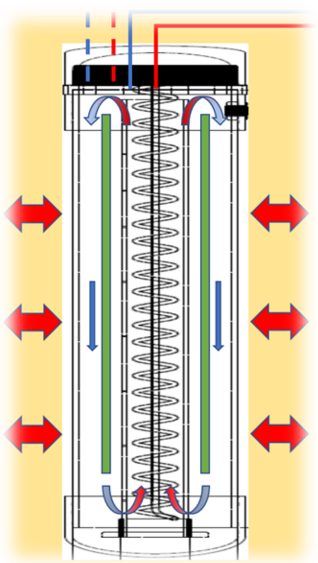
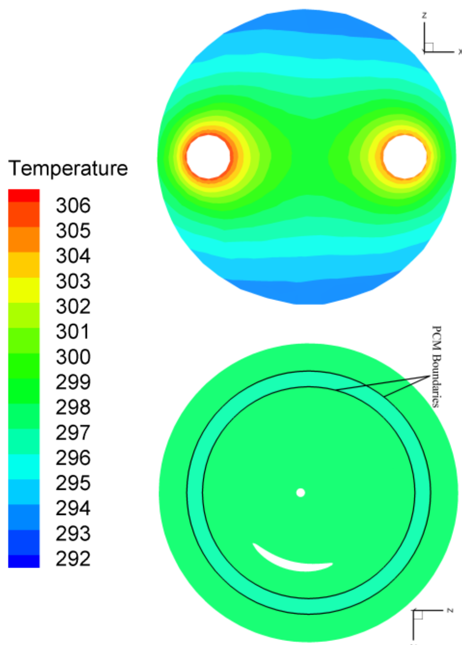
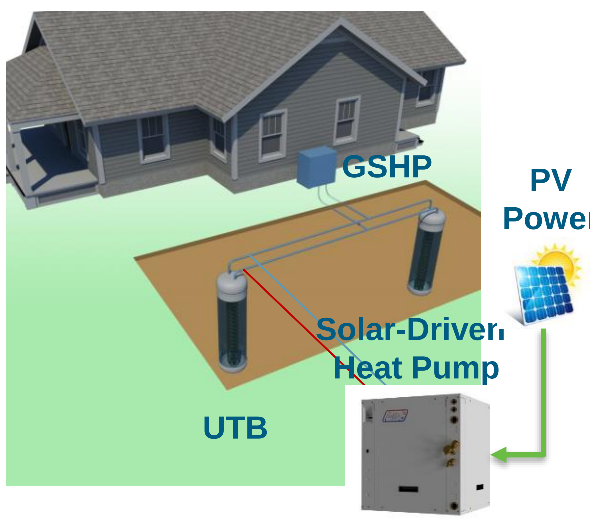
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Innovative Low-Cost Ground Heat Exchanger for Geothermal (Ground Source) Heat Pump Systems







Oak Ridge National Laboratory
Xiaobing Liu, Mingkan Zhang, Kaushik Biswas, Joseph Warner, Tony Gehl, Jerry Atchley
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Project Summary

Timeline:

Start date: 10/1/2017

Planned end date: 9/30/2019

Key Milestones

1. Lab test of a small-scale prototype: Sep. 2018
2. Numerical models for evaluating long-term performance: Apr. 2019
3. Performance and cost analysis: Sep. 2019

Budget:

Total Project $ to Date: $384K

- DOE: $384K
- Cost Share: NA

Total Project $: $510K

- DOE: $510K (planned)
- Cost Share: NA

Key Partners:

INSOLCORP

THE UNIVERSITY OF TENNESSEE KNOXVILLE

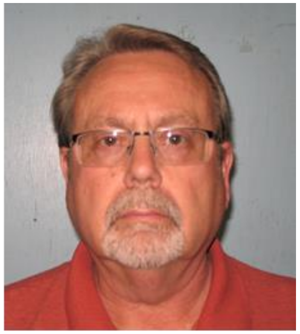
Project Outcome:

An innovative and cost-effective ground heat exchanger with the potential to make highly energy efficient ground source heat pump (GSHP) systems affordable to millions of US homes, which can significantly reduce energy consumption and associated greenhouse emissions in our nation.

Team



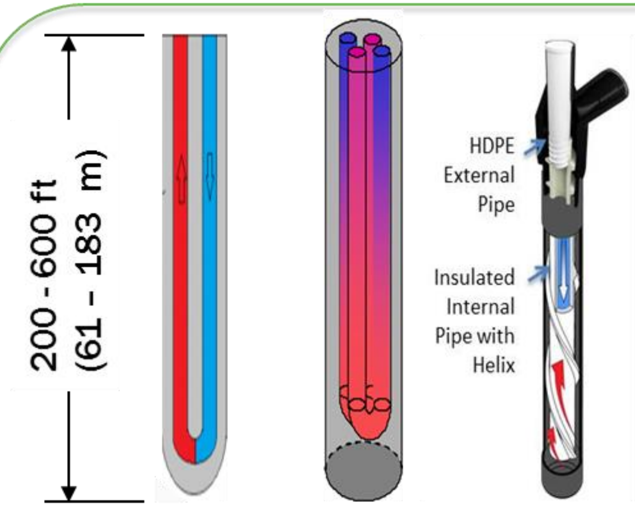


- **Xiaobing Liu**: PI, prototype design, modeling, and lab tests. 19 years experience in ground source heat pump related R&D and applications.
- **Mingkan Zhang**: Model development. 16 years experience in numerical modeling of heat transfer and fluid dynamics.
- **Kaushik Biswas**: Characterization and integration of phase change materials (PCMs).
- **Joseph Warner**: Model development and lab tests.
- **Tony Gehl and Jerry Atchley**: Experimental instrument setup, data acquisition.

Challenge: Make GSHPs More Cost Effective

- GSHPs can efficiently heat and cool buildings, but the high cost of ground heat exchangers (GHEs) prevents wider adoption
- Drilling contributes most (~70%) to GHE cost (~$3K/cooling ton)
- Previous R&D focused on improving borehole heat transfer, which resulted in limited cost reduction



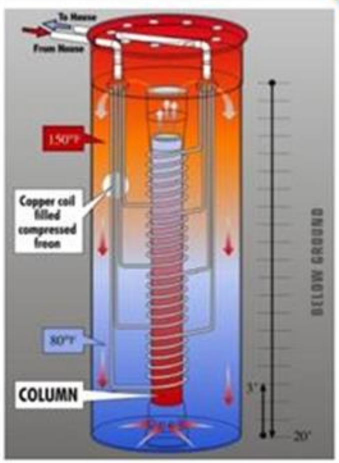
Single-U Double-U Co-axial

Installed in deep and slim bores

Multi-U ("Twister")

