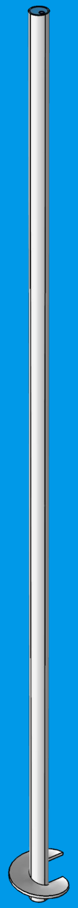

Numerical Modelling of Helical Steel Piles

as In-Ground Heat Exchangers for Ground-Source Heat Pumps

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Ryerson University

CSME Conference, 2019

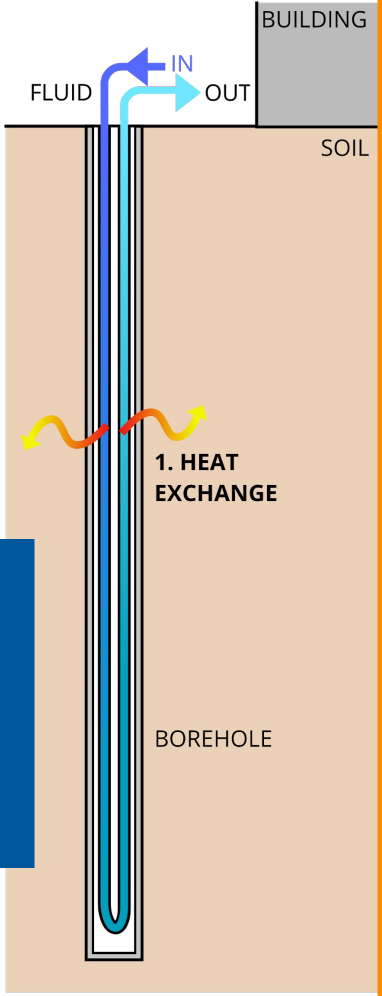
How can we improve the sustainability of heating and cooling in buildings?

Ground Source Heat Pumps (GSHPs) use the temperature of the ground to either draw or reject heat from a building.

Using the ground as natural heat exchange, these systems reduce energy demand.

Heating & Cooling with the Ground

GSHPs are efficient by currently limited to large-scale implementation.



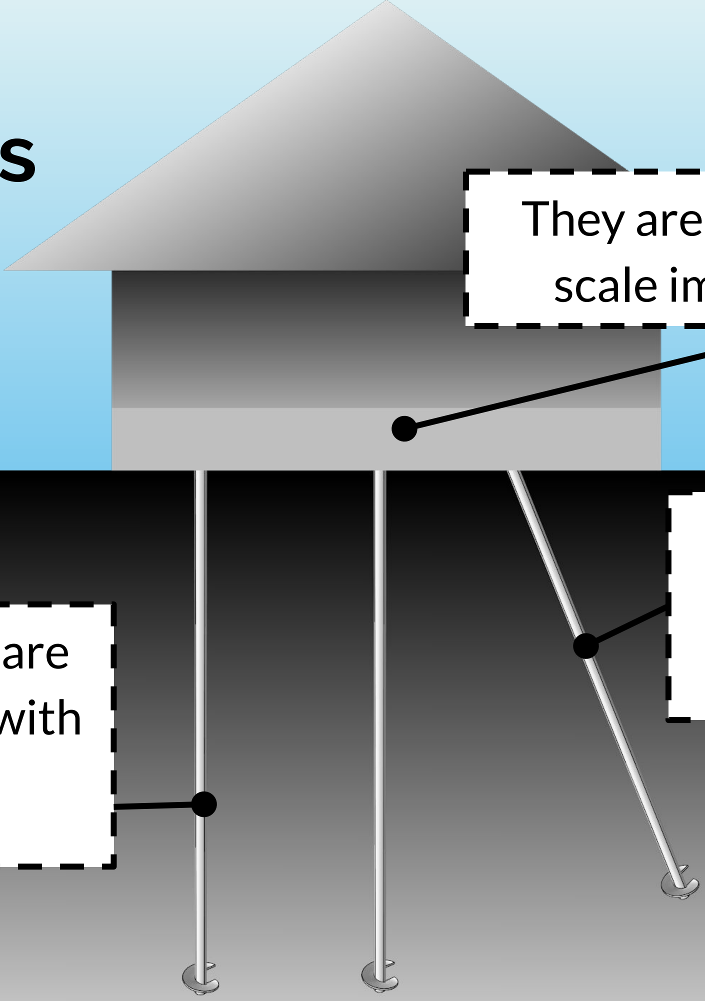
CONVENTIONAL IN-GROUND HEAT EXCHANGER

- ❑ Reduced energy demands
- ❑ Minimally intrusive borehole fields [1]
- ❑ Produce up to 3X the input required to run the pumps [2]

[1] Ahmadi, M. H., et. al., *Environmental Progress & Sustainable Energy* 37 (2018) 1241-64
[2] Rosen, M. A. & Koohi-Fayegh, S., 2017 *Geothermal energy: sustainable heating and cooling using the ground* (Sussex: Wiley)
[3] de Moel, M., et. al., *Renewable & Sustainable Energy Reviews* 14 (2010) 2683-96

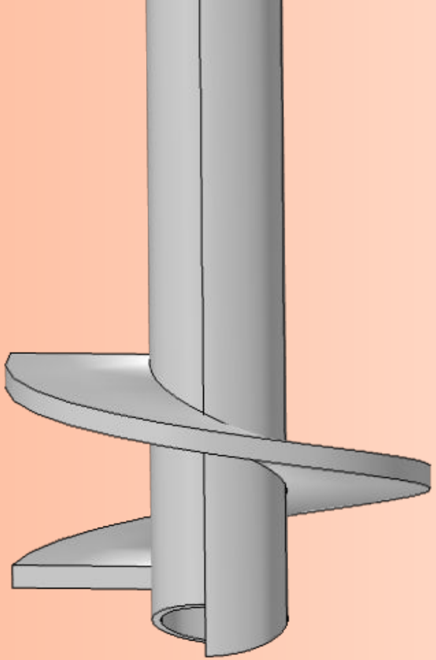
Helical Steel Piles

Existing in-ground structural systems for buildings.



