Modeling of Standing Column Wells in Ground Source Heat Pump Systems

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Outline

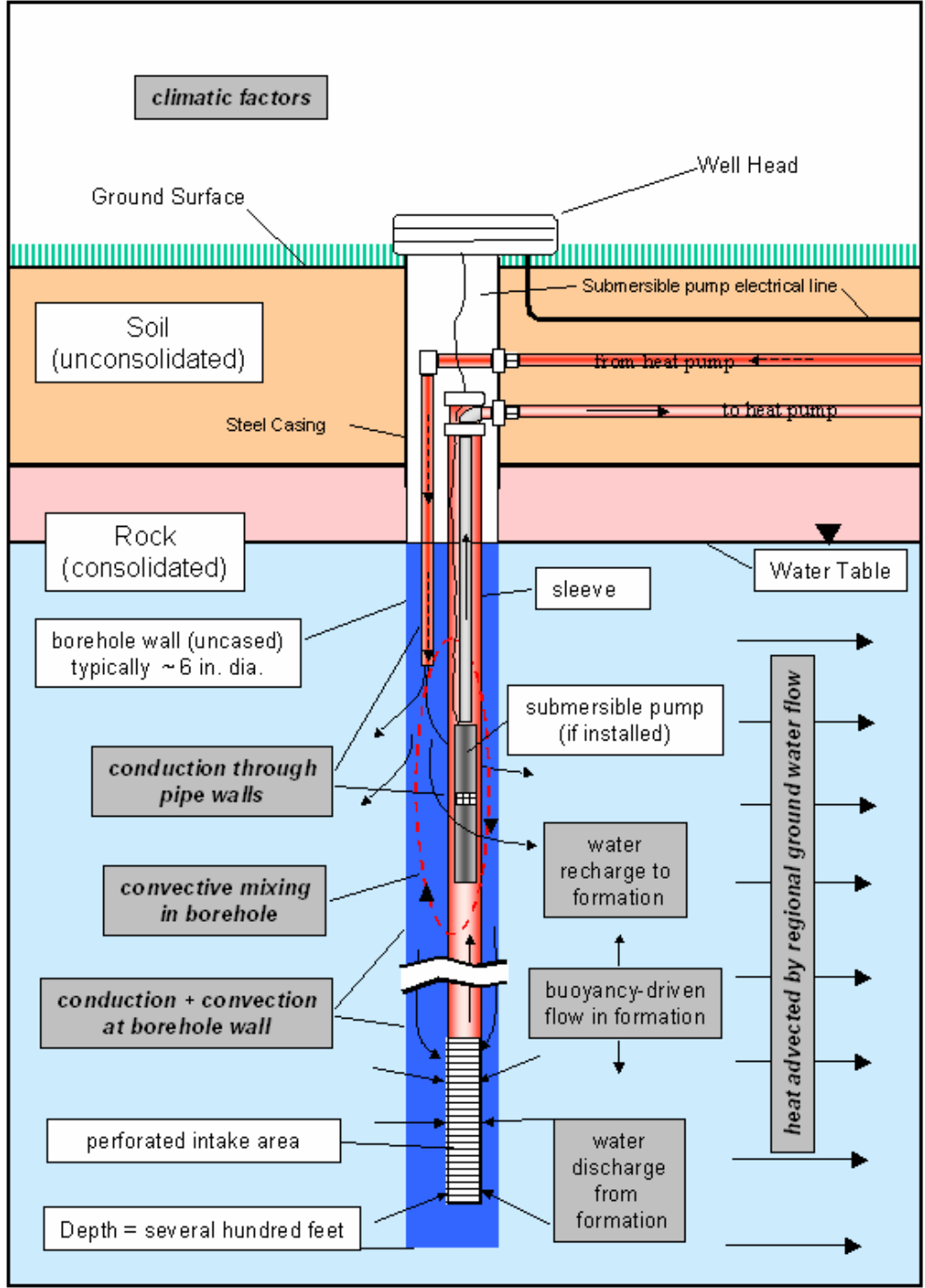
- Introduction
- Model development
- Experimental validation
- Application example
- Conclusions and recommendations

