenches
  - Coupled to buildings with hourly heating & cooling load variations
  - Long-term transients require multi-year simulations (10, 20, or more years) in vertically bored systems – what about horizontal?

Objectives

- Develop a computationally-efficient means for horizontal GHX design (possible with finite element analyses?)
- Examine long-term thermal performance
- Explore use of COMSOL in the classroom

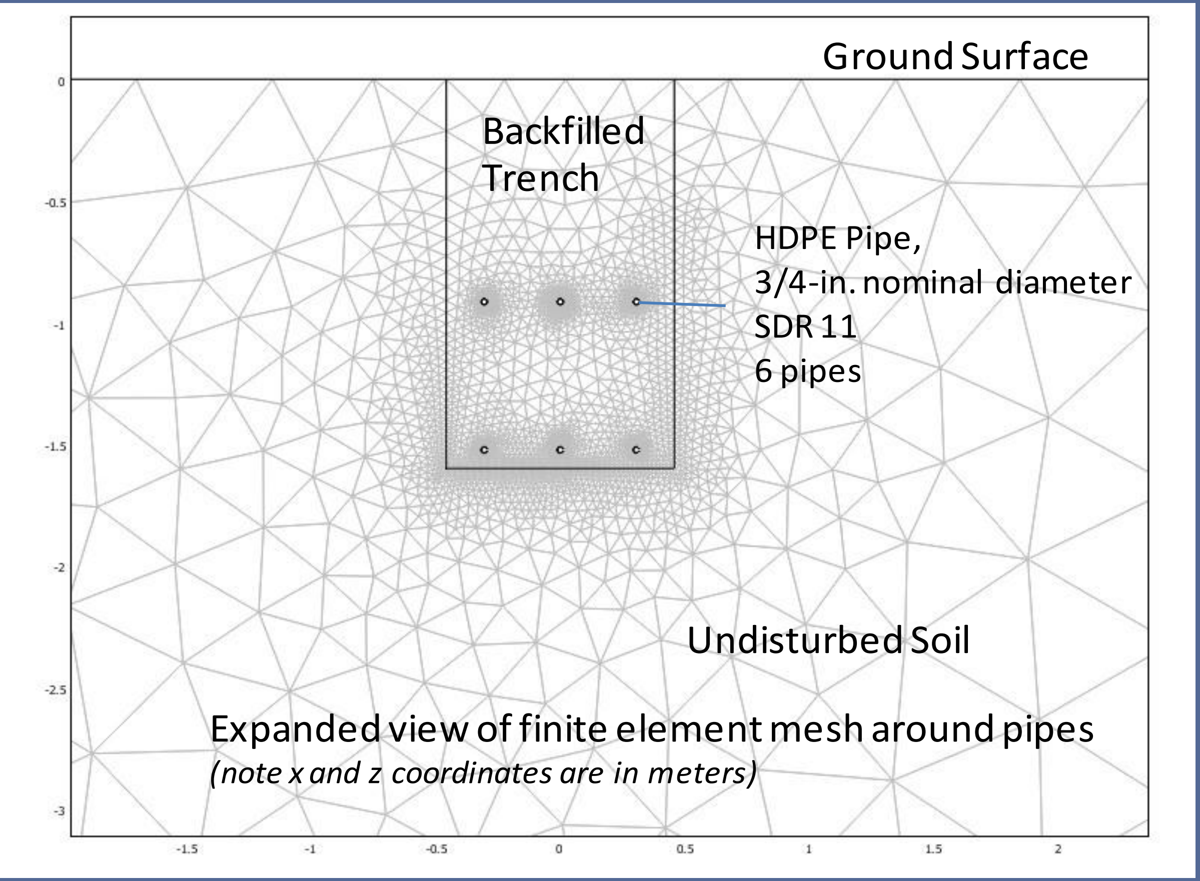
Model Implementation in COMSOL: The Physical Problem and Mesh



Average Depth = 4-5 ft

Source: WaterFurnace

Model Implementation in COMSOL: The Physical Problem and Mesh



Model Implementation in COMSOL:
Governing Equations, Boundary Conditions

- Governing PDE:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{dT}{dt}$$

- Boundary Conditions:
  - Left- and right-hand boundaries: Adiabatic
  - Bottom boundary: Constant temperature
  - Top Surface:

