GEOTHERMAL: A COMPREHENSIVE REVIEW OF ITS UTILITY AROUND THE WORLD

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Abstract - *Geothermal technology, which has always stressed on extracting naturally heated steam or hot water from natural hydrothermal reservoirs, is changing to more advanced techniques to exploit the heat and by storing heat, using the earth as a potential battery. This paper gives a review on the main types and utilities. Heating and cooling have been the main utilization through ground source heat pumps, district heating system and application for agricultural and industrial use. Power production through Geo-thermal plants has not picked up as intended but enough successful results are visible. Urban phenomena which is in an epitome of energy use necessitates sustainable solutions in geothermal powered infrastructure. Energy and structural model of residences and office spaces can be recreated with Geothermal application. A comprehensive insight coupled with relevant case studies helps in giving this future solution a great push. This paper gives a detailed note on Geothermal systems in urban quarters, cold climates, mini-type application, large system usages, residences and hospitals.*

***Key Words*: Geothermal energy, Ground source heat pump, Ground heat exchanger, Boreholes, Refrigerant,**

1.INTRODUCTION

The economic feasibility of using geothermal energy is influenced by location, resources, initial expenditure, discount rate, systemic efficiency, annual load and demand, etc. Then also, the substantial environmental and reliability advantages of geothermal energy over other energy sources must not be ignored. [1]

Geothermal-based heating and cooling systems consist of a heat pump, a ground heat exchanger (GHE) installed underground, and an air distribution system. The major cost depends on the ground-based heat exchanger, which must be sized depending on demand expectations and ancillary systems (e.g., a natural gas component for extremely cold temperatures). GHEs can be vulnerable to subsurface flow rates in permeable cases, as well as ground temperature, thermal properties of soil, and heat exchange coefficients, but can be designed optimally for a range of conditions. When geothermal energy is employed in a HVAC system, there is a potential of reducing the energy bill by half. [2]

All heat pumps function on the principle of a temperature gradient or difference. The low-T medium is the heat source and the high-T medium is the heat sink. A GSHP uses the ground as its heat source or sink, depending on the season and the GHE design mediates the heat exchange efficiency. A heating or cooling coil (air-based heat exchanger) mediates heat exchange between the heat pump and the space to be heated (e.g., through forced air circulation). When cooling (inserting heat into the ground), heat is exchanged from the cooling coil (low-temperature medium) to the refrigerant flowing in the GHE (high-temperature medium); when heating (heat removal from the ground), heat is ex- changed with the refrigerant flowing in the GHE (low-temperature medium) to the heating coil (high-temperature medium).

2. RANGE OF APPLICATIONS AROUND THE WORLD

The paper takes into case Geothermal system mainly of vertical and closed loop type in different applications around the world. Since the case studies given below are location and climate specific the applicability of it in every condition is not practical. Looking at the range of application of the geothermal systems, we get a clear picture on how this new technology will play a prime role in the green building and energy sector.

2.1 LARGE HEATING AND COOLING SYSTEMS IN UK

Initial publication about large scale geothermal systems were started in UK about an office building in Crydon, UK which was the largest in that country at that time. It has a heating and cooling capacity of 225 kW and 285 kW respectively. The Bore hole exchanger included 30 borehole each with a 100m depth. A study conducted in Shanghai which had a 2500 kW heatpump,280 boreholes with a floor are of 8000m^2. The building reported 4.7 summer COP and 4.6 COP which resulted in a 56% reduction in running costs compared to conventional system. [4]

The study conducted is on the Hugh Aston building, UK. The net floor area was 16,467m^2. It has three linked wings of between seven and five storeys formed around a central courtyard. A hybrid ventilation approach was used in order to actively cool spaces with high occupancy and high internal gains. Chilled water demand and a part of building space heating demand(underfloor) is met by Fan coil unit (FCU) and Air handling unit (AHU).

Source side: 56 borehole heat exchangers, diameter 125mm and depth 100m each. Average distance between adjacent boreholes is 5m. Boreholes are specifically in 2 arrays in which 19 located in south part of the building and remainder down below the central courtyard. A single U-tube is inserted in each borehole. The tube consists of pipe (High density polyethylene) having 32mm outer diameter. Borehole partly filled with drill cutting and grouted on the top 25m.It has Marl geology predominantly.