Installed in shallow and big bores

Basket heat exchanger

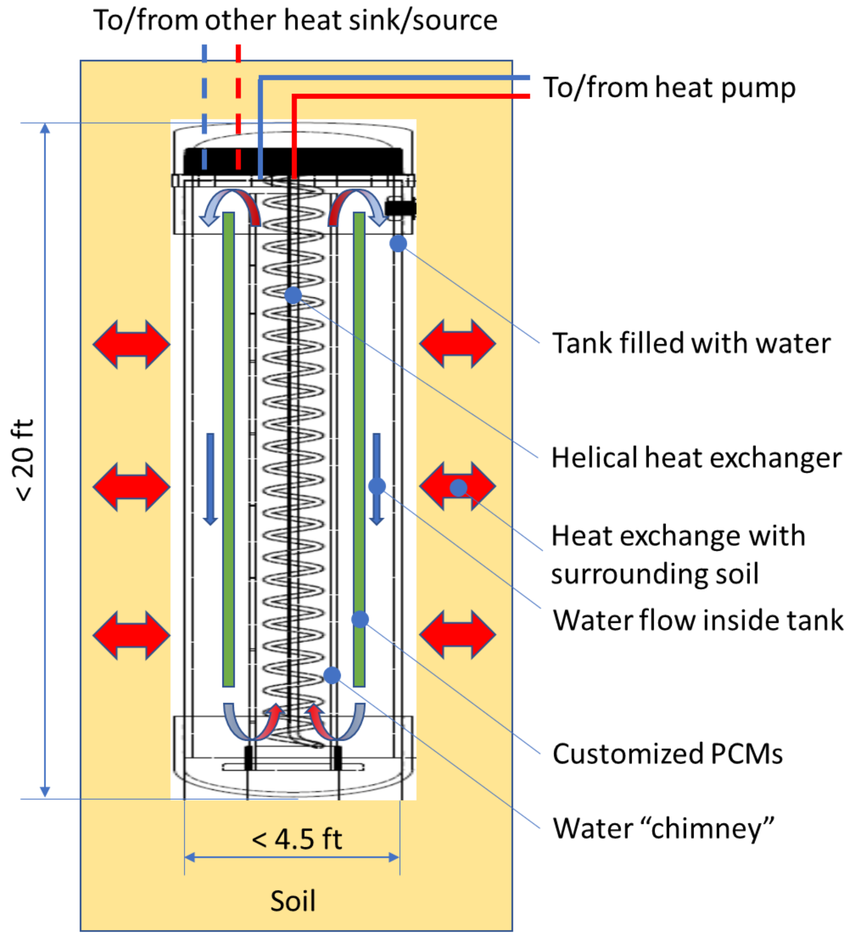


GeoColumn

The value of GSHPs could be increased if they could reduce and shift the electric demands of buildings with built-in thermal energy storage capability

Approach

Next-Generation GHE: Underground Thermal Battery (UTB)



Less drilling	• Installed in shallow bores
Larger heat capacity	• Filled with water and PCMs
Rechargeable	• Hybrid with other natural heat sinks/sources

	Soil/rock (typical)	Water	Inorganic PCM
Specific heat [kJ/(m^3-C)]	2,070	4,200	~3,000
Heat of fusion [MJ/m^3]	NA	334	~300

Invention Disclosure: 201804082, DOE S-138,749

Approach (Continued)

FY18 | FY19 | Future

Lab test

- Designed and built a small-scale UTB
- Identified and characterized PCMs
- Tested the small-scale UTB at controlled conditions

Modeling

- Created a 3D model for UTB
- Validated the 3-D model
- Created and validated a 1D model for long-term performance analysis

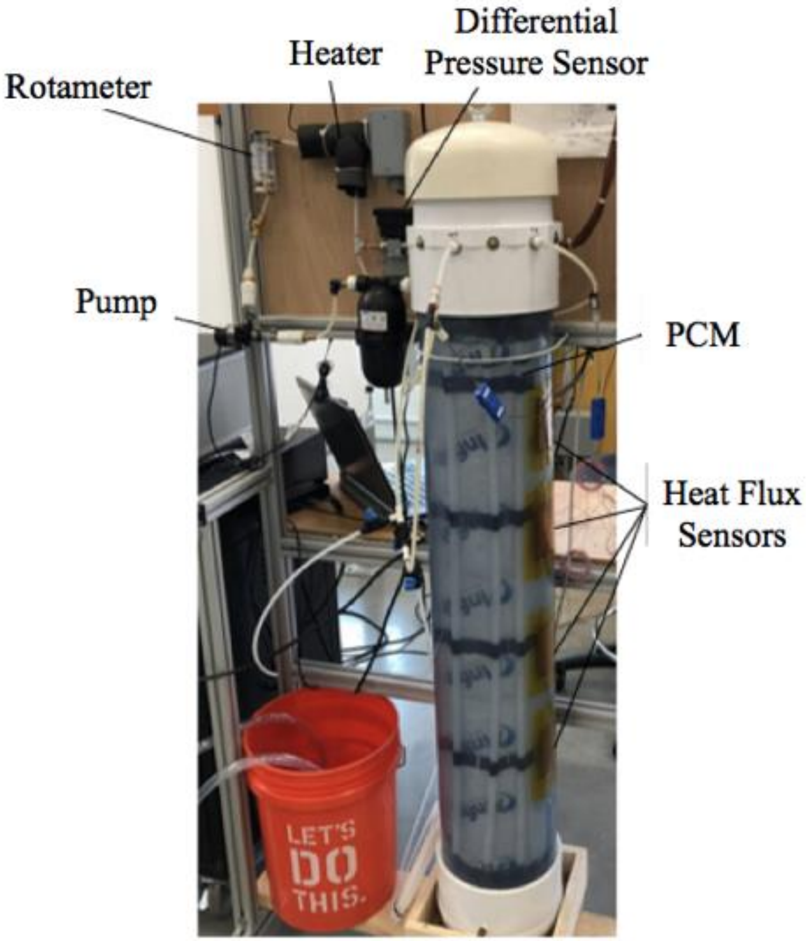
Performance and cost analysis

- Compared performance between UTB and vertical bore ground heat exchanger (VBGHE)
- Conducted a parametric study
- Perform cost analysis
- Design a full-scale UTB

