Ground Heat Exchanger Model Uncertainty
("Why Ground Loops Sometimes Do Better than the Experts Predict")

Several efforts have been developed to model ground heat exchangers and some are tied to building energy programs. Almost all of these models are conduction computations and several are quite sophisticated in spite of the fact they ignore a primary mode of ground loop cooling, soil moisture evaporation with recharge. Some make adjustments for ground water movement in spite of the fact that local water velocities can not be determined without very sophisticated and expensive tests.

In some cases these models agree with the very limited number of monitored sites that are currently available. In some cases the models can predict short-term overheated loops that occur when vertical bores are insufficiently spaced, low conductivity materials are placed in the bore annulus, insufficient loops lengths are installed in warm, dry soils, or excessive cooling-to-heating imbalances occur in buildings. There are also cases in which loops that models suggest should be overheating, that are working just fine.

A residential installation in Tuscaloosa, AL has been operating 22 years and has not experienced any upward drift in temperature even though the vertical loop consists of nine-65 ft. bores on 15 ft. centers (max. temp 87ºF). The ground was 66ºF at start-up and is clay, sandy clay and a seam of gravel and sand. A nearby installation has operated for four years and the warmest return water was 74ºF and coldest 56ºF (62ºF normal soil, four bores 165 ft., 25 ft. separation, 35 ft. of sandy clay and 130 ft. of hard shale). This installation has thermal grout but the loops in the older installation are backfilled with a mixture of cuttings and sand. The long term temperature increase at both sites is non-existent.

Because of the complexity of the ground at many sites, heat exchanger performance is difficult to predict. Furthermore, the models available do not appear to fully consider the substantial cooling effect resulting from phase change that occurs when soil moisture levels are reduced as a result of heat input. The following calculation demonstrates why models based only on conduction (even with groundwater movement corrections) grossly over-predict long term temperature rise.

Ground loop description:

10 x 10 grid with 20 ft. spacing, 250 depth, 55ºF initial ground temperature
Dry density 120 lb/ft^3, Specific heat (dry) 0.21 Btu/lb-F, 15% moisture by weight

Thus:
ρ = 120 lb/ft^3 + 0.15 * 62.3 lb/ft^3 =129 lb/ft^3 (moisture fills voids, no added volume)
c_p = 0.85 * 0.21 + 0.15 * 1.0 = 0.33 Btu/lb-F
Heat required to raise the average loop field temperature 1ºF:

Q = Volume * ρ * cp *Δt
Volume = 200 ft. * 200 ft. * 250 ft. = 1 x 10^7 ft^3

$Q = 1 \times 10^7\ ft^3 * 129\ lb/ft^3 * 0.33\ Btu/lb\text{-}F * 1°F = 4.26 \times 10^8\ Btu$

Now consider the heat required to reduce the moisture content 1%:

$m_w = Volume * \rho_w * 1\%$
$m_w = 1 \times 10^7\ ft^3 * 62.3\ lb/ft^3 * 0.01 = 0.623 \times 10^7\ lbs.$
$Q = m_w * h_{fg}\ @\ 55°F = 0.623 \times 10^7\ lb * 1062\ Btu/lb$
$= 6.62 \times 10^9\ Btu$

Thus the heat required to dry the soil by 1% moisture content is over 10 times the heat required to raise the loop field temperature 1ºF. Additionally, the moisture will be replaced after the next good rainfall if the soil is porous.

Even if a sophisticated model of the ground heat exchanger that includes, conduction, water movement, and phase change (which would also include soil freezing in cold climates) were developed, the information required to drive the model would rarely be available even with a sizable field testing budget. Thus, we should recognize the range in uncertainty of our economic predictions. The industry should place greater efforts to improve predictions by locating GSHP systems that closely follow recommended practices and measuring a few critical indicators at a large number and variety of high quality sites.

ASHRAE continues to place a great deal of creditability on energy models to predict energy performance, develop design tools, and generate life cycle cost analysis. The recent research and publication direction of Technical Committee 6.8 (Geothermal Energy) generally mirrors this approach. Although some, including myself, have suggested that an equivalent effort to gather empirical data from actual field installations is a prudent course of action since these models can not accurately predict long-term temperature change without a thorough understanding of the porosity and water movement characteristics of the entire ground formation.

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