A Dual-Purpose Structure

Proposing a new system using foundational piles as in-ground heat exchangers

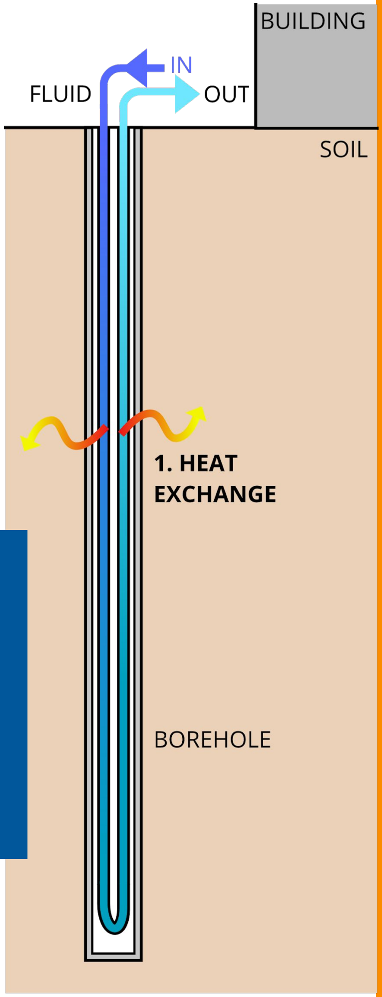


NUMERICAL MODELS + EXPERIMENTAL DEMONSTRATION SITE

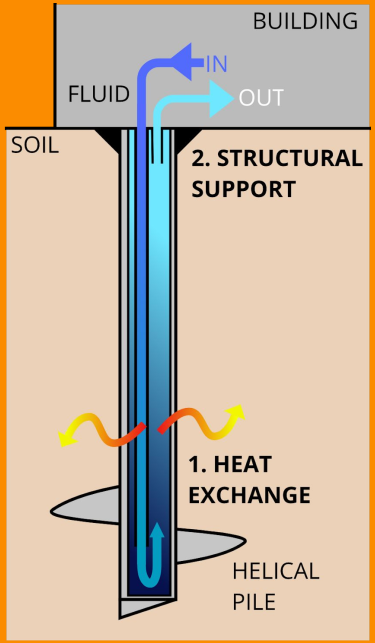
INNOVIA PROJECT PERFORMANCE

Making GSHPs More Feasible

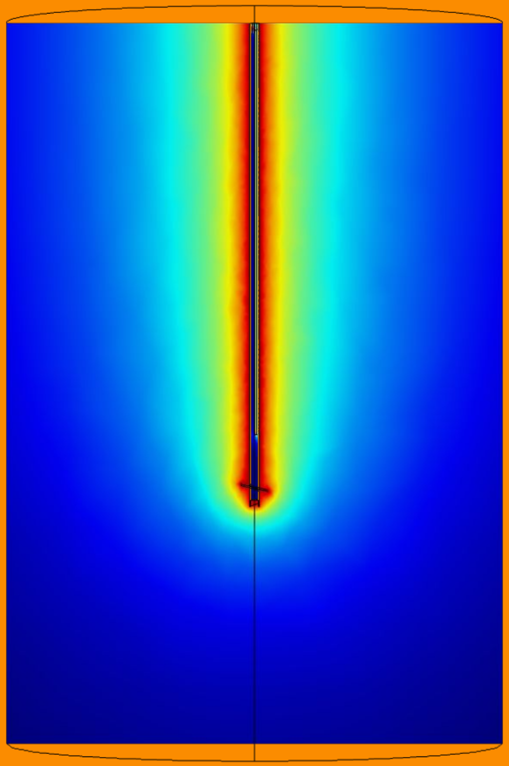
These systems are not yet understood.



CONVENTIONAL IN-GROUND HEAT EXCHANGER



NOVEL FOUNDATIONAL PILE IN-GROUND HEAT EXCHANGER



NUMERICAL MODEL SIMULATING PERFORMANCE

Measuring Performance

Comparisons will be made across three main categories:

1. Heat Transfer Abilities

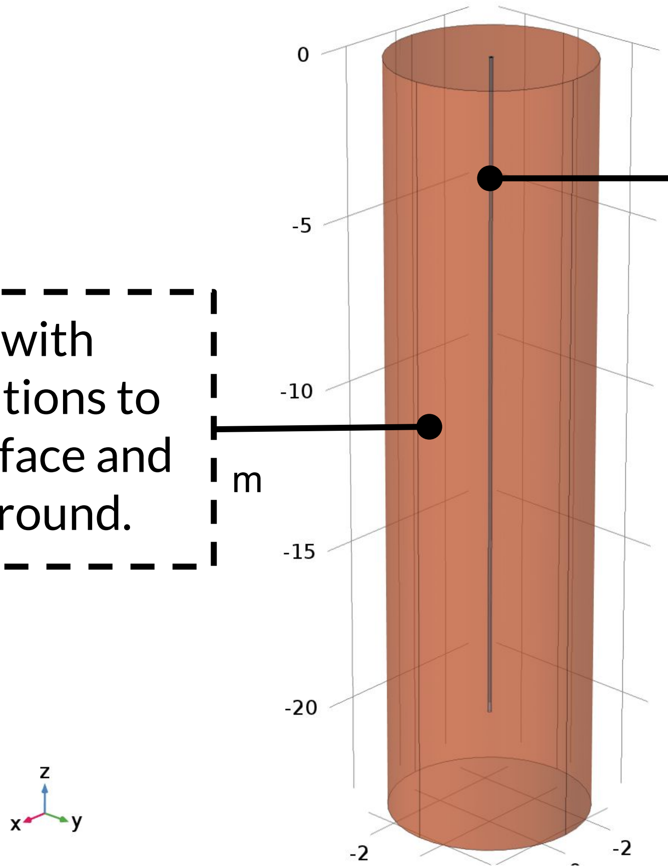
2. Economic Benefits

3. Carbon Emission Reductions

Modelling Performance

1. Heat Transfer Abilities
2. Economic Impact
3. Carbon Emission Reductions

- As an In-Ground Heat Exchanger
- As a System of Heat Exchangers
- As a Ground Source Heat Pump



Steel pile with **plastic inlet/outlet pipes**, and flowing water.

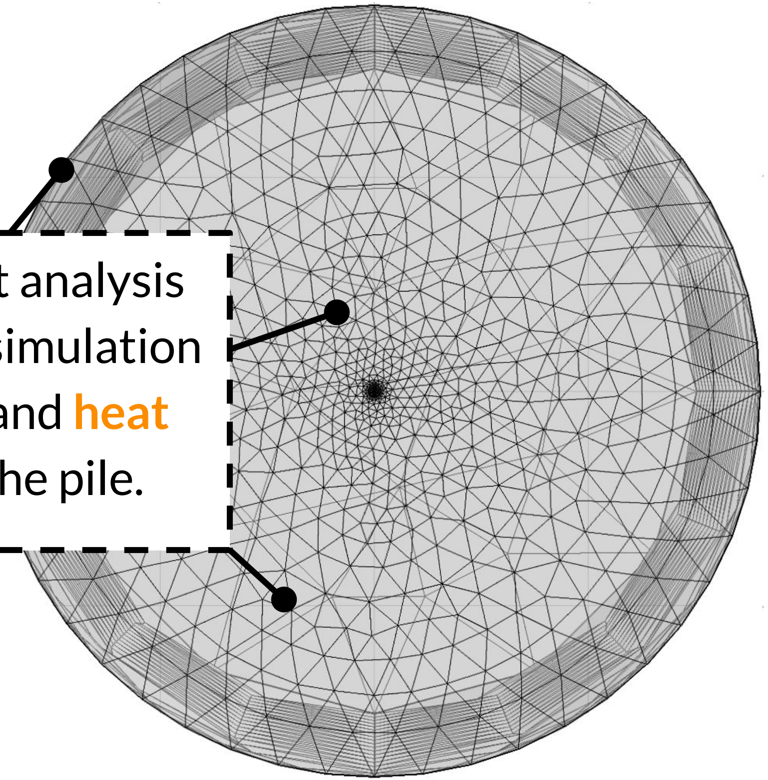
Soil domain with boundary conditions to simulate the surface and surrounding ground.

Computational Domain

Modelling the Pile

Utilizing COMSOL Multiphysics [4], a computer model of the pile was created.

Finite element analysis allows for the simulation of **fluid flow** and **heat transfer** in the pile.