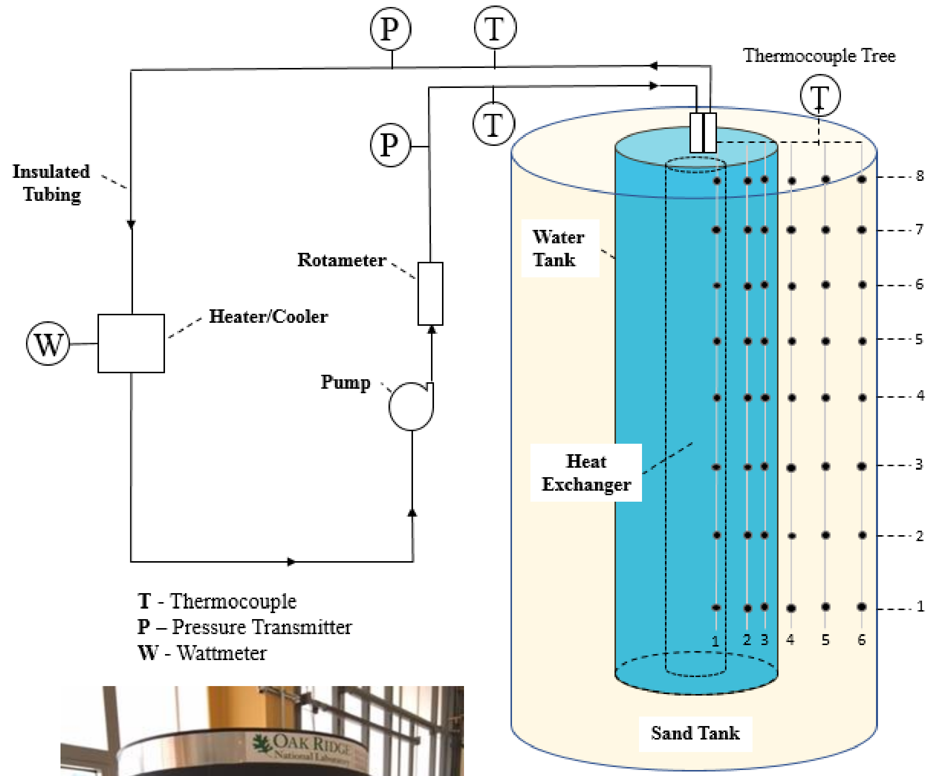
Field test

- Develop cost effective procedures for assembling and installing full-scale UTB
- Identify test site and install a full-scale UTB
- Monitor and analyze performance

