Techno-economic modeling of GENs with HEATNETS model

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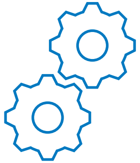
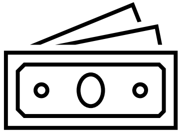
Techno-economic modeling

Technical **+** **Economic**





- Techno-economic analysis (TEA)
- Consider trade-offs between technical design and operation vs the economic impact

Modeling can answer questions like…

Before design and build:

- Does a GEN make sense in this community?
- Use only geothermal boreholes? Or a combination of thermal sources?
- What monthly payment required from customers?

After build:

- Can we add one more house to the loop?
- Will the system efficiency improve if we lower the set temperature?

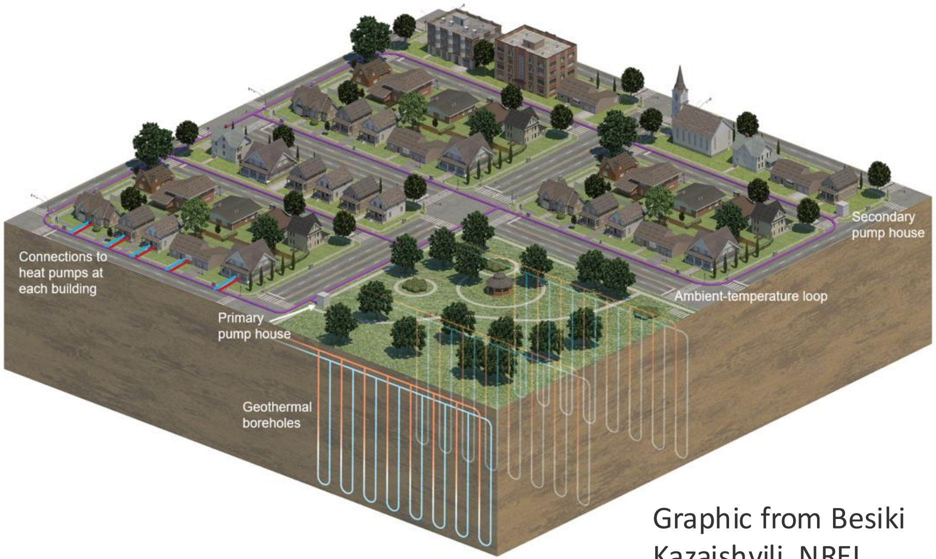
Important components to consider for modeling GENs

- Physical system
  - Building loads
  - Thermal resources (boreholes, etc.)
  - Distribution system (thermal inertia, working fluid composition, etc.)
  - Heat pump
- Economics
  - Capital cost
  - Operational cost
  - Maintenance
  - Cost recovery plan (Debt, IRR, customer payments)

HEATNETS model

Heat and Economic Analysis Tool for NEtworked Thermal Systems

- Two parts, written in Python:
  - Physics-based reduced-order model to capture flow of energy around the network and use of electricity over time
  - Economic model to estimate capital cost and calculate economic metrics



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

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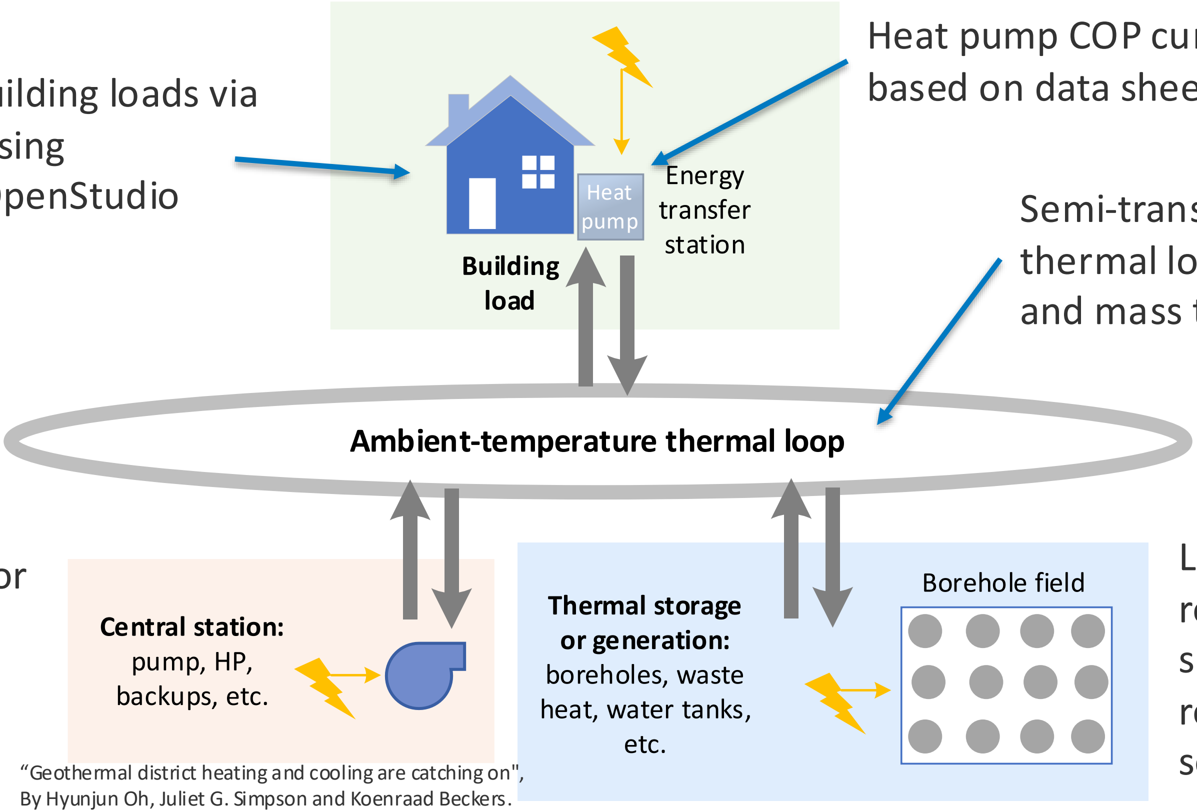
Reduced-order model for physics-based simulation

