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NREL GHP Showcase: GHP Installation and Intensive in situ and Performance Monitoring at NREL's Solar Radiation and Research Laboratory

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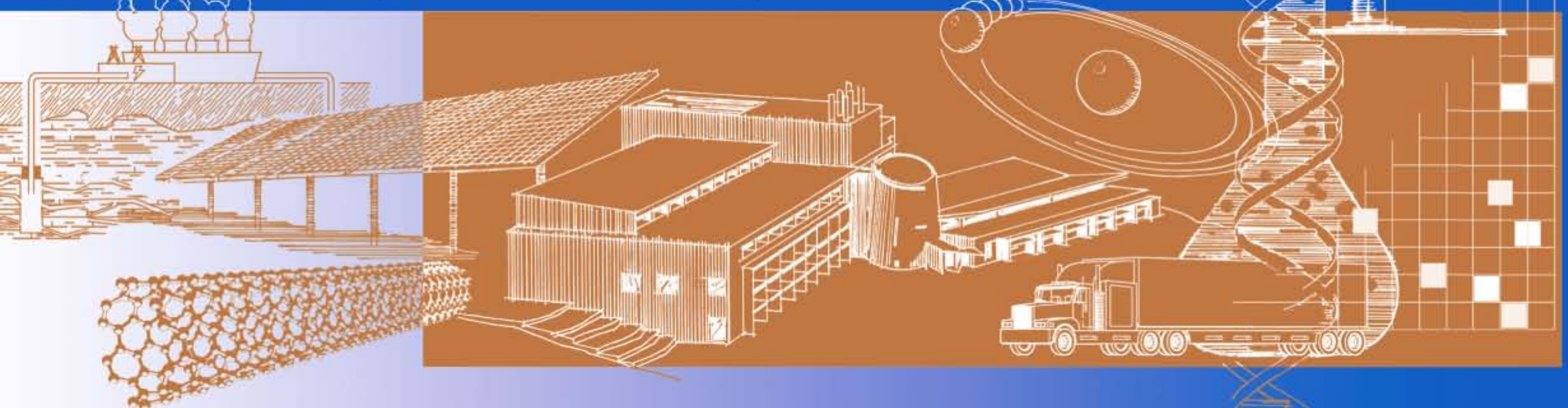

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NREL GHP Showcase: GHP Installation and Intensive in situ and Performance Monitoring at NREL's Solar Radiation and Research Laboratory

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Abstract:
The National Renewable Energy Laboratory (NREL) is developing a research and development (R&D) showcase for Geothermal Heat Pump (GHP) technology on the NREL campus. The showcase helps NREL move forward with the goal to be a model of sustainability within the NREL campus, providing an effective demonstration of GHP systems applied to space conditioning for a laboratory expansion. The design also incorporates unique monitoring and control features compared to a standard GHP installation and will allow for the system to serve as an R&D platform. The data will provide insight into the zone of influence for a borehole, the thermal interference between boreholes, heat transfer throughout the ground loop, and the long-term efficiency of the system. In addition to these uses, the project provides an educational display of renewable energy/energy efficiency that can be featured on NREL tours.

Keywords: geothermal heat pumps, ghp, ground loop design, in situ monitoring, R&D

Introduction & Project Design:
The National Renewable Energy Laboratory (NREL) Geothermal Heat Pump (GHP) Showcase project aims to focus on the design, monitoring, and analysis of a borehole field consisting of twenty-three 300-feet-deep boreholes on the NREL site. The goal of the project is to collect data on the performance of the system with the following elements:

- Provide space heating/cooling for the laboratory efficiently and effectively
- Monitor changes in soil thermal conductivity during operation
- Monitor ground temperatures within the borehole field
- Determine the zone of influence for boreholes and thermal interference between boreholes
- Determine the effects of test areas fitted with either double U-tubes or thermally enhanced grout
- Determine the long-term efficiency of the entire building system, including the electrical demand for field circulation pumps, building circulation pumps, and individual heat pumps
- Determine the temperature change down the borehole and the temperature transfer from the down-flow and up-flow pipes
- Determine the temperature difference between the top of the borehole and the header system housed in the mechanical room 200 feet from the borehole field

The data will be displayed live on a Web site and will showcase the system configuration, performance, energy use, and data readings from monitoring equipment.