Progress: Designed and Built a Prototype UTB

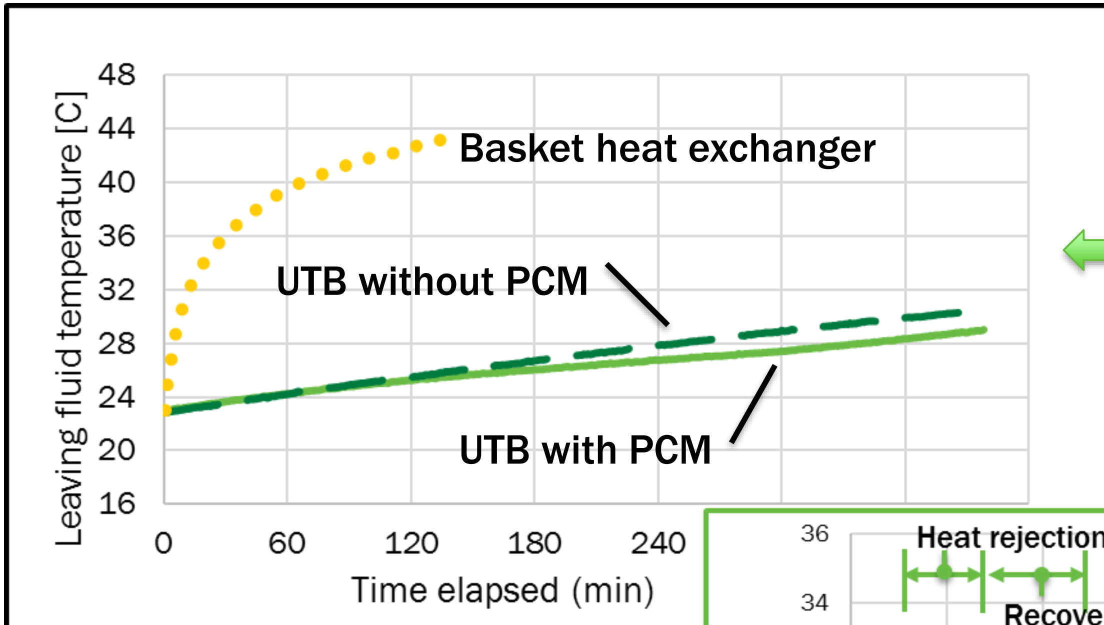


A small-scale prototype UTB: 4 ft (1.2 m) tall with 8 in. (0.2 m) diameter



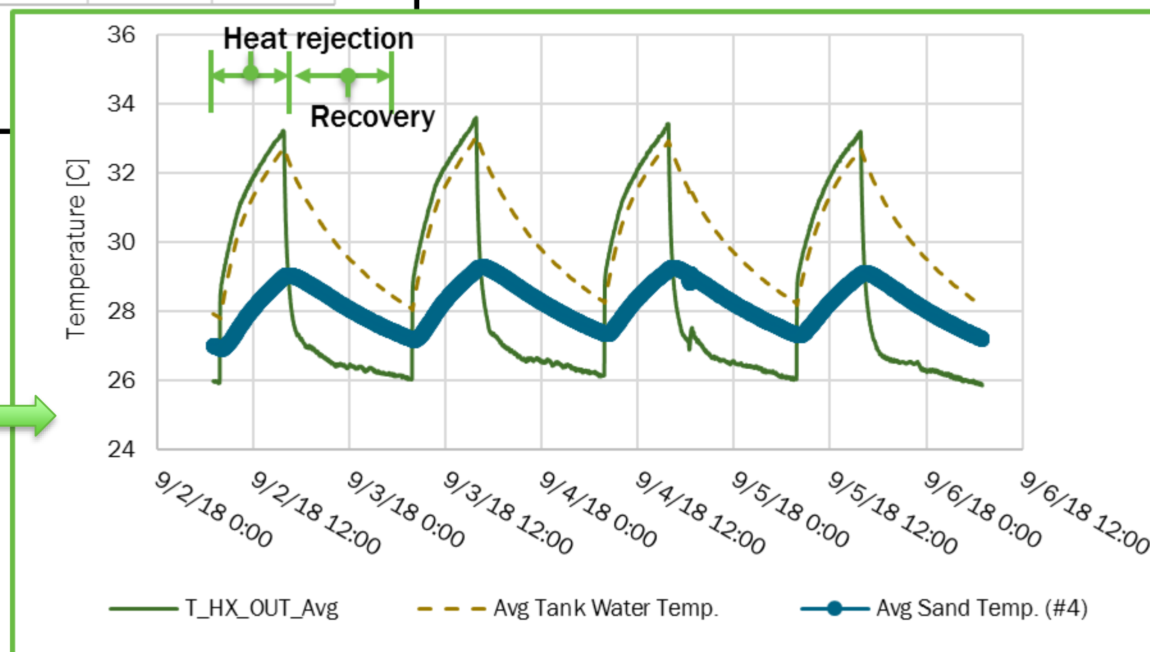
Experimental apparatus

Progress: Lab Test Results

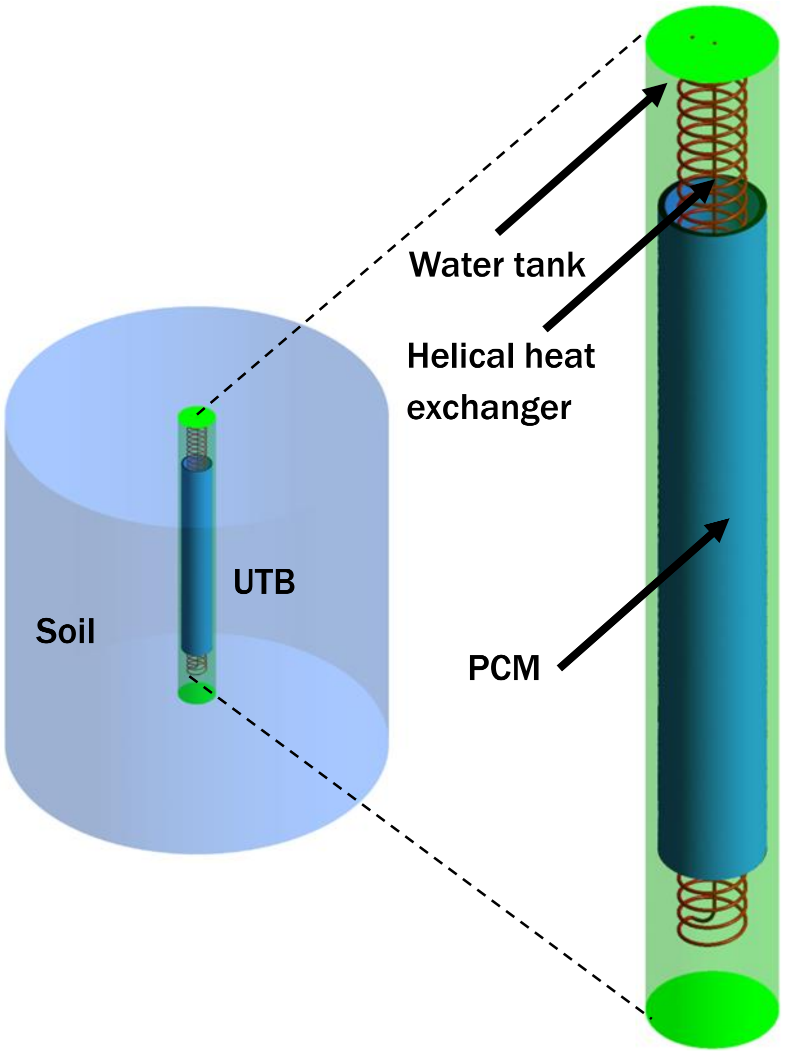


- UTB performs much better than alternative compact GHE
- PCM (9% of tank volume) has moderate impact

