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Geothermal Energy in Building Automation: An Exploration of Ground Source Heat Pumps and Heat Exchangers

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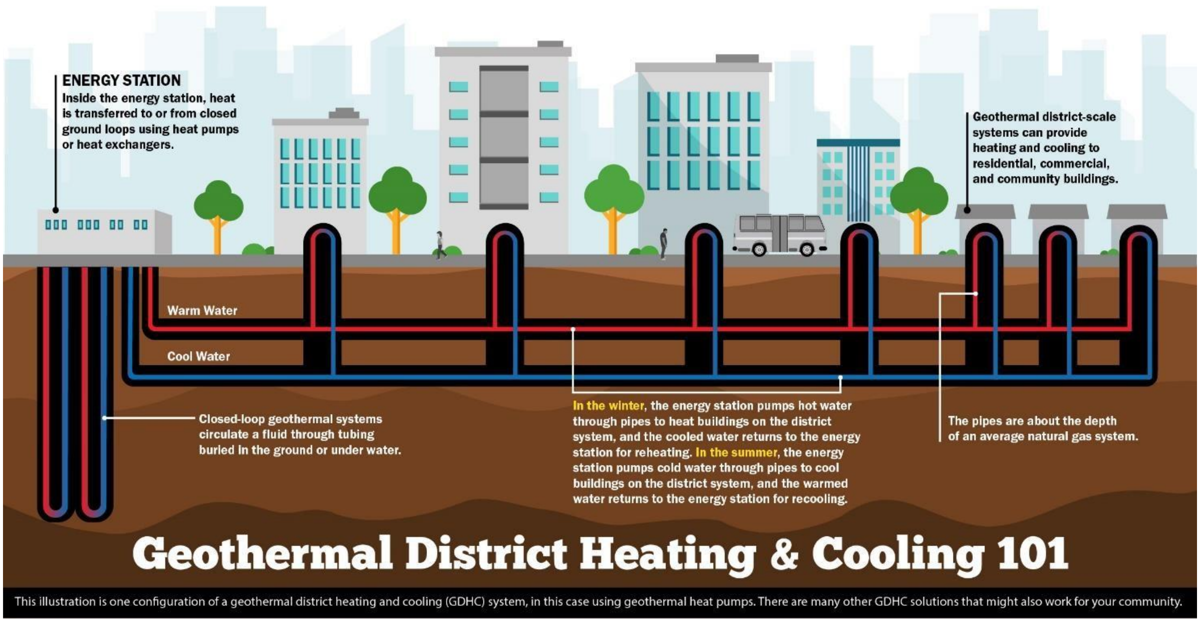
Abstract: ***Ground source heat pumps are not entirely new; they have been in use for several decades. However, their adoption rate has been influenced by various factors like initial installation cost, lack of awareness, and geographical conditions. Despite these challenges, interest in GSHPs has been on the rise, especially in regions with favorable conditions and in areas where energy prices and environmental concerns make them a viable option. In recent years, with the growing emphasis on sustainable building practices and renewable energy utilization, GSHPs have witnessed increased adoption in various parts of the world. They're especially popular for buildings aiming for green certifications, such as LEED. Introduced in the late 20th century, Ground Source Heat Pumps (GSHPs), often known by names like GeoExchange or earth - coupled mechanisms, leverage the Earth's steady subterranean temperature as their primary medium for thermal exchange. Unlike the fluctuating air temperatures that various regions experience, from intense summer heat to freezing winter cold, the Earth's underground temperature remains stable, typically ranging between 45°F (7°C) and 75°F (21°C). This underground environment, reminiscent of a cave, is naturally warmer than the winter air and cooler than the summer air. GSHPs utilize this temperature disparity, exchanging heat with the Earth via a dedicated ground heat exchanger, enhancing their operational efficiency. GSHPs, like their counterparts, can heat, cool, and when equipped, provide homes with hot water. Advanced geothermal models come with dual - speed compressors and adjustable fans, ensuring optimal comfort and energy conservation. When compared to air - source heat pumps, GSHPs offer advantages: they operate more silently, boast longer lifespans, require minimal upkeep, and their efficiency is not compromised by external air temperatures.***