NREL was approached by the U.S. Department of Energy (DOE) to develop a GHP showcase project at the lab and demonstrate the installation, use, and operation of a GHP project on campus. NREL is internationally known for its capabilities in wind, solar, biofuels, and energy efficiency, and DOE's Geothermal Technologies Program wants the same visibility for geothermal energy—in this case, geothermal energy in the form of GHP, its use, and its benefits.

The goal of the system is to create a project that is in line with the Sustainable NREL Program's mission of "walking the talk", to create a GHP R&D platform to test various components of the system, and to combine both of these into an educational opportunity for visitors to NREL and a Web site showcasing the technology. The site selection was based on several criteria, namely the timing of construction, potential to be included in site tours, and size of the application. After these criteria were evaluated, the Solar Radiation and Research Laboratory (SRRL) was chosen. The SRRL, shown in Figure 1, is a 2,688 ft^2 building, used to maintain and test a host of labs, measurement systems, and calibrations related to solar energy.

Figure 1: SRRL facility, 2010

The SRRL's core activities relate to the following labs and processes: Metrology Lab, Optics Lab, Baseline Measurement System, Absolute cavity radiometers intercomparisons, broadband outdoor radiometer calibrations, pyrgeometer calibrations, outdoor performance testing, and quality assessment.

A 1,896 ft^2 addition has been designed for the SRRL to provide additional space for the researchers. The construction will begin in September 2010 and the entire 4,200 ft^2 building will be conditioned with 10 GHPs zoned throughout the building. The heat pumps are highlighted by the red boxes as shown below in Figure 2.

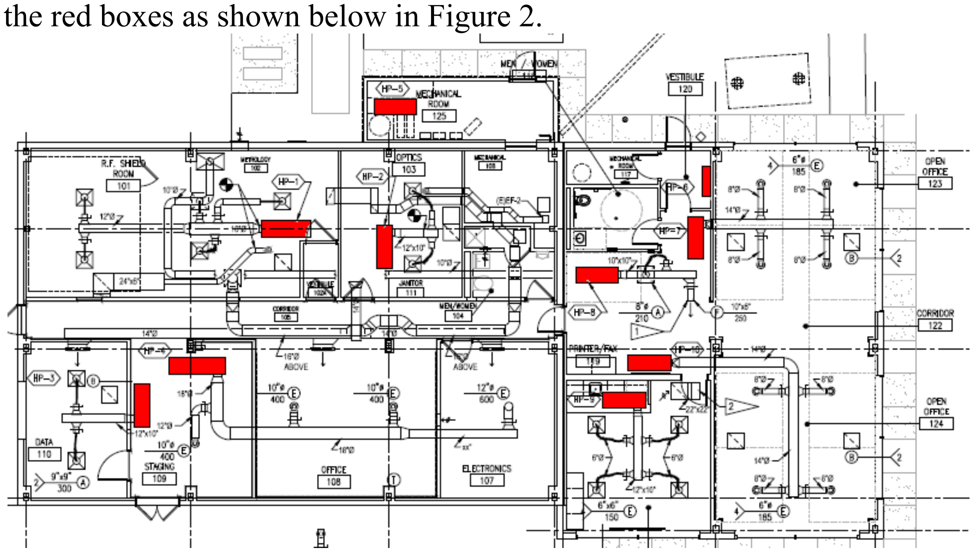

Figure 2: SRRL expansion floor layout with GHPs highlighted

Several of the laboratory tests generate a lot of heat, particularly the optics lab. As a result, this building must reject significant heat gains, upwards of 116 kBTU/h during the peak cooling load, to maintain comfortable working conditions both for the researchers and equipment.

Monitoring & Loads

Each zone will be fitted with a thermister to record the average room temperature. Additionally, the supply and return air temperature of the water-to-air heat pump unit and the supply and return water from the heat pump unit will be recorded continuously as part of NREL's data monitoring process and total system evaluation. Wattnode devices will be fitted on each heat pump to record the electrical load of each heat pump and determine operational hours over a given year.