- Stable UTB performance under moderate loading conditions

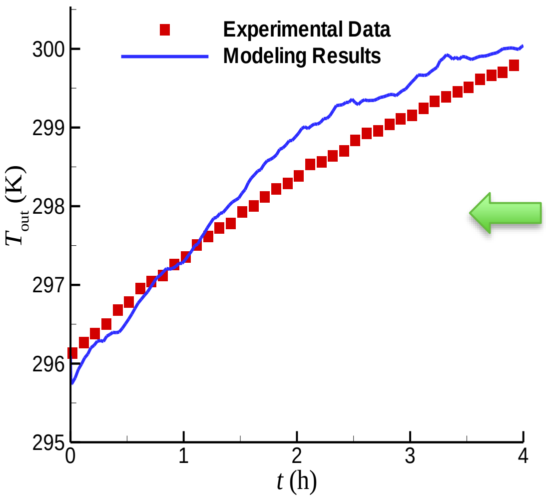


Progress: 3D Models of UTB and VBGHE

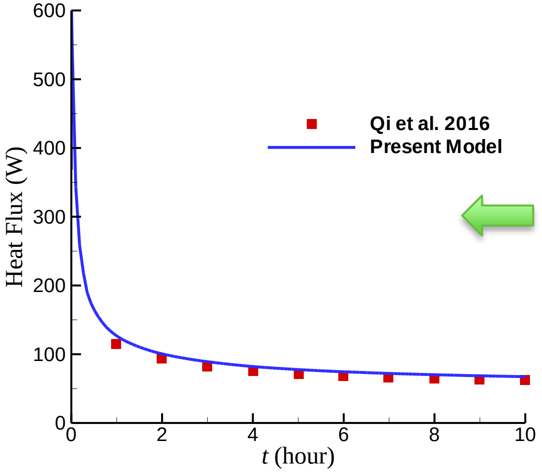


Simulation domain of the 3D UTB model

Developed and validated 3D models for both conventional VBGHE and the UTB



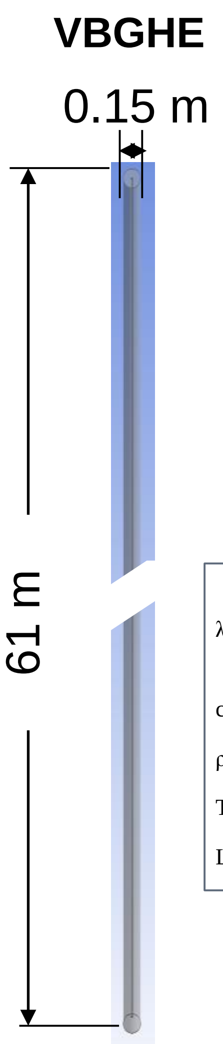
Validation result of UTB model

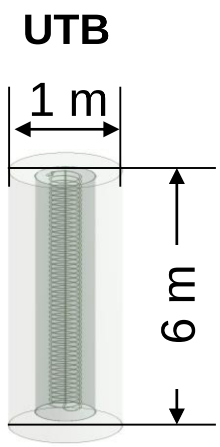


Validation result of VBGHE model

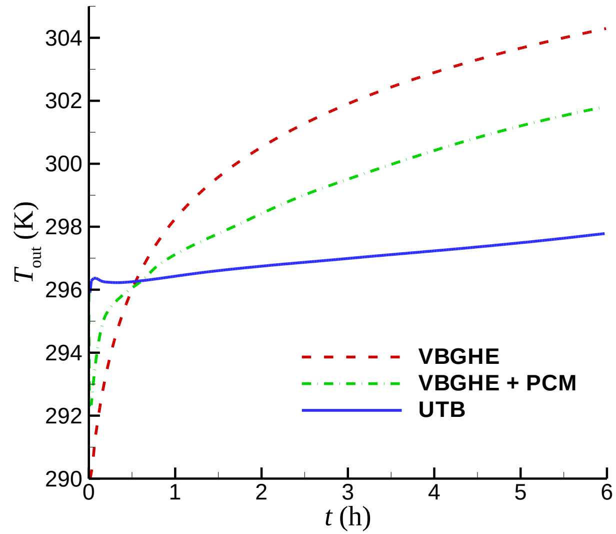
Progress: Short-Term Performance

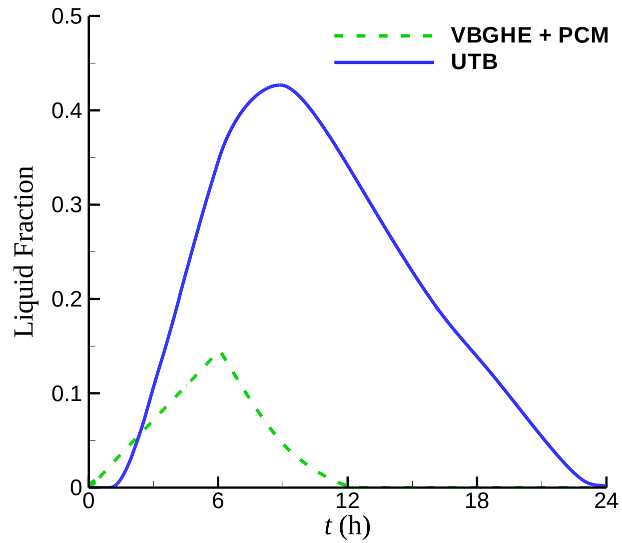
UTB outperforms conventional and PCM-enhanced VBGHEs in daily cooling operation

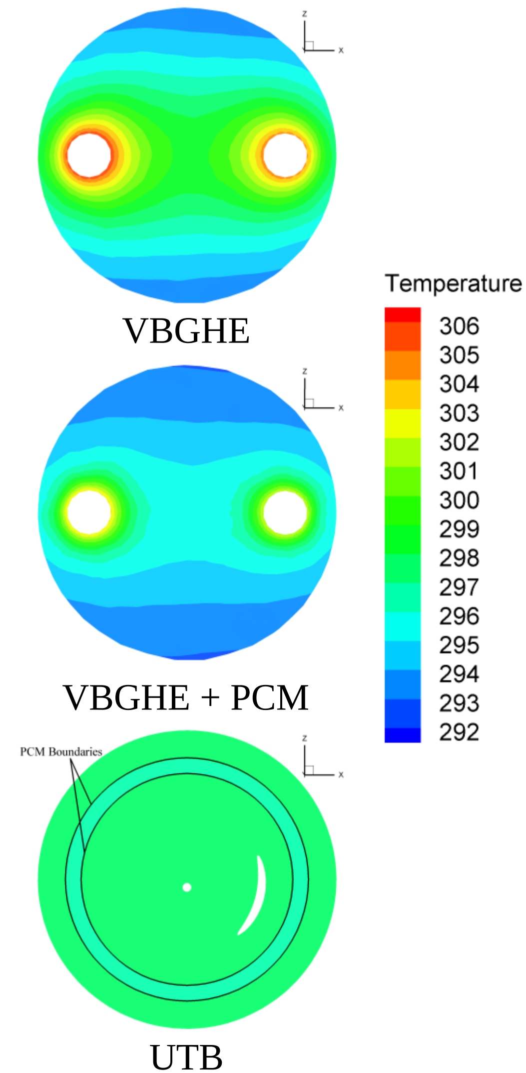




	Soil	Grout	PCM
λ (W/(m·K))	1.72	0.69	1.09(solid)/ 0.54(liquid)
c_p (J/kg/K)	2121	3106	3140
ρ (kg/m^3)	1900	1210	831
T_{melt} (K)	--	--	296
L (kJ/kg)	--	--	200



