Comparative Analysis of HEATNETS for Geothermal Network Performance

Rebecca Barney[a], Juliet Simpson[a], Guangdong Zhu[a], Jeff Thornton[b], and Brian Urlaub[b]

[a]NREL, [b]Salas O'Brien

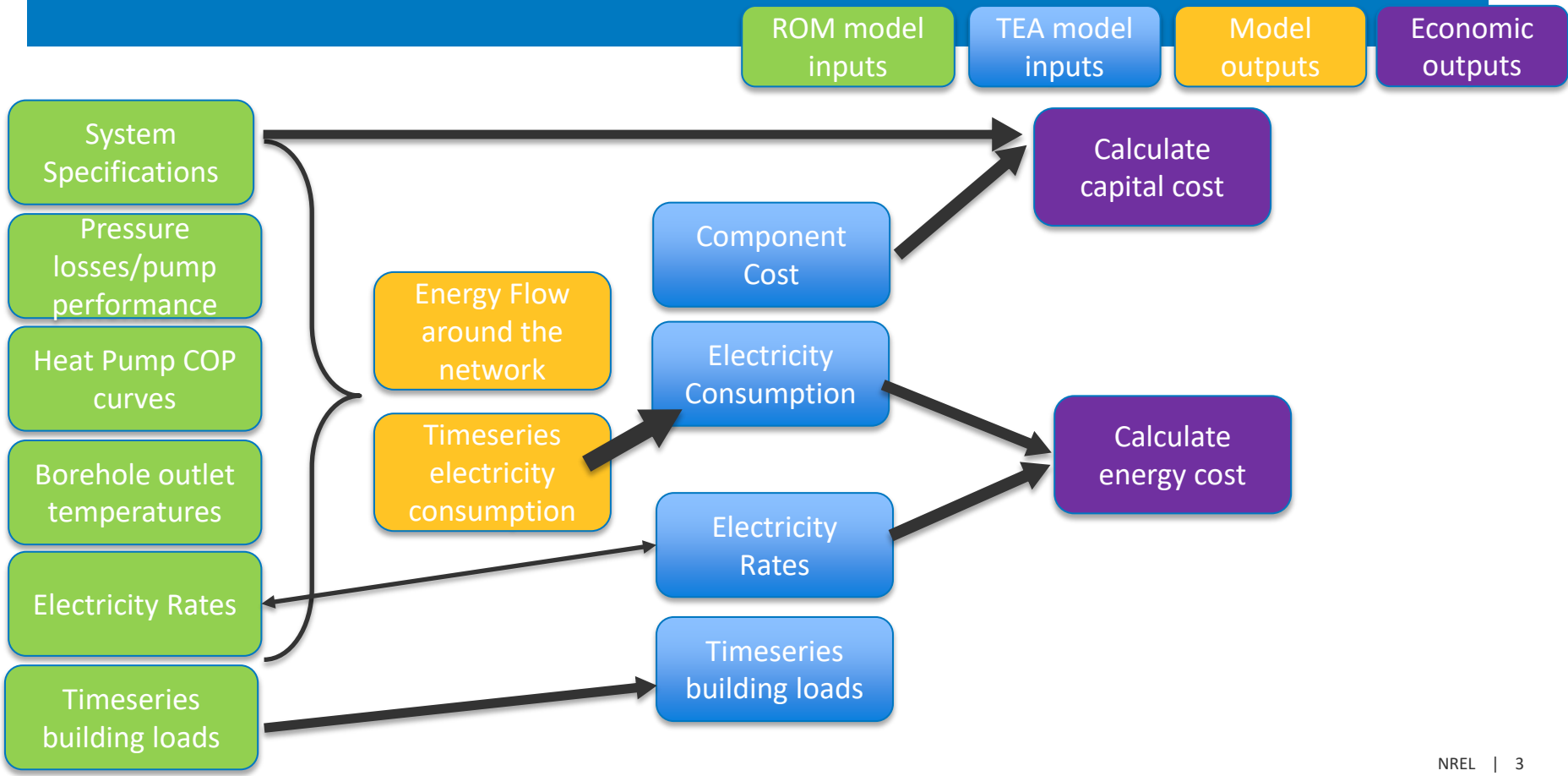
Stanford Geothermal Workshop
Palo Alto, California
02.10.2025 – 02.12.2025

HEATNETS overview

Heat and **E**conomic **A**nalysis **T**ool for **NE**tworked **T**hermal **S**ystems

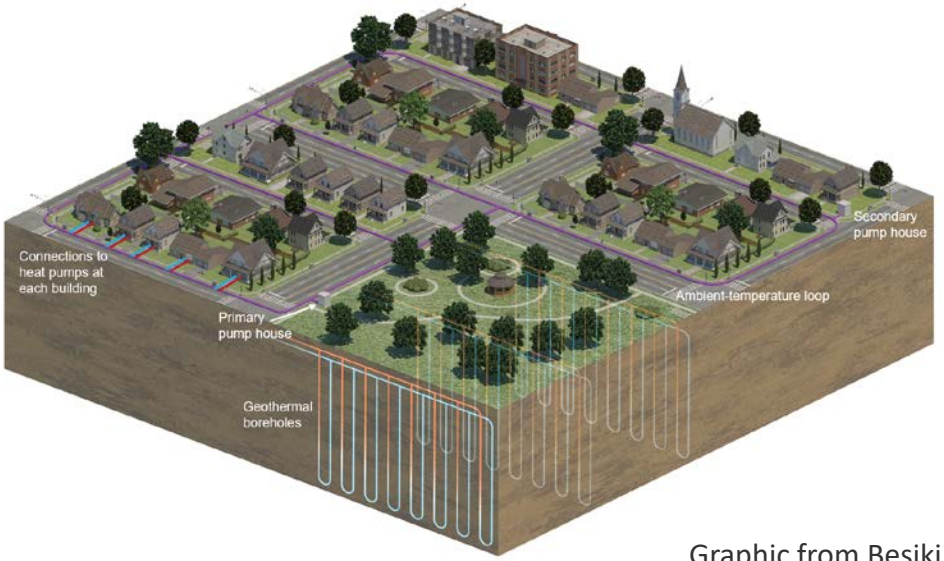
- Python-based, open-source, reduced-order model
- Simulates a single pipe 5G district energy system (DES) (thermal energy network, TEN)
- Combines physics-based reduced order model and a cost estimating and economic analysis model to do a full techno-economic analysis of TENs
- Focused on thermal loop and thermal sources, is not suited for detailed design, but can be used to compare design and operation options
- Work is produced by NREL as a part of the LeGUp project