Despite Colorado's fairly cool climate and mild summers, the SRRL building is cooling-dominated due to internal heat gains from both the laboratory testing procedures and computers. In total, the internal heat gain from both the optics lab and equipment, based on 2009 ASHRAE standards (18.12) is 2,077 watts (7,087 BTUs). The internal heat gain from the remainder of the laboratory equipment is 1,444.5 watts (4,929 BTUs). As a result, the peak cooling requirement of the building is 10 tons (116.6 kBTU/h), while the heating load is 50 kBTU/h (RMH Group, 2010). Due to the strict standards of the laboratory, heating and cooling loads have to be anticipated for a schedule of operation of 24 hours/day, 7 days/week. While the office area schedules may be adjusted to a more traditional 8 a.m. to 5 p.m. five days/week if desired, the GHP system and subsequent borehole field have to be designed for the worst case condition.

Throughout the year, the total cooling load is about 2.5 times greater than the heating load. The preliminary calculation of the total annual cooling load is 500,411 kBTU and the total annual heating load is 164,104 kBTU. Both Figure 3 and Figure 4 below show the load duration curve and the peak load for the SRRL based on current internal gains with occupancy of 24/7/365.

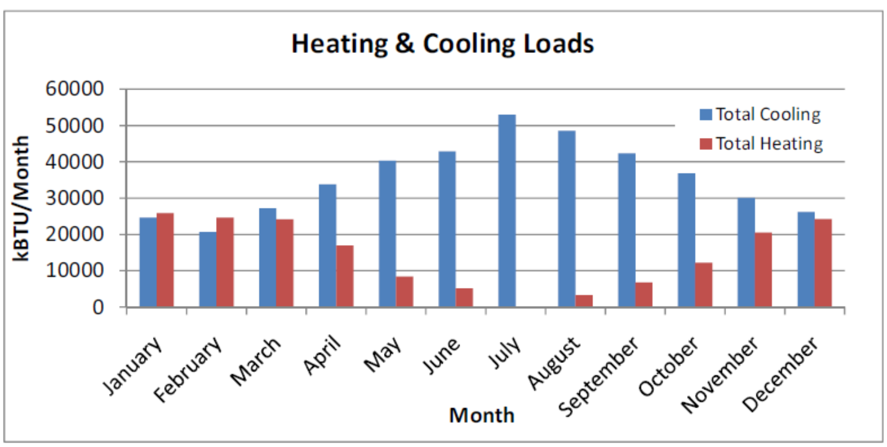

Figure 3: SRRL monthly heating and cooling loads

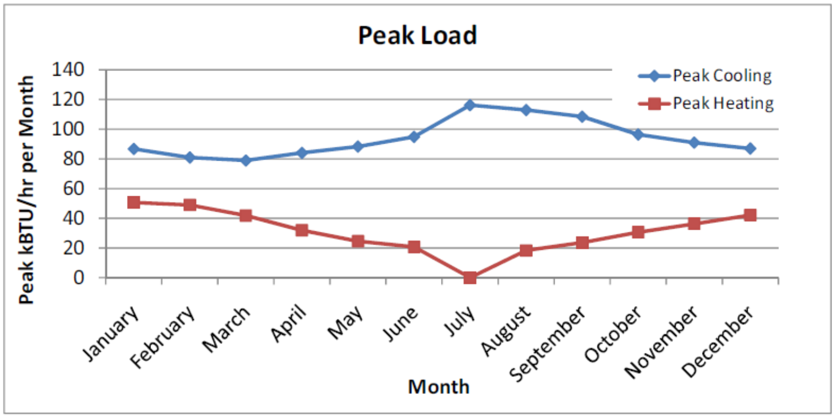

Figure 4: SRRL peak heating and cooling load curves

Borehole Field

A thermal conductivity test was performed by Major Geothermal at the NREL site in accordance with industry standards. The results for the thermal conductivity of the soil were 0.65 BTU/(hr·ft·°F) (1.12 W/(mK)). Due to the significantly high cooling loads for a building this size, and given the poor soil conditions, mostly dry sandstone and clay stone, it was determined that the borehole field had to consist of 21 boreholes, 300-feet-deep each, in order to dissipate the heat to the ground.