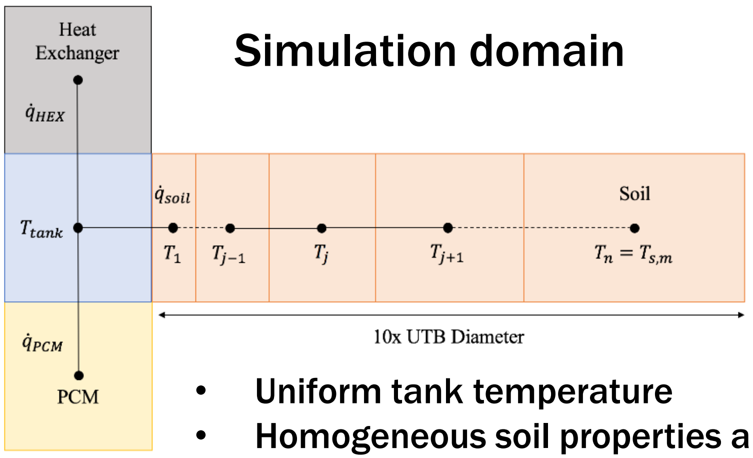




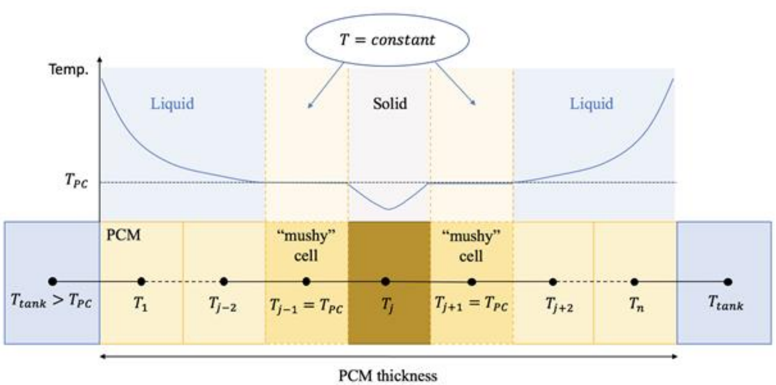
Progress: 1D Numerical Model of UTB

- **Model Development**

Simulation domain

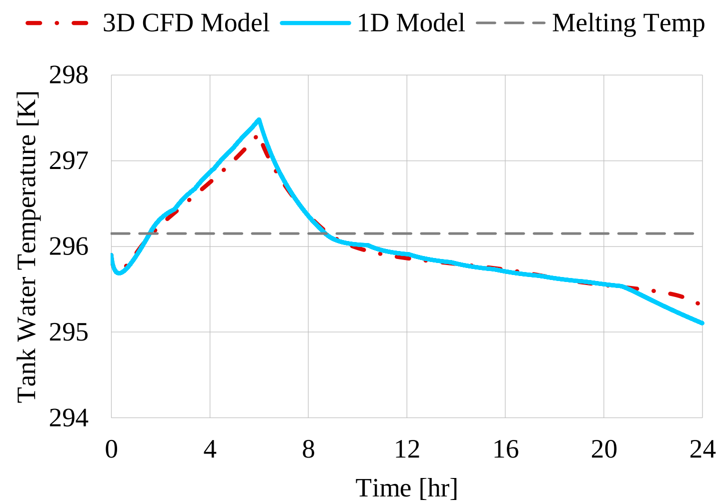


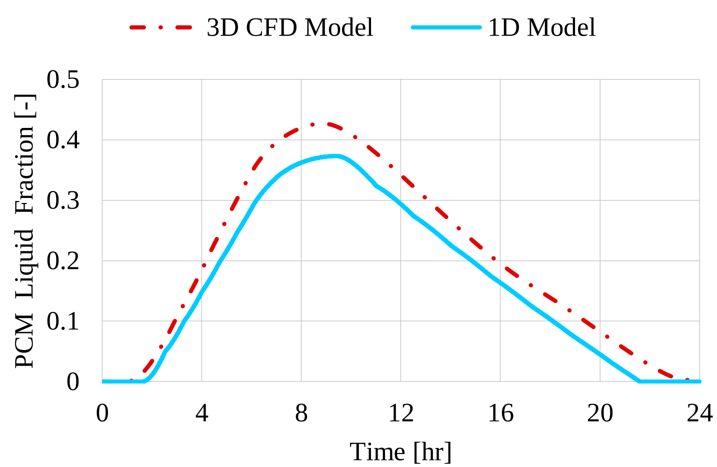
- Uniform tank temperature
- Homogeneous soil properties and uniform initial temperature



Modeling phase change process with moving boundaries and heat accumulation method

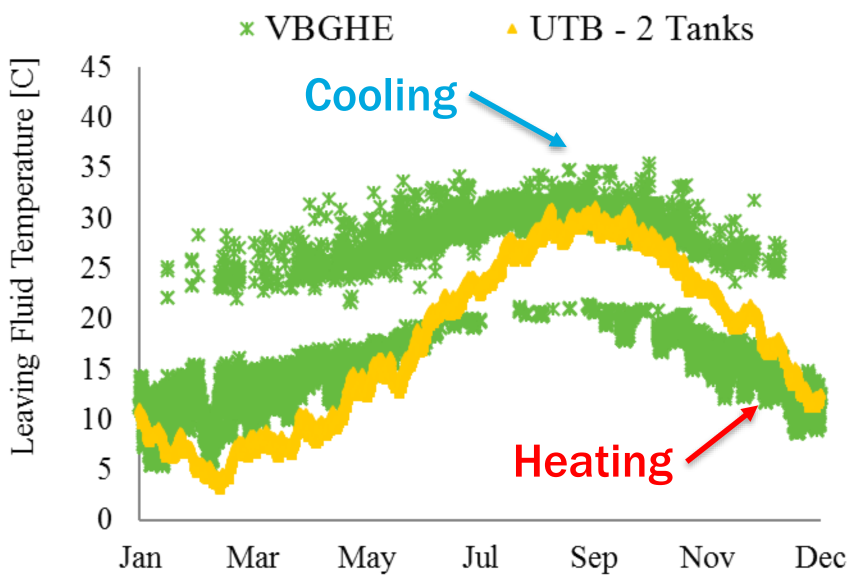
- **Validation with 3D model**



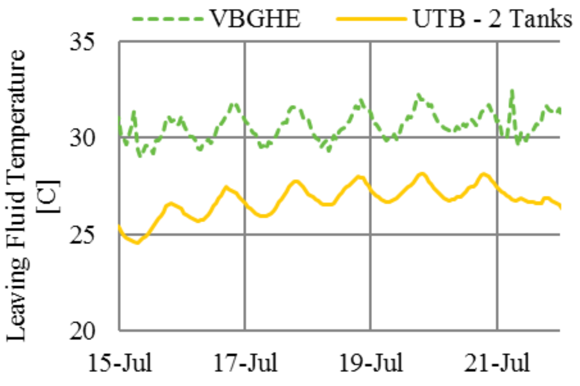


Progress: Long-Term Performance

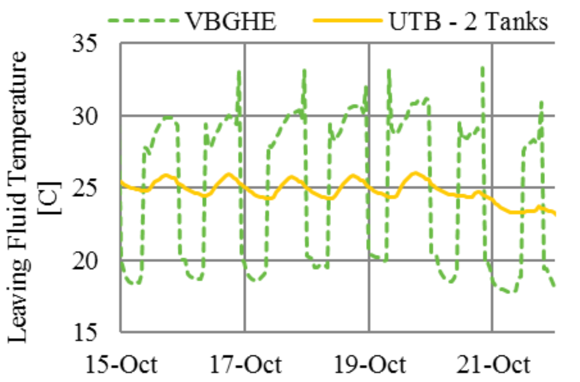
- A UTB with two tanks (20 ft long with 2.5 ft dia.) has similar performance to a 200 ft deep VBGHE during a year-long operation of a residential GSHP system in a mild climate