Flow diagram for HEATNETS



Learning from the Ground Up (LeGUp) project

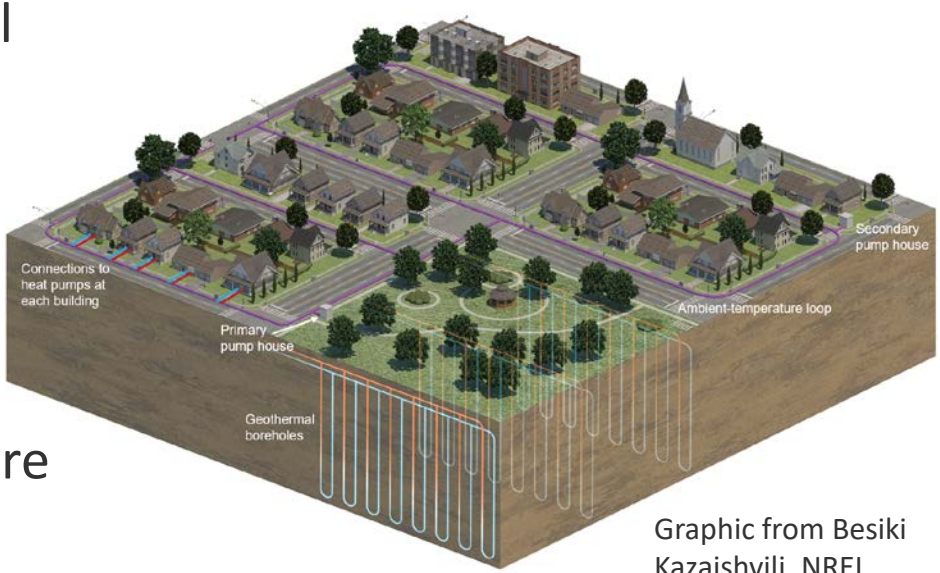
- Led by the Home Energy Efficiency Team (HEET)
  - Non-profit based in Massachusetts
- Studying one of the first utility-scale pilot geothermal networks
- It is utility-led community retrofit project



Graphic from Besiki Kazaishvili, NREL. Simpson, et al. *GRC Transactions,* 2024.

NREL's role in HEET's LeGUp project

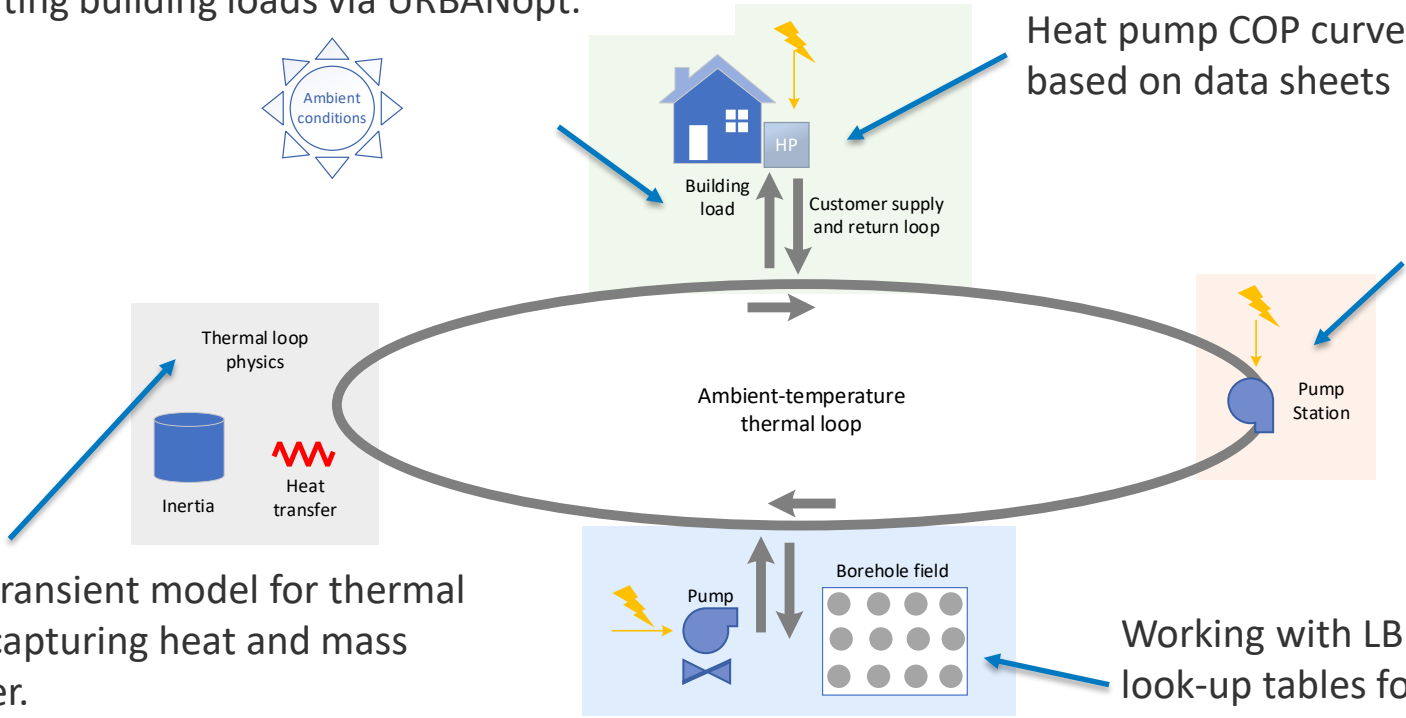
- Create a reduced-order model for fast simulation of the geothermal thermal energy networks for heating and cooling
- Create a techno-economic model to understand the economic viability of different designs
- Simulate the pilot installations
- Optimize system operation and explore alternative designs
- Consider grid impact



Graphic from Besiki Kazaishvili, NREL. Simpson, et al. *GRC Transactions,* 2024.