SCW Systems

- Standing Column Well:
  - Single borehole
  - Open loop
  - Water extracted from and returned to same borehole
  - Similar to a domestic water well, but water is returned, for the most part.
  - In some systems, some water, some of the time, is not returned. (“Bleed”)

Introduction
SCW systems

- Operation
  - Without bleed
  - With bleed
- Benefits
  - Economy, environmental benefits...
  - 50-60 feet per ton
- Limitation
  - Good groundwater quality
  - Local regulations



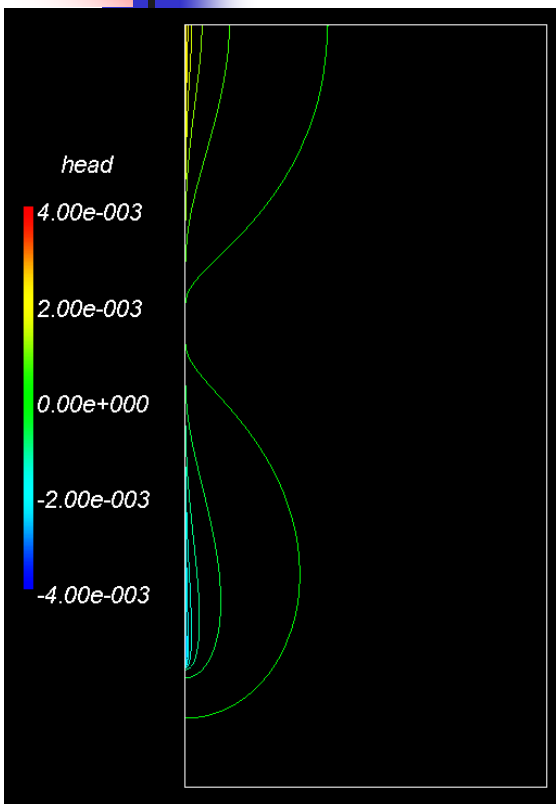
Previous work

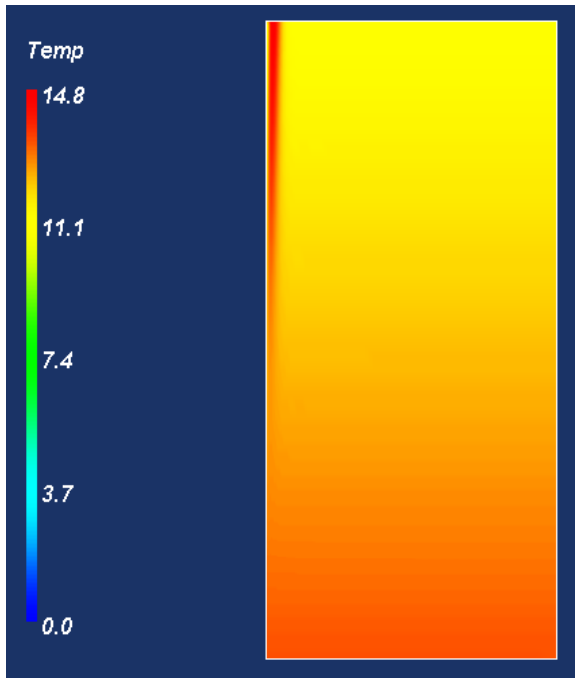
- No models available for SCW design and energy analysis purposes:
  - Effects of bleed not quantified.
  - Time varying thermal boundary conditions
  - Effects of design parameters such as borehole diameter, borehole depth, dip tube size, etc. not quantified.

