Modeling of Horizontal GSHP System for Greenhouse Heating

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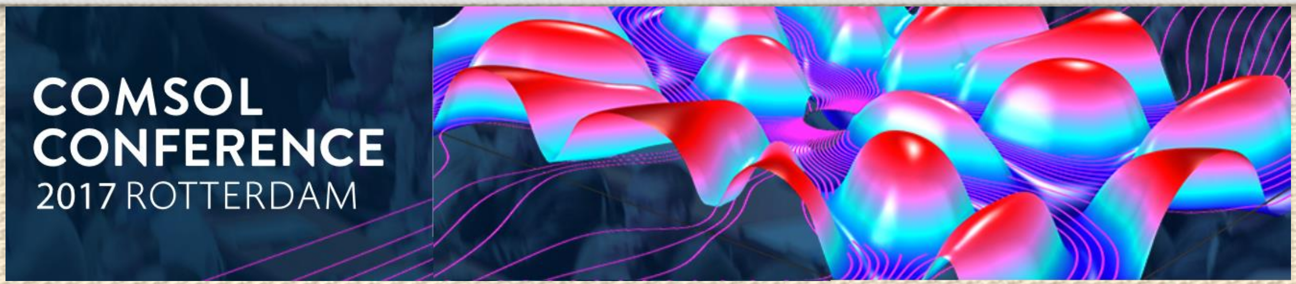
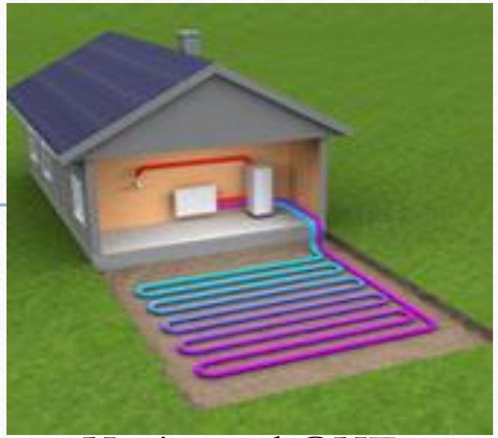


Ground Source Heat Pumps (GSHP) and Ground Heat Exchangers (GHE)

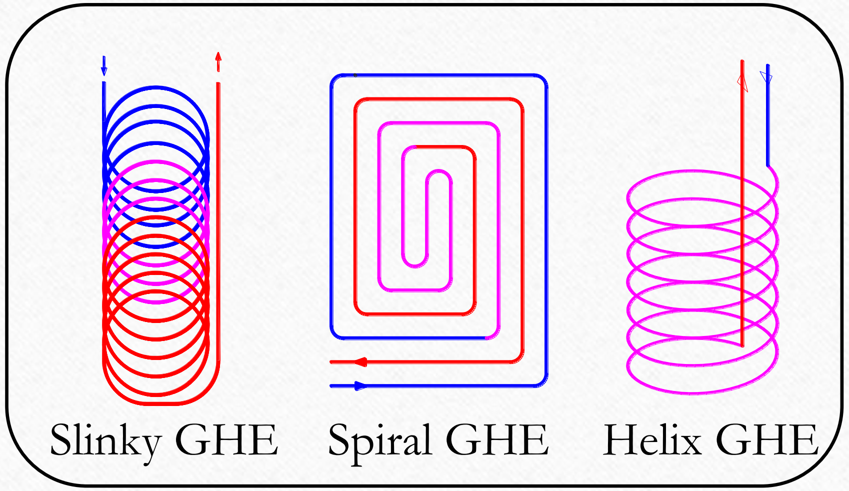
- Ground Source Heat Pump (GSHP) is one of the best efficient space heating and cooling system (USEPA).
- Heat load of a space is extracted (in heating) from ground or injected (in cooling) to ground.
- There are two common methods for GHE
  - Vertical
  - Horizontal


Horizontal GHE


Vertical GHE

Horizontal Ground Heat Exchangers (GHE)

- Horizontal Ground Heat Exchangers (GHE) have some advantages:
  - easy to apply,
  - cheaper than vertical GHEs
- Also have some disadvantages:
  - Need wider area than vertical ones,
  - Lower performance in cold days.