Initial vertical borehole evaluation was conducted using both the ASHRAE calculation procedure and the Swedish Model. The ASHRAE results concluded that the entering water temperature (EWT) into the heat pump from the field would never exceed 90°F. The Swedish Model was developed based on Eskilson's 1987 approach to temperature distribution around a borehole. Ultimately, the important information for designing a borehole field is determining the EWT into the heat pump. The size of the field will thus be adjusted to maintain an adequate EWT to condition the building. The size of the ground loop heat exchanger can be calculated using several well-known correlation equations, heat transfer laws, and basic mathematics. Eskilson's equation was transformed for a short time response by Yavuzturk and Spitler since Eskilson's model was limited by time series greater than $\frac{5r_b^2}{\alpha}$ (Spitler, 2000). The equation thus became (Yavuzturk & Spitler, 1999):

Equation 1 $$T_{borehole} = T_{ground} + \sum_{i=1}^{n} \frac{(Q_i - Q_{i-1})}{2\pi k} g\left(\frac{t_n - t_{i-1}}{t_s}, \frac{r_b}{H}\right)$$

where:

t = time (s)
H = borehole depth, ft (m)
t_s = time scale = $H^2/9\alpha$ (α= thermal diffusivity)
k = ground thermal conductivity, Btu/(hr ft °F) (W/(m°C))
$T_{borehole}$ = average borehole temperature, °F (°C)
T_{ground} = undisturbed ground temperature, °F (°C)
Q = step heat rejection pulse, Btu/(hr ft) (W/m)
r_b = borehole radius, ft (m)
i = index to denote the end of the time step, {1…n}

π = constant 3.14….
g = non-dimensional temperature response factor, Eskilson g-function

Knowing the average thermal resistance of the borehole will determine the average fluid temperature in the borehole, which can then be used to calculate the average fluid temperature entering the heat pump with Equation 2 and Equation 3 (Spitler, 2000):

Equation 2 $$T_f = T_{borehole} + Q_i R_{TOTAL}$$ Equation 3 $$T_{entering} = \frac{\dot{q}_{reinjection,net}}{2\dot{m}C_p} + T_f$$

where:

$T_{borehole}$ = *average borehole temperature, °F (°C)*
T_f = *average fluid temperature, °F (°C)*
Q_i = *current heat rejection pulse, Btu/hr-ft (W/m)*
R_{total} = *sum of the resistance of the grout, convection, and pipe conduction, °F per Btu/hr-ft (in °C per W/m),*
$_{rejection,net}$ = *the net heat rejection rate, Btu/hr (W)*
= *mass flow rate of the working fluid, lbs/hr (kg/s)*
C_p = *specific heat of the working fluid, Btu/lb-°F (kJ/(kgK)*
$T_{entering}$ = *entering fluid temperature of the heat pump, °F (°C)*

The results of the Swedish model are shown in Figure 5 below and estimate the EWT to the heat pump to reach as high as 106°F. Since both model results are based on the high design loads that are not anticipated to occur for more than short durations, these temperatures are not anticipated to be encountered during the operation of the GHP system.

