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Direct Heat Geothermal Installation Preserves a Historic Building

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ABSTRACT

Salt Lake City has some of the best examples of 19th Century architecture in the American West, but rising energy costs threaten their economic viability and survival. A local law firm chose to integrate geothermal resources into a restoration in an unusual way. The City of Salt Lake cooperated by installing a heat exchanger around a major sewer line, allowing the sewer line to act as a very efficient ground-source/sink. A second set of ground source coils were installed in the trench above the sewer line to increase capacity. A third heat source/sink was constructed in the basement using fresh water that is then used for irrigation or domestic purposes. The result is a grand old building kept in use, using 40% less energy and more comfortable than ever.

1. INTRODUCTION

The Major George M. Downey Mansion and carriage house at 808 East South Temple in Salt Lake City is a notable example of the Victorian "seaside" or "shingle" style house modeled after homes in Bristol England. Built in 1893 at a cost of approximately of $17,000, the Major Downey Mansion was one of the largest houses on South Temple with 8,000 ft^2 (744 m^2) floor area. The house is listed on the National Register of Historic Places.

The house was the primary residence of the Downey Family into the Early 20th Century. It later entered commercial service, remodeled into apartments in 1935 and again in 1975 to mixed office and residential space. The renovations took their toll on the building's historical originality and attractiveness without improving its energy efficiency.

The mansion was purchased in 2005 by Phillip and Jon Lear to be remodeled for use as a law office. The intent of the Lear restoration was to return the house to its original lay out, introduce natural light by removing non-original interior walls, and install energy-efficient lighting, insulation and windows where it did not reduce the historical exterior of the building. When natural gas prices spiked after Hurricane Katrina in August 2005, the brothers were inspired to get more deeply involved in energy efficient geothermal heating and cooling.

The Lears had a couple decades of experience with energy projects in their legal practice, so they were able to bring together a technical team with creative ideas and put them into practice. They learned of several district heating systems in Europe and Japan that successfully extract energy from sewage. For example, Oslo, Norway since 1989 has supplied more than half the heating load of a 56-building district from a sewage flow of 1000 l/s (15852 gpm) (Friotherm, 2005). Local and regional experts in ground source heat pump systems were consulted to see whether such a system could be scaled to a single building. The City of Salt Lake was interested in a demonstration program. The result is what may be the world's first free standing building to utilize a sewage-based heating and cooling system.

2. BUILDING HISTORY

Major George Downey served in the Union Army during the Civil War, including the battles of Chancellorsville and Gettysburg. Major Downey continued his career in the army after the war as an infantry officer with assignments in California, Arizona, Idaho (where his unit was involved in the chase of Chief Joseph) and Utah. He retired in 1889 and came to Salt Lake City to serve as a principal of the Salt Lake Telephone and Telegraph Company and the Commercial National Bank.

Major Downey chose one of Salt Lake's most noted 19th Century architects, Frederick Albert Hale, to build his home. Mr. Hale was educated at Cornell and began his architecture career in Denver in 1880. In 1890 he moved to Salt Lake City to build the Commercial National Bank. He became a prominent local architect, designing more than thirty structures. At one time there were more than ten mansions along South Temple designed by Frederick Hale. Mr. Hale was also an accomplished golfer and singer. He died in 1934.

The house was purchased in about 1935 by the Heber J. Grant Company and turned into seven apartments. At that time the front stairway was reoriented to provide a better access to all floors. It was renovated a second time in 1975 by Clyde Harvey (architects Cooper Roberts) and turned into a mixed use office and residential facility. One of the major changes at that time was the Carriage House (just to the east of the mansion) which was completely remodeled. The Carriage House now has about 2,000 ft^2 (186 m^2) of office space and has been used as a travel agency, film production headquarters and law offices.

Figure 1: The Downey Mansion and Carriage House (left)

3. SYSTEM DESCRIPTION

The base load requirements for heating and cooling the Downey Mansion are provide by three linked systems:

- Sewage Based Heat Exchange System
- Traditional Ground Source Coil Heat Exchange System
- Interior Water Based Heat Exchange System

The sewer heat exchanger and the traditional ground source coils are located along the street in front of the house (Figure 2) and together comprise the exterior system. The indoor system includes the water storage and recycling system, the closed loop heat pumps within the house and the circulating pumps for the exterior system.