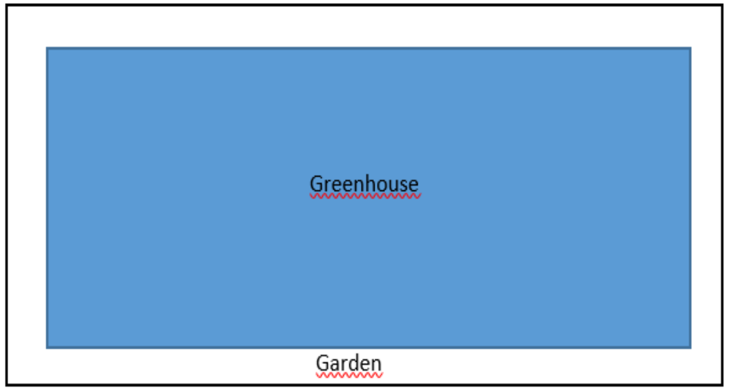


Heating-Cooling of Greenhouses

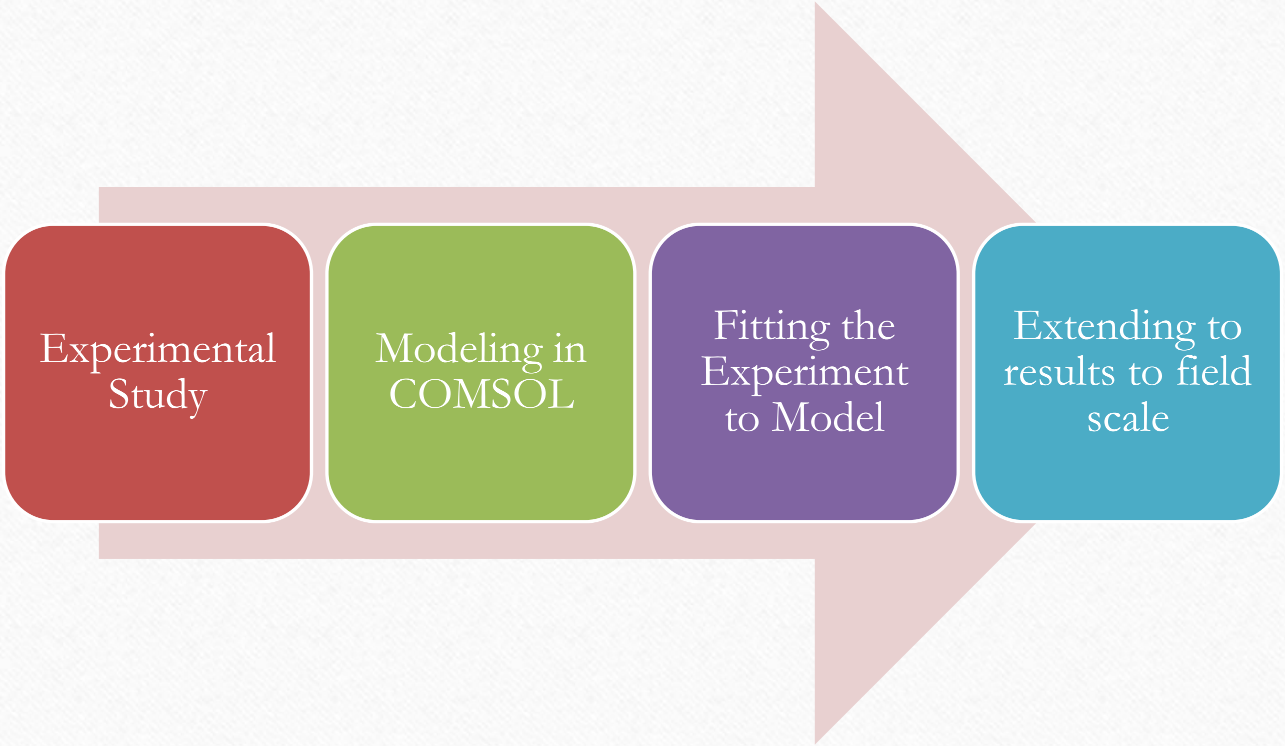
- Depending on the plant growing, inside air has to be controlled continuously,
- They need heating or cooling most of time in a year,
- Heating and Cooling expenses one of the highest expenses,
- Some of them are far from the natural gas network.