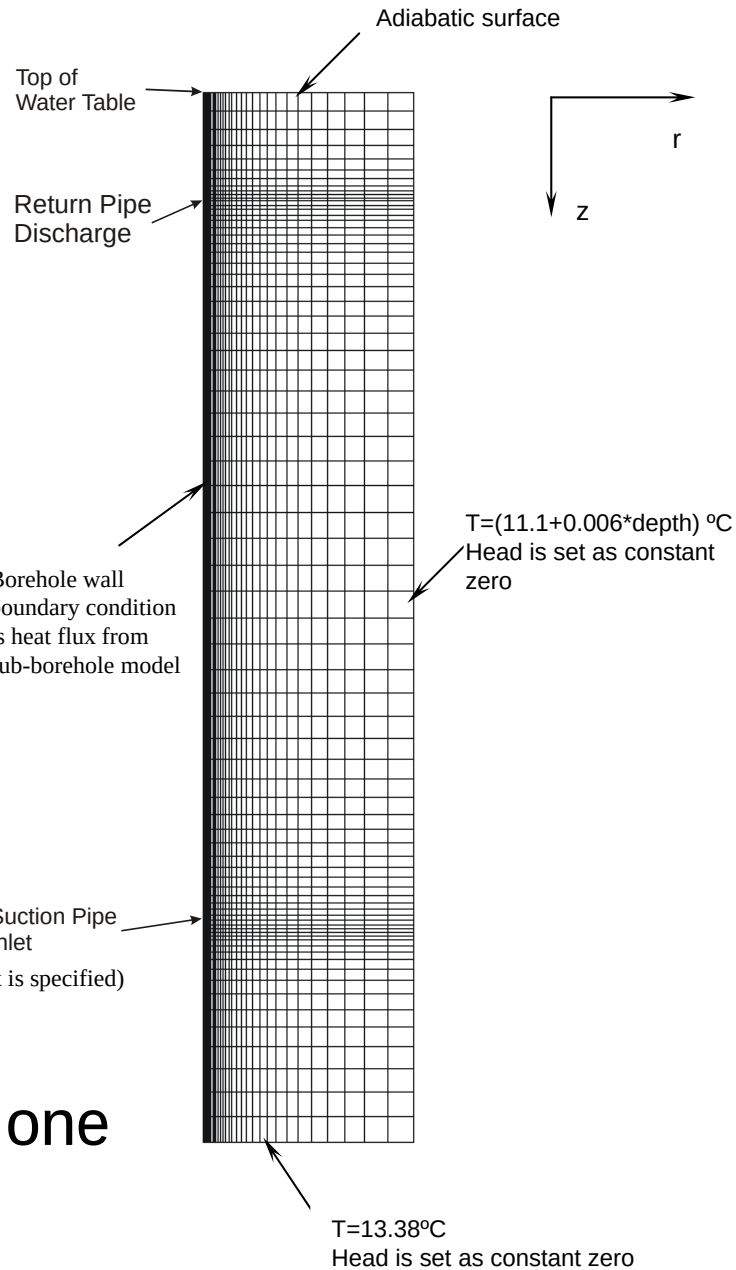
Model: Detailed model

- Detailed model (ASHRAE-RP1119)
  - Two-dimensional (radial/axial) finite volume method-composed of two coupled components
  - Well borehole model
    - Heat transfer in the borehole
  - Finite volume model
    - Heat transfer in the surrounding rock
    - Flow in the borehole and in the surrounding rock