Estimating building loads via URBANopt, using EnergyPlus/OpenStudio

Heat pump COP curve based on data sheets

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



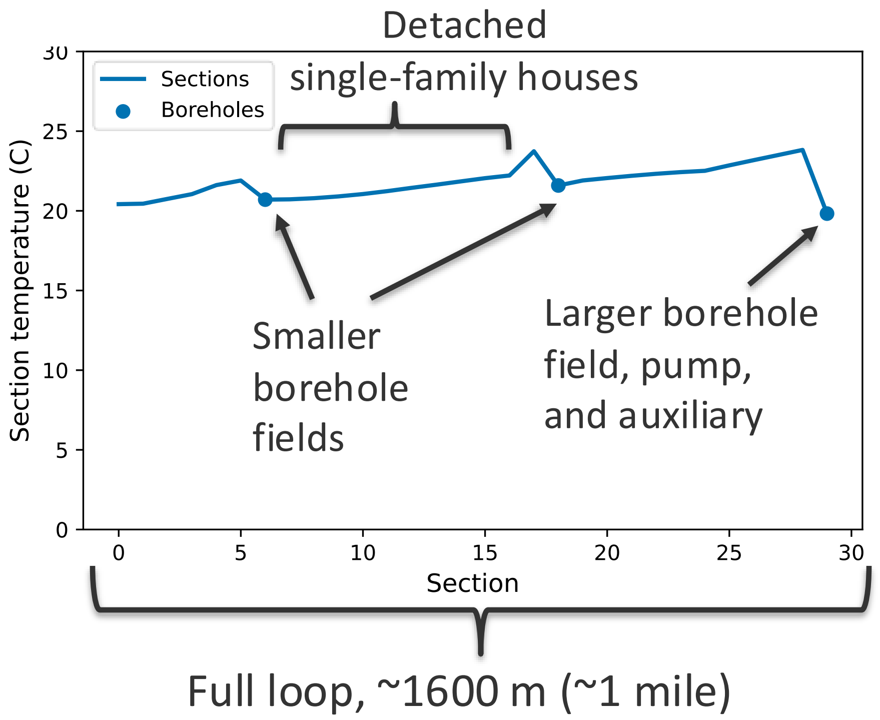
Simple relations for circulation pump, auxiliary heating and cooling, and control decisions

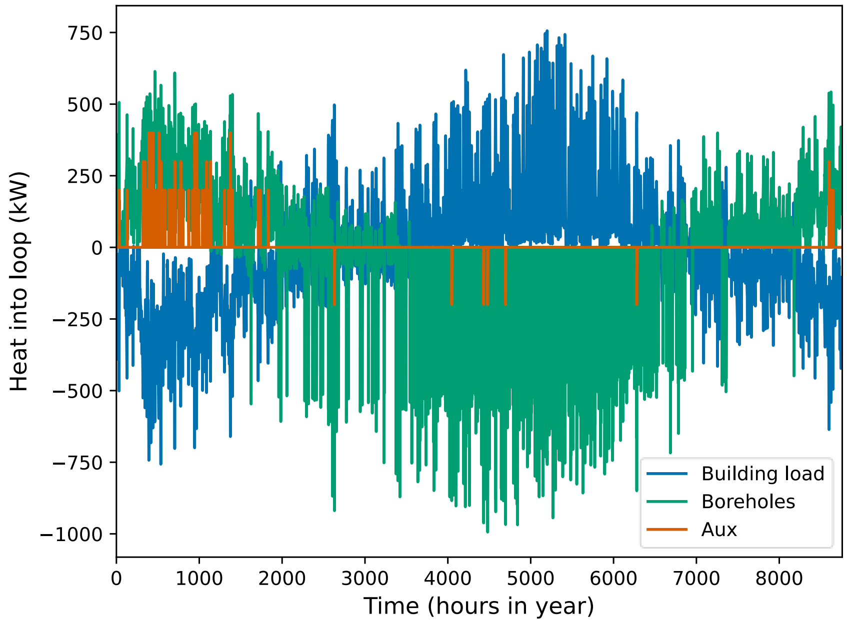
Look-up tables, regressions, or simple models to represent thermal sources

“Geothermal district heating and cooling are catching on”, By Hyunjun Oh, Juliet G. Simpson and Koenraad Beckers.

Oh et al. *District Energy Magazine*, 2024.

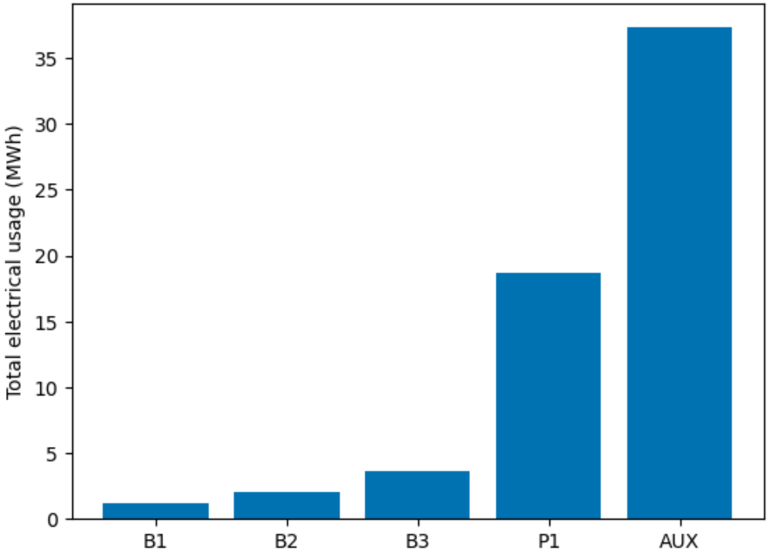
Example results: spatial and temporal trends



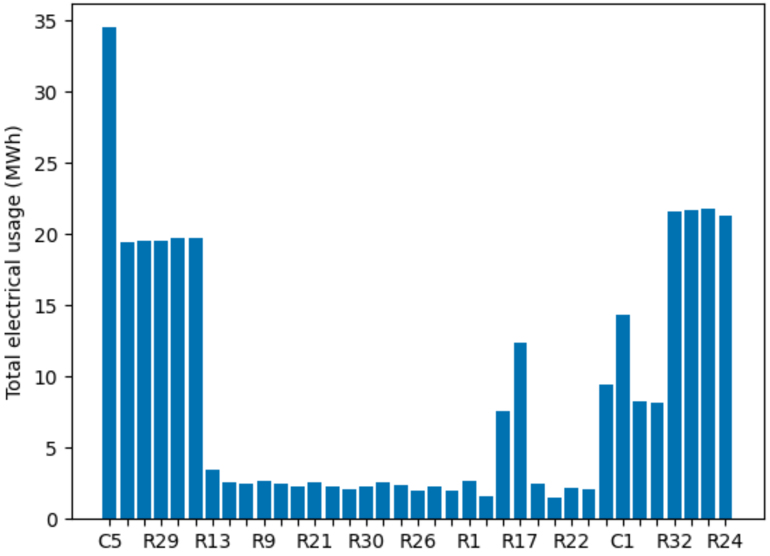


Modeled results are subject to ongoing development.

