EDITORIAL

Ground-Source Heat Pump System Research—Past, Present, and Future

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Ground-source heat pump (GSHP) systems are perhaps the most widely used "green" HVAC system, with an estimated 1.1 million[1] ground-source heat pumps installed worldwide. These systems may be closed-loop ("ground-coupled") or open-loop. The frequency of use tends to vary regionally, depending to some degree on building load profile, geology, environmental regulations, and human infrastructure. This editorial reviews past research, from the 1940s to present, and looks forward to what advances may be expected in the future.

A Swiss patent issued in 1912 to Heinrich Zoelly is the first known reference to ground-source heat pump systems.[2] In the US, some ground-source heat pump systems were installed just prior to World War II[3] and post-war, installations began to take off. At the same time, about a dozen research projects involving laboratory investigations and field monitoring were undertaken by US electric utilities. In addition, analytical investigations by Ingersoll et al.[4] provided some of the theoretical basis for later design programs. After some time, interest in further research waned—apparently, problems with drying around horizontal ground-loop heat exchangers,[5] leakage,[6] and undersizing[7] led to the gradual cessation of new installations.

Research began again in the late 1970s after the oil crisis and initially followed much of the same paths as the 1940s research, with an emphasis on experimental testing. This research did lead to solutions for several of the problems associated with the 1940s installations: drying around horizontal ground-loop heat exchangers was resolved with better backfilling techniques,[8] leakage problems were substantially resolved with the use of heat fusion and polybutylene and high-density polyethylene pipe, and undersizing problems were alleviated to some degree with new sizing algorithms[9] and programs[10] implemented on personal computers.

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[1]Lund. J, et al. 2004. *Geothermal (Ground-Source) Heat Pumps—A World Overview*. Geo-Heat Center Bulletin, September.

[2]Ball, D.A., R.D. Fischer, and D.L. Hodgett. 1983. Design methods for ground-source heat pumps. *ASHRAE Transactions* 89(2):416-440.

[3]Orio, C. 2005. Water Energy Distributors, Inc. Private communication.

[4]Ingersoll, L.R., et al. 1951. Theory of earth heat exchangers for the heat pump. *ASHVE Transactions* 57:167-188.

[5]Ambrose, E.R. 1966. *Heat Pumps and Electric Heating*. New York: Wiley. p. 16.

[6]See discussion in Sanner, B. 2001. Some history of shallow geothermal energy use. International Summer School on Direct Application of Geothermal Energy, Skopje. Available online at http://www.geothermie.de/tagungkongresse/vortragsprogramm_igd_2001.htm.

[7]Kroeker, J.D. 1949. In a comment on the paper: Guernsey, E.W., P.L. Betz, and N.H. Skau. Earth as a heat source or storage medium for the heat pump. *ASHVE Transactions* 55:321-324. Kroeker's comments may be found on pp. 336-337.

[8]IGSHPA. 1988. Closed-Loop/Ground-Source Heat Pump Systems – Installation Guide.

[9]Bose, J.E., J.D. Parker, and F.C. McQuiston. 1985. *Design/Data Manual for Closed-Loop Ground-Coupled Heat Pump Systems*. Atlanta: ASHRAE.

[10]Eskilson, P. 1987. Thermal analysis of heat extraction boreholes. Ph.D. thesis, University of Lund, Sweden.

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At the same time, installation of systems for residential buildings became increasingly commonplace in many parts of the US. In the last 15 years, commercial applications[11] have increased to the point where they are dominant. This increased focus on commercial systems drove research[12] in several areas, primarily related to reducing first cost while maintaining low operating costs:

- System simulation—To some degree, computer simulation of GSHP systems supports most of the following research topics. In its own right, however, it is of interest simply for energy calculation purposes and being able to provide estimates of operating costs to support decision making. Development of ground-loop heat exchanger models[13,14] that were incorporated into component-based modeling environments facilitated both energy calculations and investigations of various design options.
- Because commercial buildings are often cooling-dominant, the net imbalance of heat rejected to the ground each year can result in long-term temperature rise of the loop and, consequently, reduced performance of the heat pumps. In the design process, this may be mitigated by increasing the size of the ground-loop heat exchanger. Alternatively, an additional heat rejection mechanism may be incorporated into the system. This is often a cooling tower but may include useful applications such as water heating or snow melting. Initial implementations of hybrid GSHP systems used the simplest possible control strategy—switching the cooling tower on when the loop temperature exceeded a setpoint. Recent research[15] has shown that it is possible to reduce both the first cost and the operating cost by operating the supplemental heat rejection in a more optimal manner.
- Research into optimization of the ground heat transfer by increasing grout thermal conductivity[16,17] and improving the borehole design[18] has allowed reduction in ground-loop heat exchanger sizes and lower first costs.
- In situ measurement techniques[19-21] for ground thermal conductivity were developed to reduce uncertainty in the design of large commercial systems, where overly conservative estimates of ground thermal conductivity may result in ground-loop heat exchangers significantly larger than needed. For some projects, the unnecessary excess cost may rise to tens of thou-

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[11]Numerous case studies of GSHP systems applied to commercial buildings may be found at the Web site of the Geothermal Heat Pump Consortium http://www.geoexchange.org/.

