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GROUND COUPLED HEAT EXCHANGER AIR-CONDITIONING SYSTEM: A STUDY

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***Abstract*—This paper provides a literature survey on "Ground Coupled Heat Exchanger Air-Conditioning System". The study indicates the use of earth as a heat-sink with an aim of controlling global warming and moving towards a greener air-conditioning technology. Measurements show that the ground temperature below a certain depth remains relatively constant (15 °C-20 °C) throughout the year. This is due to the fact that the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases because of the high thermal inertia of the soil. The difference in temperature between the outside air and the ground can be utilised as a preheating means in winter and pre-cooling in summer by operating a ground coupled heat exchanger.**

***Index Terms*— heat sink, COP, high thermal inertia, geo-thermal cooling, heat exchanger, air conditioning.**

I. INTRODUCTION

A Ground Coupled Heat Exchanger Air-Conditioning System (GCHE) is a modern type of space heating & cooling system which exchanges heat with the ground or earth rather than the ambient air. The temperature of the ambient air fluctuates throughout the year but the temperature of ground at a certain depth remains constant throughout the year all around the globe. The ground coupled heat exchanger as exchanges heat with nearly constant temperature (15 °C-20 °C throughout the globe) heat sink (ground) rather than exchanging it with fluctuating temperature heat-sink(ambient air) consumes nearly same amount of electricity throughout the year if the cooling load is kept constant as the heat sink is at nearly constant temperature, whereas in case of ambient air as heat-sink the electricity consumption increases/decreases as the temperature of the sink fluctuates i.e. it increases in the summer due to which more amount of work and hence energy is required to pump heat from room to be cooled to a already hotter heat-sink whereas the temperature of the heat-sink in winter is low so energy consumption is comparatively low. Generally, cooling load is considered in summer season, hence comparatively ground or earth as a heat-sink is an economical way than conventional system having ambient air as heat-sink when electricity consumption is considered. A GCHE system eliminates the requirement of water required for cooling towers thus saving the water lost through evaporation in cooling waters. Depending on the amount of cooling required, a typical IT company building or a large industrial plant uses about 25,000 units of electricity and between 3-5 lakh litres of water each day — supplied through tankers or ground water for air conditioning or process cooling. This is equivalent to the water that was carried by a 50 wagon train to drought hit Latur district in Maharashtra just a few days back. And all of this water is completely lost to the atmosphere through evaporation, which is the fundamental principle on which traditional commercial and industrial air conditioning systems operate. An air conditioner consumes 40-60% less electricity than normal and zero water in the cooling process using geothermal cooling. A geothermal cooling system was installed at Nagpur in India and concluded that geothermal cooling system i.e. Earth Air Heat Exchanger (EAHE) could save up to 90% of electricity as compared to conventional air conditioning systems and 100% of water as consumed by evaporative cooling systems [18].

II. PRINCIPLE OF OPERATION

The GCHE system works on the phenomena of earth having constant temperature throughout the year around the globe below a certain depth beneath the earth surface. Usually, it is 15 °C-20 °C but may vary according to certain geological and geographical conditions [4].The heat transfer rate between the GCHE and earth depends upon the conductivity of soil, thermal inertia of soil along with many other parameters like water holding capacity of the soil, and the depth [7].

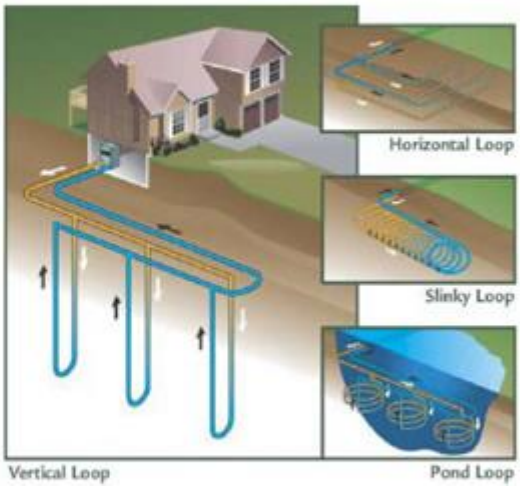

Fig. 1 Residential Ground Loops [24]