Model: Detailed model







- Head/temperature distribution after one year of normal operation

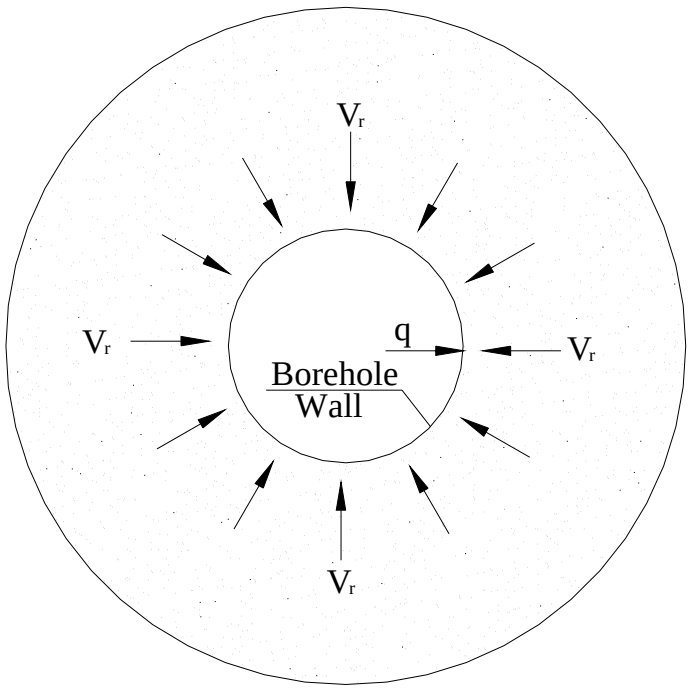
Model: Detailed model

- Significant Parameters
  - Bleed Rate; Borehole depth
  - Rock thermal conductivity and hydraulic conductivity
- Performance can be improved dramatically by introducing bleed
- As bleed rate increases, sensitivity to length decreases
- As hydraulic conductivity increases, there can be a tradeoff between convective and advective heat transfer
- Model takes several weeks (!) to simulate a single year of operation

Model: Simplified model

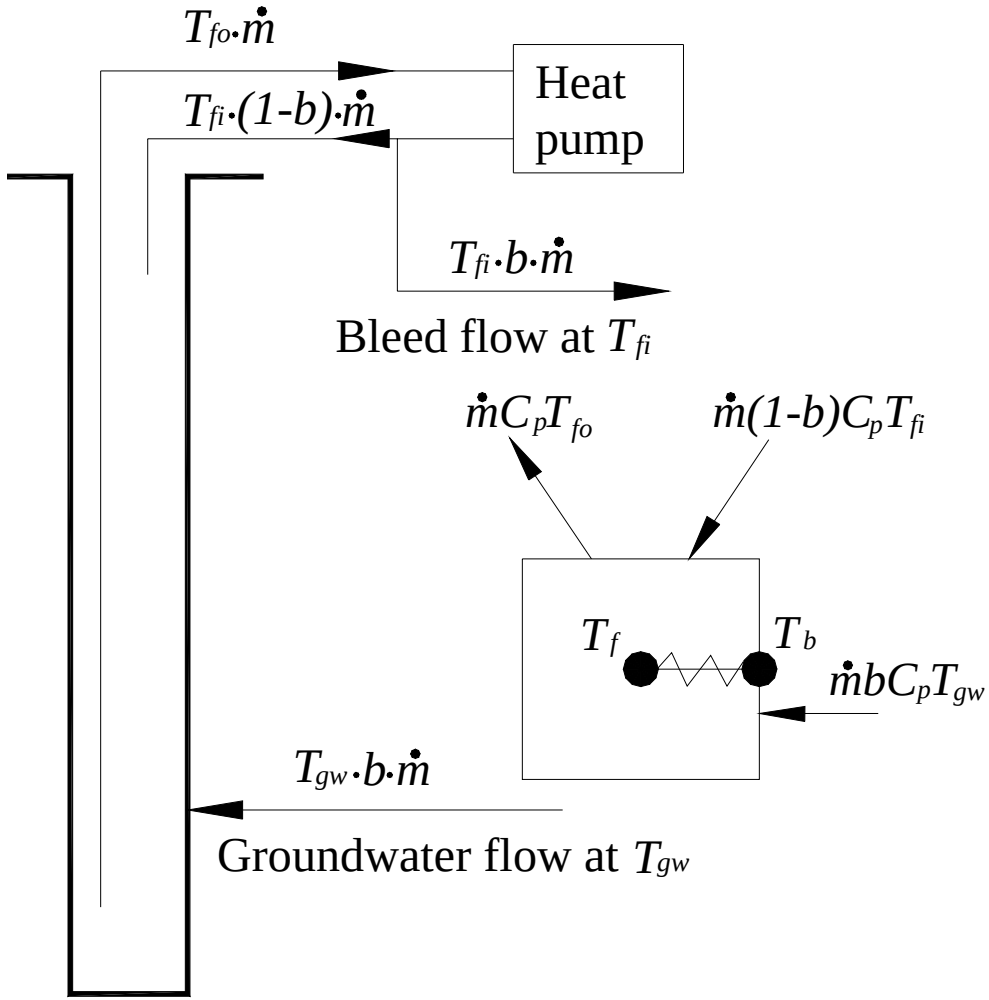
- Simplified model
  - One-dimensional finite difference method
  - For annual building simulation
    - More than a hundred thousand times faster than detailed model. ☺
  - Assumptions
    - No vertical heat and water flow
    - Zero natural ground temperature gradient