Three secondary systems were added to cope with peak weather conditions and to meet a specific zoning requirement for heated culinary water in the building:

- Attic/Basement Air Recirculation System
- Air Exchange Heat Recovery System
- Tankless Gas-fired Water Heater

The air recirculation and heat recovery systems reduce demand spikes by equalizing temperatures within the building and increasing the total heating and cooling capacity. The water heater provides an additional hot water supply in extreme cold and satisfies the City's requirement that a conventional residence be maintained within the building.

3.1 Exterior Heat Exchange System

The exterior system consists of a heat exchanger and two 2 in (5.1 cm) HDPE laterals used to circulate glycol into, through, and out of the heat exchanger. The heat exchanger consists of two 20.8 ft (6.35 m) sections of stainless steel pipe into which two 20 ft (6.1 m) sections of 8 in (20 cm) stainless steel pipe have been inserted. The two 8 in (20 cm) pipes are separated from the internal walls of the two 10 in (25 cm) pipes by a series of baffles that result in a uniform 1 in (2.5 cm) of clearance on all sides of the 8 in (20 cm) pipes. The two 10 in (25 cm) stainless steel pipes have been fabricated with a flange on each end. The flanges on one end of each of the 10 in (25 cm) pipes (with the 8 in [20 cm] pipes inside) allow the 10 in (25 cm) pipes to be bolted into one unit forming one long 40 ft (12 m) section of stainless steel pipe. The flanges on the outside ends of the 10 in (25 cm) pipe are then connected by bolts to a specially designed stainless steel adaptor that reduces the size of the heat exchanger from 10 in (25 cm) to 8 in (20 cm) so that farthest ends of the heat exchanger (which are now only 8 in [20 cm]) can be joined with the existing 8 in (20 cm) clay sewer pipe via a Furnco fitting. The total length of the stainless steel pipes and end pieces when bolted together is about 54 ft (16.5 m).

Finally, at each end of the 10 in (25 cm) section of stainless steel (just before the end pieces and the connecting flange) a 2 in (5.1 cm) HDPE pipe has been attached to the heat exchanger through a specially made connection. The 2 in (5.1 cm) HDPE pipe on the south end of the heat exchanger is for the intake of the glycol that will circulate in the heat exchanger and the 2 in (5.1 cm) HDPE pipe end connection on the north end serves as outtake for the outflow of glycol from the heat exchanger. These 2 in (5.1 cm) HDPE pipes connect the heat exchange system back to the glycol pumps inside the house. While the connections for the HDPE are on opposite ends of the heat exchanger, they actually run to and from the house in a common ditch that runs at a right angle from approximately midpoint on the heat exchanger. The 2 in (5.1 cm) HDPE pipes extend vertically out of the heat exchanger toward the surface about 8 feet. At that point each pipe is fitted with an elbow a new length of pipe which allows it to run back toward the center of the heat exchanger. At the point that the pipes meet they are equipped with a second elbow that allows them to run parallel with each other and at a right angle to the heat exchanger in an easterly direction back toward the mansion until they pass under the foundation of the house at a depth of approximately 5 ft (1.5 m). This is compared with the heat exchanger itself which lies about 13 ft (4 m) under the ground.

The additional ground source coil heat exchanger is a conventional “slinky coil” laid at 5 ft (1.5 m) depth in the same trench as the sewer line for approximately a 50 ft (15 m) distance. Circulation is via a pair of 2 in (5.1 cm) HDPE pipes laid in the same trenches as those connecting the primary heat exchanger.

Once inside the house, the two 2 in (5.1 cm) HDPE pipes running to and from the outdoor heat exchanger connect to the interior intake and outflow pipes of the internal glycol system forming a single closed loop circulation system for the heat exchange and heat pump process. The unusual aspect of the heat exchanger and the attached glycol system as described above is its’ ability to take or reject heat from the house and transfer it not only into the ground (through the outer wall of the 10 in [25 cm] pipe) but also to take or reject heat into the sewage stream.