Reduced-order model

Estimating building loads via URBANopt.



Heat pump COP curve based on data sheets

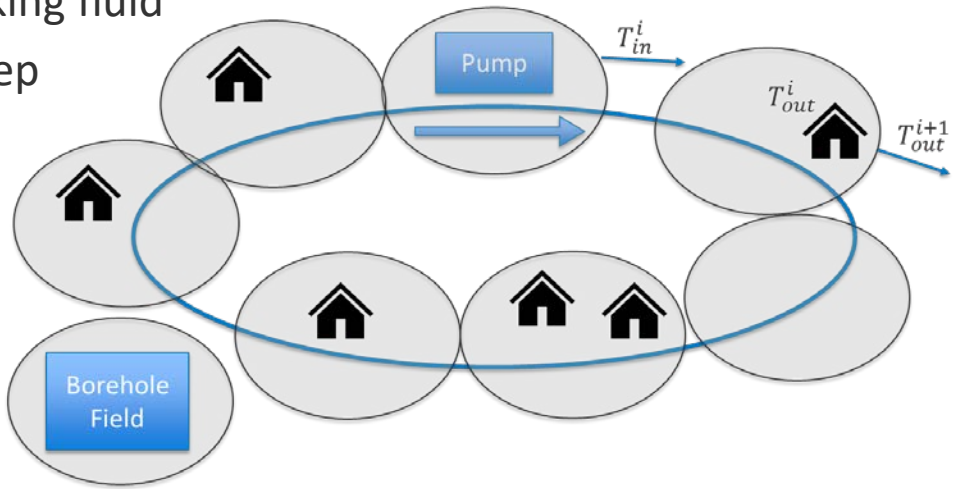
Circulation pump flow rate, bounded by installed pump sizes

Semi-transient model for thermal loop, capturing heat and mass transfer.

Working with LBNL to create look-up tables for borehole fields

ROM divides loop into sections for thermal analysis

- For each **hourly** timestep (*i*):
  - Set loop flow rate and auxiliary heating (if used/needed)
  - Subdivide into smaller timesteps based on loop flow rate
  - Calculate heat and mass balance for sections, accounting for thermal inertia within the loop and flow of working fluid
  - Save results on an hourly timestep
- Post-process data



Simplified calculations

$$Q = \dot{m} C_p (T_{in} - T_{out})$$

Inputs to ROM

Building loads, Q

Mass flow rates, $\dot{m}$

Inlet borehole temperature, T

Assumed pump efficiencies, and HP COPs

Estimate building outlet temperature

$$T_{out} = T_{in} - \frac{Q}{\dot{m} C_p}$$

Estimate outlet borehole temp. using regression model

$$T_{out} = f(T_{in}, T_{ground}, \dot{m})$$

Estimate pressure losses, pumping power, and COPs

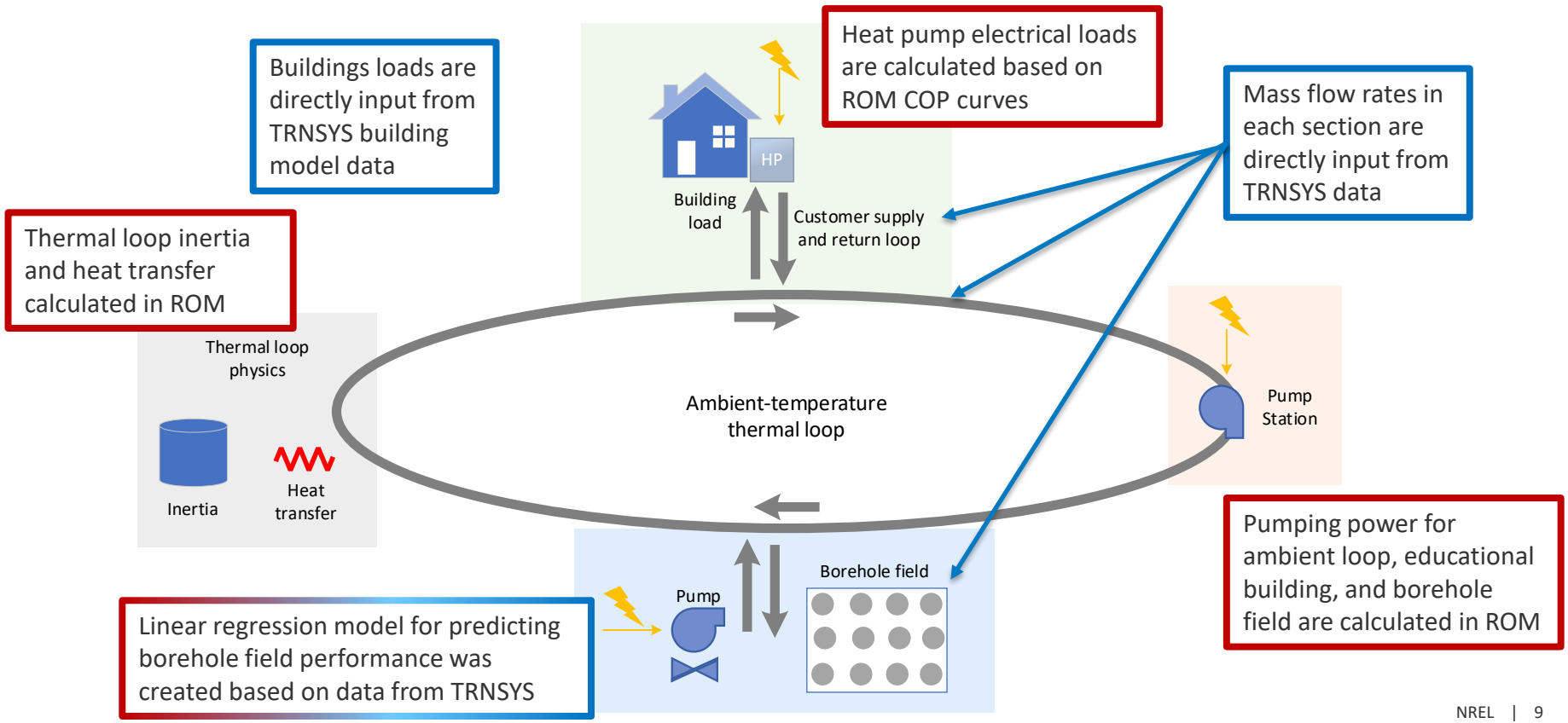
$$\Delta P = \frac{f \rho L V^2}{2D} + \sum K \frac{\rho V^2}{2D}$$