1. Introduction

A dual - source heat pump combines an air - source heat pump with a geothermal heat pump. These appliances combine the best of both systems. Dual - source heat pumps have higher efficiency ratings than air - source units but are not as efficient as geothermal units. The main advantage of dual - source systems is that they cost much less to install than a single geothermal unit and work almost as well.

Even though the installation price of a geothermal system can be several times that of an air - source system of the same heating and cooling capacity, the additional costs may be returned in energy savings in 5 to 10 years, depending on the cost of energy and available incentives in your area. System life is estimated at up to 24 years for the inside components and 50+ years for the ground loop. There are approximately 50, 000 geothermal heat pumps installed in the United States each year. For more information, visit the International Ground Source Heat Pump Association.

Efficiency of Ground Source Heat Pumps (GSHPs)

1) Efficiency Metrics:
Coefficient of Performance (COP) for Heating: The COP measures the heat delivered compared to the power

consumed. To illustrate, a COP value of 4 indicates that for every unit of electricity used, the system provides 4 units of heat. Energy Efficiency Ratio (EER) for Cooling: EER gauges the heat extracted relative to the power utilized. For instance, an EER of 20 denotes that the system extracts 20 units of heat per unit of electricity consumed.

2) Efficiency Advantages of GSHPs:

GSHPs typically outperform other heating methods by 50 - 70% in terms of efficiency and surpass standard air conditioners by 20 - 40%.

The earth's consistent temperature all year round allows GSHPs to function at a steady, high efficiency.

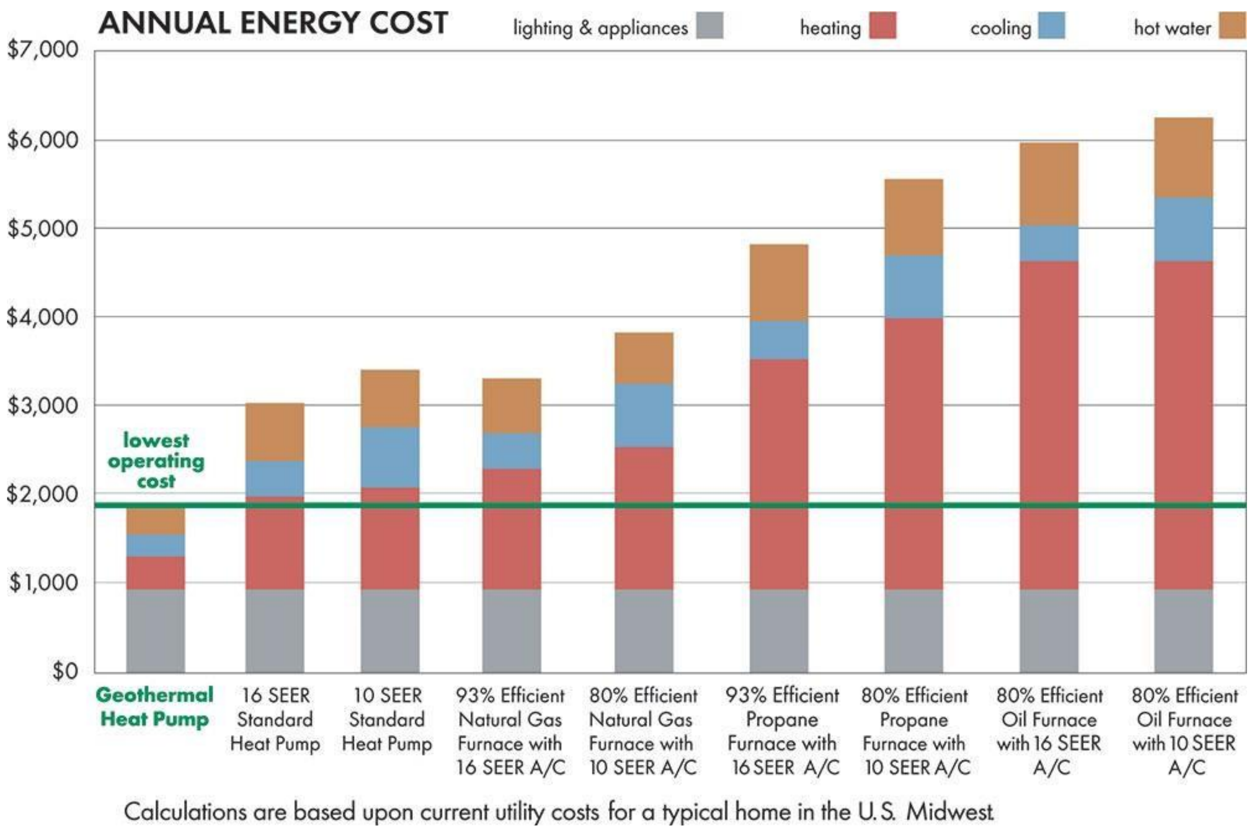
On average, GSHPs can generate between 4 to 5 units of energy per unit of electricity used, leading to a common COP range of 3.5 to 5.

