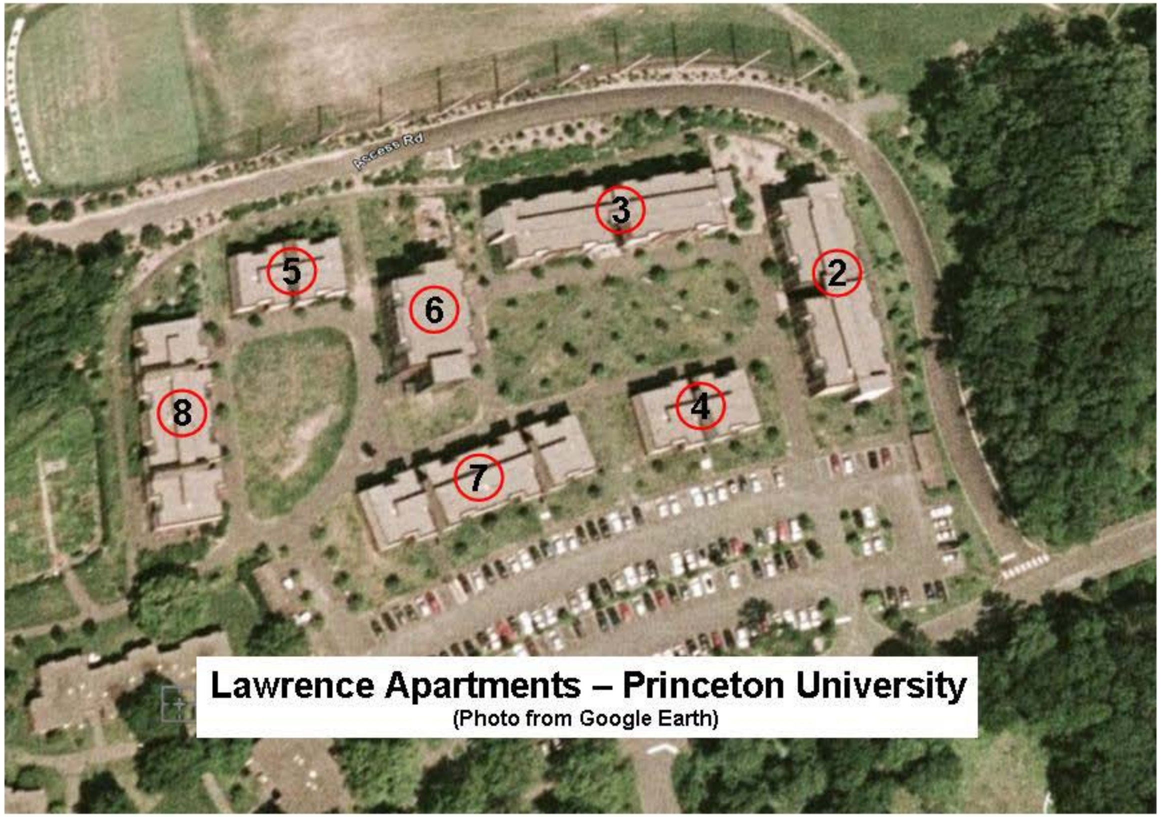

Optimal Ground-Source Heat Pump System Design

May 19, 2010

ENVIRON International

PI : Metin Ozbek

Track : GSHP Demonstration Projects

Project Team

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- David Van Kamp (Princeton University)

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Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 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