The system has 4 water to water heat pumps with a heating a capacity 110 kW and cooling capacity 110 kW each. Refrigerant used is R410A. Each heat pump has 2 single speed scroll compressors which is fully reversible. Two stage operation is possible in this configuration. Depending on the valve position and reversing mode, each heat pump can add heating or cooling to the chilled water header or heating header system respectively. To provide a heating capacity of 330 kW and cooling capacity of 360 kW, no more than 3 heat pumps would be required. Design flow temperature of 55^0C(heating) and 6^0C(cooling) has been achieved with a combination of AHU and FCU equipment. Heat is added or extracted as fluid using variable speed circulating pump. 3 sets of circulating pumps for ground loop, heating header and chilled water header are used. The speed pumps are controlled to vary the flow in steps according to how many heat pumps are operating.

Evaluating long-term behavior of the ground heat exchanger array and monthly demand of the heating and cooling systems was the approach of performance analysis. The ground behavior studies show that BHE is used more importantly used for heat rejection than heat extraction. Expressing heat exchange as mean hourly heat transfer rate, maximum heat extraction was 53kW and maximum heat rejection was 73 kW. The rates obtained are substantially less than heat pump design capacity. Looking at the flow rate data number of times more that 1 heat pump put into use is relatively small. [4]

Energy demand has been calculated for more than 2 years, it has been recorded that monthly heating demand varies between 3 -1 6 MWh and monthly cooling demand varies between 4 - 21 MWh. The peak demand being consistent with corresponding ground loop heat exchange.

It has been observed that system demands are more cooling dominated and that swings in temperature both over particular days and over each season, due to lower loads occurring in practice than expected at design stage.

Two issue found effecting the performance was operating temperatures and circulating pump demands. It would have been a benefit if lower heating circuit temperatures were used than 50^0 C and 55^0 C flow and return rate used in design. Hydraulic system design can be improved looking at the relatively high circulating pump demands.

After analyzing part load operating over the period, a mismatch was seen between the total heat pump capacity installed and size of load occurring in the system. Ground loop temperatures were also seen to be very modest. Both observations tell us that the system have been designed to deal with higher heating and cooling capacity than that occurred in practice.

The simple on-off control system adopted shows that there have accordingly been significant periods of operation with frequent short cycles of heat pump operation. When monitored operation and steady-state modelling results were compared it has been shown that this behavior introduces significant losses in efficiency. The study proposes alternative approaches than the on-off control of compresses: Incorporation of buffer tanks, Incorporation of smaller capacity heat pump, Use of variable speed compressors.

The above study shows us the importance of having system configurations and controls that are able to respond to part load conditions in practice without compromising overall efficiency.

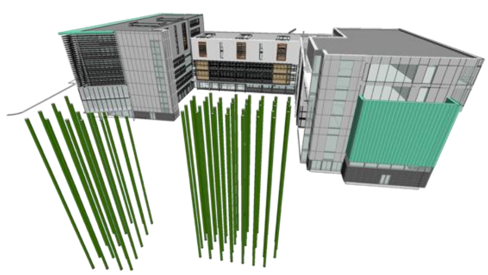

Fig 1: Large Geothermal system

2.2 MINI TYPE GEOTHERMAL SYSTEM

A GSHP system designed and installed in a green building in Shanghai is the case study. The experimental setup is in Shanghai Jiao tang university, for creating a thermal environment for heating and cooling purpose in a meeting room of $180m^2$.[6]

The depth of vertical boreholes used for mini type systems usually range from 50- 80m. Deep boreholes are costlier for construction and also efficient in heat transfer. For this study various depths have been tried to get a clearer picture. The ground heat exchangers have 9 vertical boreholes. GHEs grouped into three with 3 boreholes each. GHE I have depth 80m, GHE II has depth 60, GHE III has depth 50m. Temperatures are recoded every 1 min. An ultra-sonic flow meter is used to measure flow rate of water in the GHE, in the condenser and the evaporator.

When the performance of the system was evaluated closely, in heating mode it was seen that with deeper boreholes, temperature of outlet water temperature of GHE was higher (but temperature difference was less than 1^0 C. In a whole average outlet and inter water temperature of GHE was recorded at 10.8^0 C and 8.2^0 C. So, the average heat transfer between ground heat exchanger and soil was 26.5W/m. When looking at the heat pump as a whole It can be concluded average inlet and outlet water temperature as 36.7^0 C and 41.3^0 C respectively, yielding an average heating capacity of 20.9 kW and a COP of 3.

In a typical cooling mode, mean value of outlet and inlet water temperature of GHE was recorded as 28.3^0 C and 33.6^0 C, giving a heat transfer value between GHE and soil as 48.8 W/m. The average inlet and outlet water temperature for the whole heat pump in cooling mode was 12^0 C and 7.8^0 C respectively, yielding an average cooling capacity of 17 kW and a COP of 3.2.