$$P_{eff} = \frac{\dot{V} \Delta P}{\eta}$$

$Q = energy\ loads$
$\dot{m} = mass\ flow\ rate$
$T = temperatures$
$f = friction\ factor$
$L = length\ (of\ pipe)$
$V = velocity$

$D = diameter\ (of\ pipe)$
$\rho = density\ of\ fluid$
$K = minor\ loss\ factor$
$\dot{V} = volume\ flow\ rate$
$P = pressure$
$\eta = efficiency$

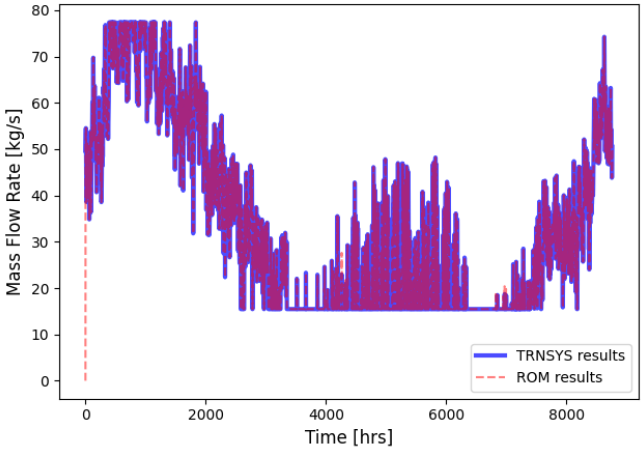
Reduced-order model, integrated with TRNSYS data