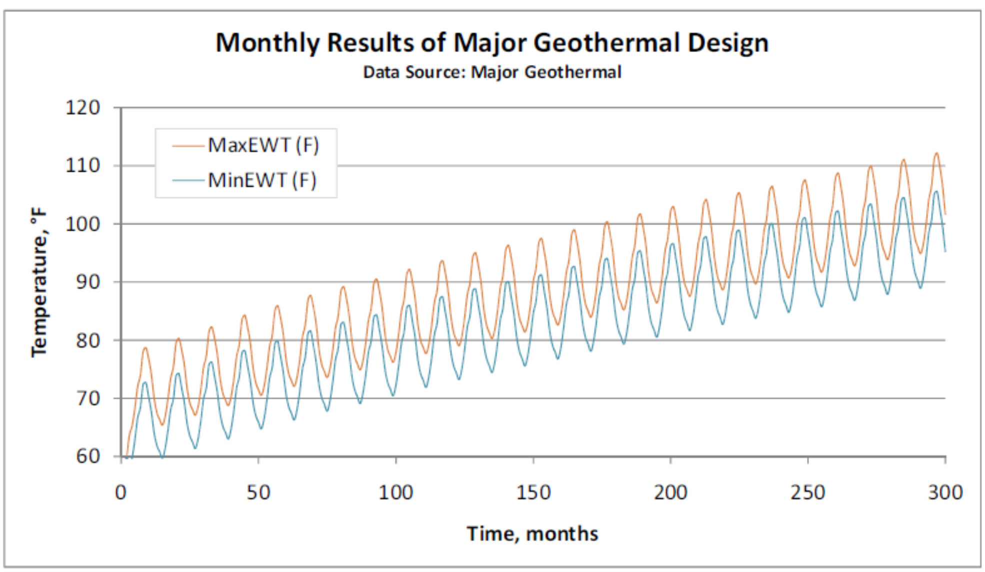

Figure 5: Swedish model EWT at the heat pump for 25-year life cycle

Both design methodologies were evaluated in the design of the SRRL and both indicated a very large loop field size based on the application of the system and the design heating and cooling loads. If the design heating and cooling loads are actually incurred during operation, the ground loop would not have to provide any heating loads to the system heating/cooling loads because they occur simultaneously or at different zones. Instead, the system could be configured as a primary/secondary system and temper the building circulation loop when it gets too warm.

Monitoring Approach & Sensor Layout

Extensive monitoring of the GHP system will help NREL better understand the design, installation, and performance of GHP systems by evaluating real data and comparing the results to various models and installation procedures within the industry.

The borehole field will be configured with a variety of design elements, including double U-tubes, enhanced grout boreholes, individually headered borehole loops, and monitoring equipment to establish the effects of those elements and the effect they have on the overall GHP system performance. The borehole field is laid out in a 3 x 6 pattern, with three additional boreholes to the south of the grid. There will be two additional boreholes to the east, which, although they are not needed to effectively condition the building, will be used to research the effects of thermally enhanced grout compared to the baseline boreholes. Double U-tubes will be installed in the northwest corner of the field. Double U-tubes are used extensively in Europe, but many installers in the United States question the effectiveness of the configuration at conducting more heat into the surrounding ground per length than single U-tubes. There are also installation concerns regarding the pipe separation within the hole and the inability to verify if there is short circuiting between the supply and return pipes. The schematic of the layout of the borehole field is show in Figure 6.

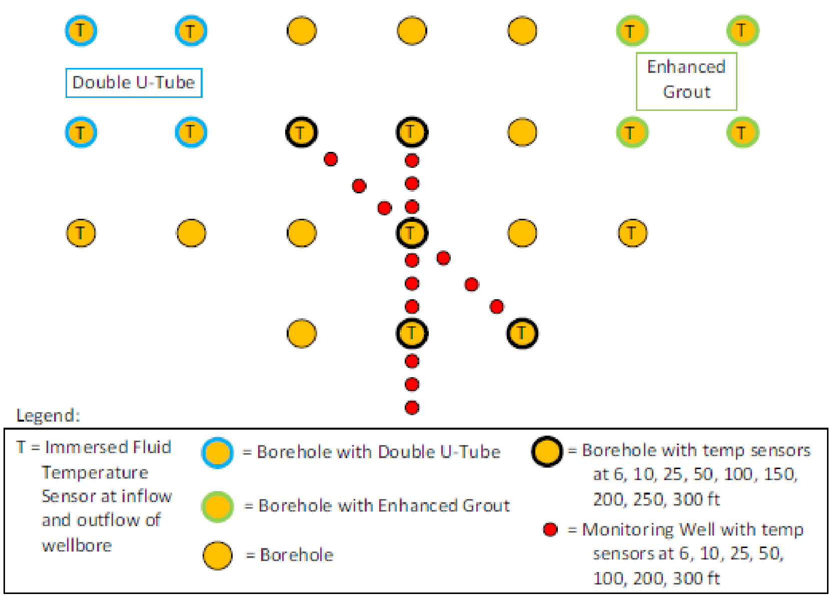

Figure 6: Layout of SRRL borehole field

Several boreholes will be equipped with temperature sensors down the length of the borehole at depths of 6, 10, 25, 50, 100, 150, 200, 250, and 300 feet on both the supply and return side. This will help to determine the temperature change over the length of the pipe and the thermal interference between the walls of the supply and return pipes within the same borehole. NREL is considering adding a thermal barrier on one or more of the boreholes between the supply and return pipes, allowing comparison to the baseline case.   Strategically placed monitoring wells will help to evaluate the ground temperature and measure the change in heat transfer rates for given soil affected by thermal interaction among boreholes during operation. In these wells, thermocouples will be placed at depths of 6, 10, 25, 50, 100, 200, and 300 feet and grouted in place with the same standard bentonite grout used in the baseline boreholes. This will also help to determine the “zone of influence” for a borehole and consequently if there is thermal interference from one borehole to another. These results will help to determine if the borehole spacing is adequate and if significant design improvements can be developed that enhance design procedures, reduce waste of both money and land, and expand the knowledge in the GHP market.