3) Factors Affecting Efficiency:

- **Soil/Rock Conductivity:** The ground's composition (be it rock, soil, clay) can alter the heat transfer rate, subsequently affecting system efficiency.
- **Ground Temperature:** Even though the ground temperature remains largely stable, differences in this temperature across various regions can impact the performance of the GSHP.
- **System Design:** Ensuring that the system is tailored to the building's requirements and that the ground loop is designed efficiently is paramount for optimal performance.
- **Installation Quality:** Only a correctly installed system can meet the estimated efficiencies.
- **Maintenance:** Regular and correct maintenance is pivotal to retain consistent efficiency levels over prolonged periods.

4) Long - Term Efficiency Benefits:

- **Lower Operating Costs:** Thanks to their superior efficiency, GSHPs usually translate to reduced monthly energy expenses compared to traditional systems.
- **Reduced Maintenance:** Owing to a lesser number of moving parts and indoor installation (shielded from external conditions), GSHPs frequently need minimal maintenance and promise extended durability.



Types of Geothermal Heat Pump Systems:

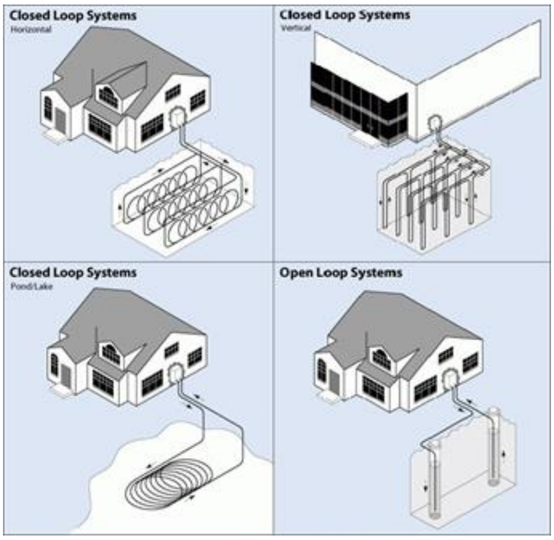
1) Closed - Loop Systems: Predominantly, closed - loop geothermal heat pumps circulate a coolant solution inside a sealed loop, typically made from a robust plastic - like material. This loop is either embedded in the ground or submerged underwater. A device known as a heat exchanger facilitates the transfer of heat between the pump's refrigerant and the coolant in the loop.

