Why do refrigerant-based geothermal systems feature such compact ground loop systems?

A refrigerant-based geothermal heat pump is a closed-loop geothermal system in which refrigerant, typically R-410A, flows through copper tubing buried in the ground. These systems feature an uninterrupted flow of refrigerant and do not rely on an intermediate pump or heat exchanger.

Thanks to the combination of R-410A refrigerant and copper, refrigerant-based geothermal systems rely on a compact ground loop system and allow for a smaller heat exchanger in residential applications. The simplicity of refrigerant-based geothermal heat pumps – relying on a one-step heat exchange process, and combining R-410A refrigerant and a highly conductive material like copper – not only translates into higher efficiencies, but also to lower installation cost, due to the smaller loop requirement per ton of nominal capacity.

This can be explained by Fourier's Law for conductive heat transfer:

Fourier's Law (1807): $Q = -k * A * \frac{dT}{dx}$

Q : Conductive heat transfer (BTUH)
k : Thermal conductivity (BTU/ (h.°F.ft^2))
A : Surface area (ft^2)
$\frac{dT}{dx}$: Temperature gradient (°F/ft)

Fourier's Law describes all conductive heat transfer processes, including the one that takes place in refrigerant-based geothermal, where heat travels through the earth, the grout (for drilled-in systems) and the copper loop to reach the refrigerant inside the tubing. The conductive heat transfer (Q) will be positive in heating mode (the loops gain heat) and negative in cooling mode (the loops lose heat). Fourier's Law shows that the heat transfer rate is directly proportional to the magnitude of the temperature difference across the layer, the heat transfer area and the thermal conductivity of the material it is traveling through, and is inversely proportional to the thickness of the layer.

Copper ground loops have a very high thermal conductivity (k), meaning the overall thermal conductivity of the ground loops is slightly higher than that of plastic or other materials. Most importantly, the combination of copper and R-410A refrigerant allows for a larger temperature gradient ($\frac{dT}{dx}$ or "delta T") than HDPE and an antifreeze solution would. Since we are trying to achieve a fixed and pre-determined conductive heat transfer amount (Q) to meet the load demand of the home, having a larger temperature gradient and a better thermal conductivity allows for a minimized surface area (A). This explains why refrigerant-based geothermal systems can rely on more compact ground loop systems than antifreeze-based systems.

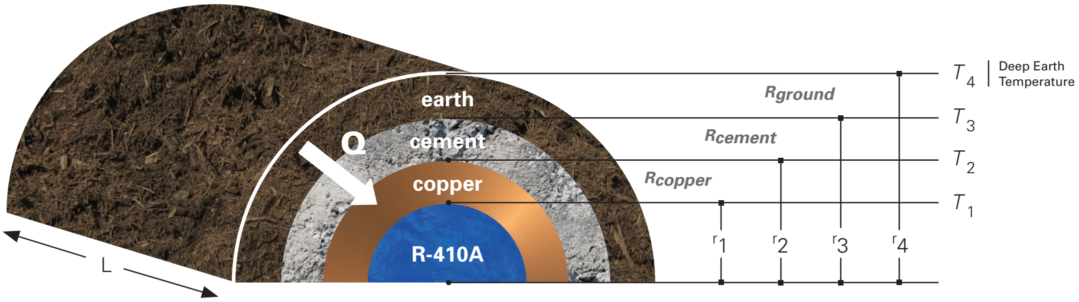
Fourier's Law also underlines the importance of proper sizing and proper installation in any and all geothermal systems: once an installation is completed, all the parameters of the equations are set by the field conditions and the loops installed. This means that the maximum conductive heat transfer (Q) that the loop field can receive is set. If the system was improperly sized or improperly installed, one may end up with a heat transfer too small to generate the system capacity necessary to meet the house heating and cooling loads, thus resulting in unsatisfactory temperatures in the home.

Case of a multilayered cylinder:

$$Q = \frac{2\pi * L * (T4-T1)}{\frac{\ln\left(\frac{r2}{r1}\right)}{k_{copper}} + \frac{\ln\left(\frac{r3}{r2}\right)}{k_{cement}} + \frac{\ln\left(\frac{r4}{r3}\right)}{k_{ground}}}$$

Q : Conductive heat transfer (BTUH)
k_{copper} / k_{cement} / k_{ground} : Thermal conductivity (BTU/ (h.°F.ft^2))
A : Surface area (ft^2)
$\frac{dT}{dx}$: Temperature gradient (°F/ft)

T1 / T2 / T3 / T4 : Temperatures at the surface of the layer (°F)
r_1 / r_2 / r_3 / r_4 : Radius of the layer
R_{copper} / R_{cement} / R_{ground} : R-value or Thermal resistance of the layer ((ft^2.°F.hr)/BTU)



For more information on refrigerant-based geothermal systems, as well as compact ground loop systems, please contact Gregor Vialette at **gvialette@earthlinked.com** or by phone at **863-701-0096 ext. 225.**