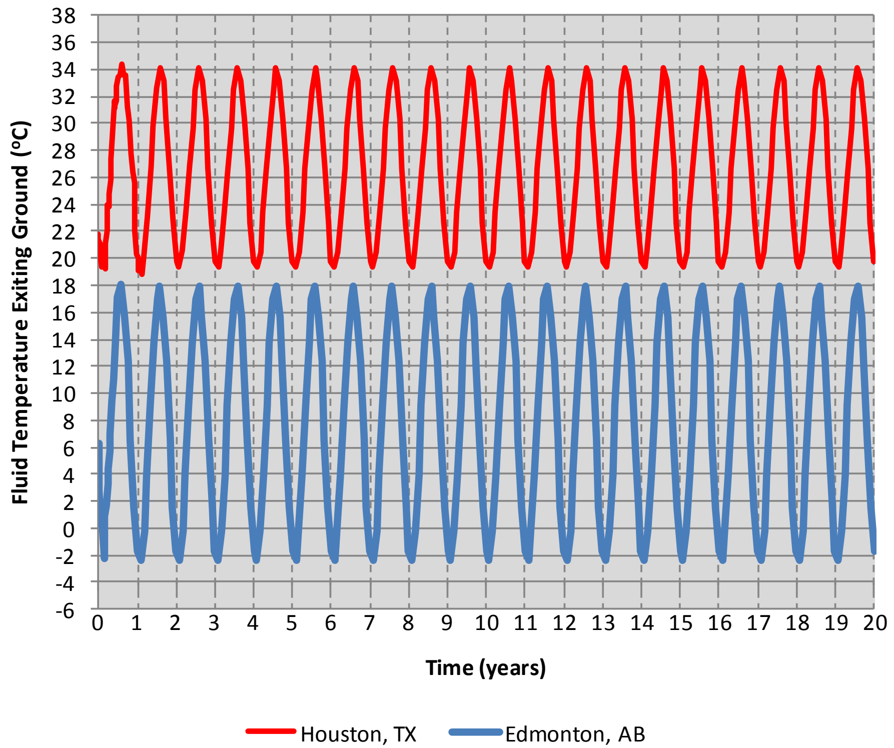
$$n \cdot (k\nabla T) = q''_{solar} + h\left(T_{inf} - T\right) + \varepsilon\sigma\left(T_{sky}^4 - T^4\right)$$

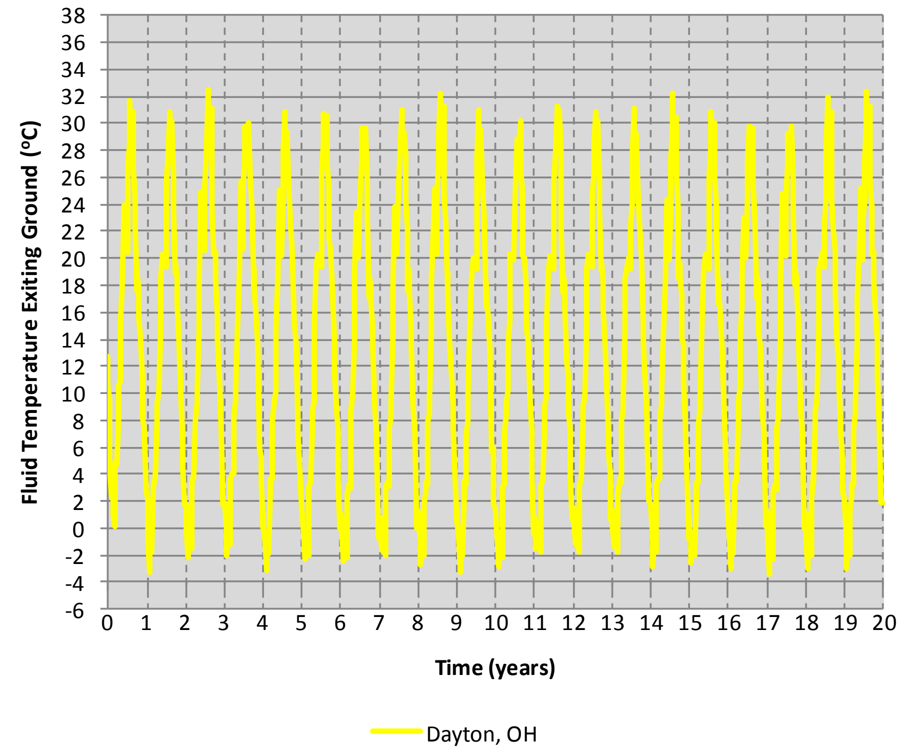
  - Internal pipe surface: Heat flux representing heating & cooling load of building
- Initial Condition: Undisturbed ground temperature

