Ground source heat pump system upgrade

Ground source water is one of the fastest growing applications of renewable energy in North America. Cold Spring Harbor Laboratories upgraded its Alfred D. Hershey Building with a direct expansion split unitary system.

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Designers and managers of commercial buildings face increased demands to improve energy efficiency to reduce energy consumption, driven by local and state energy codes and standards like ASHRAE Standard 90.1 and ASHRAE Standard 189.1, and guidelines from the U.S. Green Building Council.

For example, Cold Spring Harbor Laboratories is a private, nonprofit research/education institute dedicated to exploring molecular biology and genetics to improve diagnosis and treatment of cancer. This world-famous biomedical research campus on the north shore of Long Island, New York, is committed to energy efficiency measurement in all facilities throughout its campuses, guided by the New York City Energy Conservation Code and New York state codes. The Alfred D. Hershey Building on one of the campuses of Cold Spring Harbor Laboratories is the home of microscope imaging and 3-D rendering and image analysis. Hershey Laboratory—rededicated in June 2012—required a major improvement in its HVAC system.

The main goal of the upgrade was to provide improved temperature and humidity control and to reduce energy consumption of the condenser refrigeration units by at least 30% annually.

Open ground source loop

In 2009, the institution decided to move forward with an ambitious HVAC system upgrade in the form of a direct expansion (DX) split unitary system for cooling and heating the interior space of the laboratory.

A ground source heat pump system was selected to upgrade the HVAC with ground source condenser water because the lab did not allow for an unattractive cooling tower and because this system can achieve much greater energy efficiency than a DX split system.

These water source heat pump systems are efficient at transferring heat, when used in conjunction with a plate and frame heat exchanger that maintains a very small temperature difference between the ground loop and building loop. Water source heat

Figure 1: The Alfred D. Hershey Building, a Cold Spring Harbor Laboratories building, is the home of microscope imaging and 3-D rendering and image analysis. Hershey Laboratory—rededicated in June 2012—required a major improvement in its HVAC system. Courtesy: AKF Group

pumps recover excess heat from the building's interior and move it to the building's perimeter. They are also quite suitable for New York, whose aquifers produce a lot of water.

An open loop ground source water system is also known as a "pump and dump" system. With an open loop system, the groundwater is pulled up from one supply well (the "pump" well) and pumped through a plate and frame heat exchanger, then it is pumped back to the "dump" injection well. See Figures 2 and 3 for a diagram of the mechanical room and schematic description of the open loop system.

Design and optimization

A plate and frame heat exchanger offers high thermal performance because the corrugated pattern is pressed into each plate to produce highly turbulent fluid flows; this also allow specification of a very small approach temperature (as low as 1 to 5 F), which is sometimes useful in a ground source water application.

Described below is a three-step algorithm to properly select, design, and optimize the heat exchanger to achieve the best value of the ground source water temperature variation. It is based on the authors' experiences from past projects in both the U.S. and Canada.

STEP 1: To select a heat exchanger, the engineer must know five of the six parameters:

- Heater capacity
- Temperatures on the hot side (in or out)
- Temperatures on the cold side (in or out)
- Flow rate on the cold side and/or hot side

Figure 2: The mechanical room houses the piping in the attic of Alfred D. Hershey Building. Courtesy: AKF Group

Based on five known parameters, calculate the capacity and surface area required for transferring heat to the media using the following equations:

$$Q = U \times A \times LMTD$$

$$Q = gpm \times 500 \times P \times C \times CF \times \Delta T$$

$$A = \frac{Q}{UXLMTD}$$

Where:

Q = heat load (capacity) in Btu/hr

U = overall heat transfer coefficient in Btu/Hr/sq ft/F

A = heat transfer area in sq ft

LMTD = logarithmic mean temperature difference in F

gpm = flow rate in gallons per minute

P = specific gravity

C = specific heat in Btu/lb F

CF = fluid correction factor to take into account changing specific gravity and specific heat

ΔT = fluid temperature rise in F

The value for the LMTD is strongly influenced by the direction of the media flow. The most effective configuration is a counter flow configuration in which fluids flow in opposite directions.

The LMTD can be calculated using the difference between the incoming and outgoing temperatures of the two fluids (the hot water side and the cool water side) according to the following equation:

$$LMTD = \frac{\Delta T - \Delta t}{\ln\left(\frac{\Delta T}{\Delta t}\right)}$$

Where:

ΔT = T1 – t2 temperature on the hot side end

Δt = T2 – t1 temperature on the cold side end

Codes and standards

Regardless of the type of the heat exchanger used, construction and fabrication are governed by the American Society of Mechanical Engineers (ASME) under BPV Code, Section VIII Division I: Design and Fabrication of Pressure Vessels.