There's a variant of the closed - loop system termed the "direct exchange. " Here, there's no intermediary heat exchanger. Instead, refrigerant flows directly within copper tubes either laid horizontally or vertically underground. This variant demands a more substantial compressor and thrives in damp soil conditions. However, it's pivotal to eschew areas where the soil might corrode the copper tubing. Due to the refrigerant's direct contact with the ground, some local guidelines might restrict this method's application.

a) **Horizontal Installation:** This is the go - to choice for many residential set - ups, especially when ample land is at disposal. The installation involves trenching at least four feet deep. Typically, a dual - pipe system is laid – one at six feet deep and another at four, or both side by side at five feet. A popular method, the "Slinky, " reduces trenching costs by accommodating more pipe length in a shorter trench.
b) **Vertical Installation:** Often found in large establishments and educational institutions, this method is chosen when land availability is a constraint. Also, it's apt for areas with shallow soil layers and aims to preserve existing landscaping. Here, holes of about four inches in diameter are drilled, spaced around 20 feet apart and ranging between 100 to 400 feet in depth. A U – bent dual - pipe system is anchored into these holes and filled with grouting material to boost efficiency. These vertical setups are then linked to the internal heat pump via horizontal trenches.
c) **Pond/Lake Installation:** For sites neighboring sizable water bodies, this can be a cost - efficient option. Pipes travel from the edifice to the water body, spiraling into loops situated a minimum of eight feet below the surface to elude freezing. However, the water source must adhere to specific volume, depth, and purity standards.

2) Open - Loop Systems: Here, groundwater or surface water serves as the heat exchanging medium, circulating directly through the geothermal heat pump (GHP) mechanism. Post circulation, this water is reintroduced into the ground either via the original well, a secondary well, or a surface outlet. This design is apt only when there's ample access to pristine water and when all regional groundwater disposal norms are observed.

3) Hybrid Systems: These systems are innovative combinations of multiple geothermal resources or a mix of geothermal resources and ambient air, for example, using a cooling tower. They're especially proficient in areas where cooling demands overshadow heating requirements. A specialized variant of the open - loop design, termed the "standing column well, " is employed where geological conditions permit. This system involves one or more deep vertical wells. Water is sourced from the well's base and redirected to the top. In peak heating or cooling durations, some of the water is discharged, leading to an inflow from the surrounding water reservoir. This inflow modulates the column's temperature, optimizing heat absorption or release, andminimizing the required drilling depth.



Equations:

Calculating the COP

The Measurements

To calculate COP, you need to measure 5 things: the exact temperature of the water entering the geothermal heat pump's water coil, the exact temperature of the water leaving the geothermal heat pump's water coil, the flow rate of the water through the geothermal in gallons per minute (GPM), the amps usage of the unit, and the exact voltage at the unit.

You need to watch out for some things that can skew your measurements when you take them, and make your calculated COP useless. First, all of your measurements have to be made after the unit has been running for a minimum of 10 minutes, and while you take all your measurements. The temperature of the air entering the unit at the air coil (EAT) should be within 2 degrees of 68°F while you are measuring. The water flow through the unit must be the exact same gallons per minute the entire time you are taking all of your measurements. If you have an open loop, this means your well pump cannot start and stop; it must be running continuously (if it is starting and stopping, try increasing the water flow to the geothermal heat pump's maximum rated flow; this might keep the pump running).

When everything is running correctly, you are ready to take your five measurements:
1) Entering Water Temperature/EWT - measure the temperature of the water going into the water coil (the coil marked water in, or source water in).
2) Leaving Water Temperature/LWT - measure the temperature of the water coming out of the water coil (water out, or source water out).
3) Flow Rate in Gallons Per Minute/GPM - measure your loop's flow rate.
4) Amperage - measure the amperage used by the unit at each hot terminal, then add the amperages together and divide the answer by 2.
5) Voltage - measure the voltage at the unit; make sure you measure across the two hot terminals.