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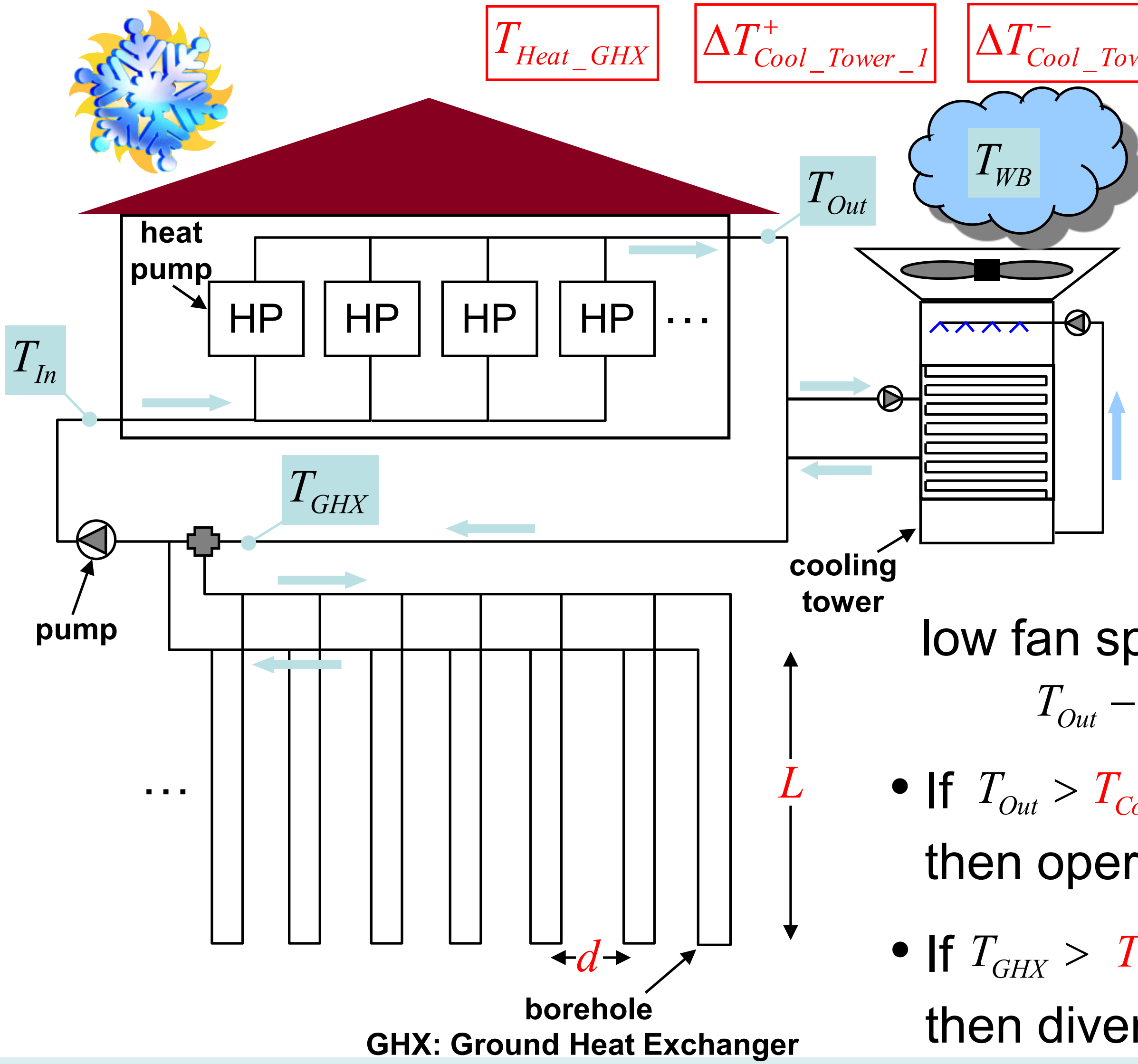
- Develop a least-cost design tool (OptGSHP) that will enable GSHP developers to analyze system cost and performance in a variety of building applications to support both design, operational and purchase decisions.

- 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 | # of boreholes | d | # of HP's | Size of HP's | Size of Tower | 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.