Model: Simplified model



T_{far}= 12°C

Far Field



Model: Simplified model

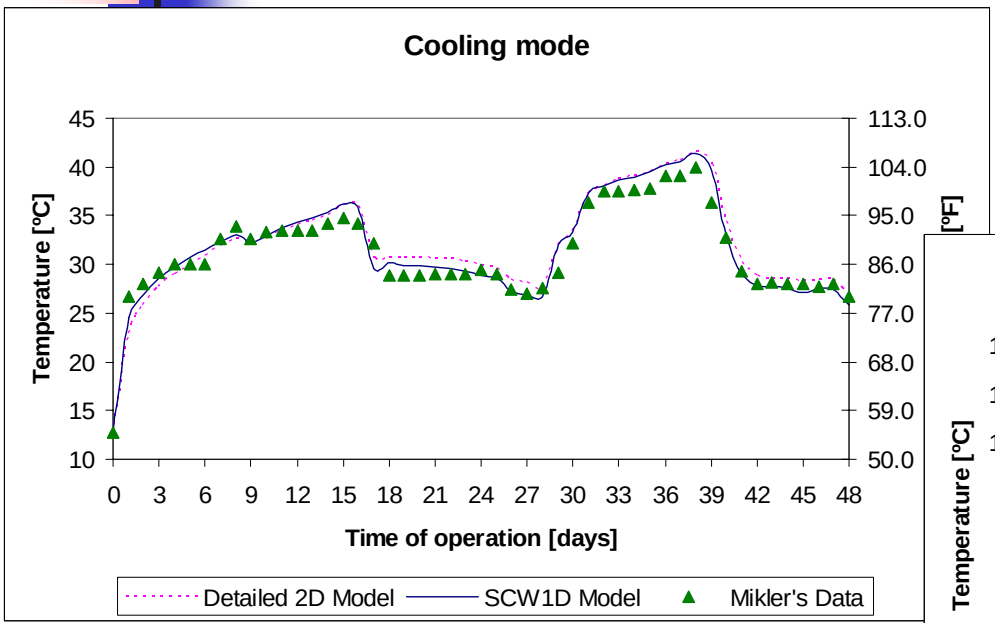
- Three different effects of water on the heat transfer in SCW system
  - Static water
    - Effective thermal conductivity
  - Induced groundwater flow (w/o bleed)
    - Enhanced thermal conductivity
  - Bleed
    - Bleed-driven advection