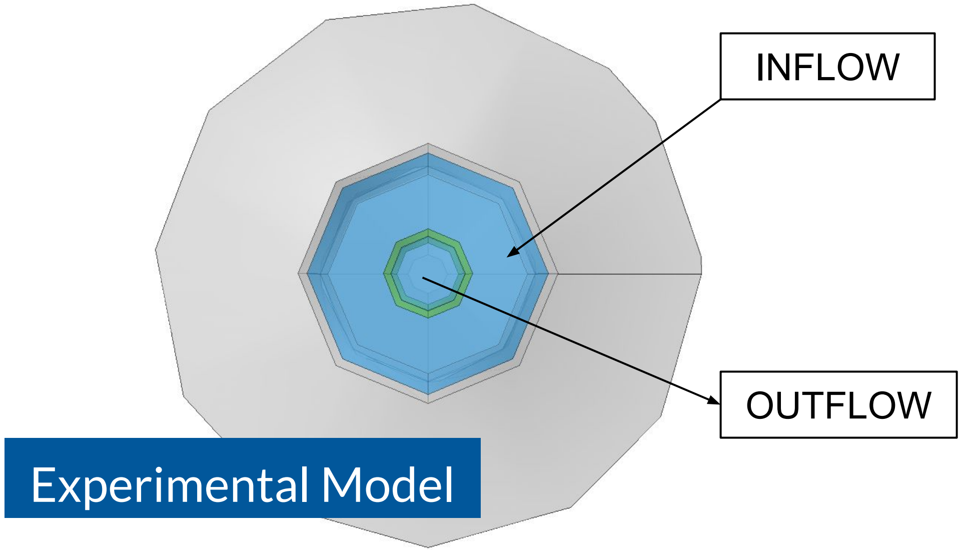


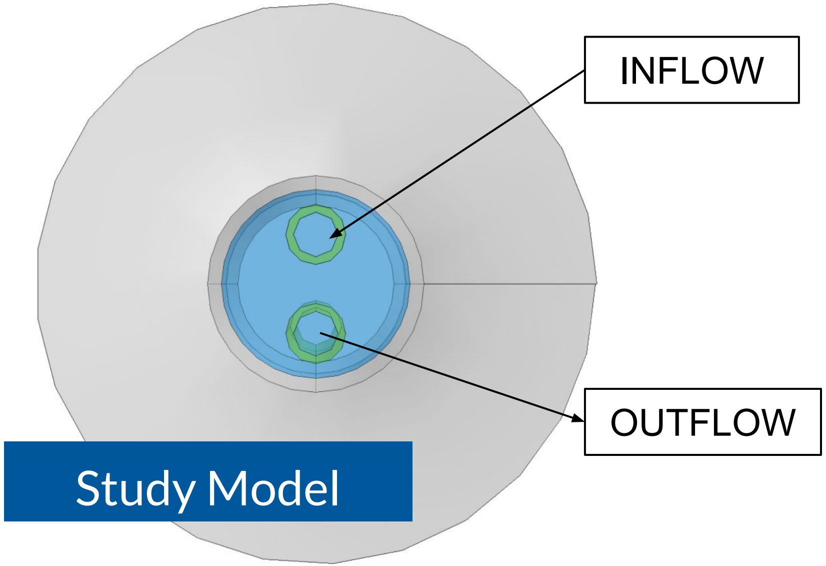
[4] *COMSOL Multiphysics* (R) v. 5.3 (Stockholm: COMSOL AB)

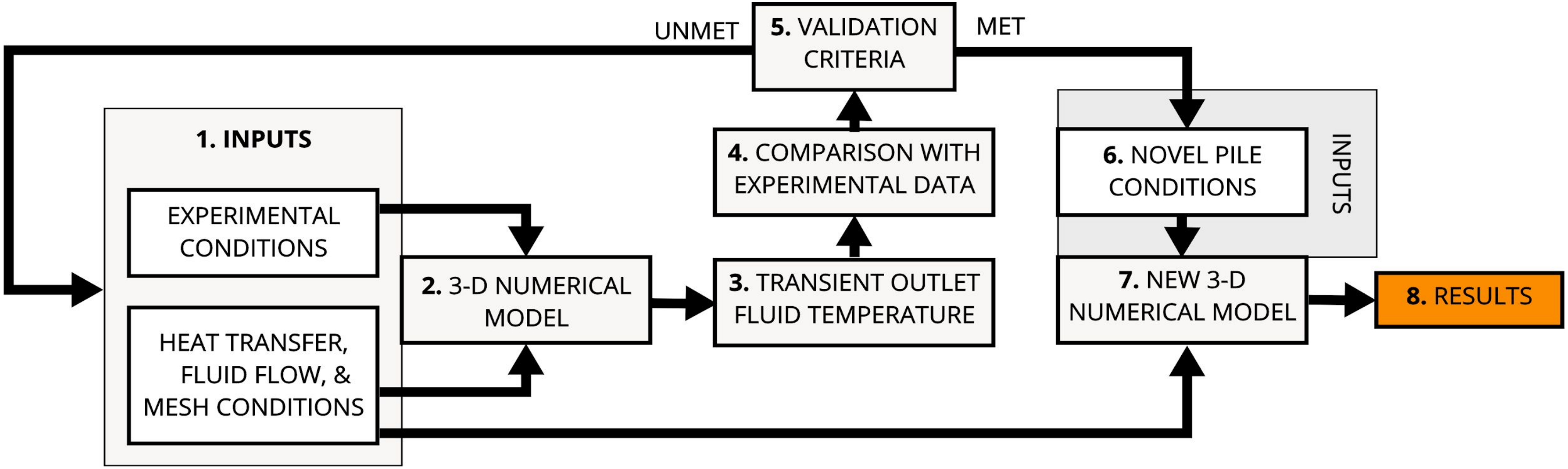
Validating the Model

[5] Jalaluddin, A. Miyara, K. Tsubaki, S. Inoue, K Yoshida., *Renewable Energy* 36 (2011) 764-771

- Validating accuracy of model through comparison with data from a **helical pile in Japan [5].**