When soil temperature was measure year around it showed little to no variations, suggesting that the system is capable of satisfying the heating and cooling demand without effecting thermal balance in earth energy.

These systems can be widely used in rural settlements and also in winter climates since it is capable of operating without frost phenomena and in summer it gives an average 14% more COP compared to air source heat pumps.

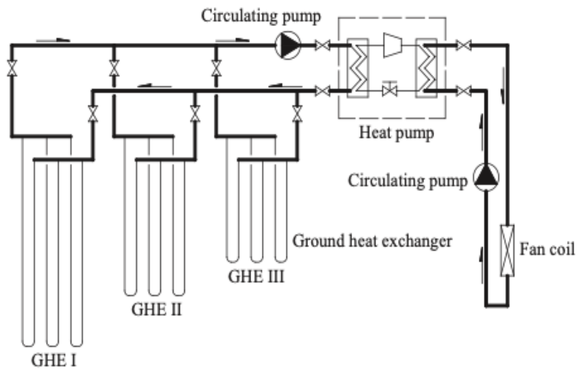

Fig 2: Minitype GSHP system

2.3 GEOTHERMAL SYSTEM IN A HOSPITAL IN NEWZEALAND

The case study is based in Taupo township (Taupo volcanic zone) located in central north island of New Zealand. It discusses about the space heating geothermal system and domestic hot water supply.

The heating system in place is a plate type HE which is suitable for the fluid temperature and pressure produced in the hospital, with a frame size M6-FG. Even though this type of HE produces high fluid pressure across plates, it has a small unit size and lower capital cost. The heat exchanger is designed to produce 600kW and a 100% redundancy. [7]

There is Bypass system in addition to the submersible pump controlling the flow rate. It is used to control the mass flow rate entering the HE thereby controlling the temperature exiting the HE.

The system which has been in operation for 3 years haven't reported in any major technical problems due to any scaling or corrosion which is likely due to the geothermal fluid containing favorable chemistry such as bi-carbonate, nearly neutral pH and relatively low silica and calcium concentration.

The most important benefit has been energy independence providing its own energy consumption for the hospital.

Fig 3: Primary heat exchanger and valve

2.4 GEOTHERMAL SYSTEM INN RESIDENTIAL BUILDING

The case study pertains to a porotype home chosen that has single-level, slab-on-grade home with wooden framing. The study mainly analyses and compares the consumption pattern of vertical ground heat exchangers and electrical air conditioning/ gas furnace system. For this purpose, a simulation template has been made using local soil properties, heating and cooling load magnitude to give bore field parameters for calculation. To understand if the prototype is suitable for geothermal system consumption savings is aligned with capital investment utility cost data, and ultimate payback period. [9]

Building Description is given as Location: Memphis, Tennessee, Area: 2401 $ft^{2.}$, Heating system is 100%natural gas and design nominal capacity: 22.2 kBtu/hr, Cooling system is 100% electricity, design cooling capacity: 2.03 tons, COP 3.97, Heating and cooling fan air flow rate: 825 CFM.

The simulation engine used here is EnergyPlus™. This platform performs computer aided annual simulation along with spreadsheet calculator to get heat pump coefficient input data. The simulation reveals a total annual HVAC energy consumption reduction of 26%., which represents the sum of electric and gas savings. This percentage represents the savings on the monthly meter based electric bill not just only heating and cooling savings. From the baseline HVAC system to the updated Geothermal system, the most significant decrease in energy is form heating. A slight increase in energy use has been observed in the cooling mode.

The design principles of the heat pump is the main reason behind the total energy use reduction. Unlike natural gas system, The GSHP borrows the heat from the earth to transfer to the zone. Similarly, in the cooling season, an electric cooling coil which relies on the heavy work of the condenser fan to dispel heat from the refrigerant, But the GSHP system simply transfers the heat absorbed from the zone back to the earth as it acts as a heat sink. i.e. The heat pump works to transfer the heat form one location to another whereby a traditional HVAC system has to create a transfer medium.

Due to Borrowing of heat to heat the zone in heating zone, the inlet temperature to the ground heat exchanger is lower than the outlet temperature. Due to rejection of heat to cool the zone in the cooling season, the inlet temperature to the ground heat exchanger is higher than the outlet temperature.

When initial monthly energy consumption is compared with the modified consumption it is observed that a reduction in electric and gas usage is achieved. Despite all these saving, the payback period of 15 years will deter most home owners from changing to the geothermal systems.