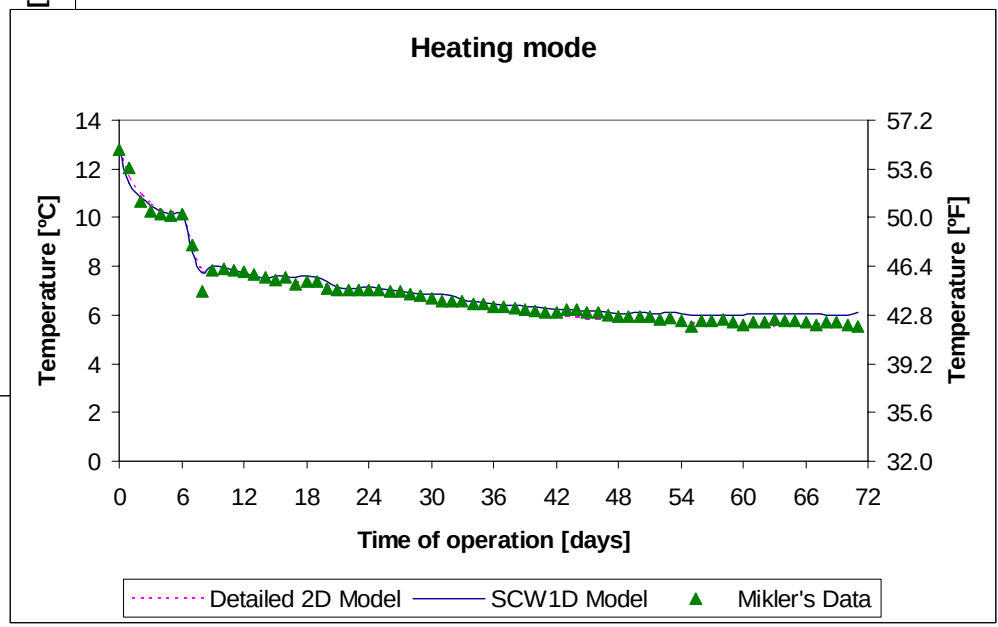
Model: Simplified model

- Use enhanced thermal conductivity
- The effect of bleed is superimposed
- Three procedures to estimate the enhanced thermal conductivity
  - Physical *in-situ* test
  - Numerical *in-situ* experiment
  - Correlations

Experimental validation-without bleed

- Penn. State University
- One SCW without bleed
- 320 m (1050 ft) deep
- 0.1524 m (6 in) diameter