Example results: annual energy usage



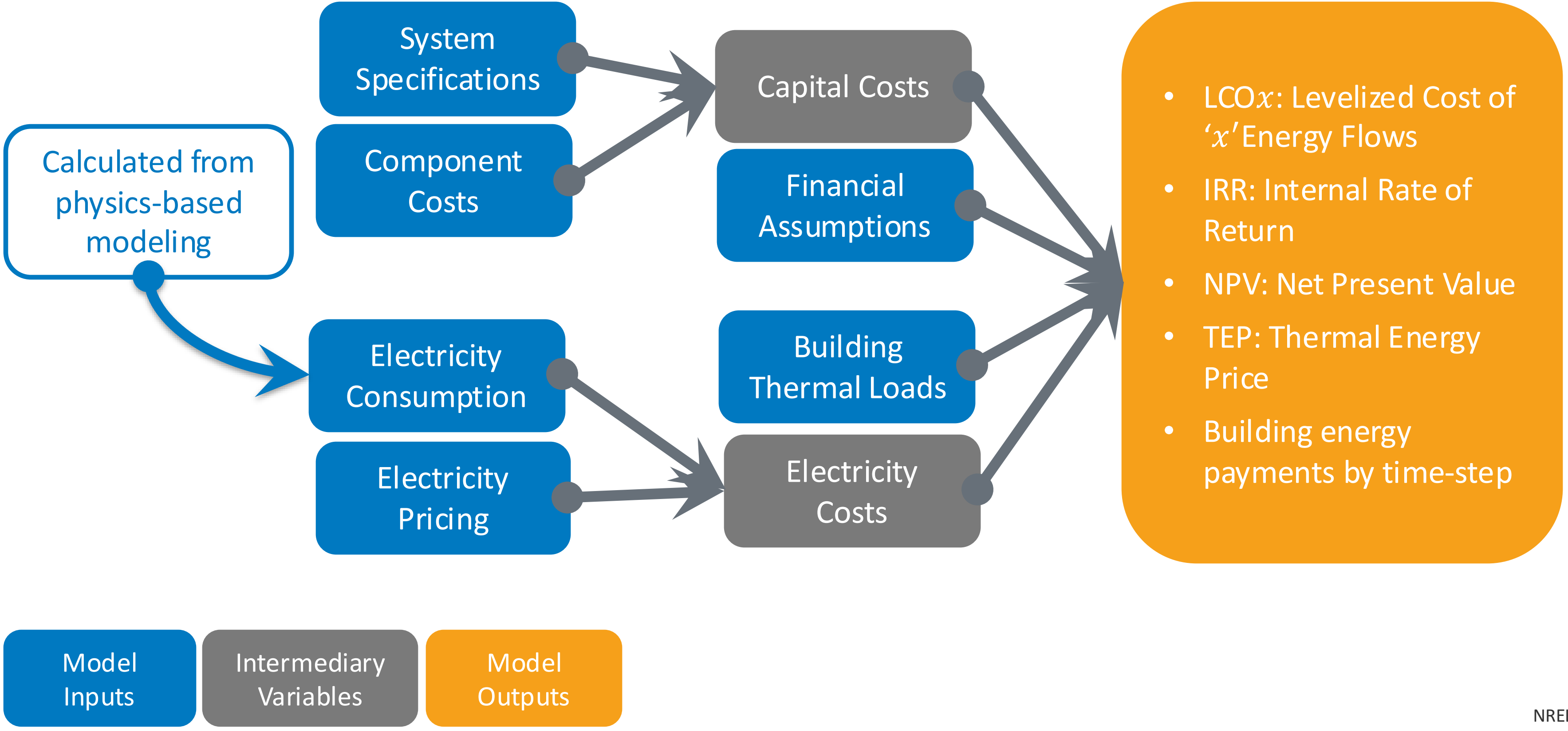
Utility components:
Borehole fields (B), Circulation pump (P), auxiliary heating/cooling (AUX)



Buildings, in order around the loop:
Commercial (C) and Residential (R)

Modeled results are subject to ongoing development.

Economic model



Capital cost +
Cost of Electricity to
Operate System

$$LCOx = \frac{Lifetime\ costs}{Lifetime\ energy\ produced} = \frac{\sum_{n=1}^{N} \frac{Revenue_{required,n}}{(1+d_{nominal})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{real})^n}}$$

Geothermal
Heating/Cooling

LCOx Base Equation

- Levelized cost of 'x' Energy Flows
- Builds off a standard LCOE equation
- Modified to fit our system's needs via "required revenue"
- Thermal Energy Price (TEP) calculation wrapped into the LCOx calculation

HEATNETS Economic Model Inputs

Input Financial Assumptions.

Basic Cash Flow Model

- Capital Costs (Direct and Indirect)
- Operation and Maintenance Costs
- Target Internal Rate of Return (IRR)
- And more…

Tax and Insurance

- Federal and State Tax
- Sales Tax
- Property Tax

Project Term Debt

Tax Credits

- Federal and State Tax Credits

Intermediary Variables Calculated from Thermal Loads.

From physics-based modeling

- Hourly Thermal Load (kWh), by component
- Hourly Electricity Usage, by component