The COP Equations

First, we plug our measurements into these two equations to give us Absorbed BTUH and Electricity BTUH:

- (EWT - LWT) x GPM x 60 x 8.35 = Absorbed BTUH (from earth loop)
- amperage x voltage x.85 (power factor) x 3.412 (BTUH per watt) = Electricity BTUH (from the unit's motors' electric usage)

Absorbed BTUH and Electricity BTUH are plugged into the final equation to give us our COP: (Absorbed BTUH + Electricity BTUH) ÷ Electricity BTUH = COP

Here is an example taken from a Florida Heat Pump geothermal heat pump GT042 - 1HZC - FLE. Measurements:

- EWT - 54.8°F
- LWT - 47.8°F
- Gallons per minute water flow – 9
- EAT - 68°F
- Amperage - 13.4
- Voltage - 243

(54.8 EWT - 47.8 LWT) x 9 GPM x 60 x 8.35 = 31, 563 Absorbed BTUH 13.4 amps x 243 volts x.85 x 3.412 = 9, 446.40 Electricity BTUH (31, 563 Absorbed BTUH + 9, 446.40 Electricity BTUH) ÷ 9, 446.40 Electricity BTUH = 4.34 COP

Calculating the EER

The Measurements

To calculate EER, you need to measure five things: the exact temperature of the water entering the geothermal heat pump's water coil, the exact temperature of the water leaving the geothermal heat pump's water coil, the flow rate of the water through the geothermal in gallons per minute (GPM), the amps usage of the unit and the exact voltage at the unit.

You need to watch out for some things that can skew your measurements when you take them, and make your calculated EER useless. First, all of your measurements have to be made after the unit has been running for a minimum of 10 minutes, and while you take all your measurements. The temperature of the air entering the unit at the air coil (EAT) should be within 2 degrees of 80°F. dry bulb, and 67° F. wet bulb when you are measuring. The water flow through the unit must be the exact same gallons per minute the entire time you are taking all of your measurements. If you have an open loop, this means your well pump cannot start and stop; it must be running continuously (if it is starting and stopping, try increasing the water flow to the geothermal heat pump's maximum rated flow; this might keep the pump running).

When everything is running correctly, you are ready to take your five measurements:

1) Entering Water Temperature/EWT - measure the temperature of the water going into the water coil (the coil marked water in, or source water in).
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3) Flow Rate in Gallons Per Minute/GPM - measure your loop's flow rate.
4) Amperage - measure the amperage used by the unit at each hot terminal, then add the amperages together and divide the answer by 2.
5) Voltage - measure the voltage at the unit; make sure you measure across the two hot terminals.

The EER Equations

First, we plug our measurements into these three equations to give us Rejected BTUH, Electricity BTUH and Wattage:

- (LWT - EWT) x GPM x 60 x 8.35 = Rejected BTUH (into the earth loop) amperage x voltage x.85 (power factor) x 3.412 (BTUH per watt) = Electricity BTUH (from the unit's motors' electric usage) amperage x voltage x.85 = Wattage
- Rejected BTUH, Electricity BTUH, and Wattage are plugged into the final equation to give us our EER:
- (Rejected BTUH - Electricity BTUH) ÷ Wattage = EER

Here is an example taken from a Florida Heat Pump geothermal heat pump GT042 - 1HZC - FLE Measurements:

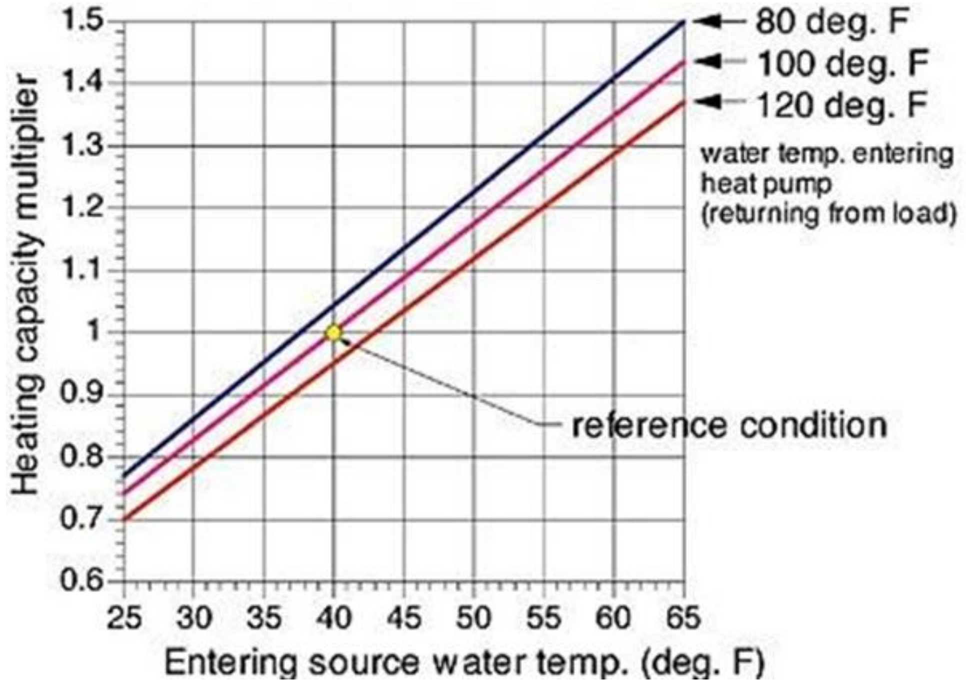
- EWT - 58.2°F
- LWT - 68.7°F
- Gallons per minute water flow - 8.8
- EAT dry bulb - 76°F
- EAT wet bulb - 62°F
- Amperage – 12
- Voltage - 242.8

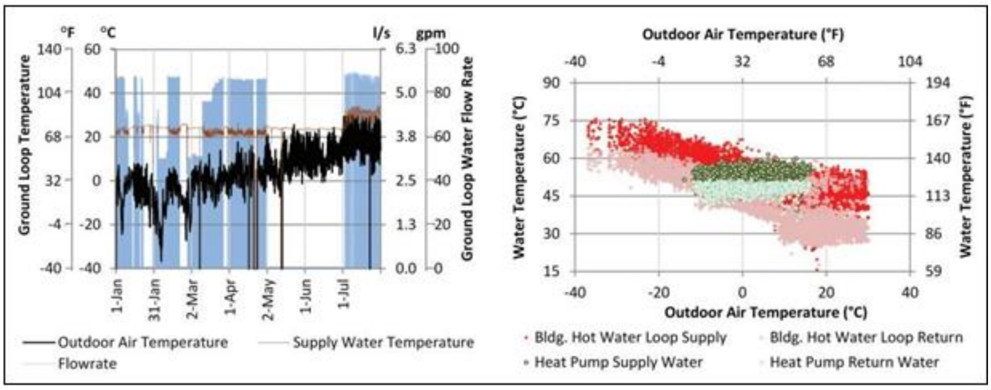
(68.7 LWT - 58.2 EWT) x 8.8 GPM x 60 x 8.35 = 46, 292.4 Rejected BTUH

12 amps x 242.8 volts x.85 x 3.412 = 8, 450.02 Electricity BTUH

12 amps x 242.8 volts x.85 = 2, 476.56 Watts

(46, 292.4 Rejected BTUH - 8, 450.02 Electricity BTUH) ÷ 2, 476.56 Watts = 15.28 EER





2. Conclusion

The push towards sustainable and eco - friendly buildings is steadily making ground source heat pumps a preferred choice. With their numerous advantages and adaptability to varying building requirements, GSHPs hold significant promise for a greener future.

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