Identification of the Problem

- An efficient heating and cooling system needs the greenhouse,
- There is not any available larger spaces,
- Greenhouses floor can be used as heat source/sink,
- Sensitivity of calculation is important because of products.



Working Scheme



Test System using in Experimental Study

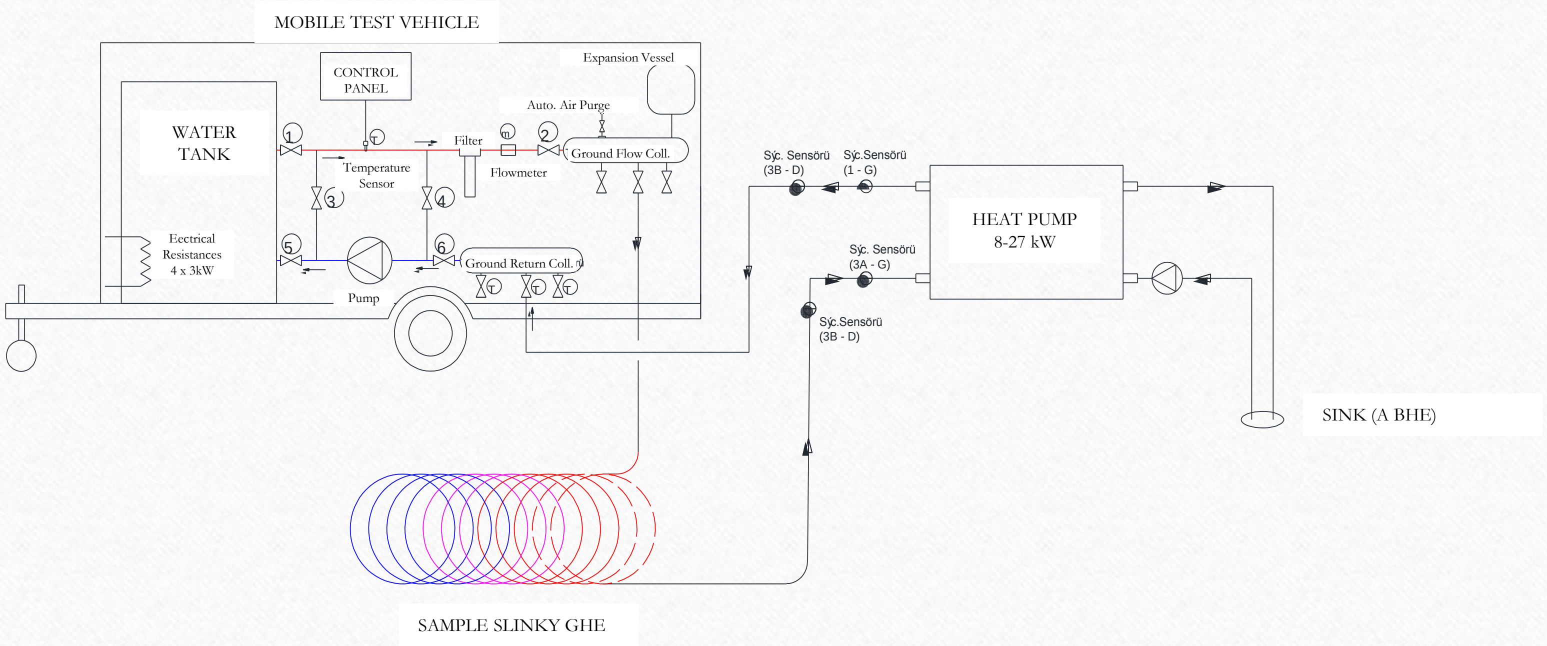


Fig. Mobile Test Vehicle and its connection to the slinky GHE.

