technical brief

Hybrid Geothermal Heat Pump Systems

A Low First Cost Option for Geothermal and Water Loop Heat Pump Systems

Retail & Power Markets: Commercial Business Development

Introduction

Geothermal heat pump (GHP) or Geoexchange systems are widely used in many commercial building applications. GHP systems offer the potential for lower energy costs and well as reduced maintenance costs. GHP systems tend to be most attractive in applications such as schools where the seasonal cooling loads are modest compared to heating loads. The ability of this simple, low-maintenance system to meet both heating and cooling loads allows for an efficient all-electric building. The largest component of the annual energy savings are realized by meeting the heating loads with high efficiency heat pumps. The cooling efficiency benefits are typically smaller since GHP cooling efficiency is only slightly better than conventional air-source equipment.

In applications where the seasonal cooling load is greater relative to the heating load, the cooling load typically drives the size and therefore price of the ground heat exchanger. Cooling conditions usually set the ground heat exchanger size because the amount of heat rejected to the loop by the heat pump in cooling is about 150% of the space load. In contrast, the heat absorption from the ground by the heat pump in the heating mode is only a fraction of the space load. Therefore, cooling loads can even drive the loop size in applications where the seasonal space cooling loads are smaller than the seasonal space heating loads.

If cooling loads are large, reducing the size of the ground heat exchanger to satisfy the heating load and adding some means to directly reject heat to the ambient can be very attractive. The heat rejection device can be a cooling tower, dry fluid cooler, or a shallow pond/ground loop. Installing one of these lower-cost alternatives to meet the balance of the cooling needs can drastically reduce the first-cost of the project while maintaining low operating costs. Combining a ground loop with a more conventional means of heat rejection is known as a Hybrid Geothermal Heat Pump System.

The Hybrid Concept

Normally a geothermal system rejects the heat from the building to the ground when cooling. Rejecting some of this heat to ambient with a heat exchanger allows the ground heat exchanger to be smaller and the overall system costs to be lower. When the annual heat rejection for cooling is significantly larger than the heat extracted during heating, an imbalance is created that results in heat buildup over time. Designers often increase the size of the ground heat exchanger to overcome this factor and account for multi-year heat buildup. Using a cooling tower or a fluid cooler to balance the load eliminates potential heat buildup allowing smaller loop sizes and lower first-costs. With installed tower costs near $200 per ton and ground heat exchanger costs over $1,000 per ton, the portion of the load shifted from a ground heat exchanger to a cooler can be met for about 20% of the original cost.

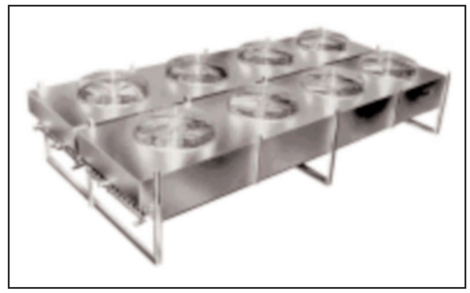

Figure 1. Air-Cooled (Dry) Fluid Cooler Example

Heat Rejection Equipment

Wet fluid coolers and cooling towers use the evaporation of water to enhance heat transfer to the outdoor air. The heat rejection performance of these systems is driven by the ambient wet-bulb temperature. Fluid coolers maintain separation between the loop fluid and the air by circulating fluid through tubes within the cooler. The cooler sprays water on the outside of the tubes to achieve an evaporative cooling effect. A cooling tower could be substituted for a fluid cooler if it is connected to the loop with a heat exchanger to maintain isolation of the loop fluid. A cooling tower cools water circulating through it directly by evaporating some of the water as it falls over a fill material with air moving through the tower.

Dry fluid coolers simply blow outdoor air across coils containing the loop fluid. The cooling capacity of this equipment is driven by the outdoor dry bulb temperature. Dry coolers generally have less heat transfer capacity but offer the advantage of lower maintenance costs because costly and complex water treatment systems are not required.

Other sources for additional heat rejection include shallow ground heat exchangers and shallow ponds. Heat exchangers can be installed directly beneath sidewalks and driveways or sod. Research at Oklahoma State University has been evaluating several ground loop options for improved loop-to-ambient heat transfer. Smith et al. (2000) discusses recent field performance and modeling experiences with these types of heat exchangers.

