GROUND SOURCE HEAT PUMPS: MEETING GLOBAL CHALLENGES THROUGH LOAD NETWORKING

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ABSTRACT

The installation of ground source heat pump systems using grids of vertical bore holes on individual building loads is growing at an increasing rate. This can be attributed to an increased awareness of the technology and a continuous increase in world wide demand for energy. System applications have broadened as awareness of the technology increases and the GSHPs are being recognized as a cost effective standard for energy conservation. The acceptance by the users of ground source technology is attributable to the soundness of the technology and its continual development and application. This paper discusses the increased benefits of networking by combining or adding thermal loads (buildings, processes, etc.) to a system for the purpose of increasing overall system energy efficiency.

Key Words: *GSHPs (ground source heat pumps), district systems, integrated building systems, pond loops, energy sharing.*

1 INTRODUCTION

Ground source heat pump (GSHP) systems exchange heat to the underground environment by providing increased cooling and heating efficiencies for an increasing number of applications. This advantage of tapping the underground thermal source sometimes comes at a higher first cost and must be offset by reduced operating costs, which give a lower life cycle cost.

Building and business owners can benefit from combining loads that support improved system performance. GSHP designs in some cases must compete with alternative choices even if there is a positive life-cycle cost advantage. Resources spent on increased first costs must have a higher rate of return than other business opportunities for the owner. First costs for GSHP systems can be reduced if annual thermal load imbalances to the ground heat exchanger are reduced. Ground heat exchanger imbalances can occur in large commercial buildings where large annual cooling loads must be rejected. This rejected thermal load is available for use in another building or system application. If thermal energy must be added back to the ground loop heat exchanger (GLHE) system to reduce system imbalance, then one alternative would be the addition of a combined heat and power (CHP) system providing electrical power generation for demand reduction and emergency power while simultaneously providing supplemental heat for the system. The careful selection of economic alternative businesses with needed thermal attributes is the key to increasing system performance and economic benefits to the owner.

2 SYSTEM ANALYSIS

Each building or thermal component in the proposed aggregated system must be identified and the following information determined:

- Existing building thermal loads and internal gains of the system components
- Energy rates and costs – gas and electric
- HVAC equipment type and efficiency
- Geographic location of thermal components in relationship to each other
- Available space for construction of new thermal loads and/or businesses

3 EXISTING BUILDING THERMAL LOADS

The system described in this paper consists of the following existing buildings and thermal heating and cooling loads:

1. Large commercial grocery store and ancillary businesses (bakery, general store, etc.) (building #1)
    - Chillers for building air-conditioning – 950 kW
    - Food refrigeration – 372 kW
    - Gas space heating for main grocery area –372 kW
    - Electric Furnace space heating – 140 kW
2. Casino/Bingo (building #2)
    - Cooling requirement – 1,047 kW
    - Heating requirement –
–Furnace – 28 kW
–Pack units (25 units) – 1,322 kW
3. Headquarters Building (building #3)
    - Cooling requirement
–Packaged roof-top units 690 kW
–Thru-the-wall (47 units) – 203 kW
    - Heating requirement
–Thru-the-wall (47 units @ 5 kW each) – 235 kW
–Gas Roof Top (22 units @ 60,000 Btuh) – 386 kW

The buildings which make up these loads are the proposed system that should be aggregated together as a thermal system. A preliminary evaluation of these loads indicates a heavy cooling load for each building. If a GSHP system were proposed for each building separately, the GHEX costs would be high and hard to justify.

3.1 Analysis of Available Thermal Loads

Results from an energy study of the project site and loads revealed that the grocery store had the potential for contributing significant energy to the total system. This contribution is based on the requirements of the adjacent casino/bingo and administrative buildings which require heating energy when the grocery store requirements have been met. At present, the waste heat from the refrigeration and air conditioning systems in the grocery store is not being used. The grocery store heating requirements are significant and the waste heat is available from four evaporative condensers. The food preservation refrigeration system runs throughout the year and the air conditioning system is seasonal. These heat rejection loads are available for grocery store heating as well as the adjacent buildings (building #2 and #3). During time periods when the three buildings (#1, #2, and #3) do not require heating, the evaporative condensers and/or a pond that is being constructed on site and near the three buildings will serve as an energy bank. Figure 1 is a photograph of the type of pond system to be constructed. The pond is needed as a runoff reservoir and will be sized to handle the maximum combined heat rejection loads of all three buildings.