Figure 2: Surface location after installation of the exterior heat exchanger system

3.2 Interior Heat Exchange System

The interior system of the Major Downey heat pump system is consistent with most traditional heat pump lay outs. It consists of thirteen heat pumps, seven of which are located in the basement and six on the third floor of the property (Figure 3). All thirteen heat pumps are connected with a single loop glycol system that begins and ends in the basement. The glycol in the interior and exterior loop is driven by two common variable speed pumps. The pumps are activated and their speed determined by thermostats in the building and increase or decrease the speed of the flow based on temperature requirements. There is about 200 gal (757 l) of glycol in the system. Since the system is closed loop this glycol should seldom or have to be replaced.

An unusual element of the internal system is its use of an 1800 gal (6814 l) indoor water storage system (Figure 4) to augment the glycol system during peak heating and cooling times. Specifically, if the heat pump and heat exchanger system as installed are unable to meet heating or cooling demands of the building (i.e. the sewer flow or ground cannot provide enough hot or cold to meet the requirements of the building) the glycol in the system will then be circulated (via a second, but integrated, closed loop pipe system) through the water in the 1800 gal (6814 l) tank as required. If the water in the internal reservoir becomes too hot or too cold it will be released via a special pump and thermostatically actuated valves into the exterior irrigation system (if summer) or circulated into the plumbing (toilets) if winter. In this way the water is used for domestic purposes without increasing the volume of overall water use.

Electricity for the mansion is supplied by purchased wind power through PacifiCorp’s Blue Energy program. This essentially eliminates the building’s carbon footprint. The total system rating is 14.5 tons.

Figure 3: Heat pumps on third floor

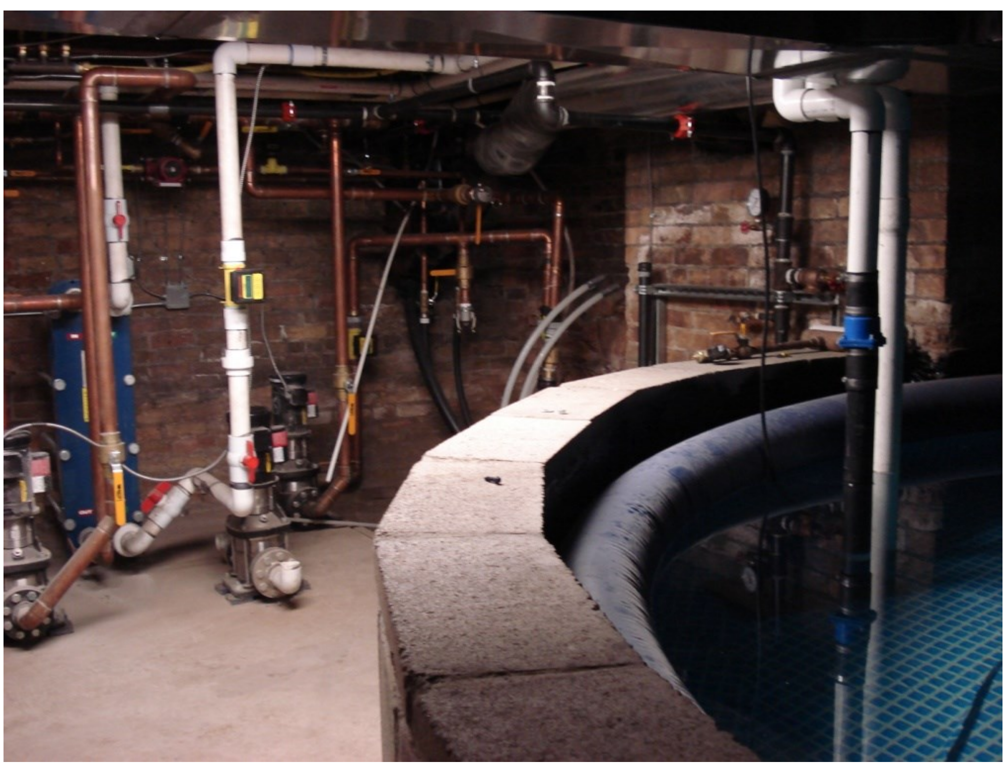

Figure 4: Mechanical room and interior water tank

3.3. Secondary (Peaking) Systems

The secondary systems were developed to minimize the total system load and cope with particular energy characteristics of the Downey Mansion. These systems recover heat that would otherwise be wasted during the air exchange process characteristics, counteract the effects of thermal buoyancy, and provide a supplemental source of hot water. Collectively these measures reduced load on the sewage based heat exchangers and helped the system meet its design specifications for high and low temperatures. They were needed since the volume of the sewage flow was variable based on the location of the Downey Mansion on the Salt Lake City sewer system. A building on a higher flow branch of the sewer might not require all of these measures.