HEATNETS Economic Model: Sample Outputs

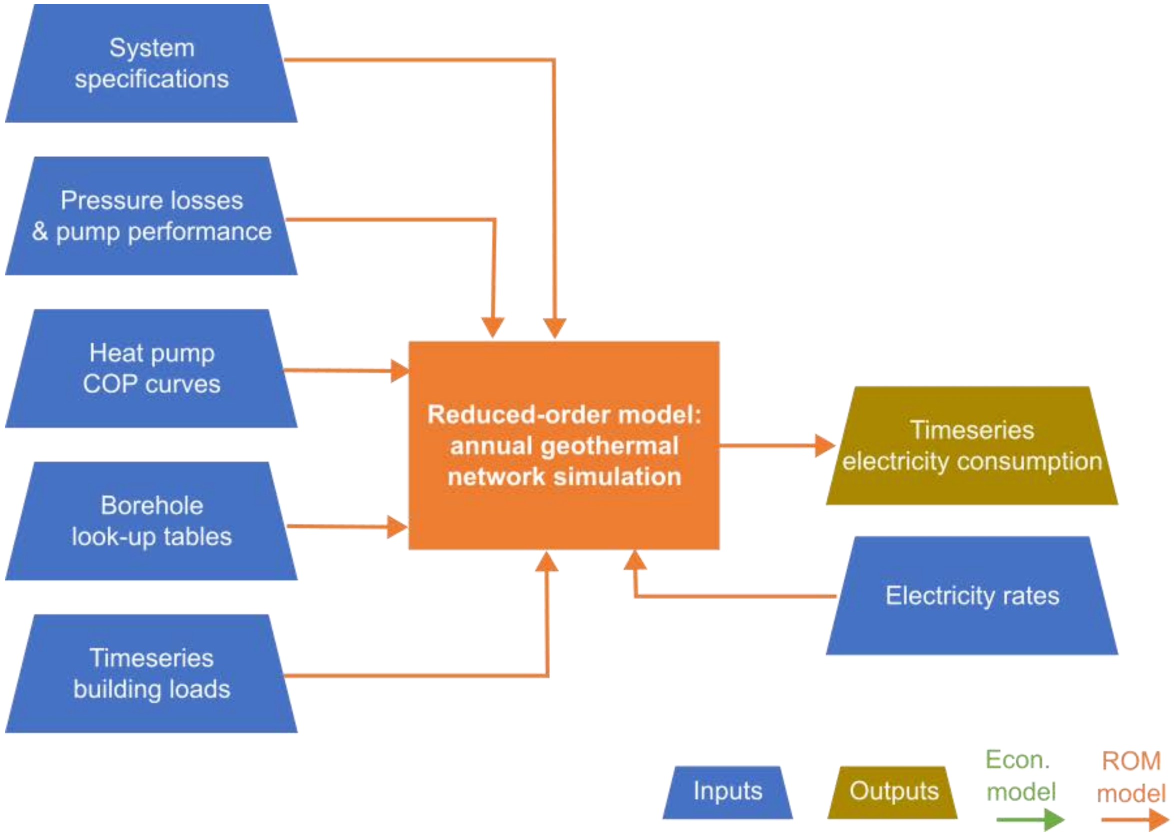
Example output for a single-family home

Annual Energy Consumption (kWh)	**Annual Payment in Year 1** ($)	**Monthly Payment in Year 1** ($)	**Daily Payment in Year 1** ($)
12,417	2,635.11	219.59	7.22

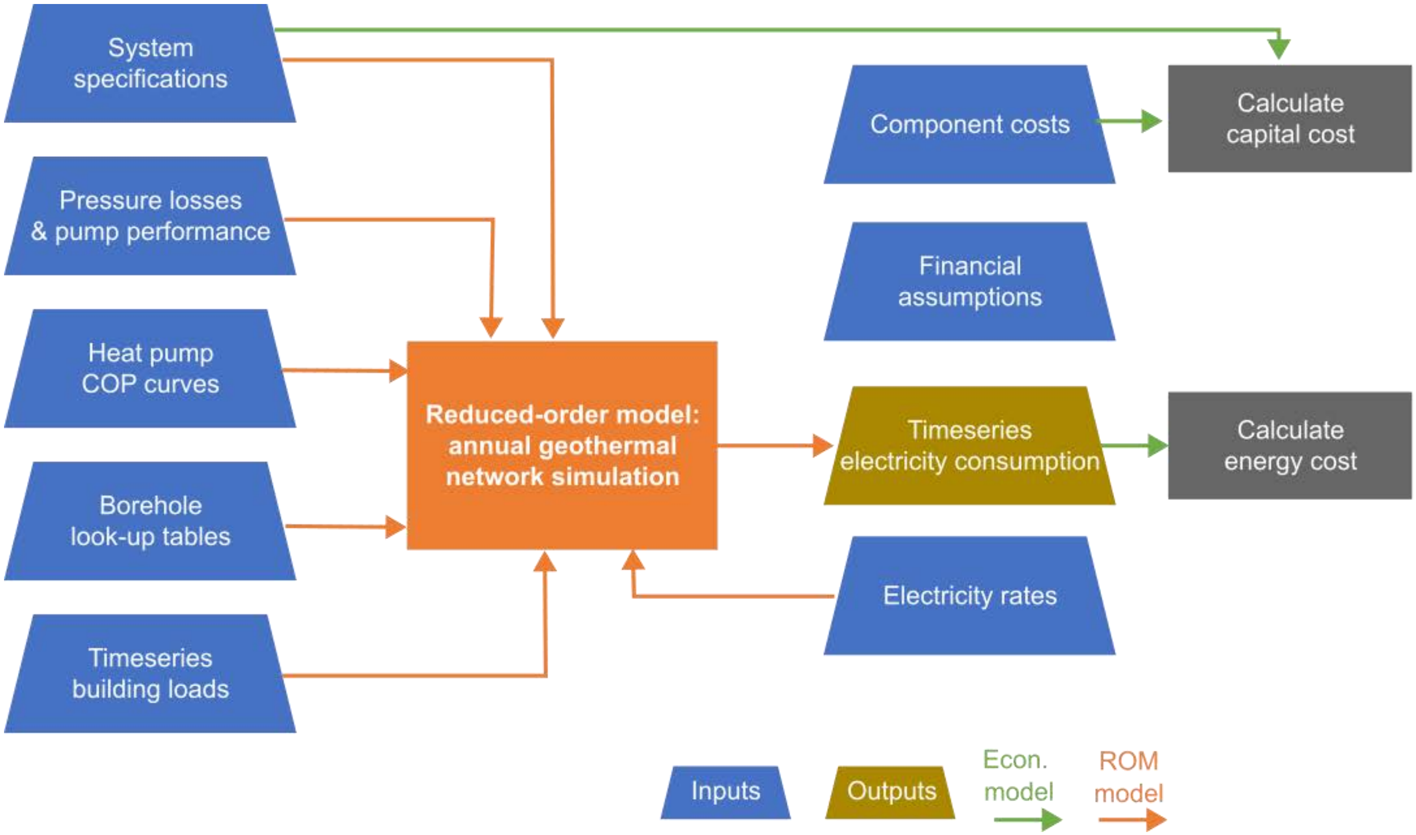
Supported Metrics:
- Financial Outputs
    - TEP price in Year 1 ($/kWh)
    - Nominal/Real LTEP ($/kWh)
    - Nominal/Real LCOx ($/kWh)
    - NPV ($)
    - IRR in target year (%)
    - IRR at end of project (%)
    - Minimum Debt Service Coverage Ratio
- Energy Payments by time step
- Simulation output report in Microsoft Word

Modeled results are subject to ongoing development.
This example is for a single residential building & includes HP cost.