The GCHE system is designed in varying configurations refer fig.1 according to the geological and geographical conditions and availability of land. The configurations are vertical loop, horizontal loop, slinky loop and pond loop [20].
The coils of GCHE are made up of High Density Polyurethylene (HDPE) pipes [14].
The cold fluid i.e. water from the GCHE enters the indoor unit of the air-conditioning system extracts heat from the room or space to be cooled and returns to the GCHE where it exchanges heat with the earth at constant temperature and gets cooled again. The point at which the warm liquid enters the GCHE is hotter than the intermediate point between the GCHE and the point at which the liquid exits the GCHE [22].
The vertical configuration is more effective when there is a limited space available, the horizontal loop is used when more space is available and soil conductivity and water holding capacity is significant, whereas the pond loop configuration gives the added advantage of extracting heat faster from the heated liquid as the water flows over the GCHE coils [20].

The GCHE system if coupled with Earth Air Heat Exchanger (EAHE) system increases the efficiency of GCHE system. The EAHE system passes air from the coils buried at a certain depth so that the air is pre-cooled before letting it into the room to be cooled [7].

III. SCOPE OF WORK

GCHE system if coupled with Earth Air Heat Exchanger (EAHE) can be more efficient.

IV. BODY OF LITERATURE SURVEY

The heating and cooling equipment involved in different domestic and business environments utilize electricity as a major source of energy which comes from the fossils fuels subsequently causing many global environmental problems. This large dependence on the conventional energy for the operation of different cooling equipment has caved in people to look for other cheaper and readily available energy sources. The refrigeration and air conditioning demand using conventional energy can now be reduced to some extent by using solar energy, biogas, biomass, geothermal energy etc. Different authors have worked on economic and optimization analysis of different types of refrigeration system.
Enrico Fabrizio, et al. [4] suggested an integrated system for space cooling and domestic water heating. The study focusses on designing and operation of integrated HVAC and domestic hot water (DHW) production systems. The study includes biomass based HVAC and DHW production systems, solar assisted heat pump (SAHP) systems, typical zeolite/water gas system coupled with a gas condensing boiler with solar supported heating in thermal driven Adsorption heat pumps, Reversible system, Variable refrigerant flow (VRF) system and so on.
F. Khalid, et al [5] studied different HVAC systems like natural gas operated HVAC systems, PV system on the basis of efficiencies. In these systems when compared, the energy inputs are the solar and wind energy driven systems are superior to the solar and photovoltaic system, due to the better efficiencies of wind compared to photovoltaic systems. Energy and exergy analyses are performed to assess the performance of heating, cooling and overall systems.
Farah Kojok, et al. [6] proposed and investigated numerous systems combining different cooling processes. A properly selected hybrid cooling system offers a great reduction in energy consumption and a coefficient of performance improvement.
S.A. El-Agouz, et al. [20] mentioned about a study regarding novel desiccant air-conditioning system, consisting of a desiccant wheel, fans, evaporative cooler, heat exchangers, electric heater unit to simulate the refrigeration unit and solar energy. The author concluded that by proper implementation of solar energy the coefficient of performance (COP) between 50% and 120%. It also showed that the efficiency is maximum at optimum value of regeneration temperature and rotational speed of the desiccant cooling cycle based on the design condition of the cooling cycle.

A study based on the review of various thermodynamic and economic parameters conducted by A. Gupta, et al. [1] suggested that the variation in the evaporator temperature from
-3 °C to3 °C decreases the power consumption of compressor by 32.9% due to the decrease in specific volume of refrigerant at the inlet of compressor. An improvement of 0.648 from 0.612 in the overall COP was shown to be achieved with an increment of 6 °C in evaporator temperature.
Arne Speerforck et al. [2], stated the study of a combination of indirect evaporative cooling coil and a ground circuit consisting of four bore heat exchangers (BHXs) was done, it showed that the combined system was more efficient than the indirect evaporative cooling coil alone.
However, the focus of this review is to study Geothermal as a source of energy in improving COP and reducing power consumption.