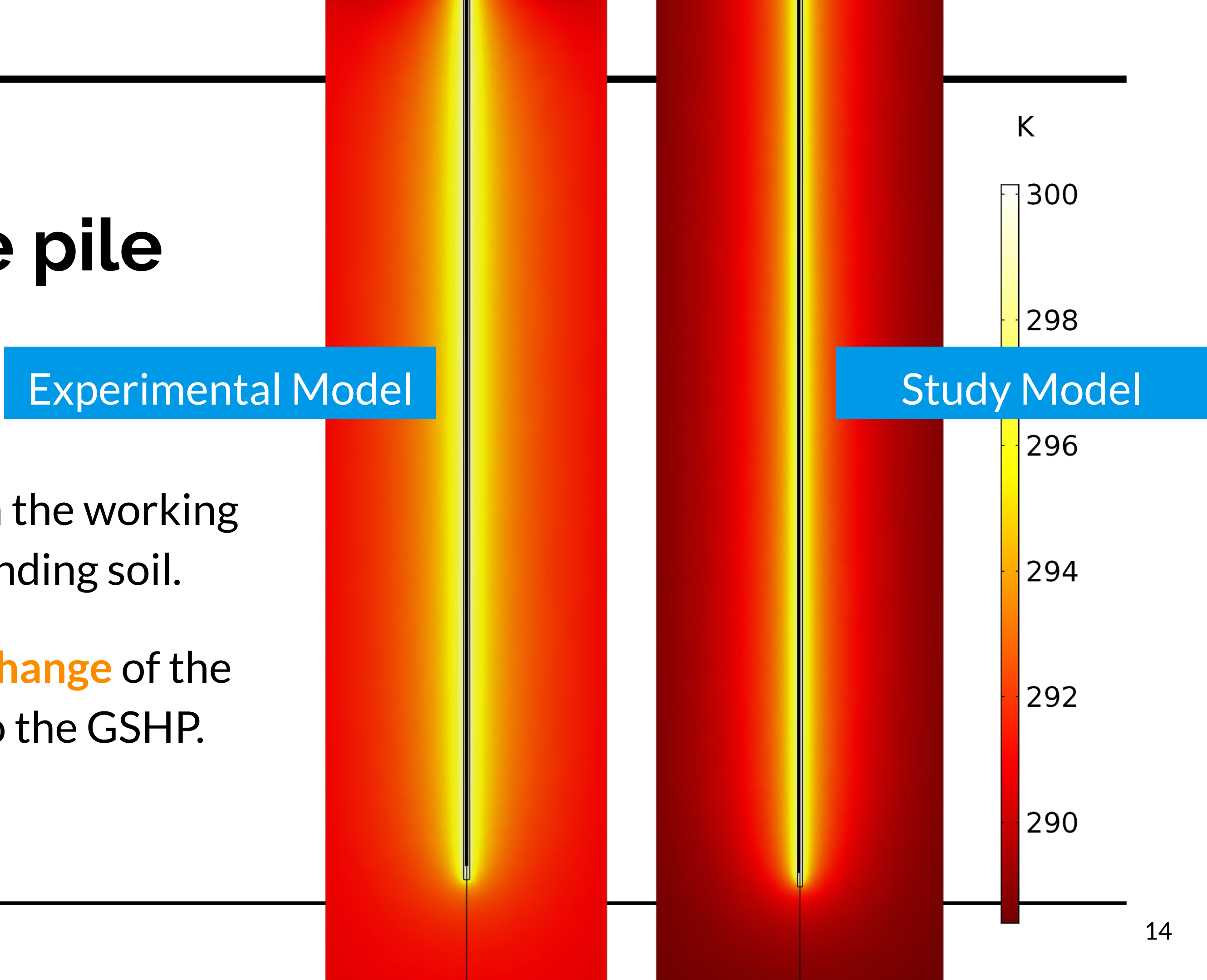




How do we check its accuracy?

Input Parameter	Experimental Validation Pile	Novel Pile
Flow Rates (L/min)	2, 4, & 8	
Reynold's Numbers	267, 545, & 1090	1979, **4037, & 8073**
Ambient Temperature (°C),	14.1, 19.5, & 20.3	
Soil Temperature (°C)	17	
Water Inlet Temperature (°C)	Transient Input - Average of 27	

How does the pile perform?

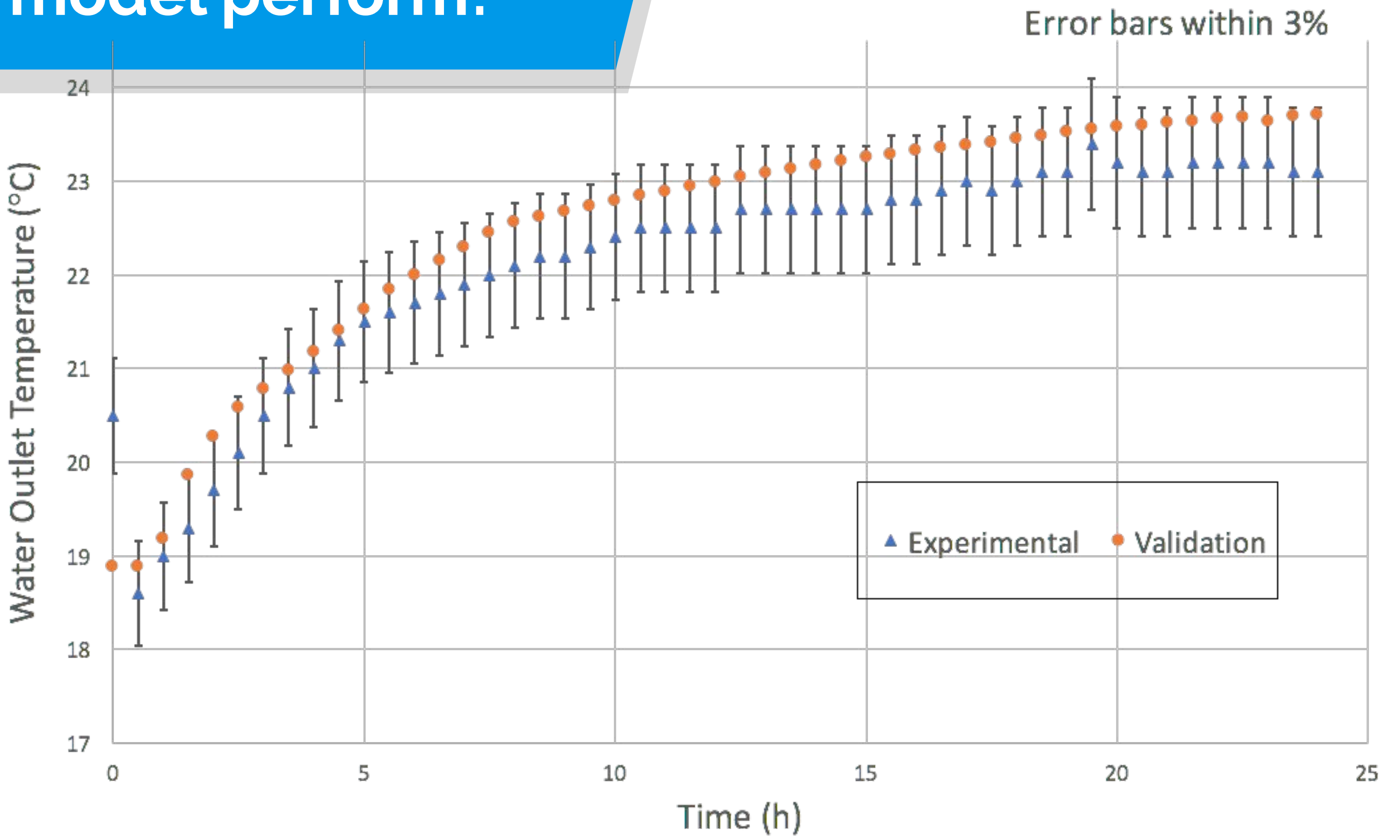


Heat is **transferred** from the working fluid through the surrounding soil.

Achieves **temperature change** of the working fluid supplied to the GSHP.

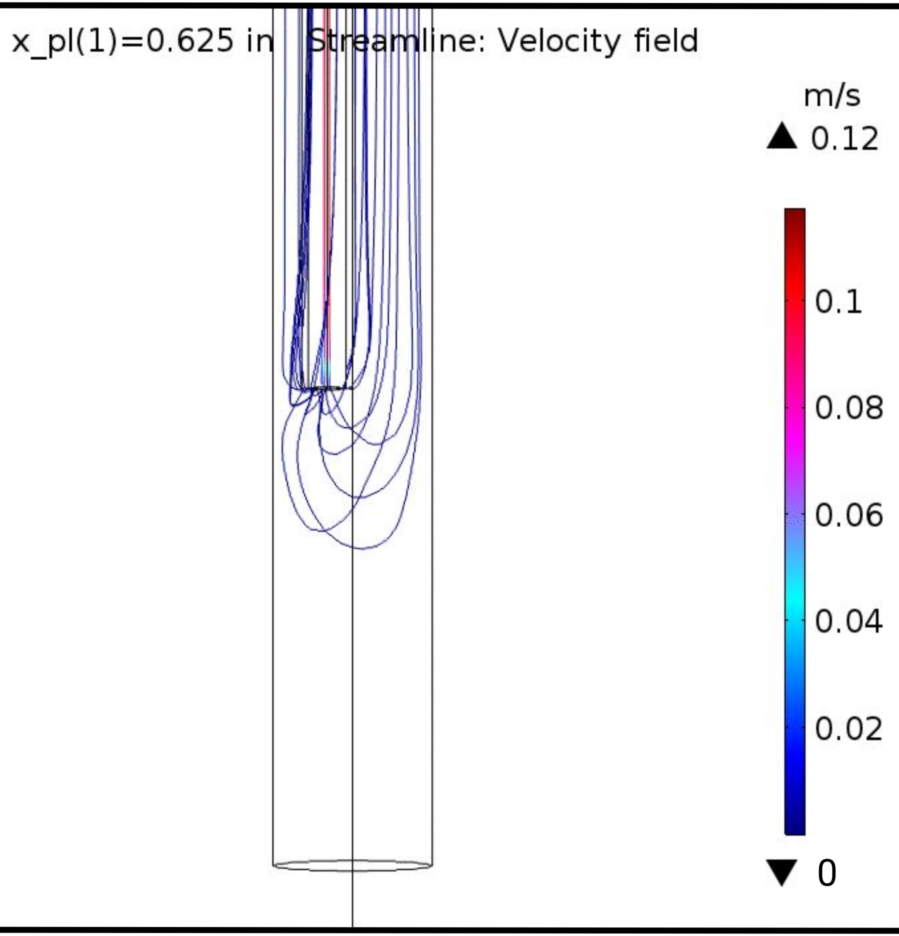
How does the model perform?

