Geothermal Cooling – An Innovative Approach for a Sustainable Future

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Introduction

Today, with rising energy demand, it is imperative to focus on the implementation of energy efficient solutions for sustainable growth. In a tropical country like India, HVAC systems are the biggest energy guzzlers among the utility loads. With peak summer temperatures soaring beyond 35°–45°C, HVAC systems may account for more than 65%–70% of the total electrical demand. When peak summer temperatures are very high, the air conditioning system has to work harder to provide a comfortable indoor environment, fighting harsh outside conditions. The load on the compressor of the chiller is higher and consequently, it draws more energy to provide the desired cooling. However, it is interesting to observe that when the outside temperatures are cooler (say during winters), the same HVAC system experiences a lesser load on the compressor and consumes less energy. The observation can be validated if the summer and winter electricity bills of a given building are compared.

Practically, if ambient temperature conditions for most places in India are plotted, we get a bell curve where temperatures are much higher during peak summer season and lower during winter months. The energy consumption of the HVAC system also follows a similar pattern. It consumes more energy when ambient conditions are hotter and less energy when ambient conditions are cooler.

This phenomenon gave birth to the concept of geothermal cooling technology in tropical climatic conditions. The technology uses the basic principle of Ground Thermodynamics, which says that ground temperatures remain constant from a depth of 10m from the surface of the ground up to a depth of 100m or so. The surface of the ground follows the ambient temperature and thus shows a major variation in temperatures across seasons. But as we start going deeper into the ground, seasonal variations in temperatures gradually converge to a constant value. From 10m depth onwards, the ground offers a constant temperature and hence this zone of the earth is called the thermal equilibrium zone. Beyond the thermal equilibrium zone, however, the temperature starts increasing as we go deeper towards the earth's core.

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About the Author

Kanad Banerjee is currently working as National Key Account Manager in Armacell, a global player in thermal and acoustic insulation solutions. He is one of the IGSHPA® (International Ground Source Heat Pump Association in association with Oklahoma State University, USA) accredited professionals in India. He has a decade of experience in HVAC industry in diverse innovative technologies such as adiabatic and hybrid evaporative cooling solutions and geothermal cooling solutions. In the past, he was associated with firms like Nicotra-Gebhardt, Baltimore Aircoil Company and GIBSS. During his tenure in GIBSS, he was leading national level teams to promote geothermal cooling solutions in diverse industrial verticals such as construction, pharmaceutical, automotive, IT and FMCG.

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Geothermal Cooling

In geothermal cooling technology, we make use of the constant temperature zone of the earth. This undisturbed, natural renewal temperature depends on the latitudinal position of a place. A place that is closer to the equator experiences a higher Undisturbed Ground Temperature (UGT) compared to a place located close to the poles. In India, since we do not have much of a latitudinal stretch from North to South, UGTs for most places are in the narrow range of 24°-27°C, which happens to be much lower than the ambient conditions for most part of the year.

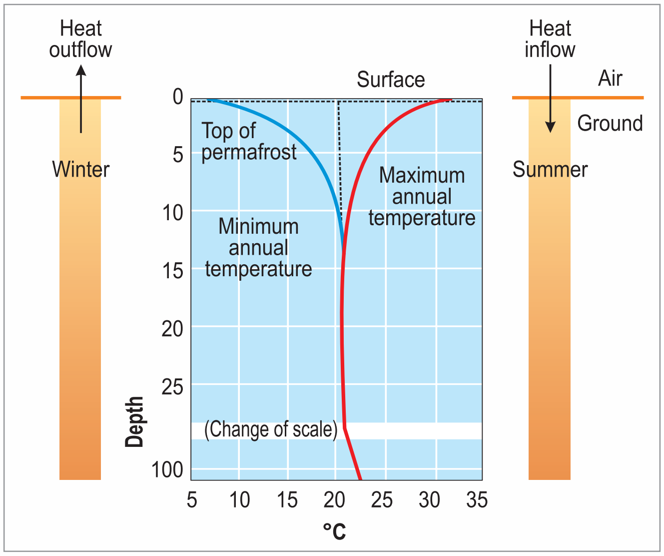

Figure 1: Ground temperature variations with depth

Geothermal cooling technology is thus about getting an access to this undisturbed renewal temperature of the ground and implementing a heat exchanger system to provide an interface with this undisturbed temperature zone and the heat rejection loop of the refrigeration cycle.