A. Overview of Geothermal systems

Ground Sourced Heat Pump has low maintenance, reduced fuel bills, high efficiency, heating and cooling both possible. It can be used in conjunction with other renewable energy. A Heat pump is able to transfer heat to and from the fluid at low temperature to fluid at high temperature.
As suggested Lale Valizade, et al. [14], the Coefficient of Performance (COP) determines the heating performance of the heat pumps, Ground source heat pumps are classified on the basis of the type of ground loop.
Similarly, Georgios Florides, et al. [8] studied and elaborated the types of ground heat exchangers. Ground heat exchanger system can be either: open or closed.

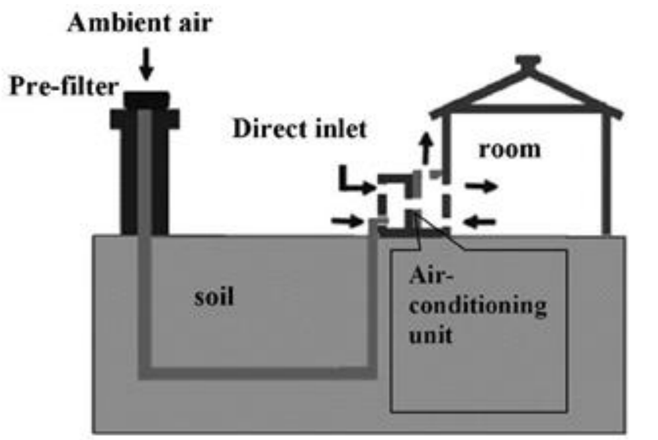

Fig. 2 Basic principle of ground preheating or pre-cooling of air in an open system [8].

The study further showed that vertical loops are generally more expensive to install, but require less piping than horizontal loops because the earth deeper down is cooler in summer and warmer in winter, compared to the ambient air temperature.
Also, the ambient climatic conditions to be taken in consideration for a GCHE that affect the temperature profile below the ground surface and need to be considered when designing a heat exchanger.
Therefore, the ground surface temperature can be estimated from,

Tsur(t)= Tm + As Re(eiwt) □□□

where Tm is the mean annual ground surface temperature, As is the amplitude of the temperature wave at the ground surface and w is the frequency of the temperature wave.

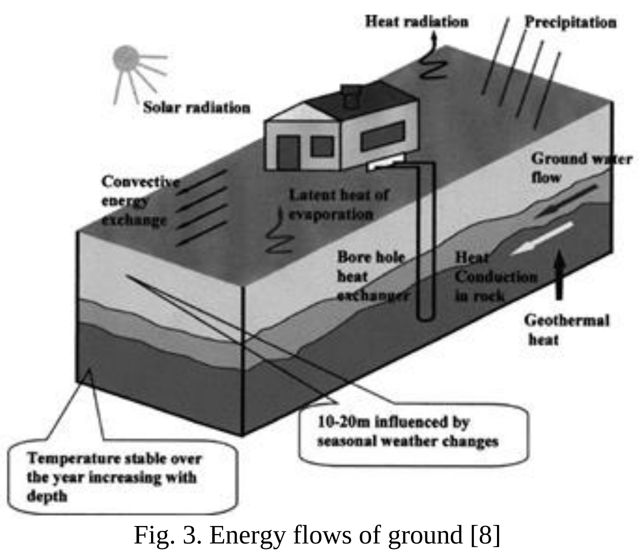

Fig. 3. Energy flows of ground [8]

G. Angrisani, et al. [7]. Suggested that during summer a Downhole Heat Exchanger (DHE) regenerates the desiccant material by supplying heat, while a certain amount of geothermal fluid is continuously extracted by the well in order to maintain high operating temperatures, which drives the absorption chiller and produces chilled water to be supplied to the cooling coil of AHU. During the winter season, the geothermal energy is used directly to cater for some space heating demand. In summer as well as winter the geothermal energy is use to supply domestic hot water.
In case of low or medium enthalpy geothermal source is directly used for space heating and conversely in case of high-enthalpy geothermal resources, heat is more profitably converted into electricity.
Further, in a research by Lynn Mueller et al. [15], a thermal superconductor material is used to manufacture a ground coil couplable to a geothermal cooling device. The device includes a thermostat controller, a blower and a thermal superconductor heat exchange coil.
The Ground Coil is made up of loops, each loop consists of a supply and return line, with an outer diameter of an inch or more for each pipe, the hole typically needs to have a diameter of 4 to 6 inches to allow the loop to be installed. The holes of this size are expensive to drill and leave large voids which must be filled with materials such as bentonite clay in order for heat to transfer from the ground to the loop.
The antifreeze solution must be pumped through hundreds or thousands of feet of small diameter piping, for the ground loop to function, consuming a significant amount of electric energy and lowering the overall efficiency of the system.