- The boundary conditions and physics were **validated within 3% error.**



How do we optimize these piles?

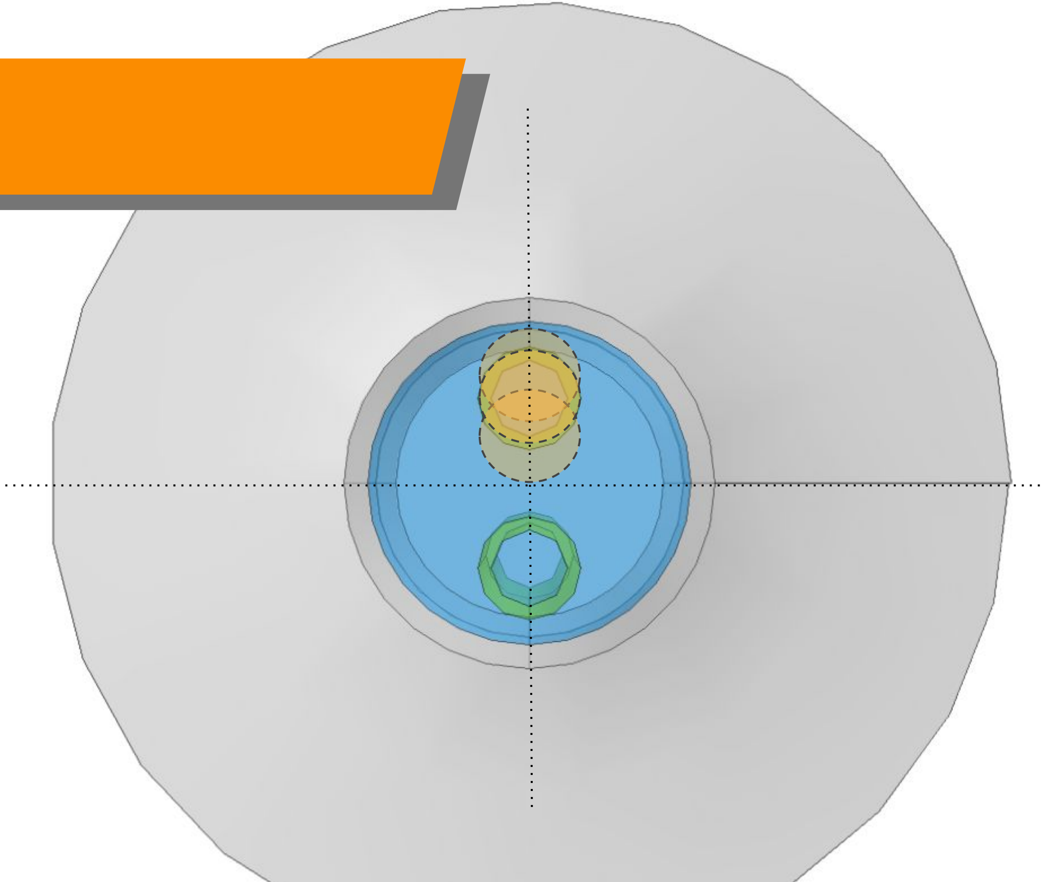
Changing the geometry can change the flow of the water, **which can change the rate heat is exchanged with the ground.**



Parametric Studies

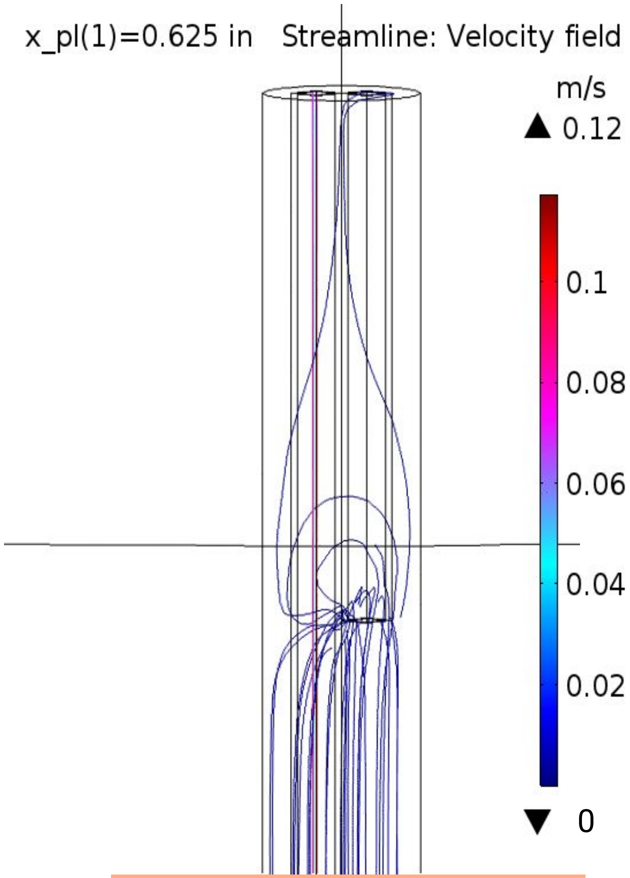
Checked the effect of varying physical parameters:

- ❑ Plastic pipe positions
- ❑ Plastic pipe diameters
- ❑ Plastic pipe lengths

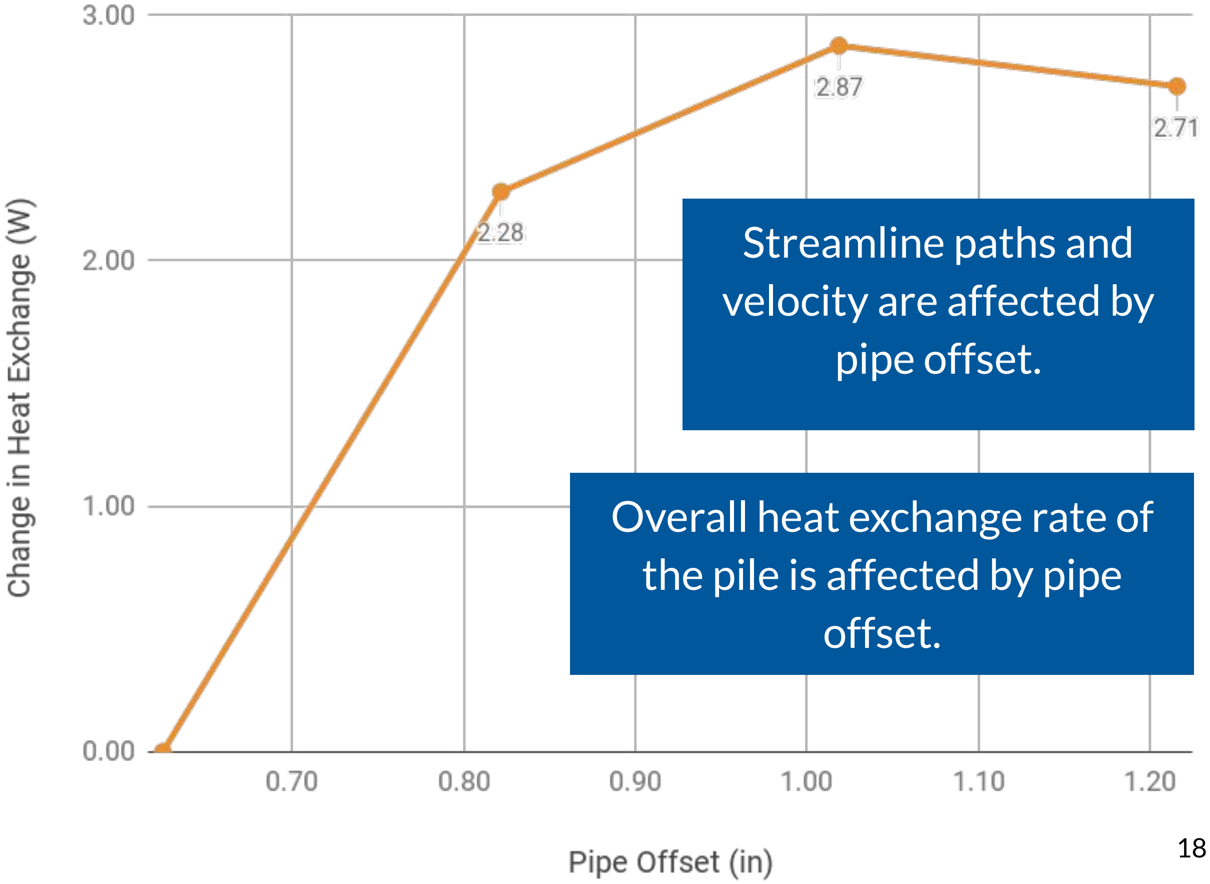


Varying Inflow Pipe Offset

Effect of Changing Pipe Offset



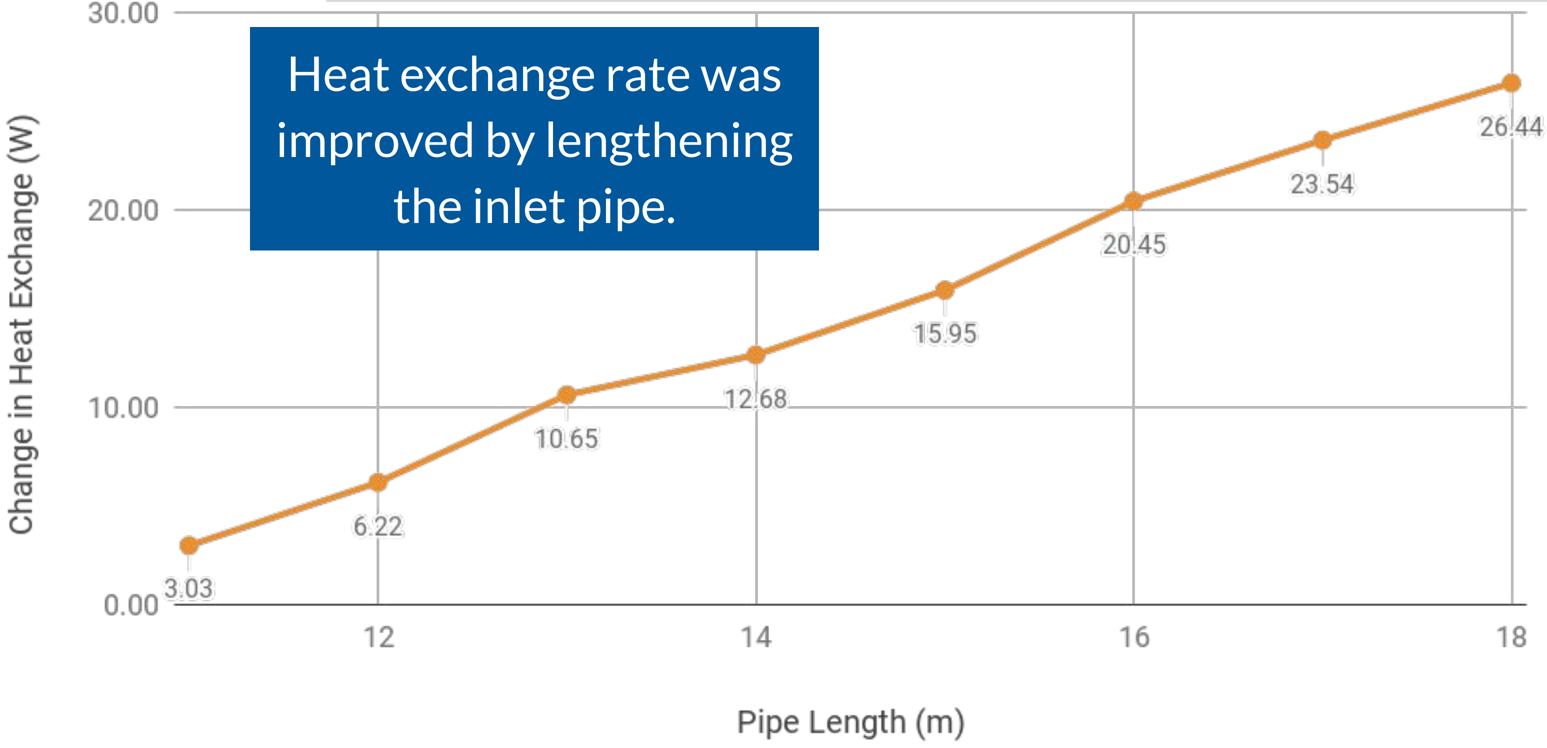
Top Section



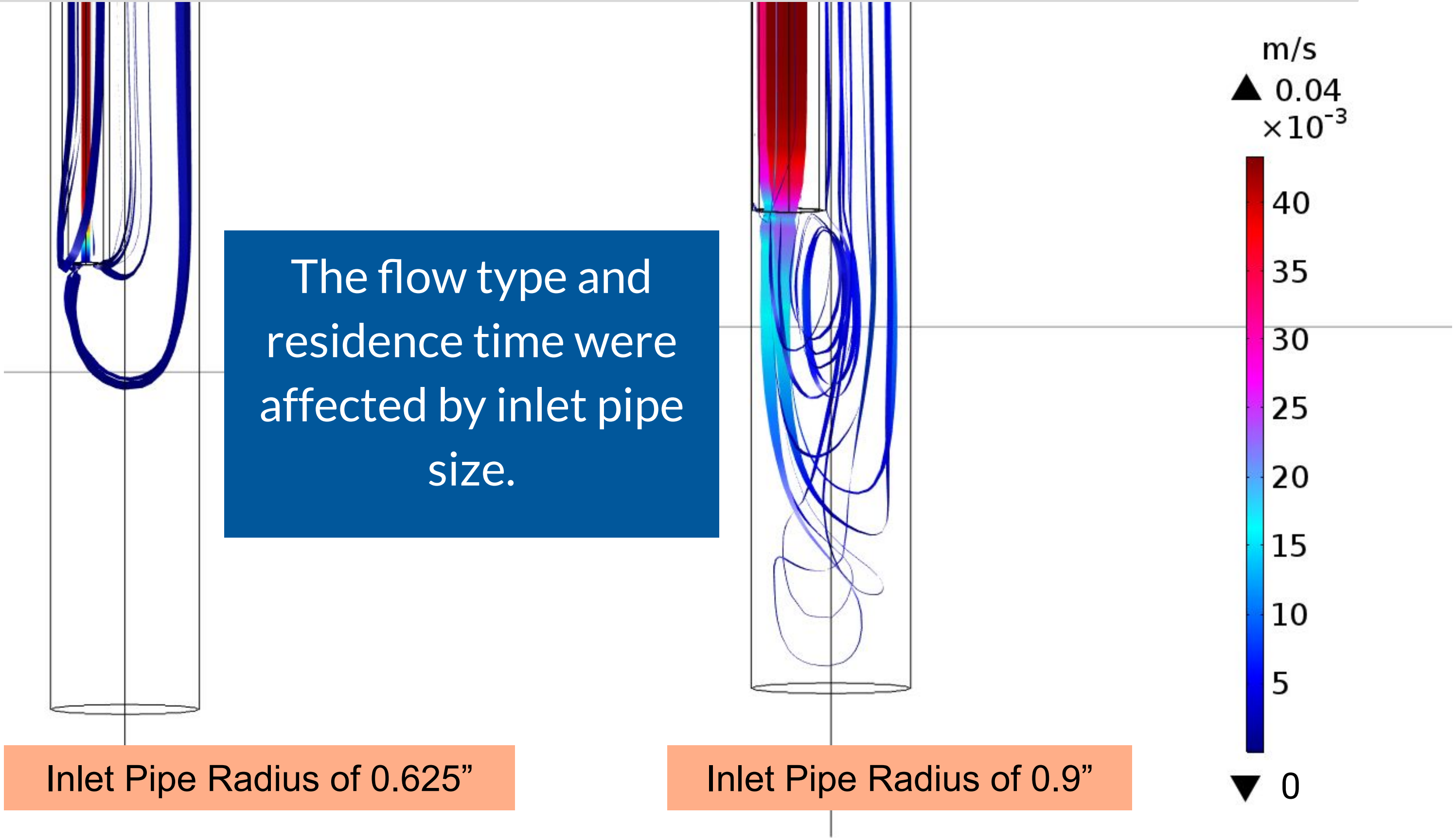
Streamline paths and velocity are affected by pipe offset.