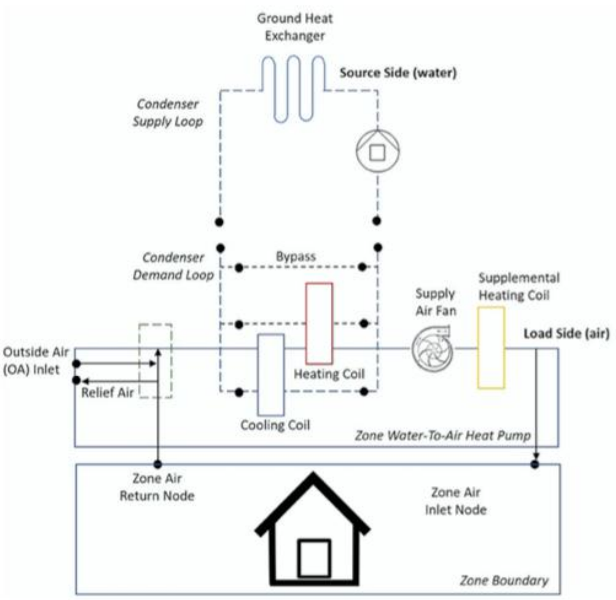

Fig 4: Schematic of the GSHP system in residential building

2.5 GEOTHERMAL SYSTEM IN COLD CLIMATES

The case study in analysis is a vertical ground heat exchanger in Erzurum turkey.

System Description: heat pump (Scroll type compressor, plate type condenser, evaporator, a 25mm thick rubber foam was insulated in all these). A thermostatic expansion valve and flow control equipment's such as solenoid valve, sight glass, dryer, suction accumulator and vertical liquid receiver and refrigerant 134a which was used as working fluid), A ground-coupled heat exchanger and a heating unit. [3]

The GHE is a two separate U-tube placed in two vertical boreholes. The U-tube is made of PE pipe with 32 mm inside diameter. The borehole is 53 m in depth and 105 mm in diameter. In order to avoid the water freezing under the working conditions during the winter, a 50% ethyl glycol mixture by weight was used. The pipes connecting the GHE to the evaporator were insulated and buried at 2 m depth to minimize the heat loss.

The annual average soil is identical to the well water temperature which is 15 0 45 m deep. The depth of the pipe buried influences the increase or decrease of the soil temperature in contact with the heat exchanger. The temperature value normally varies between 1.66- 10 C, generally considered as 5.55C. Soil temperature generally drops with the heat withdrawal. But the difference is less than cooling. Pipe surface area varies according to the heating rate. Soil thermal resistance (Rt) is much important to heat flow through soil. The depth of the pipe buried under ground, pipe sizes, number of the pipes into a hole, horizontal or vertical pipes, horizontal and vertical distances between each of pipes and soil genus have a great effect on soil thermal resistance.

The GHE has given two different value for mass flow rate of water- antifreeze solution. In the boreholes which are 10 l/min and 20 l/ min. The temperature difference between the outlet of the evaporator and inlet of the compressor resulted from super- heating and sub cooling of the heat exchanger. The hot and cold fluids were refrigerants in the outlet of the condenser and the evaporator in this heat exchanger, respectively. The heat exchanger was used for superheating of refrigerant before the inlet of the compressor and for sub cooling of refrigerant before the inlet of the expansion valve.

When the coefficients of performance of the heat pump (COP) and system (COPs) change due to power drawn by the compressor and the change in the heat capacity of the condenser is observed. the average minimum and maximum values of the COP are found to be 2.65 and 3.0 for the heat pump and 2.12 and 2.5 for the whole system. The output water temperature of the condenser remained at the desired level throughout the day (about 42–48 °C). The proposed system is more convenient to floor heating than radiator for supply temperatures of 40–45 °C. Also, during heating process, the temperature of water and antifreeze mixture in the output of the evaporator is constantly reduced. Heating systems by using heat pumps to be installed anywhere in the world today has become particularly attractive in cold climate regions.