UTB provides favorable fluid temperature for more efficient operation of a GSHP



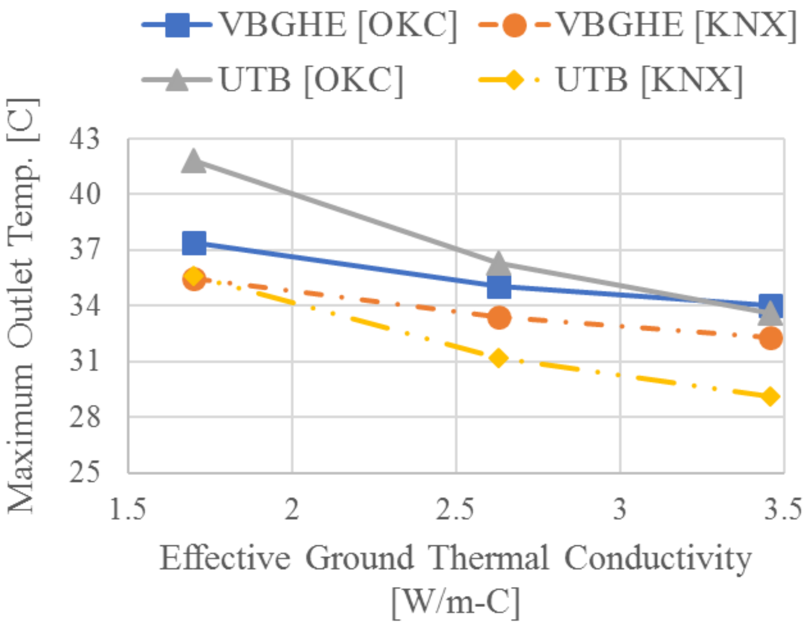
Cooler temperature in summer

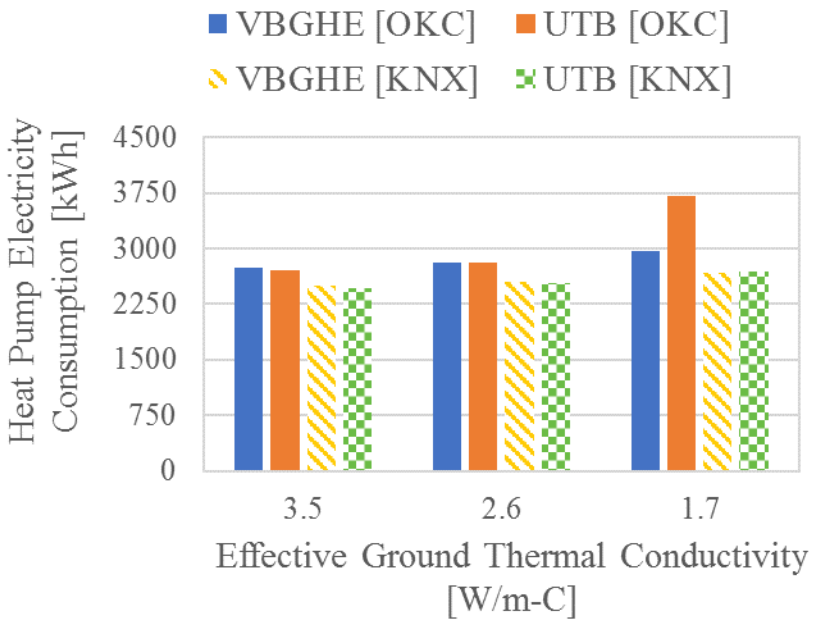


More stable temperature in fall

Progress: Long-Term Performance (Continued)

- **Parametric study of key design parameters**
  - Two building load profiles: high (OKC) and moderate (KNX)
  - Three ground thermal conductivities

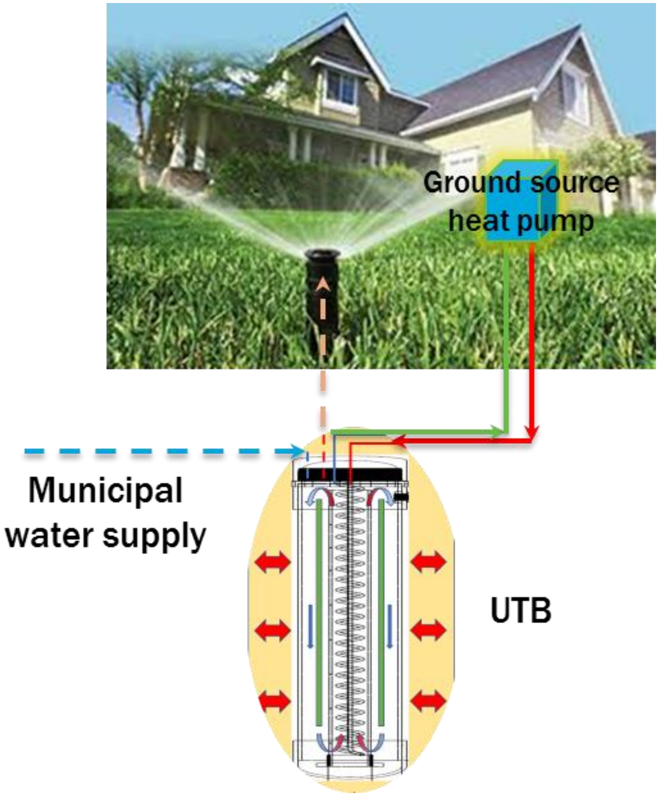


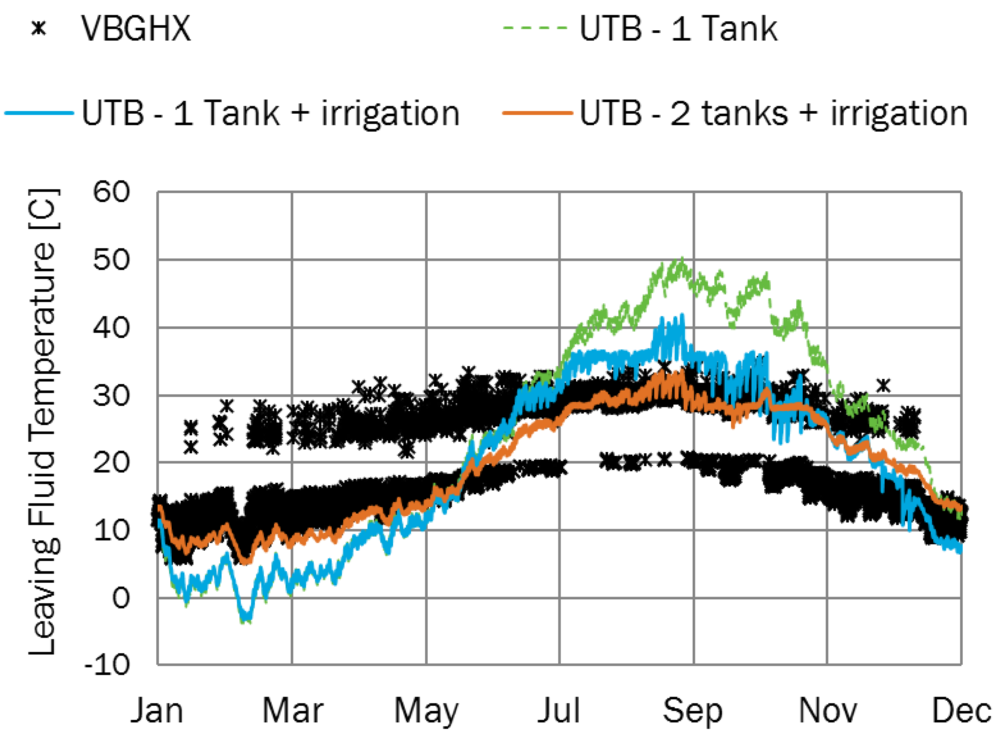


UTB works better with lower cooling load and higher ground thermal conductivity

Progress: Long-Term Performance (Continued)

- **Parametric study of key design parameters**
  - Configuration of UTB: one tank or two tanks
  - Integration with (pre-existing) lawn irrigation system





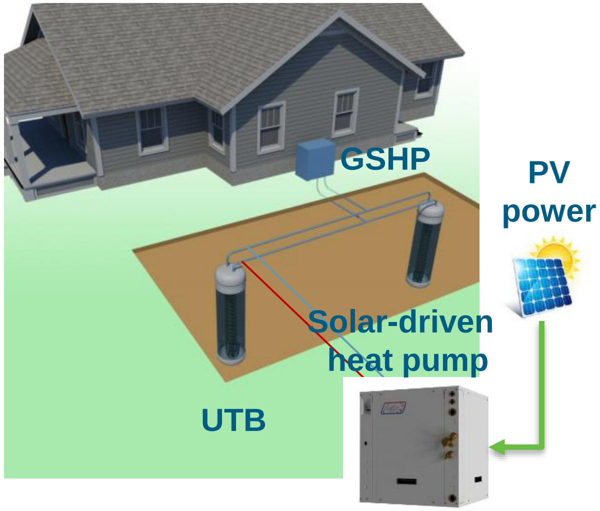
Impact

- Reduce GHE cost and enable wider adoption of GSHPs → **More energy savings and emission reduction**
- Enable flexible loads through built-in thermal energy storage → **Improved stability and resilience of electric grids**