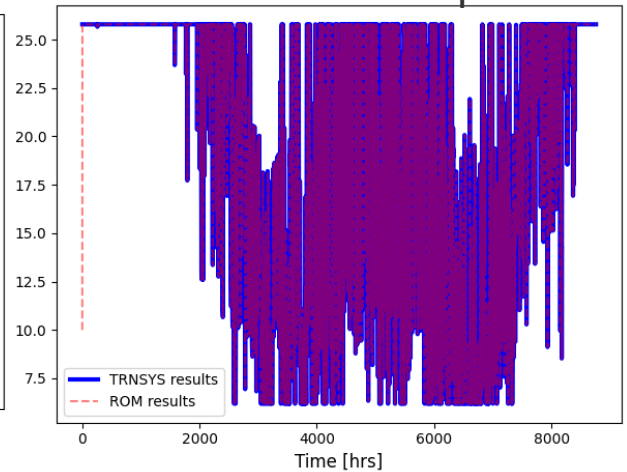
Initial comparison results

Comparing Mass Flow Rates

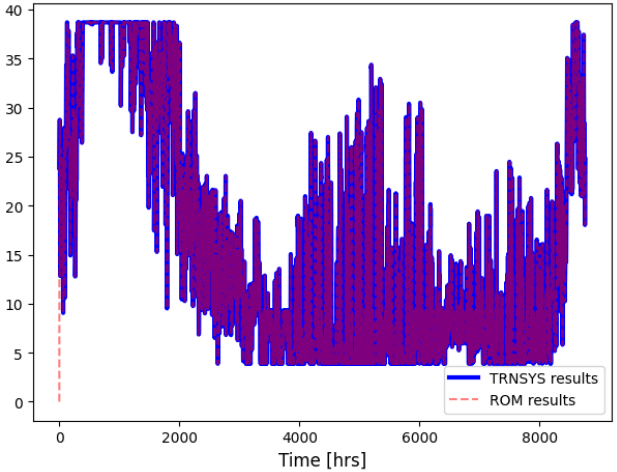
Borehole Loop



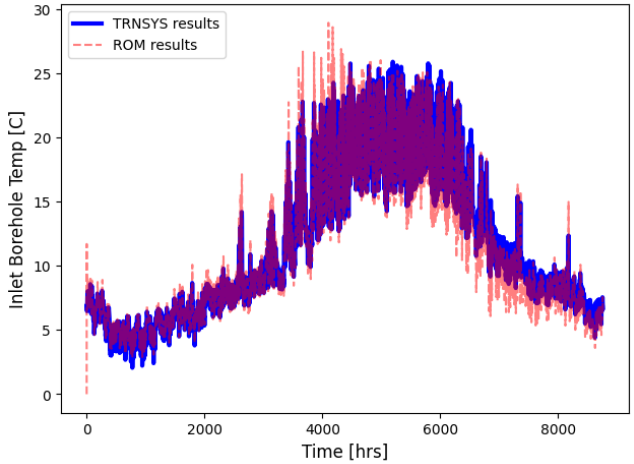
Ambient Loop

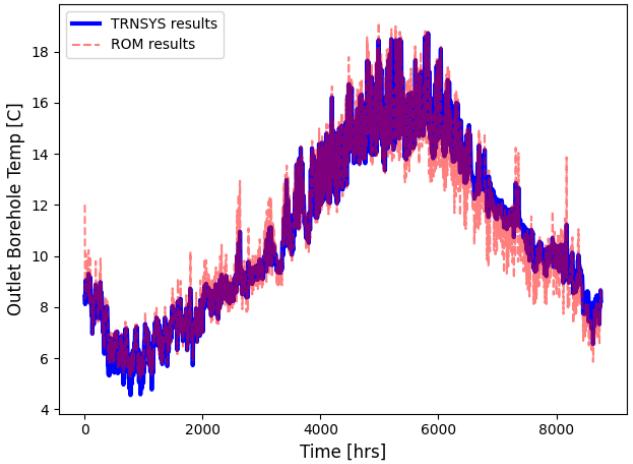


Educational Building

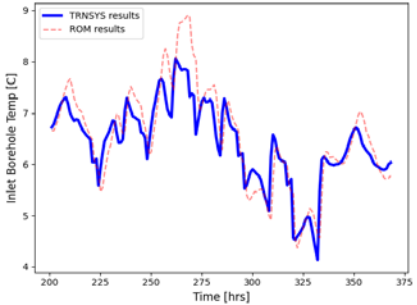


Borehole temperature data analysis: Using Regression Model

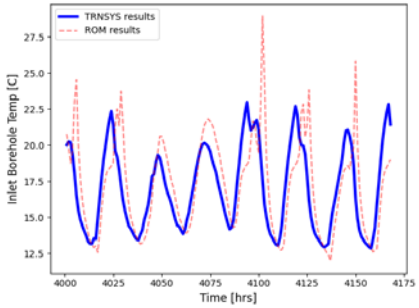




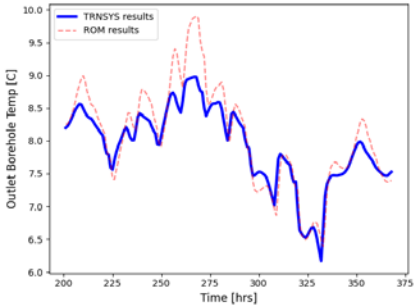
Winter week



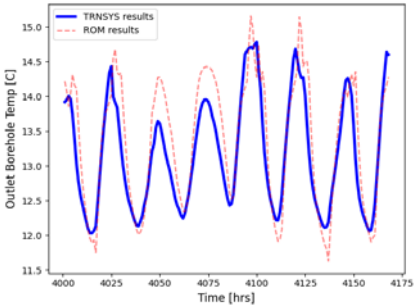
Summer week



Winter week



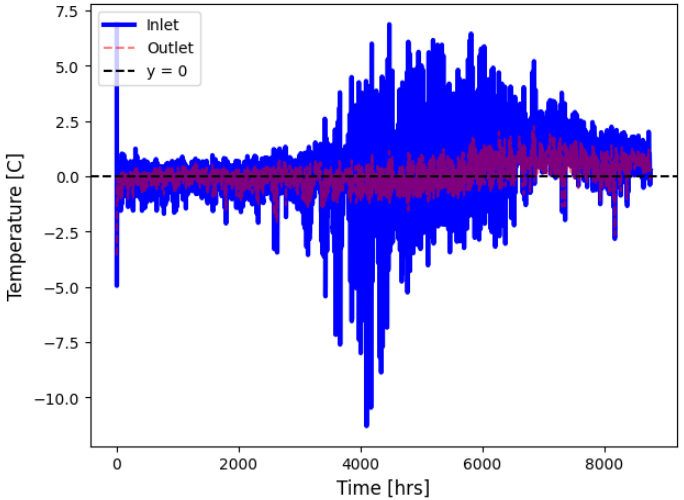
Summer week



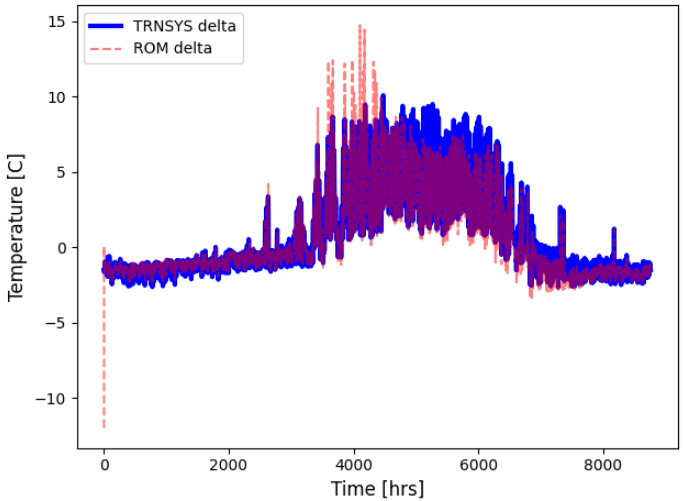
Borehole temperature data analysis

Mean Temps	ROM	TRNSYS	MSE
Inlet [C]	11.31	11.591	1.53
Outlet [C]	10.82	10.91	0.288

