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Ground-source heat pump systems: The first century and beyond

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Editorial
Ground-source heat pump systems: The first century and beyond

This special issue of *HVAC&R Research* focuses on ground-source heat pump (GSHP) systems and is published on the eve of the hundredth anniversary of the first patent (Zoelly 1912) on a ground source heat pump. Despite the early patent date, development of GSHP systems was relatively intermittent until the late 1970s (Spitler 2005). Since then, the energy efficiency of GSHP systems has led to continued growth in the number of installations and in related research. While the heat pump in a GSHP system relies on the same technology as a conventional heat pump, the ground heat exchanger and various aspects of heat transfer to and from the ground remain active areas of research addressed by papers in this special issue.

Before presenting a summary of the content of this issue and our perspective on future GSHP research, it is worthwhile to describe how this special issue came about. About a year ago, we issued a call for papers to some 80 researchers worldwide. Approximately 25 papers were submitted out of which 16 passed the review process and are presented in this special issue. The authors represent nine countries, demonstrating the worldwide interest in GSHP systems.

There are several inherent difficulties in modeling and sizing ground heat exchangers: diverse length and time scales, unknown inhomogeneity of the ground, and high capital cost. Each one of these difficulties has implications that motivate research.

Diverse length and time scales

The domain of interest for ground heat exchangers (GHX) is quite broad—short time performance is governed by heat transfer near the pipe and within the borehole, with length scales on the order of 6 in (15 cm). Long-term performance is governed by borehole-to-borehole interference and end effects, where boreholes are typically on the order of 20 ft (6 m) apart, 200–400 ft (60–120 m) deep and larger borehole fields often have dimensions that exceed 200 ft (60 m) horizontally. The shortest time scale of interest is the residence time of the fluid in the ground heat exchanger, on the order of 5 min. Daily and annual cycles are certainly important. But, unusual for building HVAC&R systems that are sized for peak conditions, long-term heat build-up in the ground is also important for many GSHP systems, taking many years to reach an approximately steady periodic response.

Accounting for all of the length and time scales properly requires vast computational resources. This, in turn, has spawned a number of innovations in modeling with the general goal being to have acceptable computational speed with sufficient accuracy. In this issue, the following papers address this subject. Claesson and Hellström examine steady-state borehole heat transfer using the multipole method. Kim et al. and Verhelst et al. apply model reduction techniques to improve computational speed. Fossa presents

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a method to generate approximate response functions (*g-functions*) for various bore field geometries. The short-time step performance of coaxial and double U-tube boreholes is examined by Zarella et al.

Unknown in homogeneity of the ground

Both of the editors come from mechanical engineering backgrounds and no matter how fervently we might wish for the simplicity of a ground that is homogeneous with constant properties and periodic boundary conditions, the actual environment is considerably more complicated. A test borehole will often reveal multitudinous different rock and soil layers that, no matter how carefully characterized by visual inspection of the drill cuttings, cannot be readily translated to a set of layer-by-layer thermal properties. Furthermore, these layers are not necessarily horizontal or uniform over the ground heat exchanger field. Ground thermal properties can vary substantially with moisture content and water table level. Heat transfer can deviate from pure conduction due to saturated and unsaturated moisture transport caused by aquifer flows, rainfall, groundwater recharge, and evapotranspiration, all of which are transient, changing throughout the year.

These complexities have led to development of thermal response tests (TRT) for in situ measurement of thermal properties and continued research into improving the accuracy, reducing the time, and improving the quantity of information provided by thermal response tests. A number of papers address these issues. Rainieri et al. reviewed the various modeling approaches involved in TRT tests. The impact of groundwater flows on TRT is examined by Lee et al. and Chiasson et al. Acuña et al. performed experiments to determine the vertical distribution of ground thermal conductivity using distributed temperature measurements along the borehole depth. Bandos et al. provide a methodology, based on the line-source theory, to estimate steady-state temperatures in grounds composed of various layers.