Each borehole will be headered separately within the SRRL’s mechanical room. This will allow individual wells to be valved off for R&D purposes to evaluate the resulting borehole field reactions in terms of fluid flow, fluid and ground temperature, and total heat transferred in the system. Additionally, if the SRRL doesn’t experience the heating and cooling loads as modeled with a 24/7/365 occupancy, then part of the field can be valved off to maintain pumping efficiency of the system.

Since each borehole will have the supply and return pipes running to the mechanical room, additional immersed thermocouples will be installed in the supply side of the header (pipes coming *from* the field). This will determine if there is a temperature gain or loss in the field circulation fluid as it travels as much as 200 feet from the top of the borehole to the mechanical room, six feet below the ground surface.

The flow within the field will be monitored with a portable ultrasonic flow meter. NREL decided to use this rather than a conventional immersed flow meter in order to eliminate possible mechanical failures of the flow meter and to eliminate the pressure drop in the pipe flow. With the temperature difference, fluid flow, and energy input into the heat pumps, field pumps, and air distribution system, the overall efficiency of the system will be monitored.

Soil Properties

A thermal conductivity test was conducted by Major Geothermal in December 2009. The results of the 300-foot borehole thermal conductivity test produced a thermal conductivity (TC) of 0.65 BTU/(hr·ft·°F) (1.12 W/(mK)) with an average ground temperature of 57.5°F. While the TC of the ground at the site location is rather low, the GHP design team at NREL wanted to demonstrate the versatility of the technology and demonstrate the operation of a system in less-than-ideal conditions. While the TC test is useful in determining the average TC for a given length of borehole, it also helps test drilling conditions for the area and indicates the level of effort needed to install ground loops. However, the test does not give reliable insight into the layers of rock, soil, or minerals, nor does it effectively characterize soil moisture. Understanding the true subsurface conditions can help NREL specify the grout properly, determine the zones of high heat transfer, and gain knowledge on the long-term performance of the system based on the soil characterization.

In order to determine true soil composition, layer depths, soil moisture, and specific TCs at each depth, a 300-foot core sample was taken. The core sample will be analyzed for the main soil engineering parameters, namely moisture content, natural density, unconfined strength, gradation analysis, permeability of the Denver Formation, and sulfate and corrosivity tests. Additionally, one-point TC tests will be performed at approximately 5-foot or 10-foot intervals on sampled material. A suite of core samples will be analyzed using scanning electron microscope to characterize the mineralogy, porosity and textures through the drill core.. The results of this test will help NREL determine why some of the engineering properties change with depth based on the rock type and mineralogy. These results will additionally help NREL create specific knowledge of the baseline soil and thermal interactions and evaluate how the TC changes during the operation of the system. Knowledge of the changes of TC during operations will help to improve current GHP ground performance models.

Current Progress:
The drilling of the borehole field and monitoring wells are scheduled for the beginning of July 2010. The completion of the building is planned for mid-November 2010. At that time, the internal monitoring points and the HVAC system are planned to be fully operational, along with the live data feeds to a monitoring Web site. NREL will host this 3D-interactive, Web-based monitoring site, which will enable the evaluation of the current system performance and the downloading of the data by interested researchers.

Summary:
The GHP system at the SRRL will be heavily monitored and used as an R&D laboratory to research the results of ground and building temperatures while in operation. NREL aims to begin the data collection process with the GHP system at the SRRL as its first showcase. Actual performance data will help to answer many industry questions and concerns, help policy makers evaluate the technology more accurately, and help the GHP industry continue to reduce installation costs.

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14. ABSTRACT *(Maximum 200 Words)*
This document provides an overview of the geothermal heat pump (GHP) showcase at NREL and how it will help the SRRL site move forward with the goal of being a model of sustainability within the NREL campus, providing an effective demonstration of GHP systems and needed space conditioning for laboratory expansion.

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