TRNSYS model minus the ROM model

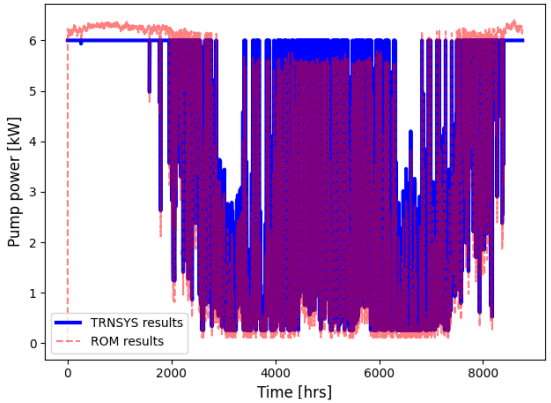


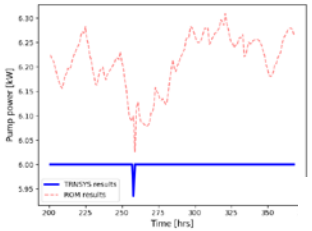
Temperature deltas



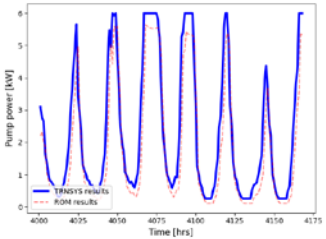
Comparing Pump Energy Columns

Ambient Loop



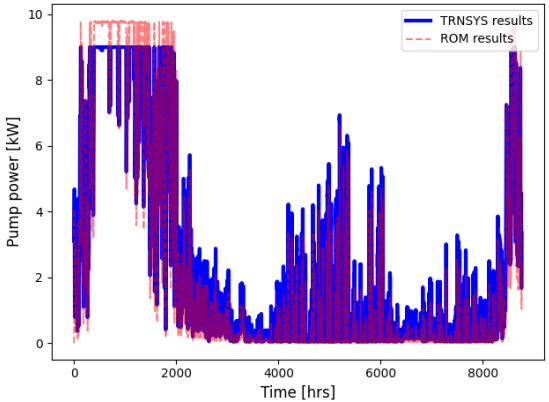


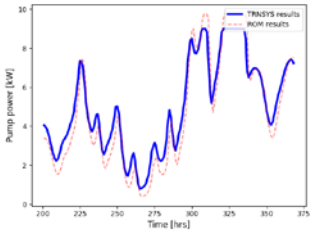
Winter week



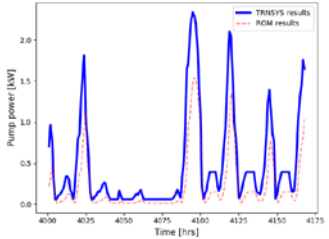
Summer week

Educational Building



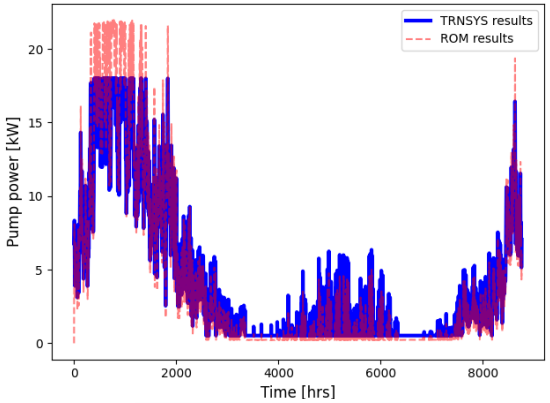


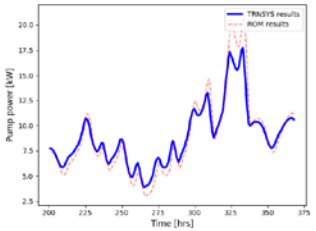
Winter week



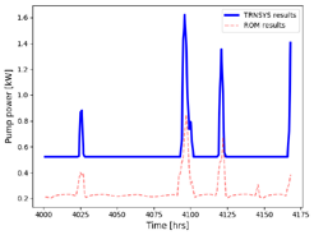
Summer week

Borehole Loop





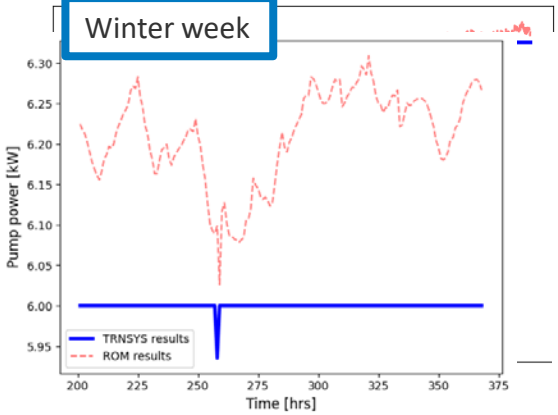
Winter week



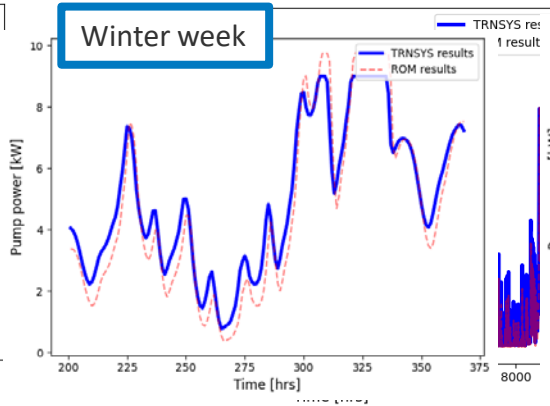
Summer week

Comparing Pump Energy Columns

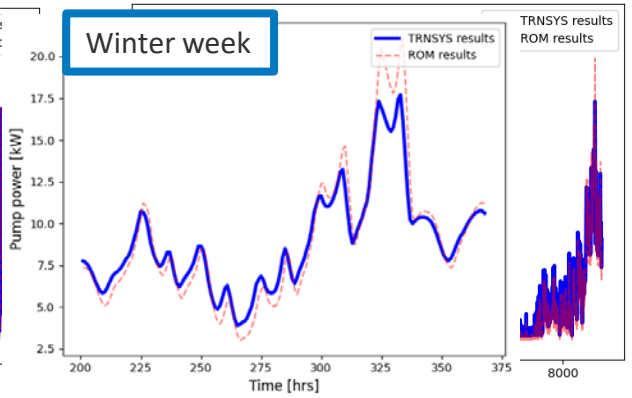
Ambient Loop

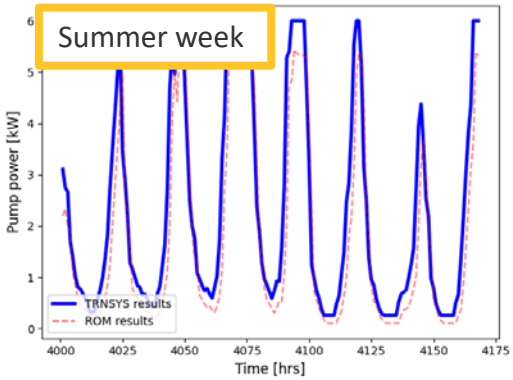


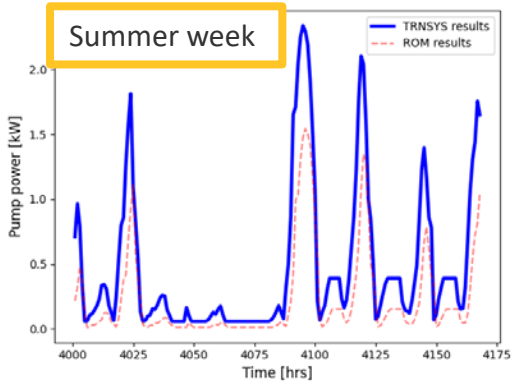
Educational Building

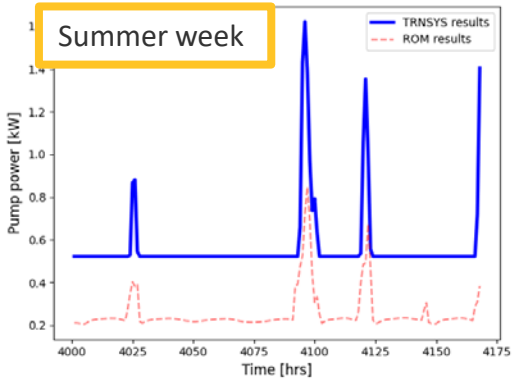


Borehole Loop



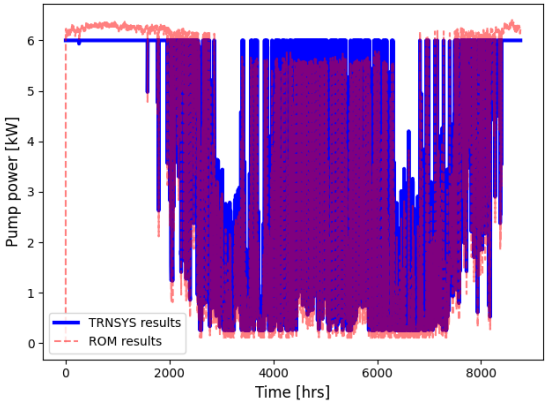




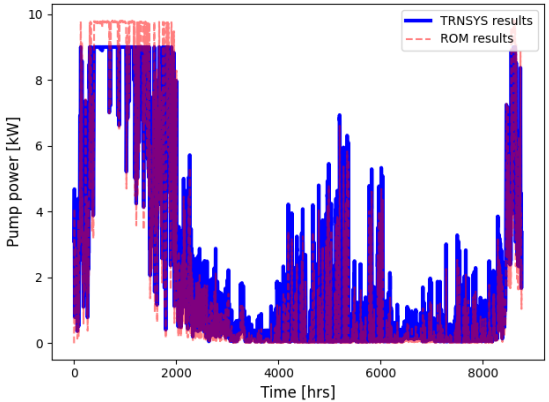


Comparing Pump Energy Columns

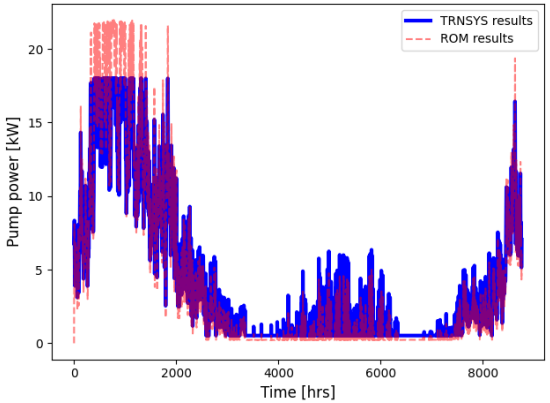
Ambient Loop



Educational Building