One potential concern about adding traditional cooling towers or fluid coolers into a hybrid systems is the added maintenance and complexity costs. Water treatment and regular maintenance is critical to maintaining performance and avoiding biological hazards with towers or fluid coolers. Dry coolers eliminate the maintenance concerns but also reduce the effectiveness of the cooler. The elimination of cooling tower maintenance may be attractive in geothermal applications where low maintenance is a main attraction. As the field data presented below will show, the dry cooler can potentially be used to reduce or eliminate the seasonal heat build up over time, depending on the available loop-to-ambient temperature difference.

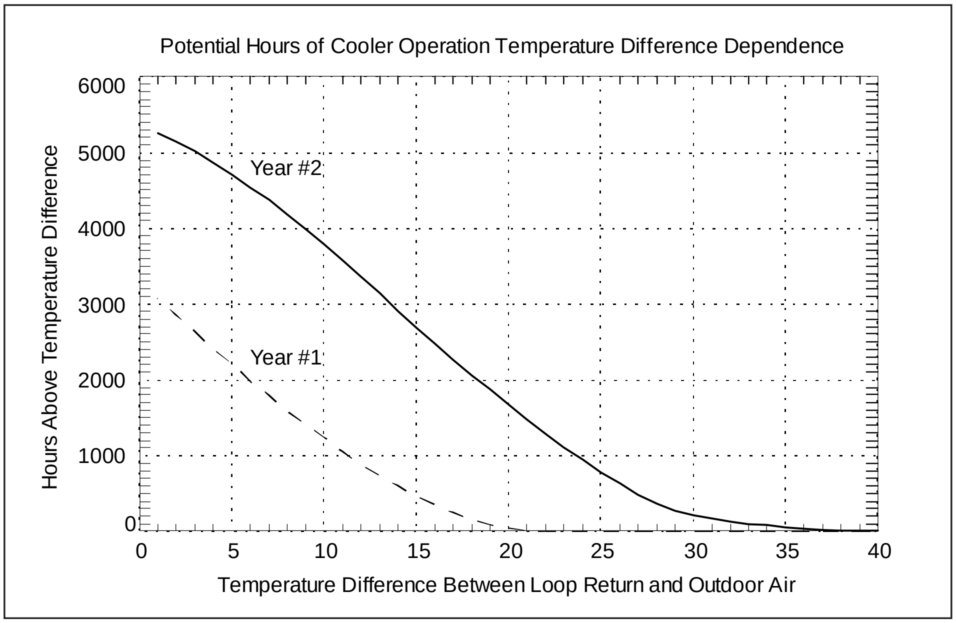

Figure 2. McDonald's Quick Service Restaurant in Detroit—The number of hours when the loop was rejecting heat to the ground and the temperature difference between the loop and outdoor air temperature determine the amount of potential operation of a dry fluid cooler.

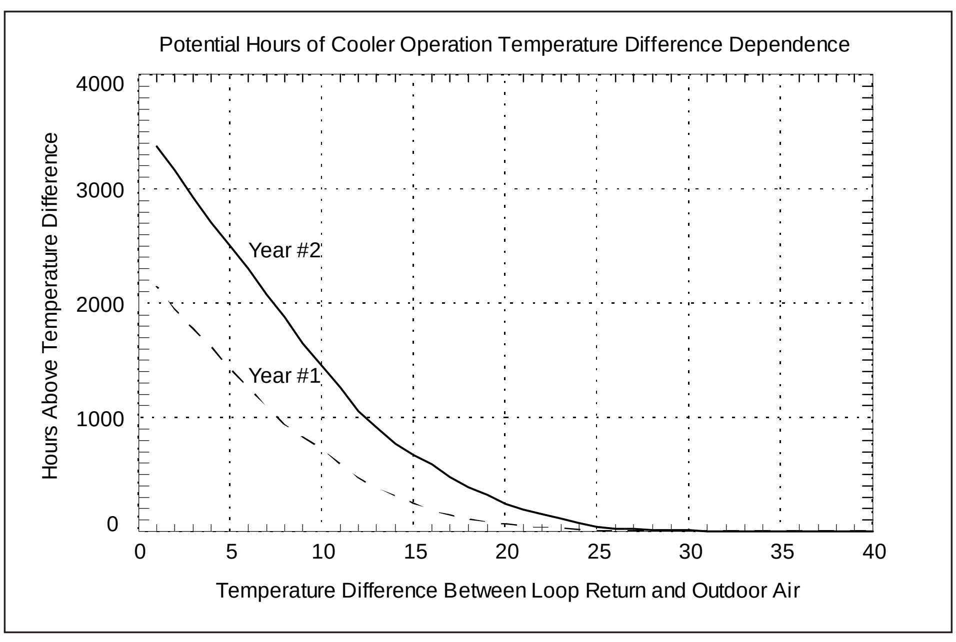

Figure 3. Tennessee High School Example—Potential cooler operation still exists with a less extreme cooling load, providing the ability to reduce or eliminate the buildup of heat over time.

