Optimal Ground-Source Heat Pump System Design

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Lawrence Apartments – Princeton University
(Photo from Google Earth)

ENVIROM International
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Track: GSHP Demonstration Projects

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Project Team

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Overview

➢ Timeline:
  • Project Start: April 1, 2010
  • Project End: March 31, 2011

➢ Budget:
  • Total Project Funding: $138,998
  • DoE Share: $109,999
  • FY10 Funding: $109,999

➢ Barrier to be addressed:
  • Reduced capital and operational GSHP cost
Project Objectives

- Develop a least-cost design tool (OptGSHP) that will enable GSHP developers to analyze system cost and performance in a variety of building applications to support both design, operational and purchase decisions.

- Integrate groundwater flow and heat transport into OptGSHP.

- Demonstrate the usefulness of OptGSHP and the significance of a systems approach to the design of GSHP systems.
Optimal Hy-GCHP Design

Design Variables:

- \( L \): Number of boreholes
- \( d \): Number of HP’s
- \( T_{Heat\_GHX} \)
- \( \Delta T^+_{Cool\_Tower\_1} \)
- \( \Delta T^-_{Cool\_Tower\_1} \)
- \( T_{Cool\_Tower\_2} \)
- \( T_{Cool\_GHX} \)

Heating (i.e., \( T_{In} > T_{Out} \)):
- If \( T_{GHX} < T_{Heat\_GHX} \), then divert to GHX.

Cooling (i.e., \( T_{In} < T_{Out} \)):
- If \( T_{Out} - T_{WB} > \Delta T^+_{Cool\_Tower\_1} \), then divert to tower at low fan speed and flow rate until:
  \[ T_{Out} - T_{WB} < \Delta T^-_{Cool\_Tower\_1} \]
- If \( T_{Out} > T_{Cool\_Tower\_2} \), then operate tower at high speed.
- If \( T_{GHX} > T_{Cool\_GHX} \), then divert to GHX.
Optimal Hy-GCHP Design - 2

System Input
- e.g., soil thermal properties

System Simulator
- Heat Pump Model
- Groundwater Flow and Heat Transport Model
- Ground Heat Exchanger Model
- Cooling Tower Model

Initial Solution
- i.e., initialized decision variables

Optimizer
- Decision Variables
- Objective Function
- Constraints

Optimal Solution

Updated Solution
- Updated State

Optimal Hy-GCHP Design - 2
Objective Function:

- Lifecycle energy consumption
- Lifecycle energy cost
- Lifecycle total cost (i.e., capital and energy)
Optimizer - 2

➢ Design Variables:

• Control set point temperatures
• Heat pump compressor speed, fan speed, circulation pump speed
• Borehole length, borehole spacing
• Groundwater well discharge/recharge rates
• Groundwater discharge/recharge locations

➢ Design Constraints:

• Physical constraints on any design variable as applicable (e.g., maximum available space for boreholes) or economical constraints (e.g., budget)
Main Application

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Main Application - 2

- **Peak Load:**
  - 73 tons (cooling)
  - 555 MBh (heating)

- **Well field:**
  - 150 wells at 450 ft deep
  - 20 ft borehole spacing
Construct a mathematical model of the GCHP system (April 1 – May 30)
  • TRNSYS (Transient Energy System Simulation)

Construct a numerical model of groundwater flow and heat transport (April 1 – May 30)
  • FEHM (Finite Element Heat and Mass Transport)

Integrate the GCHP and groundwater flow and heat transport models (Jun 1 – Jul 31)
Project Tasks - 2

- Optimize the GCHP system in the absence of groundwater (Aug 1 – Oct 11)
  - OUTER (Outer Approximation Method)
  - GenOpt (Generic Optimization Program)

- Optimize the GCHP system in the presence of groundwater with assumed or potential well locations (Oct 12 – Jan 24)

- Parallel applications of OptGSHP to other GSHP systems (Aug 1 – Jan 24)
Project Tasks - 3

- Analysis of results (Jan 25 – Feb 21)

- Final Report (Jan 26 – Mar 31)
  - Submission of data to National Geothermal Data System including “Rules of Thumb” that will serve consumers in designing and operating GSHP systems in a variety of building applications, climate zones and ground conditions.
  - Research paper preparation
The simulation-optimization based approach to the design of GSHP systems can achieve significant cost savings in the installation as well as operation of such systems.

Existing groundwater flow and related convective heat transport should be quantified and integrated into the design of GSHP systems to further reduce their installation and operational costs.