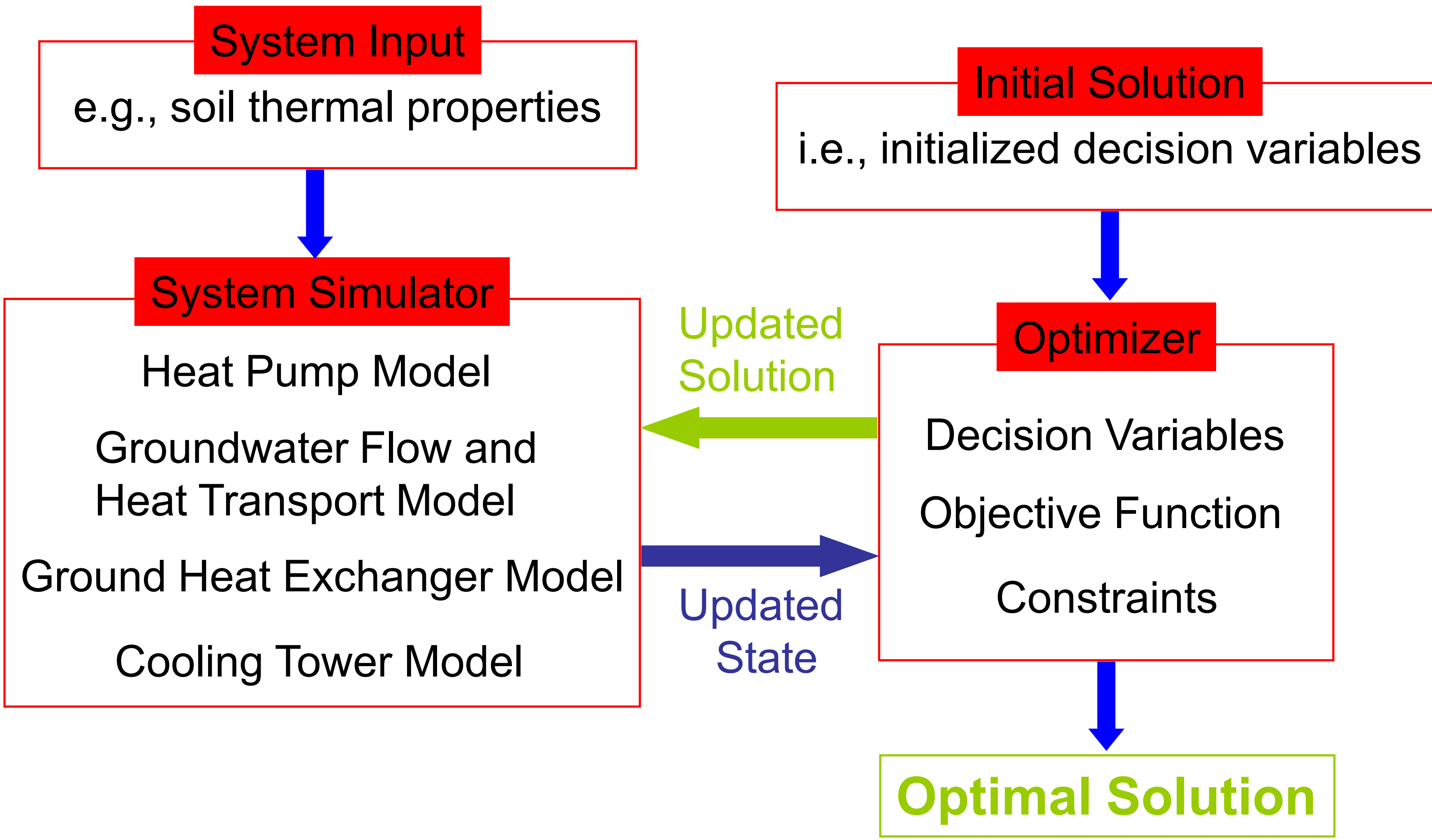
Cooling (i.e., $T_{In} < T_{Out}$):

- 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



Optimizer

➢ Objective Function:

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

Optimizer - 2

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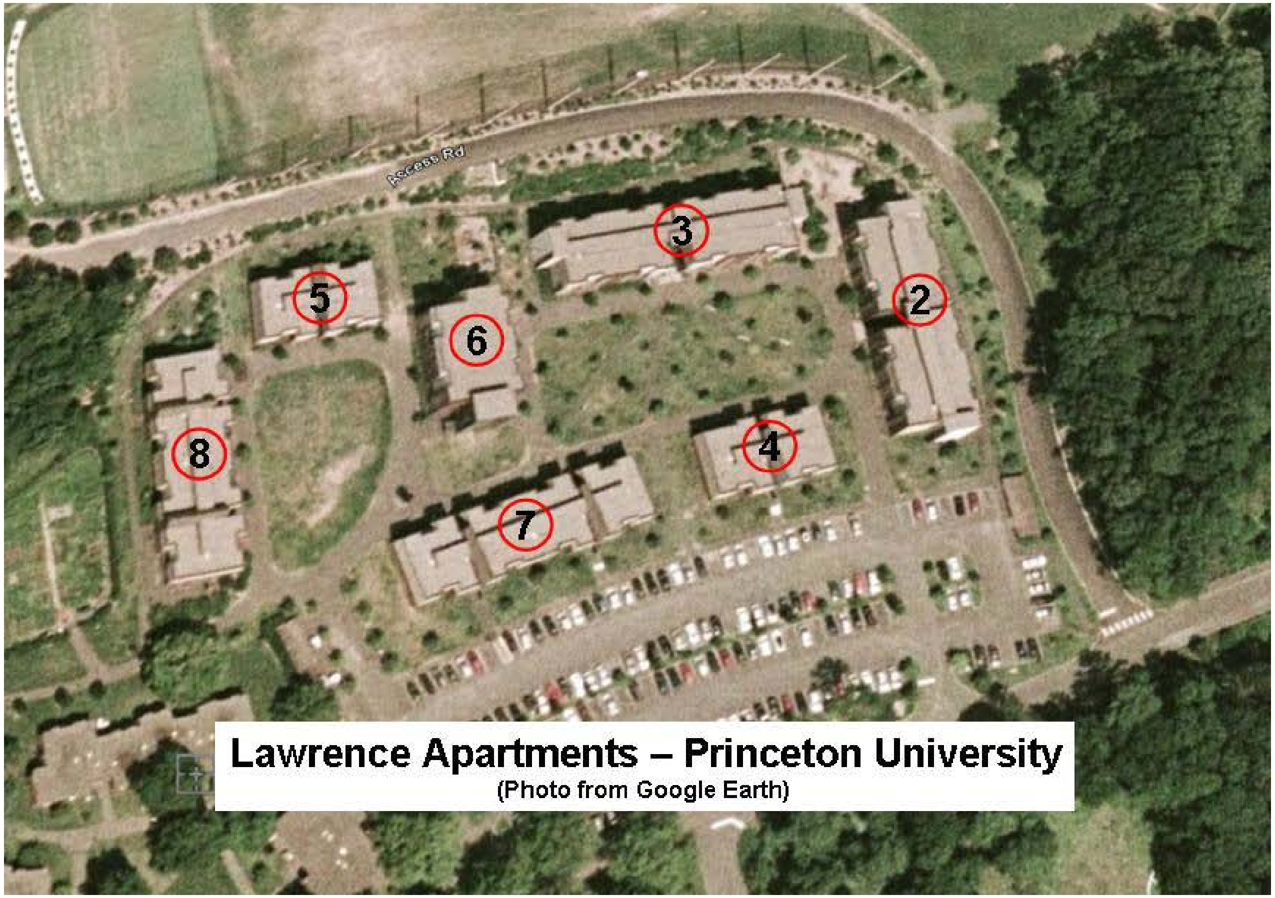
➢Design Variables:

- 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:

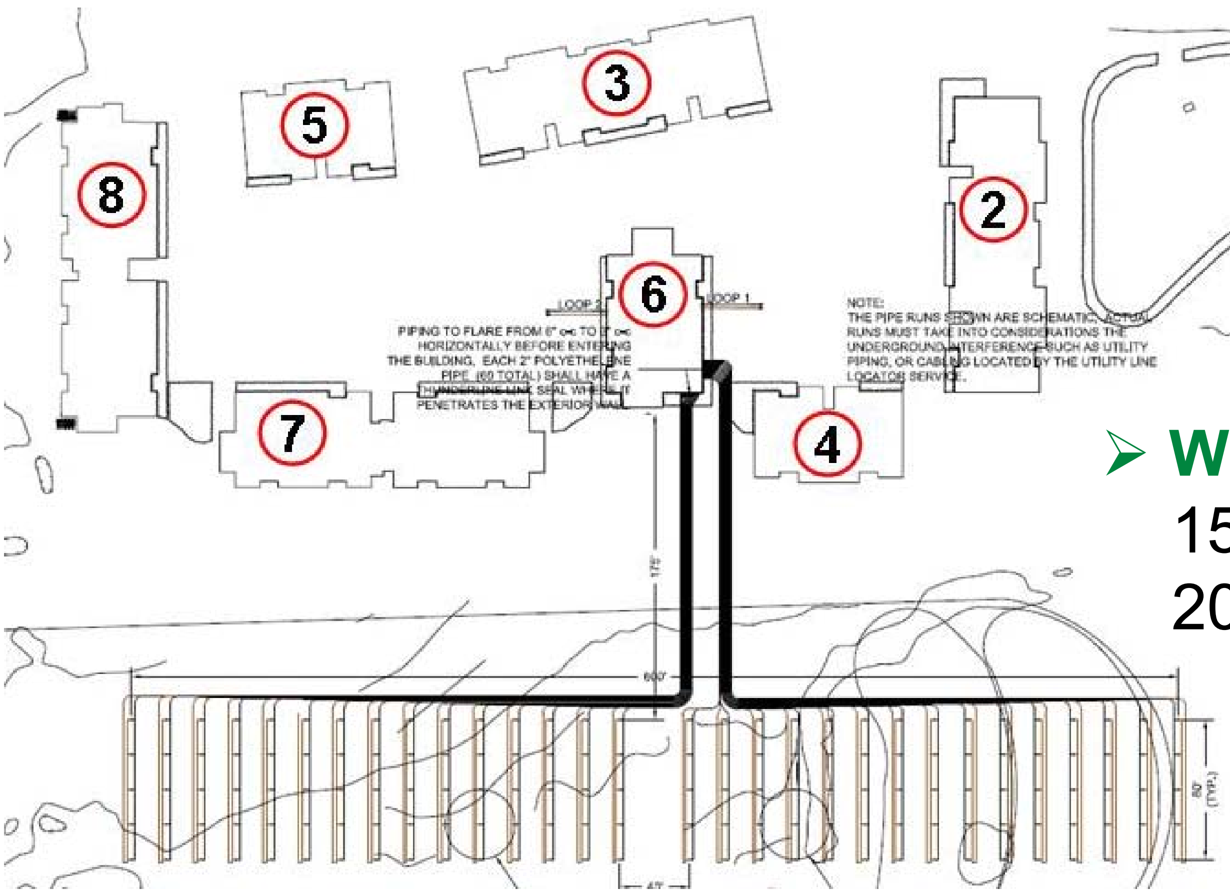
- Physical constraints on any design variable as applicable (e.g., maximum available space for boreholes) or economical constraints (e.g., budget)