Experimental Study Results

Air & Ground Conditions	
Test time	04-06 May
Total duration	57 h
Amb. temp. during the test	12 - 22 °C
Avg grou. temp. at 0.5m depth	19 °C
z =-2m temp. before the test	11 °C
Test Data	
Inlet fluid temp. to GHE	T_g= 5.6 °C
Avg. return temp. from GHE	T_d =7.0 °C
Avg. fluid temp. in GHE	6.3 °C
Flowrate	Q_v = 9.9 lt/min
Temp.diff. between slinky GHE and ground at z =-2m	4.7 °C
Average heat load	$\dot{q}$ = 999 W
Ave. heat load in unit trench	$\dot{q}'$ = 91 W/m

Table: Air and ground conditions.

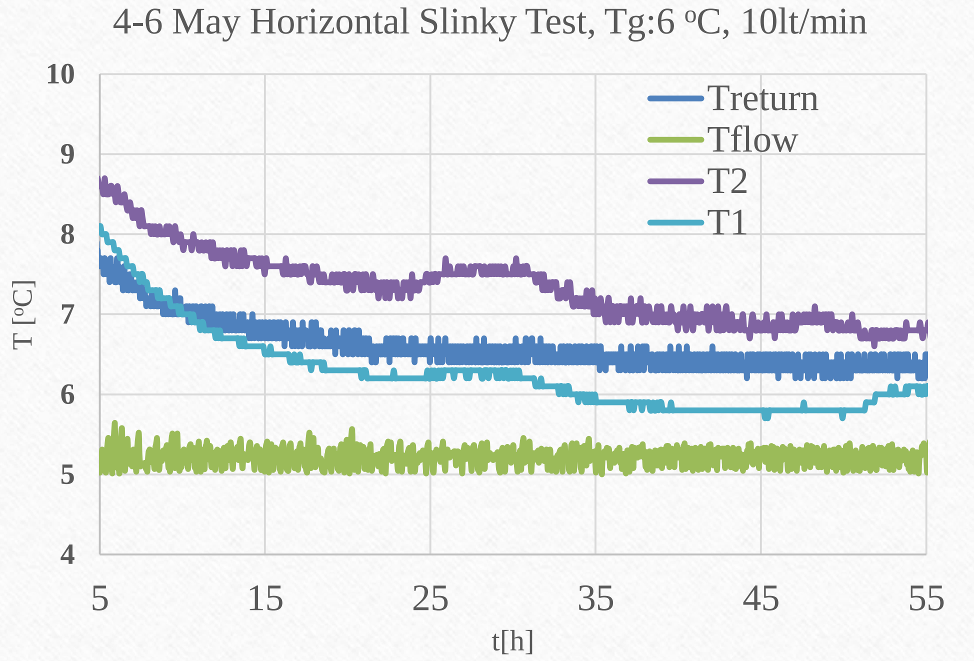
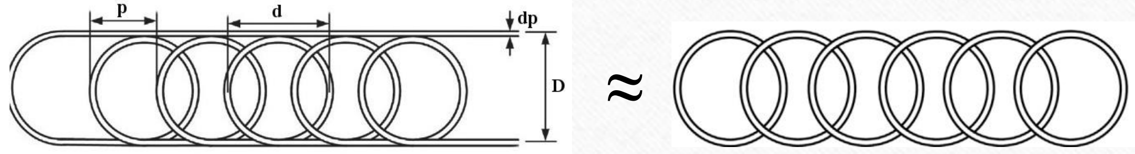


Fig. Changings in temperature sensors during the test, T1 is located on the closer to flow side on PE pipe, similarly T2 is located on the closer to return side.

Modeling



Pinch (p)	**0.25m**
Diameter (d)	1m
Inlet diameter of pipe (d_i)	0.026m
Outlet dia. of pipe (d_o = dp)	0.032m
Total length of pipe	100m
Total trench length	11m

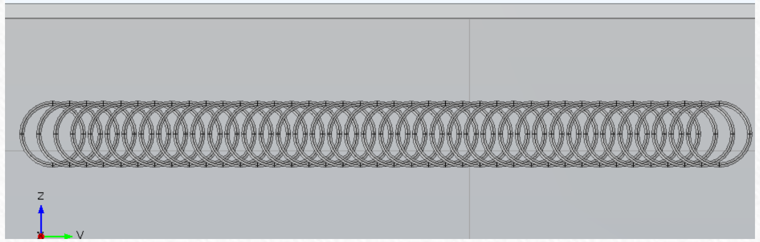


Fig. Slinky GHE.