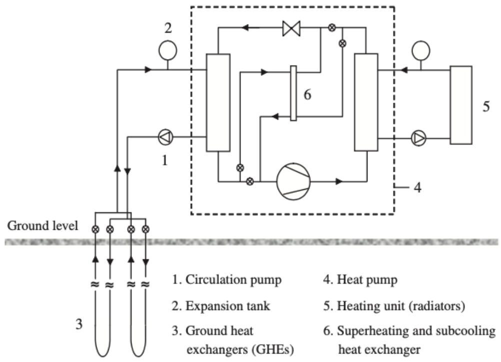

Fig 5: GSHP system in cold climate in turkey

2.6 GEOTHERMAL SYSTEM IN URBAN QUARTERS:

In Germany, GSHP systems are typically used in a new, single-family building with a low heat demand, usually supplied by two Bore hole heat exchangers. Some papers have already proposed that planning geothermal systems for an entire quarter or city is more reasonable than focusing only on small individual houses. In urban quarters, the heat demand is mostly determined by the age of the building or more specifically the energy standard. The case study site is located in "Rintheimer Feld", which is an urban quarter of 0.13 $km^{2.}$ Which is located in south west of Germany. The site is a 31 multi-family houses inhabiting around 2500 people. The feasibility study done here on the system is a spatial analysis using ArcGIS and analytically estimating heat supply rate. The heat supply rate can be defined as a ratio of the maximum amount of energy exchanged between the ground and vGSHP system to the heat or cooling demand or it is the heat content stored in a given volume of the subsurface for a given temperature reduction. The heat supply rate is evaluated in 3 steps: Spatial analysis using GIS software ArcGIS to know the specific space available. Using result from step 1, Geothermal potential (maximum extractable energy which can be harnessed annually) is evaluated.
Percental heat supply rate S is calculated by comparing the Geothermal potential with measured heat consumption before or after refurbishment. [5]

Vertical ground source heat pump system: The Borehole, which is the vertically installed plastic tubes typically have a length of 100m in Germany. The advantage of this system is the high heat extraction rate of up to 114 W/m in favorable groundwater conditions but the drilling cost is bit in the higher side. The ratio of system installation to heat demand is a decisive factor for satisfying heat supply rate. The study tells us that 60-70% area is used for the geothermal system installations. But in denser urban areas, this space is likely to be smaller and due to higher buildings with a larger heat demand per m^2 building, unless the overall amount of drilling meter increases significantly. Meeting the heating demand in Germany particularly with low number of BHEs is more likely in a residential\, less urban quarter with low rise buildings. It also concludes that the heating demand of only 40% parcels of urban area with almost 87,000 inhabitants can be satisfied with the vertical geothermal systems.

Four restrictive and influencing factor for the efficiency of shallow geothermal systems and the achievement of full heat supply rate has been identified:

Restriction of drilling depth by authorities. Critical design parameters provide heat extraction rate as 60 W/m and BHE spacing 10m. Favorable hydrogeological conditions i.e. moderate to high groundwater flow velocity, sufficient aquifer thickness. Optimal ratio of available space for system installation to heat demand to achieve satisfactory heat supply rate. Evaluation of the geothermal heat supply rate combined with a profound geological knowledge will reveal the ability of geothermal systems to satisfy the heat demand of any urban area. This way, it will help to realize future urban energy plans.

3. CONCLUSIONS

Some studies given above have been highly location specific, the main reason being calculation of exact bore length. Factors like soil property identification by type, density, porosity, and undisturbed ground temperature determine the design specifications. To achieve confidently accurate energy consumption savings and annual cost savings, there should be union of precise ground characteristics, accurate home energy use, and region specific incentive analysis.

Earth-energy technology may be more expensive to install than some natural gas, oil or electric heating units, but they are very competitive with any type of heating/cooling system. Heat pumps are most attractive for applications requiring both heating and cooling. An open-loop water-source system for an average residence may cost $10,000, while a closed-loop ground-source system may cost as much as $20,000. However, annual operating costs would be as low as $850, when compared to $2000 or more for conventional heating/cooling systems. Keeping in mind that more cost-effective drilling technology for boreholes is needed for lowering initial cost and improving the life-cycle performance of the ground-coupled heat pump (GCHP) systems

Further evolution of technology will enhance the life span and the life-cycle efficiency of GCHP systems. Methods should be developed for designing hybrid GCHPs, considering the effects of supplemental heat rejecters and absorbers, building systems, ground heat exchangers, and the complex interactions with ancillary power sources (wind, solar). Soon, these systems will be cheaper than non-geothermal active systems, and will allow the integration of other renewable energy sources into the construction of the human habitat

It can be seen that in the near future Geothermal energy sources has the great potential to be a prime energy source in near future. This energy technology has a number of positive characteristics (simple, safe, and provides continuous baseload, load following, or peaking capacity) and sustainable environmental attributes (zero emissions of CO_2, SO_x, and NO_x), It is surely an interesting solution in both developed, and developing countries as an affordable and sustainable option to produce clean energy to confirm a better environment.

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