The addition of the pond to the system is critical to ensure that when all three buildings are being cooled that sufficient heat rejection capacity is available. The pond will also serve as an energy bank to proposed new businesses (e.g. vehicle washing) that require heat energy during cooling periods. The concept of an energy bank, energy going in and energy being taken out, would take advantage of the excess heat being rejected from the grocery store A/C and food preservation chillers.

A vehicle wash system has interest as a cooling season business requiring significant heat energy. The pond serves as a buffer system during periods of mixed heating and cooling for all present buildings and those future businesses requiring heating and cooling. A summary table of installed heat rejection capacities and thermal loads of the three existing buildings and proposed new loads follows:

Existing Buildings		
Building/System Number	**Refrigeration - kW**	**Heating - kW**
1. Grocery	1,886	1,014
2. Casino/Bingo		1,310
3. Administration		621
Proposed Thermal Additions		
4. Green Houses		85 kW/unit
5. Combined Heating and Power System (CHP)		As needed for emergency electrical power and/or heat
6. Multipurpose Pond		Provides heat rejection and heat energy capacity for the total system

3.2 Energy Costs and Equipment Efficiencies

The average energy costs determined from collected data at the site based on present (2004) usage are:

1. Electric rate: 0.05$/kWh
2. Electric cost: 0.05/kWh X (293 kWh/MMBtu) = $14.65/MMBtu
3. Gas rate - $5.73/MMBtu
4. Gas cost @0.65 eff. = $5.73/.65 = $8.82/MMBtu
5. GSHP cost - $14.65/COP = $14.65/3.3 = $4.43/MMBtu

In summary, for the project, the energy costs for delivered heat are:

Energy Type	Efficiency or COP	$/MMBtu
Electric Furnace	1	14.65
Gas	0.65	8.82
GSHP	3.3	4.43

These costs then become a guide to what actions should be considered:

1. replace all electric furnaces
2. replace all gas space heaters with GSHPs.

3.3 Geographical Location of Buildings and Site Amenities

The three buildings being considered are within 300 meters of each other. There is sufficient space for additional business growth and ground heat exchanger installation. The area has an abundance of ground water which is available for water source heat pump usage.

There is also a need for water impoundment for runoff control at the system site. This runoff reservoir can be constructed to serve as a heat rejection system allowing large summer cooling loads to be managed. The ample ground water at the site ensures that normal summer water evaporation can be managed during drought periods and the rejection pond is always available.

The owners of the site have construction and technical experience in water distribution and underground piping. They have hired an employee that is experienced in design, construction, and operation of GSHP systems.

4 ADDITIONAL LOADS TO BALANCE HEATING AND COOLING LOADS

In addition to using excess thermal energy from the grocery store refrigeration equipment, the water runoff control pond is required so that heat rejection capacity is available at all times and during installation of new GSHP units on existing buildings. While the pond loop is referred to as a heat rejection system it is also a heat source for buildings number 2 and 3 during space heating requirements. This pond is sized to handle summer cooling loads for all buildings and ground source units connected to the system. Additionally there is space available to support greenhouse crops as well as a vehicle washing facility to provide the owners vehicle inventory to be serviced as well as local business opportunities.

The grocery store has more than sufficient heat rejection energy to supply its own space heating requirement which is presently heated with gas. In order to utilize the waste heat on a year round basis, heat rejection should be separated from the store and added to the system loop. The benefit would be a greater utilization of thermal energy that is now being wasted. The pond heat exchangers should improve the efficiency of the food preservation chillers thus reducing the overall energy costs.

5 DEVELOPMENTS IN SUPPORT OF LARGE SYSTEM INTEGRATION

Despite the importance of the above-described research in lowering life cycle costs and broadening applicability of ground source heat pump systems, a number of developments have come from outside the academy. These include:

- Faster, lower cost pipe-joining methods: stab, socket fittings, and electro-fusion
- New pumping configurations: variable-speed, multiple pumps in parallel, and zoned on-off circulator pumps sharing a common ground heat exchanger
- Pond/Lake heat exchangers constructed from polyethylene pipe rolls, copper coils, and stainless steel plate heat exchangers – see included photographs (Figs. 1–4).