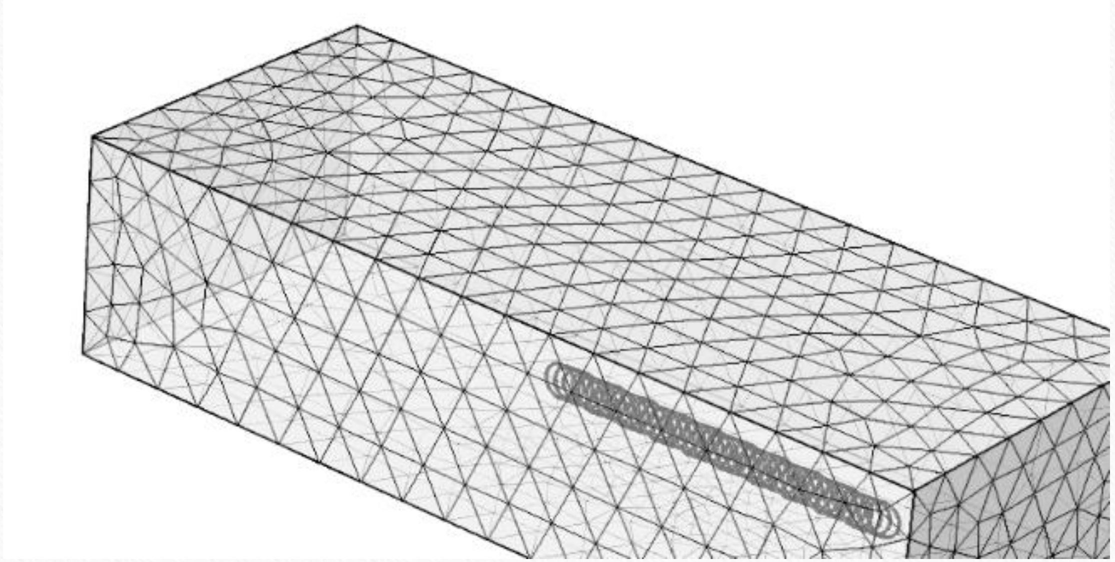


Fig. COMSOL model box for one Slinky GHE.

(6m x 10m x 25m)

Governing Equations

COMSOL Heat Transfer Module, “Heat Transfer in Solid

Governing equations in the ground:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u}\nabla T + \nabla q = Q$$