Main Application



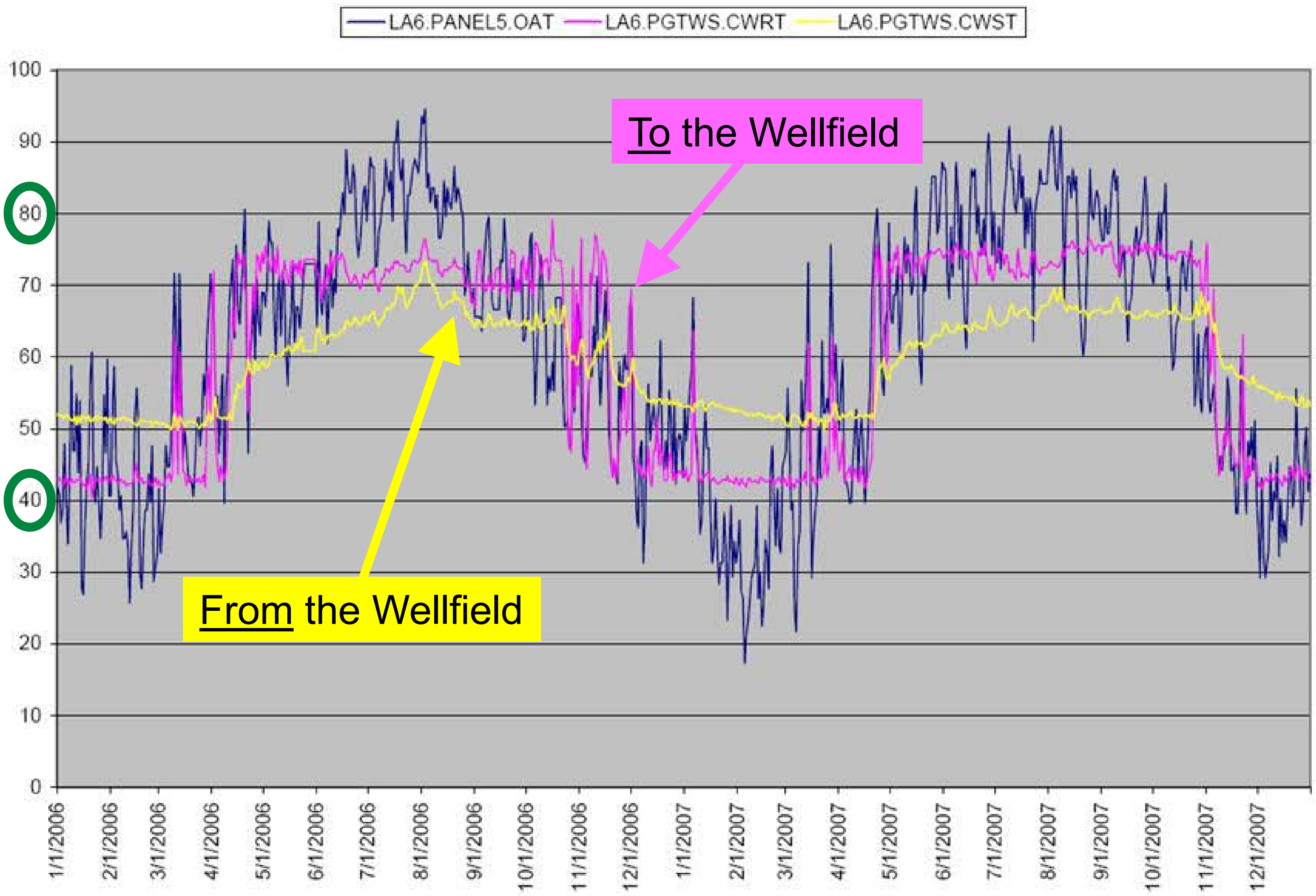
Lawrence Apartments – Princeton University
(Photo from Google Earth)