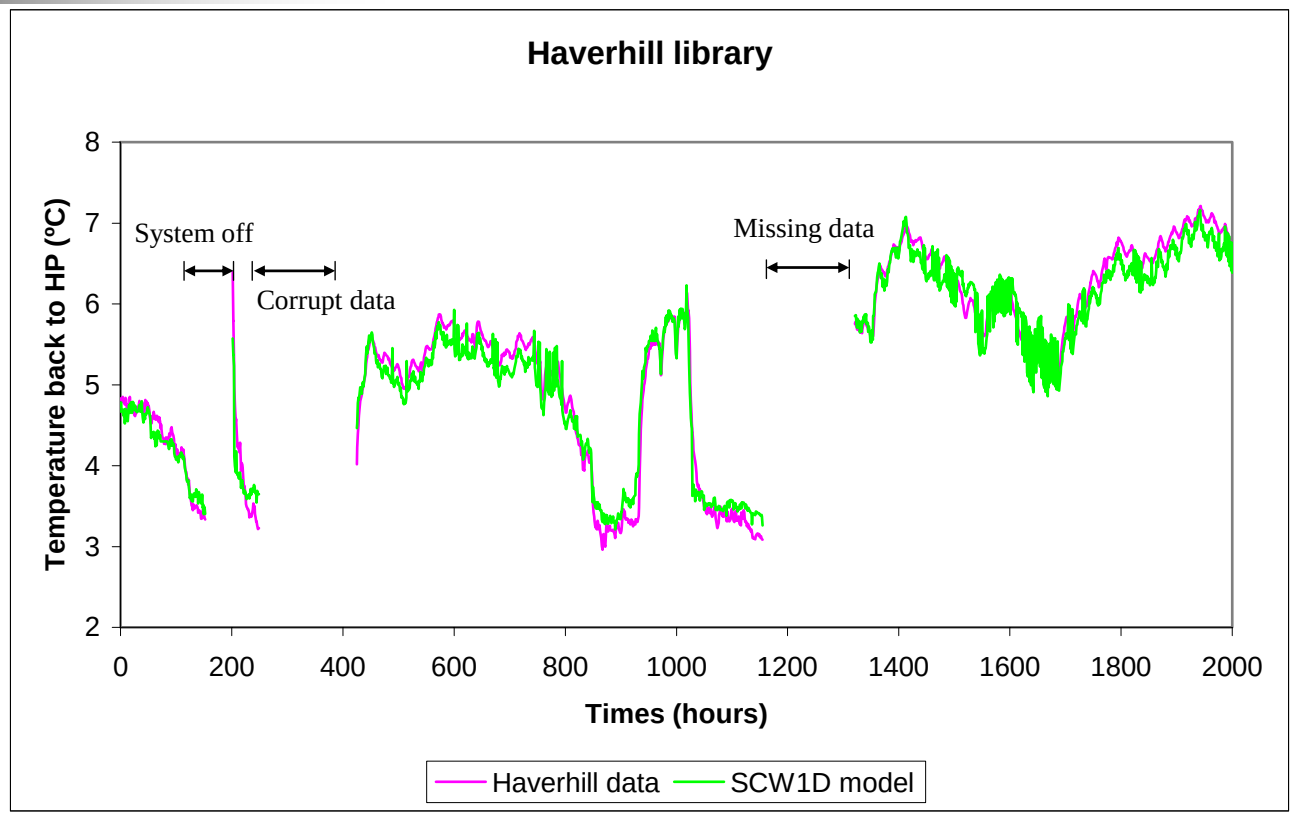


- Comparisons of temperatures at the outlet to the well for the simplified model (SCW1D), reference model, and Mikler's data in cooling and heating mode

Experimental validation-with bleed 1

- Haverhill public library, Massachusetts
- Initially two SCWs, Now four SCWs
- 457 m (1500 ft) deep
- 0.1524 m (6 in) diameter

Experimental validation- with bleed 2



- Comparisons of calculated and measured temperatures at the outlet of the well using the Haverhill Public Library installation data

Application example

- Annual energy simulation implemented in HVACSIM+
- Three different system
  - Single U-tube closed-loop
    - Short-time step g-function
  - SCW without bleed
    - Simplified SCW 1D model
  - SCW with bleed – deadband control
    - Simplified SCW 1D model