Upper Boundary Condition

$$q_0 = h(T_{amb} - T)$$

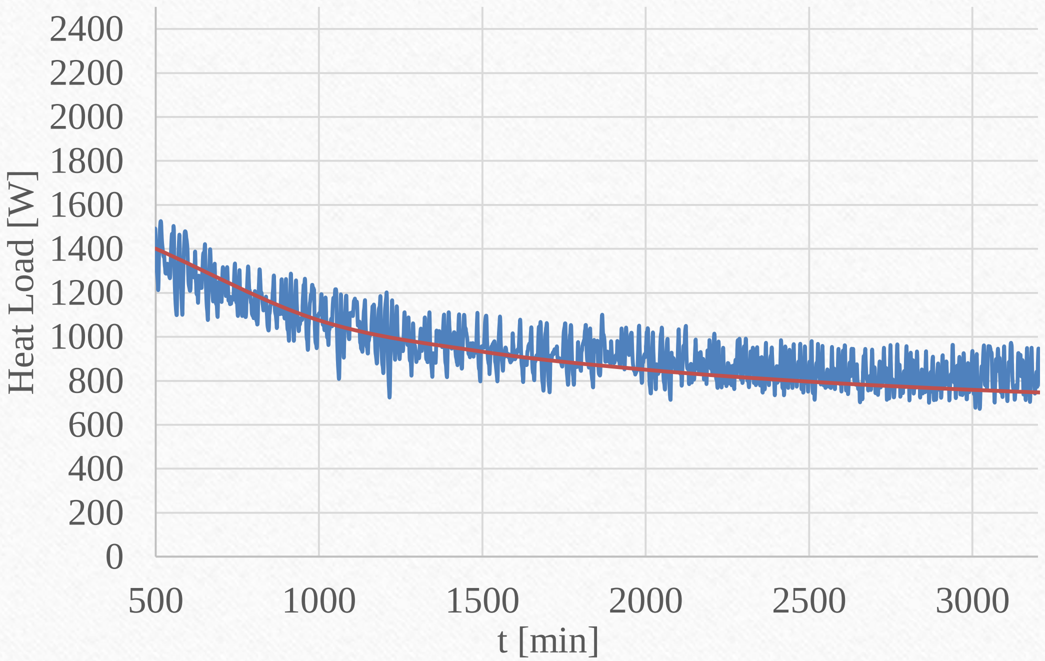
GHE Boundary Condition

$$T = T_{avg\text{-}exp}$$

Computation
Fitting Modeling Results to Experimental

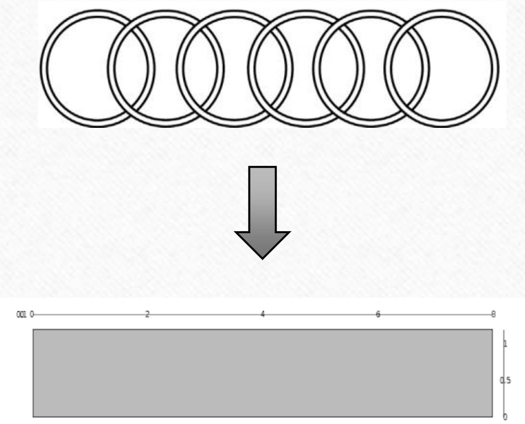
Heat load is calculated following eq.:

$$\dot{q}_{GHE-Slinky} = mc_p(T_{flow} - T_{return})$$



Extending the results to field scale

3D Slinky GHE



3D Slinky Plate Geometry

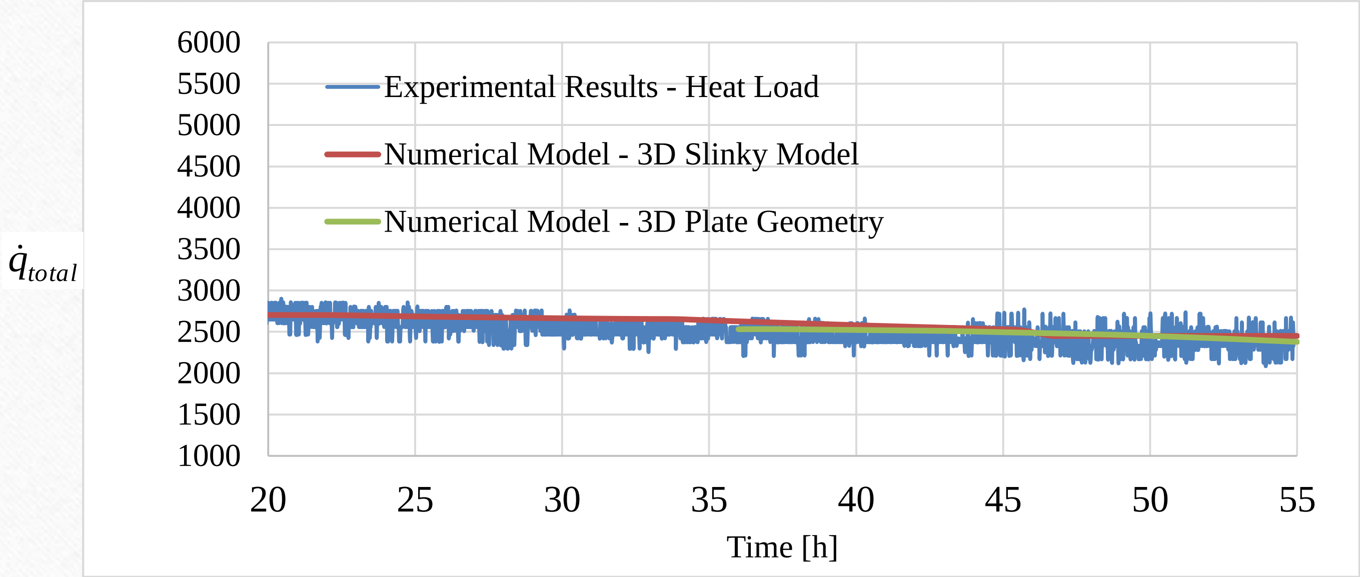
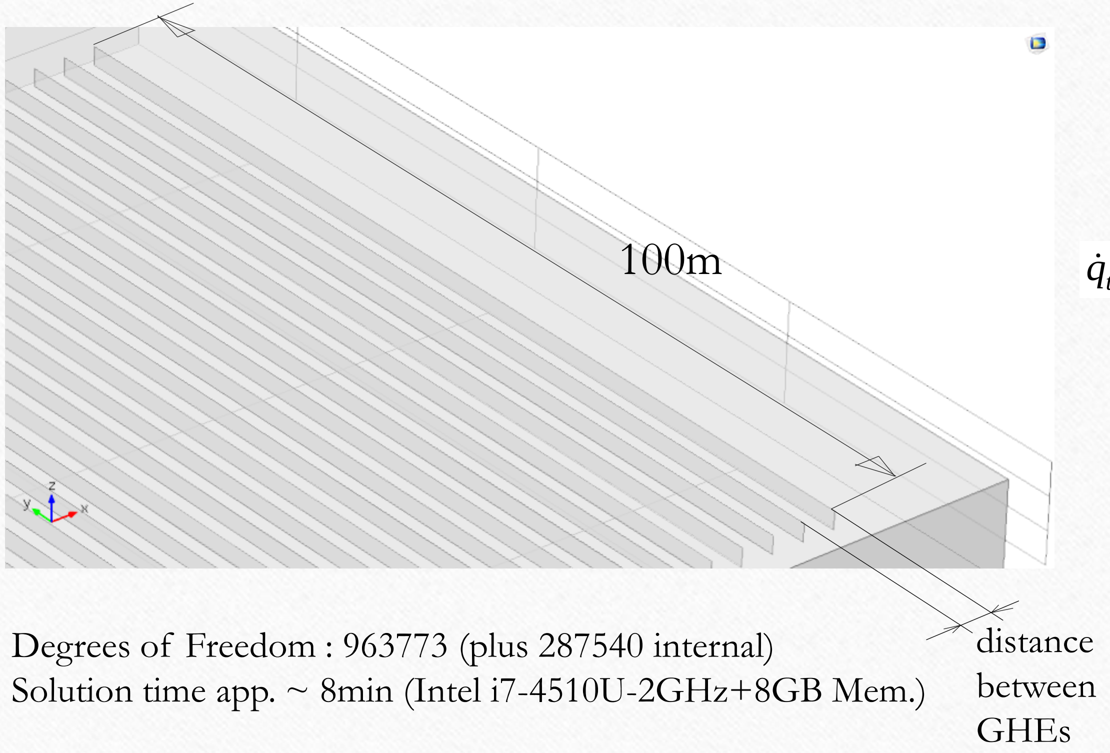


Fig. Field Application of Slinky GHE.

Effect of distance between GHEs



Degrees of Freedom : 963773 (plus 287540 internal)
Solution time app. ~ 8min (Intel i7-4510U-2GHz+8GB Mem.)