ASME codes use mandatory guides for fabrication of pressure vessels, which include rules and recommendations for material selection, design, testing, and inspection of the heat exchanger. The codes cover all aspects of the construction of heat exchangers except the types of service loads (other than pressure) and the thermal design.

AHRI 400-2001 with Addenda 1 and 2: Liquid to Liquid Heat Exchangers was developed for plate and frame heat exchangers because many applications in commercial HVAC systems were designed with very close temperature approaches. AHRI developed testing requirements more stringent than those traditionally used, such as total heat transfer rate ≥95% of published and tested pressure drop ≤110% of published.

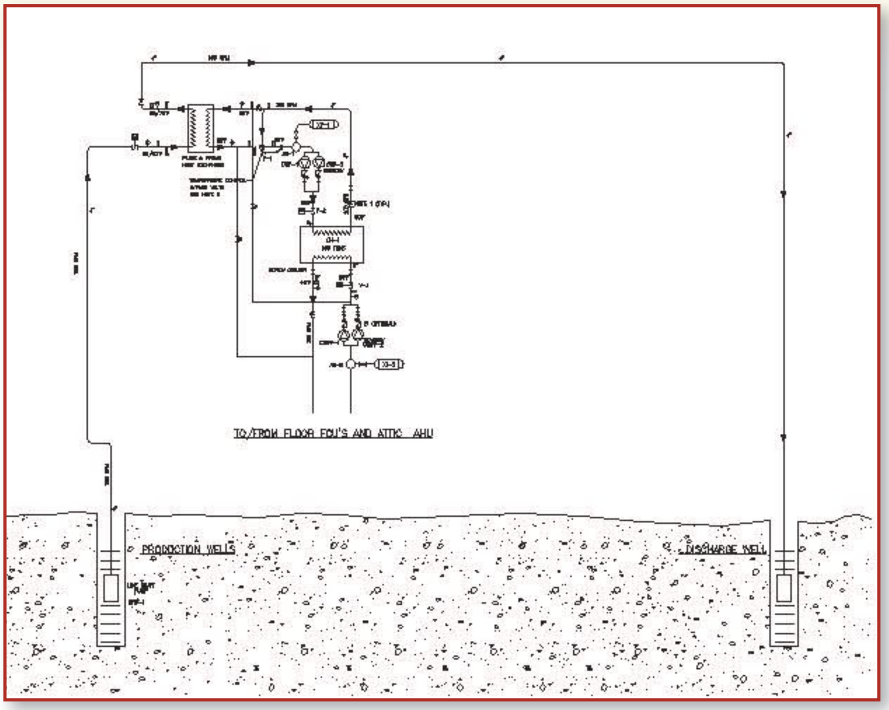

Figure 3: **This shows an example of the ground source open loop systems with plate and frame heat exchanger isolation loop. Courtesy: AKF Group**

The number of transfer units (NTU) is a dimensionless value that characterizes the performance of a heat transfer based on the LMTD and the temperature change occurring in the unit.

The importance of the NTU value lies in the fact that heat exchangers are capable of generating a given NTU for each fluid, and this value is dependent upon their specific plate construction.

The pressure drop through the plate depends on type of the corrugation, which can be predicted using the following equation:

$$NTU = \Delta T / LMTD$$

If NTU > 3 (long angle corrugation patterns). Those plates have the highest heat transfer rate and highest pressure drop.

If NTU ≤ 3 (short angle corrugation patterns). Those plates have lowest heat transfer rate and lowest pressure drop.

Select the small heat exchanger model capable of handling the flow, surface area, and NTU for the winter conditions and summer conditions of the ground source water.

STEP 2: Compare the surface areas calculated in step 1, equation 3, for winter conditions and summer conditions. Choose the model with the largest surface area between the two seasons (for instance, winter conditions).

STEP 3: Using the heat exchanger model selected (winter heat exchanger) in step 2, simulate the flow and temperature of the smallest surface area (summer condition) on the heat exchanger model with the largest surface area (winter heat exchanger).

Based on our experiences, an acceptable deviation of the inlet and outlet temperatures of the heat exchanger is approximately +/- 3 F. If the inlet and outlet temperatures are close to the acceptable value, a solution has been achieved; otherwise, repeat step 1 and continue until a solution can be reached that is closer to the deviation point.

Most plate manufactures typically use 30 F angles for short angle patterns and 60 F angles for long angle patterns in forming the plate corrugation.

Recommended specifications of a heat exchanger

Most engineers determine flow and capacity of the heat exchanger based on water. Generally speaking, the heat exchanger's flow and capacity with antifreeze fluid is not the same as water, and the selection shows different operating values because an engineer does not consider the effects of the glycol solution. In this case the flow should be adjusted by approximately 16% to compensate for the effects when you are using a 50:50 ratio of glycol: water at 100 F.

Keep in mind that when you select heat exchangers for winter and summer duties, select the units for both seasons with the same plate corrugation and avoid selecting mixed plates due to the effect on the pressure drop.