[12]It is the author's observation that, in the GSHP field, it is not unusual for practice to lead research. Some ideas that are tried by practitioners and seem to offer some promise create their own demand for research to quantify effects and develop design tools. Examples include hybrid ground-source heat pump systems and slinky-type heat exchangers.

[13]Pahud, D., and G. Hellström. 1996. The new duct ground heat model for TRNSYS. *Eurotherm Seminar No. 49*, Eindhoven, The Netherlands, pp. 127-136.

[14]Yavuzturk, C., and J.D. Spitler. 1999. A short time step response factor model for vertical ground loop heat exchangers. *ASHRAE Transactions* 105(2):475-485.

[15]Yavuzturk, C., and J.D. Spitler. 2000. Comparative study to investigate operating and control strategies for hybrid ground source heat pump systems using a short time-step simulation model. *ASHRAE Transactions* 106(2):192-209.

[16]Remund, C. 1999. Borehole thermal resistance: Laboratory and field studies. *ASHRAE Transactions* 105(1):439-445.

[17]Allan, M.L., and S.P. Kavanaugh. 1999. Thermal conductivity of cementitious grouts and impact on heat exchanger length design for ground source heat pumps. *International Journal of HVAC&R* 5(2):85-96.

[18]Hellström, G., and E. Kjellson. 2000. Laboratory measurements of heat transfer properties for different types of borehole heat exchangers. *Proceedings of Terrastock 2000, Stuttgart, Germany, August 28-September 1, 2000*. Vol. 1, pp. 183-188.

[19]Austin, W., C. Yavuzturk, and J.D. Spitler. 2000. Development of an in-situ system for measuring ground thermal properties. *ASHRAE Transactions* 106(1):365-379.

[20]Eklöf, C., and S. Gehlin. 1996. TED—A mobile equipment for thermal response test. Master of Science thesis 1996:198E Luleå University of Technology, Sweden.

[21]Gehlin, S., and J.D. Spitler. 2003. Thermal response test for BTES applications—State of the art 2001. *Proceedings of Futurestock 2003 -- 9th International Conference on Thermal Energy Storage, Warsaw, Poland, September 1-4, 2003*, pp. 381-387.

sands of dollars. The measurements are based on an inverse conductive heat transfer analysis of a thermal pulse imposed on the ground. Considerable practical interest in keeping the test as short as possible has driven quite a bit of research[22-25] into analysis procedures.

With large numbers of installations each year, and a growth rate of about 10% per year, the GSHP field is, in one sense, beyond the research stage. However, it may be anticipated that further research will allow better system performance and lower first costs. Speculating on future developments that are primarily incremental improvements on the current state of the art, one might foresee the following developments:

- *Development of computationally efficient methods for simulating ground-loop heat exchangers in configurations other than vertical borehole heat exchangers.* Little or no work has been done to model horizontal systems at a level of detail appropriate for multi-year hourly energy calculations, where interaction with the aboveground environment is important.
- *Development of more cost-effective borehole heat exchangers.* As drilling and installation of the borehole heat exchangers are generally the largest part of the first cost, efforts will continue to develop borehole heat exchangers that can be installed quickly and offer better performance, in turn allowing fewer boreholes.
- *Development of lower cost methods for estimating ground thermal properties.* Ground thermal properties are a key parameter for design of GSHP systems, but they cannot be reliably estimated without an in situ measurement involving drilling of a test borehole. Possible future advances may come from development of methods that allow faster tests or, perhaps, from some more revolutionary procedure.
- *Applications of hybrid ground-source heat pump systems will continue to grow.* Additional applications will be facilitated by design methodology that incorporates system simulation, allowing the simultaneous interactions between the building systems, supplemental heat rejecters, and ground-loop heat exchanger to be resolved.
- Furthermore, additional research into optimal control strategies for hybrid ground-source heat pump systems will result in optimal loop controllers being available as part of the building energy management system or as stand-alone devices.

In summary, after an initial flurry of research and installations about 60 years ago, and a second phase starting about 30 years ago, the ground-source heat pump industry has matured from a technology standpoint, yet continues to be dynamic, with rapid growth rates. Current and future research is expected to support additional growth in the industry, and, as a result, lower energy consumption and pollution.

[22]Shonder, J.A., and J.V. Beck. 1999. Determining effective soil formation thermal properties from field data using a parameter estimation technique. *ASHRAE Transactions* 105(1):458-466.

[23]Beier, R.A., and M.D. Smith. 2003. Minimum duration of in-situ tests on vertical boreholes. *ASHRAE Transactions* 109(2):475-486.

[24]Witte, H.J.L., G.J. van Gelder, and J.D. Spitler. 2002. In situ measurement of ground thermal conductivity: The Dutch perspective. *ASHRAE Transactions* 108(1):263-272.

[25]Gehlin, S., and G. Hellström. 2003. Comparison of four models for thermal response test evaluation. *ASHRAE Transactions* 109(1):131-142.