Model Implementation in COMSOL:
Model Simulations

- Calculated hourly heating & cooling loads for a 140 m^2 (1,500 ft^2) home in three climates:
  - Houston, TX
  - Dayton, OH
  - Edmonton, AB
- Converted hourly loads and climate data to monthly values
- Typical trench length of 50 m
  - Reduced model domain to half-distance to adjacent trench
- Simulated cases for 20 years
- COMSOL output of interest is the fluid temperature exiting the GHX (*i.e., entering the heat pump*)

Results:
Monthly Peak Fluid Temperatures Exiting GHX

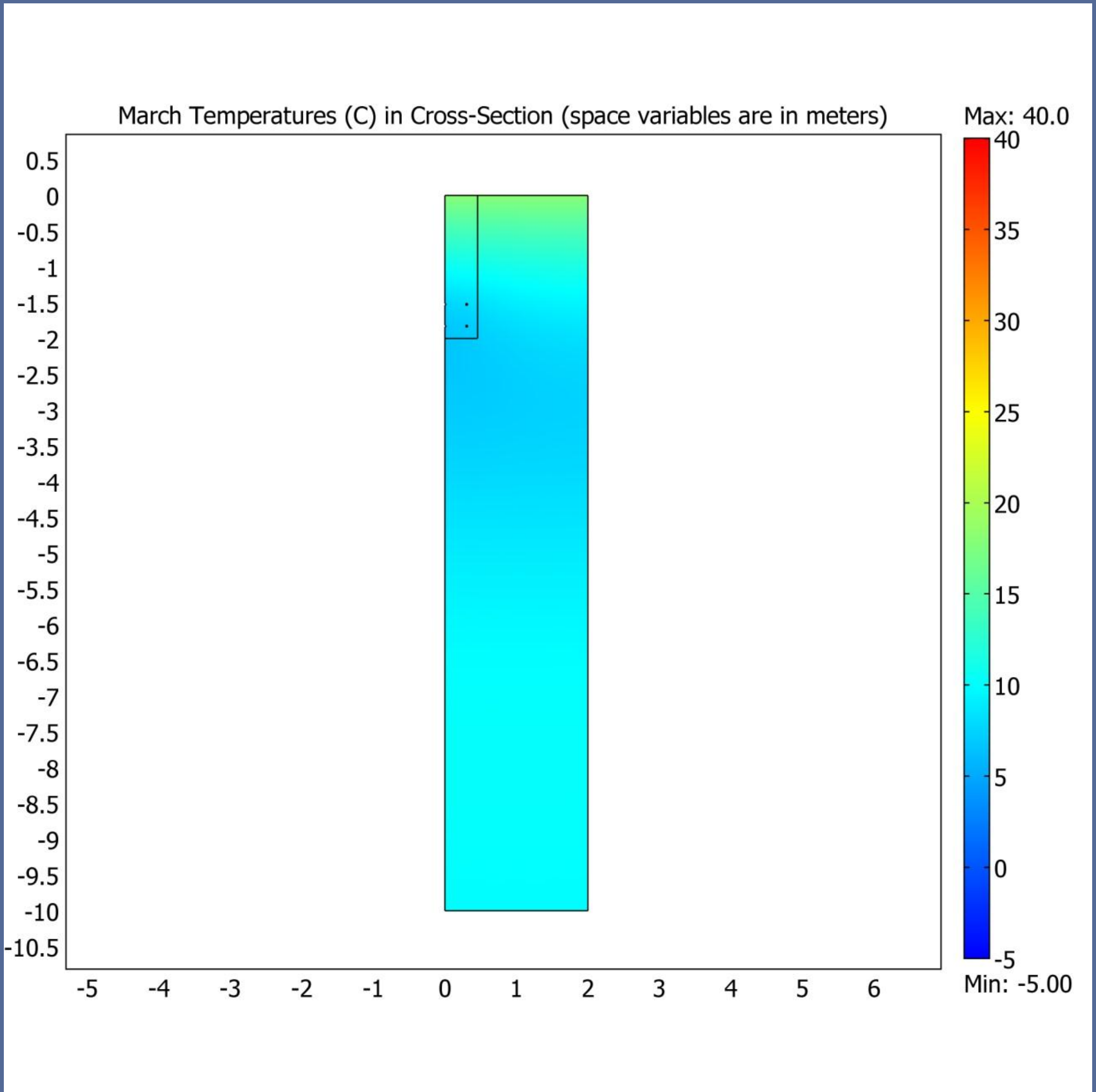




- Dayton, OH: 7 trenches x 50 m length
- Edmonton, AB: 23 trenches x 50 m length
- Houston, TX: 15 trenches x 50 m length

- CPU run times less than one minute using an Intel(R) Core(TM)2 Duo CPU with 2.96 GB RAM

Results:
Example Subsurface Temperature Distribution



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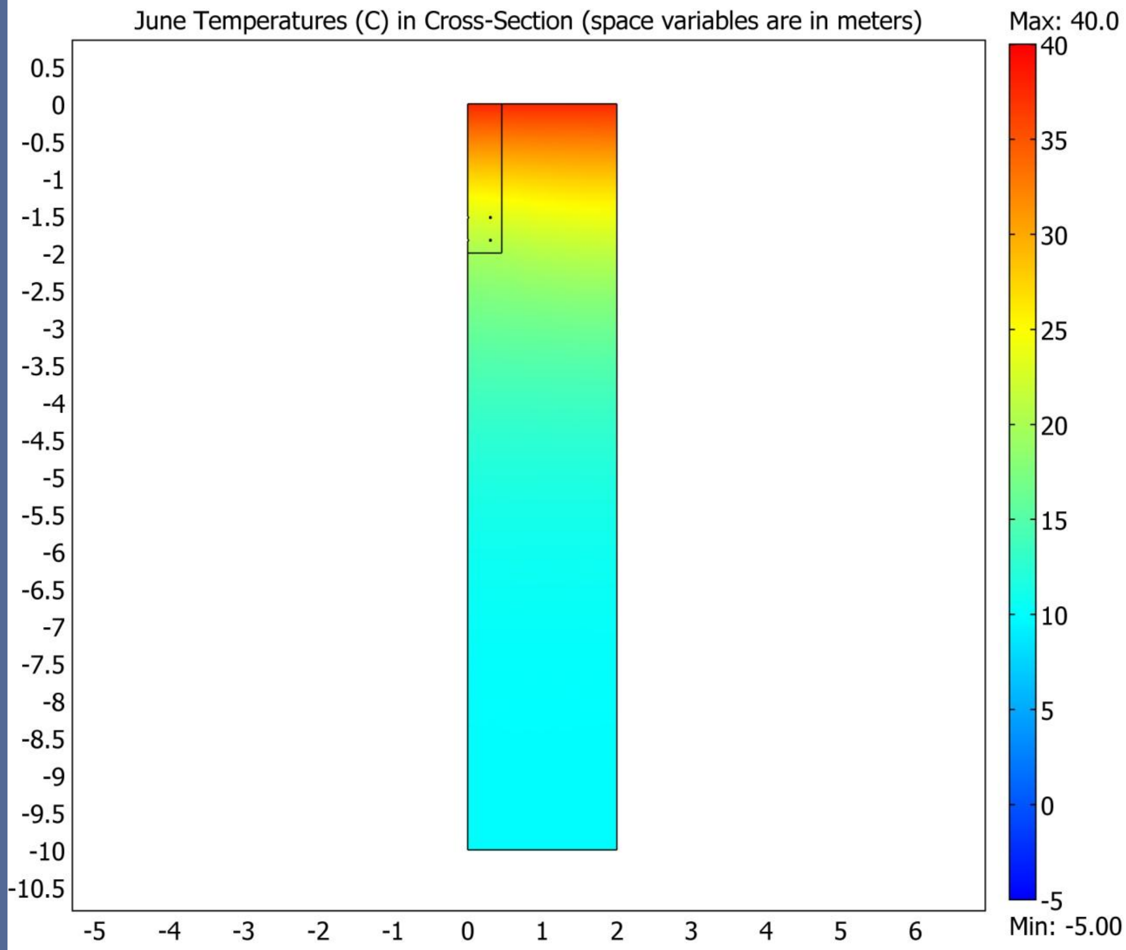