B. Implementation and applications of Geothermal systems

Suresh Kumar Soni, et al. [22] studied of recent trends in hybrid GCHE systems in comparison to the passive renewable systems and showed that EAHE systems are being widely implemented, preferably in the locations where ground temperature fluctuation level is high. On the basis of ground covered by the author, a hybrid of EAHE with evaporative cooler can increase cooling effect by 69% and reduce length of buried pipe up to 93.5%. In addition GSHP with evaporative cooling system approximately doubled the COP.
Suresh Kumar Soni, et al. [23], further reviewed the test of Earth Air Heat Exchanger (EAHE) system with parallel pipelines at Bhopal in India. The experimental setup consisted of 3GI pipes of 64mm internal diameter (ID), 3m each, connected parallel to common exhaust and intake, buried at a depth of 1.5 m in a flat land consisting dry soil. Research showed that at a depth of 1.5 m the temperature difference of air at inlet and exit sections varied from 8.6°C – 4.18° C and the COP from 6.4-3.6, in the air velocity range of 4.1–11.6 m/s. Observation was made that lower air velocities resulted in higher temperature and COPs.
He also mentioned a similar experimental study carried out in the North Eastern part of India. Locally available bamboos and soil–cement mixture plaster were used to manufactures the Earth pipe. 30–40% humidity decreased with the use of

soil– cement mixtures. EAHE system was able to reduce outlet temperature up to 30–35%.
Yuebin Yu, et al. [26] conducted the study of a coupled geothermal cooling system with an earth-to-air heat exchanger and a solar collector enhanced solar chimney to evaluate the performance of the system, in terms of passive cooling capability, active cooling capability, and soil thermal capability. The results indicate that in the horizontal level a higher gradient leads to higher heat dissipation than that in the vertical level and that the coupled geothermal system is feasible to provide cooling to the facility in natural operation mode free without using any electricity.
Joaquim Romani, et al. [12] presented the a comparative study based on a prototype built in to cubicles that houses a radiant wall coupled to a ground heat exchanger on a side and a conventional air-to-air heat pump on the other embedded a heavy brick wall. It was found that such system had potential to reduce operational costs and energy consumption by peak load shifting and pre-cooling.

A similar comparative study was realized and presented by
C. TROMBE et al. [3]. This paper presented the experimental results of a study realized on two identical timbered houses one of which is equipped with an earth tube heat exchanger.

Table 1. Main characteristics of ETHE[3]

Tube nature	Plastic (PVC)
Diameter value	Outside = 0.20 m
	Inside = 0.19 m
Mean thickness value	0.005 m
Thermal conductivity of tube	Lambda = 0.2 W/m K
Average earth depth value	$Z = -2.5$ m
Length of buried air duct	Outside of house = 33.5 m
	Under house = 8.5 m
Length of free air duct	Outside house = 1.50 m
	Inside house = 4.5 m

Taking into account, the flow rates and meteorological conditions, the thermal behavior of the earth tube heat exchanger is depicted in the graph.