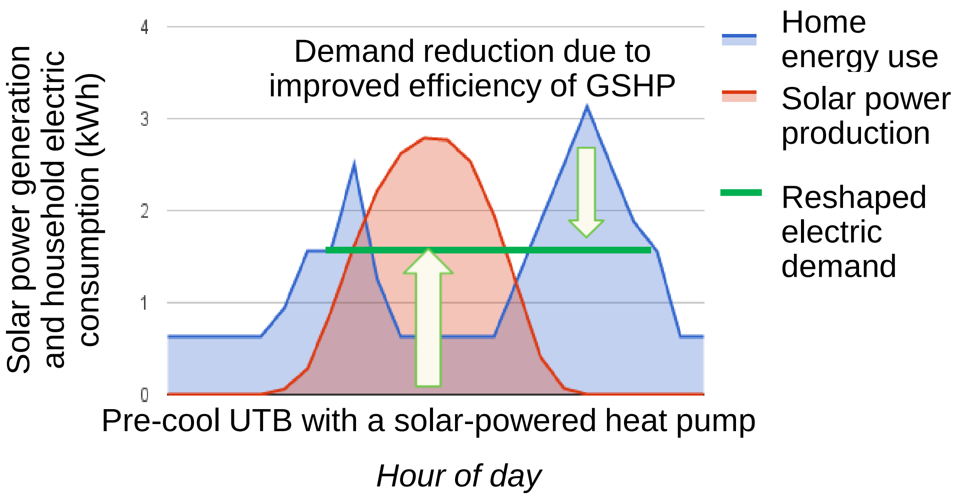
Technical Potential of GSHPs

	Annual Primary Energy Savings	Annual Carbon Emission Reductions	Annual Energy Cost Savings
	Quad Btu	Million Mt	Billion $
Residential	4.3	271.1	38.2
Commercial	1.3	85.2	11.6
Total	**5.6**	**356.3**	**49.8**

(Source: Liu et al. 2017)

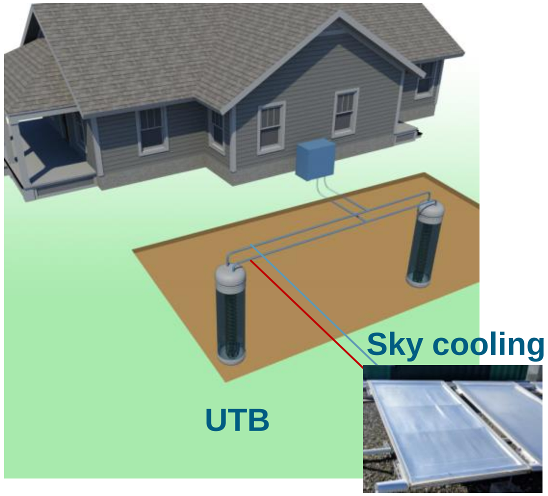


Overcome mismatch between intermittent renewable power supply and fluctuating thermal demands of buildings

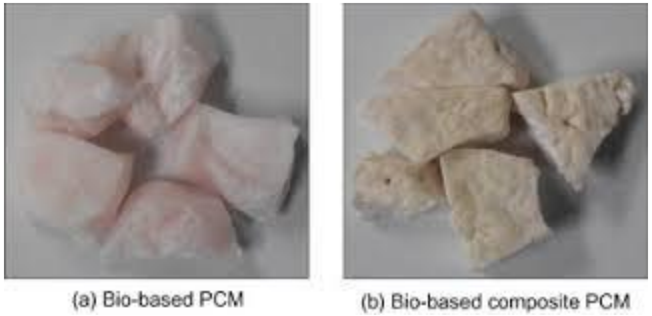


Stakeholder Engagement (Early-Stage)

- Introduce UTB to industry through publications (e.g., an article in the IEA HPT magazine)
- Develop a proposal to demonstrate UTB at a facility of US Department of Defense
- Engage with industry partners to improve UTB cost effectiveness
  - Hybridize with radiative cooling
  - Apply new low-cost PCMs



UTB integrated with a novel radiative cooling



Low-cost bio-based PCM

(**Source: Jeong et al.,** ***Int. Journal of Heat and Mass Transfer,*** **2014**)

Remaining Project Work

- **Improve 1D model (FY19)**
  - Account for seasonal variation of soil temperature in the shallow subsurface
- **Conduct lab tests to characterize performance of small-scale UTB (FY19)**
  - Characterize UTB performance in heating application
  - Evaluate impacts of improved integration of PCM
- **Perform cost analysis and improve UTB design to reduce cost (FY19)**
- **Publish results (FY19)**
  - Three papers submitted to various journals
    - A 3D Numerical Investigation of a Novel Shallow Bore Ground Heat Exchanger Integrated with Phase Change Material
    - A Numerical Investigation of the Long-term Performance of a Novel Shallow Bore Ground Heat Exchanger for Residential Ground Source Heat Pump Applications
    - Development of an Underground Thermal Battery for Enabling Ground Source Heat Pump Applications and Shaping Electric Demand of Buildings
  - Final ORNL report
- **Develop a full-scale UTB and procedures for installation (planned for FY20)**
- **Field test the full-scale UTB (planned for FY20)**

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: DOE $302K in FY18; DOE $208K in FY19
Variances: None
Cost to Date: Spent $346K (68% of project budget) by March 2019
Additional Funding: None

Budget History					
Oct. 1 – FY 2018 (past)		FY 2019 (current)		FY 2020 – (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$302K	0	$208K	0	0	0

Project Plan and Schedule

Project Schedule												
Project Start: 10/1/2017		Completed Work										
Projected End: 9/30/2019		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY2018				FY2019				FY2020			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
FY18 Q1 Milestone: Concept design of UTB												
FY18 Q2 Milestone: CFD model of UTB												
FY18 Q3 Milestone: Short-term performance evaluation through CFD simulations and lab-tests												
FY18 Q4 Milestone: Design of a full-scale prototype												
FY19 Q1 Milestone: Characterization of new PCMs												
FY19 Q2 Milestone: Long-term performance of UTB												
Current/Future Work												
FY19 Q3 Milestone: Performance of a lab-scale prototype UTB integrated with improved PCMs												
FY19 Q4 Milestone: Final report												