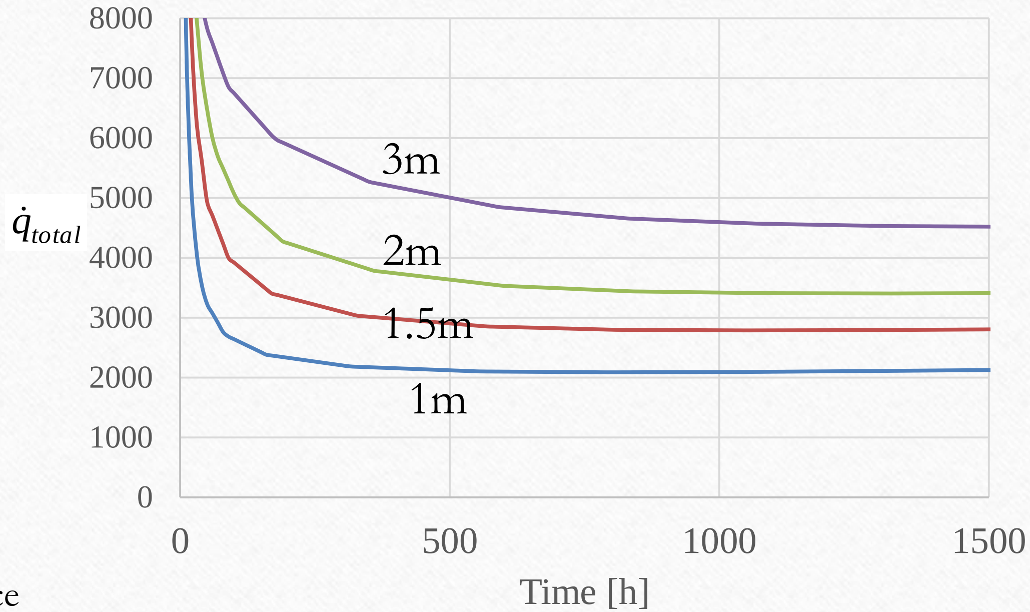


Fig. Heat load for one line(100m), for yearly working condition

Simulation Results

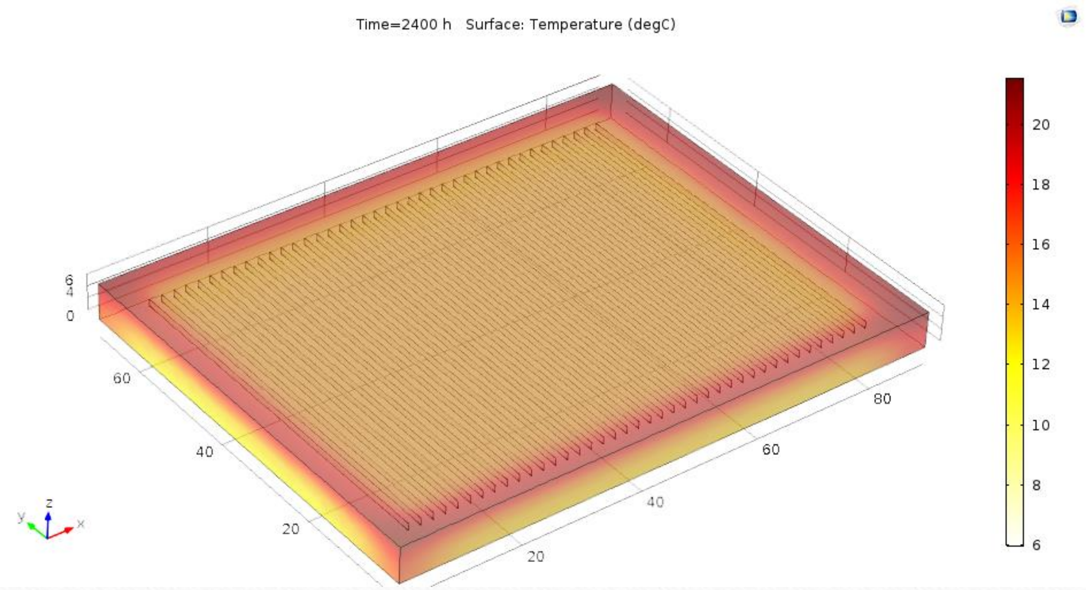


Fig. Simulation results.

Table. Heat value obtained from the 60m x 80m field at the end of the 2400h non-stop running condition.

Distance between trenches [m]	Obtainable heat load from ground [kW]		Given Heat to Greenhouse [kW]
	One Layer	Double Layers	Total Heat (COP:4)
1	172	309	412
1.5	149	275	366
2	136	258	344
3	117	228	304

Conclusions

- A horizontal ground heat exchanger system model is built for a greenhouse.
- Slinky geometry is used as vertically that can be located in narrow trench easily.
- Experimental results of a sample vertical slinky is imported in COMSOL and using them in the model, the model is validated.
- It is shown that double layer with 1.5m distance between each loop is given best performance for 60mx80m application field.
- Up to 366 kW heat energy can be supplied to greenhouse with gshp system.
- This system can be used for auxiliary system with other resources and yearly acclimating cost of the greenhouse can be decreased considerably.

Thank You For Attention