Application example

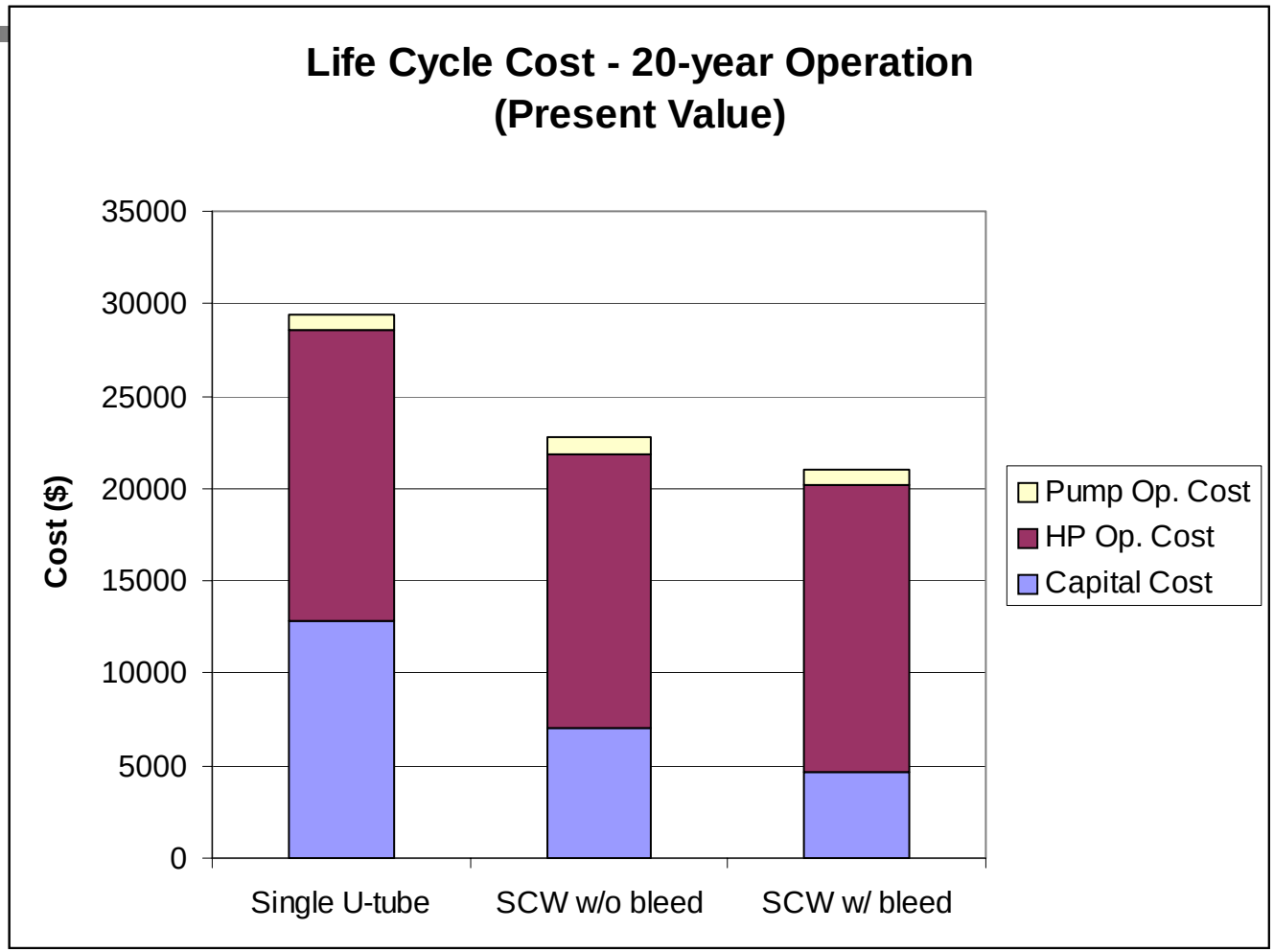
Summary of ground heat exchanger design results for Boston weather file

Ground Heat Exchanger Type	Borehole Geometry	Borehole Depth (m) [ft]	Required Total Borehole Length (m) [ft]	EFT_{max} (°C) [°F]	EFT_{min} (°C) (°F)	Feet per ton
Single U-tube closed-loop	1 × 8	82 (268)	653 (2,144)	29.7 (85.5)	3.4 (38.2)	121
Standing Column Well Without Bleed	1 × 1	391 (1,283)	391 (1,283)	22.8 (73.1)	7.0 (44.6)	72
Standing Column Well With 10% Bleed (Deadband Control)	1 × 1	263 (863)	263 (863)	28.1 (82.5)	7.0 (44.6)	48

Application example

- Required total borehole depth for different ground heat exchanger systems in Boston, MA
  - SCW without bleed requires 40% less borehole depth
  - SCW with bleed requires 60% less borehole depth

Application example



Conclusions

- Developed numerical models of standing column wells
  - Two-dimensional finite volume model
  - One-dimensional finite difference model
- Validated against experimental data
  - With Bleed
  - Without bleed
- 1-d model is suitable for either energy analysis or design purposes.

Recommendations–Future Research

- Extend the model to account for well-to-well interference in multiple standing column well systems.
- Develop and validate complete design procedure, including recommended site tests:
  - *In situ* measurement of the thermal conductivity
  - Well drawdown test for the hydraulic conductivity
- Further long-term experimental validation

Any Questions?

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