In a conventional water-cooled HVAC system, the cooling tower acts as the final node of heat rejection. It takes the heat from the condenser of the chiller and rejects the heat into the atmosphere. The outlet water temperature of the cooling tower is hence a function of the ambient wet bulb temperature and the cooling approach. Hence, during peak summer and monsoon season, when ambient temperatures are not favorable, the overall HVAC system efficiency dips down.

In geothermal cooling technology, this can be avoided. We simply by-pass the cooling tower and integrate the condenser of the chiller with the underground heat exchanging systems. In such an arrangement, the condenser will interact with a constant, undisturbed ground temperature condition for the entire year and experience a lesser compressor load and thereby consume less energy. While conventional air-cooled and water-cooled systems typically consume around 1.1 IkW/TR and 0.65 IkW/TR respectively, similar HVAC systems when integrated with geothermal cooling systems may operate more efficiently with energy consumption as low as 0.5 IkW/TR. In addition to the direct energy savings, the system may also contribute towards huge water and chemical savings when compared with conventional systems.

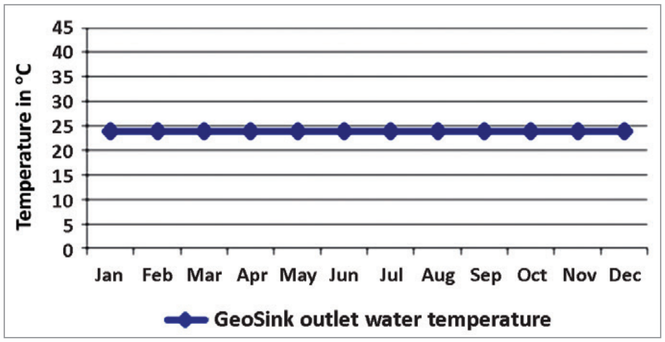

Figure 2: GeoSink's outlet water temperature across a year

Cooling towers work on the evaporative cooling principle. In other words, cooling towers reject heat into the atmosphere by evaporating a certain amount of water. Along with the direct evaporation loss, drift loss and blow-down losses also contribute towards overall water loss across the cooling tower during its operation. This, along with the use of chemical dosing (required in cooling towers) can be totally eliminated by using a Geothermal Cooling System. The operating cost savings against conventional systems can be quantified in three main categories:

1. ***Energy Savings***

Geothermal systems can generate up to 50% energy savings when compared to conventional air-cooled systems and up to 15-20% energy savings when compared to water-cooled systems. Energy savings are a result of lower Entering Cooling Water Temperature (ECWT) in the condenser since the ground offers a much lower temperature compared to the ambient environment.

2. ***Water Savings***

Geothermal cooling system uses closed loop recirculation and does not require any make up water unlike cooling towers in a water-cooled HVAC system. Geothermal systems are 100% water efficient systems as the net water usage is zero.

3. ***Chemical and Maintenance Cost Savings***

Conventional cooling towers work on the evaporative cooling principle and hence the basin water needs scheduled chemical dosing. In addition, when the contaminated water with increased concentration of dissolved solids flows through condenser tubes, it results in scaling that further deteriorates chiller efficiency. Since the geothermal system is a closed loop system, no degradation of the quality of water can take place. Hence, not only does it eliminate the usage of hazardous chemicals, it also minimizes the maintenance cost of the overall HVAC system.

Implementation of Geothermal Systems

The implementation of a geothermal system often comprises of the following steps:

Detailed Design (Phase I)

- Ground Thermal Analysis to determine thermal conductivity (TC), thermal diffusivity (TD), UGT, geophysical and hydrological conditions.

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- Modelling and Sensitivity Analysis to validate energy savings.
- Geothermal Design by an IGSHPA accredited professional using IGSHPA and ASHRAE certified tools like ground loop design (GLD) and ground loop heat exchanger (GLHE).
- Peer review and validation of design by IGSHPA accredited geothermal expert designers.
- Design basis report, workshop drawings, project scope, material specifications and BOQ.
- Detailed project plan, execution methodology and risk-mitigation matrix.