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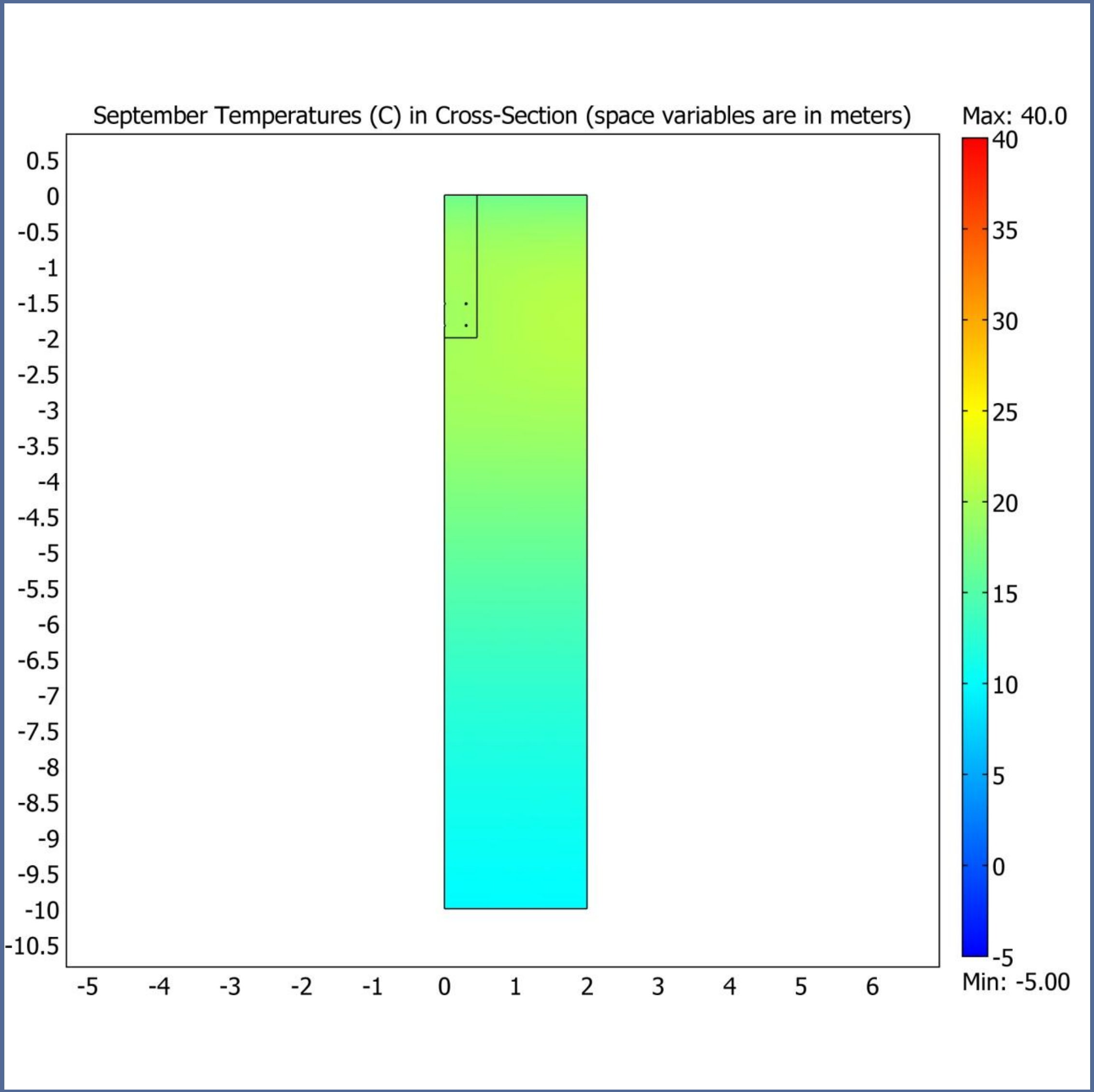