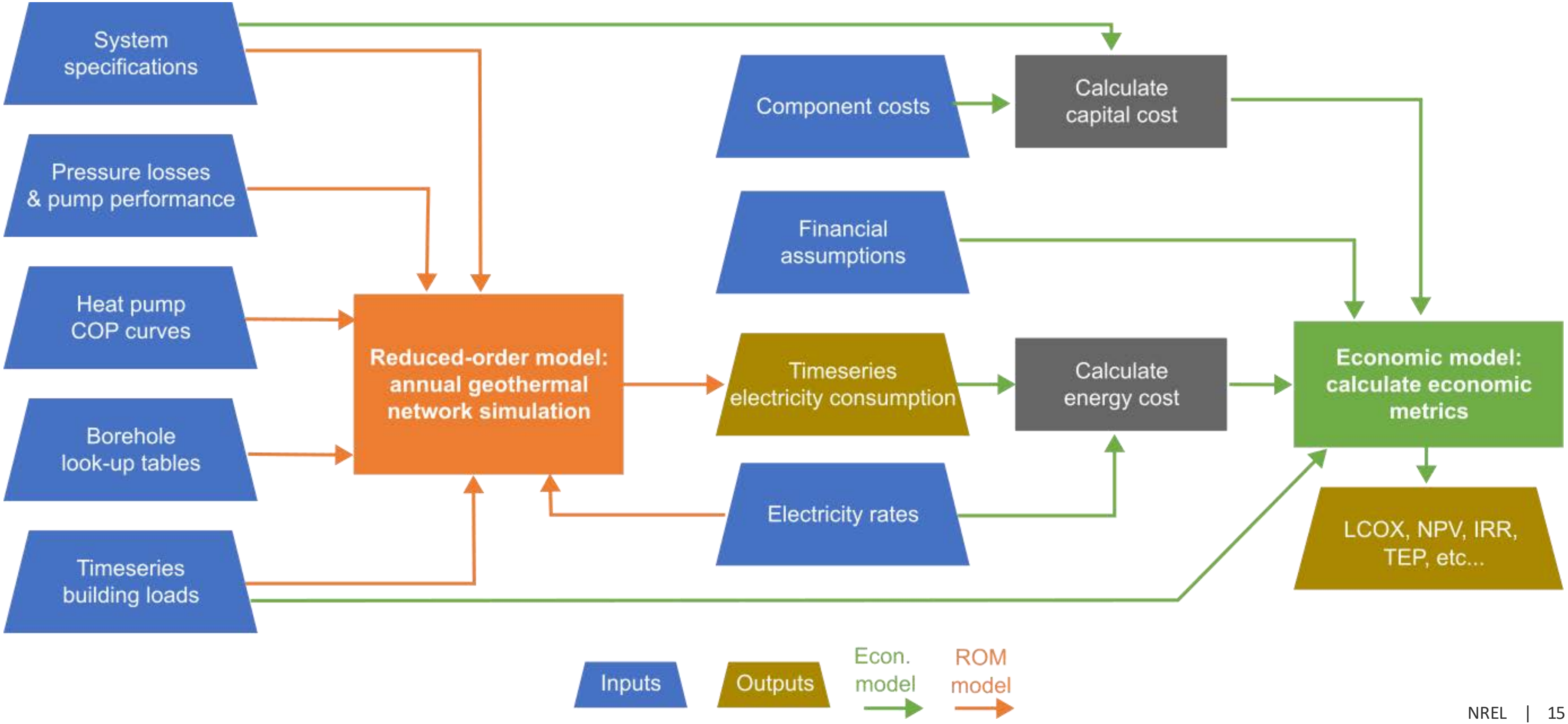
HEATNETS model data flow



HEATNETS model data flow



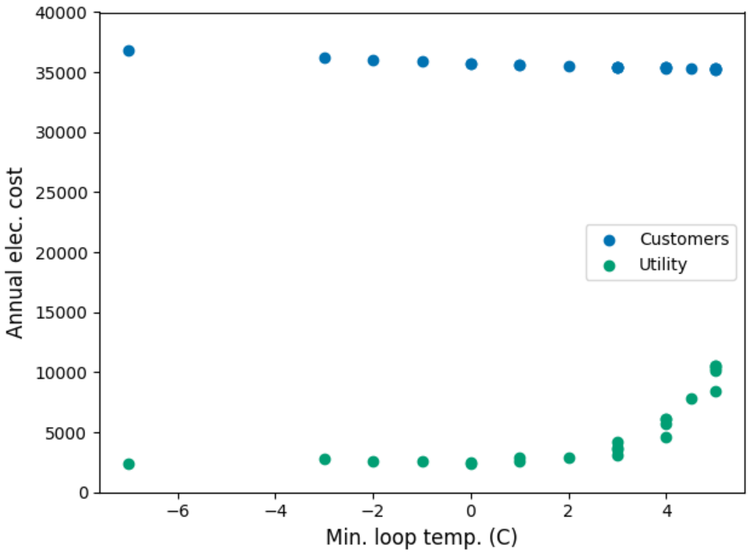
HEATNETS model data flow



What happens if…?

…the minimum loop temperature is changed?

- In this case study, as the minimum temperature increases, the utility cost rises significantly while the customer cost drops slightly
- Benefits may not be seen equally for all parties involved in the GEN



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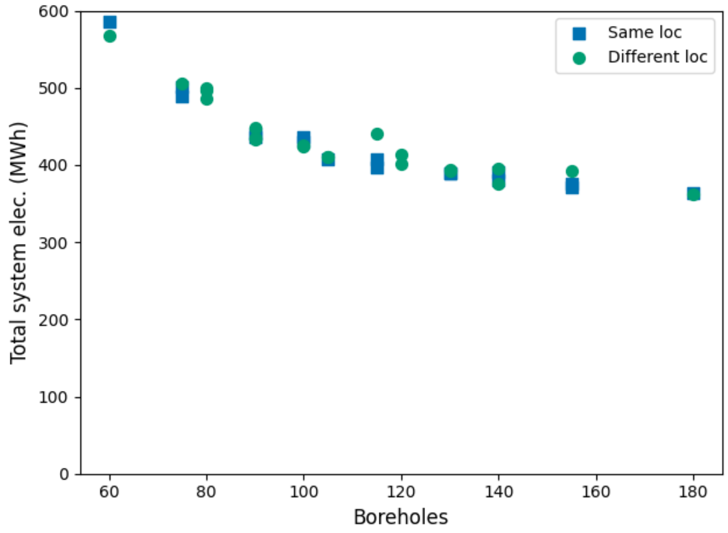
What happens if...?

