GEOTHERMAL HEAT PUMPS:
Developing New Design, Simulation Methodologies, and Tools for Geothermal Pump Systems

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KEY WORDS

heat pumps, geothermal heat pumps, ground-source heat pump systems, ground-coupled heat pump systems, ground-loop heat exchangers, boreholes, BLAST (Building Loads Analysis and System Thermodynamics)

PROJECT BACKGROUND AND STATUS

While ground-source heat pump systems initially became popular for residential buildings, they are increasingly being used in the commercial building sector. Use in these applications requires the ground loop heat exchanger design to account for the same thing as a residential design: ground thermal properties, undisturbed ground temperature, expected peak capacity, etc. However, several additional factors become very important when designing a commercial-building ground-loop heat exchanger that may usually be safely ignored in a residential design: annual load profile, usually described in terms of monthly cooling and heating loads; and borehole configuration and the resulting interaction between boreholes.

Although a number of approximations may be made when designing commercial-building ground-loop heat exchangers, designers must be careful not to fall into one of two extremes: 1) using approximations that under-estimate the required size, so that the system fails after construction; or 2) using approximations that significantly over-estimate the required size, so that the system cannot be cost-competitive.

While a number of design tools have been available, they have often been difficult to use and/or not very accurate. Research at OSU has been aimed at: improving the ease-of-use of available design software and increasing its accuracy. The work described in this report is an extension of those efforts. The tasks described in this report were jointly funded by the Department of Energy and the Department of Defense through the Strategic Environmental Research and Development Program.

PROJECT OBJECTIVES

The general objective of this project is to expedite the selection and design of ground-loop heat exchangers for commercial-building ground source heat pump systems. In order to accomplish this, improvements in the currently available design tools and methods are necessary. The specific objectives are listed below.

Technical Objectives

- Integration of an existing ground loop heat exchanger model with the water loop heat pump system model of BLAST.
- Investigate optimization techniques that can help users of such programs automatically select the 'best' ground loop heat exchanger design.

Expected Outcomes

- A version of BLAST which incorporates a ground loop heat exchanger model coupled to the water loop heat pump system model.
- New methods for selecting and optimizing ground loop heat exchanger designs for individual buildings.

APPROACH

The existing water loop heat pump system model is used for conventional systems which incorporate a number of water source heat pumps on a water loop, and a boiler and cooling tower or fluid cooler which serve as the ultimate heat source/sink. In the ground loop system, the ground loop heat exchanger replaces both the boiler and the cooling tower.

This will allow a more accurate solution, as the two models can be coupled more closely, and perhaps more importantly, will be more convenient for the designer to use. Both improvements will allow comparisons to be made between ground-source heat pump systems and conventional systems with greater convenience and accuracy.

The integration of the ground loop heat exchanger model with the water loop fan system model of BLAST was accomplished by creating a new 'control strategy' for the water loop temperature that allows the loop temperature to float based on the ground loop performance. The solution procedure iterates until the monthly fluid temperatures predicted by the ground loop heat exchanger model and the water loop fan system model converge. BLAST has also been modified to allow multiple year system simulations, so that if a user would like to simulate the 20th year of operation, BLAST will perform 20 years of system simulation, taking into account the history of the ground loop.

The selection and optimization of ground loop heat exchanger designs has been divided into two phases: automated selection of borehole configurations that will work for a specific site and determination of optimal borehole length for each configuration. The 'best' ground loop heat exchanger design is the one with the lowest life cycle cost.

The selection phase takes as input the monthly heating and cooling loads, the peak heating and cooling loads, the ground thermal properties, heat exchange fluid properties, heat pump performance data, maximum/minimum entering fluid temperatures, and the maximum length, width, and depth of the borehole field. Using the peak heating and cooling loads, a set of three candidate configurations is chosen. Each of the three candidate configurations are sized, and then an average total ground loop heat exchanger length is determined. Using this length as an estimate of the required length, all 146 vertical configurations are checked as to whether or not they meet the size constraints, if they have a total ground loop heat exchanger length as estimated above. This provides a short list of potential configurations, which then may be individually sized and/or optimized to find the best configuration.

The optimization problem is initially limited to minimizing the life cycle cost using the user-defined borehole depth as the independent variable. The input parameters for this optimization routine include rates for drilling, piping, heat pumps and circulating pumps, as well as electricity rates. Using these additional parameters, the life cycle cost can be determined for a single borehole configuration. The life cycle cost is then treated as the objective function, and a golden section search (one-dimensional, unimodal) is utilized to find the optimal borehole depth.

RESEARCH RESULTS

Several important research results have been obtained:

- The integration of the ground loop heat exchanger model with the water loop fan system model of BLAST was successful. It offers several advantages in terms of convenience and accuracy for comparison of ground source heat pump systems with conventional systems.

- The approximations that are currently made, to allow the ground loop heat exchanger to be designed sequentially after the building simulation has been performed, appear to be adequate for design purposes.

- The automated selection procedure appears to be very useful and convenient when designing a ground loop heat exchanger.

- An unanticipated result was that the optimal borehole length appears to always be the minimum borehole length that will meet the temperature constraints. While rendering the optimization procedure unnecessary, this does point to the importance of accurate sizing procedures. Even with very high electricity rates and very low drilling costs, nothing is to be gained by making the ground loop heat exchanger longer than necessary.

FUTURE PLANS

Future plans include a number of further refinements to the design tools both in convenience and in accuracy. The improvements in accuracy will primarily be aimed at allowing better comparisons to be made and allowing additional system features to be investigated.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

A wide variety of industry interest has been expressed, primarily in the improved tools for design of ground loop heat exchangers. The design tools have been cited in the new ASHRAE Comercial/institutional Ground-Source Heat Pump Engineering Manual. The ground loop heat exchanger simulation methodology has been transferred to the BLAST program through the BLAST Support Office at the University of Illinois at Urbana-Champaign.

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