Overall heat exchange rate of the pile is affected by pipe offset.

Effect of Changing Inlet Pipe Lengths



Effect of Pipe Diameters

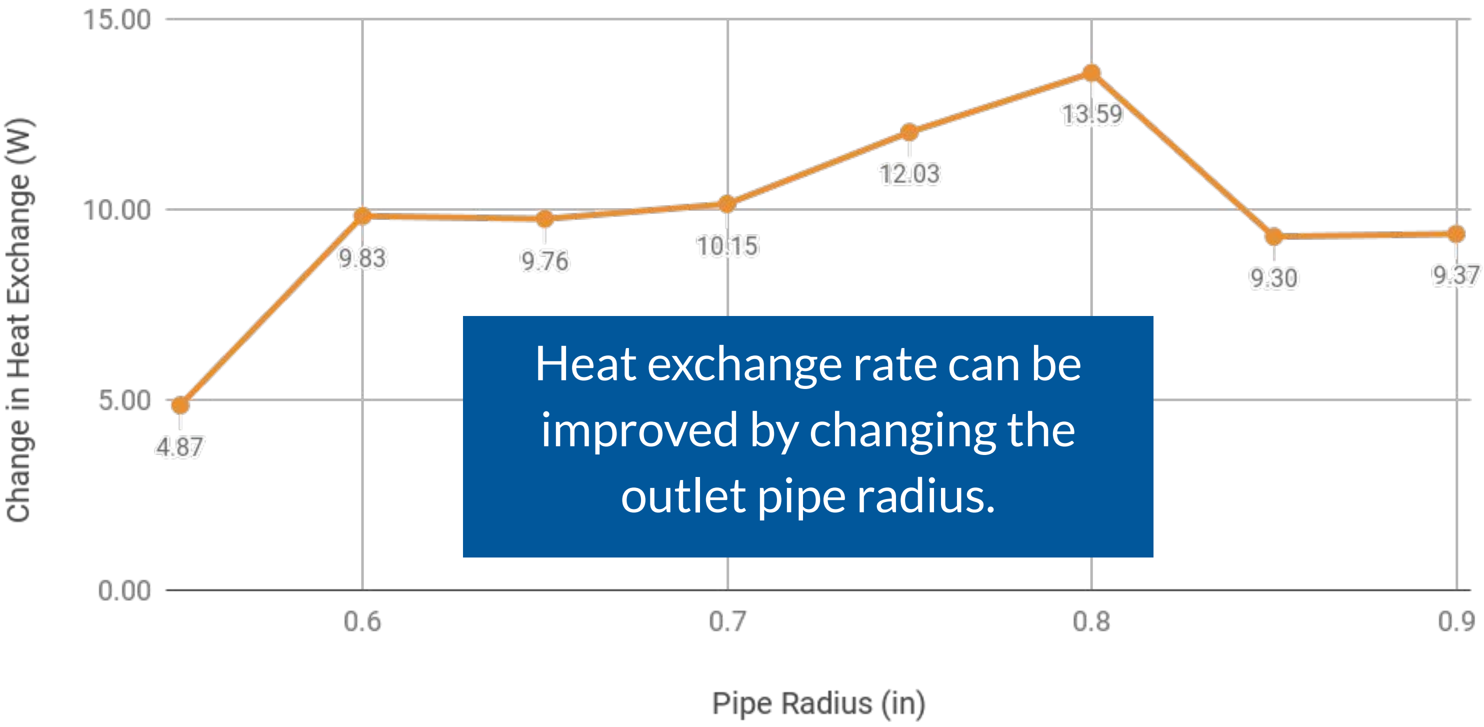


The flow type and residence time were affected by inlet pipe size.

Inlet Pipe Radius of 0.625”

Inlet Pipe Radius of 0.9”

Effect of Changing Outlet Pipe Radius



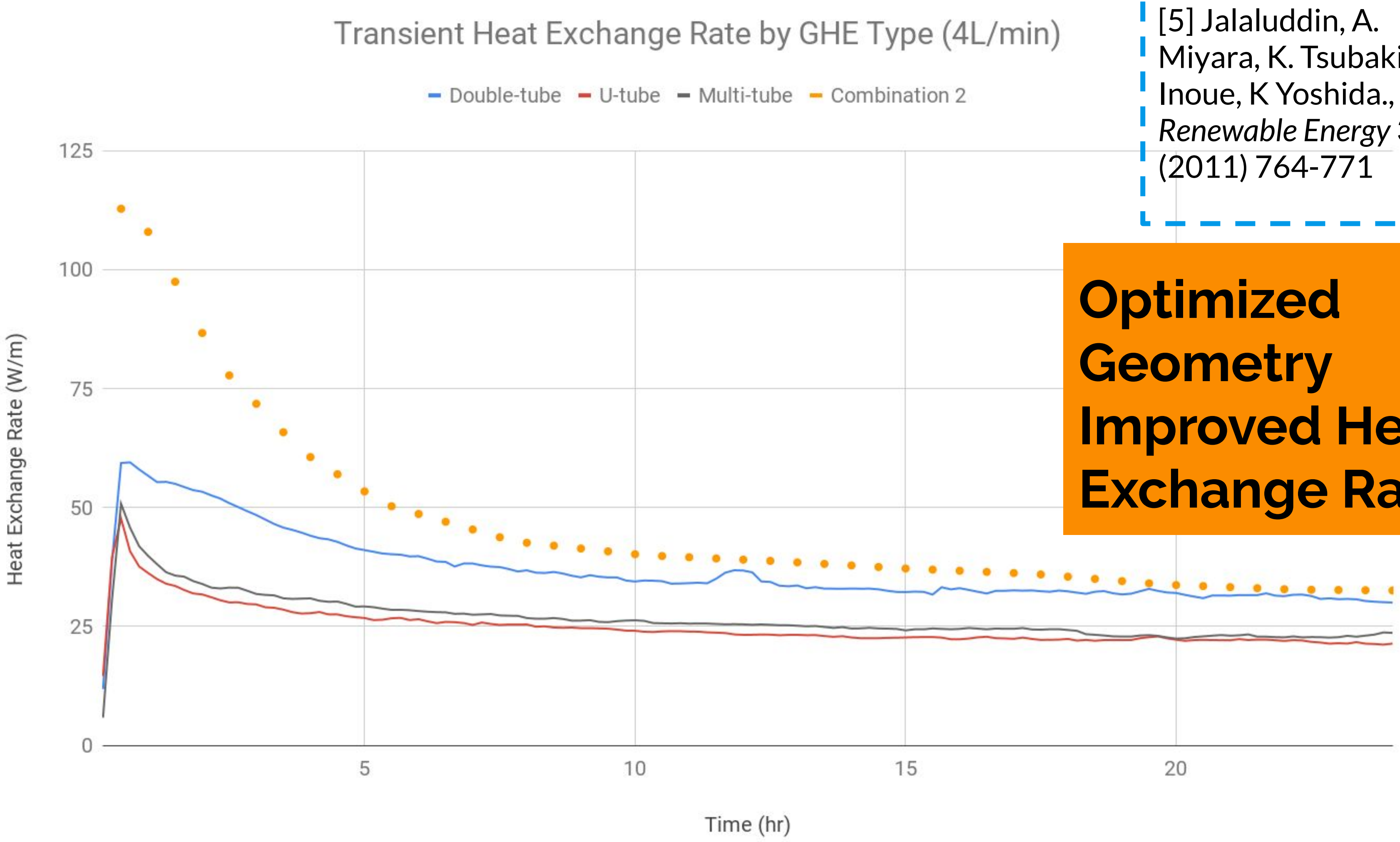
Heat exchange rate can be improved by changing the outlet pipe radius.