...the number and location of boreholes changes?

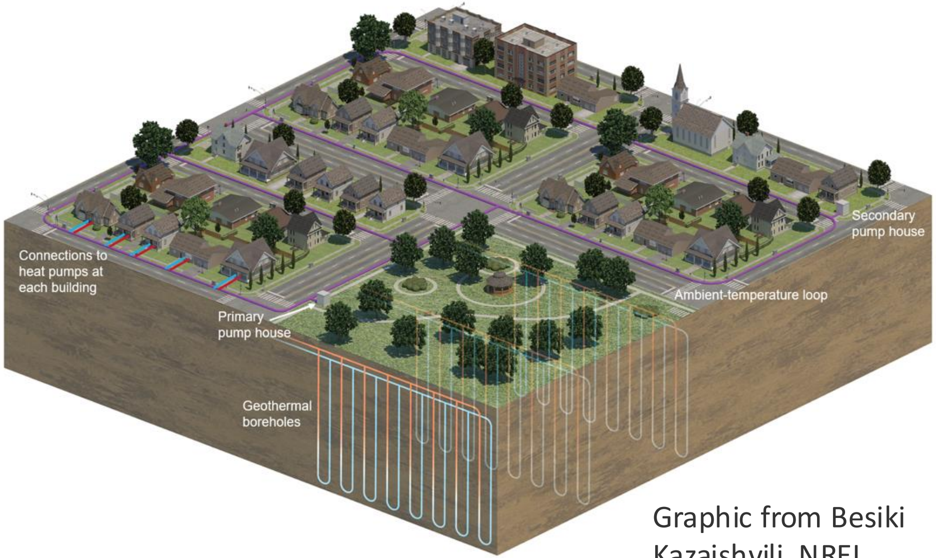
- In this case study, adding additional boreholes to the system reduces the total system electricity usage annually
- Operational benefits must be weighed against economic impacts



Modeled results are subject to ongoing development.

Summary

- Modeling can answer key questions for GENs
- HEATNETS model includes both physics-based reduced-order model and economic model
- HEATNETS allows for analysis of design and operational decisions, considering impacts to performance and economics



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

Questions?

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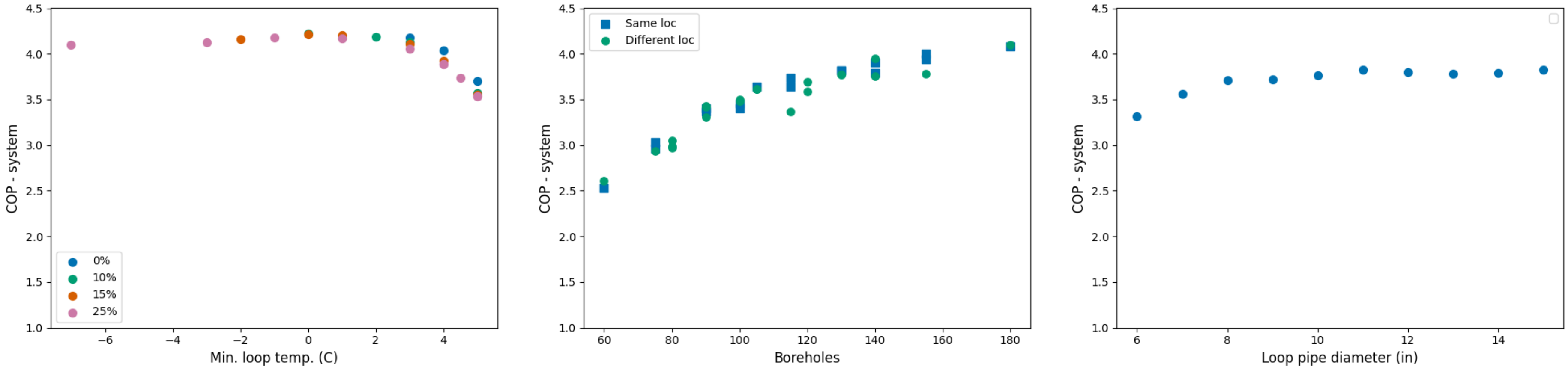
Additional slides

Compiled System COP results

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



Modeled results are subject to ongoing development.

What questions are researchers still considering?

- How to best balance geothermal boreholes with other thermal sources such as thermal storage, solar thermal, or waste heat?
  - Who is it best for?
- How densely populated does an area need to be for GENs to be economical?
- How many boreholes vs a peaking system?

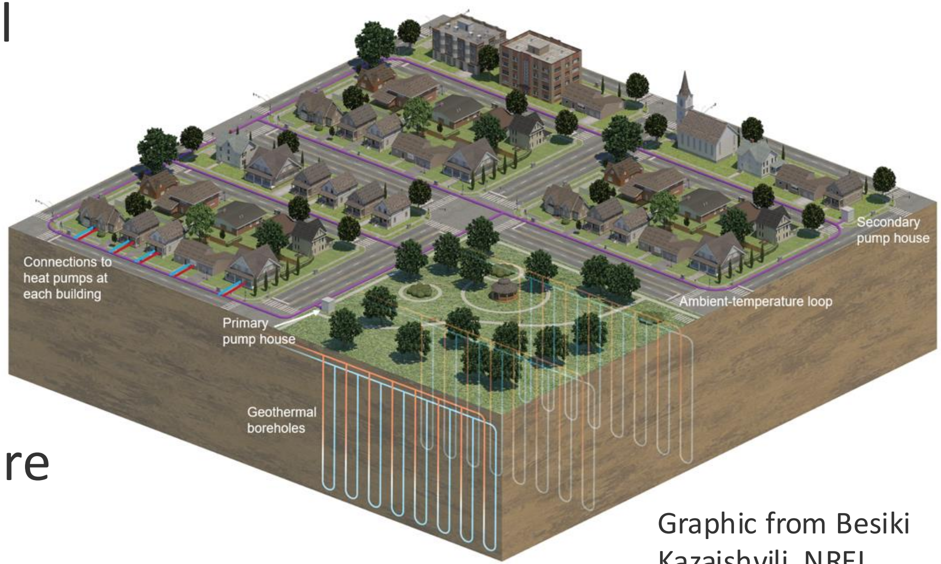
HEATNETS overview

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 DES (TENs)
- 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