Installation and Commissioning (Phase II)

- Construction of geothermal bore-field.
- Integration of geothermal bore-field with plate type heat exchanger.
- Interfacing the geothermal system with the central HVAC plant.
- System commissioning, balancing and testing.

Ground Thermal Analysis

Ground Thermal Analysis helps to analyze the geophysical, hydrological and geothermal conditions of a project site more precisely. The analysis is carried out with the help of an IGSHPA approved precision instrument called GeoCube, under the supervision of IGSHPA certified geothermal professionals.

The GeoCube is a state-of-the-art polished silver aluminum thermal conductivity/ thermal response test unit. Built for portability, durability and ease of use, the unit is built to address the thermal conductivity test needs in a wide range of environmental and geotechnical conditions. The GeoCube's centralized data collection system ensures rapid and efficient data transfer to the included computer-based software analysis suite. The data output utilizes standards that have been based on research and standards by ASHRAE and IGSHPA for closed loop geothermal ground heat exchangers.

ASHRAE guidelines are the accepted standard for determining the thermal conductivity of a borehole. The data analysis that is used by the included software G is based on the line-source analysis methodology described in ASHRAE 111-8TRP and specified in the ASHRAE 2007 HVAC Applications Handbook, Chapter 32.12-32.13. The software produces a report that provides working definitions and explanations of how the data are analyzed and used. The standard test will accurately estimate the undisturbed loop field temperature and calculate the soil thermal conductivity of the loop field.

The GeoCube utilizes a data logger system with sensors that have been tested and approved for the particular logger included with the GeoCube. Depending on the model of the sensor, there will be several types of sensors that are applied in different locations within the unit. Units that employ redundant temperature sensor sets will have multiple sensors that measure loop temperature in multiple locations within the GeoCube. The sensors exceed the requirements of ASHRAE and IGSHPA standards.

- Voltage: Accuracy ±1% from 10% to 130% of rated voltage (AC potential transformer).
- Current Sensing: Linearity accuracy ±1% from 10% to 130% of rated current (AC current transformer).
- Flow Meter: Accuracy – AWWA specification, 97-103% (pulse output flow meter).
- Temperature Sensor: < ±0.2°C in 0°C to 50°C operating range (12 bit smart sensor).

Figure 3: GeoCube

The scope of the Ground Thermal Analysis includes:

1. Grouted 75-100m boreholes with 1-1/4"U-bend pipe
2. Thermally enhanced grout
3. Drill log for formation layers
4. TC test unit/ GeoCube analysis
5. 48-hr test duration
7. Data analysis report
8. Filling the borehole to bring it back to its initial condition

Flexible HDPE U-tube | After U-tube insertion and grouting | Two ends to be connected with GeoCube

Figure 4: Connecting the GeoCube

Ground Thermal Analysis is a way to determine ground thermal properties that are critical for any geothermal HVAC system design. The test is performed by injecting a known and constant heat power into a borehole heat exchanger and then measuring the temperature response. A competent test can provide the undisturbed formation ground temperature, the calculated thermal conductivity, the calculated borehole thermal resistance and an estimate of thermal diffusivity. These values, which are critical for the optimal design of a geothermal system, can be used in a geothermal design program to design an optimized cost effective system. Thermal diffusivity may be estimated from a combination of the calculated thermal conductivity value (which is inversely related to diffusivity) in conjunction with estimates of specific heat, density and moisture content of the test bore. Thermal diffusivity reflects the rate of conductive heat transfer in

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the soil and helps determine the impact of neighbouring borehole interactions on the final geothermal loop field design.

A 6 inch bore of 250 ft is drilled at the site location and HDPE PE100, PN12.5, 40MM, SDR11 (as per IS4984) U-tube as per the guidelines of IGSHPA is inserted into the borehole to create a U tube underground heat exchanger.

ASHRAE offers a set of procedural recommendations for in-situ thermal conductivity/ thermal response tests. These can be found in ASHRAE 2007 HVAC Applications Handbook. Several of the key recommended procedures are as below:

Time between test-bore installation and start of TC test

A 5 day minimum wait time is recommended.

Undisturbed ground temperature measurement

The undisturbed ground temperature should be recorded prior to test start up.

Test duration

Test duration typically should be for 48 hours or longer.