3.3.1 Attic/Basement air recirculation system

The recirculation system comprises two 36.8 m^3/min (1300 CFM) fans. One is located in the basement and the other on the third floor. These fans transfer air to other portions of the building depending on the season. In the summer when hot air rises through the open stairwells in the building, the basement fan brings cool air up to the attic (62-67 degrees F year round) through an old chimney flue and drops it into the conference room on the third floor near a stair well. The cold air cools the conference room and is then allowed to circulate naturally to the lower floors. The third floor fan is used during the winter to move warm air that has risen to the third floor back to the first floor where it is allowed to rise again.

3.3.2 RenewAire™ Systems

The project utilizes two RenewAire™ heat exchange units, one in the basement (Figure 5) and one on the third floor. The RenewAire™ systems are located where the air for the heat pumps themselves is vented to the outside and intake air is brought into the building. In most buildings this air is captured or exhausted without treatment. This means that the ambient outside air temperature can put extra demand on the heating and cooling system. If the outside temperatures are high the heat pumps must remove that additional heat, and the converse is the true in the winter. The RenewAire™ system operates as an air heat exchange system to moderate these effects. Air coming from the outside is mixed with the air leaving the building resulting in a more uniform air temperature. This reduces heating and cooling costs and the overall size of the direct geothermal system required.

Figure 5: Heat exchange system on air intake and exhaust

3.3.3 Tankless Water Heater

The former use of the Downey Mansion as an apartment building and then as a mixed office/apartment building left the building in a "nonconforming" status according to the current commercial zoning of the area. To avoid a costly and uncertain application for an exception to current zoning requirements the building needed to retain an apartment meeting the code requirements for a rental unit. One of those requirements was for immediately-available hot potable water in quantities that would have greatly increased the cost of the heat pump system to provide. Rather than build additional hot water storage, a natural gas-fired tankless water heater was installed to meet the requirement (Figure 6). This unit is also plumbed so it can be used to add heat to the system if the outside air temperature drops too low or the sewage flow rate diminishes so the normal ground sources of heat are not adequate. Total energy use by this heater is negligible in comparison to the rest of the system so the deviation from carbon neutrality was deemed acceptable.

Figure 6: Tankless gas water heater

4. ENERGY SAVINGS

It was not possible to make true apples-to-apples energy or cost comparisons of the integrated Downey Mansion systems with either the predecessor installation or another modern gas alternative. Among the factors complicating the analysis:

i. Occupancy of the building increased, changing the effective area and demand.
ii. No operating data for the previous gas-fired boiler/radiator system, only net cost.
iii. No cooling by the previous central system, only electric window air conditioner (A/C) units.
iv. Previous system used both gas and fossil-derived electricity; new system uses premium-priced renewable electricity.

There was no way of separating the costs of the former window A/C units from other domestic living and office uses in the building. In contrast the new direct heat geothermal system operates exclusively on electricity, meaning it was particularly difficult to compare winter costs. The higher volume of summer use also made it impossible to determine a one to one relationship in the summer. The simplest high level metric available was the annualized cost of energy. The average annual energy cost of the geothermal system described here is 30% less than with the previous system.

These savings in combination with the tax credits provided by the state and federal governments resulted in a 6-8 year recapture of our investment in the direct heat geothermal system. This paper does not describe a modern gas fired system alternative for several reasons. First, it was not clear from preliminary design work that an acceptable system could even be built within the parameters required for historic preservation. The additional construction costs were therefore not fully explored. Second, the gas-fired system was incompatible with the new owners' commitment to carbon neutrality for the building.

5. CONCLUSIONS

The Downey Mansion system of spiral-tube heat exchanger, slinky ground contact coils, thirteen closed loop heat pumps, and unique water storage and recycling system, provides exception energy efficiency. The building eliminates 8 tons (7.3 tonnes) of $C0_2$ emissions annually and yields a yearly energy savings of 30% compared with a conventional HVAC system. The building now operates with comfortable occupants and virtually no carbon footprint.

6. ACKNOWLEDGEMENTS

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