6 NEEDED RESEARCH

In order to continue lowering the life cycle cost and broadening the applicability of ground source heat pump systems, additional research is needed in the following areas:

- Continue the development of computationally efficient methods for simulating ground loop heat exchangers. Although some work has been done on vertical borehole heat exchangers, little or no work has been done to model short time-step behavior of horizontal systems, where interaction with the aboveground environment is important.
- Continue development of more cost-effective borehole heat exchangers. Two loop heat exchangers have been installed in a number of large installations.
- Develop lower cost methods for estimating ground thermal properties. Currently available methods take longer and are more expensive to perform than would be ideal for widespread commercial utilization. Additional work by Beier promises to allow recovery of data for interrupted test periods.
- Development of 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.
- Develop optimized fluid pumping systems configurations and controls to reduce installation and operating costs. Central station pumping, while convenient from a maintenance standpoint may not be optimal for distributed individual heat pump installations. Large systems in the range of 1,000 tons have used load-matched pumping to significantly reduce pumping power.

To summarize, there are a wide variety of potential applications of earth energy storage. Many of the applications are economically feasible today, and many more may be feasible in the near future, with refinements in system design made possible by the thoughtful application of heat transfer engineering and system design.

7 TECHNOLOGY TRANSFER ACTIVITIES

Although the research developments described above are important, a number of other activities are important in transferring the technology to the field. These include:

- Installation workshops for contractors who specialize in residential programs. These are offered by IGSHPA and others certified by IGSHPA to offer training in its “Train the Trainer” program. Certified Geothermal Designers training is offered by IGSHPA and the Association of Energy Engineers (AEE 2002) for engineers and other designers of commercial applications.
- Marketing conferences for presentation on new technology and applications. IGSHPA is conducting one marketing-oriented conference per year.
- Technical conferences to present research and application improvements and promote installation standards. IGSHPA is also conducting one three-day technical conference per year.
- The Annual World Energy Engineering Conference, sponsored by the Association of Energy Engineers, has included a significant number of presentations at recent meetings on ground source heat pump systems.
- The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) is offering professional development seminars and short courses on ground source heat pump system design.
- ASHRAE has also recently published several relevant books: “Operating Experiences with Commercial Ground-Source Heat Pump Systems” (1998), “Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings” (1997), and has a forthcoming book entitled “Geology and Drilling Methods for GSHPs: An Introduction for Engineers.”

8 CONCLUSIONS

The research and development efforts described in this paper have primarily addressed reduction of first cost, either through combining thermal loads which allow smaller, less costly ground exchangers or through more accurate design analyses done with design software.

The technology transfer efforts have significantly improved awareness of architects and engineers. Arguably, a great deal of additional work needs to be done before ground-source heat pump systems are regularly utilized in all applications and parts of the world where they make economic and environmental sense.

9 SPECIALIZED POND/LAKE HEAT EXCHANGER HEADER SYSTEMS

The following are photographs of lake/pond heat exchangers that are available where large heat rejection loads in cooling dominated climates or in building or systems internal gains are large.

Fig. 1. Pond loop for system integration. Loop is high density polyethylene (HDPE), rated capacity is 150 kW, pipe bundles are fabricated from 19-mm pipe with spacers between loops. Each bundle has 92 meters of pipe. Header pipe sizes to and from building are 0.19 meters. Photograph courtesy of Geothermal Design Associates Inc. Ft. Wayne Indiana

Fig. 2. Copper Lake/Pond Loop was constructed and installed on the campus of Oklahoma State University. The heat exchanger is constructed from 25 mm diameter copper pipe with a total length of copper pipe of 91 meters. Rated capacity is 1.5 kW.

Fig. 3. 12-kW pre assembled stainless steel plate pond loop. Photograph supplied by AWEB Supply – Baton Rouge, Louisiana

Fig. 4. Header Vault details. Photo courtesy of Greg Wells

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