Power quality

The power standard deviation should be equal to or less than 1.5% of the average power and the maximum power variation should be less than 10% of the average power. The average heat flux should fall within the 15 W/ft to 25 W/ft range to best simulate the expected peak loads in the borehole.

Recommended test equipment

GeoCube is recommended as the test equipment.

Detailed Engineering Design

Based on the findings/outcome of Ground Thermal Analysis, detailed engineering design is carried out for the proposed geothermal system of a given capacity. The detailed engineering design basis report includes the type of the proposed optimal geothermal strategy, the number of vertical column geothermal heat-sinks required for the given heat rejection capacity, area/layout drawing clearly indicating the position and orientation of the geothermal system, type of drilling required in the given geophysical and hydrological condition along with the risk mitigation plan, and plan for integration of the geo-sinks with the chiller plant room along with control systems.

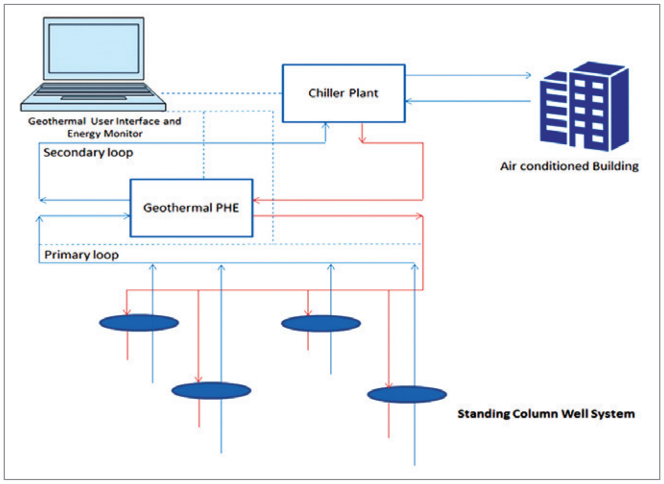

Figure 5: Concept drawing of standing column well system

Depending on the geophysical and hydrological parameters, the most optimal geothermal strategy can be identified. In India, a wide range of geophysical characteristics can be observed. For example, while in North India the ground formation mostly consists of loose alluvial soil strata, South India, particularly the Deccan plateau, offers hard bed rock strata mostly comprising of basalt rock. Different geophysical characteristics favour the implementation of different geothermal strategies. While loose soil strata with abundance of underground water may be the most ideal for Production and Diffusion Well strategy, hard rock strata with depleting water table may favour the implementation of Standing Column Well strategy or Partial Re-circulation Well strategy. In all cases, one among the thirteen broad strategies laid down by the apex body IGSHPA stands out to be the most optimal. The methodologies of drilling through diverse geophysical strata are largely different as well. While loose soil strata require rotary drills, hard bed rocks require DTH drilling technique. Needless to mention that the costs towards drilling and construction of geo-sinks or underground heat exchangers are largely different from one location to another depending on all these dynamic parameters. As a result, the cost of implementing a geothermal system is different for different project sites. Hence it is advisable to carry out a cost benefit analysis or a feasibility study before implementation.

Conclusion

With more than 5 million geothermal cooling and heating systems successfully operating in the western countries, India has also started adopting the technology at a fast pace. A geothermal cooling system of 300 TR capacity is operating at a reputed B-School in Mohali for the last 4 years. The annual electrical savings generated through the implementation of the system amount to 1.8 lakh kWh, making this a commercially viable system with a payback of less than 3 years. The system is also generating huge environmental impact through 19 million litres of annual water savings and 271 tonnes of annual carbon footprint reduction. The socio-environmental impact is equivalent to plantation of 12,500 new trees or powering up 1 small village in a developing country like India. Similar geothermal cooling systems are also getting deployed in hospital facilities, retail outlets, hotels, industrial and pharmaceutical units, data centres and premium residential buildings in the country. Collectively, over 20 geothermal systems in India are generating total savings of 19 million electrical units and 350 million litres of water. As per an independent survey carried out by WWF, scaling up of geothermal cooling applications in India may help in reducing the national energy demand by 35% and the national industrial water demand by 30%. Looking at the socio-environmental impact, the geothermal cooling solution is recognized by bodies such as WWF, FICCI and the Department of Science & Technology (Government of India). Experts believe that the geothermal cooling solution can become a potential contributor towards India's sustainable growth in the near future.