The Potential of Dry Coolers

Dry fluid coolers can also be used to solve problems with heat buildup in existing ground loop installations. If long-term heat buildup become an issue—or new additions or changes in space use increase the cooling load—fluid coolers can be added to the ground loop to keep the loop temperature below design conditions. An example application with seasonal heat buildup is the geothermal McDonalds in Detroit that was recently evaluated by EPRI (1999). Although the Quick Service Restaurant is located in cold climate of Detroit, it showed a cooling-dominated load and resulted in year-to-year increases in loop temperatures as shown in Figure 2. Assuming that a dry cooler could operate whenever the loop is rejecting heat to the ground and the temperature difference between the loop and the ground temperature exceeded 15°F, the measured data from the site indicate that there many hours when heat rejection was possible. There were 500 potential hours of dry cooler operation the first year and 2,700 potential hours of operation the second year. Operation of the fluid cooler could have reduced or eliminated the second year heat buildup. Compared to a ground loop sized to properly account seasonal heat buildup, a 20% reduction in ground loop length would have been possible if a dry cooler was used.

A dry cooler could also help with peak heat rejection, even though capacity is constrained at times when ambient temperatures are high. At McDonalds there were 327 hours in the second year where the loop supply temperature (i.e., from the ground) exceeded 95°F and the loop-to-ambient temperature difference exceeded 5°F. Even at these extreme conditions the dry cooler could satisfy as much as 25% of the peak heat rejection.

Figure 3 shows that even in applications with conservatively-sized ground loops and modest loop temperatures there can still be opportunities for dry cooler heat rejection. At this Tennessee High School, there were more than 700 hours in the second year of operation when the loop-to-ambient temperature difference was greater than 15°F.

System Configuration and Control

One the decision to add a fluid cooler had been made, it is important to integrate the cooler into the loop so that parasitic pumping costs are reduced. Loop pumping can be significantly affected by added pressure drops from the cooler depending upon its configuration within the system and the need for any additional control valves. Figure 4 shows a fluid cooler connected in parallel to the loop field and Figure 5 show a series configuration. The parallel configuration easily integrates within a variable speed drive loop pumping system. The series configuration is appropriate where the cooler handles a relatively small portion of the total flow.

In the parallel arrangement, sufficient bypass on the load side of the pump must be provided so the cooler can operate when heat pumps are inactive. An alternative configuration would place the cooler adjacent to the heat pumps to handle larger flows and directly cool the loop. However, the cooler would not have the advantage of cooling higher temperature water produced by the heat pumps during peak operation.

Arrangements with three-way valve should usually be avoided due to high operating pressure drops and poor shut-off ability. The use of variable speed pumping on the loop almost always negates many of the advantages that might be by using three-way valves, namely reducing head loss as well as flow.

The Cost Benefits of Hybrid Systems

A hypothetical Alabama office building illustrates the impact of a fluid cooler application in a report by Kavanaugh (1997). In this 100-ton building there are 1,000 equivalent full-load hours in heating and only 250 hours in cooling. Sizing the ground loop to maintain a 90°F loop temperature requires 31,500 ft of loop at a cost of up to $220,000 at $7/ft. Balancing the seasonal loop heat rejection and extraction would require only 26,000 ft of loop, if the additional cooling load were met with a fluid cooler. Under balanced conditions, the minimum winter loop temperature would stay above 67°F. Sizing the loop to maintain a minimum 45°F temperature in heating only requires 6,240 ft of loop length. This 25,000 ft loop length reduction reduces the total project cost by over $150,000 after accounting for the additional $20,000 for an 80 ton fluid cooler.