Effect of Combined Changes

	Pipe Offset (in)	Outlet Pipe Length (m)	Outlet Pipe Radius (in)	Inlet Pipe Radius (in)	Increase in Heat Exchange Rate by Depth (W/m)
Combination 1	1.0187	4.5	0.8	*0.625*	+ 34.7
Combination 2	1.0	4.5	0.8	0.8	+ 40.9
Combination 3	1.0	0.3	0.84	0.84	+ 41.5

Changes to the heat exchange rate by varying individual pile geometries don't yet give a full picture.

These effects need to be understood within a system of multiple piles, and with annual loads applied.

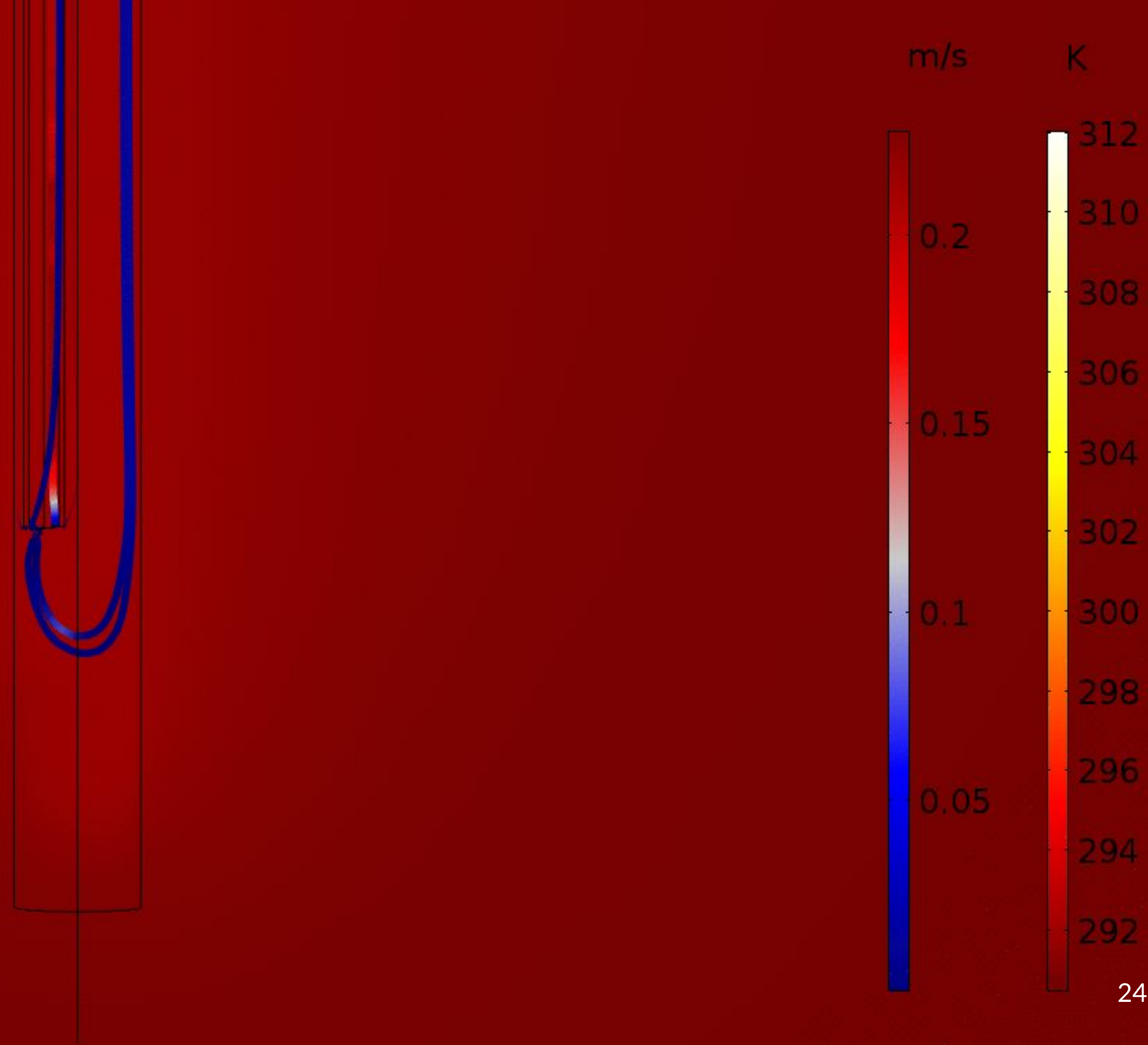


[5] Jalaluddin, A. Miyara, K. Tsubaki, S. Inoue, K Yoshida., *Renewable Energy* 36 (2011) 764-771

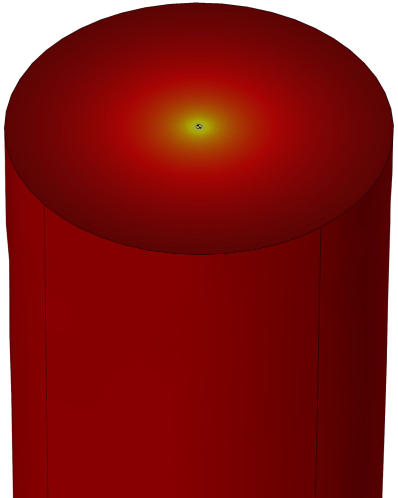
Optimized Geometry Improved Heat Exchange Rate

How do we optimize these piles?

The thermal properties of the soil can determine how well these systems perform in different regions.



What's next?



- ❑ Simulating performance **across Canada**
- ❑ Optimizing pile **geometry** in long term studies
- ❑ Getting economic and emission profiles for **years of performance**
- ❑ Installing **experimental test pile** at test site and getting sensor data
- ❑ Modelling piles at fully turbulent flows

Acknowledgments

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