Often, engineers mistakenly select the largest area of the two seasons and the heat exchanger works only for one season and not the other because the plate corrugation type selected (NTU) and pressure drop were not satisfactorily chosen.

Engineers should be concerned about the debris in the groundwater that could travel to the plate heat exchanger. Most manufactures offers two options for avoiding this problem:

1. Specify a port strainer on the plate heater. This reduces the possibility of plugging by preventing unwanted solid particles from entering the channel of the plate's package.

2. An automatic back flush system (ABS), commonly used in the Northeast, is the most expensive solution. The ABS automatically cleans the plates and frame heat exchanger without interrupting normal equipment operation.

The ABS consists of a four-way reversing valve that fits into the supply and return piping, allowing the reversal of the water flow direction in the heat exchanger. This flow reversal has been found to significantly reduce the fouling in the plate and frame heat exchanger. The flow reversal is controlled by a control panel mounted to the plate and frame heat exchanger or at a separate location as desired by the customer.

Plate materials of the heat exchanger are regulated by ASME BPV Code, Section VIII Division I: Design and Fabrication of Pressure Vessels. Usually they are built on stainless steel or titanium plates, determined by the groundwater. In most cases, stainless steel plates are specified in ground source water. If the water has a high concentration of chloride, titanium plates should be use to avoid corrosion problems in the future.

Future performance

Ground source well water combined with the plate and frame heat exchanger give the owner and designer a more efficient heat source and heat sink because the plate and frame heat exchanger can maintain a small variation of the water temperatures between the ground loop and the building loop with a minimal heat transfer loss.

At Cold Spring Harbor Laboratories, the proper selection, optimization, and specification of the heat exchanger should be suitable to perform with groundwater temperature variation all year long to maximize the energy savings of the buildings.

More importantly, plate and frame heat exchangers are the most widely used for ground source water systems because they are easy to maintain, flexible because plates can be added in the future, and compact for space saving in a mechanical room. |cse|

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Heat exchanger selection and optimization

The selection process is a trade-off between the overall heat transfer coefficient (U), which has influence on the surface area, and pressure drop, which influences the pump head on the HVAC system. In general, low pressure drop increases the surface area of the heat exchanger, thereby increasing the unit's initial cost, and the U value influences the type of chevron pattern plates to be used and pressure drop as well.

See Table 1 to calculate the surface area required for the heating and cooling load.

Using the equations described in step 1, calculate the surface area required to perform the duties using the LMTD and NTU values for summer and winter conditions. Results of the calculation are shown in Tables 1 and 2.

The key to selecting a heat exchanger is to select the smallest model with the same type of plate corrugation for both seasons (winter and summer) capable of handling the flow.

Next, simulate the heat exchanger with the largest surface area and plate corrugation type for the unit selected with the temperatures and flow profiles of the other season to obtain the duty value required for the season; see Table 4 for the heat exchanger solution.

An optimal solution has been achieved when temperature, flow, and pressure drop are within the acceptable limits.

Application notes:

Glycol system implications on the heat exchanger specification:

- A glycol/water system affects the heat transfer of the heat exchanger and the pump noise.
- Glycol does not carry heat as well as a water-only system.
- Engineers must pay attention to the corresponding flow increase of glycol solution to maintain the minimum flow of the chiller and the corresponding pressure increase on the pump and pipe to prevent a noise problem.

Recommendation: Do not use chromate water treatments or galvanized fittings because they might react with the glycol solution.

			Summer (S)					Winter (W)			
			Hot		Cold			Hot		Cold	
Tag	Service	gpm	T in (F)	T out (F)	gpm (S/W)	T in (F)	T out (F)	T in (F)	T out (F)	T in (F)	T out (F)
HX-1	CW LOOP	205	80	65	155/205	55	75	67	57	55	65

Table 1: **Use this to calculate the surface area required for the heating and cooling load. Courtesy: Wallace Eannace Assocs.**

Summer (S) HX-1		
Surface area (sq ft)	NTU	Pressure drop (psi)
231.42	2.8	9.2

Table 2: **Surface area, NTU value, and pressure drop calculated for summer conditions. Courtesy: Wallace Eannace Assocs.**

Winter (W) HX-1		
Surface area (sq ft)	NTU	Pressure drop (psi)
446.7	5	6.31

Table 3: **Surface area, NTU value, and pressure drop calculated for winter conditions. Courtesy: Wallace Eannace Assocs.**

	Winter HZ with summer duty results						
	Hot		Cold				
gpm	T in (F)	T out (F)	gpm	T in (F)	T out (F)	Surface area (sq ft)	Pressure drop (psi)
205	80	62	154	55	78	446.7	6.3

Table 4: **This shows the results of the simulated heat exchanger. Courtesy: Wallace Eannace Assocs.**