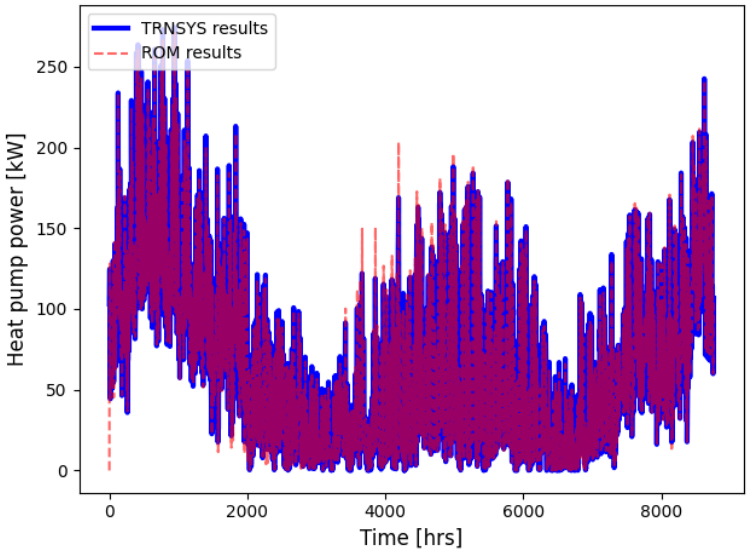


Borehole Loop

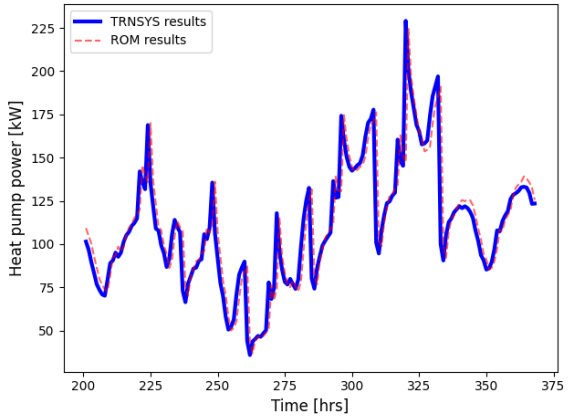


Pump	Percent Difference
Ambient Pump	4.8%
Educational Building Pump	8.4%
GHX Pump	2.4%

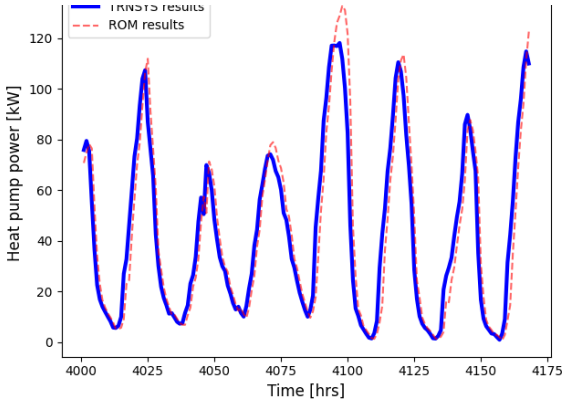
Comparing total heat pump power



Winter week



Summer week



Total Annual TRNSYS HP loads: 553, 800 kW
Total Annual ROM HP loads: 549,674 kW
% error from TRNSYS: 0.7%

System & Seasonal COP

$$COP_{system} = \frac{Total\ building\ loads\ met}{Total\ electrical\ loads\ (HPs + pumps)}$$

$$COP_{system} = \frac{\sum|building\ loads|}{\sum elec\ loads}$$

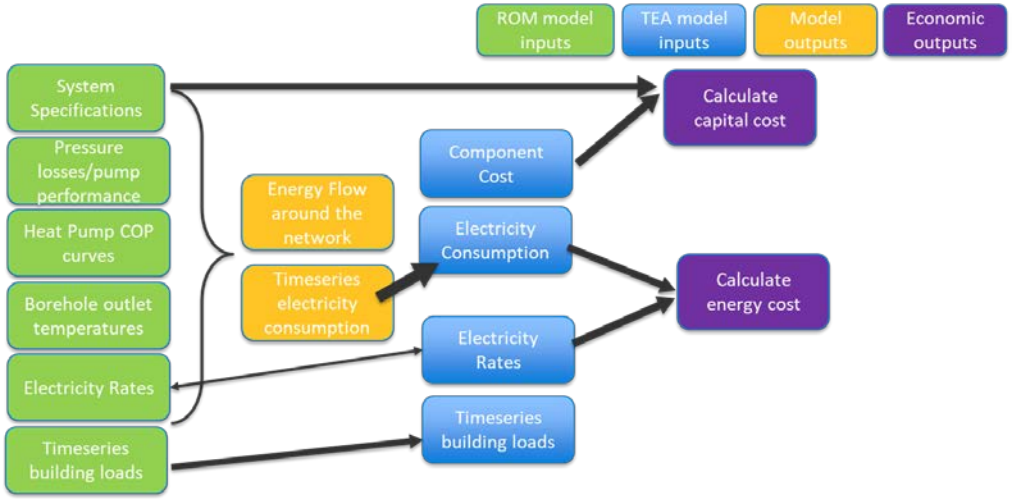
Season	ROM COP	TRNSYS COP
Spring	4.2	3.9
Summer	5.0	4.7
Fall	4.0	4.0
Winter	3.3	3.3
Total	**3.87**	**3.82**

Conclusions

- ROM can take in hourly data and produce results that closely match the TRNSYS modeling results
  - Heat pump electrical loads are closely matched
  - Pump energy consumption has a low error
  - Borehole flow temperatures show some variation
  - System COP is reasonable estimate, and with improved pump curves, may be improved
- The ROM is intended to be an opensource model alternative and shows benefits as more TENs are built for considering initial design tradeoffs & economics (TEA) quickly
- Improvements, such as pressure drop calculations, were made to the ROM model from the comparison

Future work for ROM generally

- Update pump efficiency curves
- Update pressure losses as they become known
- Continue investigating borehole heat transfer
- Integrate the ROM with the economic model & complete parameter studies



Thank you! Questions?

This work was authored by NREL for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Support for the work was provided by the Home Energy Efficiency Team (HEET) under FIA-22-23124, supported by a grant from the Massachusetts Clean Energy Center (MassCEC) to HEET entitled: Learning from the Ground Up (LeGUp). The views expressed herein do not necessarily represent the views of the DOE, the U.S. Government, or MassCEC. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

The authors would like to acknowledge the contribution of Isabel Varela, Eric Juma, Angie Alberto Escobar, Zeyneb Magavi, Mark Kleinginna, and others at HEET, as well as the contribution of Brian Urlaub and Megan Oelze at Salas O'Brien.

NREL/PR-5700-92871