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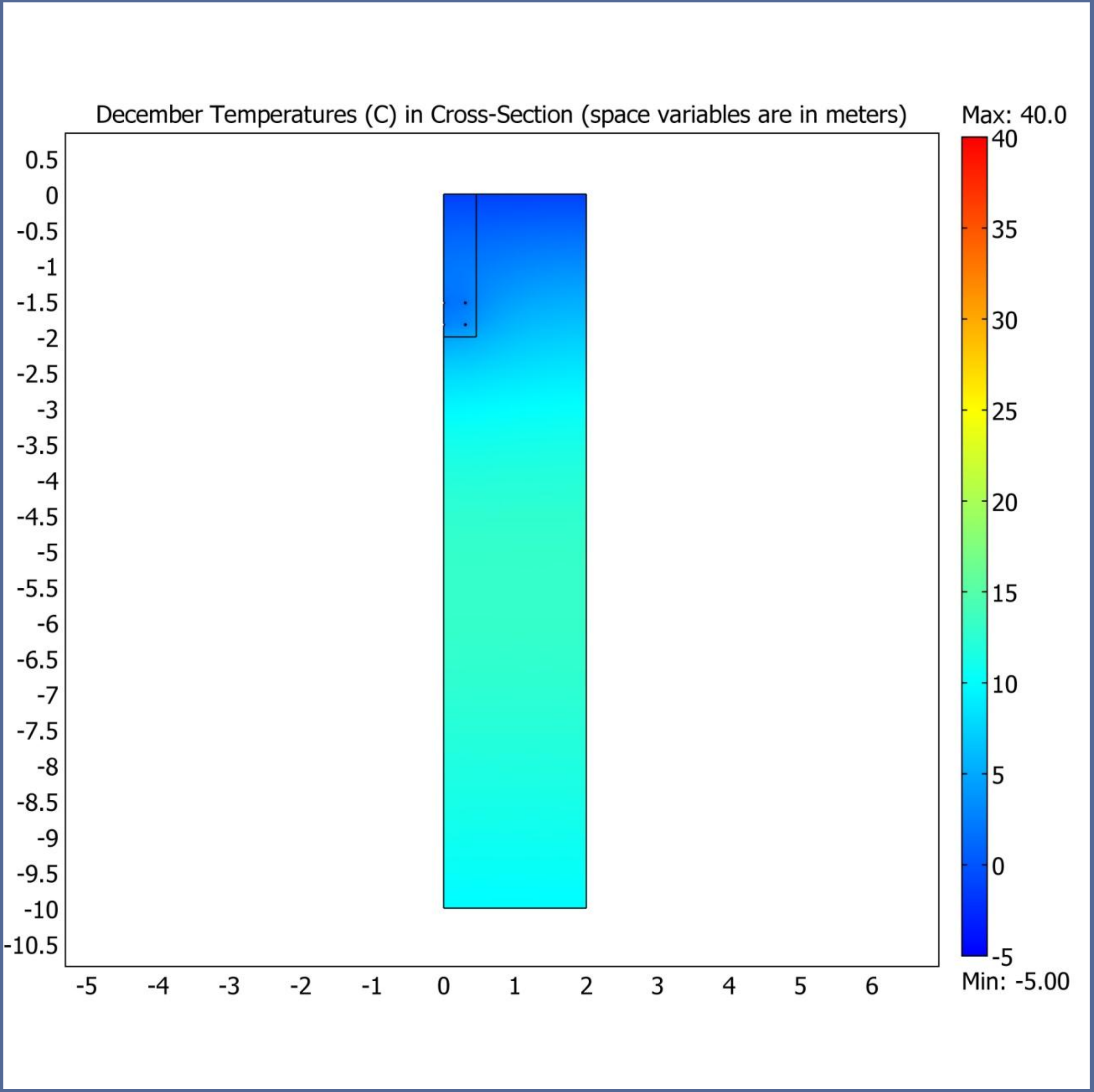
Example Subsurface Temperature Distribution



Concluding Summary

- Use of COMSOL is computationally-efficient in multi-year simulation of horizontal GHXs in simple 2-D cross-section with monthly-varying boundary conditions
- Unlike with vertical GHX systems, long-term subsurface thermal energy “buildup” or “depletion” is not observed in horizontal GHX systems
- COMSOL has pedagogical advantages in college-level geothermal courses