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



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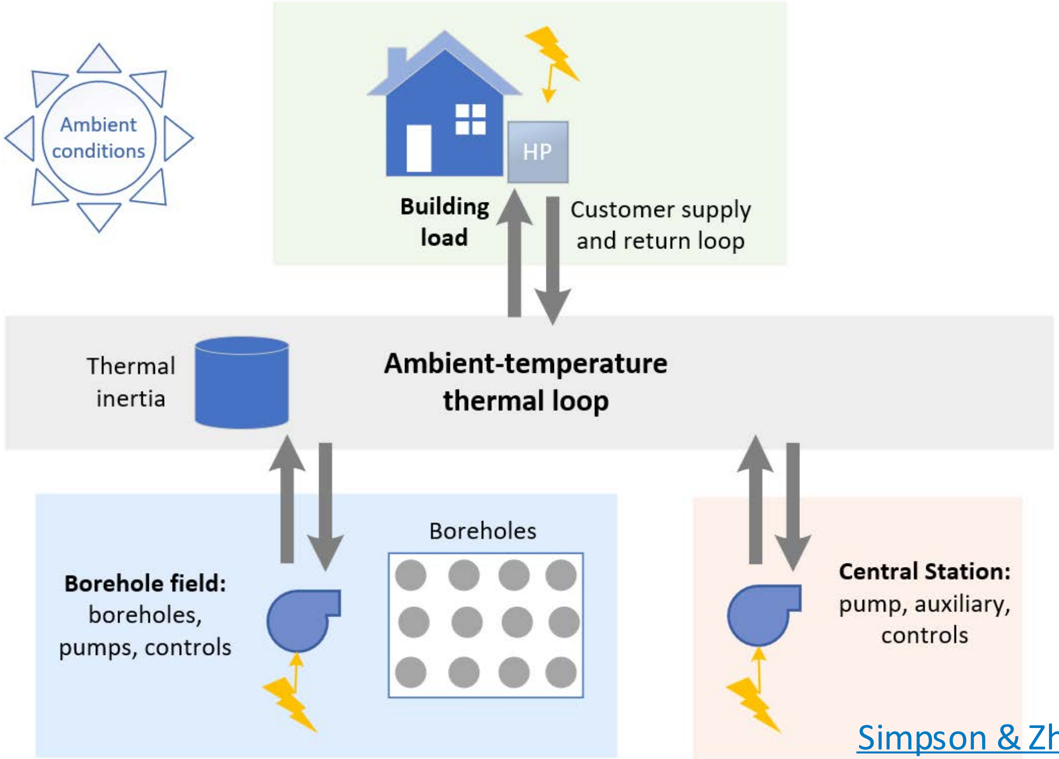
NREL's reduced-order model will focus on connecting major components with the thermal loop

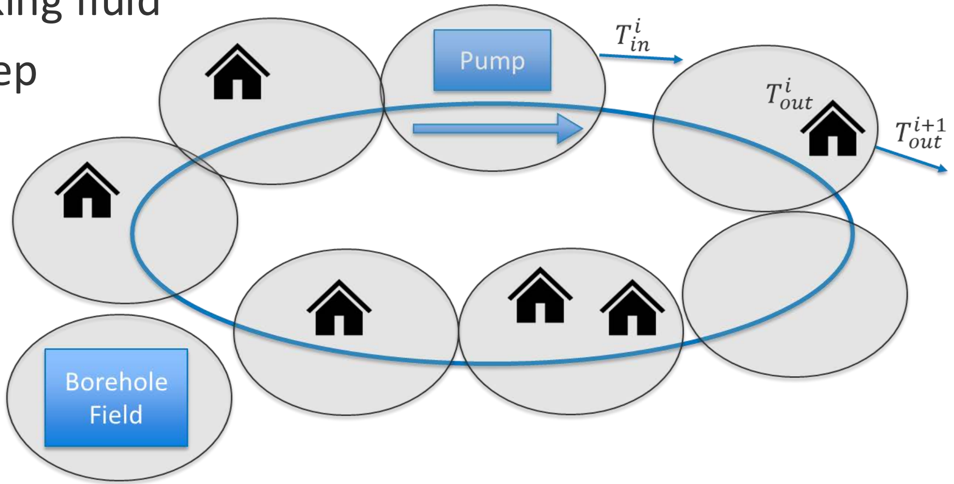


[Simpson & Zhu (2024)]