Example Site: Paragon Center

An EPRI study (Kavanaugh 1997) demonstrated how a fluid cooler could be integrated in with a geothermal loop. The hybrid concept saved a geothermal project at a four-story 64,000 sq ft office building in Pennsylvania when geological conditions and budget constraints limited the possible loop field size from 27,500 ft to 11,000 ft. A conventional "wet" fluid cooler or closed tower was added to assist with heat rejection in this 200 ton system. The fluid cooler begins operating when the loop temperature rises above 75°F. The cooler fans and spray pump only used about 3% of the total HVAC energy, while the variable speed loop pumps used 5%. Total annual HVAC costs were 6.2 kWh per sq ft. The loop temperature ranged between 42°F and 90°F providing efficient heat pump operation.

Summary

A hybrid system that combines a fluid cooler, cooling tower, or other heat rejection device into a geothermal system can potentially make these systems more attractive in a wider array of applications.

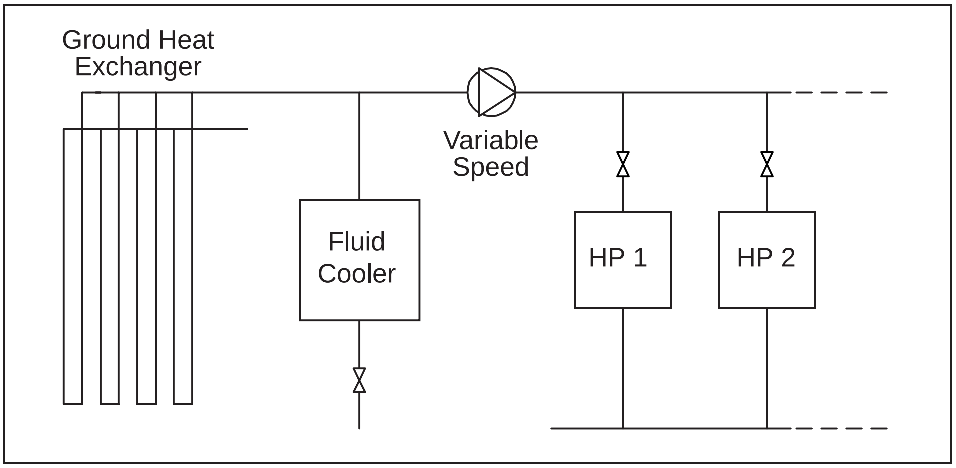

Figure 4. Possible Parallel Fluid Cooler Piping Arrangement—Allows maximum temperature through the cooler, but requires adequate bypass through the heat pumps during low load periods.

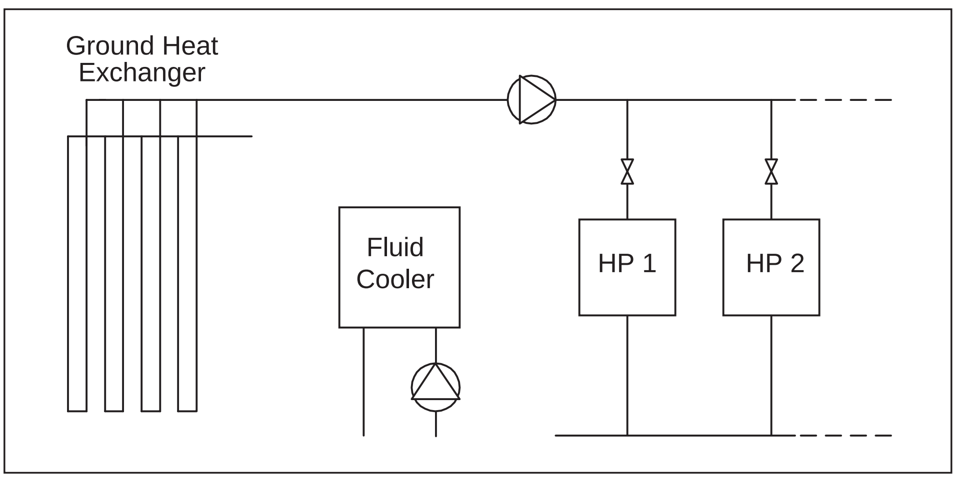

Figure 5. Possible Series Fluid Cooler Piping Arrangement—Suitable for smaller coolers where pumping head would not become excessive.

The hybrid approach reduces the required ground loop size while retaining the main advantage of this technology: efficient heating with heat pumps. Dry fluid coolers may offer a cost effective way to address seasonal heat buildup in cooling-dominated applications while retaining the low maintenance aspects of this technology. Dry coolers can operate at off peak conditions to reject heat when ambient conditions are low. Monitored data from McDonalds demonstrates the promise of this approach.

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