Main Application - 2

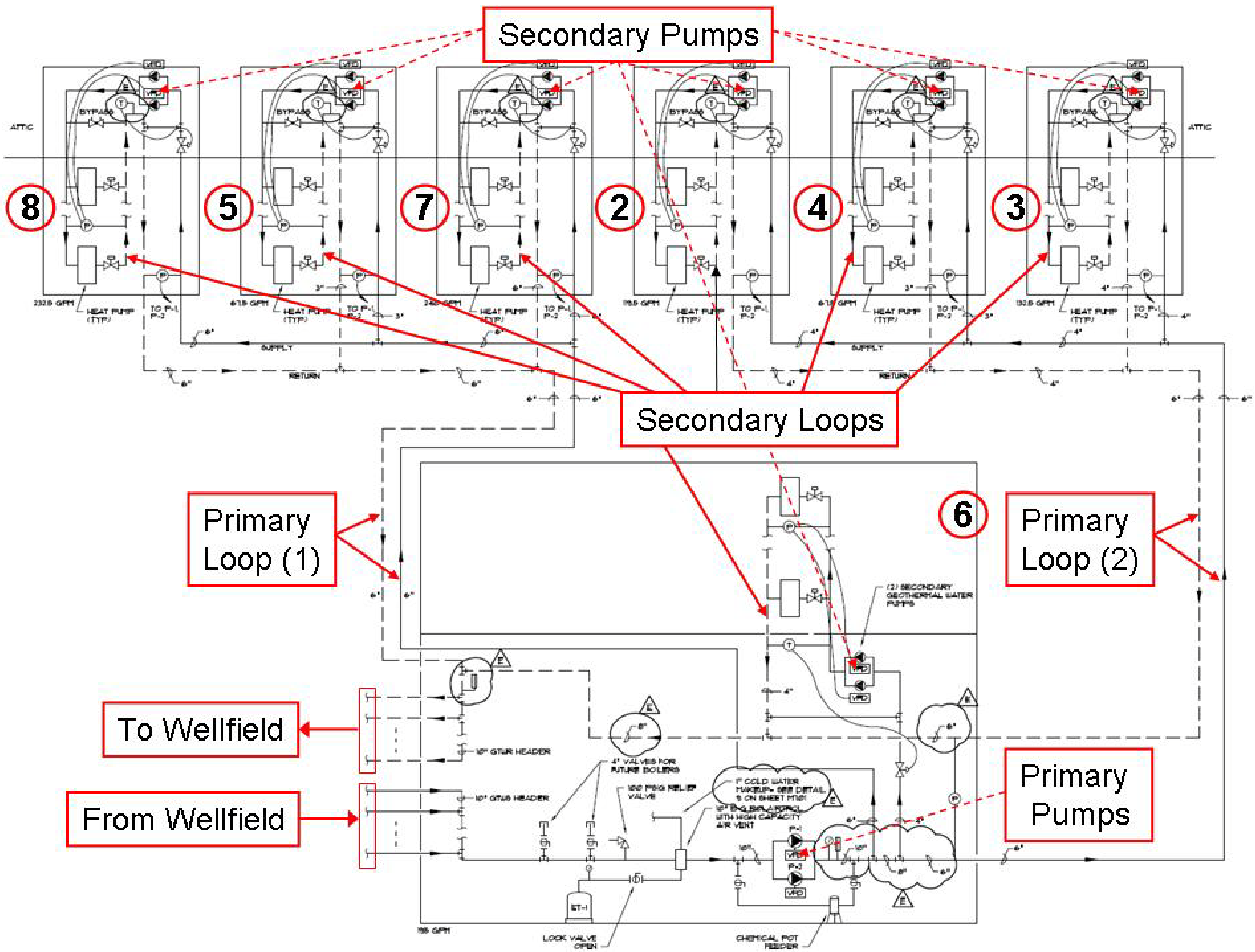


- **Peak Load:**
  73 tons (cooling)
  555 MBh (heating)
- **Well field:**
  150 wells at 450 ft deep
  20 ft borehole spacing

Main Application - 3



Main Application - 4



Project Tasks

- Construct a mathematical model of the GCHP system (April 1 – May 30)
  - TRNSYS (**Tr**a**n**sient Energy **Sys**tem Simulation)

- Construct a numerical model of groundwater flow and heat transport (April 1 – May 30)
  - FEHM (**F**inite **E**lement **H**eat and **M**ass **T**ransport)

- 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 (**Gen**eric **Opt**imization 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

Summary

- 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.