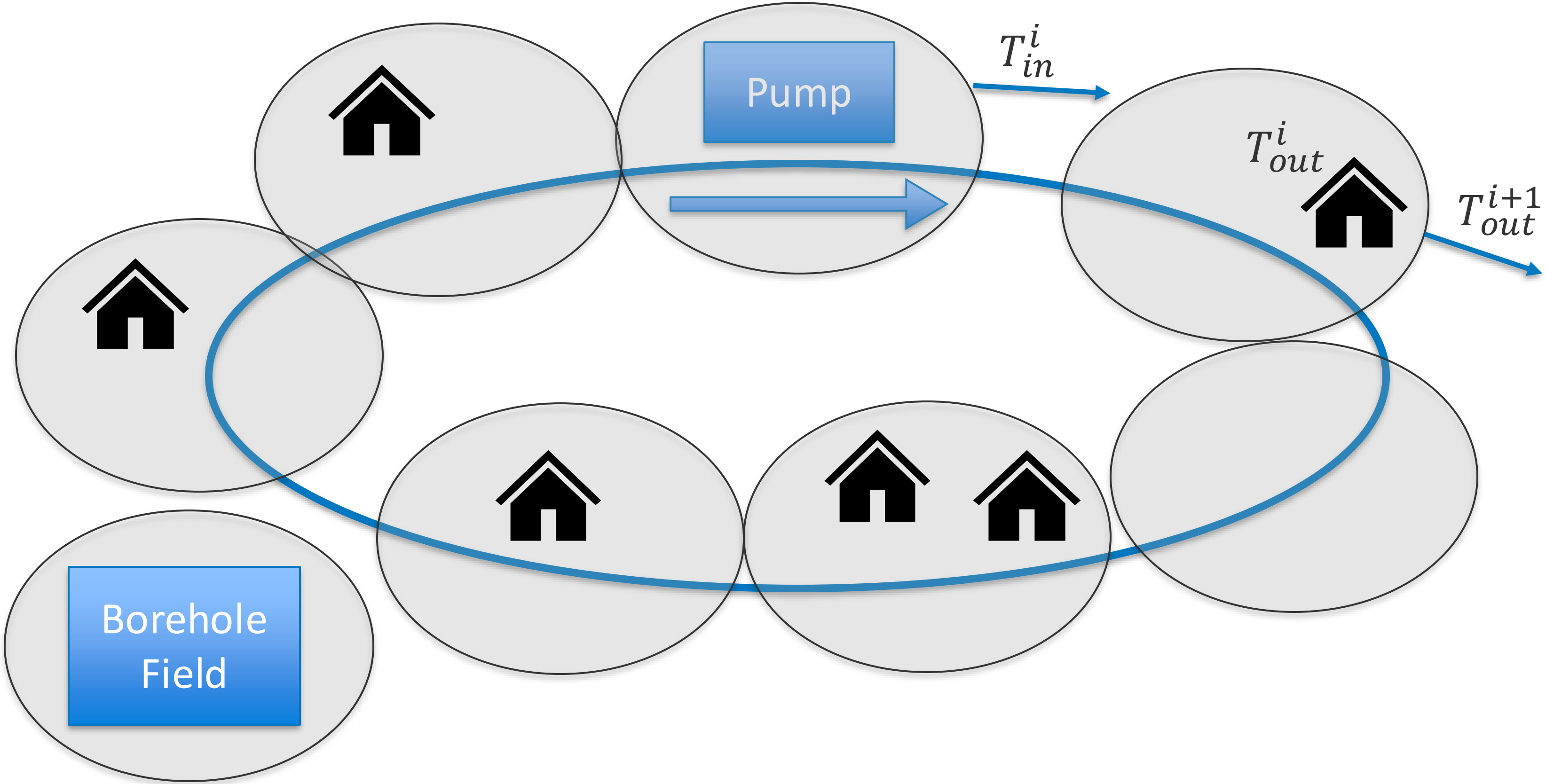
Source: public domain

ROM divides loop into sections for thermal analysis

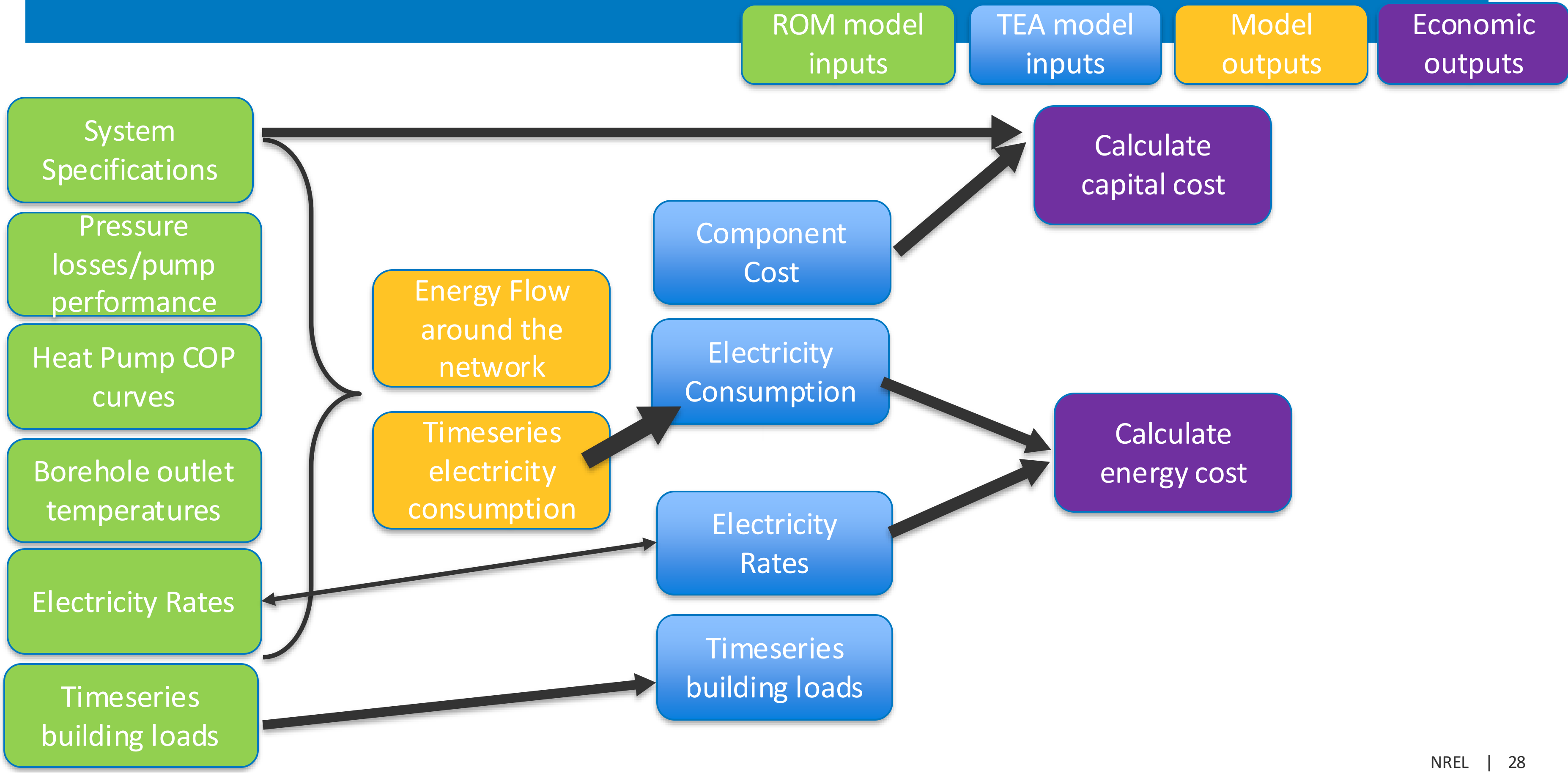
- For each **hourly** timestep (i):
  - Set loop flow rate and auxiliary heating (if used/needed)
  - Subdivide into smaller timesteps based on loop flow rate
  - Calculate heat and mass balance for sections, accounting for thermal inertia within the loop and flow of working fluid
  - Save results on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



ROM divides the loop into sections



Ongoing Development/Next Steps



RES.ENV 007 Geothermal Energy Networks (GENs): Transforming our Thermal Energy System

IAP 2025