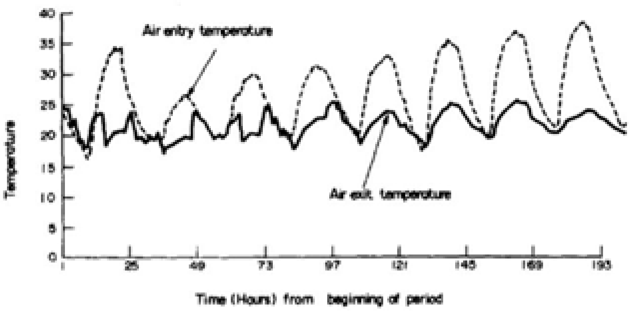

Fig. 4. Entry and Exit air temperature [3]

An Experimental study of thermal performance for space heating and cooling mode of operations of a ground source heat pump system were performed at IIT Roorkee.[24]
Similarly, earth-tube heat exchanger (ETHE) was installed in arid areas like Kutch for use in greenhouse

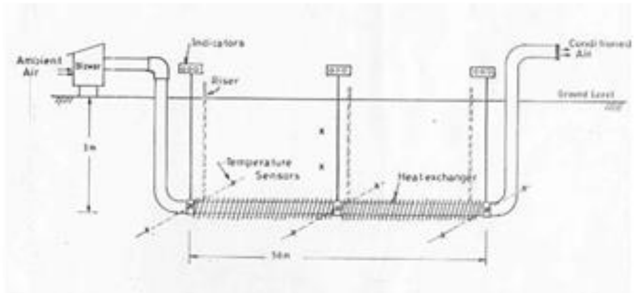
Fig. 5. Earth tube Heat Exchanger [9]

The set-up consisted of a Heat Exchanger passing throughthe ground at 1.8-m depth, enhanced by 40 fins per meter length installed on the outer surface of the pipe, and instrumented with temperature sensors inside the tube and in soil around it, fan house consisting of a 400 W blower pumps, temperature sensors and back-up risers.
The coefficient of performance (COP) of the system was found to be 3.3 in cooling mode and 3.8 in heating mode.[9]

Along similar lines, Sneha Shahare, et al. [21] recommends geothermal cooling for 10 months in a year and

solar hot water system during 2 months of winter for energy efficiency and power optimization. It is observed that the ambient air temperature of 35˚C - 40˚C in the room can be brought down to 26˚C and can be increased to 27˚C through circulation of water from solar water heater in the heat exchanger for lesser consumption of electricity.

C. Dynamic Simulation and model

Wei Ruan et al. [25] gauges the different assumptions and methodologies between these calculation methods to calculate heat transfer, predict the performance and estimate the initial cost of Vertical Ground Heat Exchangers (VGHE) for Geothermal Heat Pump Systems. These methods can be categorized in three phases. The first phase, from the 1940's to 1960's, focused on the development of fundamental theoretical models like the line source model and cylinder source model. The second phase, from the 1970's to the 1980's, focused on analytical solutions which are developed using the superposition method. Since the late of 1980's, advent of computers lead to development of numerical models.

The heat exchange tubes, arranged as U-shaped, W-shaped and spiral-shaped were studied by Qiang Zhao a, et al. [17] by building a numerical model which is combined with both the heat conductive transfer in solids model and the non- isothermal pipe flow model, by COMSOL Gyu-Hyun Go, et al. [10] studied an optimum design of horizontal ground heat pump systems for spiral-coil-loop heat exchangers based on 160 parametric studies conducted using numerical simulation models coupled with a generic algorithm. According to the analysis, the key input parameter for the system performance was the ground thermal conductivity.

J. Raymond, et al. [13] demonstrated that optimization of the design of a heat pump system of an industrial park with fully coupled groundwater flow that accounts for building energy needs i.e. Heating and cooling loads were determined from the buildings characteristics summarized with the eQUEST software. Equations for unsaturated flow and heat transfer solved by the numerical simulator HydroGeoSphere.

The energy and economic analysis of a novel heating and cooling system based on the coupling between a low or medium-enthalpy geothermal source and an Air Handling Unit, including a Desiccant Wheel was carried out in TRNSYS 17. The case study showed that a primary energy savings higher than 90% can be achieved. [7]

CONCLUSION

The GCHE system saves electricity and eliminates the use of water required in cooling towers, thus is a leading greener air-conditioning technology [18]. The GCHE system if coupled with Earth Air Heat Exchanger (EAHE) system increases the efficiency of GCHE system [24].
Geothermal cooling systems were found to be preventing 46.6 million tons of carbon and 148.2 million tons of CO2 being released to the atmosphere when its performance was analyzed on the systems installed worldwide.

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