High capital costs

GSHP systems usually cost significantly more than conventional HVAC systems, due to the high installation cost of the ground heat exchangers. This high incremental cost results in a large penalty for design procedures that oversize the ground heat exchanger and a continual motivation to search for less expensive ground heat exchangers. Therefore, validation of existing ground heat exchanger simulations that serve as the basis for design procedures and development of simulations that support alternative ground heat exchanger designs are of significant interest. The following papers address these issues. Philippe et al. present a semi-analytical model, validated with experiments, of serpentine horizontal ground heat exchangers. An experimentally-validated model for ground heat exchangers placed horizontally along the foundation of a residence is presented by Xing et al. Analytical models of pile ground heat exchangers which incorporate a spiral are developed by Man et al. The potential for using standing column wells for heating and cooling purposes is examined by Ng et al. Pertzborn et al. analyzed experimental data from a hybrid GSHP system to validate a ground heat exchanger model. Raymond et al. examine heat transfer beneath exothermic rock piles.

Future Research Needs

Looking forward to the next century of GSHP systems, we would like to offer our perspective and those of known researchers in the field on knowledge gaps and future research needs related to GSHP systems. Some of these items are on the research agenda of ASHRAE Technical Committee 6.8, Geothermal Heat Pump and Energy Recovery Applications. But this list goes far beyond the level of research funding that might be sustained by a single ASHRAE Technical Committee. In some respects this list may be considered both a "wish list" for both future research and a future special issue of this journal.

- *Experimental validation of the long-term performance of ground heat exchangers.* Despite the obvious importance of validating the simulations that form the basis of design procedures, high quality measured data covering a number of years of operation remains elusive. The Peartzborn, et al. paper in this issue illustrates some of the problems with using the type of data sets that are commonly collected with building energy management systems. Collection of high quality data will require a long-term commitment by a funding agency or other committed sponsor.

- *Accounting for near-surface effects in ground heat exchanger models.* To date, most models of ground heat exchangers have relied on extreme simplifications of the surface boundary conditions. For vertical heat exchangers, this has been justified by the presumed relatively small effect. For horizontal heat exchangers, there has been relatively little work that supports modeling of horizontal systems at a level of detail appropriate for hourly energy calculations, where interaction with the aboveground environment is important. Development of models that account for near-surface effects would allow better design and analysis of horizontal heat exchangers and investigation of the effects of the distribution system on vertical system performance.
- *More detailed treatment of the underground.* In this issue, several of the papers address thermal response test methods that may be used to estimate depth-varying thermal properties or groundwater flow. However, at present there are relatively few models that could take advantage of this information and this remains an area where further research and development is needed.
- *New ground heat exchanger designs.* With the introduction of thermally enhanced grouts and spacers and with continued refinements to borehole modeling, the required vertical borehole length for a given load has been reduced over the last few decades. New borehole designs and drilling techniques will have to be introduced to further reduce borehole length (and cost). One possible way to reduce borehole length at peak conditions would be to include phase change materials inside boreholes to take advantage of the high energy content associated with the latent heat of fusion of some materials. Research into other alternative designs, including direct expansion systems, foundation pile heat exchangers and enhanced coaxial tube heat exchangers is also needed.
- *New system configurations and supporting models.* Hybrid GSHP systems that use supplemental heat rejection equipment to balance the ground heat exchanger load from cooling-dominated buildings have been quite common in recent years. For heating-dominated buildings, limited work on hybrid GSHP systems that use solar energy or waste industrial heat to seasonally store energy has been reported. Further research would be helpful to clearly identify situations where such systems would be cost-effective.
- *Moisture transport in the ground and ground freezing.* With a few exceptions, most ground heat exchanger models neglect both unsaturated moisture transport in the ground and saturated flows below the water table. Clearly, more work is needed in this area to identify models and solution schemes that adequately represent the physics of this combined heat and mass transfer problem at acceptable computational cost. Carefully planned experiments would, as always, be an asset to corroborate any new model in this area. In heating mode and under certain soil conditions, the soil around the ground heat exchanger may freeze which can change the heat transfer significantly. This phenomenon has not received much attention in the literature.
- *Intermodel validation of GHX models.* There have been some efforts to compare vertical GHX design software (Shonder et al. 1999; Shonder et al. 2000). More recently, the present authors (Spitler et al. 2009) have been involved in a comparison of energy simulations of GHX. In both cases, notable differences were reported which prompted some changes in some methods and indicate the usefulness of such exercises. However, there is a need to standardize these tests to cover the full spectrum of conditions much like what has been done for building energy simulation programs with BESTEST.

Finally, the guest editors would like to thank the reviewers; without the help of about 50 reviewers it would not have been possible to produce this high-quality special issue. Also we would like to specially thank the Editor-in-Chief, Reinhard Radermacher, and the Journal Editorial Assistant, Mary Baugher, for their continued support through this whole process.

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